ELECTRICAL IRRADIATION EFFECTS IN SOLID DIELECTRICS

An annotated bibliography

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The Bibliography lists in alpha-numeric order, by the name of the first author, about 800 papers on electrical irradiation effects in solid dielectrics. Nearly all entries contain a short abstract. An introductory section gives a short review of the subject matter. Then follows a List of Contents and a Subject Index; the latter lists the same topics, each followed by the entry numbers of the papers relevant to the subject. The bibliography covers papers and reports published until June 1973.

The author gratefully acknowledges the assistance of the Brazilian National Nuclear Energy Commission which has enabled him to carry out this work.
It has been known for a long time that the electrical properties of insulating material are adversely affected by exposure to nuclear radiations. Some beneficial effects may derive from the fact that radiation-induced currents can be used as a measure of radiation dose rate. Investigation of changes of dielectric properties is of importance in view of the widespread use of dielectrics in a nuclear environment and the continuous increase of the amount of radiation which electrical equipment is supposed to withstand. A great number of papers has been published on the subject. The present bibliography reviews that part of the literature which deals with purely electrical effects of radiation. It omits references to chemical degradation, changes of molecular structure, and of mechanical, thermal, and optical properties. It also excludes the field of semiconductors and semiconductor devices, in particular transistors.

Within the subject field, main topics are radiation-induced conductivity, radiation-induced currents, and radiation-induced charge buildup and decay. An adequate understanding of these effects depends on the results of the basic theory of carrier injection from the electrodes, carrier transport, trapping, and recombination, carrier mobility, and of space-charge-limited currents (Sections I and II).

Radiation-induced conductivity depends on dose and dose rate. It is also a function of time and thus is a relaxation effect characterized by current transients occurring when irradiation is initiated and when it is discontinued. Behavior of dielectrics under continuous irradiation differs markedly from that under pulsed irradiation. A semiphonological theory explains this behavior in a general way. But reaction varies widely from material to material and different types of radiation evoke different response. A vast amount of partially empirical literature, difficult to be coordinated, deals with the material
problem. Special attention has been given to the behavior of polymers; effects of crystallinity have been investigated in quartz, diamond, alkali halides. Radiation effects are affecting the performance and reliability of capacitors and other types of equipment. While most papers deal primarily with variations of electrical resistivity and leakage, increase of dielectric loss and changes of capacitance have also been observed (Section III).

Measurement of transient effects, in particular carrier transit times, produced by penetrating and non-penetrating beams is an important tool for determination of carrier mobility and its dependence on temperature, on the rôle played by recombination, and of the energy necessary to generate a free electron-hole pair. To investigate dielectric behavior in an extreme nuclear environment, special high-powered pulsed machines are being developed requesting a specialized measurement technology. They generate pulses in the nanosec range at exposure rates of up to $10^{14}$ R/sec (Section IV).

Mobility measurements can also be performed by methods in which a free (electrically floating) surface of a dielectric is charged by different methods and the subsequent charge decay is monitored. Charge density on surfaces can be measured by conventional means (induction method) and by deflection of incident or grazing electron beams. Carrier emission from the surface of highly charged dielectrics has been observed (Section V).

Carrier injection from an energized electrode or irradiation with non-penetrating particle beams produces space charges in the bulk of the material. Direct determination of space-charge density can be carried out by various, destructive methods in which the surface of the dielectric is gradually removed by chemical (etching) or mechanical (sectioning) procedures. The method distinguishes between dielectric polarization and space charge polarization. Purely electrical, non-destructive
methods have also been developed which allow determination of the average space-charge depth by measurement of currents and voltages drawn from the electrodes of a special capacitor system (Section VI).

Absorption of monoenergetic high-energy electron beams is characterized by range straggling and backscattering. Absorption curves are S-shaped. Experimental results can be represented by relatively simple range-energy relations. They have been calculated in detail by modern computational methods. The differential range distribution function and the corresponding energy and charge deposition profiles can be directly monitored by electrical charge-recording methods and by thin-film dosimetric procedures. The range distribution in dielectrics may differ from that in metals due to the retardation effect of the internal space charge field set up by the trapped charge. This field can also lead to charge emission from the dielectric surface, the generation of internal voltages exceeding the accelerating voltage of the incoming beam, and the production of internal breakdown. Space charge values can be measured by mechanically triggered breakdown. Charge decay is a thermally activated process and charge measurements by means of thermally stimulated currents has become a routine method which gives also information of activation energies and trapping levels. Breakdown and charge effects are also produced by proton and ion bombardment. A theory of charge movement and dissipation has recently been developed for simple charge configurations (Section VII).

High energy X-rays and Gamma rays can cause intense electrical effects via secondary Auger, photo- and Compton electrons. The theory of these effects has recently been developed in considerable detail. It is complemented by direct measurement of forward and backscattered radiation flux and of flux distribution at surfaces and interfaces. Space charge buildup is observed in dielectrics due to the absorption of the primary photons and the corresponding
variation of the accompanying electron flux. It is particularly intense in samples whose thickness considerably exceeds the average photon range; it then might lead to internal breakdown whose occurrence in hot cell window glass first called attention to the effect. This type of damage can now be avoided by increasing the conductivity of the glass and thus reducing its electrical relaxation time. Other annoying manifestations of photon-induced electron currents are the polarity effect observed in ionization chambers operating in the build-up region and the occurrence of unwanted noise and signals in coaxial cables placed in a nuclear environment. The complex of phenomena connected with electron currents set up by a directional photon radiation flux is now known under the name of Compton current or photo-Compton current. Theory and measurement of these currents are now fairly well established. The property of photon radiation to generate Compton currents has allowed the development of special dosimetric methods and the construction of Compton dosimeters. Several types of such instruments have come into use, the vacuum diodes and the dielectric diodes. Dielectric diodes have two electrodes separated by a dielectric whose thickness is considerably greater than the maximum electron range. They are well suited for measurements under extreme conditions and now are routinely employed for nuclear burst dosimetry and monitoring where they have replaced the vacuum type instruments. Personal dosimeters have also been constructed on these principles. The measurement of thermally stimulated currents and voltages, in particular those produced by maintaining a temperature gradient along the sample, continues to be a useful research tool (Section VIII).

Electrical radiation effects can be used in a variety of other devices and systems. Intense irradiation and concomitant application of an external polarizing field can produce electrets capable of generating self-sustained electric fields over long periods of time. Sectioning methods have been used to determine the charge distribution in such radioelectrets. Irradiation of a thermo-
electret by photon or neutron radiation has been found to destroy the polarization of the electret; dosimetric methods based on this effect have been developed. Other such methods are based on the lowering of the electrical resistance of insulators during irradiation, on the change of polarization of ferroelectric substances, and others. Systems set up to favor the generation of currents by electron or photon radiation are direct conversion devices or nuclear batteries; they are high-voltage, high-impedance sources. Irradiation has also been found to lead to ignition of conventional explosives. Finally mention is to be made of NOS (Metal-Oxide-Semiconductor Systems) where high and long-lasting space charges are produced in the oxide by nuclear radiations (Section IX).
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4 - Thermostimulated Currents, Glow Curves

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7 - Vacuum Ionization Chambers
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IV.1 - Technology of Pulse Generation. Diagnostics.
67,129,130,422,432,438,524,625,627,658,689,704

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498,519,581

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29,141,184,218,366,396,405,411,418,430,431,438,498,504,505,506,507,
508,509,518,519,520,525,582,583,584,585,603,608,656,657,664,701,702

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124,363,364,430,431,582,583,584,585

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12,115,117,132,133,1741248,249,353,354,389,441,455,550,571,695,698,
715,716,717

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14,40,70,116,118,220,696,697

12,14,31,35,36,37,38,248,325,326,327,353,354,374,441,496,550,551,
582,583,584,585,652,657,707

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423,427,586,606,613,641,642,643,644,645,676,721

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627,641,642,644,645,662,666,676,677

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6,63,122,131,191,195,197,201,223,313,385,419,451,454,457,488,548,
555,600,653,667,681

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1,25,63,72,73,78,133,183,184,221,222,230,231,239,244,277,304,456,457,
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VIII.6 - Compton Currents. Theory and Measurements.
62,77,88,125,126,226,237,238,242,294,300,401,421,447,449,473,611,679,708
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139,142,291,382,383,384,616,655,656,657
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23,311,321,339,429,553
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532,541,660,693
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646,647,662,692
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533a, 540, 572, 598, 599, 600, 604, 605, 609, 610, 624, 732, 733
IRRADIATION DAMAGE TO GLASS
J.A. Aboaf, J.R. Hensler, N.J. Kreidl
Bausch and Lomb Inc. Rochester, NY. TID-17227, Octo. 1962
Measurement of space charge buildup in electron- and gamma irradiated lead silicate, phosphate, silica and pyrex glass, including measurement of dielectric properties and dc conductivity. Results do not support a space charge effect, but indicate that effects do occur in the bulk of the glass.

THE ANOMALOUS AND STEADY STATE CONDUCTIVITY OF POLYTETRAFLUORETHYLENE UNDER IRRADIATION
V. Adamec. Dielectrics (GB), Vol. 1, No. 3, 159-60 (Aug. 1963)
With X-ray equipment as the source of radiation, the current flowing in polytetrafluoroethylene sheet was measured using a wide range of dose rates ($10^{-3}-10^{3}$ rad/sec) at energies of 15, 30, and 38 keV. It was found that the steady state conductivity and also the induced anomalous conductivity rose under the action of the irradiation and that the rate of decay of the anomalous conductivities at dose rates up to 0.4 rad/sec was similar to that without irradiation.

NATURE OF ANOMALOUS CONDUCTIVITY OF POLYMERIC INSULATING MATERIALS
V. Adamec
Proc. IEE (GB) 112, 405 (1965)
Measurements of conductivity under irradiation. Electric stress was applied only after the radiation-induced polarisation could be assumed to have reached equilibrium, i.e. after some hours after beginning of irradiation with X-rays. Doses varied from 0 to 400 R/s. Several absorption and transient effects were observed. Interpretation in terms of a Maxwell-Wagner mechanism is given.

ON THE MEASUREMENT OF SMALL RADIATION INDUCED CURRENTS
G.D. Adams, H.E. Jones
Radiation Research 3, 210 (1955)
Spurious currents were observed in insulators during X-ray irradiation. Measurements of transients observed with co-axial cables are also referred to.
TEMPORARY CHANGES IN ELECTRICAL PROPERTIES OF POLYMER DIELECTRICS DUE TO IONIZING RADIATION

V. Adamec (Cables and Insulating Materials Res. Inst., Bratislava, CSSR)

J. Polymer Sci. A-2, 6, 1241 (1968)

Measurements of conductivity, permittivity, and dissipation factor on polystyrene, low-density polyethylene, poly(ethylene terephthalate) and polytetrafluoroethylene under irradiation with X-rays at exposure rates from 0.004 to 400 R/sec are presented. The radiation-induced anomalous conductivity as well as the induced dielectric loss are interpreted by Maxwell-Wagner polarization due to radiation imbalance in surface layers of specimen. The nature of the steady-state conductivity is also discussed.

DIRECTIONAL BREAKDOWN IN NaCl CRYSTALS BOMBARDED WITH ELECTRONS

I. Agarbiceanu, I. Teodorescu
Rev. Roum. 12, 927 (1967)

Bombardment of NaCl crystals with electrons of medium energy (33.5 to 44 keV) results in the appearance of the following effects: Lichtenberg patterns, starlike figures, melting structures, and dislocations. For these to be revealed, the electron beam density must be sufficiently high in order to create, on the surface, strong electric fields strong enough to produce electron avalanches. The directional breakdown figures obtained are almost identical with those obtained by scratching or by pressing the surface of the crystal by a sharp point. Characteristic values for the electron current are about 400 to 1000 microA/cm² at 50 keV and 4 to 10 min irradiation time. In some experiments, spot irradiation of short duration was used.

CONDUCTIVITY INDUCED IN DIAMONDS BY ALPHA PARTICLES BOMBARDMENT AND ITS VARIATIONS AMONG SPECIES

A. J. Ahearn
Phys. Rev. 73, 1113 (1948)

Alpha particle bombardment is used to establish an internal field corresponding to 480 V/cm.

24636 ENERGY DISTRIBUTION OF TRANSMITTED SECONDARY ELECTRONS FROM POROUS KCl FILMS


Energy distribution of secondary electrons from three types of porous films (porous KCl films, porous KCl films containing intermediate thin Al layer, porous KCl films containing small amount of amorphous Al) was measured by an ac retarding-field method. The half-width of each energy distribution curve was found to be about 10 to 20 eV. The surface potential of these films was also obtained from the rising point of the energy distribution curve. A single relationship between surface potential and yield and independent of collector voltage was found for constant primary energy. Decay characteristics of the surface potential of three films after ceasing the primary electron bombardment were similar to each other. Secondary currents from a porous KCl film containing a small amount of amorphous Al were found to be considerably more stable compared to those from two other films. A secondary electron emission is proposed using a channel electron multiplier model.
RADIATION EFFECTS IN POLYMERS
R.S. Alger
In: Physics and Chemistry of the Organic Solid State,
Under Radiation Induced Transients discusses Yield of Free Electrons, Range of Free Electrons, Electron Traps, Untrapping and Neutralization.

ELECTRON PRODUCTION AND TRANSPORT IN ELECTRONIC MATERIALS
IN A PULSED NUCLEAR ENVIRONMENT
H.B. Almond, V.H. Schmidt (Boeing, Seattle)
D2-9783-3 (Sec. II)
The chief source of high energy electrons from a fission spectrum is the Compton effect. The density of the Compton recoil electrons from a plate of thickness large compared to electron range but small compared to gamma range increases slowly with atomic number. Expressions based on the Kukla gamma spectrum are derived for the net current flow from a plate, and net rate of creation of space charge within the plate, as a function of the thickness and composition of the plate and others between it and the gamma source. An expression is also derived to take into account the backscatter and secondary electron production between plates of the same and dissimilar materials. Results of experiments with at Kukla are presented. Disagreement of theory and experiment for bare plates are attributed to unexpectedly high electron scatter anisotropy in the test area and to the backscatter effects which were not taken into account. Metals, graphite, and polyethylene were tested. The two last-named materials are susceptible to neutrons as well as to gamma rays.

DETECTION OF NUCLEAR RADIATION USING THE CUMULATIVE PHOTODELECTRIC EFFECT IN CADMIUM SULFIDE.
Thesis.
The field of nuclear radiation detection is limited at the low energy scale. Present day radiation detectors have a practical lower limit of approximately 1 keV for alpha, beta, and gamma. This lower limit is due to noise in the detectors themselves and their associated electronic circuits. The present study of x-radiation from color television receivers requires a lower energy range from the radiation detection equipment. Future applications of radioscopy tracer techniques will need a high sensitivity radiation detector. The cumulative photodlectric effect uses the ac mode of radiation detection to improve the signal to noise ratio, and extend the lower energy limit to the theoretical limit of 2.53 eV, which is the value of the bandgap in cadmium sulfide. Cadmium sulfide exhibits the photodlectric effect between 0 and 200°K. This work makes use of this property to study the ac mode of radiation detection. The work first traces the background of nuclear radiation detectors, and examines the only previous work in the area of the ac mode. The work also discusses the interaction of radiation with matter. Next a discussion of the electron traps in cadmium sulfide which are responsible for the photodlectric effect are discussed. Primary emphasis is on the effect of radiation on the dielectric constant of cadmium sulfide, and a series of equations is derived explaining the change in the dielectric constant due to radiation. Experimental procedures are explained, along with the preliminary design problems and preparations. Techniques for measuring the change in dielectric constant using radiofrequency electromagnetic waves are explained. Finally, the work demonstrates that the cumulative photodlectric effect can be used to detect low intensity, low energy beta particles. In this case the source of radiation used was radioactive carbon-14. (Diss. Abstr.)
NEGATIVE ION BOMBARDMENT OF INSULATORS TO ALLEVIATE SURFACE CHARGE-UP
C.A.Anderson, H.J.Roden, C.F.Robinson

APPROXIMATE ENERGY SENSITIVITY OF LASL DIELECTRIC RADIATION DAMAGE
W.C.Anderson, L.P.Harker
Calculations for infinite parallel plate geometry.

COMPARATIVE EFFECTS OF ION BOMBARDMENT AND PARTIAL DISCHARGES ON POLYETHYLENE FOILS
A.Antoniou, Bui An, R.Lacoste, C.Kayoux

ELECTRON-BOMBARDMENT CONDUCTIVITY OF DIELECTRIC FILMS
F. Ansbacher, W. Ehrenberg
Reports measurements with low energy (up to 50 keV) electrons.

The main net effect of the electrons is excitation and ionicization of atoms along the electron path. Some secondary electrons and positrons will migrate through crystal until they recombine or are trapped or reach the electrodes. Trapping and recombination are illustrated by the existence of a critical voltage $V_0$ necessary to observe a significant effect: below $V_0$, the pairs recombine near their places of origin because charges carried beyond the irradiated region (here supposed to be considerably smaller than the sample thickness) are trapped and set up a counter space charge field, preventing further carrier movement.

ELECTRON-IRRADIATION CONDUCTIVITY CHANGES IN DIELECTRICS DURING 2.5 MEV X-RADIATION
F.D.Armistead, J.C.Pennock, L.W.Mead
Phys. Rev. 76, 860 (1949)
The volume conductivity of polyvinyl chloride, vinylidene chloride, and polystyrene have been measured. The observed increase of conductivity is interpreted as caused by a reduction of the barrier at the electrode-dielectric interface. The increase during irradiation was rather fast, but the recovery time after cessation of irradiation was of the order of hours.
The experimental procedure used to measure the dependence of the L-125A detector's relative sensitivity on the width of incident gamma pulses is described. When exposed to bremsstrahlung pulses whose widths were changed from 1 nsec to 4 μsec, the detector was found to be linear to within ±2%. The value of the time domain reflectometry (TDR) technique for improving the time response of the L-125A detector was established by comparing its results with those obtained by measuring the frequency response of the detector using a 50-psec bremsstrahlung pulse. These studies show that properly interpreted TDR techniques can give information that can be applied to the design of detectors with a higher frequency response than that of the L-125A detector. The peak linear output current of the L-125A detector was also measured and results are presented on the influence of excitation amplitude on detector linearity.

Electrification of polystyrene previously subjected to the action of gamma radiation
G. Asch, Marie-Claude Felix, R. Ongaro
Compt. Rend. 258, 3932 (1964)

Samples were irradiated at 10^5 r/h up to 160 h. Subsequent application of a polarizing field up to 20 kV/cm during 4 to 5 days produced a persistent polarization. One quarter of it decays in short circuit during within 2 days. Max If the sample is exposed again to gamma radiation, the shorted sample is discharged completely within less than one hour.

Space charges in irradiated dielectrics
G. Asch, Marie-Claude Felix, R. Ongaro
Industries Atomiques No 9/10, p. 80, No 11, p. 68 (1966)

Survey article on effects of electron bombardment and gamma irradiation, including Compton current theory.
ELECTRIZATION OF POLYTHERENE AND POLYSTYRENE AFTER GAMA IRRADIATION

K.C. Asch, M.C. Cedix, M.R. Ongaro
Lab. Electronique, Faculte des Sciences, Lyons, France
Physica Status Solidi 17, 49 (1966)

Reports a study on the behavior of radioelectrets of polythene and polystyrene. Samples are irradiated and concomitantly or subsequently exposed to an external electric field. Surface charges are measured by the induction plate method. Stable heterocharges are found in all cases. Charge values are calculated under the assumption that trapped electrons are untrapped by thermal excitation.

DOSE MEASUREMENTS IN THE BUILDUP REGION FOR COBALT -60 RADIATION

N. Aspin, R.G. Baker, H.E. Johns
Journal de L'Association Canadienne des Radiologistes
8, December 1957

Radiation absorbed in the build-up region is usually measured by a thin window, parallel plate ionization chamber. Thin absorber sheets placed over the window serve to increase the depth of the chamber. Dosage measurements made in this manner have been found to depend on the polarity of the collecting voltage. This polarity effect is greatest at the surface. The effect is described and interpreted in terms of forward driven Compton electrons.


Gamma radiation effects on the electric conductivity of the Rochelle salt and ammonium dihydrophosphate (ADR) were studied at room temperature to 200°C, using 5 x 3 x 3 mm crystals of Rochelle salts irradiated with γ rays at 6.8 x 10^3 r/hr and ADR irradiated at 12.6 Mr/hr. At room temperature, the electric conductivity of ADR changed very little, while in Rochelle salts it increased from 1.4 x 10^-10 ohm^-1 cm^-1 for nonirradiated to 1.6 x 10^-4 ohm^-1 cm^-1 in specimens irradiated with 80 Mr. A linear dependence of electric conductivity was observed up to 40 Mr in Rochelle salt and up to 200 Mr in ADR. (R.V.J.)

ON THE APPEARANCE OF AN EMF INCIDENT TO ANNEALING OF THE BETA-IRRADIATED ALKALI METAL HALIDE CRYSTALS

V.A. Avonin, I.A. Vasilev, G.A. Mikhachenko, B.I. Plachenov

Crystals irradiated with beta-rays at 900K exhibit, upon heating, a free surface charge at the surface of incidence (in addition to the optical glow curve). The charge is believed to result from a nonuniform distribution over the sample thickness of trapped charges.
THEORY OF AN ELECTROSTATIC ENERGY SUPPLY; ANALYSIS OF NONDESTRUCTIVE METHODS FOR THE MEASUREMENT OF INTERNAL CHARGES.

Boerwald, H.G.

Physical background, analysis, and tentative design of a type of electrostatic energy supply based on charge embedment in insulators is discussed. Potentially available emfs and charges look attractive. A class of electromechanical dynamic methods enabling one to measure entrapped charges non-destructively is proposed and analyzed in detail. They are based on electrostriction. They are also capable of high precision determination of electrostatic constants.

GAMMA-INDUCED ELECTRIC CONDUCTIVITY IN FUSED SILICA

K. Bagge, U. Jansen
Atomkernenergie 10, 197 (1965)

Measurements were made for dose rates of 1 to 2 x 10^6 r/h. Considerable variations were found between different samples with no apparent correlation with the degree of purity of the quartz glass. Decay rates of conductivity after cessation of irradiation are also reported.

LONG-TERM RADIATION-INDUCED CONDUCTIVITY IN POLYETHYLENE TEREPHTHALATE

Ballard, Lewis Franklin

Radiation induced conductivity (RIC) in polyethylene terephthalate (PET) is studied in amorphous and partially crystalline samples exposed to ^60Co gamma rays. Emphasis is placed on persistent RIC which exists for a long period of time after exposure. The drift mobility of holes in PET is observed by a pulsed photoconductivity technique to be near 2 x 10^{-7} cm^2 V^{-1} sec^{-1}. By the same method, the carrier mobility in dimethylterephthalate (DMT), a model compound for the PET polymer, is found to be near 0.8 cm^2 V^{-1} sec^{-1} for holes and 0.05 cm^2 V^{-1} sec^{-1} for electrons. Significant reduction in the mobility after irradiation is observed. The primary source of the long term RIC which becomes significant at radiation doses above 10^8 rads is concluded to be an increase in the carrier concentration. A model and experimental evidence are presented which relate this increased carrier concentration to free radical accumulation in doping levels lying within a few kT of the valence level. These carriers move through PET by a hopping process which is limited in the steady state by traps located near 1.6 eV having a density of about 10^{19} cm^{-3}.

(Diss. Abstr. Int., B)
DISCHARGE CHARACTERISTICS OF PHOTOCONDUCTING INSULATORS
I.P.Batra, K.K.Kanazawa,H.Seki
Discusses a method in which the floating surface of an insulator is charged up to a voltage \( V_0 \) and its subsequent decay measured upon exposure to intense light. Knowing the relation between the instantaneous surface voltage and the exposure time one can obtain the value for the carrier mobility from the theoretical expressions of the paper.

RADIATION INDUCED TRAPPED CHARGE CARRIERS IN ORGANIC POLYMERS: A MODEL OF THERMOELECTRIC CURRENT GENERATION
J.E.Barnes,F.E.Hoekerlardian, L.Kevan
Trapping and detrapping of radiation-induced charge carriers in FIMA, PVC, and other polymers were investigated. Thermoelectric currents were generated after irradiation by thermally stimulating the release of the trapped charges and subjecting them to a temperature gradient. Heating similarly irradiated samples in the absence of a temperature gradient produced a tenfold reduction of the observed current. The charge carriers were determined to be positive from the polarity of the colder electrode. To observe these currents, electrons liberated during irradiation had to be trapped to prevent recombination with trapped positive charges. This trapping is not done by the polymer matrix of FIMA at 25°C but by added impurities. PVC contains a built-in trap in the polymer chain at the C-Cl group. The electron trap in commercial FIMA (Lucite) is benzol peroxide or another chemical

initiator. Electron Traps were also internally generated in pure FIMA polymer by radiation followed by heating up to 120°C.


The electrical conductivity induced by pulsed x-ray irradiation was measured for the materials Mylar, polythene, and PTFE. Dose rates in the range \( 10^3 \) to \( 10^8 \) rad/sec at x-ray energies up to 4.5 MeV were used. For a given material, the results exhibit considerable scatter from sample to sample. This is attributed to minor variations in the electrode structure and in the composition of the materials, their effects being enhanced at the low conductivity levels involved. The results indicate that the conductivity varies linearly with dose rate, no strong evidence being found for saturation effects up to the maximum dose rate of \( 10^8 \) rad/sec.

(auth)
SPATIAL AND TEMPORAL EVOLUTION OF CHARGE CARRIER DISTRIBUTIONS FOLLOWING PULSED PHOTINJECTION
I.P.Batra, B.H.Schechman, K.K.Kanazawa
Solid State Communications 8, 1433 (1970)
Fundamental Eqs. for charge carrier dynamics in photoconductors without intrinsic conductivity are solved.
Time-dependent spatial distributions of carriers, field, and conduction current are obtained and related to the observable (measured) quantities of current and voltage.

PHOTOCURRENTS DUE TO PULSE ILLUMINATION IN THE PRESENCE OF TRAPPING.I.
I.P.Batra, H.Sold

DISCHARGE CHARACTERISTICS OF PHOTOVOLTAIC INSULATORS
I.P.Batra, H.Kanazawa, H.Seki
IBM Corp. Res. Lab., San Jose, Calif. 95114
The conventional techniques for measurement of mobility sandwiches has the sample between two electrodes, at least one of which is transparent. The sample is illuminated through this surface, the resultant current is measured under constant voltage. In the present method one surface of the sample is grounded, the other left floating. The latter is charged to the initial voltage $V_0$ and the voltage decay under illumination is measured. The relation between the voltage $V(t)$ at time $t$ and the exposure time $t$ is the "photoinduced discharge characteristic" PIDC of the plate. From this the mobility can be calculated with the aid of expressions derived in the paper. Measurements on amorphous Se films deposited on Al substrates are reported. Good agreement with theory is found. The method is based on illumination with a light pulse that must be intense enough to inject all carriers stored on the surface into the bulk in a time much less than the transit time. Once the carriers are injected, pulse duration is of no consequence since further injection becomes impossible. With no electrode required on the illuminated surface, the need for strictly blocking ohmic contact is eliminated.

TRANSIENT SPACE-CHARGE LIMITED CURRENTS IN PHOTOCONDUCTOR-DIELECTRIC STRUCTURES
I.P.Batra, B.H.Schechman
CHARGE CARRIER DYNAMICS FOLLOWING PULSED PHOTOINJECTION
I.P.Batra, K.K.Kanazawa, B.H.Schechtman, H.Seki
J.Appl.Phys. 42,1124(1971)
Spatial and temporal behavior of carrier density, field, and conduction current are calculated for a configuration in which the free surface of a photoinsulator is charged to a potential and carrier injection generated by a short pulse of intense light. Results provide a physical picture of carrier dynamics and allow a qualitative discussion of trapping effects.

PULSE INDUCED PHOTOCURRENTS AND FIELD DISTRIBUTIONS IN PHOTOCONDUCTOR-DIELECTRIC STRUCTURES
I.P.Batra, B.H. Schechtman
The fundamental Eqs. for carrier dynamics are solved for pulsed injection, excluding diffusion and trapping, for a photoconductor sandwiched in between two dielectrics or one electrode and a dielectric.

ON THE "CROSS-OVER" EFFECT IN SURFACE POTENTIAL DECAY
I.P.Batra, K.K.Kanazawa
Japan. J.Appl.Phys. 11,267(1972)
When polymers, in particular polyethylene, are charged by surface charge deposition on a free surface, the slope of the decay curves increases with increasing value of deposited charge. Experimentally this has been found to lead to decay curves for the surface potential, which eventually cross each other, the "high-charge" curves becoming situated below the "low charge" curves. It is shown that contrary to a previous (Wintle) believe theoretical curves assuming a finite field-independent depth of penetration of the space charge nor the introduction of a field-dependent mobility, thermally generated carriers, field-dependent injection and thermally activated release of the surface charge are unable to explain the effect. No satisfactory explanation exists so far for it.

THE EFFECTS OF 25 MEV BETATRON BREMSSTRAHLUNG AND 14 MEV NEUTRONS ON THE ELECTRICAL CONDUCTIVITY OF POLYMER DIELECTRICS.
Bozin, A.P.
Fiz. iVerdego Tela, 4, 2885 (1962)
Results of measurements carried out with 5 polymers irradiated by bremsstrahlung (average energy 9.5 MeV) and by neutrons are given. In the bremsstrahlung beam the volume resistivity decreases instantaneously by 2 to 3 orders of magnitude, but recovers its original value after irradiation had ceased. At the energies concerned only Compton effect and pair production are of importance. Absorption cross sections for carbon at 9.5 MeV for the two processes are related as 4 to 1. The primary radiation effect in organic dielectric is ionization and excitation of molecules resulting in the dissociation and breakage of chemical bonds with the formation of free radicals. The secondary effect is the interaction of free radicals among themselves or with other molecules. In some cases these secondary effects are accompanied by ruptures and contractions of polymeric chains and in other cases by recombination of free radicals and branching of the initial structure.
A persistent problem in this technique has been charge buildup on the insulator surface, affecting counting of implanted ions or actually causing surface damage due to electrical discharge. Techniques for charge removal were heating to increase conductivity, use of pulsed ion beams, conductive layers or strips applied to the surface. Authors have studied effectiveness of these methods for removing charge buildup in 140 to 300 keV proton implants into insulating substrates by monitoring the ion-induced characteristic X-rays emitted from the target ions. The number of X-rays produced per incident ion is a strong function of the energy of the incoming beam. Therefore any Coulomb slowing or deflection of the ion beam can be detected as a change in the accumulated X-ray yield per unit ion fluence. Any charging or discharging effects will be revealed by simultaneous changes in X-ray production rate at a fixed ion flux. It was found that successful implantation was achieved when a thin metal coating was applied to the insulator surface or if there was a conducting mask making good contact with the implanted surface. Ion current is measured from the film or mask. The beam should be defocused to flush the entire sample.

A method of neutralizing the positive charge buildup is presence of a hot electron-emitting filament near the surface, with several bias voltages applied. X-ray output during proton bombardment was below normal and always irregular. Some bremsstrahlung X-ray output, sometimes in bursts, was seen. It was believed to be due to electrical discharge and attraction of groups of electrons from the filament to the highly charged insulator.
EFFECTS OF HIGH-ENERGY RADIATION ON THE ELECTRICAL PROPERTIES OF EPoxy RESINS
H. Boine
Technische Hochschule, Ilmenau, Germany 1965 (Thesis)
Reports experiments with 1.5 keV electron irradiation at $10^5$ rad/sec, total doses between $10^6 - 10^9$ rad.
After-irradiation colouring, breakdown, surface effects, and conductivity were investigated. Samples irradiated with $10^9$ rad are destroyed when they are heated during irradiation beyond 80°C. Conductivity is decreased but after some days returns to normal values. It is believed that irradiation produces lower molecular compounds which are gradually absorbed.

TABLES OF ENERGY LOSSES AND RANGES OF ELECTRONS AND POSITIONS
M.J. Berger, S.K. Seltzer
Tables are given for about 40 materials and 30 energies between 10 keV and 1000 keV. They contain mean energy loss of electrons by collision with atomic electrons and by bremsstrahlung, mean range, radiation yield (conversion of electron kinetic energy into bremsstrahlung + brems energy).
Auxiliary tables contain information about restricted collision losses in water, critical energies (at which collision and bremsstrahlung losses are equal), electron-positron differences in regard to energy loss and range.

TABLES OF ENERGY LOSSES AND RANGES OF ELECTRONS AND POSITIONS
M.J. Berger, S.K. Seltzer
NASA SP-3012 (1964)

ADDITIONAL STOPPING POWER AND RANGE TABLES FOR PROTONS, KLEOPS, AND ELECTRONS
M.J. Berger, S.K. Seltzer
NASA SP-3036 (1966)
CALCULATION OF TRANSIENT PHOTOCURRENTS IN INSULATORS WITH TRAPPED SPACE CHARGE
A.N. Heilmann
J. Appl. Phys. 44, 226 (1973)
Transit time and pulse shape of photoinjected carriers moving in the presence of trapped space charge with different profiles (uniform and exponentially decreasing from surface of injection) are calculated.

TRANSIENT RESPONSE OF COPPER SELF-POWERED NEUTRON DETECTORS
H. Boeck, H. Stilmier, O. Strindberg

SHORT-TERM RADIATION-INDUCED CONDUCTIVITY IN POLYSTYRENE FILMS WITH NARROW MOLECULAR WEIGHT DISTRIBUTIONS
H. E. Boeck, A. S. Hill
Measurements are reported on thin disk dielectric film capacitors. Doses rates were 10^7 to 5 x 10^10 rad/sec, time resolution 5 ns. A kinetic model dominated by carrier trapping is used. When
\[ \alpha_{st}, \alpha_{sh}, \alpha_{db}, \alpha_{sb}, N_{sh}, N_{sb}, N_{sh}, N_{db} \]
are rate constants, carrier densities, trap densities for shallow and deep traps, one has
\[ \eta = \eta_0 + \alpha_{st} n_{st} - \alpha_{st} n (N_{st} - n_{st}) - \alpha_{db} n (N_{db} - n_{db}) \]
It is assumed that no ionization occurs from deep traps.

From Conference on nuclear and space radiation effects, University Park, Pa. (7 Jul 1969).
Thin disk dielectric film capacitors were prepared from a series of special monodisperse polystyrenes and irradiated in a flash x-ray facility. Transient conductivity in the films was measured with time resolution 5 ns, for dose rates from 10^7 to 5 x 10^10 rad/sec, and related to a kinetic model dominated by carrier trapping. Estimates for constants associated with a class of shallow traps were obtained for the assumed model. No significant molecular weight dependence of the early-time induced conductivity was found. Molecular weight-dependent departures from second order decay kinetics were noted. (auth)
The effects of radiation pulses are described for transistors and capacitors and interpreted in terms of semi-empirical models. These and other effects are then applied to the analysis of switching circuit behavior under a pulse of radiation. Some basic considerations on component selection and circuit design practice that will reduce the sensitivity of circuits to transient radiation effects are also included. (P.C.H.)

Irradiation lifts electrons from the valence band into the conduction band and leaves free holes in the valence band. The electrons traverse the sample and are scattered by lattice atoms and/or defects until they recombine with holes, directly or via a recombination level in the forbidden gap. Thus both holes and electrons contribute to the conductivity. A mathematical analysis in terms of Fermi level shows that the conductivity under irradiation is given by the unirradiated conductivity times exp(W/kT) where W is the absolute value of the shift of the Fermi level. Agreement with experiment for several metal oxides is found.

RADIATION DOSIMETRY BY CURRENT GLOW CURVES IN DIAMOND
D.K. Bose, H.K. Henisch
Solid State Electronics 11, 273 (1968)
Dosimetric capabilities of current-glow processes in neutron bombarded diamond in the u.v. and visible light regions are described. The effect of bombardment on the spectral characteristics of excitation and infrared quenching has been studied. On that basis a self-consistent model for the trap distribution before and after bombardment is formulated.
PYROELECTRIC DETECTION OF X- RAY ABSORPTION BY TOURMALINE
D.N. Bone, J.M. Henisch
Solid State Electronics (GB) 12, No. 2, 65 (1969)
Pyroelectric properties of tourmaline may be used for measurement of large X-ray doses. The pyroelectric voltage across a specimen subjected to uniform heating between 300 to 600°K goes through a maximum which is dependent upon the previously received X-ray dose. This behavior is correlated with thermally stimulated current measurements. Sensitivity is low, but storage capacity is high, of the order of $10^2$ to $10^5$ rads. At room temperature energy does not decay measurably over a period of two weeks. The decrease of pyroelectric voltage is due to thermal generation of free charge carriers. X-rays have the effect of exciting such carriers into traps, from which they can be released later by heating.

NOISE SIGNALS AND CARRIER MODULATION ARISING IN ELECTRICAL CABLES DURINGNUCLEAR PULSE IRRADIATION
Effects were measured as a function of voltage and history of sample. Strong memory effects were observed.

From 14th Annual Meeting of the American Nuclear Society, Toronto, Ontario.
The problem of currents induced in a coaxial cable was studied. An equation is given for the currents from gamma-ray absorption by photoelectric and Compton processes. Experiments were carried out in a Co gamma source and a TRIGA reactor. The current was negative and proportional to the dose rate in the gamma source, while both negative and positive currents were induced in the reactor. The bulk conductivity of the MgO insulator was also measured. (D.L.C.)
THE EFFECT OF SPACE CHARGE ON THE TRANSMISSION OF CATHODE RAYS THROUGH THIN INSULATING FILMS
C. Bowlt
Brit.J.Appl.Phys. 18,1585(1967)
The energy distribution of cathode rays transmitted through thin dielectric films changes during bombardment. Measurements of this effect are reported and are interpreted in terms of an accumulation of space charge. Electron beam energies were of 30, 35, and 40 keV. Dielectric (absorbing) films were used of As$_2$S$_3$ sandwiched between thin gold electrodes (~500Å). A suppressor voltage was used to repel secondary electrons and a retarding voltage allowed to measure the energy spectrum of the transmitted electrons recorded by means of a Faraday cup. Considerable time effects were observed. It must also be noted that even in thin films of insulator completely penetrated by cathode rays, sufficient space charge can accumulate to affect the transmitted electrons.

THE THRESHOLD ENERGY IN THE ELECTRON BOMBARDMENT CONDUCTIVITY OF DIELECTRIC FILMS
C. Bowlt, W.Ehrenberg
Cathode rays induce steady state conductivity in an amorphous film only if their energy exceeds a threshold. A comparison between threshold values and theoretical data for the differential energy dissipation of fast electrons in solids shows that the threshold value the electrons penetrate only half the film thickness. The space charge which develops under these conditions and which is made responsible for the occurrence of the threshold, is studied by experiments in which both sides of self-supporting films of arsenic trisulphide are exposed to cathode rays.

ABSOLUTE YIELDS OF X-RAY INDUCED PHOTOEMISSION FROM METALS
J.H.Bradford
IEEE Transactions Nucl.Sci. NS-19, 167(1972), 156
Absolute electron yields from tantalum, molybdenum, copper and aluminum have been measured for general X-ray bombarding geometries. Photo spectra used were derived from filtered bremsstrahlung generated in a tungsten anode at 50 kV, constant potential.
Measurements of induced conductivity were made on samples of boron nitride, quartz, mica compositions, polystyrene, and glass which were electron irradiated at $10^4$ rads/hr. Natural mica and Corning 1723 borosilicate glass exhibited the lowest induced conductivities of the materials tested.

Field strength of polyethylene terephthalate is found to be sensitive to radiation. After irradiating a $5 \times 10^{-3}$ cm sample with $10^7$ rad of 2 MeV electrons, at a dose rate of $10^6$ rad/min, breakdown field is decreased by 10%.

Economic deposition, ratio of polar to radial component are determined for Compton currents due to the secondary photons, for source altitudes up to 50 kfeet.
TIME AND TEMPERATURE DEPENDENCE OF IRRADIATION EFFECTS IN SOLID DIELECTRICS

R.G. Brown
Decay of electron distribution injected into polymers were investigated for 2 keV electrons. Breakdown and charge release were triggered by a grounded probe. The decrease of charge with time (at constant temperature) was interpreted in terms of resistance. For poly-methylacrylate and polypropylene, resistance values at room temperature are of the same order for irradiated and non-irradiated material, while for polystyrene, a large change of resistivity is observed. Activation energies or trap depths estimated from temperature dependence were about 0.6 eV for the two first-named materials and 0.4 eV for polypropylene. These values are lower than those inferred from steady-state conductance with no irradiation. Carrier creation by injection may reduce the observed activation energy to that characteristic of nobility.

IONIC THERMOCURRENTS IN DIELECTRICS

C. Bucci, R. Fieschi
Thermally activated release of dielectric polarization is studied in detail for alkali halides. The theory for monomolecular kinetics is developed and applied for interpretation of activation energies.
Electron Beam Diagnostics: Part I

Methods for performing pulsed electron beam diagnostics are presented and techniques for determining energy deposition profiles and beam energy density are discussed. Techniques for the determination of electron beam pulse profile and differential energy spectrum are considered.

Data refer to the Sandia model 705 Pedelectron and Heinen 1.


The effects of small γ doses up to 982 R on the dielectric constant and losses of KDP crystals were studied. The temperature dependence of the constant shows an increase at and below the Curie point. The initial maximum in the losses decreases and a second maximum at −160°C appears whose magnitude decreases somewhat with dose. The changes are stable with time. It is suggested that irradiation reduces the mobility of the domain walls.


(Air Force Cambridge Research Laboratories, L.D. Henman Field, Bedford, MA 01730) USA

Log energy electron emission from several metals exposed to Co-60 γ-rays, 10 keV electrons, and 0.1 to 1.0 keV electrons has been studied. Experiments described here, together with other results, indicate that for a given metal the emission of electron with energies up to 50 eV is proportional to the absorbed dose, independently of type and energy of the primary radiation. For common metals one gets about 1 - 3 x 10^-13 coul/rad. The magnitude of the emission due to high energy radiations can be predicted from the low secondary emission yield observed under low electron energy bombardment. Data seem to be consistent with internal isotropic low energy electron distribution given by \( \gamma(E) \sim E^{-3} \). Investigation was undertaken in view of the importance these emission processes have for a number of radiation effects in solids, such as replacement currents, space-charge buildup in dielectrics, and generation of transient electromagnetic fields. Secondary emission can also be a source of troublesome noise in experimental studies of radiation effects. Currents produced by these low-energy electrons are essentially a sensitive function of relatively low differences between components.
PHOTOGRAPHIC REGISTRATION OF TRANSIENT RADIATION ON A DIELECTRIC
I. Cabak
(Fac. Sci. Palacky Univ., Olomouc, Czechoslovakia)

An experimental proof of the existence of transient radiation originating at electron transience from vacuum into a dielectric is given. The radiation originating at the passage of the electron into a PVC cylinder was registered on a photographic emulsion.

SPACE CHARGE IN PLASTICS BY LOW ENERGY ELECTRONS (Revised)
V. J. Caldecourt
Report, Dow Chem. Ind., 9-29-65

Space charges are introduced by injection of low energy electrons (below 1 keV). This is done by plasma formed by a corona point above sample and reaching through a screen in front of it. Conductivity measurements give a current which decreases with time. Final current is a function of voltage applied. Conductivity in a vacuum is about the same as in a gas. Therefore it is due to charge carriers present in the polymer. b- Electrostatic field measurements were made with a rotating probe and induction plate system. Charge decay curves are measured and a charge storage effect is found. c- Net charge was measured with a Faraday cage system. They indicate a positive charge layer at the bottom of the film attributed to holes left by electrons emitted from the bottom surface into ground.

The space charge results from the ability of many plastics to trap electrons. A direct indication of the presence of space charge was obtained by recording the electric field strength. A film of the sample was charged using a corona point and screen device and then rotated under a field strength meter. The latter was a small vibrating-vane version of a generating type electrostatic voltmeter. The film was recharged several times and the decay was plotted on a log-log paper. The results for polystyrene are discussed.
R. N. Dasu
DISCUSSIONS PHOTO DIODE LINEARITY, SATURATION DATA, CALIBRATION TECHNIQUES, FLUORS AND RADIATORS, TEST LIGHT SYSTEMS, LOGARITHMIC DETECTORS, COMPTON DETECTORS, PHOTOMULTIPLIER DETECTORS, PHOTODIODE DETECTORS, SOLID STATE DETECTORS.


A description of the design, fabrication, and testing effort conducted to provide a prototype gamma radiation detector capable of operating in the severe environment that will be encountered in the vicinity of a nuclear powered rocket engine is presented. The detector is based on currents produced by Compton scattering in a dielectric material. The technical discussion centers on the theory of detector operation, specific details of fabrication and the results of performance qualification testing. The ruggedized gamma radiation detector is designed to measure gamma radiation intensities in the range of 100,000 to 1 E7 roentgens/hour in a space, ambient and liquid helium environment. It is a self powered device that is capable of operating in a high neutron field, and under extreme conditions of shock and vibration. The three prototype detectors developed have successfully demonstrated compliance with all of the technical requirements. (auth) (USGRDU)

THE COMPUTATION OF PHOTON RADIATION INDUCED ELECTRON EMISSION
W.L. Chadsey, I. Kohlberg
IEEE Transactions Nucl. Sci. NS-19, No. 6(1971)
Describes simple analytical models to determine the transport of charge due to "Photo Compton Currents". The model is one-dimensional and predicts the relative magnitudes of the photoelectron, Compton, Auger, and secondary electron contributions to the emission current. Theoretical results are compared with theory.

TRAPPING OF ENERGETIC ELECTRONS IN SOLID DIELECTRICS
Wm. W. Chang

RADIATION CHEMISTRY OF POLYMERIC SYSTEMS.
Chapiro, A.
A chapter "General aspects of radiation effects in solid polymers" contains a survey and bibliography on radiation-induced conductivity and on spark discharges in irradiated plastics.
THE DOSE RATE RESPONSE OF A DYE-POLYCHLOROSTYRENE
FILM DOSIMETER
S.E. Chappell, J.C. Humphreys
IEEE Transactions Nucl. Sci. NS-19, 175(1972)
Measurements performed at low (10^3 rad/sec) and high (10^{15} rad/sec) dose rates showed no influence of the dose rate.

ENERGY DISSIPATION NEAR AN INTERFACE: AN ILLUSTRATIVE REALISTIC
APPROACH TO ELECTRON RANGE AND STOPPING POWER
D.S. Charlton


18558 EFFECT OF PROTON BOMBARDMENT ON THE
CONDUCTIVITY OF ALKALI HALIDE CRYSTALS.
V.A. Chernyshev.
Irradiation with 4.3 MeV protons resulted in reduction of the electrical conductivity of KCl and KI crystals and gave rise to a break in the linear variation of log \( \sigma \) with the reciprocal temperature 1/\( T \). In contrast, irradiation of KBr crystals with the same doses of 4.3 MeV protons resulted in increase of the conductivity in the temperature range from 20 to 70°C and a small decrease of the conductivity in the temperature range from 70 to 140°C. The values of the activation energy in KCl, KBr and KI crystals, estimated from the slope of the log \( \sigma \) versus 1/\( T \) plot, increased with increase of the radiation dose changed differently in different temperature ranges: in the temperature range up to the point of the break in the log \( \sigma \) versus 1/\( T \) plot the activation energy is reduced, while at temperatures above the break point it increases and, in fact, becomes greater than the activation energy in unirradiated crystals. In the series KCl-KBr-KI the peak in the temperature dependences of \( \sigma_{\text{int}}/q_{\text{rad}} \) shifts to the side of higher temperatures. For each type of crystal, however, the peak shifts to the side of lower temperatures with increase of the radiation dose.

Mica was selected as typical of the B-type insulators. DC, ac, and impulse voltage was applied to the γ-ray-irradiated samples after constant-time doses and time-variable doses. The dielectric breakdown voltage and dielectric constant were measured. It was found that the dielectric breakdown voltage variations are relatively large, but the dielectric constants are almost constant. The above result is useful for the selection and application of the inorganic insulators under irradiation, and it is expected that the result can apply not only B-type insulators but also inorganic insulators. (TSS) (Korean Sci. Abstr.)


The various work undertaken on behalf of the Ministere du Developpement Industriel et Scientifique during the last ten years is examined. The most important problems are defined, and the processes involved in interactions between radiations and insulating materials are discussed in the framework of recent theories. The principal results obtained at the C.E.A. are reviewed, and the idea of associating them with a damage criterion is considered. The opportunity for studying certain fundamental processes not yet well understood is examined. Certain recent, very interesting, results on radiation-excited currents are discussed; these results have led to the proposal of certain new research projects. (France)

A PARAMETRIC STUDY OF DIRECT NUCLEAR ELECTROGENERATOR CELLS USING A BETA EMITTING SOURCE
A.J. Cohen, C.A. Low

NASA-TN-D-2070 (1963)

Reports a design analysis for cells using Co\textsuperscript{144} as a beta emitter. Factors to be considered are the particle energy spectrum, energy losses in the fuel and the support foil, and the relativistic motion of the particles in the electric field. Geometric factors must also be considered. Analytical methods are described which give operational characteristics including weight to power ratio, load characteristics, etc.

ENERGY DEPOSITION RATES AND RADIAL AND POLAR COLOTTON CURRENTS FROM GAMMA-RAY AND NEUTRON SOURCES IN THE INTERMEDIATE ALTITUDE RANGE
H.O. Cohen, R.D. Schamberger
UNC 5154, June 1963
U.C.-Elmford (United Nuclear Corporation, Grassland Road, Elmford, N.Y. 10601)
Results indicate that high insulation resistance can be maintained under radiation if the insulator has been previously irradiated with a sufficient dose.

ELECTRICAL CONDUCTIVITY IN ALKALI HALIDES INDUCED BY ELECTRON BEAM ILLUMINATION
P.R. Collings, J. Hirsch
Brill. J. Appl. Phys. 15, 797 (1964)
Measurements are reported for microcrystalline layers of several alkali halides. Current gains varied, no primary voltage threshold for the effect being found. Saturation of the current was found in some cases.

RADIATION EFFECTS ON DIELECTRIC MATERIALS (Final Rep.)
J.F. Colwell, D.W. DeKichele, R.F. Overmeyer
EOO-01412-F (Report General Dynamics Co., San Diego, Calif.)
AD 64-7335
A detailed description of the techniques and equipment employed in the ion-implantation process is presented. Results of high-energy electron irradiation of a Mylar capacitor with ion-implanted electrodes are compared with the response of a control sample. The ion-implanted electrodes exhibit better carrier injection than conventional foil electrodes. Transient radiation effects data from irradiation of a monolithic ceramic capacitor are included. The transient radiation effects in Mylar versus temperature appear to fit a band model for the conduction process in which the forbidden zone and one sign of carriers is immobilized. An examination of the energy loss process of moderately fast electrons in insulators indicates that from 1.5 to 3 eV the loss is primarily to excitons whereas energy loss to optical and acoustical phonons occurs down to thermal energies.

RADIATION-INDUCED CONDUCTIVITY IN PLASTIC FILMS AT HIGH DOSE RATES
D.M. Compton, G.T. Cheney, R.A. Poll
J. Appl. Phys. 36, 2434 (1965)
Reports a study on Mylar films with 30 MeV electron pulses from a linear accelerator. Since polarization is not observed conduction is assumed to be electronic. Conduction is a bulk effect, an instantaneous and a delayed component are observed. The first increases as the 0.8 power of dose rate, being independent of pulse width; the second increases more slowly with dose rate and saturates at about $10^{10}$ rad(Mylar)/sec. Conductivity increases with temperature from 100 to 300°C. It is assumed that carriers of one sign are permanently and rapidly trapped, whereas carriers of the other sign eventually recombine. Saturation of delayed component indicates existence of a finite number of traps.
GAMMA INDUCED PHOTOCONDUCTIVITY—
IN A POLYETHYLENE TEREPTHALATE CAPACITOR
E.R. Conrad, S.M. Marcus
Diamond Ordnance Fuze Laboratory Report TR-1037 (1962)

TRANSIENT RADIATION EFFECTS IN ELECTRONICS
E.E. Conrad
In: Advances in Nuclear Science and Technology. Vol. 3
Effects of neutrons, gammas and electrons in the energy range from 0.25 eV to 10 MeV are discussed.
Only ionization phenomena which alter the properties of electronic components are considered, but both dose and rate effects on metals, insulators, semiconductors and gases are included, particular attention being given to radiation effects on insulators.

DIELECTRICS WITH PREDICTABLE RADIATION RESPONSE. Conrad, Edward E. (Harry Diamond Labs.,
See CONF-691042.
A review on radiation response in organic dielectrics concluded that the observation of highly mobile short-lived carriers in liquid organic dielectrics is now possible. Furthermore the capability exists to vary the free carrier lifetime by the removal or introduction of a specific impurity. The proved feasibility of these techniques constitutes a major step toward a better understanding of radioinduced conductance in organic dielectrics. (P.C.H.)

THE MOD III FAMILY OF PRODUCTION COMPTON DIODES
M.M. Conrad
SC-TM-72 0217 (Rep. Sandia Corp., to be published)
CHARGE DISTRIBUTION AND RANGES OF HIGH-ENERGY ELECTRONS IN LIGHT MATERIALS

R.D. Cooper, W. Alexander, A. Brynjolfsson


U.S. Army Natick Laboratories

Measurements are reported for water, oil, and Al irradiated with monoenergetic electrons between 4 and 25 MeV. Near the beam entrance point charge is removed and driven deeper into the material, leaving a net positive charge near the surface. The peak of the charge distribution is at a depth of 0.4 g/cm² for energies above 10 MeV and somewhat at a lower depth for lower energies. Integration of the distribution curves gave charge transmission curves.

TRANSIENT PHOTOCONDUCTIVITY OF POLYSTYRENE AND POLYISOBUTYLENE EXPOSED TO PULSES OF NEUTRON AND GAMMA RADIATION

F.N. Coppage

PAPER CP 62-1238, IEEE Summer Meeting, Denver, June 1962

TEMPERATURE DEPENDENCE OF PHOTOCONDUCTIVITY INDUCED IN POLYSTYRENE BY TRANSIENT RADIATION

F.N. Coppage, F.C. Peterson

(Sandia Corp., Albuquerque, N. Mex.) July 1964, Contract AT(29-1)-789 (CONF-617-3)

Special Technical Conference on Nuclear Radiation Effects, Seattle, July 1964

Results substantiate existence of internal field resulting from trapped space charge and reaching saturation at small doses (~20 rad at -80°C). Saturation dose increases with temperature. The space charge results from migration of carriers with subsequent trapping at metastable states.
SOME PROPERTIES OF CONDUCTIVITY INDUCED IN POLYSTYRENE BY PULSED GAMMA RAYS
P.N.Coppage, P.O.Peterson
From IEEE Annual Conference on Nuclear and Space Radiation Effects, Ann Arbor, Mich.

Measurements with pulsed radiation avoid space charge and polarization effects. Both the instantaneous current (during irradiation) and the long-lived photocurrent are observed. The latter depends on temperature, its time dependence corresponding to a bi-molecular reaction. This is shown by 1/current versus time being a straight line. Results permit to determine conductivity parameters, including no and drift mobility of carriers, average distance travelled, and average energy to create a carrier, the latter being of the order of $10^5$ eV. The charge current integral of the long-lived component increases linearly with voltage, thus showing that carriers drift over distances which are only a small fraction of the inter-electrode distance. The temperature effect permits to determine a well-defined activation energy of 0.2 to 0.3 eV.

The long-lived component is attributed to a thermally activated drift mobility.

PHOTOCONDUCTIVITY PROCESSES IN LOW MOBILITY ORGANIC MATERIALS
P.N.Coppage, R.G.Kepler

Measurements on high purity anthracene crystals are reported. In such samples lifetimes of electrons and holes are in the 1.0 μsec range. Thus the number of carriers produced can be obtained by sweeping them out of the sample with a sufficiently high field and measuring the externally collected charge. It is found that a few 000 V are needed to produce one external carrier pair, with samples under 600 keV X-radiation. The high energy, or low yield, is caused due to “preferential” recombination, i.e., an electron-hole pair once created does not appear as free carriers unless they are created in such a way that they become separated by a minimum distance r, which is the distance at which the thermal kinetic energy of the electron ($3/2 kT$) is equal to the potential energy of the electron in the Coulomb field of the hole. Applications are also made to polystyrene whose chemical composition is identical with that of anthracene.
EVALUATION OF THE EFFECTS OF TRANSIENT RADIATION ON CAPACITORS
F.N.Coppsage
Sandia Corp., Albuquerque, New Mexico. Contract AT(29)-789
Increased leakage current results from creation of charge carriers within the irradiated material. The prompt current component is coincident with the incident radiation; the delayed or long-lived component persists following radiation exposure. Both components were characterized for some materials as functions of temperature, for pulsed radiation. Gamma radiation is more effective in current production than neutrons. An RC time constant is more descriptive of the effect and figure of merit of materials than current intensity or dielectric loss angle.

Measurements of photoconductivity in several organic dielectrics irradiated with neutrons and gamma rays reveal that neutrons, relative to gamma rays, are less effective, per unit absorbed-dose rate, in causing photoconduction. Photoconductivities of polystyrene, polyisobutylene, Mylar, H-film, reconstituted mica, cellulose acetate, and polycarbonate were measured during exposures in the Sandia Pulsed Reactor. The ratio (\(\frac{n}{\gamma}\)) of the neutron absorbed-dose rate (\(n\)) to the gamma-ray absorbed-dose rate (\(\gamma\)) was varied with preferential shielding to separate the components of photoconduction arising respectively from neutrons and gamma rays. The empirical equation,

\[ \sigma = A_n n + A_\gamma \gamma \]

was found to fit the data of the measured photoconductivity (\(\sigma\)), where \(A_n\) and \(A_\gamma\) are empirical constants characteristic of a dielectric material. The ratio, \(\frac{A_n}{A_\gamma}\), is a measure of the effectiveness of neutrons relative to gamma rays, in producing photoconduction for the materials studied. 0.06 \(\leq \frac{A_n}{A_\gamma}\) \(\leq 0.55\). The ratio, \(\frac{A_n}{A_\gamma}\), for two samples of the same dielectric type contained in capacitors of two manufacturers was observed to differ by as much as a factor of two. The origin of the difference was not determined. (auth)

USEFUL TECHNIQUES FOR ANALYZING CAPACITOR TRANSIENTS IN RADIATION ENVIRONMENT
W.A.Cordwell
Analysis methods to relate the capacitor's radiation-induced current generator to the basic parameters, \(d(t), K_d, K_a,\) and \(t_d\), using existing techniques of circuit analysis programs. An expression relating the change-in-voltage resulting from an absorbed dose for an arbitrary burst shape is also derived.
DISTRIBUTION OF ABSORBED BETA ENERGY IN SOLID MEDIA
W.G. Cross
Canadian J. Phys. 47, 75 (1969)
Chalk River Nuclear Labs., Chalk River, Ontario, Canada

Distributions of deposited beta energy have been measured in plane geometry, in Al and NE 102 plastic (C19H21) for seven emitters with endpoint energies of 0.16 to 3.55 keV.

GAMMA-RAY INDUCED ELECTRICAL DISCHARGE IN A RADIATION SHIELDING WINDOW.
Culler, V.
In Proceedings of the Seventh Hot Laboratories and Equipment Conference, Cleveland, Ohio, 1959. p. 120.

An electrical discharge of a dry type radiation shielding window was accidentally produced during the cleaning of a hot cell. A brief analysis showing how gamma-irradiation of a dielectric material can produce the large electric fields needed for breakdown is given. A discussion of measurements on mock-up windows includes estimations of the irradiation time, dose, and the geometrical configuration needed for the electric field buildup. The resting time needed for decay of the field is also discussed. Other measurements show that similar discharges can be produced in many glasses and other dielectric materials.

GAMMA-RADIATION INDUCED CONDUCTIVITY IN GLASS.
Culler, V.E., Rexford, H.E.

Measurements were made on Corning borosilicate, aluminosilicate, and lead silicate glasses and on fused silica. Source of gamma radiation were four fuel elements freshly removed from the core of a reactor. Temperature effects were observed.
GAMMA-RADIATION INDUCED CONDUCTIVITY IN GLASSES
V.M. Culler, H.E. Rexford
Measurements are reported on fused silica, aluminosilicate, borosilicate, and alkali lead silicate glasses. The highest effect is found for fused silica, where 10 rad(H₂O)/sec produce an increase by a factor of 10² in conductivity at room temperature. Results are interpreted in terms of Rose's theory.

GAMMA RADIATION - INDUCED CONDUCTIVITY IN GLASSES
V. E. Culler, H. E. Rexford
Measurements are reported for fused silica, aluminosilicate, borosilicate, and alkali-lead silicate glasses, with dose rates up to 10 rad(H₂O)/sec. For fused silica, which shows the greatest effect, conductivity at room temperature increases from 10⁻¹⁰ mho/cm to 10⁻¹⁵ mho/cm for 10 rad/sec. Temperature effects are measured and effects are interpreted by Rose's theory of photoconductivity.
In the derivation of the conductivity expression, a general theoretical development for the production of conduction band electrons by gamma photons is presented. When charge carrier mobility is considered, the development was limited to crystals having ionic bonding. Due to difficulty in evaluating constants in the developed expression, all constants were combined into one constant, which was considered to be independent of temperature and radiation. This constant was evaluated experimentally. A model was developed for predicting the conductivity of ionic insulators as a function of temperature and radiation dose rate. The model is \( \sigma(T,P) = \sigma(T) + PG \exp(-W/RT)(T^{3/2}) \), where the first term on the right represents the ionic conductivity of the material without a radiation field present and the second term describes the radiation-induced conductivity. The term \( P \) represents the gamma photon dose rate in R hr\(^{-1}\), \( G \) is an experimentally determined constant, and \( W \) represents the energy necessary to raise trapped electrons into the conduction band. The temperature dependence of the mobility is represented by \( T^3 \). Evaluation of experimental data for alumina gave \( W = 0.056 \pm 0.014 \text{ eV} \) and \( G = 7.4 \times 10^{-21} \text{ (ohm}^{-1}\text{ cm}^{-1}\text{ K}^{-3/2}\text{ R}^{-1}\text{ hr})} \).
THE GENERATION AND DISSIPATION OF STATIC CHARGES ON DIELECTRICS IN A VACUUM

D.K. Davies


Describes an experimental technique for measurement of carrier mobilities based on determination of the decay of the surface potential of a surface-charged dielectric with a floating surface.

CARRIER TRANSPORT IN POLYMERS

D.K. Davies


Reports in vacuo mobility determinations using a charge deposition technique. Mobility has also been determined in two of the polymers impregnated with iodine. The latter increases mobility by about a factor of 10^4. Results are discussed in terms of a hopping transport mechanism and indicate a significant barrier in transition between crystalline and amorphous regions. Iodine reduces trapping either by carrier acquisition and transport, or by charge exchange complex formation.

CHARGE TRAPPING IN POLYMERS

D.K. Davies, P.J. Lock

J. Electrochem. Soc. 120, 266 (1973)

THE PENETRATION OF keV PROJECTILES IN SOLIDS

J.A. Davies

Conf. 670534-5 (AECL-2757) August 1967

From 15th Annual Conf. on Mass Spectrometry and Allied Topics, Denver, Col.)

Discusses information on the penetration of energetic (0.5 to 500 keV ions) in solids. Technique consists in bombarding the solid with a monoenergetic beam of radioactive ions and subsequently measuring the depth distribution of the embedded radioactivity by a high precision sectioning technique. In amorphous targets results agree well with Lindhard's theory, but in oriented crystalline targets the mean penetration is increased up to 10-fold by channeling of the beam along the open direction or planes in the lattice. The dependence of this effect on energy and atomic number of the ions has been studied, also its dependence on radiation damage, surface imperfections, and crystal misalignment.
DERIVATION OF AN EXPRESSION FOR RADIATION-INDUCED ELECTRICAL CONDUCTIVITY IN IONIC INSULATORS
J. G. Day
BNW-SA-247, University of Arizona, September 1965

ION BOMBARDMENT AND IMPLANTATION
G. Dearnley
Reports on Progress in Physics 32, 405 (1965)
Atomic Energy Res. Establishment, Harwell, Berkshire, England

ELECTRIC BREAKDOWN IN PLASTICS IRRADIATED WITH CHARGED PARTICLES. Dee, Yu. S.; Kruglyi, M. S.;
The tree-shaped cracks formed in poly(methyl methacrylate) after exposure to fast electrons have been attributed to radiolysis
and secondary processes induced by it. It may be assumed that the space charges created by the slowing down of electrons generate internal stresses in the material by means of electrostatic interaction. This in turn causes the formation of trajectories with greatly reduced mechanical and electric strength and with a short half-life. The mobility of the molecules of the polymer is greatly reduced in the vitreous state, resulting in low relaxation rates; under such conditions the time of life of the trajectory may become sufficiently long to create a discharge. The proposed mechanism allows prediction of the behavior of organic glasses with respect to the tree-shaped fissuring process on the basis of the physical and mechanical properties of the material. (TTT)

PULSED NUCLEAR-RADIATION-INDUCED TRANSIENTS IN ELECTRONIC PARTS AND MATERIALS (GODIVA IV and V).
Pulsed nuclear radiation-induced changes in the electrical characteristics of electronic parts and materials obtained in two experiments at the Godiva II Reactor (Los Alamos) are described and discussed. The electronic parts investigated and monitored during exposure include coaxial cables, resistors, capacitors, rectifiers, and magnetic cores of various types, values, and materials. Most of the parts during exposure show transient parameter changes which exceed the tolerance values and then generally recover to their nominal values some time after completion of the radiation pulse. Some of the data show inconsistencies which prevent definite and quantitative conclusions at the present time. In some cases, e.g., low and high value resistors, NiCr thin film resistors of various values, and ceramic capacitors, the data show certain repetitive patterns in the behavior of these parts which seem to permit a limited qualitative prediction of the responses of these components under similar environmental conditions. Experiments at Godiva-type (pulsed) facilities are being continued.
Paper presents an analytical method to determine the forward, backward, and net photo-Compton currents in unbounded media that includes the effects of electron multiple scattering. The method gives the exact solution for the transport equations modeling primary electrons (i.e., Compton, photoelectric, and Auger electrons) and provides current predictions within a few percent of the more complete Monte Carlo models. A code QUICKS! has been written to perform these calculations for arbitrary elements or compounds irradiated with 10 keV to 20 keV photons. Representative results are presented which are directly applicable to the calculation of the fields generated within an irradiated dielectric cavity or of the magnitude of charge trapped at insulator surfaces. Furthermore, the forward and backward currents in an unbounded medium are upper bounds respectively on the forward and backward emission currents at vacuum-medium interfaces and are thus useful in worst case analyses. Finally, a simple model is proposed to use the data on the photo-Compton currents in unbounded media in hand calculations of the spatial dependence of the nonlocal energy and charge deposition at interfaces.
Using short pulses of non-penetrating electrons, electron and hole mobilities are found to be about 1 cm²s⁻¹V⁻¹ in the case of single crystals. The field dependence of the collected charge and the current gain observed for penetrating electrons are explained by a simple model.

Data on response of various capacitor types to various transient gamma radiation environments are tabulated. Tables were computer-generated. Values represent averages of many similar capacitors.

A current monitor has been developed to measure the electron current pulse from the NES 2 MeV pulsed electron generator. This monitor features low inductance and a risetime of the order of a hundred picoseconds, enabling it to faithfully reproduce high frequency components present in the electron beam pulse. In addition, a charge integrating system comprised of an integrating capacitor and a precision integrator has been developed to measure the total charge contained in the electron beam pulse.

The monitor is essentially a Faraday cup with low resistance and low impedance output which permits to measure the incoming current as a function of time, or to obtain its integral by the integrating capacitor circuit.

The definition of response function and the convolution integral are presented for purposes of predicting detector signals. Response functions are determined for a Cherenkov photodiode detector, a fluor photodiode detector, a vacuum Compton diode, and a fully-depleted silicon p-n semiconductor detector.
ELECTRICAL DISCHARGES IN ELECTRONIRRADIATED SHEETS OF PLEXIGLAS AND EPOXY RESINS
P. Dokopoulos, E. Marx
ETZ (Elektrotechnische Zeitschrift) A, 88, 617 (1967)

Experiments were carried out with 3 MeV electrons, and a current density of 150 micro-A/samples are moved under a scanning beam with 2.5 cm/sec. Discharge figures are similar to those by Gross, their average distance from the electrode of incidence is given by U/3d where U the voltage and d the density of the material. It is found that discharge figures obtained after irradiation differ from those which might spontaneously develop during irradiation, in that in the latter case there might be crossing channels. It is believed that this is due to partial discharges. It is possible to fill the (empty) discharge channels with a liquid of the same refraction index as the plastic and thus to make them invisible. Currents and charges have been measured with an oscillograph. Maximum currents of about 60 A were observed, duration of the discharge was of the order of 200 ns for the negative and the same value for the positive pulse. Thus a current reversal was observed, the area under the positive section somewhat smaller than under the negative one. Before the discharge the sample as a whole was, however, neutral, as was found by measuring its total charge by dropping it into a Faraday cage. (The negative pulse corresponds to the discharge of the electron layer, the positive one to that of the surface compensation charge which have opposite polarities. The difference between the two is probably due to the fact that not all the compensation charge did flow to the electrode, there being some corona discharge. It is interesting to note that the two charges can indeed be separated by their different relaxation times.

LIFETIME OF TRAPPED CHARGE IN ELECTRONIRRADIATED DIELECTRICS
J. Dow, S. V. Nablo

Trapped behavior of trapped charges in dielectrics produced by 2 MeV electron bombardment is investigated. Charges are measured by deflection of a low energy (10 keV) electron beam grazing the surface of incidence of the beam. Total charge retention and charge decay curves at different temperatures are measured. Lucite and aluminosilicate glass gave nearly 100% retention, while polythene and teflon gave lower numbers. Charge decays faster with increasing temperature; decay curves can be represented as a series of exponentials with short time components enhanced by dosage.
The grazing electron beam probe technique has been used to study the behavior of the electric field external to planar irradiated samples in vacuo. The trapped charge density is determined from the experimental results and its behavior during and after irradiation studied with microsec resolution. Secondary phenomena associated with bombardment dose rates from \(10^6\) to \(10^{10}\) rads/sec include charged particle emission, backscatter, and luminescence. The trapped value of the trapped charge during and after irradiation has been determined.

**Measurement of Gamma Ray Induced Secondary Electron Current from Various Elements**

P.J. Ebert, A.F. Lauzon

UCRL-14270, IEEE Nuclear Science Symposium, San Francisco 1965, CONF-651001-16 (Lawrence Radiation Lab, Univ. of Calif., Livermore).

Angular distribution and absolute efficiency for gamma ray produced secondary electrons must be known for development of fast radiation detectors, dosimetry, and transient effect studies. These quantities were measured for \(1.25\) MeV gamma radiation, for elements with atomic numbers \(6, 13, 29, 48, 82\). Target thickness was a) approximately equal to extrapolated electron range and b) \(1/10\) of this range. A difference between total target current and total forward current was observed which increased with atomic number and target thickness, due to electron backscattering. Application of Mar’s electron transmission formula gives results in agreement with experiment.
MEASUREMENT OF GAMMA RAY INDUCED SECONDARY ELECTRON CURRENT FROM VARIOUS ELEMENTS
P.J. Ebert, A.F. Lauzon
IEEE Transactions on Nuclear Energy 1, 735 (1966)

VACUUM DIODE DETECTOR FOR MEASURING HIGH INTENSITY GAMMA-RAY FLUX
P.J. Ebert, A.F. Lauzon
Describes a Compton vacuum detector. A theory of detector sensitivity is given, positive pulses resulting from electron loss of plate and negative pulses due to electron gain are mentioned. In the steady-state mode, a sensitivity of $10^{-12}$ A is found. Linear signals greater or equal to $5 \times 10^{-2}$ A have been found corresponding to a 1.25 MeV energy dose rate of greater than $10^{10}$ R/hr for fast pulses. Scillograms of pulse shapes are given. Minimum signal measurable depends on sensitivity of recording system which is $2 \times 10^{-3}$ A or 0.1 V into a fast scope with a 50 Ohm termination. Currents up to $10^{-2}$ A were measured. In the dynamic case the travel-time of the electrons depends on their energy, thus departure from linearity depends on plate voltage and on rate of rise of plate voltage.

MEASUREMENT OF X-RAY INDUCED ELECTRON CURRENTS FROM METAL TARGETS
P.J. Ebert, J.L. Gaines, C.R. Leipelt
UCRL-50691, June 23 (1969)
Discusses photoelectric diodes (PED) mostly for X-rays with energies between 10 and 100 keV, giving forward to backward yields, quantum efficiency as a function of angle and of thickness. With low-energy X-rays saturation is reached with thicknesses of 8 mg/cm². Some measurements are shown for reaching secondary electron equilibrium with Al and Pb for the case of Co $^{60}$ 1.25 MeV radiation and thickness up to 2.6 g/cm².

52492 FURTHER DATA ON GAMMA-INDUCED ELECTRICAL CHARGE AND COLORATION OF SHIELDING GLASSES.
Two cerium-protected shielding glasses, now available commercially, have been shown by irradiation testing to be immune to spontaneous electrical discharge during total exposures of at least $1 \times 10^{8}$ R at exposure rates as high as $1 \times 10^{6}$ R/hr. One, a lead glass of 3.27 specific gravity with greater than normal stabilization against gamma darkening, is Code 84S9 produced by Corning. The second, a borosilicate glass of 2.32 specific gravity which also contains greater than normal stabilization against gamma darkening, is RS33G/25 by Schott Glass Inc. In addition, this second glass did not discharge electrically when given an impact shock immediately (within 20 min) after cessation of irradiation. Such glasses should be of interest to buyers of shielding windows where the first thick slab of glass is subjected to total exposures $25 \times 10^{8}$ R at rates as low as 40,000 R/hr. These were the conditions under which the March 1970 incident of spontaneous discharge occurred in a shielding window installed in an active hot cell. (auth)
A series of measurements was undertaken to study short-time phenomena in several representative plastic and ceramic materials including polyethylene, polytetrafluoroethylene, polystyrene, alumina, magnesia, silica and beryllia. The frequencies were in the 1-10 GHz range, corresponding to L, S and X bands. A resonant cavity method was used and moving film records were obtained of response curve oscillograms. The irradiation was performed in a General Atomics Triga pulsed reactor of the swimming pool type. Results are given in detail.

ENERGY RESPONSE AND EFFICIENCY OF COMPTON AND PHOTOELECTRIC CONVERSION DETECTORS

Tech.Memo L-161,EGG-1183-1252,July 26,1966

Gives

137 Cs $1.85 \times 10^{-11}$ A per R/sec

60 Co $3.77 \times 10^{-11}$ A per R/sec

STATIC VERSUS DYNAMIC SENSITIVITY OF SEVERAL WEAPONS DIAGNOSTIC DETECTORS

EGG 1183-2236,May 1970

Describes results of the measurement of dielectric detector sensitivities as a function of pulse width (1 ns to 4 micros). Results showed the dielectric detector to be independent of pulse width.

Comparison with the L 125A detector showed, however, that this latter (vacuum) detector showed some non-linearity. However, since the current from the vacuum detector was small, the error involved was very large; thus no definite conclusions were possible. Yet, the experimenters could think of several reasons why the dielectric detector might be not linear, but none while the vacuum detector should be non-linear. This motivated further research by Artuso (EGG 1183-2277) which showed that the non-linearity appeared to be due to the cable response which was causing distortion for the less sensitive vacuum detector.

ELECTRON BOMBARDMENT CONDUCTIVITY IN ZINC SULFIDE

W.Ehrenberg,N.J.Hidden


Measurements on vacuum deposited films of zinc sulfide and on plates of wurtzite with 2 - 50 keV electrons are reported, for blocking contacts. Only the induced currents, not the primary electron currents, are investigated. The effect of the range of the electrons with regard to sample thickness is discussed. It results that films respond to steady bombardment only if the electron energy exceeds a threshold value necessary to guarantee that the electron range is almost equal to sample thickness, while the crystals respond only if the bias is high enough so as to exceed the potential drop set up in the crystal when all deep traps are filled.
Penetration of Electrons into Luminous Materials
W. Ehrenberg, B. N. King

The glow production in a number of phosphors due to a narrow bundle of cathode rays is studied, giving electron ranges in the 10 - 80 keV energy range. These range values are found to be proportional to the integrated path lengths given by Bethe's formula. Energy dissipation values are also determined.

Electron Bombardment Induced Conductivity in Fused Silica
W. Ehrenberg, V. B. Gutam, L. K. Vodopyanov

Cathode ray and beta ray induced conductivity is studied. Fused natural quartz samples show the weakest effect, while crystal samples and amorphous specimens give higher results. Amplification factors of up to 300 are observed. Metallic impurities reduce the effect. An interpretation in terms of recombination centers and an alternative one in terms of exciton generation and decay are offered.

Columnar Ionization in the Electron Bombardment Conductivity of Amorphous Dielectrics
W. Ehrenberg, B. Gosh

Conduction induced in arsenic trisulphide films by beta and cathode rays is studied as a function of film thickness and incident beam currents. Films between 2 and 20 micrometers thick have been studied, beam energy being sufficient for complete penetration of the films. The majority of the carriers is generated along the paths of the primary electrons and only those escaping recombination in these columns are available for conduction. The low escape probability is probably responsible for absence of saturation of the induced conduction with voltage bias. Under steady-state conditions the free path of the carriers which escape columnar recombination is normally long enough not to reduce the efficiency of their collection appreciably.
THE USE OF CAT, TL THERMOLUMINESCENT DOSIMETERS FOR MEASURING ELECTRON-DOSE DISTRIBUTIONS IN DIELECTRICS

MARSHALL EINICH

It has been pointed out in the literature that, for the high electron fluences encountered per pulse in modern high-current pulsed electron generators, energy deposition in dielectrics occurs at shallower depths than in conducting media, and that, with an increase in electron fluence, there is a shift in the location of the peak of the depth-dose curve toward shallower depths.

Although the dynamic range of thermoluminescence (TL) dosimetry systems precludes their use for the very high fluences for which the above results were obtained, it was, nevertheless, considered of interest to examine the response-in-depth of these dielectric systems in a dielectric environment, and compare the results with theory. A Cat, phantom containing tracks of Cat, was radiographed in vacuum with a collimated beam of 3 MeV electrons. The total electric charge collected in the phantom varied from about 2 x 10^-10 to 6 x 10^-9 C.

Curves of response-in-depth will be presented which demonstrate that, even for the relatively low total electric charges injected into the Cat, in the present experiments, there is a significant difference between the shape and peak location of the TL response-in-depths curves and corresponding depth-dose curves computed without consideration of charge trapping. The peak of the experimental curves occurring at shallower depths than the peak of the corresponding depth-dose curve. If an aluminum phantom (equivalent but non-conducting) is used instead of the Cat, phantom and the stack of TL plaques is interposed with thin aluminum foils, the discrepancy between experimental TL response-in-depth and computed depth-dose curves is somewhat smaller. Over the charge range investigated, no significant change in peak location with a change in collected charge could be demonstrated.

1. B. Ucker, I. Kohlberg, S. V. Hablo, J. Appl. Phys. 36, 2064 (1965)
4. W. J. Berge and S. N. Saltzer, NASA SP-2012 (1966), and private communication


A universal curve of energy-dissipation range vs normalized electron energy is proposed, which includes the average atomic number Z of the material being bombarded in the energy normalization factor. Range—energy expressions of the form \( R = kE \beta \) derived from the Bohr-Bethe energy-loss relation, are valid over limited energy ranges, but the exponent \( \beta \) differs for materials of greatly different atomic numbers over the same energy range. For the aluminum/silicon dioxide/silicon system used here, \( k = 4.0 \text{E} \text{g}\text{cm}^{-2} \text{keV}^{-1} \) was found accurate for \( 5 < E < 25 \text{ keV} \). Using this value of range, and taking the steady-state electron-beam-induced current through a thin insulating layer of SiO\(_2\) as a measure of the energy dissipation in that layer, an energy-dissipation (depth-dose) function was determined that should be valid for 10 < Z < 15. Using this normalized expression \( A(E) = 0.50 + 6.32 - 12.65E^2 + 5.69E^3 \) and the range \( R_0 \), the energy dissipated at any depth may be determined, and hence the carrier-pair generation in semiconductors, light generation in phosphors, etc., may be predicted. An expression relating the depth-dose function to the applied voltage drop across the oxide provided an independent check on the experimental measurements.

The use of radiochromic dye films (hexahydroxyethyl paranorezaline dye cyanide in nylon) for electron dosimetry has been extended to absorbers with atomic numbers in the range 13 to 50. The depth-dose profiles in slab targets of aluminum, copper, and tin irradiated by a plane parallel 2.00-MeV electron beam are presented for incident beams at 0, 30, and 60 degrees with respect to the surface normal. Absolute energy deposition per unit fluence was determined by using calibrated films, a fluence measurement, and a stopping-power ratio correction. The results are compared with the ionization measurements of Nakai and to the theoretical calculations of Berger and Siltzer; all agree within 10 percent. The stopping-power ratio, necessary to convert dose in the dye film to absorber dose at that point, is determined three ways and the results compared. The three techniques range from a detailed computer transport calculation yielding a variable stopping-power ratio with depth to the use of a constant stopping-power ratio obtained from tabulations. It is demonstrated that the use of the constant stopping-power ratio gives depth-dose distributions that differ by no more than 1 to 2 percent for aluminum, 3 to 5 percent for copper, and 4 to 8 percent for tin from the results obtained with the more rigorously evaluated stopping-power ratios. (auth) (UK)


The effects of temperature on the decomposition of polycrystalline samples of NaNO₃ during irradiation with 5-MeV protons and 20-MeV α particles were studied. In the ln G vs 1/T graph, two regions were noted that differed in their energies of activation. The common boundary of these two regions was 324°K for protons and 345°K for α particles. (K.S.W.)

GAMMA-RADIATION-INDUCED CONDUCTIVITY IN NUCLEAR SHIELDING GLASSES AS DETERMINED BY SPACE CHARGE DECAY

F. K. Ernsberger, T. E. McGary

Glass samples were charged by irradiation with 2 MeV electrons from a Van de Graaff generator. The decay of the charge was measured by discharging the samples at various times into a capacitor arrangement and measuring the resulting voltage. Measurements were taken at various times after irradiation, with and without gamma irradiation. In this way both the normal charge decay and the speed-up of this decay by gamma-ray-induced conductance was determined. The influence of the composition of the glass, of gamma-ray intensity, and of temperature were observed.
UV DOSIMETRY BY ZnS ELECTRET DISCHARGE.


A method of uv dosimetry is described which depends on electric depolarization in single crystal and powder specimens of ZnS by the incoming radiation. The residual polarization can be measured by optical or thermal readout procedures. In both cases, the mechanism is electronic. The dosimetric characteristics of these systems are described and comparisons made with corresponding dosimetric procedures based on pyroelectricity and current-glow. Measurements of the type described also yield information on trap distributions in insulators. (auth) (UK)

POLYMER THERMOELECTRET DOSIMETRY

G.W. Fabel, H.K. Henisch
Phys. Status Solid (a) 6, 535 (1971)

Measurements are reported with nylon, mylar, polystyrene, and teflon electrets. Samples were irradiated without a covering electrode on the exposed surface. Polarization was measured by monitoring the surface potential with a contactless voltmeter probe. The effect of storage environment, forming temperature, and forming field were studied. Except nylon, all materials gave stable electrets under normal conditions. In the presence of X-rays or thermal neutron irradiation they undergo a rapid cumulative discharge. Total dosage received can be inferred from a comparison of initial and final polarization. For 50 kV X-rays, 1 mR is easily detectable. Higher sensitivities are believed to be attainable in principle. Similar high sensitivities are reported for neutrons.

STUDIES IN PENETRATION OF CHARGED PARTICLES INTO MATTER

U. Fano, ed.

Collection of articles, including extensive tables. The following definitions of "Range" are given:

- "Range" of a particle should indicate its "mean" (rectified) path length from its relevant point of departure to the point where it comes to rest, that is where further displacement is not detectable. "c.d.s.a." indicates the quantity \( \int_0^{\infty} (\frac{dE}{ds})^{-1} dE \) which represents the range in the continuous slowing-down approximation.
- "Projected range" indicates the mean depth of penetration into the material, that is the mean projection of a particle's path on its direction of incidence on the material. "c.d.s.a." range is the path length which a particle would travel in the course of slowing down in an unbounded homogeneous medium, from initial to zero energy, if its rate of energy loss along the entire track length were always equal to the mean rate of energy loss. Thus it differs from "Projected range" and "Extrapolated range", which are usually defined with reference to transmission through a plane-parallel absorber.
Measurements are reported of the photoconduction spectra of several electron-irradiated type Ia and type IIa diamonds in the neighborhood of the GR1 and NDI absorption systems, and the absorption lines which have been labelled GR2 to GR8, R9, and R10. Minima occur in the photoconduction spectra at the positions of maxima in the GR1 absorption system. Sharp peaks which persist at temperatures down to 8°K are observed in the photoconduction spectra at the positions of maxima in the NDI absorption system and the lines GR2, etc. Mechanisms which might give rise to these sharp photoconduction peaks are discussed.

Dissipation of charge layers in dielectrics
G.L.Ferreira, B.Gross
Rev. Brasil. Fisica 2, 205 (1972)
The paper discusses the dissipation of a uniformly charged layer (box distribution) embedded in a dielectric with intrinsic conductivity. It is shown that an exact analytical solution can be found. Applications to the short-circuit case are given.

Currents and charges in radioelectrets
G.F.L.Ferreira, B.Gross
The paper discusses the discharge current produced by the detrapping and transport of charge carriers from a nonpolar charge layer located deeply in a dielectric. For the cases of no retrapping and of fast retrapping in a single trapping level it is shown that the initial current rise is independent of the shape of the charge distribution. Exact analytical expressions for the external current and for the space-charge density as functions of time are given. They are valid as long as the space charge does not reach one of the electrodes.
COMPTON DIODES: THEORY AND DEVELOPMENT FOR RADIATION DETECTORS

T. R. Fewell
Instrumentation, Dosimetry, and NTS Projects Division, Sandia Laboratories, Albuquerque, NM 87115
Printed October 1972

The Compton diode is examined from an engineering aspect. A brief operational-type discussion of the detector is presented; each component of the Compton diode is examined in both theory and experiment. Special emphasis is placed on designing a Compton diode which is very reliable but simple in construction. It is shown that one can design a detector whose signal is nearly equal to the number of electrons impinging upon the collector. At radiation levels and rates used in our experiments, the detector is essentially insensitive to problems such as charge buildup in dielectric, electron backscattering, and other factors. Some design hints are also given to solve problems which could occur at higher radiation levels.

OBSERVATION OF RADIATION-INDUCED THERMALLY STABLE ELECTRICAL ACTIVATED DEPOLARIZATION IN LITHIUM FLUORIDE
D.E. Fields, P.R. Horan
Phys. Rev. Lett. 29, 721 (1972)

A large permanent electrical polarization can be induced in LiF by ionizing radiation, in particular X-rays. Specific radiation-induced polarizations, after thermal depolarization (e.g., cooling) can be regenerated optically (e.g., by illumination with optical light and simultaneous exposure to a polarizing field), but not by thermal repolarization (e.g., heating with an external field applied). Rate parameters characterizing thermal depolarization differ from those of other thermally activated processes. The effect has a signal-to-noise ratio comparable to simultaneous thermoluminescence measurements, which suggests practical applications in dosimetry and other fields. A discussion with regard to radioelectret properties is given.

STUDY OF EFFECTS OF IONIZING RADIATION IN CAPACITORS
T.W. Blanigan, J.W. Harrity
Gulf General Atomic Report GA-10002, April 1970

Reports measurements of RIC (rad-induced cond.) at $10^7$ to $10^{10}$ rad/s for Teflon.
Design, construction, and testing of an integrating gamma-ray dosimeter for high dose rates are discussed. The sensor is a silicon surface-barrier detector operating as a current device. The detector output current is integrated on a capacitor. When the voltage on the capacitor rises to a predetermined level corresponding to 10 rad-equivalent-air of gamma-ray dose, the capacitor is discharged and the instrument produces an output pulse to signal the event. The number of output pulses indicates integrated dose, and the pulse repetition rate indicates dose rate. The detector proper is cooled with a thermoelectric cooler to minimize and stabilize leakage current. The instrument is designed for operation in the dose-rate range of 10 to 100,000 rad-equivalent-air per second. The detector is constructed to make it function as a Bragg-Gray device over the gamma-ray energy range of 80 keV to 12 keV. The detector is reasonably isotropic. Cumulative errors due to all causes are less than about 3%. The electronics is insensitive to gamma-radiation transients for dose rates up to $10^6$ rad/s. Results with radioactive sources, a fast-burst reactor, and bremsstrahlung pulses are given.

OPTICAL IONIZATION OF ELECTRICAL BEAM LANDING ENERGY ON SEMICONDUCTORS

M.A. Foss
J. Appl. Phys. 43, 914 (1972)

Charging effects of semiconductors (with $10^2$ to $10^4$ Ohm cm) are investigated. An electron beam is scanned along a semiconductor target parallel to an adjacent metal reference electrode. The leading edge of the beam charges the semiconductor to a level determined by surface and bulk conductivities of the conductor. This conductance varies with optically exciting carriers in the semiconductor thereby altering the maximum charge-up potential and thus the total electron landing energy. The potential can be determined by measuring secondary emission current from the target. The electron landing energy can be changed by several hundred volts on Si and CdTe targets depending upon the photon input flux. Primary currents were $10^{-5}$ down to $10^{-7}$ A, beam voltage 1.5 keV.

CONDUCTIVITY INDUCED IN INSULATING MATERIALS BY X-RAYS

J.R. Fowler, F.T. Farmer

Measurements on polythene show conductivity $\propto$ (dose rate)$^{0.8}$. Small doses, below $10^4$ r, create traps and deep levels which do not decay with time. For perspex, the conductivity increases linearly with dose rate, independently of temperature, indicating a uniform trap distribution in depth with a gap between superficial and deep traps.
CONDUCTIVITY INDUCED IN POLYTETRAFLUOROOETHYLENE BY X-RAYS
J.F. Fowler, F.T. Farmer
Measurements in a vacuum chamber show conductivity proportional to \( \exp(-W/kT) \) with \( W = 1.1 \) eV before and 0.5 eV during irradiation. Dose rate dependence indicates a trap distribution which is approximately exponential below the conduction band. After irradiation has ceased, the conductivity decreases slowly, taking 6 h at 80° to fall to 10% of its former value.

CONDUCTIVITY INDUCED IN UNPLASTICIZED "PERSPEX" BY X-RAYS
J.F. Fowler, F.T. Farmer
Nature 175, 516 (1955)
It is found that the conductivity increases to the 0.55 power with dose rate.

CONDUCTIVITY INDUCED IN MICA BY X-RAYS
J.F. Fowler, F.T. Farmer
Nature 175, 640 (1955)

CONDUCTIVITY INDUCED BY X-RAYS IN POLYETHYLENE TEREPTHALATE: A POSSIBLE INSULATOR FOR RADIOLOGICAL APPARATUS.
Measurements of the conductivity induced by x-rays in "Melinex" (polyethylene terephthalate sheet) have been made, using the d-c amplifier technique.

X-RAY INDUCED CONDUCTIVITY IN INSULATING MATERIALS.
Fowler, J.F.
A co-ordinated explanation of the conductivity induced by ionizing radiation in solid insulating materials, including amber, mica, and a number of plastics is put forward. A model based on the conduction by free electrons and including the presence of electron traps is proposed, and the theoretical predictions based thereon are shown to be in good agreement with the experimental results. The dependence of induced conductivity and of the subsequent decay upon temperature and dose rate have been investigated. Physical parameters are given for each material: Recombination cross section, number of traps, their distribution in energy, mean distance diffused by free electrons and probability factors of release from traps. Results suggest that when crystalline regions are present in a material (e.g., polyethylene), the boundaries of these regions provide trapping sites in addition to traps of unspecified nature present in completely amorphous materials.
SOLID STATE ELECTRICAL CONDUCTIVITY DOSIMETERS
J.F. Fowler

SPACE-CHARGE EFFECTS ON EMISSION-LIMITED CURRENT FLOW IN INSULATORS
R.I. Frank, J.G. Simmons
J. Appl. Phys. 38, 832 (1967)

Paper extends well-known theory of effect of electron traps on current-voltage characteristic and space charge from space-charge limited into emission-charge limited region.

THE THERMALLY STIMULATED EMF ARISING IN IRRADIATED SOLID HYDROCARBONS IN THE PRESENCE OF A TEMPERATURE GRADIENT
E.L. Frankevich, V.L. Talroze


Samples of 1x3x5 mm3 wax were irradiated at 200°C with 1.6 MeV electrons. During heating up "bursts" of EMF were observed within such temperature ranges where strong recombination and strong increase in electrical conductivity were believed to occur. The temperature gradient was of the order of 20°C. During isothermal heating no EMF was observed. The reason for the effect is seen in an inhomogeneity in the current carrier density within the volume were carriers are trapped.

INVESTIGATION OF THE MOTION OF CARRIERS IN ORGANIC SUBSTANCES
E.L. Frankevich, E.I. Balabanov
Fiz. Tverd. Tela 1, 1667 (1965)

Conductivity of thin films of paraffin wax was observed under 3–8 keV electron bombardment. Current transients decrease in amplitude with increasing number of electron pulses, reaching eventually a steady state value. The amplitude reduction is due to a polarization effect caused by the internal field produced by the ionization-induced charge.
RADIATION EFFECTS ON ELECTRONIC PARTS AND MATERIALS

P. L. Frankovsky
Quarterly Report No 7, June 15-Sept. 14, 1966,

Measurements on mica, mylar, and polystyrene at the
Physics International Advanced Flash X-Ray Facility
were reported. Capacitors were tested to determine
induced current and replenishment charge as a function
of voltage. Data for each dielectric exposed to the
short pulse and high radiation level are presented.

REACTOR AND LINEAR ACCELERATOR INDUCED EFFECTS IN DIELECTRICS.

P. L. Frankovsky, M. Shatskans

Nuclear radiation induced currents as obtained with pulsed
reactors on several commercial capacitors are compared
with those obtained by LINAC electron beams. Effects
of applied voltage, geometry, dose, and dose rate are studied
for mylar, polystyrene, mica, tantalum, glass, and ceramic
capacitors. Interpretation in terms of a suitable model is
given and characteristic parameters established.

The relative effectiveness of gamma and neutron radiation
is also investigated. Theory is based on Eq.

\[
\frac{\delta E}{\delta t} = K_{p} E(t) + \sum_{n} K_{d_n} \int_{0}^{t} \exp[-(t-t')] \frac{E(t')}{T_{d_n}} dt'
\]

where

- \( \delta E/\delta t \) dark conductivity
- \( E(t) \) absorbed rad. dose rate leading to
- \( K_{p} \) absorbed total conductivity
- \( K_{d_n} \) delayed dose constant
- \( T_{d_n} \) time constant
- \( p \) (prompt) d (delayed)

If \( V \) is the voltage and \( C \) the capacitance, the induced
current \( i_{\text{r}} \) is given by \( i_{\text{r}} = (\delta E/\delta t) CV/\delta E_{0} \). Then

\[
i_{\text{r}} = CV \int_{0}^{t} K_{p} E(t) + \sum_{n} K_{d_n} \int_{0}^{t} \exp[-(t-t')] \frac{E(t')}{T_{d_n}} dt' dt
\]

In a mixed rad. field \( E = F \phi + D \), where \( F \) a prop. const. relating
to absorbed neutron dose rate, \( D \) refers to neutron dose rate;
\( D \) to gamma assuming all gamma loss due to ionization. The
scheme below gives

\[
i(t)/CV \int_{0}^{t} \int_{0}^{t} (FR+1) K(t) dt = \int_{0}^{t} (FR+1) K(t) dt\]

A plot of the left hand side of this Eq. versus \( R \) for different shielded bursts
results in a slope of \( KF \) and intercept \( K(t) \). The ratio of neutron current to
total current due to the mixed field is therefore

\[
\frac{i_{\text{total}} - i_{\text{gamma}}}{i_{\text{total}}} = \frac{FR}{1+FR}
\]
The currents induced by nuclear radiation from a pulsed reactor on several commercial capacitors were compared with those induced by the electron beam of a linear accelerator (LINAC) source. Dependence of the radioinduced current on applied voltage, geometry, dose, and dose-rate was contrasted for Mylar, polystyrene, mica, tantalum, glass, and ceramic capacitors. The effects were analyzed in terms of models appropriate for the various capacitors, and values of parameters defining these relations are given. The relative effectiveness of neutron and gamma radiation in producing induced currents in these capacitive elements at the reactor environment was also obtained. (auth)

TOTAL ELECTRON BACKSCATTERING AND BACKEMISSION YIELDS FROM MATERIALS BOMBARDED AT SEVERAL ANGLES BY 0.4 TO 1.4 KeV ELECTRONS

A.R. Frederickson, E.A. Burke
IEEE Transactions Nucl. Sci, NS-19, no. 6, 160(1972)

Total high energy electron backscatter yields have been measured for Al, Cu, Ta, at angles of 0°, 15°, 30°, 45°, 60°, 75° from the surface normal. A new experimental measuring apparatus has been developed and tested to measure total electron yield from irradiated materials. It is relatively free from problems associated with electron emission from the device itself.

IONIZATION, SECONDARY EMISSION, AND COMPTON CURRENTS AT GAMMA-IRRADIATED INTERFACES


Energy and charge transport by secondary electrons across interfaces between gamma-irradiated materials can be important for accurate predictions of radiation effects. In order to measure these charge-transport effects, air ionization and secondary electron emission currents were observed in a multiple-cavity aluminum chamber adjacent to tungsten and beryllium under 60Co γ-radiation. It was found that low-energy secondary emission measurements were within 3% of air ionization measurements made in the same chamber and that both measurements agree with previously reported ionization measurements of energy deposition profiles. Also, profiles obtained in relatively thin aluminum chambers (~20% of the maximum energy electron range), sandwiched between different combinations of beryllium and tungsten, can be accurately predicted from a linear superposition of single interface data. Finally, electric charge separation is observed at gamma-irradiated boundaries even in the presence of applied electric fields. The sign and magnitude of the charge is found to depend upon the direction of the incident beam as well as the material combination. The change in electron current as a function of the distance from the interface can be obtained from the data presented. (auth)
ON THE CONDUCTIVITY PRODUCED IN CdS CRYSTALS BY IRRADIATION WITH GAMMA RAYS

R. Froehichs
Phys. Rev. 76, 1869 (1949)

CdS crystals kept in the dark for a long time and then exposed to a low density of excitation require a long time to develop their photocurrents. The photocurrent versus time curve bent sharply upwards. The same latent period can often be observed after a CdS crystal has had a strong exposure to infrared quenching radiation. This "radiation activation" of the crystal is interpreted as a filling of traps. But this concept must be completed by the assumption of existence of two types of traps and transfer of electrons between them. Paper reports also a series of time-dependent effects, for intermittent and periodic irradiation.

RADIATION INDUCED ELECTRICAL EFFECTS IN DIELECTRICS

D.C. Fritz, J.J. Yentis
LIMSC Rep. (Lockheed missile Systems Division), Palo Alto, California, August 1966

Discuss irradiation and space-charge induced breakdown effects.

THERMALLY STIMULATED CONDUCTIVITY AND LUMINESCENCE IN KBr DUE TO gamma IRRADIATION AT 10°K.


The annealing behavior of KBr, gamma-irradiated at 10°K, was studied by means of simultaneous measurements of the thermally stimulated conductivity and luminescence and of the optical absorption. Over the investigated temperature range between 10 and 30°K, the conductivity and luminescence behaved very similarly, and the latter did not change its spectral distribution. All observed peaks have been ascribed to the annealing of the radioinduced imperfections of the lattice structure. Four peaks, appearing at 14, 17, 20, and 24°K with characteristic activation energies between 0.053 and 0.058 eV, which saturate in intensity after a moderate irradiation dose, are believed to be due to the generation of conduction electrons. A smaller peak at 22°K, which was observed only in the conductivity data, may be due to ionic motion. The most prominent peak appeared at 27°K, and it was shown by "thermal cleaning" experiments that this peak is caused by processes with activation energies of 0.062 and 0.100 eV. Here, too, the signals are believed to be caused by conduction electrons and their consecutive recombination with traps. The 0.062-eV process has "mixed-order" kinetics, i.e., there is an excess of recombination centers. At higher irradiation doses, the 0.100-eV process becomes dominant. This process seems to be associated with the first annealing stage of the H band, which had an activation energy of 0.097 eV. A tentative model of the H-center decay involves the dissociation of the H center followed by an interstitial—vacancy recombination. (auth)

ION DISPLACEMENT CURRENTS IN IRRADIATED ALKALI HALIDES

W. Fuchs, A. Taylor
RADIATION DAMAGE OF SHIELDING GLASS WINDOW
J. Furuta, S. Okamoto

A detailed analysis is presented. First a list of incidents is given. The damage is examined. If a ruptured window is irradiated again by gamma rays from Co$^{60}$, numerous new light flashes are observed the frequency of which decreased however with irradiation time. It is believed that the gamma irradiation charges up the areas around existing fracture cracks, eventually a high potential is reached and a discharge ensues. The conductivity of the shielding glass was measured. It was found to be nearly independent of dose rate and the usual $1/t^n$ decay law for the current was observed, $n$ being about 0.6.

DISCHARGE FIGURES IN DIELECTRICS BY ELECTRON IRRADIATION
J. Furuta, S. Okamoto

Report refers to a study of the formation characteristics of the discharge pattern in methy/methacrylate polymer. The size of the resulting discharge pattern depends on the total dose; the pattern can be controlled by the depth of the indentation obtained by pricking the surface prior to irradiation and subsequent discharge.

GAMMA-RAY DETECTOR USING INSULATING MATERIALS
J. Furuta, S. Okamoto, S. Kanazawa

DISCHARGE FIGURES IN DIELECTRICS BY ELECTRON IRRADIATION (II)
J. Furuta, E. Hiraoka, S. Okamoto, T. Ohnishi, Y. Tsujii

Paper reports results concerning charge decay, change of electrical conductivity, and after-effects in insulators irradiated by a 15 MeV LINAC. The method of triggered discharge was used. The stored charge was measured with a photocell receiving the scattered light from the discharge pattern, it having been found that the extension of the pattern is proportional to the residual charge.
GAMMA RAY INDUCED CONDUCTIVITY IN INSULATING POLYMERS
J. Furuta, E. Hiraoka
Currents were measured for various linear polymers, at room temperature. Polyethylene and teflon showed the highest current values. During irradiation currents generally were found to increase slowly with time, dose rate being constant and equal to 3200 R/h from a Co$^{60}$ source. Compton currents were eliminated by a sandwich arrangement similar to Meyer's. When irradiation was discontinued, a fast initial current decrease was observed, followed by a slow further decrease. An analysis by exponentials was attempted.

GAMMA RAY DECTECTOR USING INSULATING MATERIALS (II)
J. Furuta, E. Hiraoka, T. Ohnishi
Measurements with a PMMA scatterer are reported. a) Integrated dose was determined by observing the voltage rise. With doses between 0 and 6000 R voltage increase was linear, dose rates being between 9 and 120 R/min and final voltages up to 250 V. b) Directional dependence was determined for a planar and a spherical detector. c) The energy dependence was measured between the energy of Co$^{60}$ rays and 15 MeV given by a LINAC. For this purpose a detector with a 7 cm lead absorber and 2.5 cm thick scatterer was used. When the target current of the LINAC is constant, the bremsstrahlung intensity in the forward direction increases as the third power of the energy. Such a relation was observed with the detector, showing that the energy response is flat. Comparison with a Victoreen ionization chamber showed the latter to be with a lower increase due to saturation deficit. d) Measurements with a liquid scatterer were taken. The liquid contained in a plastic container and its thickness was varied between 0 and 70 mm. Water with $10^5$ to $10^7$ and salt solutions with 5 Ohm-cm specific resistance were used. The resistance had little effect.

GAMMA-RAY INDUCED CONDUCTIVITY IN INSULATING POLYMERS (II)
J. Furuta, E. Hiraoka, S. Okamoto
DISCHARGE FIGURES IN DIELECTRICS BY ELECTRON IRRADIATION
J. Furuta, E. Hiraoka, S. Okamoto
J. Appl. Phys. 31, 1073 (1966)

Breakdown discharge of different shielding window glasses were investigated. The relation between radiation dose and size of discharge figure and the decay of the discharge pattern after irradiation were studied. Relaxation times vary widely different for glasses of different composition varying between approximately half an hour and nearly 100 hours.

GAMMA RAY DETECTOR USING INSULATING MATERIALS (III)

LIQUID SCATTERER
J. Furuta, E. Hiraoka, T. Ohnishi

Measurements are reported with a liquid scatterer placed inside a plastic container between top electrode and measuring electrode. Results are independent of the conductivity of the liquid (water, ethyl alcohol, saline solutions, glycerine). Current varies with density of the scatterer, decreasing slightly with increasing density. The method can be used to measure simultaneously the total dose if the liquid is a Fricke solution so that the system is equivalent to a Fricke dosimeter. In this case a flow method might be used where the scatterer is connected with tubings to an outside system.

FAST NEUTRON DETECTOR USING INSULATING MATERIALS. I
J. Furuta, E. Hiraoka, T. Ohnishi

Recoil protons from a plastic scatterer are detected by parallel-plate electrodes which sandwich the plastic plate. Monitor sensitivities observed were 5.6 x 10^{-19}, 2.8 x 10^{-19}, 3 x 10^{-19} A/neutron/min for the neutrons from T(d,n){sup 4}He, D(d,n){sup 7}He, {sup 9}Be(d,n){sup 10}B reactions, respectively.

GAMMA RAY INDUCED CONDUCTIVITY IN INSULATING POLYMERS (III)
J. Furuta, E. Hiraoka, S. Okamoto
Annual Rep. Radiation Center Osaka Prefecture 8, 95 (1967)
10247   COMPARISON OF THE EXTRAPOLATED RANGES OF ACCELERATED ELECTRONS IN WATER AND POLYSTYRENE.
Polystyrene can replace the water used in photographic dosimetry along the axis of a 10- to 34-MeV electron beam from a betatron; in this way the extrapolated ranges of the electrons may be determined. (France)

ABSOLUTE CALIBRATION OF A COBALT-60 GAMMA RAY BEAM
S. Genna
Radiology 65, 394 (1955)
Considerations about the polarity effect due to forward scattered Compton electrons.

An investigation was made of the influence of irradiation with 3.5-MeV electrons and of heat treatment on the electrical and optical properties (temperature dependence of electrical conductivity and cathodoluminescence spectra) of synthetic diamonds. The irradiation and heat treatment (800°C) altered the luminescence spectra of synthetic diamonds doped with various elements in the 3000- to 10,000-Å range. Irrespective of the nature of the dopant, the spectra which were originally different in various details became similar to the luminescence spectra of irradiated and annealed natural diamonds. The resistivity of semiconducting crystals was increased by irradiation to various degrees depending on the amount of the dopant present (the increase was greater for crystals containing fewer dopant impurities). It was found that annealing at 600°C after irradiation enhanced those changes in the luminescence spectra which were due to irradiation but such heat treatment reduced appreciably the radiation-induced changes in the resistivity. It was concluded that the changes in the luminescence, observed after irradiation with fast electrons, were due to the formation of stable complexes, in which nitrogen atoms took part, and that the changes in the resistivity were due to the generation of simple defects or of unstable complexes. (auth)

PERSISTENT INTERNAL POLARIZATION OF INSULATORS PRODUCED BY ELECTRON BOMBARDMENT
D. J. Gibbons
Nature 198, 177 (1963)
Measurements on 0.3 and 1 micron thick insulating layers between 0.1 micron thick metal (Al) contacts show that a) the externally measured charge during depolarization might greatly exceed the charge incident from from the bombarding electron beam (for energies between 5 and 15 kV) b) space charge saturation occurs c) persistence of polarization in As2S3 and ZnS layers is of the order of minutes at 20°C d) polarization and depolarization can be achieved rapidly with low-bombarding current densities. Irradiation was, however, performed while an external voltage was applied.
TRANSIENT PHOTOCURRENT FOR FIELD-DEPENDENT MOBILITIES
W.D. Gill, K.K. Kanazawa
J. Appl. Phys. 43, 529 (1972)

Two specific electric field dependencies, a simple power law, and an exponential dependence on the square root of the field have been discussed. For the exponential dependence, which is of current experimental interest, step-function and pulse-illumination are treated. Results show that the pulse shape is insensitive to the functional form of the mobility. For drift mobilities increasing with the field, the transit time decreases but reaches a lower limit for high fields. The magnitude of the pulse does depend on the functional form of the mobility. Drift mobility increasing with the field results in decreasing current flow. Velocity saturation occurs at high fields.

RADIATION EFFECTS ON GLASS: AN ANNOTATED BIBLIOGRAPHY
B. A. Oillmore, W. F. Heenan REIC-MEMO-26
(Radiation Effects Information Center, Battelle Memorial Institute, Columbus, Ohio) Sept. 15, 1965. Contract AF 33(615)-1124. 31 p. 8. 050 REIC-MEMO-26

About 150 abstracts on glass, glass devices, and dosimeters.

STEADY-STATE GAMMA-RAY DETECTION USING FERROELECTRICS
D. D. Glover, D. L. Hester
Transactions American Nuclear Society Vol. 8, No. 1, p. 66 (1965)

A poled ferroelectric is used for measurement of steady state gamma dose rates. The current density is found to be proportional to dose rate. With a dose rate of 245 rad (H2O)/sec the constant of proportionality is 1 x 10^-12/rad/sec. A polarization effect is observed: Within the first couple of minutes the current decreases to about 30% of its initial value, subsequently remains constant. On short-circuiting a discharge transient analogous to the charging transient is found.

coaxial cables; gamma radiation; mev range 01-10; neutron density; neutrons; photons; polarization; polyethylene; pulsed irradiation; radiation effects.
SELF CHARGING NUCLEAR BATTERY
U.S. Patent 3,200,269 (1965)
M. Goldstein, H.C. Lieb,
Describes a Sr90 battery.

THE ELECTRET EFFECT IN PARAFFIN WAX.
Gomulkiewicz, J.
Phys. Status solidi (Germany) 3, 276 (1963)
Measurements are reported in which samples of pure paraffin wax were irradiated with beta rays from a 25 mc Sr90 source and subsequently polarized by application of a constant voltage. Currents and surface charges are measured. In addition to absorption effects heterocharges are obtained for fields up to 2000 V/cm and homocharges for higher fields. The charges decay, however, within a maximum of 30 days.

ON THE RADIOELECTRET EFFECT IN PARAFFIN WAX
J. Gomulkiewicz
Describes preparation of electrets from beta-irradiated wax.

ON THE NATURE OF RADIOELECTRET EFFECT IN PARAFFIN WAX
J. Gomulkiewicz
The effect is interpreted in terms of trapping of electrons. The theory gives a model for the phenomena responsible for the production of free electrons and their confinement in traps.

A thin-foil calorimeter designed to measure energy deposition profiles for electrons with ranges less than 100 micrometers has been tested with two pulsed electron beams. In addition to the diagnostic determination of the beam spectra obtained from the measured deposition profiles, the spatial fluence patterns of the beams have been measured with a total-stopping calorimeter array. The calorimeters are capable of operation over a dose range of a few kilorads to nearly 100 Mrad. Fluence measurements with the calorimeters can be made accurately with the error probably not exceeding 2 percent. In contrast, the dose-path measurements are less accurate although the probable error has not been determined.
When an ion chamber containing a low conductivity liquid is exposed to a very short pulse of ionizing radiation ($<10^{-2}$ seconds), the current in the external circuit is high during the pulse and then falls rapidly and nonexponentially towards zero. Further, the shape of the curve depends on both the delivered dose and the collecting field. A theoretical analysis of the liquid ion chamber under these conditions is given quantifying the effect of space charge and deriving expressions relating the observed current to the fundamental physical properties of the liquid. Experimental data for n-hexane are also shown covering six decades of both time and current for various collecting fields and incident doses for which data essentially establish the theoretical treatment. One-MeV electron beam irradiations were used ranging from $0.8$ to $120 \text{ mA}$ in pulse lengths from $10^{-8}$ to $10^{-2}$ second. Besides values for the recombination coefficient and other parameters, evidence is given of ionic charge multiplicity and free unattached electrons during the initial stages of the process. (auth)

- $\beta$ particles; calibration; currents; emission; errors; neutron detection; neutron flux; performance.

30093 ELECTRIC DISCHARGE IN RADIOACTIVE DIELECTRICS. Gromov, V. V.; Surikov, V. V. At. Energ. (USSR); 32: No. 2, 172-3(Feb 1972). (In Russian).
- When samples containing radioactive isotopes are placed in a conducting medium, (e.g., ionized air), accumulated charges may be neutralized by current carriers in the surrounding medium. Experiments were conducted with samples of glass containing $30 \mu\text{Ci}^{90}\text{Sr}$ (in equilibrium with $90\text{Y}$) per gram of glass. A large electric charge was accumulated within the poorly conducting glass, and eventually led to a microrupture of the surface layers of the glass by discharge. (2 figures) (K.S.W.)

ELECTRON IRRADIATION OF GLASS DISKS.
- Short report on charge storage effects in electron irradiated borosilicate glass.

IRRADIATION EFFECTS IN BOROSILICATE GLASS.
- Gross, B. Phys. Rev., 107, 368 (1957)
- Samples of borosilicate glass are irradiated with high energy (2MeV) electrons, the range of which is smaller than the thickness of the sample. Irradiation introduces space charges in the dielectric by electron trapping. The charge distribution is investigated by method of thermal release. During heating charges (by the induction plate method) and short-circuit currents are measured. To obtain more detailed information on the spatial distribution, a sectioning method is used which allows to determine by thermal release charges contained in different sections of the original sample. It is found that the trapped electrons build up a layer of negative charge; in addition a positive compensation charge is found. Heating releases electrons from traps and increases the conductivity of the glass matrix. Discharge occurs by migration of the electrons to the nearest electrode under the influence of the internal space charge field.
When an ion chamber containing a low conductivity liquid is exposed to a very short pulse of ionizing radiation (~10^{-7} seconds), the current in the external circuit is high during the pulse and then falls rapidly and non-exponentially towards zero. Further, the shape of the curve depends on both the delivered dose and the collecting field. A theoretical analysis of the liquid ion chamber under these conditions is given quantifying the effect of space charge and deriving expressions relating the observed current to the fundamental physical properties of the liquid. Experimental data for n-hexane are also shown covering six decades of both time and current for various collecting fields and incident doses for which data essentially establish the theoretical treatment. One-MeV electron beam irradiations were used ranging from 0.8 to 120 mA in pulse lengths from 10^{-7} to 10^{-9} second. Residual values for the recombination coefficient and other parameters, evidence is given of ionic charge multiplicity and free unattached electrons during the initial stages of the process. (auth)

When samples containing radioactive isotopes are placed in a conducting medium, (e.g., ionized air), accumulated charges may be neutralized by current carriers in the surrounding medium. Experiments were conducted with samples of glass containing 30 mCi ^{24}Sr (in equilibrium with ^{24}Y) per gram of glass. A large electric charge was accumulated within the poorly conducting glass, and eventually led to a microrupture of the surface layers of the glass by discharge. (2 figures) (K.S.W.)

Short report on charge storage effects in electron irradiated borosilicate glass.

Samples of borosilicate glass are irradiated with high energy (2MeV) electrons, the range of which is smaller than the thickness of the sample. Irradiation introduces space charges in the dielectric by electron trapping. The charge distribution is investigated by method of thermal release. During heating charges (by the induction plate method) and short-circuit currents are measured. To obtain more detailed information on the spatial distribution, a sectioning method is used which allows to determine by thermal release charges contained in different sections of the original sample. It is found that the trapped electrons build up a layer of negative charge; in addition a positive compensation charge is found. Heating releases electrons from traps and increases the conductivity of the glass matrix. Discharge occurs by migration of the electrons to the nearest electrode under the influence of the internal space charge field.
IRRADIATION EFFECTS IN PLEXIGLAS.
Gross, B.
J. Polymer Sci., 27, 135 (1958)

Samples of methyl methacrylate are irradiated with 2 MeV electrons. Stopping and trapping of the incident electrons in the dielectric leads to the formation of a negative space charge. Under proper conditions, i.e. sufficiently high irradiation, the electric field of this charge can produce breakdown accompanied by the appearance of a characteristic discharge pattern. The nature of the effect and mechanism of the breakdown is discussed. It is shown that the bulk of the space charge is concentrated in a narrow layer at a depth corresponding to the effective range of the electron beam. The quantity of charge released during breakdown is measured for various doses and compared with the value of the intercepted charge. Breakdown is induced by pressing a pointed electrode to the dielectric surface. The electrode is connected to a capacitive measuring device. Storage efficiencies of up to 40% are found; charge leakage at room temperature is high so that breakdown can be induced only within a few minutes after irradiation.

ARRANGEMENT FOR THE MEASUREMENT OF PENETRATING ROENTGEN- AND GAMMA RAYS.
Gross, B.
German Patent 1 107 350. (1959)

Describes a device in which the Compton current or the voltages produced by the absorption of radiation in insulators are used for radiation dosimetry. It contains a scatterer, a measuring electrode connected with an electrometric measuring system, and a grounded top electrode. The top electrode might be a conducting paint applied to the scatterer. The measuring electrode is of metal; it must be thick enough to absorb most of the incoming photon radiation to avoid a back-component of current and it must be completely covered by the scatterer to avoid charge leakage through the ionized air.

The scatterer is made of a highly insulating and radiation resisting dielectric; its thickness must be several times the average electron range to avoid backscattering effects at the top surface of the metallic measuring electrode. The photon flux in the scatterer produces a Compton current carried by the secondary Compton electrons moving preferentially in the direction of the primary photon beam. The current is proportional to dose rate and by suitable dimensioning of the measuring electrode can be made largely independent of energy. The system might operate also in open-circuit, the voltage of the measuring electrode after a given time being proportional to the dose.

THERMOVOLTAIC EFFECT IN GAMMA-IRRADIATED BOROSILICATE GLASS.
Gross, B.

Borosilicate glass was irradiated with a high dose of gamma rays from a Co60 source. After irradiation the glass was heated while a temperature gradient was maintained between its surfaces. During the heating an external current was observed. The direction of the current in the dielectric corresponded to a transport of negative charge to the electrode with the higher temperature. The observation of open-circuit voltages of up to 10 V excludes a thermoelectric effect. Heating to 400°C produces complete annealing.

THE COMPTON CURRENT.
Gross, B.
Z. Phys., 155, 479 (1959)

The secondary electrons produced by penetrating X-rays and gamma rays move preferentially in the forward direction. In an insulator absorption of the photon beam is therefore accompanied by an electron current. This can be measured by a suitable receiver that collects the electrons and absorbs the photons. An approximate expression for the Compton current is established. Results of measurements are found in satisfactory agreement with theory.
CHARGE DISTRIBUTION AND RANGE EFFECTS PRODUCED BY 3-MEV ELECTRONS IN PLEXIGLAS AND ALUMINUM.
Gross, B., Wright, K.A.
Phys. Rev., 114, 725 (1959)

Charge distribution curves of nearly parallel beams of monoenergetic electrons of 3 MeV are measured in plexiglas and aluminum by a method in which an isolated "catcher" connected to an electromagnetic charge measuring system is sandwiched between different thicknesses of absorber. The charge distribution in depth reaches a maximum at approximately 2/3 of maximum electron range. The maximum in plexiglas is sharper than in aluminum. Results confirm the existence of a space charge layer in dielectrics after electron bombardment. The measured charge distribution reflects the differential range distribution of monoenergetic electrons.

BETA PARTICLE TRANSMISSION CURRENTS IN SOLID DIELECTRICS.
Gross, B., Bradley, A., Pinkerton, A.P.

Short-circuit currents are calculated for a device in which a particle source, which constitutes one electrode, is separated from a counter electrode by dielectrics of varying thickness. Particles which do not reach the counter electrode contribute to the current due to induction. Thus the total current contains a transmission and an induction (displacement) component. Theoretical results are in close agreement with experimental results. It is shown that the current versus thickness characteristics can be used for a determination of beta absorption curves.

SOLID STATE NEUTRON-GAMMA DOSIMETER.
Gross, B., Murphy, P.V.
In Selected topics in radiation dosimetry; proceedings of a symposium, Vienna, 1960.

A direct flux of gamma rays produces in an insulating scatterer a Compton electron current, the intensity of which is proportional to the radiation flux. Similarly a directed flux of neutrons produces in a hydrogenated insulating substance a current of recoil protons which is a measure of the neutron flux. A device can be constructed which combines both effects in such a way that it differentiates between neutrons and photons in a gamma-neutron field. The construction of such an instrument and results of measurements are reported.

STORAGE AND LIBERATION OF ELECTRIC CHARGE IN IRRADIATED DIELECTRICS.
Gross, B., Murphy, P.V., Costa Ribeiro, S., Milanez, F.

Samples of quartz and polystyrene were irradiated with high energy electrons a) from a Van de Graaff machine (2 MeV) and b) from a 5 curie Sr$^{90}$ source. Doses varied between 5 and 15 Mr for the Sr irradiation and 80 Mr for the Van de Graaff. After irradiation samples were irradiated with the ultraviolet light of a Hanau quartz lamp. During and after irradiation current and charge release were measured. It was found that ultraviolet light produced charge release. The bulk of the released charge was measured during the first minutes of irradiation. But while the electronic charge actually absorbed in the samples was of the order of $10^{-4}$ coul, the released charge was of the order of $10^{-8}$ coul, giving an efficiency of the process of only a tenth of one per cent.
ELECTRICAL IRRADIATION EFFECTS IN SOLID DIELECTRICS.
Gross, B., Murphy, P.V.
Nukleonik, 2, 279 (1961)

Review article dealing with space charge and current effects induced by particle and
gamma irradiation. Contents: Electrical breakdown induced by electron bombardment.
Charge storage in borosilicate glass. Differential range distribution of monoenergetic
electrons. Beta particle transmission autotrons in solid dielectrics. Thermovoltaic effect
in gamma-irradiated borosilicate glass. Gamma-powered detectors and power sources.
Current production by neutrons and neutron dosimetry.

COMPTON DOSIMETER FOR MEASUREMENT OF PENETRATING X-RAYS AND GAMMA
RAYS.
Gross, B.
Radiation Research, 14, 117 (1961)

An unidirectional beam of photons produces in an insulator a current in the absence of an
external electric field. This allows construction of a gamma ray battery which might
operate in short-circuit or in open-circuit. A detailed calculation of current and voltage
output as a function of dose rate and dose is given. It takes into account directional
sensitivity, effects of dimensions, and energy dependence. It is shown how back-
scattering can be minimized by using as top section of the measuring electrode a so-called
"solid Faraday cage".

CURRENTS FROM GAMMAS MAKE DETECTORS AND BATTERIES.
Gross, B., Murphy, P.V.
Nuclonics, 19, 86 (1961)

Paper describes the production of currents and voltages in systems containing solid di-
electrics under the effect of gamma irradiation.

GAMMA IRRADIATION EFFECTS ON ELECTRETS.
Goss, B., De Moraes, R.J.
Phys. Rev. 126, 930 (1962)

Samples of Caracuba wax (2 cm height) were polarized at 73°C
by application of a voltage of 1.4 keV. After
polarization, cooling, and short-circuiting they were irra-
diated symmetrically in a Co-60 facility with doses
up to 5 Mr. They were then kept in short-circuit for 2
month. Subsequently the polarization was determined by
heating in short-circuit to 74°C. The released charge,
and therefore the polarization, were found to decrease
approximately exponentially with a decay constant of 1 Mr.
Thus electrets are depolarized by gamma rays, this being
a volume effect.
METHOD AND APPARATUS FOR MEASURING THE DOSAGE OF X-RAYS AND GAMMA-RAYS
B. Gross
US. Patent 3 122 640, Feb. 25, 1964

CHARGE STORAGE EFFECTS IN SOLID DIELECTRICS
B. Gross
Elsevier Publishing Co., Amsterdam, 1964

Bibliographical review on the electrot and related effects.

GAMMA-RADIATION INDUCED CURRENTS IN TEFLOW.
Bernhard Gross (International Atomic Energy Agency, Vienna)
Nukleonik, 6+20-3 (Feb. 1964)

Absorption of gamma radiation in dielectrics is accompanied by a current (Compton current) which is due to the forward scattering of Compton electrons. Measurements of this current are reported for radiation detectors with a teflon scatterer and a teflon or lead absorber. Polarization and surface effects were observed and radioinduced conductance was measured. With the help of a mathematical model the influence of conductance on short-circuit current and open-circuit voltage is discussed.

COMPTON CURRENT AND POLARIZATION IN GAMMA-IRRADIATED DIELECTRICS
B. Gross
J. appl. Phys. 36, 1635 (1965)

Attenuation of a directional flux of gamma radiation in a solid dielectric is accompanied by the production of Compton current and space-charges. Under proper conditions the space-charge field can be high enough to produce breakdown. A phenomenological theory of these effects is developed, which is based on Compton-current theory and experimental results of breakdown-induced charge release in glass. It takes into account space-charge formation due to the trapping of high-energy Compton electrons and persistent internal polarization associated with the production of electron-hole pairs by low energy secondary electrons.
Bombardment of high-resistivity solid dielectrics leads to electron trapping and space-charge build-up. The space-charge field in the dielectric can become high enough to reduce significantly the range of the incident electrons. It has been conjectured that the space-charge field in the dielectrics leads to an internal potential drop which might exceed the accelerating potential of the electrons. A simple mathematical model is developed which gives a semiquantitative picture and confirms the possibility of achieving within the dielectric potentials in excess of the electron potential. It is shown that there is no contradiction with the principle of conservation of energy; rather, the system transforms the radiation energy (i.e., kinetic energy of the incident electrons) into electric field energy. The efficiency of the conversion is calculated as a function of the reduction of the electron range.

DEVICES FOR MEASURING HARD X-RAY GAMMA RADIATION

List of References

THE SECTIIONING TECHNIQUE FOR THE DETERMINATION OF THE VOLUME POLARIZATION OF THE THERMOELECTRIC

B. Gross.

Paper discusses the principle of the sectioning technique for the determination of charge distribution in charged and/or polarized dielectrics. It is shown that the method allows to distinguish between dipole and space charge polarization.
Detailed theoretical and experimental investigation, dealing with the characteristics of Compton diodes under transient and stationary conditions. A circuit model is developed which allows to calculate the transient response and predicts occurrence of high-frequency oscillations. The advantages of systems with low internal resistance are discussed. Experiments were performed with the Photon radiation of an 15 keV Betatron. The influence of geometrical parameters (absorber thickness of center and front absorber) and of absorber material on amplitude and direction of the external current are studied. They are in satisfactory agreement with the predictions of the model.

Short-circuit currents in charged dielectrics and motion of zero-field planes
B. Gross, K. Ferman
J. Appl. Phys. 42, 653 (1972)
When a previously charged dielectric is short-circuited, discharge currents result due to the movement of charge carriers in the field of the space charge. It is shown for plane-parallel geometry, that the discharge current is given by the product of charge density at, and velocity of, the zero field plane. The resulting expression includes the displacement current. It can also be applied when the dielectric is exposed to the beam of penetrating radiation, where it allows to evaluate the effect of space charge on external current. In this connection the behavior of Compton diodes is discussed.

Charge buildup in electron-irradiated dielectrics
B. Gross, J. Nov,
Electrets, Charge Storage and Transport in Dielectrics.
Extended Abstracts, No.115, p.296 (1972)
Irradiation of dielectrics with non-penetrating electron beams generates long-lasting space-charge. A simple experimental and mathematical method is developed for the investigation of charge buildup during irradiation. Time resolved charge measurements carried out with pulsed beams of monoenergetic electrons of 1 MeV energy, pulse duration of 4x10^-5 sec, and average current density of 10^-2 A/cm^2 allow to analyse effects of charge leakage caused by radiation induced conductivity and of electron range reduction caused by retardation of the incident electrons in the internal space-charge field. Leakage is found to predominate in Silica and Borosilicate Glass while range reduction predominates in Polyethylene.
Charge diagnostics for electron-irradiated polymer foils

B. Gross, G.M. Sessler, and J.E. West

Bell Laboratories, Murray Hill, New Jersey 07974
(Received 26 December 1972)

Polymer foils carrying thin vacuum-deposited electrodes on both surfaces are irradiated with nonpenetrating monoenergetic electron beams of various energies. Measurement of the currents and charges drawn from both electrodes and of the voltage buildup between the electrodes during and after irradiation allows one to determine charge storage parameters of such electrets.

Bulletin of the American Physical Society

March 1973, Series II, Vol. 18, No. 3 P. 432

Irradiation of dielectrics with nonpenetrating electron beams generates long-lasting space charges. A simple experimental and mathematical method is developed for the investigation of charge buildup during irradiation. Time-resolved charge measurements carried out with pulsed beams of 1-MeV electrons, pulse duration of 4×10⁻⁵ sec, and an average current density of 10⁻³ A/cm² were used to analyze effects of charge leakage caused by radiation-induced conductivity and electron range reduction caused by retardation of the incident electrons in the internal space-charge field. Leakage is found to predominate in silica and borosilicate glass while range reduction predominates in polyethylene.
Avalanche electron images are collected on thin insulating films covering the anode of a parallel plate capacitor. Charge images are developed by xerographic techniques. The influence of foil thickness and developing techniques are studied. The minimum number of electrons which can still be detected is $3 \times 10^7$. Images do not give direct information on avalanche mechanism when more than one avalanche has occurred. An application of the method for measurements of alpha particle traces is indicated.

**Electrostatic Charge Distribution on Ultrahigh Vacuum Cleaned Silicates**

J. J. Grossman


Design and fabrication of UHV systems to measure charge distributions are described.

**Ranges of Low Energy Electrons and Positrons in Al**

Z. F. Awad 152, 163 (1958)

Reports measurements in the energy range 10 to 150 keV, giving the relation

$$ R_b = 773 E^{1.70} $$

for $E$ in keV, $R$ in $\mu\text{c}m^2$ where $R$ is the maximum range.

**Generation of Electricity by Radioactive Zones**

R. C. Guinnaclen, J. O. K. Lockris

US Patent 3 250 925 (1966)

The system employs a pair of juxtaposed electrodes immersed into an electrolyte containing radioactive elements emitting alpha, beta, and gamma radiation. In the electrolyte a gradient of radioactivity is imposed by a shielding arrangement.

**Individual Dosimeter for Radioactive and Other Penetrating Radiation**

P. S. Guzenov, O. A. Kuzavikov, U. V. Sinjelnikov

USSR Patent 115 132 (1959)

The decrease of the surface charge of an electret after irradiation by gamma rays is used as a measurement for exposure dose. A device is described.
ELECTRICAL CONDUCTIVITY OF GAMMA-IRRADIATED KONOLERS
AT LOW TEMPERATURE
K. Nadoi, Y. Tabata, K. Oshima

THEORY AND APPLICATION OF THERMALLY STIMULATED CURRANTS
IN PHOTOCONDUCTORS
R. R. Huening, E. N. Adams

The paper discusses the properties of a band model with
localized states in the band gap for the two extreme
cases of fast retrapping and slow retrapping.

PHOTOEMISSION FROM POLYMERS
F. Hui, J. Bornstein
IEEE Transactions PB-18, 176 (1971) No 6
Photoemission from polymers, including polyethylene, kapton,
teflon, and PVF irradiated by 15-25 keV photons has been
done. Emission intensities were compared to those from
cell conductors, ranging from carbon to tantalum, and from
other insulators, such as glass and mica. For all materials,
the relative emission intensity was found to be mainly
proportional to the photoelectric absorption coefficient.
Under the pulsed irradiation, the insulators emitted
as conductors when backed by conducting sheets but exhibited
reduced emission associated with trapped charges when
isolated.

RADIATION EFFECTS ON CAPACITORS AND DIELECTRIC MATERIALS.
Donald J. Hamman ( Battelle Memorial Inst., Columbus, Ohio).
p. 523-60 of "Institute of Environmental Sciences, 1963 Annual
Technical Meeting Proceedings." Mt. Prospect, Ill., Institute
of Environmental Sciences, 1963.

Transient and permanent radiation effects on organic and
inorganic electrical insulation materials are discussed. Radiation
effects on capacitor dielectrics of glass and vitreous
enamel, mica, ceramics, paper, plastics, and electrolytes are
discussed. 19 references. ( R.E.U.)
Thermally stimulated conductivity (TSC) that is attributed to the release of charge from electronic and ionic defects during thermal annealing of single crystals of KBr and NaCl was examined. A $^6$Co gamma source, or a monomeric neutron source employing the $^6$Li(p,n)$^7$Be reaction, was used to create and/or excite these defects. Irradiations were performed at either 10 and 77 K followed by linear rise annealing to room temperature, at rates ranging from $2 \times 10^4$ to $2 \times 10^5$ K° per second. A field of 1000 V/cm was applied to the crystal just before annealing. The current resolution of the electrometer-crystal system was $\sim 10^{-14}$ A. Typical TSC peaks ranged from about $10^5$ to $10^7$ times this amplitude for neutron or gamma dose of the order of $10^{12}$ neutrons or $10^{14}$ photons, respectively. The prominent low-temperature TSC peak occurs at 31 K after gamma irradiation at 10 K. This effect is characterized by an activation energy of 0.093 ± 0.005 eV and is correlated with optical absorption measurements at the H center. Two small peaks on the leading edge of the H center correlate with an optical absorption effect that has been attributed to interstitial-vacancy recombination of cation defects. Since the H center peak is not present after the 10 K neutron exposure and the two small peaks predominate, it is concluded that gamma rays at low temperatures predominantly form the H center, and that low-temperature neutron exposure results in the Br$^-$ interstitial. The amplitude of the H$^+$ peaks is sensitive to the energy of the bombarding neutrons. In contrast, the prominent TSC peak after 77 K gamma irradiation occurs from 110 to 120 K, and is characterized by an activation energy of 0.27 ± 0.02 eV. This effect correlates with annealing of the V$^-$ center. Although this peak is prominent after 10 K neutron exposure, it is not present after the 10 K gamma irradiation. Hence, when the H center can be formed, the V$^-$ TSC peak is not observed. The observed reaction kinetics of the H and Br$^-$ peaks can be explained by these assignments, and the appearance of the V$^-$ peak is also consistent with expectations based on these assignments. (Diss. Abstr. Int., B)

**PASSAGE OF FAST ELECTRONS THROUGH THICK METAL LAYERS**

D. Harder

Ph. D. Thesis, University of Würzburg, Germany, Jan. 1965

A detailed theoretical and experimental study of the problem, including discussion of the "charge deposition" method using a Faraday cage system. It is pointed out that due to forward-scattered secondaries the absorption curves measured with the charge deposition method and particle counting methods giving only primaries do not fully coincide.

**THERMOELECTRICITY IN IRRADIATED GLASS**

P. C. Hardtke, Argonne National Lab., Argonne, Ill

1962 Conference Radiation Effects on Glass, Rochester, NY

Summary Paper N. 10

Measurements on $^{60}$Co $\beta$-irradiated Cabal$^3$ glasses are reported. The thermoelectric effect is attributed to the penetration of Compton electrons from the Al jacket of the cobalt source into the glass. A Mel$^2$ effect on $\alpha$- and $\beta$-irradiated similar effects.
ELECTRICAL PROPERTIES IN IRRADIATED GLASS.
Hardtke, F.C.

THERMOELECTRICITY IN IRRADIATED GLASS.
Hardtke, F.C.
Measurements are reported on the thermal charge release from gamma irradiated Cabal-type glass (calcium-alumino-borates). Doses up to several Mrad were used. The glass was heated in a temperature gradient (20-40°C/mm). Charges up to $10^{-6}$ coulomb/cm² are observed. The discharge current is proportional to the temperature gradient and shows several peaks which are attributed to release of electrons from traps of different stability energies. Once carriers are released they can drift under the influence of the temperature gradient until retrapping or recombination occurs. The effect of thickness and nature of shield interposed between the radiation source and the sample are investigated and found to be quite strong, shielding decreasing the charge displacement.

THERMOELECTRICITY IN IRRADIATED DIELECTRICS
F.C. Hardtke
Report, Argonne Ntl. Lab. 1963

F.C. Hardtke, K.R. Ferguson, A.K. Conh
THE FRACTURE BY ELECTRICAL DISCHARGE OF GAMMA IRRADIATED SHIELDING WINDOW GLASS
Report (Argonne Ntl. Lab.) (1963)

THERMOELECTRICITY IN IRRADIATED DIELECTRICS
F. Hardtke
IEEE Summer General Meeting, Toronto 1963 paper #63-1142

THE FRACTURE BY ELECTRICAL DISCHARGE OF GAMMA-IRRADIATED SHIELDED WINDOW GLASS
Measurements on four-inch cube samples of commercial shielding window glass. Glasses were discharged after exposure to $5 \times 10^6$ R by an impact probe. Pictures of fractures and light flashes are shown, light flashes, oscilloscope traces are given, and charge measurements are reported, the charge being measured by a capacitor arrangement. Released charge increased with exposure rate and decreased with exposure temperature. It is found that a small dendritic fracture once initiated will continue to grow with subsequent exposure.
Gamma-irradiated dielectrics are observed to produce charge release when heated in a temperature gradient (5 to 40 °C/mm, radiation dose up to 10^7 R). The released charge (in one direction) was found to be proportional to the temperature gradient and to dose up to about 1 mega-R when saturation maximum is observed. Discharge currents show several peaks and current reversals are observed. The effect of metal shields between radiation source and sample and of metal back plates were found to be surprisingly high. It is concluded that part of the effect is due to the incoming electron flux, where the absorption of radiation increases and that the maximum the difference between the absorption coefficient of the shielding material and the dielectric is relevant. Compton current theory is used for a qualitative interpretation of results.
If radiation-induced conductivity is limiting the internal field and assuming that this cond. and hence dose is uniform over section of sample traversed by incident electrons, trapped charge density is

\[ Q/A = C \frac{dE}{dt} = \int_0^t (J - qE) \, dt \]

where \( k = 2.5 \) is dielectric constant, \( E \) electric field, \( J \) both current density, \( q \) rad. induced conductivity. Differentiating and equating to 0 to find limiting field one has \( E = J/k \) and \( E = 10^{10} R/KE \), where \( E_{\text{mean}} \) is effective mean energy of electrons, \( R \) their range, \( K \) ratio of prompt conductivity to dose rate. Using the observed limiting field of 2.85\( \times 10^6 \) V/cm one gets \( K = 1.6 \times 10^{-18} \) /(ohm cm)(rad/sec) injection charges of 1 micro-C/cm\(^2\) and above produced.

"saturation", i.e. no further range decrease(beyond about 1/3 of initial range, 0.28 against max. 0.78 g/cm\(^2\) with 1.5 MeV electrons. The second Eq. follows from the expression for dose rate \( \phi \) in terms of \( R \) and electron energy, in MeV.

**RADIATION WINDOW GLASS**

R.V. Harrington

U.S. Patent 3,565,792, Jan. 29, 1971

Describes a glass resistant to dielectric breakdown from gamma radiation up to \( 10^{15} \) R, consisting essentially of up to 47.2 wt. \% SiO\(_2\), 33.2 wt. \% PhO, 17.5 wt. \% \( K_2O, 2.8 \) wt. \% \( CeO_2\). Glass is characterized of being substantially free of halogens, soda, and lithium, having an initial luminous transmittance for a one inch thickness of greater than 90\% at wavelength of 5500\( \AA \), and having an electric resistance in terms of the logarithm of resistivity of less than 16.5 at 50\(^\circ\)C.
PHOTOCONDUCTIVITIES HAVE BEEN MEASURED IN THE RANGE 1 RAD/ MIN TO 3.10^5 RAD/ MIN.
SOURCE OF GAMMA RADIATION HAS BEEN THE FISSION PRODUCT INVENTORY OF REACTOR FUEL ELEMENTS.

DETAILED INVESTIGATION. RADIATION SOURCES USED ARE SPENT FUEL ELEMENTS, THE ARRANGEMENT BEING SYMMETRICAL SO THAT COMPTON CURRENT IS ELIMINATED. INFLUENCE OF DOSE, DOSE RATE, TIME, AND VOLTAGE HAVE BEEN STUDIED.

MEASUR ED BEHAVIOR OF GAMMA-RAY PHOTOCONDUCTIVITY IN ORGANIC DIELECTRICS
S.E. Harrison

It has been found that decay can be represented by sum of exponentials.

GAMMA RAY AND NEUTRON-INDUCED CONDUCTIVITY IN INSULATING MATERIALS
S.E. Harrison, P.M. Coppage, A.W. Snyder
IEEE Paper CPA 63-5156 (issued by Sandia Corporation, Albuquerque, New Mexico, USA)
Measurements by steady state and pulsed sources are reported for polythene, polyethylene, mylar, teflon etc.). Steady state gamma dose rates were 1 x 10^-3 to 1 x 10^4 r/s, combined pulsed neutron-gamma dose rates were up to 2 x 10^8 r/s. Onset of radiation, conductivity increases and reaches an equilibrium state according to an exponential law with a single time constant. Conductivity decay after radiation has ceased is represented by a series of exponentials. The equilibrium conductance contains a component arising from direct excitation of carriers by to the conduction band by irradiation and another component arising from thermal excitation of carriers trapped in non-conductive states to conducting states. The influence of the release of trapped carriers is responsible for the the induced conductivity response and its decay. This influence is, however, notable only in the steady state measurements.
Conductivity decay can be represented by a sum of exponentials. Amplitudes and time constants for this representation were measured for Teflon, polyethylene, polyvinyl chloride, polystyrene, Kel-F, and nylon, for temperatures between 29°C and 80°C and doses between 3.3 and 6.7 r/s. Results were interpreted in terms of a trap-controlled process. Carriers are of only one type and the rate at which they enter the traps is during the decay assumed to be small compared to that at which they leave the traps.

Irradiation effects by 30-MeV electrons, samples mounted in a vacuum chamber. Effects are believed to be due to space charge caused by migration in the field of the low energy electrons (a few 100 eV) produced along the tracks of the high energy electrons. Conductivity of various materials (sapphire, quartz, Pyrex etc) were also investigated. Successive pulses on a sample with a constant voltage bias resulted in increasingly lower current pulses. On removal of bias, subsequent pulses gave a current flow opposite to the previous one. This polarization effect is believed to be caused by the space charge production. The effect was observed in all samples, but was small except in sapphire, which also exhibits an induced conductivity 2 orders of magnitude greater than in other dielectrics. Samples were 20 mils thick. Up to 10⁴ rads were applied. Single-crystal sapphires exhibit an induced conductivity 30 to 50 times greater than of other materials tested.
RANGE OF SECONDARY ELECTRONS IN SAPPHIRE

J.W. Haynes

IEEE Transactions Nucl. Sci. NS-20, 1016-1020 (1973)

The ionization yield for a 25 keV electron from a LiF crystal is 1.2 x 10^{-6} per electron cm. The energy loss rate for a 25 keV electron in a LiF crystal is 20 keV cm. The ionization yield for a 25 keV electron in a LiF crystal is 1.2 x 10^{-6} per electron cm. The resistivity of a LiF crystal is estimated to be 1.2 x 10^{-4} ohm cm. The rate of ionization is given by n = 

\[ \frac{d}{dt} \left( \frac{n \tau}{n + \tau} \right) \]

where n is the carrier density, \( \tau \) is the generation rate of carriers, and \( \gamma \) is the recombination rate constant. The trapping time constant, \( \tau \), is the time constant of the detector.

THE COAXIAL COMPTON DIODE

D.W. Hart

Preprint, Applied Phys. Division, NBS (1965)

Refers to Compton dielectric detectors. It is suggested that account must be taken of the volume charge distribution in a dielectric Compton detector. It is also shown that the dielectric constant should be independent of frequency over the envisaged range of operational frequency and that, for convenience of calibration, the resistivity should be high. A general theory of the detector is given.

TRANSIENT SPACE-CHARGE PERTURBED CURRENTS FOLLOWING TIME-DEPENDENT INJECTION

C.C. Hartmann, N.O. Lipari

J. Appl. Phys. 44, 1676 (1973)

The problem of space-charge perturbed currents in dielectric media is studied for the case where the charge injection at one electrode is time dependent. Since the analytical approach is very difficult, the governing charge carrier dynamics have been solved numerically. The special case is considered where injection has an exponential time dependence. A constant voltage boundary is assumed. Results are given for configurations consisting of one and two dielectric layers.
The behavior under X-irradiation and UV radiation is quite different with regard to dependence on voltage, temperature, activation energy, dose and dose rate. Previous X-irradiation by X-rays reduces the current conduction under voltage; this is explained by the production of recombination centers.


The mobility and carrier number in orthorhombic sulphur crystals bombarded with pulsed x-rays at 100 kV were measured as a function of the applied electric field or x-ray intensity at room temperature. Results show that the hole mobility is 0.26 cm/V sec in fields from 20 to 55 kV/cm and the produced carrier number is approximately proportional to the square of the intensity. (auth)

Photoconductivity Associated with Trapping

J.R. Haynes, J.A. Hornbeck
Phys. Rev. 90, 152 (1953)

Discusses effects of two sets of traps, a shallow trap with lifetime of $10^{-2}$ sec and a deep trap with lifetime (time electron spends in trap) of 260 sec, while lifetime of electron in conduction band is 20 microseconds. When light switched off, conduction band empties before electrons are released from traps which occurs in two stages.

Radiation - Induced Electrical Conductivity in Polyamide Copolymers

P. Hedvig
J. Polymer Sci. A, 2, 4097 (1964)

Radiation-induced conductivities up to $10^{-12}$ ohm cm were measured in polyamide copolymers under X-ray or gamma ray damage dose rates between 0.1 and 20 R/sec. No temperature effect was noted between 10°C and 60°C. For dark conductivities an exponential rule with an activation energy between 1 and 2 eV was found.

Space-Charge-Limited Currents in Anthracene and the Determination of Electron Mobility

W. Helfrich, P. Mark

The paper discusses the movement of electrons injected through a non-blocking (ohmic) contact. The steady state current and the transient current are calculated. Eqs. for the transient current are rigorously solved for times smaller than the transient time. When the first electrons reach the counter-electrode, a current maximum (cusp) is reached whose position determines therefore the transit time. The mobility follows.
A STUDY TO DETERMINE THE PRESENCE OF VOLTAGE BREAKDOWN DUE TO PROTON IRRADIATION IN POLYMERIC MATERIALS


A series of polymeric materials was investigated. Kanto (H-7111), Teflon (TF2), Pyrophyllite, Molyb and polyethylene were studied. Proton energies varied between 9140 and 3.75 MeV, with a flux of 10^9, 10^10, 10^11, or 2x10^11

42162 (NYO-3409-10) ROLE OF TRAPPING PROCESSES IN SOLID STATE RADIATION DOSIMETRY, Final Report, Hendrich, H.K. (Pennsylvania State Univ., University Park, Materials Research Lab.), May 1971, Contract AT(30-1)-3409, 40p, Dep. NTIS. Research progress on new ideas in solid state dosimetry including field enhancement of thermoluminescence, photo-stimulated radiation dosimetry, current glow methods, pyroelectric method, and dosimetry by electric depolarization is reported. Polymer electron dosimetry and a technique for the measurement of pyroelectric coefficients are discussed in detail. (W.H.K.)

IRRADIATION DAMAGE TO GLASS

J.R. Hensler, N.J. Fried, E. Joll, J.L. Rood


Discharge experiments in electron- and gamma-irradiated glasses are reported. Gamma radiation induced discharges occur only when the gamma beam strikes the sample from one direction; discharges were never observed for isotropic irradiation.


AN 3 Contactless, Local Free Carrier Property Determination in Semiconductors. J.C. Herper, I. Falco, New York Univ., R.R. Stern, Bell Laboratories, and E.K. Axelrod, Norman N. Angstrom Associates, N.Y., N.Y. — A new diagnostic technique simultaneously measures the free carrier lifetime (τ) and diffusion coefficient (D) with spatial resolution in localized regions within a semiconductor. The technique uses pulses of above band-edge light incident on the surface of a semiconductor to inject bursts of excess carriers near the surface. These carriers diffuse into the bulk and decay (e.g., by recombination). A narrow probing beam of below band-edge light traverses the semiconductor sample parallel to the illuminated surface. The changing excess carrier density along the beam path causes a corresponding absorption in the probing beam intensity, and is monitored as the beam emerges from the sample. D and τ are obtained by computer fitting the absorption curves to an equation for carrier transport for different beam scan positions normal to the illuminated surface. Experiments with a 100 watt xenon lamp, a 3.39μm HeNe laser beam and a 1500 ohm-cm silicon sample yielded values of D=20cm^2/sec and τ=0.6μsec, in good agreement with independent measurements and calculations. P. 554
A pocket dosimeter for the measurement of x, gamma, and neutron radiation made up of two cylindrical conductors under vacuum arranged concentrically and of different sensitivities to the electron energy is described. The exterior cylinder forms one part of a wall enclosing the vacuum. There is also an electrometer indicating the difference in potential between the two cylinders. A switching foil is arranged in the vacuum enclosure but maneuverable from outside the enclosure, serving to discharge the electrometer. (J.F.P.)

**USE OF FERROELECTRICS FOR GAMMA RAY DOSEMETER**


Special Technical Conference on Nuclear Radiation Effects, Seattle, July 1964

Irradiation of a poled ferroelectric causes a release of charge which was found to vary linearly with dose. Sensitivity was $10^{-12}$ coulomb per rad and cm$^2$ of electrode surface area, for polycrystalline Pb(Zr$_{0.65}$Ti$_{0.35}$)$_3$O$_{12}$ and Nb$_2$O$_5$, irradiated in Sandia pulsed reactor. A similar charge release was observed in poled barium titanate.

The change of induced conductivity and depolarization current for various polymers, transient effects can be represented by Schweidler's law. These dielectrics which without irradiation showed the lowest conductivity showed a strong permanent increase of up to $10^6$ and more remains of the paraelectric susceptibility remains after high irradiation doses. It is attributed to stable changes of molecular structure.
The use of thermally stimulated ionic currents with a hyperbolic heating rate to measure sodium lost in regrettably sputtered SiO$_2$ films


T.W. Hickmott

Analysis follows Haering and Adams for thermally stimulated conductivity curves in photoconductors. Assumes single trapping level, $n_t$ concentration of trapped charge, $n_0$ of mobile charge, first order kinetics. Gives

$$\frac{dn_t}{dt} = -n_0 \exp(-E/kT) + n_0 (N_t - n_t) s v \frac{dn_t}{dt} = - \frac{N_t}{\tau_0}$$

First order kinetics.

$$\frac{dn}{dt} = \frac{dn_0}{dt} = \frac{N_t}{\tau_0}$$

$E = V/d$, $s = n_0 q \mu$, where $E$ is trap depth, $N_t$ total trap number, $v$ velocity of mobile charge, $s$ cross section for retrapping, lifetime of carriers freed from traps. Integration carried out for retrapping neglected.

**SELFR-POWERED NEUTRON DETECTORS FOR REACTOR FLUX MONITORING**

J.W. Hillborn

Nucleonics Vol. 22, No. 2, page 69 (1964)

Describes detectors made of coaxial cables in which the electron emitter is a conducting or semiconducting material that spontaneously emits energetic electrons under neutron irradiation, the insulator a solid dielectric, and the collector a conducting material that produces few electrons in a neutron flux as compared with the emitter. A system for compensation of the Compton current is described. Measurements made in reactor cores are described.

**POOLE-FRENKEL CONDUCTION IN AMORPHOUS SOLIDS**

R.C. Hill

Phil. Mag. 23, 59 (1971)

The theory of the ionization of local lattice defects by an applied field is investigated. The Poole-Frenkel effect is shown to be a limiting case of a more general analysis covering the experimentally available field of electrical stress and temperature. At low temperature, conduction is due to tunneling emission of carriers into the quasi-conduction band of host material. At high temperature, thermal emission becomes predominant. In between, a thermal-field emission process has been identified. Poole's law occurs when the density of ionized defects is sufficiently great to give overlap of coulombic potentials surrounding the defects, and Poole-Frenkel effect occurs when the centers are non-interacting.
ELl'ETRIC CURRENT DUE TO GAMMA-RAY IRRADIATION
H. Hirakawa, Y. Kimura
A theory of the current is developed supposed to be valid up to 50 keV. Multiple scattered quanta are neglected. It is also assumed that pair production does not result in any measurable current.

HIGH DOSE DETECTOR FOR GAMMA-AND X-RADIATION USING
COMPTON SCATTERED ELECTRON
E. Hiraoka
Describes a Compton Dosimeter identical to that of Gross. Measurements are reported for 60Co gamma radiation 15 keV linear radiation. Sensitivity was of the order of 2.5 x 10^-14 A/cm^2 per R/min.

A SIMPLE ADDITIVL MODEL FOR THE ELECTRON-BOMBARDEMENT-
CONDUCTIVITY IN ANOMOLOUS ARSENIC TRISULFIDE
J. Hirsch

ELECTRON INDUCED CONDUCTION IN PLASTICS.II. THE
EXCITATION BY FULLY PENETRATING AND OTHER INCIDENT ELECTRONS
J. Hirsch, W. Martin
J. Appl. Phys. 42, 1025 (1971)
Effects due to pulsed bombardment by fully penetrating electrons are investigated. Kinetics obeyed by the "fast" component of induced current are predominantly first-order, those of the "long-lived" current second order. Results confirm the interpretation of the decay time of the long-lived current as a bimolecular recombination lifetime. A simple model for radiation induced conduction in polymers, based on topological considerations, is developed. Long-lived current is associated with intermolecular jumps. While the effective mobility of the long-lived component is deduced from its kinetic behavior in polymer, it is controlled by the intermolecular jump probability at that in polyethylene is subject to an additional limitation, viz. strong localization of carriers in the U bands of the molecules.

THE RESPONSE MEASUREMENT OF LASL DIAGNOSTIC DETECTOR
L. P. Hocker
EGG 1183-2238, S-490-R (1970)
A study is made of utilizing electron trapping in dielectrics as a means of reducing bremsstrahlung in spacecraft at synchronous altitudes. Traps retain electrons, and large internal fields are induced in the dielectric. Electrons penetrating the material can lose most of their kinetic energy to the field with a corresponding decrease in bremsstrahlung loss. This acts to reduce bremsstrahlung and lowers the average radiation energy of that which is produced, thus increasing absorption probability in the wall. Breakdown phenomena cause shielding effects to be cyclic. A thin dielectric layer on the external surface of a spacecraft should provide an effective, light, and inexpensive shield against bremsstrahlung without interfering with any of the system's functions. Electron-trap shielding is applicable wherever a dielectric-charge layer is allowed to accumulate.

Radiation Effects on Coaxial Cables and Insulation: An Annotated Bibliography

W. L. Hollister
Lockheed Missiles and Space Company, Sunnyvale, California,
Special Bibliography SB-62-12 (1962) AD 278 674

Refers to the effects of mixed reactor radiation on transients and damage effects in both coaxial cables and electric insulation materials.


A survey has been made of radiation effects literature pertinent to effects of low-level steady-state neutron, gamma, and proton environments on electronic components. A bibliography of over 300 references was compiled. The data were scanned and an analysis made of the radiation effects state-of-the-art for electronic components on a deep space mission that might be exposed to planetary radiation belts and on-board radioisotope thermoelectric generator environments. Emphasis was placed on permanent parameter degradation, temporary parameter drift, parameter degradation factors, hardening techniques, and screening techniques. (auth) (SAAH)
RADIATION DETECTOR WHOSE OUTPUT IS INDEPENDENT OF THE ENERGY DISTRIBUTION OF INCIDENT RADIATION

R. Hosemann, H. Warrikhoff


A detector-electrode structure composed of two types of electrodes at least one of which consists of a plurality of layers each made of a material and having a thickness such that the radiation responsive charge carrier emission characteristics of the layers combine to cause the net flow of charge carriers between the electrodes to be independent of the energy distribution of the incident radiation is described.
A NEW DIRECT-READING PERSONAL DOSEMETER WHICH DOES NOT REQUEST MAINTENANCE

R. Hosemann, J. Hanse
Acta Nudiotecnica 4, 42 (1970)


The radiation element is a vacuum cell with two special electrodes that are charged when irradiated. The resulting potential difference is measured with a quartz-fibre electrometer. Radiation elements are self-powered, measure radiation doses independent of dose rate and have a practically unlimited storage time due to their extremely good insulation. Radiation elements become charged if the electrodes emit different numbers of electrons. This is achieved for X-rays and γ-rays by using electrodes made of materials of different atomic numbers. Slow neutrons are captured in an electrode made of silver or rhodium by a (n,γ) process producing short-lived γ-active isotopes. For fast neutrons a moderator must be used. Fortunately the human body has the optimum dimensions required for this purpose. Dosimeters with radiation elements therefore cannot measure free air doses of neutrons, but careful investigations have proved that they are reliable indicators for neutron fields that are of interest in accident dosimetry. Dosimeters with silver electrodes of 0.9 cm o.d. yield a sensitivity of about 3.5 V/rd to thermal neutrons and 0.5 V/rd to epithermal neutrons, which correspond to full-scale readings of about 30 rad and 200 rad, respectively. Dosimeters with the same sensitivity to thermal and epithermal neutrons and γ-rays have full-scale readings of 500 rad. Doses between about 50 and 500 rad, which require immediate medical attention, can be read off directly, whereas the less dangerous doses, between 5 and 50 rad, are stored internally and can be read off later.

PHYSICAL MEASUREMENTS ON A 2 keV X-RAY GENERATOR
J.C. Lowth, J.L. Jones, H. Miller
Brit. J. Radiol. 24, 665 (1951)
Reports polarity effect in ionization chamber measurements.

PHOTON CROSS SECTIONS, ATTENUATION COEFFICIENTS, AND ENERGY ABSORPTION COEFFICIENTS FROM 10 keV TO 100 GeV
J. H. Hubbard
IUSRD-IBM 29 (1969)

ELECTRON BEAM DETECTION OF CHARGE STORAGE IN MOS CAPACITORS
E.E. Huber, M.S. Cohen, D.O. Smith
MIT, Lincoln Lab., Lexington MA 02173

Transient currents in anthracene crystals were measured under bombardment by pulses of 700-keV protons. Electron–hole pairs are generated by an intrinsic process, the yield varying linearly with the intensity of the bombarding beam. The average energy for pair production is found to be 10^6 eV. The temperature dependence of the carrier yield can be characterized by an activation energy of 0.07 eV. The results are discussed with regard to different models of the generation process. Drift mobilities of 0.40 cm^2/V sec for electrons and 0.88 cm^2/V sec for holes are determined in good agreement with other authors. A reduction of the current pulse height with the number of bombarding pulses is observed and explained in analogy to the known deterioration of luminescence under ion bombardment. Thereby, the higher deterioration constant for the conductivity can be understood. (auth)

ELECTRIC FIELD DISTRIBUTION IN GAMMA IRRADIATED LEAD GLASS
R.C.Hudson, R.A. Weeks (Oak Ridge)

Field is calculated supposing incidence of a beam not accompanied by secondary electrons.

HIGH DOSE PROTON IRRADIATION OF ALKALI HALIDES
A.E. Hughes, J.J. Pooley


Experimental evidence is given which indicates that the yield of charge carriers excited by a given dose of x rays in thin films of poly-N-vinylcarbazole (PVK) is dominated by geminate (initial) recombination of the ion pairs. The yield as a function of applied field gives a very good fit to the theory of initial recombination developed for gases by Onsager. Two competing mechanisms, the Poole–Frenkel effect and track recombination, may be rejected on the basis of the field dependence. A comparison of the charge transients in PVK with other organic materials is given along with a discussion of the possibility of trap modulation of the mobility in PVK. The role of three different kinds of carrier recombination, bulk, track, and geminate, is described in terms of the experimental results expected for each of them. (auth)

A recent controversy is discussed concerning the relative importance of geminate and track recombination of charge carriers excited by ionizing radiation in single crystals of anthracene. Data are presented that strongly support the geminate recombination hypothesis for bulk excitation by x rays in the 50 to 500-kV range. In agreement with the earlier work of Kepler and Coppedge, it is found that it requires about 2700 eV to create a pair of charge carriers in anthracene at an applied field of 10 kV/cm. (auth)

Measurements were carried out with a Dubetron, 600 keV, giving 3 ns pulses. Electron trapping lifetime was about 50 micro-sec. Bulk recombination coeff. for anthrac is about $3 \times 10^{-6}$ cm$^3$/sec.


Charge-carrier generation by pulsed x rays and carrier transport in fields from $10^4$ to $10^6$ V/cm were investigated in single-crystal quartz. The photoconductivity is found to be practically independent of the angle of electric field to the crystal axes, and the carrier lifetime in both synthetic and natural quartz crystals is very short (less than 10 nsec). The average carrier mobility during the short lifetime is determined to be on the order of 0.1 cm$^2$/V sec, which is lower than predicted for electrons in quartz.

It is shown how the photoconductivity can be used to predict the magnitude of the space-charge buildup in the Sandia quartz gauge subjected to intense radiation environments and that the dynamics of the intrinsic charge carriers are insufficient to explain the shock-induced conductivity observed in the Sandia quartz gauge in certain high-shock environments. (auth)

CONDUCTIVITY INDUCED IN SOLID INSULATING MATERIALS

G.C. Huth

General Electric Company Aircraft Nuclear Propulsion Department, Paper no. 58-331, 1958 (TLD 15 901)

Reports on radiation-induced conductivity in ceramic insulators at elevated temperatures and dose rates of $10^4$ to $10^6$ R/h. Time effects are also discussed.

641000 Hvolby, J. (Radium Centre, Aarhus (Denmark)).

Depth dose near the surface by fast electron irradiation. Measurements with thermoluminescence dosimetry.

EFFECTS OF GAMMA RADIATION ON THE CURRENT-VOLTAGE
CHARACTERISTICS OF ANTHRACENE FILMS
W.Huang, K.C. Kao
Radiat. Eff. 12, 133 (1972)
Current-voltage curves are shown before and after
irradiation. The current for a given voltage decreases with
increasing dose, approaching a saturation value when
the integrated dose approached about 6x10^7 Rad. At a fixed
temperature, the higher the trap concentration created
by radiation the greater the removal of traps per unit
time, and saturation is reached when the rates of
trap removal and introduction are in dynamic equilibrium.
A theoretical treatment of the effect is given.
ELECTRIC CONDUCTION OF IRRADIATED POLYETHYLENE

H. Ieda, S. Kosaki, V. Shinohara

Reports measurements on temperature influence on MIG of high
density polymers, e.g. polyethylene, after electron irradiation,
for exposure doses of 3.15 and 45 kR and 2 MeV electron energies.
A hysteresis effect is observed. Conductivity during the first
heating is much higher than for non-irradiated specimens. At a
temperature near the melting point the crystalline regions of
different specimens, conductivity decreases within a narrow
temperature range by a factor of about 10. The decrease is
irreversible; during the cooling period the conductivity
remains lower than during the first heating. During a subsequent
second heating it is only slightly lower than during the previous
cooling period. It is concluded that charge carriers created
in polyethylene by irradiation are captured in crystalline
regions, but not in amorphous ones, their thermal release
contributing to electric conduction of irradiated polyethylene.

5071 EFFECT OF HIGH-ENERGY RADIATION ON ELECTRIC
CONDUCTION OF VARIOUS COPOLYMERS CONTAINING
POLYETHYLENE.
M. Ieda, Y. Yamada and U. Shinohara,
Electrical Insulation, Buck Hill Falls, Pennsylvania, 1966 (Washing-
pp. 103-6.

The specimens used were copolymers comprising polyethylene
and various percentages of other polymers e.g. polyvinyl acetate,
polypropylene and polylethyl methacrylate. Irradiation was done
with gamma-rays of 5 megrad from Co^{60} at room temperature
with a dose rate of 10^4 rad/hr.

DECAY PROCESSES OF DIFFERENT KINDS OF SURFACE
ELECTRIC CHARGES ACROSS POLYETHYLENE FILMS
M. Ieda, G. Sawa, R. Takeuchi
Japan J. Appl. Phys. 8, 809 (1969)

It is found that the charge decay is
influenced by the type of charged particles
accumulated on the film after it has been exposed
to the discharge from a point corona. Thus it
depends on polarit, initial field, and O_2/H_2 ratio in
the surrounding atmosphere.

A DECAY PROCESS OF SURFACE ELECTRIC CHARGES ACROSS
POLYETHYLENE FILM
M. Ieda, G. Sawa, U. Shinohara
Jap. J. Appl. Phys. 6, 793 (1967)

After corona charging, sample is transferred to shielded
room where surface potential decay is measured. Results:
1) When initial field E_0 is less than a few hundred keV/cm,
lnV versus t show linear relation meaning exponential decay.
2) For higher initial fields decay is not exponential and
its rate is increased. This leads to crossover between curves.
Postulating instantaneous charge injection and movement in
own field the following relation is obtained:
V \approx V_0 - (\mu V_0 \alpha/2d^2) t
in apparent agreement with results.
ELECTRICAL CONDUCTION OF IRRADIATED POLYETHYLENE AFTER ANNEALED

M. Ioda and G. Sawa
Nagoya University Gifu Technical College
Nagoya, Japan Japan

The electric conductivity is known to change upon exposure to high energy radiation due to the production of excess carriers during irradiation and the occurrence of chemical and physical changes. To discern these two factors, the electric conduction current was measured of gamma-ray irradiated low density polyethylene which was annealed after exposure near the melting point to annihilate the excess carriers. The conductivity of the polyethylene between 40\(^\circ\) and 110\(^\circ\)C was found to increase monotonously with irradiation dose, while its activation energy varied in a complex manner. The sample which was irradiated and annealed in vacuum gave only a small increase in conductivity. This observation together with infrared absorption spectra of these polymers suggests that the presence of oxygen during the chemical reaction may account for the observed increase in the conductivity. A study on the sample doped with a surfactant also has been made.


additives; breakdown; enthalpy 60; electric arcs; electric conductivity; electric potential; epoxides; gamma radiation; hardening; medium temperature; radiation effects; temperature dependence; time dependence.


aromatics; brittleness; carboxylics; chemical radiation effects; coaxial cables; dielectric materials; dielectric properties; dose rates; electric conductivity; elongation; gamma radiation; irradiation; photo beams; polyethylene; pvc; radiation doses; tensile properties.

TRANIENT CURRENTS IN PLASTIC INSULATORS AND THE EFFECTS OF GAMMA-RAY IRRADIATION

3. Ide, T. Urai
Chem. High Polymers 20,583(1963)(In Japanese)
The results of studies on the physical characteristics of direct-charge detectors ("radiation elements") designed to measure gamma- and neutron radiations are presented. Data on the relationship between accumulated charge and the form, material and thickness of electrodes, and electrode spacing are discussed. The influence of space charge on the upper measurement limit is considered from a theoretical viewpoint. Detector sensitivities calculated on a computer are also given. Various aspects of the practical application of direct-charge detectors are discussed. (auth)

Paper deals with vacuum detectors. At high dose rates the space-charge formation reduces sensitivity, this being due to very-low-energy secondaries. The effects of chamber air pressure are discussed. A current reversal occurring at low pressures might be due to the Ohmart effect.

The motion of a thin layer of ions produced by ionizing radiation is used to determine the field distribution in a highly insulating dielectric liquid. For the application a thin layer 0.3 to 1 mm thick was produced at one of the electrodes of the chamber of 0.5 to 1 cm thickness. The layer thickness must be small compared with the extension of the region of field inhomogeneities. Its charge density must be low enough to allow one to neglect diffusion, and its electric field should not deform the charge distribution in the liquid. The method was successfully applied to paraffin hydrocarbons, cyclohexane, silicones and carbon tetrachloride.
During the ionization of liquid or air contained between the electrodes of an ionization chamber there is produced a potential difference of the order of one volt which causes ionization current to flow. In the case of chambers filled with liquid hexane, carbon tetrachloride and octamethyltrisiloxane the short-circuit current reached values of the order of $10^{-14}$ to $10^{-13}$ A. In air these values were of the order of saturation current of current-voltage characteristics, also of the order of $10^{-14}$ to $10^{-13}$ A. The experiment shows that the produced potential difference is induced by the bulk photovoltaic effect of the metal-dielectric-metal system and by the surface photovoltaic effect.

Primary (columnar) and secondary (volume) recombination in dielectric liquids is discussed theoretically in analogy to effects in dense gases. The primary recombination is interpreted in terms of an expression for the recombination of single ion pairs given by Onsager; Jaffa's theory is found to be not applicable. The mean escape probability for ions in hexane in the absence of an external field is of the order of $3\times10^{-4}$ and the mean effective initial distance of the ions in a primary pair approximately 80 millimicron. Measurements were made with a parallel-plate ionization chamber, for different values of electric field, electrode distance, and dose rate. The possibility of application for dosimetry is discussed.

Irradiation produced pulses which were counted in a satellite-type detection system. The greatest number of pulses were observed at 77°C (liquid nitrogen temperature). The number decreased with increasing temperature, but pulses still occurred at 363°C. They are believed to be caused by electron storage and subsequent internal discharges. Electron dose rate varied from $3.1 \times 10^7$ e/cm² sec to $3.1 \times 10^{16}$/cm² sec.
A method is described which enables thin, uniform layers to be sectioned off from the surfaces of insulators and semiconductors. It is based on the formation of bombardment-induced disorder in a layer of definite thickness by low-energy ion bombardment and subsequent dissolving the disorder layer in a suitable solvent. The thickness of the layer thus removed after various times and conditions of ion bombardment is determined for silicon and mica using neutron activation analysis. The method is applied for determination of depth distribution of radon decay products injected by recoil from a planar radon source into mica.

CURRENTS INDUCED IN THE DIELECTRIC OF IONIZATION CHAMBERS THROUGH THE ACTION OF HIGH-ENERGY RADIATION
H.E. Johns, A. Aspin, G.G. Baker
Radiation Research 2, 394 (1955)
Reports the polarity effect in connection with measurements with of surface ionization chambers.

BETA-AND GAMMA-INDUCED CONDUCTIVITY IN SEMICONDUCTORS: APPLICATION TO CdS NEUTRON DETECTORS
R.T. Johnson, Jr.
Methods for determining the mobility-lifetime product of high-resistivity n- or p-type semiconductors, using induced conductivity resulting from high-energy beta and gamma irradiations, are developed. The $\mu\tau$ product is determined, under conditions of steady-state excitation, from the measured induced conductivity and the calculated electron-hole generation rate $g$. The carrier-free lifetime $\tau$ is determined from the ratio of these results using the measured Hall mobility. For gamma irradiation, $g$ is determined from the exposure rate, density, mass energy-absorption coefficients, and radiation-ionization energy $e$. For beta irradiation, $g$ is determined from the excitation results from the beta decay of radioisotopes that are produced by neutron irradiation. $g$ is determined from the radioactive decay rate, energy of the beta radiation, and $e$. The absorbed dose rates resulting from these radiations are also determined. Gamma-induced conductivity experiments were performed using $^{60}$Co gamma irradiation on high-resistivity n-type CdS, CdSe, GaAs, and ZnS single crystals. The measured $\mu\tau$ products ranged from $10^{-2}$ to $23 \text{ cm}^2/ \text{V} \cdot \text{s}$. $\tau$ varied from $10^{-2}$ to $10^{-1} \text{ sec}$. Some reduction in $\mu\tau$ resulting from high-temperature annealing of CdS and GaAs was also observed. Beta- and gamma-induced conductivity experiments ($^{197}$Hg beta decay and $^{60}$Co gamma irradiation) were performed on neutron-irradiated CdS single crystals. Comparison of these results shows: (1) The $\mu\tau$ products determined at a given dose rate from the beta and gamma irradiations are in very good agreement (within 15%). Thus, the theories developed for determining $g$ and $g^*$ are valid. (2) For samples which have considerable neutron damage, $\mu\tau$ is dependent upon exposure rate (or absorbed dose rate), decreasing with increasing exposure rate. This is in contrast to samples which have minimal (or no) neutron damage, where very little dependence on exposure rate is observed. (3) The $\mu\tau$ product is also dependent upon the conductivity or Fermi level position. For irradiated high-resistivity crystals $\mu\tau$ is 1 to 6 $\text{cm}^2/ \text{V} \cdot \text{s}$, and $\tau$ is of the order of tens of seconds. The dependence of $\mu\tau$ on the excitation intensity, defect concentration, and Fermi level position in neutron-damaged samples results from sensitizing centers associated with neutron-induced defects. The concepts developed here have resulted in new techniques for measuring neutron fluences using electrical changes associated with induced radioactivity in semiconductors. Gamma-induced conductivity provides a valuable technique for "calibrating" these detectors (i.e., determining the $\mu\tau$ product). (auth)
ELECTRONIC TRANSPORT IN INSULATING FILMS

W. C. Johnson

IEEE Transactions Nucl. Sci. 19, No. 6, 33 (1972)

Review paper discussing the following topics:
- Trapping properties of localized states.
- Space-charge limitation of current.
- Bulk-trap-limited currents.
- a) Hopping conduction b) Poole-Frenkel effect c) Tunneling emission (field emission) from traps.
- Ionic conduction.

TRANSIENT RADIATION EFFECTS ON ELECTRONIC COMPONENTS AND SEMICONDUCTOR DEVICES

D. C. Jones, F. J. Reid, W. D. Chapin, D. J. Manson, R. W. Wyler


The application of self-powered neutron detectors in nuclear power reactors is described. Details are given of their use in-core detectors in flux-mapping systems and in full-power control and safety circuits. The advantages of platinum detectors are discussed, and reference is made to recent interest in detectors for fast-flux environments. (UK)
The electric conductivity of solid monomers irradiated by γ rays at ~190°C was measured during temperature elevation and compared with that of nonirradiated systems. For the nonirradiated systems, peaks in the current-temperature curve were observed at the transition points that were determined by x-ray diffraction and thermal analysis. Activation energies for nonirradiated systems ranged from 0.3 to 1.2 eV in the higher temperature region.

At low temperatures there were pronounced differences between the irradiated and nonirradiated systems, although a negative current was observed in both cases. In nonirradiated systems this negative current might be explained as arising from the depolarization of the oriented permanent dipoles, whereas in the case of irradiated systems it might result from the annihilation of charge pairs produced by the irradiation. In the latter case, the average migration distance of the electron was estimated to be about 100 Å.

To develop a fast x-ray detector with a memory, we have performed experiments with metal-oxide-semiconductor capacitor (MOS-C) devices. For time-resolved recording of the x-ray pulse, a linear array of detectors is uniformly irradiated while the elements are sequentially biased at Δt time intervals; significant positive charge trapping occurs in each element of the array only during the period Δt when the high field bias is applied across the dielectric. Detection of 10-ns resolution has been recorded. Time-resolution is presently limited by the bandwidth limitation of the bias strobing method.
ENERGY TRANSFER DURING TRANSIENT NUCLEAR PULSES
H.P. Kallmann
High energy radiation effects on insulators are examined. Ionization, excitation, and chemical changes accompanying radiation are considered. Radiation extends from soft X-rays to gamma rays. Experimental methods are described.

ENERGY TRANSFER DURING TRANSIENT NUCLEAR PULSES
H. P. Kallmann
A method is proposed for the reduction of the radiation response in cables and capacitors. It tries to neutralize the charge accumulation at interfaces. The insulator should have a sandwich structure, composed of several layers each of which having a thickness smaller than the extension of the width of the charge layer (0.25-0.5 mm). These layers should be separated by thin mylar films or the like.

ENERGY TRANSFER DURING TRANSIENT NUCLEAR PULSES
H. P. Kallmann
Effects of X rays on insulators are investigated without applying external electric field during irradiation. Anthracene crystals are electrically polarized by light or X rays with an external field applied while the effects of the X rays are investigated only in the internal polarization field of the crystal. This method shows that X rays applied concomitantly with external field produce polarization persisting for more than 1 hour after removal of radiation and field. This polarization develops also with blocking electrodes. Similar effects can be produced in polystyrene and influenced by X irradiation.
Photoconductivity induced in zone-refined Silicon doped with As, P, and Sb has been studied after bombardment with 1.5 keV and 45 to 50 keV electrons. For the high energy electrons an "energy band" extending from 1.5 micron to 4.5 micron is made responsible, for the 1.5 keV electrons well defined energy levels dominate.

DECAV OF SURFACE POTENTIALS IN INSULATORS
K.K. Kanazawa, I.P. Batra, W. J. Wintle
J. Appl. Phys. 43, 719 (1972)
The potential decay of surface charged insulators is analyzed, assuming movement of injected carriers (excess charge) and presence of thermal carriers. General solutions are obtained. The case where the injected carriers never reach the grounded electrode is also discussed.

DEEP TRAPPING KINEMATICS
K.K. Kanazawa, I.P. Batra
J. Appl. Phys. 43, 1845 (1972)
The paper discusses charge transport in an open-circuit system for the case of deep trapping in a single trapping level. Carriers are introduced through photogeneration by highly absorbed illumination. Pulse and continued injection are discussed. Recombination and field-dependent photogeneration of carriers play no role in view of the short penetration depth of the radiation. Field-dependent injection is treated, where injection is proportional to the mth power of the surface field.

THE ELECTRIC CONDUCTION IN XXXXX n-HEXANE UNDER ULTRAVIOLET AND GALO RADIATIONS

THE EFFECTS OF GALA RADIATION ON PHOTOCURRENT-VOLTAGE CHARACTERISTICS OF CdS FILMS
E.C. Kao, A. Sadhu
Radiation Effects 14, 279 (1972)
CHANGES IN THE CONDUCTIVITY OF NONLINEAR RESISTORS OF BLACK SiC UNDER THE ACTION OF GAMMA RADIATION

N. Kashkoukev, S. Ribarov, K. Krezhov, V. Todorov
Doklady Bolgarskoi Akademii Nauk 24, 35 (1971)

Range of energetic electrons
L. Katz, A. S. Penfold
Rev. Mod. Phys. 24, 26 (1952)

All observed data could be represented by the relation:
\[ R_E = 4.12E_0 \left( 1.265 - 0.554 \ln E_0 \right), \]
where \( E_0 \) is in MeV, \( R \) in m cm².

PENETRATION OF ELECTRONS INTO ANTHRACENE CRYSTALS

M. Kawabe, K. Kasuda, S. Namba

Penetration depths and energy loss profiles of electron beams in anthracene crystals are measured by observing cathodoluminescence assuming that luminescence intensity is proportional to the absorbed electron energy. Current density was about 10 mA/cm², energies between 25 and 40 MeV. The method was first used by W. Ehrenberg and D. E. N. King,

COMPTON DIODES: THEORY AND CONJECTURES

J. G. Kelly
Discusses detailed theory of Compton dielectric diodes under the assumption of a perfect dielectric. Several cases, including a cylindrical detector system irradiated by a plane wave parallel to the axis, pancake systems (where transition or barrier effects are important) are discussed. Space charge problems, breakdown, and conductivity currents are mentioned.
The apparent electrical conductivity of high-resistance plastics was examined from the standpoint of dielectric relaxation processes as well as steady-state conductivity. The observed, time-dependent conductivity of high-purity polystyrenes, commercial plastics of lower purity and of the copolymer in use for dosimeters can be accounted for on the basis of dielectric charging and low values of conductivity, both varying with the polar nature of the base polymer and the impurities. During irradiation the conductivity increases greatly depending on the dose rate and decays after irradiation with a time dependence related to the composition of the specimen. To be suitable for dosimeter use, the radiation-induced conductivity must decay rapidly, to values below $10^{-12}$ mhos/cm in $10^4$ seconds. The currently used material, a copolymer of styrene and α-methyl styrene (Corex 250B), was found to have unusually rapid decay of conductivity following irradiation. By polymer fractionation and by varying the synthesis ingredients, the chemical species active in reducing conductivity was identified as sulfate chain ends arising from persulfate initiator in the polymerization recipe. Styrene homopolymers were synthesized with sulfate end groups and shown to have low conductivity as the copolymer. Polymers with sulfate end groups and (NH$_4^+$) cations showed low but erratic conductivity and polystyrenes having end groups of moderate polarity have lower dielectric charging prior to irradiation and some reduction in postirradiation conductivity. Methods are proposed for development work to exploit these possibilities for improving plastic insulators.

**COMPUTATION OF ELECTRON TRANSPORT IN DIELECTRICS**
E. Kennedy, I. Kohlberg
Trans. Amer. Nucl. Soc. 11, No. 1, 407 (1968)

**Charge Carrier Mobility and Production in Anthracene**
R.G. Kepler
Phys. Rev. 112, 1226 (1960)

**Generation and Recombination of Electrons and Holes in Anthracene**
R.G. Kepler, E.H. Cepage
Phys. Rev. 151, 610 (1966)

Measurement with pulsed 600 keV X-rays are reported. Average energy to create an externally measurable electron-hole pair was found to be 3 keV, number of carriers being temperature-independent between -25°C and +25°C. Recombination coefficients were determined, taking into consideration that under an external field recombination takes place in a volume which decreases as carriers are swept out. The high value of $W = 3$ keV indicates that only a small fraction of the primarily created electrons and holes become free. These are those for which the electrons have enough energy to overcome the minimum range necessary to escape the potential of the hole.
It is shown that the number of carriers generated by high energy \( \gamma \)-rays in anthracene is small and can be calculated on the basis of a simple model. The only condition necessary for the validity of the model is that the charge carriers have to have a very short mean free path. The model then should be directly applicable to polymers thereby making it possible to calculate the number of carriers created in almost any high energy environment.

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**Radiation Induced Conductivity in Polyethylene Terephthalate and Polystyrene**

Kepler, R. O.; Sandia Laboratories.

Electrical conductivity produced in thin films of polyethylene terephthalate (Mylar) and polystyrene by three nanosecond x-ray pulses from a 600 kV flash x-ray machine has been studied. The current observed in these experiments is proportional to the intensity of the radiation pulse, decays approximately as the reciprocal of the time after the x-ray pulse, and is very temperature dependent. Free carriers produced by the radiation are apparently all trapped in times less than a few nanoseconds and all the current observed appears to result from the relaxation of ionic species created when the carriers are trapped. The results are consistent with the hypothesis that the number of carriers generated varies with the applied electric field as expected for low mobility materials.

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**Radiation Effects in Coaxial Cables**

Kerris, K. G.; Berggren, C. G.; Carter, D. B.; Spehar, G. G.

The results of a systematic study of the interaction of cable systems with ionizing radiation fields are presented, with a view toward achieving a fundamental understanding of the effects governing radiation induced cable signals. The study led to the construction of a physical model which was used to obtain a quantitative description of the dominant processes involved in the interaction. The model is sufficiently comprehensive to permit the calculation of the current induced in the conductors of a coaxial or triaxial cable system (or, indeed, almost any other system of conductors separated by an insulating medium) for any combination of incident photon and electron spectra. A number of experiments was performed to support the calculations. The validity of the model is demonstrated by showing that the experimental data verify the theoretical calculations.
The theoretical curve shows a maximum (in the differential spectrum) in agreement with experiment. A rather narrow region of charge accumulation exists. The difference between charge deposition profiles and absorption curve is small since the directional distribution of incoming electrons is isotropic. At small depths a narrow region of positive charge is found. At 20 keV a small amount of "reconstruction" is found in spite of the low atomic number of the scattering material.

**GAMMA-RAY INDUCED CONDUCTIVITY IN POLYETHYLENE COAXIAL CABLE.**

The electrical conductivity changes in a 3C-2V-type polyethylene high-frequency coaxial cable are reported for conditions of high dose rates of gamma radiation. The dose rates ranged from 4.2 x 10^3 to 1 x 10^6 r/hr and potentials of 0 to 1000 V at currents of 10^-11 to 10^-9 amp. Relations between the induced currents and dose rates give straight lines of slope 0.63 except for zero voltage. The direction of the current for V = 0 is reversed to that for the voltage supply, resulting in a greater value for the slope.

**ACCEUMULATION OF ELECTRIC CHARGE IN GAMMA-IRRADIATED SHIELDING WINDOW GLASS.**
E. Kikuchi
Nuclear Engineering (Tokyo) 11,11 (1965)

Different types of window glass were irradiated with 60Co radiation, at room temperature, dose rate of about 6x10^9 R/h and total dose of up to 3x10^1 R. Non-irradiated conductivity as a function of temperature, and thermal depolarization currents, and thermoluminescence were measured. Currents were measured for unidirectional and for isotropic irradiation. Several current peaks were observed and conclusions about trapping levels and charge carriers drawn.

**SENSITIVITY OF A COMPTON DETECTOR.**
R.M. Kloepfer, V.A. Madsen
LA-1930, Los Alamos Sci. Lab., New Mexico, 1955

Paper discusses behavior of a vacuum detection system.
ELECTRICAL POLARISATION IN LEAD-SILICA-GLASS AFTER X-RAY IRRADIATION
G.Knechtel,A.Schermann
Zeitschrift f. Angewandte Physik 124,389(1965)

Measurements were carried out after irradiation with 90 kV X-rays and doses between $2 \times 10^3$ and $2 \times 10^4$ R. The irradiated samples were rapidly heated to temperatures between 800°C and 1600°C. Discharge currents were measured. For temperatures up to 1400°C currents reach a maximum within a few minutes and subsequently decrease while the temperature is kept constant. For higher temperatures a current reversal is observed and for the highest temperature at which measurements were taken the current has polarity opposite to that for lower temperatures. Effects are interpreted by assuming that due to photo- and Compton effect a space charge field is built up. Heating released $\pi$ electrons trapped in color centers which move in the polarization field. The reverse current at high temperatures is interpreted as a positive ion current.

BEHAVIOR OF CAPACITORS EXPOSED TO HIGH-ENERGY RADIATION
M.Kobale,G.Seebacher
Electronic Engng. (GB) 42, no. 505, 52(1970)

ENERGY DEPOSITION BY ELECTRON BEAMS
E.J.Kobetiob,R.Katz
Phys.Rev. 170,391(1968)

The product of two empirical relations, for the practical range $r$ and for the transmission probability $p$ of normally incident electrons is differentiated to yield an Eq. for the energy deposition. Combined with $E$-formulation this provides theory of spatial ionization energy about the path of a rapidly moving ion. If $3 < w < 20$ keV is the electron energy, $A=5.37 \times 10^{-4}$, $B=0.9875$, $C=3.123 \times 10^{-3}$/keV (in Al):

(1) $r = Aw(1-B(1+Cw)/mc^2$ keV). Electrons of range $r$ which have penetrated a foil thickness $x$ have a residual energy $W$ which is found from above Eq. as the energy to go to the residual range $r-x$. The residual energy $W$ may be written as $W(x,r)=w(r-t)$. The energy transmitted through a foil is approximated by the product of transmission probability $p$ and residual range $W$. For monoenergetic electrons

$\frac{1}{1+\exp(-gh)} \cdot \left\{ 1+\exp\left[-g(x/r-h)\right] \right\}$

where $p$ again is fraction of incident electrons of energy $w$, range $r$, transmitted through absorber thickness $x$. In absorber of thickness $x$, atomic number $Z$, mass number $A$, one has $g=9.2 Z^{-2} + 16 Z^{-2} e$ and $h=0.63(Z/A)+0.27$. 
PHOTOCONDUCTIVITY IN ELECTRICALLY STRESSED DIELECTRICS

M. J. Kofoid and H. V. Cleve
Boeing Scientific Research Laboratories
Seattle, Washington

Conference on Electrical Insulation. October 23-25, 1972, P. 332

Application of a high electric field to a thin sheet of polyimide insulation produced a large increase in conduction current when the polyimide was illuminated with visible light. Without irradiation, this material is an excellent insulator. The conditions under which the theory allows photoconductivity to occur in insulation are examined. In the experiments described here the electric field was produced by depositing in vacuum either electrons or positive ions on the exposed top surface of a dielectric sheet which had its lower surface resting on a plane electrode. Some initial results are presented.

ON PENETRATION OF GAMMA RADIATION THROUGH HETEROGENEOUS BARRIERS

A.M. Kolchuzhkin, V.V. Uchaikin
Atomnaya Energiya 22, 442 (1966)

MEASUREMENTS OF ELECTROMOTIVE FORCES INDUCED IN DIELECTRICS IRRADIATED BY X-RAYS.

Kolomoytsev, F. I., Yakunin, A. Ya., Sviridenko, O. N.

The emf induced in polyethylene insulation and its temperature variation were measured from -30°C to +70°C. It obeys an activation law. At -30°C values up to 105 V were obtained. The temperature dependence of conductivity was also measured.

THE EFFECT OF ELECTROMOTIVE FORCES PRODUCED IN DIELECTRICS BY IRRADIATION UPON THE BEHAVIOR OF THE INDUCED CURRENT

P. I. Kolomoytsev, A. Ya. Yakunin
Fizika 2, 127 (1958)

Izvestiya vysshikh uchebnikh zavedenii, Fizika
(Transactions of Higher Educational Institutions Establishments.

Measurements are reported which indicate that irradiation of dielectrics by X-rays and gamma rays produces electromotive forces which superpose on the applied field and can reach hundreds and thousands of volts. It is believed that they are due to diffusenmexminx transient effects occurring and the front and back surfaces of the samples, where the density of the absorbing medium undergoes a sudden change.

THE EFFECT OF EMF'S ARISING IN DIELECTRICS IRRADIATED BY X-RAYS UPON THE BEHAVIOR OF THE INDUCED CURRENT


Reports production of emf in X-ray irradiated insulators.
IONIZATION CURRENTS IN DIAMONDS IN CASE OF 500-100 keV ELECTRON BOMBARDMENT

E.A. Konorova, S.F. Kozlov, V.S. Vavilov
Fiz. Tverdogo Tela 3, 3 (1966) 3-8

It is shown that with fields exceeding $10^3 \text{V/cm}$ the linear dependence of the product of the drift velocity by the carrier lifetime on the magnitude of the electrical field is not strictly obeyed and that at $10^4 \text{V/cm}$ this value (which one - the dependence or the product ?) has been observed to be saturated. The results obtained have been interpreted in terms of the theories that predict the mobility of carriers as a function of the field strength; calculations are in satisfactory agreement with theory. In natural diamonds the electron lifetime has been proved to lie in the $10^{-11}$ to $10^{-10}$ sec range and to be determined by the nitrogen content if it exceeds $10^{17}$ cm$^{-3}$.

EFFECT OF HIGH-ENERGY RADIATION ON ELECTRIC CONDUCTION OF POLYETHYLENE

M. Kosaki, Y. Yamada, U. Shinohara
Conf. on Electrical Insulation, Cleveland, Oct. 1964 (CONF-769-8)

Measurements are reported, results being represented as graphs giving conductivity against inverse temperature. For polyethylene resistance decreases with dose at room temperature, but near the melting point the decrease ceases and resistivity jumps to the pre-irradiation value. The radiation effect can be eliminated by annealing; the "jumping" is explained by recombination of radiation-induced charge carriers upon melting. Polypropylene gives continuous curves.

X-RAY INDUCED PHOTOCONDUCTIVITY OF ANTHRACENE

G. Kramer, K. Challa, J. Canfield

With a beam fully penetrating the sample induced conductivity of crystals has been measured as a function of dose rate, field strength, and temperature. Currents increased linearly with dose rate and field strength. At 630 V/cm charge production was about $7 \times 10^{-12}$ C/cm$^2$ rad. Currents increased with increasing temperature exponentially, exhibiting two different activation energies, one below

and the other above 250$^\circ$K. The activation energy decreased with dose rate. The mobility-lifetime product for the carriers could also be determined.

GODIVA II IRRADIATION OF SEMIKAD

S. Kronenberger, H. J. Murphy
HP 7576, December 1958
IRRADIATION OF SEMIRAD AT THE GENERAL ATOMIC LINEAR ACCELERATOR
S. Kronenberger
USASRD TR-2070, May 1959.

TACTICAL RADIATION DOSIMETRY IN THE U.S. ARMY.
Kronenberger, Stanley (Army Electronics Command, Fort Monmouth, N.J.) Health Phys., 14: 41-4
(Jan. 1968)

The army is interested in the dosimetry problems associated with tactical warfare in which small tactical nuclear weapons might be used. Therefore a tactical dosimeter is required. This should be a high range direct reading device measuring both gamma and neutron radiation to provide a means for rapid determination of the total dose personnel have received. A quartz fiber dosimeter based on secondary electron emission in a vacuum (Radiacmeter IM-185) is under development. It is hoped that this dosimeter will satisfy all of the requirements of a tactical dosimeter. Physical principles, construction, and performance of Radiacmeter IM 185 are discussed.

DIELECTRIC BREAKDOWN IN LiF CRYSTALS BOMBARDED BY ELECTRONS
K. Kubo
J. Appl. Phys. 37, 4722 (1966)

Breakdown induced by bombardment with 1-2 MeV electron was investigated, beam intensities being between 1x10^5 and 2x10^7 electrons/cm^2. Sparking was observed during and after bombardment. The breakdown layer contained the electron range plane (corresponding to the extrapolated range), but the middle plane of breakdown paths (i.e., where the maximum population of breakdown paths was found) was located beyond the extrapolated range. It is concluded that electron straggling played an important role. The number of breakdown paths increased with dose and with discharge period and decreased with time between irradiation and breakdown inset. Dendrites consisted mainly of straight paths, sometimes accompanied by curves paths, especially at branching points. The paths, which were clearly visible in the microscope due to total reflection, were hollow channels left by the evaporated material. Material brought out along the paths were found attached to the surface where the path exit was found. Structural alterations such as formation of Li metal colloid and molten material were found near large breakdown channels, indicating instantaneous electrolysis with heating and subsequent cooling.
NEGATIVE ELECTROLYTIC BREAKDOWN IN PROTON-BOMBARDED LiF CRYSTALS

K. Kubo

Dielectric breakdown under 1.9 MeV proton bombardment was studied. A negative discharge figure was observed similar to the conventional electrolytic-type point to point discharges. In correspondence to what happens with electron bombardment it was believed that a positive space charge would be formed which when discharged would result in a positive Lichtenberg figure. However, the actual figure was not like a positive one but more like the electrolytic breakdown due to conventional point to point discharge (so-called negative surge). It is believed that the proton field produced by the layer of trapped protons accelerates electrons present in the crystal. These will cause ionization of ions or atoms leaving a trail of positive space charge behind which shields the proton field and inhibits further electron acceleration, thus preventing the Lichtenberg type breakdown which depends on instantaneous neutralization of the space charge field. The breakdown Fig. consists of random and (100) paths with layers of precipitated Li metal.

PENETRATION OF MONOMERGONIC ELECTRONS THROUGH DIELECTRICS

J. Kuczera
Nukleonika, No. 7-8, 503 (1966)

Measurements are reported for the energy range between 0.59 MeV to 1.185 MeV, and for several dielectrics (paraffin, polyethylene, epoxy resin, methyl polymethacrylate, cellulose, cellulose acetate, and mica). As the beam source a beta spectrometer was used.

The construction of very large arrays of electronic components on a single semiconductor chip implies a need for new methods of component testing. The presently used contact pads take up too much space. The method proposed uses primary electron beams to excite low-energy secondary electrons which are used to sense surface potentials. The primary electrons are to be allowed to strike only very small diameter metallic contact areas on the interior of a chip, in an environment where surface electric fields are carefully controlled (i.e., no exposed insulator surface). Data are presented for a preprototype system using a mockup target and a single large-diameter electron beam. Two operating modes, potential stabilization (corresponding to voltage signal input) and potential measurement (corresponding to voltage signal output), were demonstrated. Accuracies better than 100 mV were observed for both modes using a 5 kV, 10^-4 A, primary beam. If the method could be extended to multiple small-diameter beams, it could be used to simultaneously inject several voltage signals while measuring output signals from extremely small... circuits, (auth)

PHOTOLUMINESCENT YIELD

L. Kuznetsov (Palo Alto, Calif.)


An extended noncoherent beam of photons incident normally on a plate several electron ranges thick. In the paper the number of electrons emitted is calculated, including Photo-and Compton electrons and Auger electrons. Calculation is done for electrons emitted into the half-space to the right of the plate, into that to the left, and the difference of the two, applicable to charge transfer between two closely spaced plates of the same material. Calculated yield curves are given for fluorescent and Auger distributions for Au at 50 keV, as function of plate thickness between 10^-7 and 10^-2 cm, and electron-transport yield for Cu and Au up to 10^-5 keV.

METAL-OXIDE-METAL (MOM) DETECTORS

S. P. Khokhlov, G. I. Haddad, G. I. Ibov

J. Appl. Phys. 42, 554 (1971)

Properties of MOM tunneling detector are presented and parameters influencing operation are discussed. Theory of operation at small and at large signals and experimental results are discussed. Polarity reversal at large signal levels is predicted theoretically and observed experimentally.

Methods of estimating the permanent damage, in terms of the variations in the electrical and mechanical properties, suffered by insulations and cables subjected to irradiations are described. With the aid of the results obtained, the lifetimes of the materials were determined, and an attempt was made to define an acceptable dose limit.

Six groups of different products were studied: (1) basic insulating materials, in the form of films or sheets, such as polyethylene, polyamides, and heavy molecular plastics; (2) impregnating varnishes; (3) impregnated cloths; (4) enameled wire; (5) wire and cables; and (6) laminated copper for printed circuits. Two radiations were used: 1.3-MeV gamma and 6-MeV electrons. (France)


The changes in the electrical characteristics of several types of capacitors after exposure to high energy radiation were investigated. In order to obtain a better understanding of these effects, the influences of different parameters of the radiation, the environment, and the component geometries were studied. (France)

PRODUCTION OF LARGE ELECTRIC FIELDS IN DIELECTRICS BY ELECTRON INJECTION

H. Leckner, I. Kohlberg, S. V. Nablo

J. Appl. Phys. 36, 2064 (1965)

Targets of Lucite and polystyrene were irradiated by 1.5 KeV electrons until the occurrence of spontaneous breakdown. Framing camera pictures of the fluorescence zone show that the regions steadily decreases until the breakdown is observed. This indicates a decrease of electron range due to change buildup and increase of an internal space-charge field. Fields of up to 6.3 KeV are inferred. It is pointed out that the potential within the dielectric might exceed the accelerating potential.

ELECTRICAL DISCHARGE IN SHIELDING WINDOW GLASS OF MULTI-KILOCURIE CELL NO. 1, BUILDING 3029.


An electrical discharge in a four inch thick pane of shielding glass produced a typical branching pattern. The glass had been subjected to the gamma radiation from 13,000 curies of Co60 during the five days prior to the discharge. The cause of the discharge may be explained by the entrainment of Compton electrons which would result in an electrical field gradient sufficiently high to exceed the dielectric strength of the glass. The danger of electrical shock during the cleaning of an irradiated piece of glass would exist.
PULSED NUCLEAR RADIATION EFFECTS ON RESISTORS AND CABLES, SPRF IV.
C.P. Lascaro, W. Schlosser, J. Newberg
(AROY Electronic Labs., Forth Monmouth, N.J.) Dec. 1964, 35 p. S.0.50

Transient response was measured during the pulse. Behavior of different cables was compared.

STUDIES OF ABSORPTION OF HIGH ENERGY ELECTRON BEAMS

J. S. Laughlin

Penetration of electrons and charge deposition profiles are measured in an experiment in which a stack of alternating layers of conducting and non-conducting polystyrene was bombarded with high energy electrons. Kessari's theory was roughly confirmed.


In the passage of a charged particle through matter, the energy lost by the particle, in general, will not be the same as the energy retained by the material. Calculations of the differences caused by escaping electrons (delta rays) are presented for two experimental situations, but the methods used can be generally applied. e.g., 50-MeV protons in a carbon foil 1 mg/cm² thick would lose 11 keV; 10% of this energy loss would escape from the foil in the form of kinetic energy of delta rays. An escaping delta ray would appear only for about 1 in 25 protons. In a rough approximation, for protons in light elements, on the average, an energy amounting to 50 eV per MeV of initial proton energy is removed by delta rays.

EL TRONIC TRANSPORT IN AMORPHOUS SILICON FILMS

P. G. LeComber, W. E. Spear

RADIATION INDUCED CURRENTS ACROSS Al₂O₃ FILMS
R. S. Ilee

Films of Al₂O₃ sandwiched between thin metal electrodes were irradiated with continuous radiation from a Co-target X-ray tube of 35 kV. Currents versus time and versus voltage were recorded during irradiation. Induced charge trapping effects are discussed. Measurements with d.c. and a.c. seem to allow to distinguish between electron and hole effects.
RADIATION EFFECTS ON FERROELECTRIC MATERIALS

I. Lebrovitz
Summary Report, Research and Development Laboratory, Glencoe Corporation, 1965
AD 655 051

Materials used were barium titanate-type materials. Reactor radiation and 60Co radiation were used. Measurements included charge release during radiation exposure, surface charge measurements, piezoelectric properties. Several effects can be interpreted in terms of Coulomb current. In ferroelectrics additional factors interfere, however. These are a photovoltaic effect, contribution of the polarization state of the system to the charge release, a surface charge layer, and a possible anomalous charge release.

DIELECTRIC MEASUREMENTS IN SOME IRRADIATED CLASSES
E. Lell, (Bausch and Lomb Inc. Rochester NY)
R.A. Weeks (Oak Ridge National Lab.)
1962 Conference Radiation Effects on Glass, Rochester, NY 1962
Summary Paper No. 11

Effects of 1.5 MeV electron and 60Co gamma irradiation on dielectric relaxation spectrum and intrinsic electrical conductivity of high purity silica, lead silicate glass, phosphoric glass and pyrex are investigated.

EFFECTS OF IRRADIATION ON POLARIZATION CURRENTS IN LEAD SILICATE GLASS
E. Lell, R.A. Weeks

For 60Co irradiation, the conductivity of a lead silicate glass was measured as a function of voltage, sample thickness, and temperature.

RADIATION EFFECTS IN QUARTZ, SILICA AND GLASSES
E. Lell, N.J. Kreidl, J.R. Hensler

Survey article including electrical and electrostatic phenomena induced by particle and gamma radiation.

NEUTRON AND GAMMA RADIATION EFFECTS ON DIELECTRICS
E.O. Linden, C.F. Lascaro
USAREL, RD-2323 (Army Electronics Res. and Development Lab., Fort Monmouth, NJ USA)

Measurement of effects of pulsed radiation on dielectrics such as asbestos-fabric phenolic, asbestos-filled phenolic, paper phenolic laminate etc. Exposures have no significant permanent aftereffects on dielectric properties.
The charge distribution in the oxide is determined by measuring the change in charge density in the Si inversion layer as the oxide is gradually etched off.

J. Lindmayer

THE SYSTEM KIPTAL-OXIDE-SILICUM (KOS)

J. Lindmayer
Ph.D. Thesis, Technical University Aachen 1963
The charge distribution in the oxide is determined by stepwise etching of the oxide. Measurement of the channel conductivity then allows to reach conclusions concerning the amount of charge remaining in the oxide.

RADIATION AND OXIDE-OXIDAL INTERACTIONS IN KOS

J. Lindmayer
IEEE Transactions ED-10, 21(1971), No. 6

ABSORPTION COEFFICIENTS AND BUILD-UP FACTORS OF NUCLEAR SHIELDING GLASSES

J. Lindmayer
Nucleonics Data Sheet No. 27, Vol. 16(1958)
Also reproduced in Technical Glass Bulletin No. 103, Pittsburgh, Pa., Plate Glass Co., One Gateway Center, Pittsburgh, 22, Pa., October 1, 1963.

RADIATION EFFECTS ON INSULATION-STATE OF THE ART

V. J. Linnebo
Insulation (Libertyville) 10, 21(1964)

TRANSIENT RADIATION EFFECTS ON ELECTRONIC PARTS

V. A. J. van Lint, R. F. Overmeyer, D. K. Nichols

AD - 623 904 (1965)
(Gen. Atomic San Diego Cal., Special Nuclear Effects Lab.)

Prompt and delayed conductivity in mica, ceramic, tantala oxide, and Mylar dielectrics with various types of electrodes under Linac irradiation were reported. A theory of neutron induced ionization has been developed which predicts linear relation between conductivity and neutron energy deposition rate.
The effects of gamma and neutron radiation on coaxial cables should be described as a current due to ionically moved charge and a conductivity. Simple models, using known cross sections for gamma and neutron interactions, can be used to calculate the amount of charge displacement. The radiation-induced conductivity of a cable can also be estimated from data on the dielectric material. Experimental data frequently show larger initial responses than the estimates. The observed current is proportional to instantaneous dose rate or flux, but the proportionality factor is a generally decreasing function of dose or fluence, even changing signs in some cases. The anomalies suggest relaxation of space charges created in the dielectric by the manufacturing process or by physical motion.

The effects of ionizing radiation on insulator parts are discussed as being the results of four associated phenomena: conduction, charge transfer, space charge buildup, and air ionization. Techniques for estimating these effects under some circumstances of interest are described.

Reports two experiments on Lucite to see what effect the primary stopped charge might have in work with keV pulsed electron beams. In the first experiment, energy deposition profiles were measured using calorimetric techniques. Measured profiles were compared with Monte Carlo electron transport code calculations. Shapes of profiles were not much different than for equivalent thickness conducting materials, but integration resulted in anomalous high beam energy fluences. This effect was measured by measuring electron beam energy fluences through equivalent conducting and dielectric absorbers. It was found that the dielectric has an effect upon the electron beam spatial distribution. For discussion, two models were used: 1) No trapped charge 2) Dielectric breakdown model in which charges build up to a specified breakdown potential where all charge is released, and remains zero for the rest of the calculation. The increased beam energy absorption is interpreted as beam focusing producing
on-axis incident energy densities much higher than the energy fluences measured with the conducting carbon calorimeter beam focusing were investigated by studying effects of dielectric absorbers on the radial intensity distribution of the electron beam. As the thickness of the dielectric absorber on top of the sample is increased, the transmitted fluences becomes enhanced with respect to an equivalent Al absorber. A possible explanation is a buildup of positive space charge in the bulk of the sample which tends to neutralize the negative space charge associated with the electron beam allowing its magnetic field forces to cause self-focusing. A thin conducting film (foil) overlay on the front surface of the dielectric eliminates the beam focusing effect. Note that in the dielectric focusing measurements to ground surfaces were usually employed.


The electrical breakdown of mylar micromega-\vend detectors was studied under simulated space conditions to determine the amplitude range of trapped electron breakdown pulses, a method of discriminating them from micromega-\vand produced pulses, and the temperature dependence of electron breakdown pulse. Pyrogen panels, used as test specimens, were placed in a controlled temperature heat sink, with the electron source mounted inside the heat sink volume and parallel to the panels. The entire assembly was located in a large vacuum chamber held at approximately 10^-4 torr. Temperature was varied and controlled from ambient to 790 F.

Principal test results indicate pulses were of both polarities with respect to the bias voltage of the panel, pulse rise time was of the order of micro-sec., amplitudes and polarity of breakdown pulses are apparently independent of bias or load resistance. Breakdown rate varied approximately inversely with temperature and practically vanished at room temperature. The spectrum of breakdown amplitudes decayed rapidly with amplitude, no pulses being observed greater than 2.7 V.
All II. Piezoresitivity in Electron-Irradiated Silicon. C. B. Leggadie and R. A. Littlejohn, North Carolina State University.---The piezoresitivity of n-type silicon irradiated with 7 keV electrons was studied. Uniaxial compressive stresses up to $2.5 \times 10^8 \text{ dyn/cm}^2$ were applied to samples of three different orientations ((100), (110) and (111)) in obtaining the data. Over the experimental temperature range (250 K to 350 K), the piezoresitivity of these samples exhibited a behavior markedly different from that of unirradiated silicon. A mathematical model has been developed which agrees quantitatively with the observed experimental results. It was necessary to include in this model contributions to the piezoresitivity due to the temperature variation of the relaxation time anisotropy as well as the contributions due to the presence of compensating irradiation-produced acceptors, such as the silicon F-center. This model will be discussed and its predictions compared with the experimental results.


B10. High Energy Density Response of Materials Using Intense Relativistic Electron Beams. A. Miyake, J. Reaugh, C. Yunas and J. W. Spence, Physics International Co.---Pulsed relativistic electron beams with several hundred kilowatt mean electron energy at current densities up to 100 kA/cm$^2$ have been used to study material response to high energy density front surface loading. Diagnostics successfully used in the electron beam environment include: (a) a ballistic pendulum to measure total impulse delivered to a sample, (b) quartz pressure transducers to measure the early (0.5 ns) stress vs. time profile, (c) manganin piezoresistive gauges to measure late time (>10 ns) stress profile, and (d) streak and framing camera photography of vapor and liquid expansion from the front surface. Observations of mixed-phase phenomena are discussed.

Work supported in part by the Defense Atomic Support Agency.


ELECTRIC BREAKDOWN VOLTAGE OF ELECTRON-IRRADIATED POLYVINYL CHLORIDE

R.J. Lujan, S.A. R. Lujan
Rev. Mexicana Fis. 16, 1, 1 (1967)

The relation between breakdown voltage and radiation dose was investigated with PVC films for electron irradiation in the range of 0.6 to 1.0 keV and 0.1 to 5 krad. Use of electron spin resonance techniques permit to determine the relative concentration of free radicals in the films. The relationship between this concentration and the breakdown voltage and the variation of concentration with time is discussed.
Particle range is determined by the very sensitive method of removal of thin surface-layers by low energy sputtering. Range distributions in copper crystals are measured by using Kr95 ions between 25 and 150 keV.

The bombarding particles produce induced radioactivity. The measurements are carried out with a "shaving-of" method.
PHOTO-COMPTON CURRENTS IN UNBOUNDED MEDIA

C.J.MacCallum, T.A.Dellin

J. Appl. Phys. 44, 1876 (1973) (cf. Dellin)

The theory covering the 10 keV to 20 keV range is based on the following idealizations:

a) medium homogeneous and unbounded, e.g. all interfaces are more distant than one electron range (10^{-4} \text{g/cm}^2 \text{ in H at 10 keV} to 10 \text{ g/cm}^2 \text{ in U at 20 keV}).
b) Photon flux spatially uniform over one electron range. Thus pertinent nonuniformity given by ratio of mean forward electron range by photon interaction length \( J_{ep} / \beta \).
c) Steady state, e.g. photon flux uniform in time.
d) Electron transport calculated taking account of multiple-scattering angular effects but using code (continuous slowing down approximation).

Results for net current can be applied as source terms for calculation of electromagnetic fields generated within irradiated dielectric-filled cavity. Net current differences in differing media determine magnitude of radiation-induced charge deposited in vicinity of an interface. The forward and backward currents in an unbounded medium are upper bounds, respectively, for forward and backward emission currents at vacuum/medium interfaces and play a role in construction of empirical models of current variation and charge deposition across interface.

TRANSPORT RADIATION EFFECTS IN OPTICAL MATERIALS

P.W. Jace, L.L. Gill

Law-DC-8646  (Ney-Jac Alliance Scient.J.N., New Mexico)

The use of the prototype Linac electron irradiation to simulate high-dose-rate nuclear environment is discussed. The free electron density produced in optical materials by the machine beam, and that expected from a typical incident prompt-gamma radiation flux are compared. An experimental setup to measure the effects of transmission of selected materials is described, and data obtained on these materials are presented. Transient or permanent loss of transmission was observed in optical glasses and Ge-101 fused quartz, but no effect was seen in purified fused silica. Reflectivity of front-surface aluminum and dielectric mirrors was also checked and no effects were seen.

60382 ENERGY LOSS OF THE HIGH ENERGY ELECTRONS


The electron energy-loss measurements within the 90- to 550-MeV region and at 31 GeV were made. The experimental dE/dx values are an attractive fit to the theoretical ones without using radiative corrections. These measurements were performed at the 250- and 600-MeV electron synchrotrons of the Lebedev Physical Institute and the electron beam of the 70-GeV BNL proton synchrotron (Gorshkov). (auth)
THEORY OF TRANSIENT SPACE-CHARGE-LIMITED CURRENTS IN
SOLIDS IN THE PRESENCE OF TRAPPING

A. A. Avron, G. Gakkavi

Phys. Rev. 126, 1900 (1962)

Paper given a mathematic treatment of the problem for insulating and for conducting crystals. Simplified solutions are obtained for current and space-charge distribution following inset of injection from one electrode, the latter taking place via an ohmic contact under an applied voltage pulse. Exact analytical solutions are, however, given for the two limiting cases of no trapping and of fast retrapping. For "slow" retrapping in insulators approximate solutions are given valid for times larger than twice the transit time. Numerical solutions are given for shorter times.


The physical changes in five plastic-bonded high explosive compositions induced by 60Co gamma rays were studied for exposures up to $3.5 \times 10^4$ R at two rates, $4.5 \times 10^4$ and $2 \times 10^4$ R/hr. Some samples were given a single continuous exposure while others were exposed in successive increments to the same total dose and measured after each exposure. Diameter, length, and weight were measured, and volume and density were calculated. Detonation velocity and plate acceleration capability were tested on samples which have been continuously exposed. The explosives studied were 9404 HMX/Nc, HMX/Kxon, KMX/Ps, KRX9 HMX/Kc, and DATB/Kxon. (T.F.D.)

ELECTRON SHIELDING CODES FOR EVALUATION OF SPACE RADIATION HAZARDS

B. W. Mar


Boeing Report D2-90414, June 1963

Theory of electron transmission in matter for electrons produced at a given depth in a target, having a given energy and scattered at a given angle. The theory refers to the case where electrons are produced by Compton or photo-effect in matter and permit to calculate the number of electrons which escape the target.
A nomograph for electron number of electrons transmitted and an expression for the differential energy spectrum of the penetrating electrons are developed from Monte Carlo calculations. Normal incidence is supposed, calculations are carried out for different materials (Be, Al, Nb, Ag, Pb) and for approximate electron energies in the range of 0.4 to 10 MeV. Comparison with experimental data and some other calculations show the method to be satisfactory. None calculations are also made.

SPACE-CHARGE LIMITED CURRENTS IN ORGANIC CRYSTALS
P. Mark, W. Helfferich
J. Appl. Phys. 33, 205 (1962)
Conductivity measurements were made with 50 microm single crystals of anthracene, p-terphenyl and quaterphenyl supplied with aqueous electrodes, one an iodine-iodide solution and the other an iodide solution. The acceptor electrode forms an ohmic contact for hole injection and the current can be drawn from the crystal. The theory of the steady state and transient currents is developed. Hole trapping states form an exponentially decreasing distribution from above valence band. In p-terphenyl, hole concentration is about $10^{13}/\text{cm}^3$ and mobility $3 \times 10^{-2} \text{cm}^2/\text{V sec}$.

IONIZATION CHAMBERS, FREE OF POLARITY EFFECTS, INTENDED FOR ELECTRON DOSIMETRY
B. Leunus
Two parallel plate chambers (phantom and extrapolation) were constructed for electron dosimetry. They are freed of the polarity effect by use of a new principle, e.g. diminished collector volume. Origin and behavior of the polarity effect are discussed and measurements for 5 and 15 keV electrons are reported.

DETERMINATION OF CARRIER MOBILITY IN PLASTICS BY A TIME-OF-FLIGHT METHOD
E. H. Martin, J. Hirsch
The predominantly mobile carrier in mylar is negative and transports by hopping. Mobility-lifetime products are in the range $10^{-11}$ to $10^{-10} \text{cm}^2/\text{V}$.
SUMMARY OF THE HERMES FLASH X-RAY PROGRAM.

T. Martin, K. R. Prestwich, D. E. Johnson


As a result of the rapid growth of pulsed power technology, attributable in part to research performed by Sandia Lab., has developed, fabricated, and is operating Hermes II, the largest flash X-ray machine presently available. It has produced a 150 kA beam of electrons of 12 keV for 100 ns. Hermes I, a 1/10 scale model, was constructed to perform necessary experimentation for the development of Hermes II; it was later used as an operational electron beam facility. The components of the Hermes machines are a low-inductance Marx generator, a Blumlein transmission line, and a vacuum tube in which the beam is formed by field emission and accelerated across the cathode-anode region by means of applied voltage. All high voltage portions are submerged in transformer oil for insulation. The Hermes II components are housed in a steel cylinder 85 feet long and 22 feet in diameter containing about 150,000 gallons of oil. The Marx generator was designed for 13 kV and 0.5 J, with 16 capacitor stages consisting of two (1/2) F, 100 kV capacitors.
MEASUREMENT OF DEPTH DOSE DISTRIBUTIONS DEPOSITED IN A Plexiglas phantom IRRADIATED WITH A BEAM OF 10-, 15-, 20-, OR 30-MeV MONO-ENERGETIC ELECTRONS. Mathieu, Jacques; Blanc, Daniel; Casanova, Joseph (Toulouse Univ. (France), Centre de Physique Atomique et Nucleaire); Dutreix, Andre (Institut Gustave Roussy, Villejuif (France)); Wambacq, Andre; Friguet, Michele (Louvain Univ. (Belgium)). (In French).

The ionization produced in depth in a Plexiglas phantom irradiated by a monenergetic electron beam was measured by means of an ionization chamber with dielectric liquid. The sensitive volume is a thin film of liquid (0.5 mm thick), the electrodes are beryllium discs 0.5 mm thick and the chamber walls are of Plexiglas. The in-depth yield was measured for 10, 15, 20, and 30 MeV electrons; the results are compared with those obtained with a Baldwin chamber and with a ferrous sulphate dosimeter. (auth)


The effects of γ radiation on electrons in vacuum and in air on the dielectric behavior of polyethylene, polypropylene, polystyrene, and poly-α-methylstyrene were studied for a wide range of doses (to 800 Mrad) and dose rates (to 7.3 x 10⁴ rad/sec). Dependence of tan δ on the dose of γ radiation in air was determined for all the polymers. The increase of tan δ on irradiation in air is related to radiation oxidation. The latter has diffusion character and the increase of tan δ is determined not only by the dose, but mainly with the time of contact with oxygen. For polyethylenes a formula is found (for 200 to 1000 rad/sec) that relates tan δ to the radiation dose in air, thickness, and crystallinity of the sample. Tan δ of polyethylene irradiated in a vacuum increased on storing in air, which caused migration of radicals from the crystalline phase. (auth)


Reversible changes in the dielectric loss induced by γ radiation were investigated for the following polymers: polyvinyl chloride (PVC), polytetrafluoroethylene, the copolymer of tetrafluoroethylene and vinylidene fluoride, and polyethylene. The radiation effect was different for each polymer. The reversibility effect in PVC and PTFE was associated with an accumulation of volatile products of radiolysis. The effect observed in the other polymers was connected with the formation of unstable peroxide compounds such as free radicals. (tr-auth)

THE CONDUCTIVITY CHANGE IN POLYETHYLENE DURING GAMMA-IRRADIATION

S. Mayburg, W. L. Lawrence

J. Appl. Phys. 23: 1096 (1952)

Measurements with a Co60 radiation source, at room temperature and at liquid nitrogen temperature are reported. The latter give twenty-fold decrease of the normal conductivity and a 25-fold decrease of the radiation induced conductivity. An ionic mechanism is suggested, proton-current proton conduction.
RECOVERY OF AN INSULATOR FROM A RADIATION PULSE

S. Kayburg

Proc.IEE 24, 3013 (1966)

Spurious voltages are frequently produced in insulators in a pulsed nuclear radiation field. They are due to positive charges left in the insulator after a nuclear blast has expelled electrons from the material. Recovery of the system can be expressed in terms of a single time constant.

LOW ENERGY ION BOMBARDMENT IN SiO₂

C.V. McClatchy, V.T. Murphy

IEEE Trans.Nucl.Sci. NS-19, No. 6, 249 (1972)

Evidence has been presented for the presence of mobile ions in ion bombarded SiO₂ which are possibly protons or Na ions. A model involving neutralization of the incident ion beam at the surface, followed by impurity ion transport to the interface under the influence of the field building up across the SiO₂ film during bombardment has been constructed to explain the experimental data.

ELECTRON BOMBARDMENT CONDUCTIVITY IN DIAMOND. I. II

K.C. McKay

Phys. Rev. 74, 1606 (1948); 77, 616 (1950)

It is observed that the ionized electrons and holes become trapped at energy levels with sufficient lifetimes and densities to establish an appreciable space charge. Measurements have been made of current decay due to space-charge buildup which are in agreement with theory. A double pulsing method is developed which tends to neutralize the space-charge effect and provides a novel method to study rates of release of positive holes and electrons from traps. The voltage-current eq. is \( D = \frac{W}{1 - \exp(-W^{-1})} \) where \( D = \frac{\delta}{\delta_\infty} \) is the normalized yield, \( \delta \) the observed current passing through crystal divided by bombarding current, \( \delta_\infty \) the yield for infinite applied crystal field, \( W = w/l \) the normalized range, \( l \) crystal thickness, \( w = FT \) the probable electron range, \( v \) electron mobility, \( F \) applied field, \( T \) probable time an electron would spend in semi-infinite crystal before being trapped. This assumes step voltage, homogeneous distribution of traps, space-charge effects negligible. Bombardment performed through thin electrode connected to meter.
ION BEAM ELECTROGRAPHY

R.J. McClure


Properties of a variety of materials for collecting charge patterns produced by ion beams in mass spectrometers were investigated. Among the materials listed were mylar bonded to a glass plate by epoxy, such mylar coated with a transparent layer of aluminum on the reverse side and others. Images were made visible by a semitometric method.

THE MEASUREMENT OF ELECTRON AND GAMMA-RAY DOSE DISTRIBUTIONS IN VARIOUS MEDIA

W.L. Haughlin, E.I. Haukstrum

Intense Radiation Sources for Industrial Processes, Proceedings of Symposium, Munich, 16-22 August 1965, p. 579

Measurements with radiographic dye films and gases are reported. Some results are given for an aluminum-flon-aluminum-dylon system. Transition and backscattering effects are seen. The interface problem is discussed.

ELECTRONS TRANSPORT IN THIN INSULATING FILMS

C.A. Ladd

Phys. Rev. 123, 2039 (1962)

Paper reports tests on Re-Te-Ge-Au diodes of various thicknesses at different temperatures T, to determine the current flow mechanism. This is found to be field ionization of trap states at low T and thermal ionization of these states at high T. High temperature current-voltage characteristics and low temperature comparisons between forward and reverse characteristics agree with a bulk-limited hypothesis and are in disagreement with a barrier mechanism. A discontinuity in oxide properties occurs at 500Å thickness. High T measurements with an applied voltage smaller than the difference in metal work functions yield Ohmic behavior with an activation energy of about 0.1 eV, consistent with impurity conduction, but not with a barrier process.

RADIATION INDUCED CONDUCTIVITY IN POLYMERS.

Meyer, R.A., Bouquet, F.L., Alger, R.S.

J. appl. Phys., 27, 1012 (1956)

Measurements of conductivity of polyethylene and teflon under exposure to 2 MeV X-rays and to Co 60 gamma radiation are reported. Currents are found to increase approximately linearly with dose rate. Observations of the current caused by the forward scattering of Compton electrons are reported. A sandwich system is used to eliminate this component.
PHOTOPOLARIZATION OF ANTHRACENE
F.C.S.Milanes, P.V.Kurphy
An Acad Brasil Ci. 35, 134 (1963)

Anthracene single crystals were polarized perpendicular to cleavage plane by simultaneous action of electric field and u.v. light. Decay currents, effect of anthracene fluorescence radiation, and anthracene polarization saturation effects were observed.

GAMMA-ELECTRIC CELL THEORY AND EXPERIMENT
G.H.Liley, H.T.Sampson
Proceedings Int. Conf. on Energy, Univ. of Rochester, N.Y.
August 1965

The gamma cell directly converts gamma-ray energy into electrical energy. Basic theory and preliminary experimental results from reactor and cobalt-60 irradiation are presented. Results for both types of irradiations are in good agreement.

MISSION-FRAGMENT TRANSPORT EFFECTS AS RELATED TO FISSION-FRAGMENT ELECTRIC CELL EFFICIENCIES
G.H.Liley
DIRECT CONVERSION OF NUCLEAR RADIATION ENERGY, PREPARED UNDER THE DIRECTION OF THE AMERICAN NUCLEAR SOCIETY FOR THE DIVISION OF TECHNICAL INFORMATION UNITED STATES ATOMIC ENERGY COMMISSION, AMERICAN NUCLEAR SOCIETY, 1970. 318 P. AMERICAN NUCLEAR SOCIETY, MONOGRAPH SERIES ON NUCLEAR SCIENCE AND TECHNOLOGY

Includes detailed discussion of Compton current and gamma electric cell behavior.

EFFECTS OF SHUNT CAPACITANCE ON TRANSIENT EFFECTS CAUSED BY ELECTRON IRRADIATION OF A POLYETHYLENE TEREPHTHALATE INSULATED RIBBON WIRE
An investigation of the effect of external shunt capacitance upon the electron radioinduced voltage pulses from a 20.5 cm strip of wire irradiated with 60 keV electrons is reported. Average max. pulse height varied inversely with total capacitance, while a change in load resistance caused negligible variation in pulse height. After the discharge, Lichtenberg electron discharge figures are found in the p.t. insulation.

THERMALLY STIMULATED CURRENT RADIATION DOSEMETER
J. Mitchell, D. G. Delure
Describes a gamma dosimeter based on heating the irradiated dielectric in a temperature gradient.
The electron-beam-scanning technique allows for the study of the dielectric properties of grain boundaries and interfaces. One side of the crystal is irradiated by a scanning electron beam through a grounded reference collector grid. The other side is covered by a metallic back-plate electrode where signals are read off through an amplifier in the form of a video signal. The advantage is that the area of dielectric evaluation can be of beam-spot size. Physically, the measurement depends on the charging of each point of the scanned surface by secondary emission to a constant and well-known potential with reference to the ground-reference collector grid. A typical measurement consists of two phases: establishment of working potential across specimen and measurement. First phase is accomplished by applying voltage ramp to backing electrode while front face is being scanned by beam. Second phase makes use of the definition of the dielectric measurement to be performed. As the video signal is just the net charge as a function of position deposited on specimen between successive scans, conductivity phenomena would be displayed because cond. is time-dependent; permittivity as a function of position phenomena is displayed because charge per unit area deposited on specimen is different for areas of different permittivity for a given unit voltage between scans. Results are reported for KCl crystals and BaTiO₃ ceramics.
Two major aspects of the problem are considered:
1. Charge storage in the dielectric capacitor dielectric
2. Spontaneous discharge resulting from electron irradiation.

Measurement on electron irradiation effects on a capacitor structure are reported. Electrons were in the low energy range (up to 50 keV). Electron trapping in the dielectric and the decay of the trapped charge after ceasing of the irradiation have been observed. Decay curves are consistent with a no-retrapping release model which assumes uniform trap density with respect to energy measured from the conduction band. A saturation effect for trapping is observed which gives a maximum trap density and a maximum value of the internal electric field. Measurements with beta irradiation have also been performed. In this case spontaneous discharge can be induced. Breakdown is believed to be initiated primarily at defects in the dielectric film; it does not usually liberate the total amount of trapped charge.
Electron irradiation of capacitor-type systems results in a negative charge distribution in the dielectric provided the electron range is smaller than the thickness of the dielectric. Experiments were performed with a non-penetrating beam of $5 \times 10^{-3}$ A/cm$^2$ in the 10 to 20 keV range. External currents observed after irradiation has been discontinued are related to charge decay in the dielectric. A simple model, using uniform charge distribution within the irradiated volume, gives a charge density of about $10^{15}$ electrons/cm$^3$. For a 14 keV beam, the field near the electrode of incidence is calculated, an approximate value of $2 \times 10^3$ V/cm is obtained.

A detailed model of space-charge effects resulting from trapping of thermalized irradiation electrons in insulating materials is presented. Analytic solutions for the particular case of polyethylene terephthalate have been obtained. When the trapping sites are uniformly distributed in energy below the energy level where charge transport occurs, the rate of charge build-up and of charge release depends primarily on a ratio of the material relaxation time constant to a release rate of electrons from traps. Agreement is for the case considered where this ratio is of the order of unity. When the ratio is small, however, very little external current and charge is observed and trapping parameters are not conveniently studied by this method.

It is found that charge storage of electron irradiated blocks can be prolonged by several orders of magnitude, if the blocks are cooled with dry ice before irradiation and then maintained at this temperature.
Electron states in the pseudo-gap may be strongly localized, so they cannot contribute to the conductivity except through processes like thermal excitation. In this sense the pseudo-gap behaves in the same way as a true band gap to electrical conduction.

Detectors for measuring exposure dose rates in the range $10^{-3}$ to $10^6$ R/sec

N.V. Lukashchev, G.K. Rudakova, P.S. Semchlov


Describes ionization chambers and vacuum Compton detectors. These "Gamma" detectors operate between $10^3$ to $10^6$ R/sec at temperatures up to 400°C. Examples of applications in gamma-emitting isotope facilities and reactors are given. To avoid the effect of slow secondary electrons moving in the field set up between the electrodes due to possible potential differences (contact potential) the emitter and collector electrodes were separated by a quartz tube of 0.5 cm thickness. Thus it is not quite clear whether the device operated as a pure vacuum detector.
This study was concerned with the generation of electrical currents in a solid dielectric, Lucite, upon heating it after exposure to x- or gamma radiation. These currents are generated without the application of an external electric field. Insight into the nature of the potential gradient responsible for charge carrier movement was obtained by observing the currents generated under various heating and irradiation arrangements. Heating was carried out both with and without a net temperature gradient in a direction normal to the electrode surfaces. Samples were irradiated both isotropically and directionally with $^{60}$Co gamma rays and directionally with 250 kVp x rays. Different sample thicknesses and temperature gradients were employed along with externally applied electric fields to obtain some information on the magnitude of the potential gradients. Samples were irradiated directionally with thin filters (100 mg/cm$^2$) on the entrance and/or exit sides. This irradiation configuration resulted in trapped space charges in the samples. The effects of these trapped space charges on the magnitude and the polarity of the thermally induced currents were studied. For samples heated in the presence of a net temperature gradient, it was concluded that the potential gradient responsible for charge movement is thermovoltaic in nature. The direction of the currents is such that the colder electrode is always positive. This indicates that the sign of the mobile charge carrier during heating an irradiated sample is positive. For samples heated in the absence of a net temperature gradient, the direction of the potential gradient is determined by the direction of the gamma rays through the sample. Upon heating, the exit side of the sample always becomes positive. The magnitude of this potential gradient appears to increase as the proton energy increases. Results obtained using thin lead filters during directional irradiation of samples suggested that production of trapped internal space charges, associated with regions of under or overdose, can also serve as sources of electric fields in the sample for the movement of thermally released trapped charge carriers. Using filters of different atomic numbers, the variation of the magnitude of the underdose, for $^{60}$Co radiation, at the filter/Lucite interface, was measured. These results agreed with those of others who obtained them by ionization measurements.
Thermoelectric currents were observed in thin lucite disks after exposure to γ radiation. If an electric potential difference is also impressed upon the sample during the heating cycle, the currents are enhanced or depressed depending on the magnitude and polarity of the applied voltage. The measured charge is a linear function of the applied electric field strength, and the field strength necessary to completely suppress the currents appears to be more closely related to the radiation dose than to the temperature gradient in the sample during heating. (auth)

Charge as a function of heating rate. Values are approximately constant, a light decrease being noted for very low heating rates. Charge as a function of storage time: Decay curves seem to fit an expression with two exponentials. Charge as a function of sample thickness: Values strongly increase for very thin (1 mm) samples. It seems that there are two components, one constant and the other increasing with decreasing sample thickness.

ELECTRICAL IRRADIATION EFFECTS AND ENERGY CONVERSIONS IN SOLID DIELECTRICS.
Murphy, P.V.

I. Gamma ray polarization of insulators. Gamma ray induced electrical polarization of insulators is described and a theory proposed. II. Effect of persistent polarization on various scintillation materials. The radiation detection sensitivity for polarized scintillation crystals is investigated. Anthracene shows a two-fold increase in efficiency after polarization in a 5 kV/cm field. III. Photovoltaic effect in electron irradiated insulators. Regions of space charge in insulators resulting from high energy electron bombardment were released by ultraviolet light. The charge released from fused silica samples was a very small fraction of the initial space charge. The photoconductivity of irradiated samples was studied.
POLARIZATION OF DIELECTRICS BY NUCLEAR RADIATION. II. GAMMA RAY INDUCED POLARIZATION.

Murphy, P.V., Gross, B.


It is shown how Compton scattering in dielectrics leads to space charge formation. The bulk distribution of polarization is discussed for various experimental conditions. Measurements were carried out on carnauba wax. Charge values were obtained by thermal release. To obtain the spatial charge distribution a sectioning method was used; after irradiation the dielectric was cut into several sections which were heated separately. Discharge currents during heating were measured. Care was taken to avoid any temperature gradient across the sample; therefore results were not affected by any thermoelectric effect. The influence of different absorbers placed between the source and the dielectric was investigated. It was found that already a very thin absorber greatly reduced the released charge. Measurements without absorber indicated that space charge density was particularly high in the top layer of the dielectric. It was concluded from these observations that the effect is strongly depending on how far the incoming radiation flux is in equilibrium with its secondary Compton electrons.

THE FORMATION AND DISCHARGE OF CARNAÚBA WAX ELECTRETS IN NUCLEAR RADIATION FIELDS.

P.V. Murphy

Paper, Annual Lidiceon Solid State Conference, 10th.

Kansas City, 1962.

Polarization of wax electrets is measured by the method of thermal activation. The polarization is shown to contain a radio-sensitive component which is destroyed by 2 to 3 Mrad and a constant component which is not affected by radiation. Radioelectrets were formed from various dielectrics using Sn350 beta radiation. Materials used included carnauba wax and plastics.

THE FORMATION AND DISCHARGE OF CARNAÚBA WAX ELECTRETS IN NUCLEAR RADIATION FIELDS.

Murphy, P.V.


The density of unpaired electron spins for electrets was determined by paramagnetic resonance before and after exposure to massive gamma radiation. The irradiation caused a large reduction both in polarization and in density of unpaired spins. Subsequently carnauba wax samples were polarized by simultaneous action of penetrating radiation and electric field.

GAMMA RAY DOSIMETRY BY RECOIL ELECTRON CURRENTS IN SOLID DIELECTRICS

P.V. Murphy

THE EFFECT OF PENETRATING RADIATION ON THE PRODUCTION OF PERSISTENT INTERNAL POLARIZATION IN ELECTRET FORMING MATERIALS.

Murphy, P., Costa Ribeiro, S., Milanez, H., de Morces, R.J.
J. chem. Phys., 38, 2400 (1963)

Samples of teflon and carnauba wax were polarized by the simultaneous action of penetrating radiation and application of an electric field. Isothermal depolarization curves and thermal depolarization curves were observed; this method allowed to calculate activation energies for the depolarization process in teflon, giving an average value of 0.93 eV. It is believed that the persistent heterocharge in carnauba wax and certain polymers is caused by the orientation of dipolar units composed of a positive molecular ion and a partially solvated electron.

POLARIZATION OF DIELECTRICS BY NUCLEAR RADIATION. I RELEASE OF SPACE CHARGE IN ELECTRON IRRADIATED DIELECTRICS.

Murphy, P., Costa Ribeiro, S.
J. appl. Phys., 34, 2061 (1963)

Irradiation of solid dielectrics with high energy electrons produces a region of negative space charge which may persist for a long time. Experiments are reported in which various dielectrics (fused silica, pyrex, resin, carnauba wax) were irradiated with S.90 beta rays. Following irradiation the samples were stored in short-circuit for a few hours and then heated or illuminated by ultra-violet light from a high pressure mercury vapor lamp. Thus thermal and photoelectric charge release was achieved and the capacity of the various dielectrics for charge storage was determined. Charge storage was found highest in electret forming materials and in materials with a high density of deep "traps". The highest storage photo-release efficiency was obtained for fused silica at low beta ray doses (approximately 40%)

POLARIZATION OF DIELECTRICS BY NUCLEAR RADIATION. II. GAMMA-RAY INDUCED POLARIZATION

J. appl. Phys., 35, 171 (1964)

P. V. Murphy, B. Cross

The electrical polarization produced in solid dielectrics by gamma ray bombardment is treated as a space charge polarization resulting from the production and absorption of Compton electrons. For a gamma ray beam in equilibrium with secondary electrons, the calculated net space charge is negative in sign and decreases with distance in proportion to gamma ray attenuation. The space charge distribution is studied experimentally by cutting away sections of irradiated carnauba wax and measuring the charge released on heating for each section. The relationship of thermally released charge to sample polarization and the effect of a temperature gradient are determined.

HIGH LEVEL PASSIVE RADIATION MONITOR: THE SOLID COMPTON RECOIL ELECTRON DETECTOR

P. Murphy

AD 675501 (1968)
IVth International Congress on Radiation Research

PASSIVE, SELF-READING DOSEMETER USING RECOIL ELECTRON SCATTERING

Presid. W. H. Walker
Thermo Electron Corporation, Waltham, Massachusetts, 02154, U.S.A.

The development of a new type of high level (10-500 r) gamma ray dosimeter for personnel or area monitoring is described. The read-out technique is similar to that in current usage; however, the detecting element derives an electrical read-out charge from the radiation field, and thus eliminates the need for a separate charging unit. Charge is generated by recoil electron scattering in an electrode-dielectric matrix.

The detecting element is a cylinder of heavy metal, covered with a foil of light metal, encapsulated in an insulating plastic, and the assembly (approximately 1" diameter by 2" length) enclosed by a thin metal shell. The heavy metal cylinder acquires a negative charge by virtue of a difference in the incident and emergent electron flux. The charge is proportional both to the forward scattered component of the Compton and photoelectron flux in the plastic insulator, and to the photon attenuation in the heavy metal cylinder. The effect of charge scattering of detector size, configuration, and materials is discussed.

An evacuated, inverse-reading fiber voltmeter with extended linear range has been developed to read detector charge. The required vacuum quality is not critical; pressures as high as 500 produce negligible ionization losses, while 1 is unacceptable in secondary emission gamma detectors. An overall ionization resistance of 10^12 ohm has been achieved readily, and is adequate for general usage; comparable detectors have core stringent requirements.

Typical dosimeters have an output of 0.3 to 0.6 V/R, are energy independent from 20 to 1200 keV and do not saturate at high dose rates. Compared to the ion chamber, there are potential advantages in simplicity, reliability, and cost.

PHOTO-STIMULATED RADIATION DOSIMETER

K. Iyashita; H. Henisch
Solid-State Electronics 2, 615 (1966)

Photo-stimulated transients in single crystals of ZnS are used for u.v. and X-ray dosimetry.

METHOD OF PREPARATION OF ELECTRETS

Myazdrkov, O. A.

USSR Patent 120 273 (1957)

Dielectric is polarized by fields up to 30 kV/cm and simultaneously subjected to action of beta, gamma, or X-rays. The absorption of such radiation leads to the formation of electron-hole pseudodipoles, whose moments are oriented preferentially in the direction of the applied field. This results in the production of a polarization in the dielectric.
RADIATION EFFECTS IN SILICON

J. A. Nabers, E. J. Wickner (Gen. Dynamics, San Diego, Cal.; Gen. Atomics Division)
NASA-CR-80 135; GACD-6249; QPR-7
The electrical conductivity of high purity n-type Si was investigated by microwave technique after irradiation by 30 MeV electrons at room temperature. Electron-spin resonance techniques and studies were made on high resistivity material to establish coordination between microwave resonance and carrier life time studies.

Transient and quasistatic electrical conductivity in high-purity n-type silicon was studied by the microwave technique after irradiation by 30 MeV electrons at room temperature. The electron flux was controlled so that the introduction of the recombination center was detected. Pre-irradiation lifetime measurements were made using a flash X-ray machine, and the results are shown. The samples and microwave apparatus were moved to an electron linear accelerator (Linac) where extra precautions were taken so that during Linac tuning the sample was not irradiated with high-energy electrons. The pre-irradiation lifetime of the high-resistivity Si samples was analyzed using Shockley Read theory. The dc conductivity transient measurements on Si samples of carrier concentration of $\sim 10^{14}$/cm$^3$ are also briefly discussed.

Measurements of the sheet conductivity of ion-bombarded MoO$_3$ and V$_2$O$_5$ show that there is a conductivity increase of many orders of magnitude for doses of $2 \times 10^{14}$ to $2 \times 10^{16}$ ions/cm$^2$ of 40-keV Kr-, the final bulk conductivities being 20 to 200 $\Omega^{-1}$ cm$^{-1}$ for MoO$_3$ and 20 to 600 $\Omega^{-1}$ cm$^{-1}$ for V$_2$O$_5$. Reflection electron diffraction indicates major structural changes in the irradiated materials. Thus, the initially crystalline MoO$_3$ and V$_2$O$_5$ first amorphize ($1 \times 10^{13}$ and $2 \times 10^{14}$ ions/cm$^2$, respectively) but subsequently crystallize to lower oxides, the appearance of the latter being an indication of bombardment-induced oxygen loss. The lower oxides, MoO$_2$ and V$_2$O$_3$, are known from other work to be metallic at room temperature, and there is thus no difficulty in attributing the increase in conductivity to their formation. The reason for bombardment-induced oxygen loss with MoO$_3$ and V$_2$O$_5$ is only partly understood. The fact that the altered layers have thicknesses of roughly 150 ± 250 Å suggests, however, that neither normal sputtering nor bombardment-enhanced vaporization is by itself the cause. Rather, a long-range effect, i.e., one that correlates with the ion mean range or which involves diffusion, must be participating. The conductivity increases found are regarded as having several important applications. For example, they imply a severe limitation on the use of MoO$_3$ or V$_2$O$_5$ in a radiation environment though at the same time they suggest a new approach in developing
Measurements were made with a 1.27 cm thick Pb absorber sandwiched between 2 PdA disks of 1.27 cm thickness. A calculation using an equation gives excellent agreement in the 0 to 50 R/min range, currents being of the order of up to 10 pA.
LICHTENBERG FIGURES AND EFFECTIVE ELECTRON RANGE
Y. Nakai
Isotopes and Radiation (Japan) 3,76(1966)
Measurements of electron beam energy versus Lichtenberg figure depth are reported for irradiated B.A. samples at -196°C and -78°C.

IONIZATION OF DIKLIÜCTIC LIQUIDS BY GAMMA-RAY
Some characteristics of ionization phenomena in dielectric liquids irradiated by γ rays from 60Co were studied. Ionization current was measured with a parallel plate ionization chamber. In the chamber, not only the field intensity but also the electrode spacing could be changed independently. Applying Jaffe's theory on columnar recombination to the obtained characteristic curve of ionization, the saturated value of ionization current was estimated. The collection efficiencies for ions in several kinds of dielectric liquids were studied as a function of field intensity. The average energy per ion pair, W-value, for several kinds of dielectric liquids was estimated from the value of ionization current from which the influence of secondary electrons emitted from the chamber wall was excluded. Using the W-value of carbon disulfide measured by Mohler and Taylor as the relative standard, the following W-values for dielectric liquids were obtained: n-hexane 25 eV; cyclohexane 22 eV; isooctane 22 eV; toluene 53 eV; carbon tetrachloride 54 eV; tetrachloroethylene 50 eV. (nuth) (Japan)

IONIZATION OF SOLID DIELECTRICS BY X-RAYS (INVESTIGATION OF CERESIN)
Maslowod, D., Schravnsky, P.
Ann. Phys. (Leipzig) 3, 63 (1929)
Increase of conduction and absorption is observed. After irradiation is discontinued, the current decreases slowly as in dielectric absorption.

INDUCED VOLTAGE STUDIES IN A COBALT--60 GAIKA IRRADIATOR
L.W. Nelsm
An investigation into the basic mechanism of gamma-radiation induced current and voltage in electrical systems has been started by using the NARP 1500-curie Co radiation source. Steady-state measurements of electric potentials induced in a specially constructed hollow cylindrical capacitor as a function of gamma field direction, gamma field strength, and apparatus temperature are described. From these data, it is concluded that the Compton process is the dominant mechanism involved. A theory is developed explaining in detail how electrons from Compton collision might produce currents in a simple insulator-conductor system. The validity of the developed equations was tested by experimentally investigating the dependence of induced current upon gamma field intensity and upon thickness of dielectric interposed between the electrode and the radiation source. It was found that within the narrow range of gamma field intensity available, the induced current depended linearly on field intensity, as predicted by the theory.

STUDY OF VOLTAGES INDUCED WITH 1300-CURIE COBALT-60 IRRADIATION AND A 3-MW NUCLEAR REACTOR
L.W. Helms
, New Mexico, March 1966

REVERSIBLE RADIATION ELECTRICAL EFFECTS IN DIELECTRICS.
Nesterov, V.M., Nesmeltova, E.S., Olshanskaya, N.I., Mikhailova, T.H.,
Pothakova, G.I.
Fiz. Tverdogo Tela, 4, 3010 (1962)
Measurements are reported on the behavior of the loss factor of various dielectrics under irradiation from a Co60 source. During irradiation a gradual increase of losses is observed; eventually a steady state is reached. After cessation of irradiation losses decrease and after a certain period the original condition is re-established.

EFFECT OF GAMMA RADIATION ON THE DIELECTRIC PROPERTIES OF SEVERAL CABLE MATERIALS.
V.M. Nesterov, E.S. Nesmeltova, N.I. Olshanskaya, and T.G.
Mikhailova (Tomsk State Univ., Siberian SSR), Izv.Vysshikh
Uchobn. Zavedenii, Fiz., No. 1, 147-52 (1964) (In Russian)

The effect of gamma radiation on the dielectric properties of natural and synthetic rubber are investigated. The dependence of the dielectric loss tangent, the dielectric constant, and the electric conductivity of these materials on irradiation time is plotted. (tr-auth)
ELECTROCHEMICAL CHARGING OF THERMAL SiO₂ FILMS BY INJECTED ELECTRON CURRENTS

B. L. McCollian, C. V. Berglund, P. P. Schmidt, J. J. Andreas
J. Appl. Phys. 42, 564 (1971)

An electron current flow in thermal SiO₂ films exposed to water leads to negative charge buildup in oxide. This is due to the formation of water-related electron traps acting as an electron trap. When one of these centers is formed, atomic hydrogen is formed which diffuses away and eventually a stable negative charge is left. These etch-off experiments were performed to determine spatial distribution of the charge, as well as to determine water diffusion kinetics. The thickness after each etch-off was measured electrically from pulse C-V characteristics.

THE EVALUATION OF TRAPPING PARADIGMS FOR CONDUCTIVITY GLOW CURVES IN CARBON SULFIDE

K. K. Nicholls, J. C. Cool
Brit. J. Appl. Phys. 15, 763 (1964)

Experimentally determined curves for a variety of C₃S crystals are presented. A survey of available analytical methods for interpretation of experimental results is given. Data are evaluated by means of different methods. An adequate experimental procedure gives consistent values of trap depth and capture cross section for at least 6 different sets of traps.

THEORY OF TRANSIENT ELECTRICAL EFFECTS IN IRRADIATED INSULATORS

D. K. Nicholls, V. A. J. van Lint

Transient effects caused by gamma rays, electrons, neutrons and heavy particles in irradiated max insulators of energized capacitors are discussed. The "microscopic" approach of the paper takes into account the fact that the ionization is deposited along discrete particle paths. For sufficiently low doses and dose rates trap overlapping is minimal and responsive from several paths is additive. The average trap occupancy during carrier immobilization, and thus lifetime, is determined by ionization density along the trap and not by average ionization density throughout the sample.

At higher dose rates path overlapping starts and trapped carriers trapped along a previous path may change trap occupancy and/or electron-ion recombination probability for subsequent paths crossing the first one. Then the additive law fails. For the strongly ionizing heavy particles externally measured currents and charge transfer are smaller than for gamma rays or electrons because of preferential recombination of carriers along the density ionized path.
RADIATION- STIMULATED IMP in CsI CRYSTALS
O.R. Njyskova, O.A. Elinskova
Fiz. Tverdogo Tel. 8, 375 (1966)

Measurements with X-rays incident on single crystals are reported. Photostimative spots up to 200 kV were observed, the effect had a threshold of 30 kV. Maximum used energy was 60 keV in kV. The influence of the position of the irradiated section of the crystal and time effects were investigated. The irradiated surface of incidence was found to become negative. It is concluded that the observed effect is associated with diffusion of structural defects away from the irradiated section of the crystal.

A bibliography of 154 references in abstracted form is presented which is arranged into two parts covering respectively the periods of 1952 through 1957 and of 1958 through March 1963.
PULSIVE RADIATION-INDUCED CURRENT IN ELECTRIC INSULATORS. I.
Radiation induced currents (RIC) in various kinds of insulators were measured at the beginning of the irradiation and its pulse shape was observed with an oscilloscope. Radiation was produced by an 18 MeV electron linear accelerator. Variations of the RIC pulse shape with time and temperature showed almost the same features in some cases. Pulse shape depended on the direction of the crystal axis of the sample against the radiation. Pulse shape is discussed in terms of a trap and hole model.

PULSIVE RADIATION-INDUCED CURRENT IN CRYSTALLINE AND FUSED QUARTZ.
S. Okabe, K. Tsunori, T. Tabata
Radiation Center of Osaka Prefecture
Reports studies carried out with 5 micro-sec pulses of 13 MeV electrons, current density of about 100 μA/cm² peak, average a few microamps. The pulse shape of the induced current varied remarkably with time within a few minutes of irradiation and with the temperature of the samples. The variation in shape showed a dependence on crystal orientation of the sample. The effect of the internal space charge field was found to be negligible. A qualitative explanation is applied to part of the results in terms of an interaction between excited carriers and traps.

Pulsed shapes of the radiation-induced current in crystalline quartz were observed using pulsed electrons from a linear accelerator. The variation with time of this current was found to depend on the direction of the applied electric field with respect to the crystal axes, and the dependence on direction of the incident 13-MeV electron beam was significant.


Transient phenomena of physical interest using pulsed radiations from a linear electron accelerator are studied including (1) drift of the pulsed-radiation-induced current in crystalline quartz with irradiation time and its dependence on angle between the crystal axis and the applied electric field, (2) after-pulse phenomenon in the ionization chamber filled with various kinds of gas, occurring with some dependence on radiation intensity and applied electric field, and (3) transient emission in ionization chambers, probably caused by charged gas molecules adsorbed on the surface of chamber material. The third phenomenon is considered to have a serious effect on the use of ionization chambers.


Dependence upon sample orientation of the pulsed radiation-induced current (RIC) in crystalline quartz was studied using 5-ns pulses of electrons with an energy of 13 MeV. The variation with time of the RIC was found to depend on the direction of the applied electric field with respect to the c axis of the crystal, but not appreciably on the direction of the incident electron beam. Detailed dependence of the pulsed RIC on the angle θ between the applied electric field and the c axis was measured also for θ from 0 to 90° at intervals of 15°, and the variation with time of the RIC was found to be large for θ < 30° and very small for θ > 60°. The dependence on θ was confirmed by measuring the average RIC with a picoammeter.

TRANSIENT ELECTRON CURRENT OBSERVED IN GAS IONIZATION CHAMBERS
S. Okabe, K. Tsunomi, T. Tabata

Gas filled ionization chambers, irradiated with pulsed electrons or X-rays, have been found to show a transient electron current (TEC) after the applied voltage has been cut off. Building up and decay of TEC, effects on TEC of temperature, radiation intensity, nature and pressure of filling gas, and electrode material have been investigated. The TEC is believed to be caused by gas molecules and ions adsorbed on the chamber walls and electrodes. One component of TEC might affect the accuracy of current measurements performed with the voltage applied. Repeated pulsed irradiation changes the current pulse shape.
Purpose of the investigation was to determine whether the reported drastic decreases and disappearance of the hysteresis loops and blurring of the peak in the dielectric constant versus temperature curve were due to destruction of ferroelectricity itself, or to the progressive masking of ferroelectric characteristics by presence of large accumulation of radiation-induced defects in a still ferroelectric environment. It was found that the ferroelectric characteristics are well preserved up to doses of 10^5 Mrad, for the sulfate, and up to 2 Mrad for the salt. In the latter case the effect was due to the collapse of both Curie points.

**GAMMA RAY INDUCED ETHER E-CONDUCTIVITY IN INSULATING POLYMERS**

S. Okamoto, J. Furuta, E. Kiraoka


High Co60 doses modify the molecular structure of polyethylene in such a way that the induced current and conductivity might decrease after pre-irradiation. The paper reports a series of measurements.

Decay curves of polyethylene after irradiation are decomposed into 4 exponential decay components. Decay time constants for these components are independent of the 60Co gamma dose rates. Using Fowler's model, the dose-rate dependence of the induced current during irradiation does not agree with the one estimated using decay curves after irradiation. By the use of our model it can be shown that the dependence of induced current on dose-rate obtained from growth curves is in good agreement with the one from decay curves at the dose-rate range of more than 5 x 10^2 R/h in this experiment. (auth)

Decay time constants at 26°C are 3.6 min, 13 min, 41 min, 130 min. The last one has the highest initial amplitude. This time dependence affects measurements of radiation-induced conductivity during irradiation as a function of dose rate.

**RADIATION EFFECTS ON ELECTRONIC SYSTEMS**

H.L. Olesen (Missile and Space Division, Gen. El. Company)

Plenum Press, New York 1966
SUPRA_LINEAR CURRENT-VOLTAGE DEPENDENCE IN IRRADIATED FUSED SILICA
D. Onnasch

The measured field- and temperature dependence of gamma-ray induced currents is explained by field-dependent electron capture cross section. Comparison with a model gives a constant mobility between 8 and 300 K. The acoustoelectric effect is observed at high field strengths.


The γ-ray-induced electric conductivity in fused silica is studied theoretically and experimentally as a function of temperature, electric field strength, sample thickness, and irradiation time. Synthetic glasses containing water show the highest induced conductivity. Caused by an increase of positive centers capturing the excited electrons, the conductivity decreases as $T^{-2}$ with the irradiation time $t$, where $\alpha < 1$ is a constant, depending on temperature. Within the range from 8 to 300 K, induced currents are measured with voltages up to 2500 V and dose rates between 10 and 200 Mrad/sec in synthetic samples 0.2 to 4 mm thick.

The gradual transition from constant conductivity at high temperatures and low field strengths $F$ to an increase of conductivity proportional to $F$ or $F^2$ at low temperatures and high field strengths is explained by the deformation of the Coulomb potential of $2 \times 10^{14}$ to $5 \times 10^{14}$ cm$^{-3}$ singly ionized, electron-capturing centers under the action of the applied field. The comparison of the theoretical dependence of the electron lifetime on field strength and temperature with the measurements allows one to conclude that the mobility is independent of temperature. This implies the elastic scattering of the electrons at about $5 \times 10^{14}$ cm$^{-3}$ neutral impurities. Furthermore, the mean free path of the electrons for loss of a phonon at 8 K is determined to be 106 Å.


The γ-ray-induced current in synthetic fused silica (containing water) is saturated at field strengths $\leq 1.4 \times 10^7$ V/cm caused by two effects. Besides the Schottky saturation known from photoconductors with blocking contacts, the saturation of the drift velocity of the electrons at the level of the velocity of sound is demonstrated. In some samples, especially at lower temperatures, the effect is accompanied by instabilities of the induced current explained by charge redistributions.

RECOMBINATION OF IONS
L. Casager
Phys. Rev. 54, 554 (1938)

The probability of geminate recombination is computed from the laws of Brownian motion. In the absence of forces other than Coulombian, the escape probability equals the reciprocal of the Boltzmann factor. The results indicate the correlation between temperature and pressure coefficients of ionization by light particles in ionization chambers. The effect of an external field is to increase the fraction of escaping ions which in the incident stage is proportional to the field intensity and independent of the initial distance, though dependent on the orientation of ion pairs. The predicted increase is little more than 1/2 for every 100 V/cm. A reasonable amount of columnar recombination helps to explain the greater effects at weak fields.
Studies on transient radiation effects on capacitors are reported. Irradiation facilities used included pulsed Triga reactor and accelerator pulsed fast assembly. Air trapped inside small molded-case capacitors might have caused some anomalous transient effects. A program for proton irradiation has been outlined. Numerical estimates of neutron-induced conductivity and charge transfer in dielectrics have been improved. Neutron and proton irradiation effects are discussed and a model is developed. Charge transfer due to recoil protons is also discussed.

Irradiation experiments to verify theories of transient radiation effects in insulators are discussed. High-energy electron, proton, and neutron irradiations of specially designed klylar capacitors are planned. Experiments designed to measure polarization and secondary emission effects in thin-film capacitors and thin-film circuitry on sapphire are described. Initial results of irradiation of Lucite samples by electrons from a 3 keV flash X-ray machine indicate internal discharges resulting from strong nonuniform electrical fields created in the material by radiation ion-implanted electrodes on klylar capacitors indicate better carrier injection characteristics than foil contacts, but some polarization effects attributable to the contact still remain. Lucite samples irradiated by electrons from 3 keV flash X-ray machine showed strong internal discharges due to radiation generated strong non-uniform internal fields.

Gamma radiation produces an electric current in a polarized BaTiO₃ crystal in such a manner that the induced emf is proportional to the radiation level. Upon varying the temperature of the experiment between 5 and 150°C, a maximum emf was observed at 30 to 40°C, a minimum at 90°C, with the curve passing through null points at 60 and 130°C. A mechanism is proposed for this effect. (K.S.W.)

The drift of carriers after uniform instantaneous ionization throughout an insulator

A. C. Papadakis, P. H. Keating

Brit. J. Appl. Phys. 16, 513 (1965)

The theory of one-carrier motion, neglecting recombination and diffusion, are obtained for the external current, induced charge, and transit time.

Theory of transient-space-charge-perturbed currents in insulators

A. C. Papadakis


Aer refers to currents resulting from drift of excess carriers. The latter are assumed to be produced instantaneously in a narrow sheet close to one electrode. While blocking contacts exclude secondary currents, carrier capture at deep and shallow trapping centers is considered. The space charge field causes a broadening of the initially narrow carrier sheet, even without diffusion. The current pulse, as a function of time, depends on the ratio of applied field to space charge field. The theory is compared with that of many and Rakavy.

A pulsed electron beam apparatus for the study of carrier properties in insulators

A. C. Papadakis

Conf. on Energy Beams and Their Uses, York, England, 29-30 September 1966. (AES Conf. 66-305-4)

Describes an apparatus for study of luminescence and carrier properties in high resistive CdS by Spear's method, with energies of 50 keV, vertical sensitivity 10 V/div, horizontal 0.5 nsec/div.
TRANSIENT HIGH-ENERGY RADIATION-INDUCED FREE CARRIER
ABSORPTION IN SILICON
W.R. Reifley,

Highes Aircraft Co., Fullerton, Calif.

The time-dependent free-carrier absorption induced by pulsed 10 keV electrons was studied. In contrast to previous investigations, carriers were generated at these energies throughout the bulk of the irradiated material. Also the free-carrier lifetime was appreciably greater than the pulse duration.

CONDUCTIVITY INDUCED BY ELECTRON BOMBARDMENT IN THIN INSULATING FILMS
L. Pensak
Phys. Rev. 75, 472 (1949)

ROLE OF TRAPPING PROCESSES IN SOLID STATE RADIATION DOSEMERTY
(Pennsylvania State Univ., University Park, Materials Research Lab.)

A study of the use of electrets for uv dosimetry is described.

26520 (NYO-3409-9) ROLE OF TRAPPING PROCESSES
IN SOLID STATE RADIATION DOSIMETRY. Progress Report,
1970-1971. (Pennsylvania State Univ., University Park,
3409, 36p. Dep. NTIS.

Research on radiation dosimetry by polymer electret depolarization is described. Also, the characterization of non-luminescent near-insulating materials by the measurement of thermally stimulated currents and thermally stimulated depolarization is discussed. Radiation dose measurements based on carrier trap filling are considered. Equipment and results are discussed including the measurement of pyroelectric coefficients and the characterization of lunar materials. (W.H.K.)
TSC study of traps in electron-irradiated Teflon and polyethylene

M. PERLMAN and S. UNGER
College militaire royal de Saint-Jean, Saint-Jean, Quebec, Canada

Abstract. Thermally stimulated currents (TSC) have been measured from Teflon (FT) and polyethylene (HDPE) exposed to a 0.1 MeV electron beam. The spectra from both materials are virtually identical, and consist of seven overlapping peaks. Each material contains at least three different traps in spite of the lower injected charge. The results support the idea that traps in the TSC of partially melted samples are due to ionization of the amorphous regions. The results also show that the thermal stability of certain ionized defects must be attributed to the trapping rather than the detrapping step.

MS received 26 June 1972

P. 315

529
With very short and very intense pulses of fast electrons such as from a Van de Graaff machine, many explosives can be initiated at doses clearly insufficient for uniform heating to initiation temperature. This provides an opportunity for further testing of the hot-spot theory of initiation of explosives. In this study, a stochastic model is presented to describe the nonuniform spatial distribution of energy packets arising from absorption of electrons or photons. Computer calculations using an appropriate heat conduction equation determine what average temperature (or dose) and corresponding hot-spot temperatures are required for initiation. Critical doses calculated for PbN, PETN, RDX, HMX, and nitroglycerine are 37.3, 21.4, 38.5, 37.3, and 21.0 cal/g, respectively. Experimental doses for deuterated PbN, HN, basic lead styphnate, and normal lead styphnate, are estimated from limited experimental data as 11, 18, 18, and 10 cal/g, respectively. Factors responsible for differences between calculated and observed values are indicated. The correct order of magnitude of the calculated results is considered as evidence supporting the thermal mechanism in initiation of explosives by high-energy radiations.
Each glow peak of LiF(TLU-100) in the temperature range from 100° to 600°K displays a shape, peaking temperature dependence on heating rate, and lack of peaking temperature dependence upon total light output which are in detail as predicted by the most simple thermally activated kinetics in the first order Randall–Wilkins limit. However, the glow curve breadth is anomalously large at low temperatures and anomalously small at high temperatures. While physically reasonable, although improbable, mechanisms might explain the larger breadths, there seems to exist no physically reasonable direct mechanisms to explain the narrower breadths. An indirect explanation is proposed in which the activation energy is itself slightly temperature dependent. How this effect explains the observed results is discussed and other implications are considered. (auth)

**SOLID STATE INVESTIGATIONS UTILIZING ELECTRON–BOMBARDEMENT PHENOMENA**

M.A. Pomerantz  
(Bartol Res. Foundation, Swarthmore, Pa.) Oct. 29, 1965  
Contract AT(30–1)-2730, 77 p.

Measurements on electron beam effects on conductivity in diamond, RbBr, NaBr) as well as effects on desorption of atoms from surfaces and connected effects.

**ON THE EFFECTS OF QUARTZ CRYSTALS IRRADIATION BY MEANS OF ELECTRONS.**

Poreco, F.  
Nuovo Cimento, 23, 859 (1962)

Quartz crystals of thickness greater than the electron range have been bombarded with monoenergetic electrons between 0.5 and 2 MeV. The relation between depth of coloration produced by irradiation and the electron range is determined. The intensity of coloration is found to be constant over the electron range. Absorption spectra have been measured.
EFFECT OF GAMMA RADIATION ON THE DIELECTRIC CHARACTERISTICS OF QUARTZ

G.I. Potekhova

Effects concerning dielectric loss, capacitance, conductance, and polarization have been investigated. Both single crystals and and fused specimens of quartz were employed. Measurements were taken between 40 and 10^4 cycles per sec., at room temperature, and under pressure of 10^-3 MPa (to prevent effects due to air ionization). 60Co-gamma's were used.

In crystals, effects due to polarization by trapped electrons were observed which were absent in fused specimens.

THE USE OF POLARIZATION TO DETERMINE OXIDE CHARGE DISTRIBUTIONS AND INTERFACE PROPERTIES IN MOS STRUCTURES

L.J. Pendall (Bell Telephone, Murray Hill, N.J.)

Because of the scattering mechanism dominating the voltage dependence of photoionization currents in SiO, MOS structures, the presence of charge in the oxide has profound effects on the V-I characteristics. The theoretical V-I curves for exponentially distributed oxide charge have been derived and it has been shown that examination of both I-V and C-V curves permits to distinguish between charge in the oxide from interface charge. Using this fact evidence has been presented to show that both intrinsic interface fixed charge and the charge associated with fast surface states are located within about 20 Å of the Si-SiO₂ interface. Finally it has been shown that one can actually extract oxide charge distributions from photoionization data and a preliminary charge distribution obtained from a charged, steam-grown SiO₂ film has been presented.

EVALUATION OF SELF-POWERED DETECTORS IN EBR-II

C.C. Price, J.R. Karvinen
Trans. Amer. Nucl. Soc. 15, No. 1, 366 (1972)

X-RAY INDUCED ELECTRICAL POLARIZATION IN GLASS.

Proctor, T.M.

Electrical polarization is found to be induced in a lead silicate glass by action of X-rays.
X-RAY INDUCED ELECTRICAL POLARIZATION IN GLASS.
Proctor, T.M.

Measurements on polarization and charges induced by X-rays are reported. Charges are measured by heating the previously irradiated samples and measuring the ensuing discharge currents. The effect is attributed to the formation of dipoles.
Charged radiation from reactors is used to produce currents in a dielectric reactor shield.

A STUDY OF SELF-POWERED DETECTORS FOR MIXED NEUTRON-CAUSIA RADIATION FIELDS

G. Ramirez, L. David

Properties and behavior of self-powered detectors in a mixed n-gamma field are studied. Various elements are used as electron emitters to find best suitable electrode couples for neutron detection with very low gamma sensitivity as well as for pure gamma detection only. Construction, experimental results, and analysis of response data are discussed.

DETERMINATION OF MEGA-VOLT ELECTRON SPECTRA FROM DOSE DEPOSITION PROFILES.

First, the equations are developed which are needed to compute a dose deposition profile from a given electron spectrum. The dissipation distribution in aluminum as a function of electron energy is considered as the fundamental parameter used in the calculation. Modified Nakai values of the dissipation distributions are used. Next, a brief account of the actual calculations used in the computer program is presented with a sample case for illustration. The uniqueness of the spectral determination is discussed by considering the results obtained by three different initial spectra. Although the final spectra are different and contain many of the properties of their respective initial spectra, the calculated doses correspond to the measured doses extremely well and the same mean electron energy is obtained in all three cases. The use of the resulting three final spectra for the calculation of dose deposition in high atomic number materials is illustrated by showing comparison deposition calculations in aluminum and tantalum for the three spectra. The agreement of the calculated dose deposition for the three spectra is very good. Finally, an appendix is included on the experimental measurement of dose from a pulsed electron source using thin calorimeters and blue cellophane.
Breakdown of Dielectrics Due to Pulsed Electrons

J. B. Rauch, A. Andrew

IEEE Transactions Nucl. Sci. 13, No. 6, 109 (1966)

Measurements on Plexiglas were made with a 2 keV electron producing electrons with a maximum energy of 1.9 keV, a rather broad spectrum, and secondary maximum at 1.4 keV. Spontaneous breakdown was induced with minimum flux of 4.1 x 10^12 ions/cm^2/s on 1/4 inch diameter area. To measure charge buildup, 1 mil Al foils were embedded at various depths in dielectric, connected to ground. With such foils, the induced darkening extended to greater depths than without the foils which avoided charge buildup. Charge buildup were measured by a 50 Ohm grounding resistor, monitoring its voltage, and integration of the current-time curve, assuming that this is indicative of charge deposited in one half of sheet in front and one half behind the foil. Energy deposition was measured with 10 mil thick, coloring, inserted filters. Charge buildup prevents energy deposition from reaching same level behind thicker samples. Multiple measures did not introduce new breakdown patterns. Since a monoenergetic beam is absorbed in a S-shape, charge density decreases with increasing depth. The field peaks at the surface of incidence and goes through zero at center of space charge region. Thus breakdown initiates at surface. It is concluded that the surface field for breakdown initiation is about 1.6 x 10^4 V/mil which exceeds the usually given value of 400 V/mil of Plexiglas. To study breakdown effects, potentials on collection foils placed at back of samples were monitored. Breakdown was observed about 30-40 ns after main charge deposition, with a rise time of 10 ns. Charge buildup was found to play a role in increasing the absorbed charge density. Multiple breakdown paths perpendicular to the main breakdown plane show the existence of highly charged regions outside that plane.

Radiation Effects on Glass

BeG Technical Memo No. 9
AD 207701 Defense Documentation Center, Cameron Station, Virginia

Migration and Trapping of Extrinsic Charge Carriers in Polymeric Films

A. Reiser, J. W. B. Lock, J. Knight


The behavior of thin polymeric films charged negatively in air by a corona discharge is described quantitatively in terms of diffusion and trapping of the extrinsic charge carriers. Mobilization between 10^-9 and 10^-13 cm^2/V sec are found to be field-independent up to 10^5 V/cm. Subsequently they become linear function of the field. Their temperature dependence is described by an Arrhenius Eq. Charge trapping is indicated by a persistent residual potential. A mathematical model is developed which assumes a) a single charge layer penetrating the dielectric without trapping or b) partial (weak) trapping. In neither case is the contribution of intrinsic carriers considered.
GC 6  Photoemission of Charge Carriers From Metal Electrodes into Poly(N-Vinylcarbazole).* P.J. RENCROFT and S.K. GHOSEH, Univ. of Kentucky —Photoemission of holes from the metal electrode in metal-PV=O film samples (30%) with high work function metal electrodes has been investigated. Photoemission thresholds were found at 1.4, 1.7, and 1.7 eV for Pt, Au, and Ag electrodes respectively with the metal electrode at positive bias. The threshold obtained with Mg electrodes at positive bias coincided with the photocurrent threshold observed for all samples with the metal at negative bias and for SnO-PV=O samples. The latter process is due to a photocarrier generation mechanism involving electronic transitions in the polymer and onset at -1.9 eV. Photoemission of holes from the electrode thus cannot be readily observed if the metal work function is less than 3.8 eV. The photoemission studies and studies on the dark current-voltage and dark current-temperature characteristics in PV=O films(1) support Schottky-Richardson field-assisted hole emission as the best description of the dark conductivity characteristics observed in PV=O films with Pt, Au and Ag electrodes.

ELECTRICAL EFFECTS OBSERVED IN IRRADIATED RHOMBOIC CRYSTALLINE SULFUR
S.C. Ribeiro, P.V. Murphy

Single crystals of low dark conductivity were irradiated with 9°Sr beta rays. Induced conductivity was proportional to dose rate and field. Temp stance. Activation energies of the order of 0.1 V were observed. Persistent internal polarization could be induced by simultaneous action of an electric field and radiation. The polarization decay curves were exponentials with an activation energy of about 0.9 eV at room temperature.

EFFECT OF CHAMBER VOLTAGE ON ELECTRON BUILD-UP MEASUREMENT
J.E. Richardson
Radiology 62, 584(1954)

Observations on polarity effect due to secondary Compton electron production in the wall of ionization chambers.


The effect of 60Co gamma rays on the lifetimes of photoinjected electrons and holes in anthracene has been studied. Reciprocal lifetimes of both carriers vary linearly with dose. Steady-state space-charge-limited current measurements gave a production rate for deep electron traps of 1x10^16 cm^-3 R^-1. The variation of lifetime with dose is interpreted in terms of radiation-produced traps with trapping cross sections comparable to the geometric cross section of a unit cell. (auth)
Cubic glass samples were exposed to various doses up to 45 Mr. Discharge was induced by an impact probe and discharge patterns observed. Effect of composition, of cerium content, of lead content, physical dimensions, and density were observed and discharge thresholds determined. A mathematical model implying the formation of radiation-induced dipoles is developed, giving field distribution and potential.

EXPERIMENTAL ANALYSIS OF GAMMA BATTERY
P. Rodriguez
Reps.I-IV, Nuclear Engineering Program, University of Illinois, 1963

CALCULATION OF THE EFFICIENCY OF THE 85Kr NUCLEAR BATTERY
P. J. Rodriguez
Acta Cient.Veneaol. 16, 104(1965)

BREMSTRAHLUNG SHIELDING FROM ELECTRON TRAPPING IN DIELECTRICS
D. L. Rollie
Nuclear Technology 10, 325(1971)
A study is made of utilizing electron trapping in dielectrics as a means of reducing bremsstrahlung in spacecrafts at synchronous altitudes. Traps retain electrons, and large internal fields are induced within the dielectric. Electrons penetrating the insulating material can lose most of their kinetic energy to the electric field with a subsequent decrease in energy loss to bremsstrahlung, reducing production of the latter. It also lowers the average radiation energy of that which is produced, with consequent increase in probability of absorption by the wall. Breakdown phenomena causes the the shielding effect of the trapped electrons to be cyclic. A thin layer of dielectric material on the external surface of a spacecraft should provide an effective, light, and inexpensive shield against bremsstrahlung while not interfering with any of the system functions. Electron-trapping shielding is applicable not only in space, but wherever a dielectric layer is allowed to accumulate.

DIRECT CONVERSION INTO ELECTRICAL ENERGY OF GAMMA RADIATIONS EMMITTED BY NUCLEAR REACTORS OR RADIOISOTOPES
Carlo Roma
Describes a Compton current detector employing two metal electrodes in vacuum, one of which having a considerable greater thickness than the other. A theory of the device, based on statistical considerations, is developed.
INCREASED CONDUCTIVITY OF SOLID DIELECTRICS ON EXPOSURE TO X-RAYS.
Rosc, C.
Z. Phys., 36, 18 (1926)

AN OUTLINE OF SOLID PHOTOCODUCTIVE PROCESSES
A. Rose
RCA Review 12, 362 (1951)
Both space charge limited and volume excited currents are considered. The nature of the latter depends on the presence and distribution of traps, the mobility of one or both kinds of carriers, and the supply of carriers from the electrodes. Initially, insulators are considered. The two time constants, i.e., that for the observed decay of the photocurrent and the mean life time of the free carriers, are separated. Items discussed include also infrared quenching, spectral response, non-uniform illumination of semiconductors, and the effects of barrier fields.

RECOMBINATION PROCESSES IN INSULATORS AND SEMICONDUCTORS
A. Rose
Phys. Rev. 97, 322 (1955)
Discrete states in the forbidden zone can be divided into ground states and shallow trapping states. Major recombination traffic passes through ground states. Shallow traps cause the observed decay time of free carriers to exceed the lifetime of the free carriers in the conduction band. At low excitation rates, free carrier concentration less than concentration in ground states) electron and hole lifetimes are independent and fairly different. At high excitation rates both are equal. For insulators having one class of ground states (class defined by capture cross sections for holes and electrons) the high-light lifetime is bracketed by two low-light lifetimes–large than one class of ground states is required to account for infrared quenching, superlinearity, and ability of added ground states to reduce recombination rate. These effects involve redistribution of carriers amongst ground states and give meaning to terms like "filling of traps" and "saturation of centers". The capture cross section of free states can range from $10^{-13} \text{cm}^2$ to arbitrary small values.

ELECTRON DEPTH-DOSE DISTRIBUTION MEASUREMENTS IN FINITE POLYSTYRENE SLABS.
Rosenstein, Marvin
eisen, Harvey; Silverman, Joseph (Univ. of Maryland, College Park).
Experimental depth-dose curves for 2.00-MeV electrons incident on layers of polystyrene were obtained for broad-beam geometry as a function of slab thickness and incident beam angle. Calibrated radiochromic dye films were used as dosimeters. Continuous spatial-absorbance changes in the irradiated film were recorded with the aid of a scanning densitometer. Data were obtained for the following conditions: (a) polystyrene thicknesses 0.42, 0.63, and 1.3 times the electron range, and (b) electron-beam incidence angles of 0, 15, 30, 45, 60, and 75° to the normal. Comparisons were made with theoretical depth-dose histograms generated by the Monte Carlo computer code EPD. Close agreement was found for the two thicker slabs, but energy absorption in the thin slab was observed to be lower than that predicted by the calculations by 5 to 10%. (auth)
CURRENT TRANSIENTS GENERATED IN VARIOUS TYPES OF COMMERICAL CABLES UNDER IRRADIATION FROM MIXED GAMMA AND NEUTRON PULSES WERE MEASURED AS A FUNCTION OF VOLTAGE, DISTANCE FROM SOURCE, AND SHIELDING. MEASUREMENTS WITH NO VOLTAGE APPLIED WERE ALSO TAKEN. REPEATED EXPOSURES UNDER UNCHANGED CONDITIONS MIGHT LEAD TO STRONG CHANGES OF THE RESPONSE SIGNAL; EVEN INVERSIONS OF POLARITY WERE OBSERVED.

RADIATION SHIELDING WINDOW GLASSES
J. S. Rothwell
Corning Glass Works, Res. Lab, Corning NY

DESCRIPTION OF 3 GLASSES DEVELOPED BY CORNING. THEIR PROPERTIES.

THE NON-LINEAR ELECTRIC FIELD IN DILECTRICS IONIZED BY RADIATION
A. S. Rezeckanta
Elektrichesto(USSR) 6,52(1966)

THE REVERSIBLE CHANGES IN THE ELECTRIC FIELD DUE TO SPACE-CHARGE REDISTRIBUTION ARE CONSIDERED AND THEIR IMPLICATIONS ON INSULATION, MEASURING METHODS, AND AUTOMATIC CONTACTS ARE DISCUSSED.

INVESTIGATION OF THE ELECTRIC CONDUCTIVITY OF INSULATING MATERIALS BEFORE, DURING, AND AFTER IRRADIATION.


A device is described which measured gamma radiation rates between 0.075 r/sec and 10^3 r/sec at threshold energies independent of energy between 300 keV and 26 MeV. Inside a titanium envelope, which is the active element, is a collector electrode held in place by a ceramic spacer that serves also as an insulator. The inside of the titanium envelope is coated with a thin layer of magnesium oxide and magnesium oxalate. The magnesium-oxide layer is processed by techniques developed for magnesium-oxide cold-cathode electron tubes. Incident gamma rays eject Compton electrons from the titanium envelope and start a multiplication process through the magnesium-oxide layer. Response is instantaneous and the device is particularly suitable for pulse measurements.

AN ELECTRON BEAM TECHNIQUE FOR VISUALIZATION OF CHARGE DISTRIBUTION

H. Saito

Japan J. Appl. Phys., 4, 886 (1965)

An electron beam is used for scanning the charge. By its deflection a characteristic pattern describing the charge distribution on the dielectric surface, is obtained on a screen. The pattern is analysed in terms of the interaction between electron beam and charge distribution. Experiments on various charge distributions were performed.

From Conference on Properties and Use of MOS Structures, Grenoble, France.

Transistors and capacitors of very simple geometry, formed with a layer of wet thermal silica and a layer of aluminum, were irradiated by 1-MeV electrons. The threshold potential of the MOS transistors and the capacity and conductance of the MOS capacitors were measured. The phenomena of formation of the space charge zone with both continuous and pulse polarizations are presented. Mechanism of the space charge annealing during the thermal annealing process is explained.

GAMMA-ELECTRIC-CELL THEORY AND EXPERIMENTS

H.T. Sampson

Abstracts, Fourth Ann. NSS Study Conf., University of Illinois, April 22-23 (1966)
Stable voltage outputs exceeding 10 kV have been obtained with two multicollector gama-electric cell designs using epoxy or polystyrene dielectric. Short circuit currents ranged from 3 to 5x10^-14 A/cm² per R/h. Voltage breakdown and erratic output, observed in certain cell designs and ranges of gama dose rates, are attributed to radiation effects, including induced polarization of the dielectric. A theory for high voltage operation, involving both the collection of Compton electrons and leakage currents, is developed.

Measurements are reported for cylindrical cells with cylindrical electrodes and a lead-disc backing plate to minimize secondary electron losses associated with transmitted gamma radiation. Dimensions are 8 in. x 8 in. TRiga reactor irradiation and 60Co facilities have been used, with dose rates up to 10^6 R/h. Dielectrics used were polystyrene and silicone rubber insulators. For 10^3 R/h maximum voltages of nearly 15,000 V were found; deterioration of the dielectric caused, however, the voltage to decrease after the peak had been reached. For 2,5 x 10^4 R/h a stable voltage of about 11,000 V was obtained with polystyrene. A new theory was developed for the open-circuit behavior. Calculations were coded for the IBM-7094. Initial calculations for 0.662 MeV gamma yield 0.55 x 10^-15 A/(cm² R h) for a polystyrene cell at 0 and 1500 V respectively. In contrast, short-circuit currents of 2.5 x 10^-15 A/(cm² R h) for reactor irradiation and 0.46 x 10^-15 A/(cm² R h) for 60Co were measured.


ON THE CHANGE OF THE DIELECTRIC LOSS FACTOR OF SOME PLASTICS UNDER GAMMA RADIATION AT 9.4 GHZ
H.Sauerbrey, H.Suhr

In the temperature range well below the melting point, the conductivity of a sample of annealed polyethylene can be expressed by the formula \( \sigma = \sigma_0 \exp \left(-\frac{U}{kT}\right) \), where \( \sigma_0 \) is constant, \( k \) is Boltzmann's constant, \( T \) is the absolute temperature, and \( U \) is the apparent activation energy. Exposure to gamma radiation changes both \( \sigma_0 \) and \( U \). A plot of \( \log \sigma_\text{irr} \) vs \( U \) yields a straight line for the irradiated polyethylene, but a plot for the unirradiated sample is somewhat off this line. For the irradiated polyethylene the compensation rule, \( \log \sigma_\text{irr} = \alpha + \beta U \), applies. It was found that, for polyethylene free of additives, the compensation rule holds for different radiation doses but not for zero dose. This result suggests that the predominant conduction process may be different for irradiated and unirradiated polyethylene. (R.W.R.)

INFLUENCE OF X-RAY AND GAMMA RADIATION ON THE CONDUCTIVITY OF PARAFFIN WAX.
Seidl, F.
Z. Phys., 73, 45(1932)

In this and following papers the effects of X- and gamma radiation on conduction in paraffin, amber, and seignette salt is investigated. In particular transient effects are studied. Effects are reversible in so far that dielectrics recover their original properties after irradiation has ceased.

NORMAL CONDUCTION CURRENT AND DELAYED EFFECTS OF SOLID PARAFFIN EXPOSED TO GAMMA RADIATION.
Seidl, F.
Z. Phys., 92, 695(1936)

Both conduction and absorption are found to increase. Prolonged irradiation results in fatigue effects.


AD 1. Theory of Pulse Induced Transient Photocurrents in Insulators. H. Seki and I.P. Batra, IBM Research, San Jose. The transient photodischarge process in a photoconductor-dielectric sandwich structure due to pulsed light is analyzed. It is assumed that the light is absorbed at one of the surfaces of the photoconductor layer and its duration is short compared to the transit time of the leading edge of the charge carriers. The theory is developed for one type of trap but can be extended to multiple trap types. Time dependent approximations which give the upper and lower limits of the observable parameters are derived up to the transit time and beyond in some cases. It is shown that the two limits are sufficiently close to each other under a rather wide range of experimental conditions so that important transport properties such as mobility, lifetime, and trapping times can be experimentally determined. Examples of calculated results are given for cases involving one type of trap and two types of traps.
Electron Transport in PVK:THF

H. Seki, W. D. Gill

In 12th Int. Conf. on Conduction in Low Mobility Materials.
Eilat, Israel, 5-8 April 1971. Taylor and Francis, London, p. 409

Electron transport properties for electrons in this organic
photoconductor have been determined by measurement of transient
currents due to pulsed illumination. Analysis in terms of a
multiple trap theory indicates as main effects: inter-trapping
drift mobility and trapping and detrapping by two sets of traps.
Mobility, free carrier lifetime, and trapping times depend strongly on the field.

Photocurrents due to pulse illumination in the presence of trapping II.

H. Seki, H. Batra

J. Appl. Phys. 42, 2407 (1971)

The transient photodischarge process in a photoconductor-
dielectric structure is analyzed. Light is assumed to be absorbed in a very thin layer, its penetration being neglected.
A one-level trapping model is discussed, which can however be extended to several trapping levels. Solutions are given mostly for times up to the transit time of the leading edge of the charge distribution.

Photocurrent and carrier distribution due to steady light absorbed in finite thickness

H. Seki, B. N. Schechman

J. Appl. Phys. 43, 523 (1972)

The steady-state current through a layer of photoconducting material was investigated when one surface is illuminated by constant light source, material being intrinsic and free of deep traps. Light absorption characterized by optical absorption coefficient, bulk recombination is taken into account. With an applied field, the experimentally accessible photo-injection efficiency is the product of free-carrier generation efficiency and recombination yield. Monomolecular and bimolecular cases are discussed.

A study of the initial photocurrent due to pulsed light absorbed in finite thickness

H. Seki

J. Appl. Phys. 43, 1144 (1972)

Paper investigates effect of finite light penetration on the initial photocurrent for a trap-free material assuming an initial exponential carrier distribution in space and simple bulk recombination. The initial current contains 3 components e.g. a current due to carriers which get photo-injected into the sample (constant), a current due to carriers of opposite polarity collected at the illuminated surface, and a current due to carriers which recombine. The 2nd and 3rd component decay rapidly to zero. Cases approximating monomolecular and bipolar recombination are treated.
LONG-TERM AFTER-EFFECT CONDUCTIVITY OF THIN FILMS OF LiF PHOSPHIDE AND Zn SULPHIDE
L.A.Serebrov, V.L.Shmulovich
Radioteknika i Elektronika 14, 1084 (1969)
Paper studies excess space charge from bombardment of 0.5 micrometer thick films by 10 keV electrons. This forms a cathode electret of high internal resistance used for storage, long-time protection, and subsequent reproduction of signals.

STUDIES OF ELECTRET CHARGES PRODUCED BY POLYMER FILMS BY ELECTRON BOMBARDMENT
G.L.Sessler, J.West
Polymer Letters 1, 367 (1969)
Formation and behavior of electrets produced by electron bombardment are discussed. Thin sheets of Teflon FEP, Mylar, and polycarbonate foils were used. One effect considered was secondary emission on the upper foil producing a positive charge. The foil is also exposed to secondary emission and backscattering from the plexiglas plate. Surface and volume recombination produce the polarity reversal resulting in monocharge electrets.

CONDUCTIVITY GLOW CURVES OF ELECTRON-BOMBARDED POLYMER FILMS
G.L.Sessler, J.West
1. Conductivity Glow Curves of Electron-Bombarred Polymer Films: G.L.Sessler and J.E.West, Bell Telephone Laboratories, Murray Hill, N.J.—Space charges injected into 2 to 25 μm polymer films by means of monoenergetic electron beams (energy range 10 keV to 1 MeV) have been investigated by measuring the depolarization current as function of time at increasing temperature (conductivity glow curves). The glow curves indicate multiple trapping levels for electrons at δ:E of between 1 and 1.5 eV below the conduction band for such polymers as polyethylene terephthalate (PET), poly carbonate, and polytetrafluoroethylene (PTFE). The trapped charge density appears to be greatest on the thinnest films. Typical initial full-trap densities on 2 μm poly carbonate and 3.8 μm PET are 2.1×10^{18}/cm^3 and 1.2×10^{18}/cm^3, respectively. This is within the expected range of trap concentrations for low conductivity materials and about an order of magnitude higher than previous experimental results.
CHARGING OF POLYMER FOILS WITH MONOENERGETIC LOW-ENERGY ELECTRON BEAMS

C.H. Seuser, J. West


Results of charge deposition on 12.7 and 25.4 micrometer polymer foils with 10 to 40 keV electrons are reported. The trapped charges have densities of about $10^7$ C/cm$^2$, with area uniformity of about 50%. The time constants of the charge decay are of the order of tens of years. Conductivity decay curves show a more densely populated high-temperature portion than glow curves for other methods of charging.

CHARGE DECAY CHARACTERISTICS OF POLYMER FOILS

C.H. Seuser, J. West


Foils were charged by breakdown and by electron beam irradiation. Materials included 12.7 and 25.4 μm foils of polyethylene terephthalate, polyfluorocarbon, polytetrafluoroethylene, nonmetallic or metallicized on one surface. Current densities up to 0.1 μA/cm$^2$ were used. Breakdown charged foils gave up to $1.5 \times 10^{-7}$ C/cm$^2$; others about $10^{-7}$ C/cm$^2$. Charge densities were measured with dissectible capacitor or a capacitance method, as reported Rev. Sci. Instr. Electron energies were up to 20 keV. Beam-charged foils keep charge better than thermocharged ones. The initial charge decay was measured through conductivity measurements as a function of voltage generated across foil. Conductivity was measured by measuring the displacement current between electrodes placed on both sides of the foil (presumably noncontacting electrodes). Electron conduction was inferred. It is stated that "The integrated current, corrected for foil-electrode spacing, equals the total measured surface charge". Electron beam charged foils, studied by thermally stimulated current, show predominance of high-temperature peaks. The average penetration depth of electrons was determined assuming that with charge clouds near one electrode practically all charge migrates to the nearest electrode, as has been proved by several authors. Once the discharge current is integrated, a second time the induced charge on an opposite noncontacting electrode. Average penetration depth is found to exceed electron range, mainly for low energy electron energies, due to bulk retrapping of electrons initially deposited near the surface.
ON THE APPEARANCE OF AN EMF INCIDENT TO ANNEALING OF THE BETA-IRRADIATED ALKALI METAL HALIDE CRYSTALS

V.A.Sh'baev, V.P.Avdonin, I.A.Vasilev, G.A.Mikhalechenko, B.T.Flachenov

If a crystal is irradiated at 900K and subsequently heated, a free charge is observed on the surface of the crystal facing the source. The corresponding emf is called thermostimulated concentration emf. The charge was collected on an electrode covering the sample and measured by using a compensating voltage. Simultaneously, glow curves were measured and found to peak at about the same temperature as the charge. It is believed that the effect is due to a non-uniform distribution over the sample thickness of trapped carriers.

GAUSS-RADIATION-INDUCED CURRENTS BETWEEN INSULATED DISSIMILAR ELECTRODES

R.B.Shields

Results of an experimental study are given. The principle variables were electrode material and thickness, geometry and insulation. An attempt to rationalize detector behavior with respect to the analytical model proposed by Sovka and Truant has been moderately successful. Some considerations are given to problems of spectral response. Measurements refer to Pb and Al electrodes, polymeric insulators (lucite, polyethylene) radiation from a Co source, dose rates of the order of 10^6 rad/h. Insulator thickness was 0.002 in., but effects of varying insulator thickness were also investigated and indicated presence of very weak radiation (since 0.005 in. insulator gave already an output decrease of 25%). Radiation-induced insulator conductivity was also investigated, being ohmic and proportional to dose rate.

TRANSIENT CURRENT FROM PLASTIC INSULATORS AND ITS CHANGE BY GAMMA RAY IRRADIATION

Shigeru Ide, Tatsuo Urai

Thin plastic films were irradiated by nearly 3 MR. Before and after irradiation a constant dc voltage was applied. Transient currents were observed for periods between 20 and 10^3 s. They were found to follow a t^-n law, where n=1. An effect of irradiation was observed, but was also found to disappear soon after cessation of irradiation.
The statistics of the recombination of holes and electrons in semiconductors is analyzed on the basis of a model in which the recombination occurs through the mechanism of trapping. A trap is assumed to have an energy level in the energy gap so that its charge may have either of two values differing by one electronic charge. The dependence of lifetime of injected carriers upon initial conductivity and upon injected carrier density is discussed.

The physics of failure of MOS devices under radiation

MOS devices undergo a change of operating region, this being in the nature of a shift of the characteristic curve of the device, produced by the trapping of radiation-induced holes within the 2000 A insulator and the consequent build-up of a fixed bulk space charge in the insulator. Variations in the shape of the of the characteristic curve and increased leakage current are also observed.
Charge storage in silicon dioxide resulting from low energy electron irradiation has been observed. The positive charge build-up has been studied in MOS type structures for various oxide thicknesses, a function of beam energy, electron fluence, sample bias, electrode thickness, and a number of oxide-related parameters. The effective radiation-induced oxide charge appears to be a function of beam energy dissipated within the oxide near the oxide-silicon interface; this charge increases with electron fluence up to a saturation level which is observed in some steam-grown oxides; the experimentally observed dependence of induced charge on applied bias is compared with that predicted by several models for charge accumulation. Optical and thermal annealing of the trapped charge has been studied in an effort to derive information on the nature of the oxide trapping levels. Reduction of trapped charge by irradiation at small negative biases has also been explored. Finally, the development of a two-carrier model for space charge build-up in an MOS structure is discussed and the experimental results obtained for silicon dioxide are related to device performance in the radiation environment.

Some observations on charge buildup and release in silicon dioxide irradiated with low-energy electrons

M. Simons Jr., I. K. Monteith, J. R. Hauser

The positive charge build-up produced by 0 to 50 keV electrons is investigated as a function of beam energy and oxide thickness. Some measurements with higher energy electrons are also reported. The induced charge, as measured from displacement of capacitance versus voltage plots, was found to be a function of beam energy dissipated within the oxide in the vicinity of the oxide-silicon interface. At a given fluence level, it increases with energy (at constant thickness of sample) up to some level E\text{max} beyond which charge buildup rate falls off as the beam energy is increased furthermore. Continued falloff in the buildup rate was observed in several samples irradiated at energies of 200 keV and \( E_{\text{MAX}} \) was found to correspond to the beam energy which, according to predicted range-energy data, produced maximum energy dissipation per unit length in the oxide near the interface. The charge in samples irradiated at these higher energies was considerably more difficult to remove. From 30 to 60 min at 300°C was required to completely anneal these units. The introduction of deeper trapping levels associated with localized defects produced in the oxide by the high energy electrons explains this increased difficulty in annealing. Isochronal annealing of samples irradiated at both high and low energies was performed to obtain an activation energy for the trapped charge. Constant-temperature annealing is linearly depending on the logarithm of the elapsed time over a finite interval. Such a function can result either from thermal activation of trapped carriers from a uniform trap distribution or from thermal emission of recombination electrons over a Schottky barrier from the silicon into the oxide.

Previous calculations of spatial moments over the distribution of ion ranges and bombardment damage were extended into the range of ion energies where electronic stopping is important. Numerical solutions are given of well-known integral equations, under the assumption of Thomas-Fermi screening and velocity-proportional electronic stopping, for equal masses of ion and target and five values of the electronic stopping constant, over a range of four decades of ion energy. The results are compared with experimental damage distributions, with good success. Implications on sputtering are mentioned briefly. (auth)

RAPID ANNEALING OF PULSE RADIATION-INDUCED SPACE CHARGE IN SILICON DIOXIDE
K. Simons (Research Triangle Inst., N.C.) H. L. Hughes
J. Appl. Phys. 42, 3000 (1971) (June)


The existence of a rapid annealing phase in the decay of space charge induced in silicon dioxide by pulsed irradiation has been demonstrated. This effect has been observed in MOS structures prepared from both wet and dry thermal oxides and also in seven commercial N-channel MOSFET's. A simple model involving thermal release of the trapped positive charge from a distribution of oxide trapping levels conveniently approximates the major features of short-term annealing. (auth)

DETERMINING THE ENERGY DISTRIBUTION OF PULSE-RADIATION-INDUCED CHARGE IN MOS STRUCTURES FROM RAPID ANNEALING MEASUREMENTS
K. Simons, H. L. Hughes
IEEE Transactions Nucl. Sci. NS-19, No. 6, 282 (1972)

A rapid annealing phase characteristic of space-charge decay in SiO₂ following exposure to pulsed radiation has been reported. It is believed to be due to a thermal activation process whereby positive charges trapped in a continuous distribution of levels in the bandgap are released to the valence band and escape without retrapping. In the present measurements a 10 keV ion beam irradiated the surface. Then annealing experiments were made following exposure to a 3 nsoc electron pulse.

PHOTOELECTRON CURRENTS AND FIELDS IN AIR-FILLED CAVITIES
L. D. Singletary, D. Kelleher

A model has been developed for the calculation of electron transmission currents and potentials generated in partially gas-filled enclosures as a result of photon irradiation.
RADIATION INDUCED ELECTRICAL PHENOMENA IN ORGANIC DIELECTRICS
W.A. Smith
EGG Tech. Note No. 8536 R ECC 1183-2096, June 1966

Report presenting results of a study of major electrical effects induced in a polymeric insulator. The latter is supposed to be placed between metallic electrodes, and irradiated by high intensity gamma field and concomitantly subjected to the electron field produced by the interactions of the gamma-ray photons with the electrodes and with the dielectric material. Effects
Principal effects are: Characterization of primary energy transfer process (photo-electron or photon-nuclei interaction); Characterization of secondary energy transfer (energetic electrons to atomic or molecular systems); Discussion of measurements of system and material properties before, during, and after irradiation, with emphasis on radiation induced conductivity.

RADIATION STUDY ON MOS STRUCTURES
E.H. Snow, A.S. Grove (Fairchild-Semiconductor-Lab., Mountain View, Cal.)
June 1966, AFCRL-66-449

Ionizing radiation causes build-up of positive space charge within the oxide of the structure. The location of this charge and the kinetics of its formation and annealing have been studied experimentally. A model is proposed which relates the space charge to the defect structure of the oxide. Photocurrents flowing in the oxide following the X-ray irradiation and UV irradiation have been used for constructing the detailed energy band diagrams of the MOS structure.

EFFECTS OF IONIZING RADIATION ON OXIDIZED SILICON SURFACES AND PLANAR DEVICES
E.H. Snow, A.S. Grove, P.J. Fitzgerald

Effects of high and low energy electrons, X-rays, and UV are considered. The following effects are noted:
(1) Build-up of positive charge in the oxide
(2) Creation of fast surface states at Oxide-Si interface, resulting in increased surface recombination velocity. The effects of dose and dose rate, bias bias during irradiation, and of structural parameters are discussed.
Theoretical studies are reported of the production of electrons in a semi-infinite plate by gamma-rays interacting by Compton scattering and photoelectric absorption. Electron yields per incident photon were obtained as functions of gamma-ray energies from 0.15 to 1.50 MeV, plate atomic numbers from 13 (aluminum) to 92 (uranium) and for plate thicknesses up to 1.5 mm. A limited comparison was made with results obtained from $^{60}$Co Gamma-Cell experiments. The analytical investigations are helpful in describing the behavior of coaxial self-powered detectors operating in a similar gamma-ray flux. Extension of the analysis to electron generation in a radiation field containing neutrons and gamma-rays, as in a reactor core, is recommended. (auth)

RESPONSE OF COBALT NEUTRON FLUX DETECTORS

J.A. Sovka


For monitoring the detector current due to beta-decay of short-lived isotopes ($^{104}$Rh, 42 sec and $^{52}$V, 3.76 m) provides adequate response time. For fast flux transients the prompt-response Co detectors were developed. However, neutron activation products contribute to background signals that increase with detector irradiation. Paper gives mathematical study of response function.

ELECTRON BOMBARDMENT EFFECTS IN THIN DIELECTRIC LAYERS

W.E. Spear

Prof. Phys. Soc. B 68, 991 (1955)

Abstract. Dielectric layers of mica, Pyrex, arsenic sulphide and antimony sulphide, between 0.7 and 4 microns thick, have been investigated under electron bombardment with electron energies up to 50 keV. The specimens carry evaporated Al electrodes, which are practically transparent to the primary electrons. The results include transmission curves for the primaries; the range values are in agreement with the Thomson-Whiddington law. With both electrodes at the same potential a steady secondary current begins to flow to the bottom electrode when the bombarding electrons have penetrated about half the specimen. Experimental values of primary and secondary currents for specimens of different thickness and dielectric fall on common curves when plotted against a suitable independent variable. The secondary current is shown to depend on the absorbed energy. Results for mica with applied fields up to 1000 v/cm across the specimen are included. An interpretation of the secondary current curves is given in terms of the displacement of charge carriers in the space-charge field within the dielectric.
DRIEF MOBILITY TECHNIQUES FOR THE STUDY OF ELECTRICAL
TRANSPORT PROPERTIES IN SOLIDS

J. Non-Crystalline Solids 1,197(1969)
(Univ. Dundee, Scotland)

Paper reviews principles and experimental techniques involved
in mobility measurements. Detectors are fitted with electrodes
on opposite sides and charge carriers are generated near the
top electrode by a fast excitation pulse (light or electrons).
A steady or pulsed applied field can be used to transport the carriers
through the specimen and the transit time is determined by
charge integration or from the observed current transient.
Trapping in shallow and in deep traps is also discussed.
The first causes multiple trapping and release, the second
carries distortion polarization effects and ultimately limit
the applicability of the method. Space charge neutralization
techniques are discussed.

27429 (CONF-690540, pp 524-31) A SELF-CHARGING
ROENTGEN DOSIMETER WITH EFFICIENT UTILIZATION OF
PHOTO AND COMPTON EFFECTS. Speyer, Klaus (Allgemeine
Elektrizitäts-Gesellschaft, AEG-Telefunken, Ulm (West Ger-
many)). (In German).

A new type pocket dosimeter was developed which consists of
the roentgen detection element, the electrometer, and the optical
system. The roentgen detection element consists of an outer
electrode of lead and an inner electrode of carbon. Because of
the difference in atomic number between lead and carbon, x ra-
diation produces a voltage difference between the two electrodes
which is indicated by the electrometer. Advantages of the new
dosimeter are stability of zero point, maintenance of a given
charge for long times, and no saturation effects at high dose
rates. (H.B.G.)
Recombination parameters are determined for $^{60}$Co gamma-irradiated n-type germanium (low resistivity) and n-type silicon. A study of transient photocconductivity decay in the presence of traps for both irradiated and unirradiated silicon and germanium is presented. Measurements of the injection-level dependence of minority-carrier lifetime for n- and p-type silicon with neutron dose as a parameter are reported. Useful relationships for recombination studies are presented, including a method for determining capture-probability temperature dependencies. Short-term annealing studies include an investigation of transient recovery in p-type silicon following pulsed 1.4-MeV electron irradiation and an analytical treatment of the effects of metastable charge states on short-term annealing in p-type material. Data presented indicate that heavily doped, Czochralski-grown Al-doped silicon that undergoes an appreciable resistivity increase during heating at $450^\circ$C is significantly more resistant to both neutron and gamma irradiation than B-doped material. A technique for performing diffusion-length measurements using a scanning electron microscope is described, and results of preliminary radiation effects studies on silicon employing this method are presented. (auth: G.TIS)

**NUCLEAR RADIATION-INDUCED CURRENTS IN COAXIAL CABLES**

J.L. Stringer, J.K. Bourne

NRL-1549 (Ballistic Northwest, Richland, Wash., Pacific Northwest Lab.) June (1966)

A qualitative model relating the nuclear radiation induced current to cable material, dimensions, and dose rate is developed. It predicts polarities for each radiation component. Currents up to $10^{-8}$ A/cm$^2$ were measured in a 0.250 in. OD coaxial cable placed in a TRIGA reactor.

**DIRECT-CURRENT CONDUCTIVITY OF POLYETHYLENE AT HIGH FIELD-STRENGTHS**

G. Stetter


Field, voltage, and temperature effects are investigated. Measurements of the discharge (short-circuit) currents after polarization of thin (30 micron) samples with fields between 1.8 and $7.3 \times 10^5$ V/cm gave current reversals. They start could first be observed with about $5.9 \times 10^5$ V/cm. At the highest voltage the current inversion occurred shortly after short-circuiting, subsequently the discharge current had the same shape but opposite polarity as it would have normally, i.e., it was in the same direction as the charging current. Observations were made with mercury electrodes.
THE INFLUENCE OF GAMMA IRRADIATION ON THE ELECTRICAL CONDUCTIVITY OF GLASSES

T. Sugiura, K. I. Nakai, H. Tanaka
Yogyo Kyokai Shi, 70, 38 (1962)
Gamma radiation effects and application of irradiated glass to semiconductive glass or radiation dosimeters are discussed.

A METHOD FOR THE ROUTINE MEASUREMENT OF DIELECTRIC PHOTOCONDUCTIVITY

U. H. Sullivan, R. L. Ewing (Sandia Labs.)
IEEE Transactions Nucl. Sci. NS-18, No 6, 310 (1971)
Peak conductivityxx of Teflon and H-film have been mea-
sured during intense ionization radiation burst (about 40
ns) (~6x10^11 R/s). It is concluded that 1) common capacitor
dielectrics should be examined to determine whether they
can be driven into the bimolecular recombination region
2) the apparent disappearance of polarization effects at
high doses should be examined 3) the technique could be
used with the older integral of conductivity measurement
to obtain detailed conductivity data over the entire
history of irradiation and decay. Results are at 6.3x10^12 rad/s

\[ K_p (\text{rad}^{-1}) \]

Teflon \[ 1.1 \times 10^{-5} \]

H-film \[ 2.16 \times 10^{-6} \]

A delayed component with a decay time constant of 15 ns was

ELECTROCONDUCTIVITY FEATURES OF ALKALI SILICATE GLASSES IN HIGH ELECTRIC FIELDS DUE TO GAMMA IRRADIATION

A. I. Syriak
Izvestiya Vysshikh Uchebnich Zavedenii, Fizika, No. 4, 31 (1966)

CHARGE EFFECTS IN DIELECTRIC FILMS ON SILICON

J. R. Szedon (Westinghouse Res. Lab., Pittsburgh, Pa.)
Thin Film Dielectrics, Conference, Montreal, Canada,
7-11 October 1968 (New York, Electrochem. Soc. 1969, p. 84)

Paper reviews ion migration, injection trapping, electron irradiation effects in materials currently used in Si planar technology. The use of capacitance voltage analysis of metal-insulator-semiconductor structures is discussed. The application of these analytical methods to study of reactively sputtered SiO₂ and TaO on Si is mentioned. Examples of how to control dielectric charge behavior are given.
X-RAY FLASH TUBE FOR THE STUDY OF FAST PROCESSES
H. Schaff's
Institut für Technik 8, 247 (1972)

RADIATION-INDUCED CABLE CURRENTS. PART I.
Dale R. Schallhorn, Edward E. Conrad, and Elmer I. Ellsworth
(TR-1167)

RG-59/u, RG-59 B/u, and RG-62/u coaxial cables were exposed
to pulsed radiation in the Diamond Ordnance Radiation Facility
(DORF) reactor. Conductance and replacement currents were
measured with two different cable configurations— one with the
irradiated portion looped into a hairpin shape, the other with
the irradiated end of the cable fastened to a terminal board and
the entire assembly exposed to the radiation. Data were obtained
as a function of distance from the radiation source in
the reactor and in a neutron-free Co-60 gamma ray environment.

The test results suggest that the polarity of the replacement
current depends on the energy and type of incident radiation.

It was determined that cables can be used to perform experiments
in DORF without introducing more than 0.5 µA replacement current
at the peak of the reactor pulse.

PREDICTED AND MEASURED DEPTH DOSE PROFILES FOR PULSED
ELECTRON SPECTRA
D.R. Schallhorn, L. Buxton

Experimentally measured profiles were compared with theoreti-
cal profiles. Measurements were carried out in the following way:
materials were exposed to pulsed electron beam from flash
X-ray unit. The materials rear surface motion induced by
the exposure was measured with a laser interferometer. The mea-
sured responses were converted to velocity histories which
can be related to depth dose profiles. Nine materials
with Z between 13 and 79 were studied.

024203 Schaar, K.; Mohr, R.K. Temperature dependence
of photocurrents produced by x and gamma rays

electric currents; gamma radiation; radiation effects; si-
semiconductor detectors; temperature dependence; x
radiation.
BULK SPACE CHARGE AND TRANSIENT PHOTOCONDUCTIVITY IN AMORPHOUS SELENIUM
M.E. Scharfe, M.D. Tabak (Xerox Co., Rochester, N.Y.)
The drift of a small photoinjected sheet of free carriers can be used as a probe of space charge field and distribution in the bulk of amorphous Se.

The results of a recent series of experiments conducted on electronic parts at the Sandia Pulsed Reactor Facility are discussed. Cables, resistors, and ferrite cores were included in the program. Four cables including RG-62A/U, RG-59B/U, RG-81/U, and a twisted pair wire cord were exposed in various geometries, circuits, and applied voltages. Exposed also were 100-ohm, 1-kohm, 10-kohm, and 100-kohm carbon film resistors, a 100-ohm wire wound resistor, as well as manganese-zinc and nickel-zinc ferrite cores. Peak induced currents observed in cables were:
- +3000 to -2650 microamp in looped RG-62/U, +600 to -2500 microamp in looped RG-81/U, +300 to -380 microamp in looped RG-59B/U, +400 to -1650 microamp in looped twisted pair, +80 to -90 microamp in straight potted RG-62A/U, and +800 to -500 microamp in straight unpotted RG-62A/U cable. Low-value resistors appeared quite stable, but resistors greater than 10 kohm showed a spurious and inconsistent behavior, attributed largely to lead cable effects. The measurements on cables and resistors seem to bear out the fact that reliable data cannot yet be obtained for many exposed component parts because of unpredictable behavior of the cables used for signal transmission.

PULSED NUCLEAR RADIATION INDUCED TRANSIENTS IN ELECTRICAL CABLES
W. Schlosser, J. Newberg, J. A. Key
AD-623,016, July 1964
(USA Army Electronics Labs., Port Monmouth)
Observed currents contained 3 components: a replacement current, a conduction current, a charging current. After repetitive exposure the first component predominates. The charging current is attributed to introduction of charges and in an initial exposure and to redistribution of them in an exposure accompanying a change of applied voltage. The transients were produced by irradiation in a TRIGA pulsed reactor.
A theory which explains the details of the radiation-induced charge release phenomenon of ferroelectric detectors has been developed. This theoretical development provides additional insight into the operation and application of ferroelectric devices in the broad field of radiation measurement. When placed in a radiation environment the detector responds by virtue of its pyroelectric properties. In this process the absorbed energy causes a slight change in temperature which results in a change in the internal polarization. The theory which has been developed predicts that the polarization change causes a perturbation of equilibrium electric fields and the appearance of free charge at the electrodes. The quantity of free charge which is released is proportional to the energy which is absorbed from the radiation. Ferroelectric detectors respond to ionizing radiation and have found applications in the areas of flash x-ray dosimetry and spectroscopy, laser calibration systems, linear accelerator calibration, plasma diagnostics and pulsed reactor dosimetry. The detector's ruggedness, small size, very fast time response and zero-bias operating characteristics make it ideal for the measurement of intense sources of pulsed radiation.

The electric conductivity technique was adapted to the study of the transient charged species appearing in the range of 77 to 125°K in 2-pentene following its γ-irradiation. Three peaks corresponding to different species were observed.

FOR CALIBRATION OF HIGH-INTENSITY FLASH X-RAY MACHINES


Describes monitoring methods using a Compton detector consisting of a 3-element (Pb-C-Cu) emitter, a biased grid (for suppression of unwanted electrons), mounted in vacuum chamber. Compton spectrometer used for energy analysis.


The effects of electron radiation on capacitor-type detector systems similar to those used on the Pegasus satellite were investigated. Each system that was tested consisted of a polyurethane foam panel containing two capacitor-type meteoroid detectors, several meters of polyethylene terephthalate insulated electrical leads, and other items such as rubber shock mounts and polyethylene terephthalate adhesive tape. Three different target thicknesses for the meteoroid detectors were tested, 40, 200, and 400 microns. The incident kinetic energy of electrons used in the tests ranged from 30 keV to 1000 keV, and the temperature of the detector systems was maintained at either 197 or 207°K. It was found that radiation-induced dielectric breakdowns were produced in the systems and that some of these signals were indicated as meteoroid penetrations. It was determined that the primary source of the breakdowns and, hence, the penetration indications was the polyethylene terephthalate insulated wire. The number of breakdowns and penetration indications obtained for a fluence of 5 × 10^14 e/cm^2 was found to be dependent on the incident kinetic energy of the electrons and the system temperature; that is, more breakdowns and penetration indications occurred at the lower temperature (197°K) and the lower energies (30 to 100 keV). Tests were performed with different modifications made to the signal processing circuits. Several of these modifications resulted in a significant reduction or the total elimination of the radiation-induced penetration indications. Finally, it was found that those systems containing 200 and 400 micron detectors with 200- and 400-micron-thick targets suffered severe decreases in resistance in the capacitor-type detectors.


Experimental results from an investigation of self-powered gamma detectors with emitters of lead, zirconium, Inconel 600, magnesium, and graphite are presented. The detectors are intended primarily for in-core applications in power reactors, and the detector design is the same as that for a type of neutron sensitive self-powered detector previously utilized for in-core measurements. Detector sensitivities measured both in a 60Co gamma cell and in a test reactor are given. For detectors with lead emitter the measured sensitivity in the gamma cell is 8 × 10^-16 A/µR, and for detectors with magnesium emitter 1.2 × 10^-16 A/µR. (auth)
NUCLEAR RADIATION INDUCED CURRENTS IN COAXIAL SIGNAL CABLES.
J.L. Stringer, R.R. Bourassa
BNWL - 749 (1968) (Batelle-Northwest, Richland, Washington, Pacific Northwest Lab.)
The following problems are discussed: (a) Gamma ray sources with isotropic distribution outside coaxial cable shield. (b) same, with cable shield (c) Electron sources distributed within the cable shield. Parameters are: radiation flux and energy distribution; physical and chemical cable characteristics. A circuit diagram is considered with a true internal current source, noting that the current is independent of the voltage which is proportional to the internal resistance. It is shown that by adjustment of cable parameters the current can be made positive or negative. Pair production, while producing increased noise, gives zero net current. But annihilation of positrons occurring internally can give a current source; this is exactly the internal source problem. Since the distribution is essentially isotropic, only the geometrical factors remain. Thus, the current might be positive or negative. Finally, neutron interactions are considered.

4520 (BNWL-1148) NUCLEAR RADIATION INDUCED CURRENT AND INSULATOR ELECTRICAL CONDUCTIVITY MEASUREMENT TECHNIQUES APPLIED TO COAXIAL CABLES.
The techniques used in measuring the nuclear radiation induced current and the combined temperature and radiation induced electrical conductivity on metal oxide (MgO) insulated coaxial cables are described. An analysis is presented for each technique described and several problems encountered in applying the techniques are discussed. Data are presented for the induced electrical conductivity as a function of temperature to 750°C and radiation dose rate to 8 x 10¹⁴ R/hr. (auth)

The dielectric relaxation behavior of KCl crystals after exposure to 1.5-MeV electrons was studied by means of the ionic-thermocurrent (ITC) method. At least four ITC relaxation peaks are observed over the range from 80 to 200°C after irradiation at 260°C. The irradiation temperature is found to have a strong influence on both the form of the ITC spectrum and the total amount of polarization. The production of dipolar defects, assumed to be responsible for the relaxation, is highest for irradiations in the range 200 to 260°C and it is rather small for exposures at 125 and 300°C. Once produced, the dipolar defects are relatively stable but they can be nearly completely removed by a 400°C anneal. The effect seems to be intrinsic in nature since the total polarization builds up linearly with exposure after the F center has substantially saturated and since it is essentially the same for high-purity crystals from several ingots. Assuming that unit dipoles are responsible for the ITC spectrum, the initial ratio of formation is 0.05 times the initial rate of F-center production. Since it is difficult to conceive that such a variety of stable dipoles can be constructed from anion Frenkel defects, it is concluded that defects on the cation sublattice also result from the irradiation. It is shown that the yield of dipoles is at least an order of magnitude higher than can be expected to result from direct displacements induced by electron-ions collisions. The same types of defects may be precursors to the crystalllographic voids and dislocation loops observed by electron microscopy in heavily irradiated alkali halides. (auth)
Range Distribution of 4- to 24-MeV Electrons

Tatsuo Tabata, Rinsuke Ito, Shigeru Okabe and Yoshiaki Fujita*

(Received December 25, 1969)

Experimental data are presented of the range distribution of electrons in the absorbers of Be, Al, Cu, Ag, and Au. The measurement has been made with a thin charge collector inserted in the absorber, and the energies of the incident electrons investigated are 4.09, 7.79, 11.5, 14.9 and 23.5 MeV. The distributions observed have been fitted with an empirical equation in which an expression for the transmission curve given by Mar is utilized in a slightly modified form. The most probable range $R_m$, the practical range $R_p$, the mean projected range $R$, the 1-% range $R_1$, and the range straggling parameter $\Delta R$ have been determined from the distributions.

Two types of empirical equation for expressing the ratios of the range parameters to the theoretical mean range have been compared, and the one originally proposed by Harder and Poschet has been found to give a better fit for all the range parameters considered.
Charge deposition profiles of monoenergetic electrons normally incident on thick absorbers were measured using the Gross-Wright method, modified in so far as the charge on the catcher and that of the rest absorber was measured. Results are compared with the Berger-Seltzer theory. Considering the absorber system, suppose that the region from $x-\delta x/2$ to $x+\delta x/2$ serves as an insulated charge collector. One measures the charges $\theta q(x)$ and $Q(x)$ due to net absorption of electrons in catcher and in the rest of the absorber. The net charge absorbed by whole absorber is given by their sum. The ratio $y(x)dx$ of the net charge deposited in a layer of thickness $dx$ at depth $x$ to the total charge of electrons absorbed in the whole absorber is determined from $y(x)dx = \theta q(x)dx + \int_0^x \theta q(x')dx'$. The ratio $\theta \frac{0}{x} \frac{x}{dx}$ of the net charge in $dx$ to the total charge of the incident electrons is given by $y_o(x)dx = (1-n)y(x)dx$ where $n$ is the backscattering coefficient at saturation of the incident electrons for the material considered. It seems that the same method was used by W. Alexander, R. Bryn-Johnson, Cooper, U.S. Army Natick Lab., Technical Rep. No. PD-2(1964), unpublished.

EXTRAPOLATED AND PROJECTED RANGES OF 4 TO 24 keV ELECTRONS IN ELEMENTAL MATERIALS
T. Tabata, R. Ito, S. Okabe, Y. Fujita
J. Appl. Phys. 42, 3361 (1971)
Extrapolated and projected range values were determined from charge deposition profiles. Measurements are reported for Be, Al, Cu, Ag, Au.

OBTAINING A SYSTEM OF DOSIMETRY
S. I. Taimuty
ASTIA, AD 205351

A REVIEW OF DOSIMETRY FIELD
S. I. Taimuty
DDC, AD 296591
Recent and critical evaluation of literature on high-level gamma and electron beam radiation dosimetry published since 1958.
X-Ray INDUCED BULK PHOTOVOLTAIC EFFECT IN INSULATORS
S.I. Tainat, L. Feinstein, S.D. Softky
Science 164, 173 (1964)

When an insulator sandwiched between metals of dis-
similar work functions is irradiated by X-rays, a voltage
related to the contact potential of the metals is found.
This "bulk photovoltaic" effect, previously shown only with
UV and visible light, has now been demonstrated for a vari-
ety of metal combinations. The voltage, for insulator
layers of 10^-9 to 10^-2 cm, is of the order of up to 2 V.

THERMALLY STIMULATED CURRENTS FROM
GAMMA-IRRADIATED ORGANIC POLYMERS: POLY(METHYL-
METIYCHLATE). Tumsky, Morgan Jerome. Lawrence,
Order No. 70-20,410. Thesis.

The phenomenon of thermally stimulated currents (TSC) from
\gamma irradiation was studied for the following polymers, especially
poly(methylmethacrylate) (PMMA), isotactic PMMA, syndiotactic
PMMA, commercial PMMA, polyethylene, polypropylene, poly-
styrene, polytetrafluoroethylene, polyvinylchloride, and carnauba
wax. Disk shaped samples, a few cm in diameter and about one
cm thick, were omnidirectionally irradiated in a 60Co source to
Doses of 1 Mrad at 31°C. The TSC was measured by heating the
samples at controlled linear rates, 1.5 to 6.3°C/min, with a vi-
britating reed electrometer in the same circuit with the sample.
The major conclusions of the present study apply to PMMA spe-
cifically but are not restricted to only this polymer: 1) The

ELECTRICAL CONDUCTION OF HIGH POLYMERS
T.Tanaka, Y. Inuiishi

Substances like polyethylene and polycarbonates were
investigated from the standpoint of electronic transport
theory. Carrier trap centers are found to be of importance
in by measurement of low and high-field conductivity, photo-
conductivity and breakdown.

SUBSTANCES LIKE polyethylene and polycarbonates were
investigated from the standpoint of electronic transport
theory. Carrier trap centers are found to be of importance
in by measurement of low and high-field conductivity, photo-
conductivity and breakdown.
In the paper the absorption length is defined as the upper limit of the mean free path of the electrons. For very thin films the properties so determined are characteristic for "hot" electrons because the electrons are injected with a kinetic energy which is high when measured from bottom conduction band, compared to equilibrium energy in the bulk of the material.

EFFECTS OF IONIZING RADIATION ON INORGANIC AND ORGANIC STRUCTURES.

Taubman, A.B., Yanova, L.P.

Reports on electron irradiation of plastics and breakdown effects. The "growing rate" of the discharge pattern was measured for a constant irradiation dose. It was found to be much slower in polystyrene than in polymethylacrylates or in Kel-F. For a given polymer it rapidly decreases with increasing temperature of irradiation. No discharge pattern was observed when the irradiation was carried out above the glass transition temperature of the polymer.

THERMALLY STIMULATED CONDUCTIVITY OF IRRADIATED KBr

A. Taylor
physica status solidi 37, 401(1970)

The thermally stimulated conductivity of KBr crystals irradiated at 100K with monenergetic (500-keV) neutrons and γ rays was studied over the temperature range 10 to 200K. The peak spectrum below 70K was associated with the annihilation of lattice defects created by the irradiation, while the higher-temperature peaks were interpreted as due to the depopulation of impurity traps. The annealing kinetics of the low-temperature peak were consistent with defect annihilation processes controlled by the migration of the Br⁻ interstitials. Neutron bombardment enhanced significantly the low-temperature peaks above the level established by background γ rays. (auth)
A vacuum dosimetry system. The charge collected depends strongly on the geometry of the electrodes. Any gain or loss of charge of the central electrode depends on electron transfer between the walls and the central electrode, not on gas ionization.

EFFECTS OF TRANSIENT NUCLEAR RADIATION ON TRANSUDERS AND ELECTRICAL CABLES
F. D. Terry
IDO-16914

R gives empirical results on cable measurements under different conditions and fluxes and for different types of cables. Both currents and voltages are given. The radiation from SPERT (pulsed reactor) is used where both gamma and neutrons are present. Dose rate was up to 0.6x10^6 R/sec, pulses symmetrical, duration 13 msec. Currents between -82 and +37 micro-A were found, due to Compton scattering and ion pair formation. A bibliography of other work on induced currents in cables is attached.
O(s)3-10 DIELECTRIC COMPTON DETECTOR DEVELOPMENT

REPORT

E.I. Tolman (Berkeley, California, USA)

Describes spherical Compton detector. It is similar in construction to spherical Compton diodes previously in use, except that the space between the outer electrode and the (center) collector electrode is filled with a dielectric (polybutene oil, grade 32). The outside steel electrode has an outside diameter of 2 3/4", inside 7", oil thickness 13/4", max. Sensitivity is 10-10 A per n/sec., maximum current capacity about 100 A into 500 ohm system, signal transit time 25.88 nsec. System is sensitive to gammas and to neutrons due to recoil protons from the oil.

THE PENETRATION OF ELECTRONS INTO MATTER

S.C. Tomlin


A dosimetric procedure is described which makes use of the pyroelectric properties of a material. Single crystals of ZnS (wurtzite) and tourmaline (green variety) are used as dosimeters for ultraviolet and x-ray radiation, respectively. The crystals are in the form of platelets with the large area surface normal to the polarization axis. Polarization is produced when the crystal temperature is increased linearly by heating the oil bath in which the crystal has been immersed, or by means of a specially designed test chamber. The measured polarization is governed by the pyroelectric coefficient as well as the internal resistance of the specimen. The latter is diminished, in the course of heating, by electrons released from traps previously filled by the incoming radiation. The behavior of the system is analyzed in terms of an equivalent circuit which regards the material as a constant current generator. Comparisons with thermoluminescence and current glow processes are described. ZnS is found to be an extremely sensitive dosimeter for u.v., but has a very limited range and poor storage capabilities. Tourmaline on the other hand, as an x-ray dosimeter, is quite insensitive but has extended range and long term storage capabilities. Both materials are similar in their behavior as dosimeters. (Diss. Abstr.)

THERMO-VOLTAIC RADIATION DOSIMETRY


Nature 213, 698 (1967) (Feb. 18)

The incoming radiation is expected to charge electron traps in proportion to dose. Subsequent heating in a temperature gradient should give a temporary thermoelectric effect which is lower than that of unirradiated spaxx specimens due to release of free carriers from traps. After recombination of these traps, the original value of the thermoelectric effect should be restored. Studies with ZnS are described using u.v. and x-radiation. Complications are due to space charge regions due to local variations in the population of filled traps and contact parameters. These factors cause the observed polarity reversals. Other materials including CdF2, LiF, SrF2, CaF2, BeF2.
The effects of electron radiation on electronics include: nuclear-weapon-burst environment, simulated versus burst environment, interaction of transient radiation with matter, discrete semiconductor devices, integrated circuits, capacitors, miscellaneous electronic materials and devices, circuit hardening, circuit-analysis techniques, system hardening, bibliography.

Conductivity induced by electron bombardment
O. Trodden, R. O. Jenkins

Investigations on cadmium sulfide crystals are described.

DISTRIBUTION OF IONIZATION IN MATERIALS IRRADIATED WITH TWO AND THREE MILLION VOLT CATHODE RAYS
L. A. Wright, J. O. Trump
J. Appl. Phys. 21, 345 (1950)

Measurements are reported for Al. The variation of the beam current density in a plane transverse to the beam, the effect on this transverse distribution of additional Al scattering foils, and a practical method of dosage are given. The latter is obtained from the distribution in depth curve.

Development of rupture in plexiglas under the action of electron radiation.
Tsarkin, B. L., Zaitseva, N. G., Kargin, V. A.

Reports discharge patterns produced by electron bombardment in a series of homologues of poly(methyl methacrylate) and also in polystyrene and polychlorotrifluoroethylene (Kel-F). A series of photographs for different doses are given. The temperature influence is discussed.

Storage of charge in an isolated mica plate due to bombardment with fast electrons
N. P. Tsalalov
Izvestiya Vysshikh Uchebnykh Zavedeni, Fizika No. 1, 113 (1972)
A new method, which avoids making measurements or applying an external voltage while the x rays are on, was used in investigating the ionization process by x rays in organic crystals (tetracene and anthracene). The following results were obtained: The x-ray-induced current is linear with electric field strength over a large range of field strengths and saturates at field strengths above 10^6 V/cm; it is proportional to the intensity of irradiation and to the thickness of the sample for the same field strength; about 1000 eV are required to produce one charge pair in anthracene and 400 eV in tetracene. It was also found that the saturation field strength is independent of the x-ray intensity (the intensity was varied by a factor of ten). From these results, it was concluded that recombination occurs mostly between the electron and the hole from which it was separated. It was also found that a large x-irradiation (8 x 10^6 ergs absorbed) produces trapping sites in the bulk of the crystal that trap charges and thus produce some bimolecular recombination.

The crystal is sandwiched between a practically non-conducting mylar sheet and an electrode. a) X-rays and field are applied concurrently. After their removal the charge accumulated at the crystal-myrar interface is measured by the light-release method. b) The barrier is charged to a known charge Q by light. After removal of the external field, an internal field persists. Under x-ray ionization it moves the x-ray produced charge which partially compensates the original charge. The remaining charge is then measured.
The development of self-powered fast-neutron detectors for use in reactor cores is discussed. The detector is in the form of a coaxial cable with a Pd core, a NaI dielectric, and a stainless-steel outer conductor. A Co(Al,α) reaction provides a flow of charge which can then be monitored by electronic instrumentation outside the reactor. A rod in this manner has a sensitivity of about 10^-12 amp/μv; hence, for a flux level of 10^17 μv, the sensor produces 1 μA of dc current. The 5% burn-up rate predicts a burn-up of only 0.41 x 10^-15 μv; this means a 10% drop in signal power after 60 years for the stated flux level. (K.W.R.)

The dependence of the rate $v$ of radiation-induced creep of six polymers (oriented and nonoriented Kapron, poly (methyl methacrylate), polycarbonate, polytetrafluoroethylene, and atactic polystyrene) on the dose rate $\lambda$, temperature $T$, and stress $\sigma$ was investigated. The dependence $v \sim \lambda^\alpha T^\beta$ established earlier was confirmed. A quantitative relationship was found for the parameters $\alpha$ and $\beta$ required by the model proposed earlier, which takes account of the rupture of stressed bonds caused by interaction with thermal electrons. The dependence of the radiation-induced electric conductivity $\kappa$ of poly (methyl methacrylate) and polycarbonate in loaded state on the dose rate was studied. The value of the parameter $\Delta$ depending on $\kappa \sim \lambda^\rho$ for each of these polymers was found to be the same as in the case of radiation-induced creep.


The charging of insulating surfaces by irradiation with gaseous ions is discussed from the viewpoint of basic interactions between individual ions and surfaces. Experiments are reported in which mass-selected beams of low-energy positive and negative ions are used to irradiate insulating amorphous selenium films. The surface-charging efficiency (the number of charges retained on the surface per incident ion) is found to be initially equal to 1, independent of the ion species and ion kinetic energy. As charge accumulates on the surface, the charging efficiency decreases, the extent of decrease being a function of species and kinetic energy. The results are shown to be consistent with a model in which the ion injects a hole or an electron into the solid and the injected carrier is trapped in a surface state. The deviation of the charging efficiency from unity arises as a result of free carrier generation in the solid by means of a transfer of kinetic and/or potential energy from the neutralized ion. Implications of the selenium results to insulator charging in general are considered.


An experimental evaluation of the parameters involved in charge deposition from high-energy electron beams (10 to 32 MeV) in water is described, with particular reference to radiotherapy. Experimental and theoretical values of the parameters are compared, and a qualitative explanation of the differences is given. (auth)

In agreement with Kearsarri, a large number of electrons come to rest in a narrow depth near the end of the distribution with a most probable depth $D_n$. Linear extrapolation through the inflection point gives range $R_n$.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>$T (\text{MeV})$</td>
<td>9.5, 17.8, 31.7</td>
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<tr>
<td>$D_n/R_n$</td>
<td>0.74, 0.77, 0.78</td>
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<tr>
<td>$D_n (\text{g/cm}^2)$</td>
<td>5, 10, 11.7</td>
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</tbody>
</table>
Charge deposition in water produced by irradiation with 10 to 32 MeV electron beams is measured by the method of Gross-Wright. Metal and plastic catchers are used, preferentially the latter (as solid Faraday cages). The lateral spread of charge deposition (normal to beam direction) was also measured. Charge deposition profiles, transmission curves (giving the number of electrons traversing a specific depth), extrapolated range, most probable depth (at which maximum charge is collected) were determined. Results are:

Practical range \( R_p = 0.55 T - 0.71 \text{ g/cm}^2 \)

Most probable depth \( D_m = 0.48 T - 0.91 \text{ g/cm}^2 \)

Practical (extrapolated) range \( R_e = 0.60 T - 0.71 \text{ g/cm}^2 \)

where \( T \) is the kinetic electron energy in MeV.

**Polarization Induced by Radiation in Perspex**

V.J. Vanhuyse, G. J. Vanpraet, J. F. Van Landuyt


Optical properties of perspex irradiated with 2.5 MeV electrons are reported. Irradiated blocks were observed with a polariscope. After irradiation an interference pattern could be seen that behaved as if the block was an uniaxial double refractive crystal, the optical axis coinciding with the direction of the electron beam. The picture disappears very quickly at first, slowly afterwards. If the sample was discharged while the interference could still be seen, this disappeared immediately. It is concluded that the optical properties are due to an electrical effect, only a fraction being due to the mechanical strain. Something like the Kerr electro-optic effect is considered.

**Radiation-Induced Current and Photon-Induced Deflection of Electrons in Dielectrics**


Reports measurements (apparently of short-circuit currents) with X-rays of up to 30 kV, using samples of LiF, NaF, CaF₂, single crystals, sample diameter 17 mm, thickness 1.5 mm. Polyfluoroethylene was also studied. From 10 to 15 kV upwards currents are proportional to X-ray tube voltage. Only the photoeffect was found to be operativ. The Dember effect (movement of ions in a concentration gradient) was too small to interfere with results. It should be noted that the electrodes were separated from the samples by so that electrons could not be exchanged between the electrodes. Currents were of the order of \( 10^{-12} \) A for about 600 R/sec.
Temperature and frequency characteristics of dielectric permittivity and loss angle in polyethylene, fluoroplastic, and other plastics were studied before and after exposure to gamma radiation.

A POSSIBLE EFFECT OF LIGHTNING DISCHARGE ON PRECIPITATION FORMATION PROCESS.

Vonnegut, B., Moore, C.B.

Dielectric breakdown of methyl methacrylate blocks electrified by electron bombardment is considered as an analog to lightning discharge processes. From the study of the breakdown figure it is concluded that the spark which occurred in the plastic did not neutralize a good part of the charge within the plastic but merely balanced this negative charge with an equal and opposite positive charge.
VOLUME CHARGE IN DIELECTRICS PRODUCED BY AN ELECTRON BEAM

A.A. Vorobev, O.B. Evdokimov, N.P. Tubaev
Soviet Phys.-Solid State 13,3116 (1972)

Electron injection produced a negative volume charge. This can be explored by investigating electron transmission properties of the charged dielectric after irradiation (cf. Bovit). Such measurements are reported here. Plexiglas disks were charged with 0.8 to 1.2 keV electron irradiation beams of 0.5 A/cm² current density and 15-20 sec irradiation duration. Subsequently specimens were irradiated with beta particles from a Sr-Ir source whose penetration was measured for periods up to 10 days. If \( n_0 \) is the number passing through an uncharged sample and \( n \) that passing through the charged sample, the function \( \delta = (n-n_0)/n_0 \) decreased with time. As after irradiation with 0.8 and 1.2 keV electrons it changed sign and subsequently decayed again. The effect is interpreted by assuming, according to Gross' measurements, that the negative injected charge decays faster than the positive compensation charge occurring at the non-irradiated side of the sample. The equation for the retardation of the beta particles is written

\[
d\rho/dx = eB(x) - \int T(x) dX \quad \text{where } T \text{ is the kinetic energy at depth } x, B \text{ the specific energy loss, } eB \text{ the retarding electrostatic force. For the shorted dielectric this gives the range reduction}
\]

\[
R - R_0 = \int _0^T V x(t') \int e^{-2} (dB/dt') dt'
\]

THE EFFECT OF GAMMA RADIATION ON THE ELECTRICAL CONDUCTIVITY OF INSULATORS

B. M. Vul
Fiz. Tverdogo Tela 3, 2264-2266 (1961)
translated Solid State Phys(Soviet) 1962, No.3, p 164

Current-time curves are given for various dielectrics (quartz, polyethylene) for different dose rates, applied voltages, and temperatures. Rise and decay curves are investigated. A theoretical treatment is given.
CONDUCTION MECHANISM IN GAMMA-IRRADIATED DIELECTRICS.
Vul, B.M.
Acta phys. Hungar., 14, 225 (1962)

Refers to behavior of quartz, polyethylene, sulfur, ceramics, and similar materials. They can be divided into two groups characterized by a different dependence of current on time of irradiation. For one group the current increases steadily with time, for the other the current attains with the onset of irradiation a maximum and then decreases. A theory is developed taking into consideration the recombination coefficient and the concentration of traps for electrons and holes.

THE EFFECTS OF GAMMA RADIATION ON THE ELECTRICAL CONDUCTIVITY OF INSULATORS
B.M. Vul
Soviet Physics—Solid State, 2(8), Feb. 1962, p. 1644
A review of some diagnostic techniques and instrumentation used at Sandia Laboratories for studying intense electron beams and laboratory pulsed-x-ray sources is presented. Included are descriptions of current monitors, radiation sensitive polymer films, and calorimeter arrays for beam energy density measurements. Also discussed is the real-time-on-line digital computer used for calorimetry measurements. A new technique for measuring electron energy as a function of time is presented and representative data from Sandia's Hermes-II facility are shown. These data are in turn used with a Monte Carlo code to determine the bremsstrahlung spectrum, which is compared with a direct photon measurement made with a large Compton spectrometer.

Finally, a discussion is given of the use of these data in radiation effects experimentation. The results of combined photon-electron transport calculations are shown which demonstrate the edge and interface effects which are important for thin and inhomogeneous samples. (auth)

Characteristics of the machines:

Hermes Machine stores 1/6 J of energy, delivers 60 kJ in 100 ns pulses of 11 keV, min beam current being 50 kA. A 60 mil Ta target gives bremsstrahlung; EBBAT Stores 100 kJ, delivers 10 kJ in 70 ns pulses of 3 keV and 50 kA. It will be expanded to give more than 100 kJ, 1-2 keV, allowing max. doses of 2-3 kcal in 0.1 ns.

In the development stage: Machine for 3 to 10 kJ at about 1 keV.

CALM DOS DISTRIBUTION AT AND NEAR THE INTERFACE OF DIFFERENT MATERIALS

J.A. Neil, B.A. Burke

IEEE Transactions Nucl. Sci. NS-17, No. 6, 305 (1970)

Profiles in Al and Au adjacent to materials of different Z were measured with multiple parallel plate ionization chambers. Dose distribution varies significantly at high (1.25 keV) gamma energies where mass energy coefficients differ relatively little from material to material. Enhancement or reduction of dose is very sensitive to the direction of incident photon beam. Energy deposition in a material is enhanced when it is next to one of lower atomic number provided gamma beam penetrates first the low Z material. A reversal in beam direction reduces the dose to a level below what it would be for each material alone.

Conductivity-time curves are obtained. After a strong and prolonged increase, the conductivity eventually is found to decrease.


An improved self-powered detector which affords a prompt response to changes in the neutron and gamma flux involves a yttrium emitter by using a thickness of insulator between the emitter and collector that is sufficient to absorb delayed electrons emitted at a lower energy level from the emitter and yet allow prompt electrons emitted at a higher energy level from the emitter to reach the collector in described. By thus eliminating the delayed electrons, the signal output current of the detector represents the instantaneous value of the incident neutron and/or gamma flux. (auth)


Radiation effects on carrier drift mobilities and lifetimes were studied in anthracene single crystals irradiated with gamma rays. Measurement of the hole drift mobility at various temperatures and radiation doses show that for doses above $10^4$ r, holes interact with a new defect center introduced by gamma irradiation that is located about 0.4 eV above the valence band and have a concentration of $10^{17}$ cm$^{-3}$, and the effect of temporary trapping at shallow traps in the host crystal is not important. The hole lifetime, which is 85 μsec before irradiation, decreases to a value of 6.1 μsec after a dose of $6 \times 10^4$ r. This probably is due to a large cross section of $10^{-16}$ cm$^2$ for holes of the deep center that have an effect on hole transport for high radiation doses. The lifetime for electrons also diminishes when the total dose increases. A similar tendency is observed for the mobility, as its temperature dependence remains unchanged. (auth)


The conventional cathode of a conductivity cell is replaced by a scanning electron beam which injects a uniform charge pattern into the top layer of the (liquid or solid) dielectric. A current or a uniform surface charge-buildup is measured by means of a second electron beam that passes parallel to the "injection" surface several millimeters above it and whose deflection is a measure for the surface potential. Steady state and transient processes can be investigated.
FUSED FLASHOVER IN VACUUM
A. Watson
J. Appl. Phys. 38, 2119 (1967)
Experiments with dielectrics subjected to 35 to 75 ns high energy electron pulses show strong influence of cone angle of dielectric on insulation strength. Theory assumes that electrons are emitted from surface by thermionic emission. Rate depends on square of electric field strength because electrons are "heated" by the field according to an activation law $\exp(-E/kT_0)$ where $T_0$ the electron temperature, and $E$ proportional to energy acquired in the field, which is proportional to square of field strength. The emitting surface charges up positively, drawing eventually other electrons into it where they will multiply by secondary emission into breakdown condition. Thus while the breakdown is produced by the secondary, surface charging on and thus the lag is governed by thermionic emission of hot electrons from within the dielectric.

EMISSION PROCESSES ACCOMPANYING MILLIVOLT ELECTRON ILLUMINATION IN DIELECTRICS
A. Watson, J. Roy
J. Appl. Phys. 32, 5923 (1968)
Thick dielectric samples were irradiated with 1 keV electrons. The temporal growth of the external field from the trapped charge was punctuated by either total or partial collapses associated with electron emission and followed by pulses before the process repeated itself. Secondary electrons are thought to be heated by the growing internal space charge field until thermionic emission induces a regenerative growth of positive surface charge sufficient to oppose it. Electron emission then ceases until recombination can restore the outside surface of the dielectric to a field-free condition from which it grows again. Analysis of the model proves it to be adequate.

ELECTRON INJECTION TECHNIQUES FOR INVESTIGATING CONDUCTION PROCESSES IN INSULATING LIQUIDS AND SOLIDS
P.K. Watson, T.M. Clancy
Rev. Scient. Instr. 36, 217 (1965)
Describes a new type of dielectric cell which avoids using a metal cathode. An electron beam injects a uniform charge pattern into the top layer of the dielectric. The bulk current through the system is measured by an electrometer connected with the bottom electrode. A second electron beam passing 7 mm above the top surface is used to measure the surface potential. It indicates the charge build-up and charge decay in the dielectric.
STUDIES OF THE PERSISTENT POLARIZATION OF SINGLE CRYSTALS SrTiO$_3$
ELECTrets PRODUCED BY NEUTRON BOMBARDMENT.

Weik, H.

Neutron bombardment of SrTiO$_3$ electrets is found to produce ionic displacement and surface charges which remained unchanged over a measuring period of 1000 hours. Annealing the crystal reduces the surface charge to zero, but restores the lattice only partially. It is concluded that potential traps play a role in the heterocharge effect.

X-RAY INDUCED PHOTOCO nductivity IN D I ELECTRIC FILMS

R.C. Weingart, R.H. Barlott, R.S. Lee, W. Hofer
IEEE Transactions Nucl. Sci. NS-19, No. 6, 15(1972)

Induced conductivity was measured in films of polyethylene, epoxy, polystyrene, polyethylene terephthalate, polyimide, and glass, by X-ray pulses of about 40 ns width, about 10 keV energy, and dose rates of $10^9$ to $10^{10}$ rad/sec. Films were 0.05 to 1.25 mm thick. Induced photocurrents were found to obey Ohm's law at biases up to 1 kV. Above this value, the peak conductivity from some of the 0.05 mm samples increases slightly more than linearly with the field. Glass samples exhibited no delayed conductivity, other showed various amounts, most the fluorocarbons, an effect compatible with some sort of field-assisted carrier generation (Poole-Frenkel effect). Magnitude and time dependence of conductivity signals could be quantitatively explained by a simple trapping model.
Charge Storage in Electron-Beam-Ion Polymer Films

J. E. Miley and G. R. Sokoloff, Bell Telephone Laboratories, Inc., Holmdel, N.J.-A variety of thin polymer films, such as polyethylene, polyethylene terephthalate, polystyrene, and polyisobutylene isopropylene (PIB) have been irradiated with monoenergetic electron beams in the energy range 10 keV to 1 MeV. As in related experiments, quasistationary charges of opposite sign on the two sides of the films are present after irradiation. It appears that the negative charges are trapped electrons. Charge densities, as measured by ionization methods, are initially of the order of $10^{-7}$ C/cm², decreasing to about $2 \times 10^{-8}$ C/cm² within a period of a few months. On PIB the remaining charge decays with a time constant of about 100 years at room temperature. At high relative humidity, water molecules absorbed in the polymer were found to (1) reversibly compensate the external field of the space charge by means of their dipolar characteristics and (2) cause an increase in conductivity leading to irreversible charge decay with time constants of 3 to 5 years on PIB at 35°C and 95% relative humidity.

TRANSPORT CONDUCTIVITY IN CAPACITOR DIESLECTRICS FOR GAMMA RADIATION PULSES

B. W. McKeen, H. Rutley, J. M. Ferry

IEEE Transactions Nuclear Sci. NS-10, No. 5, 131 (1963)

Reports on measurements performed with X-rays, gamma rays, and electrons, in mylar, Vitamin Q, fixed paper, ceramic, tantalum, and mica capacitors, for dose rates between $10^6$ and $10^9$ r/min and pulse widths from 0.2 to 11 ms. The conductivity current depends on the pulse shape and the form of the current-time curve for rectangular pulse shape. A superposition integral is given which would permit to calculate current forms for different pulse shapes provided the time dependence for rectangular pulses is exponential.

HIGH ELECTRIC FIELDS IN SILICON DIOXIDE PRODUCED BY CORONA CHARGING

R. Williams, K. E. Woods


SiO₂ films thermally grown on Si, with one free surface, were corona charged in air with about 7 keV. After charging, the surface potential (by means of a vibrating probe) and the current were measured. Both decrease with time, rapidly first, slowly later. When the current has dropped to $10^{-2}$ A/cm², the surface potential changes only a few $\mu$V per minute and the field across the oxide has become nearly stationary. This field $E_0$ is compared with the conventional breakdown field, noting that there appears to be no destruction of the sample in these experiments. $E_0$ is independent of the conductivity type and the Si doping level even when it is degenerate. When the free surface is charged negatively, $E_0$ is about twice as large as for positive values. Apparently the intrinsic dielectric strength ($7.9 \times 10^6$ V/cm) could be obtained. In the measurement the sample equals the incident current.
Radiation-Induced Currents in Solid Insulators

J.N. Winslow, R.S. Alger

USNR-216-343 (1959)

Photocurrents and currents induced by 250 keV and 2 keV X-rays in polyethylene films and pulse-induced transients in PTF cables were measured. Mostly a sandwich structure was used. Bulk conductivity, induced conduction, and Compton current were measured. Induced and Compton current were proportional to $\phi^2$, where $\phi$ was dose rate and 0.5 for $\phi$ being different for induced and Compton current. Subsequent values at room T were 4 A/m at 375 V/cm and 1000 A/m at 37 kV/cm and 1 kV/cm. Lower values are found at lower T. It is believed that at low T and low $\phi$ electrons are restricted to near their parents, while at high $\phi$ and high T they may escape permanently. Measurements of charges collected during pulsed operation showed strong polarization effect, decreasing for successive pulses. Both space charge and dipole mechanisms are operative.

A CONTROLLED-TRANSIENT TECHNIQUE FOR MEASURING RADIATION-INDUCED CONDUCTIVITY IN DIELECTRICS


Measurements under constant irradiation (60 rad/sec 60Co gammes) in fields below 50 keV, up to 1.5 krad, with polyethylene and polystyrene. Values are strictly proportional to inverse thickness, indicating existence of a bulk phenomenon. Appreciable transient effects were found when the voltage was changed stepwise. It is concluded that the conductivity measurements can give information on conduction mechanism and internal phenomena, related to it. Sensitivity to neutrons is surprisingly small.
RADIATION-INDUCED CONDUCTIVITY IN INSULATORS.


It is shown that experimental results from many sources are consistent with the relation \( \sigma = 10^{-15} \) \( \text{R} \) where \( \sigma \) is the reduced conductivity in \( \Omega^{-1} \text{cm}^{-1} \) and \( R \) the dose-rate in \( \text{rad min}^{-1} \). Polythene is an exception and the relation \( \sigma = \) is found to hold over a wide range of dose rate.

THE CONDUCTIVITY OF POLYTHENE UNDER GAMMA IRRADIATION.

H.J. Wintle
International Journal of Applied Radiation and Isotopes 8,132(1960)

The electrical conductivity of specimens of polythene film was measured in vacuo with and without gamma irradiation. The specimens were 0.005 in. thick, and silver electrodes were evaporated onto each side of the specimen to provide an intimate contact with the dielectric material. The measurements were made at about 25°C with a dose rate of 0.014 \( \text{Rmin}^{-1} \) from a small \( \text{Co}^{60} \) source, using an applied potential of 90 v. Data are tabulated and results are compared with previous measurements by others.

Reports influence of dose rate, rise time, decay time, and variations observed with different specimens. Rise and decay times were found to be of the same order, of the same hours. Conductivity increase was found to be proportional to a power of dose rate, with an exponent of the order of 0.8.

DIFFUSION RECOMBINATION IN POLYETHYLENE

H.J. Wintle
Nature 162,478(1963)

The decay of conductivity with time after irradiation has previously been interpreted in terms of a hyperbolic, bimolecular related recombination mechanism. In this note a diffusion controlled process, leading to first order kinetics, is proposed. In case of polyethylene, irradiated with 50 keV X-rays, at 1 - 10 \( \text{R/min} \), recombination is governed by a first order law during the first 10 min, later it becomes hyperbolic.

EXPONENTIAL TRAPPING AND CONDUCTION PARAMETERS IN POLYMERS

H.J. Wintle
Photochemistry and Photobiology 6,663(1967)

Photoconduction and gammaray induced conductivity can be interpreted by a model assuming an exponential interband distribution of trapping states.
DECAY OF STATIC ELECTRIFICATION BY CONDUCTION PROCESSES
IN POLYETHYLENE

H.J. Wintle

Paper develops the theory of transfer of charge from an
electrified (charged) surface layer through the bulk of the
dielectric for transient space-charge limited current con-
ditions. The inclusion of ohmic conduction and of diffusion
is discussed. Comparison with data for polyethylene indicates
carrier mobilities of the order of $10^{-11}$ cm$^2$/V sec at room
temperature.


DECAY OF EXCESS CHARGE IN DIELECTRICS HAVING SHORTED
ELECTRODES

H.J. Wintle
J. Appl. Phys. 42, 4724 (1971)

New equations are derived for the discharge of dielectrics
having an arbitrary initial charge and shorted electrodes.
The case of an initial charge distribution which is uniform
down to a given depth $y$ is discussed in detail, including
under non-isothermal conditions. It is shown that only a
small fraction of the initial charge can be observed in
the external circuit while a greater fraction is retained
in the specimen when the external current flow ceases.

SURFACE-CHARGE DECAY IN INSULATORS WITH NONCONSTANT LOCALITY
AND WITH DEEP TRAPPING

H. J. Wintle
J. Appl. Phys. 43, 2927 (1972)

Motion of charge initially deposited on the free surface of
an insulator is studied. Results are given for a) mobility
proportional to a power of the field b) proportional to a
power of the free-carrier concentration c) fast deep trap-
ing going to completion (e.g. until all carrier traps are
filled). After one transit time the surface voltage becomes
a unique function of time. Polyethylene results do not fit
this scheme, discrepancies are discussed. The observation
of thermally stimulated currents in thin-film electrets
implies that they are electrically inhomogeneous.

The treatment of deep trapping assumes instantaneous trapping
to level given by number of deep traps, rectangular distri-
bution, and refers to case where leading-edge has already
reached electrode. The situation before this has happened
was treated by Many and Rakavi, Phys. Rev. 126, 1960 (1962)
A variety of experiments are carried out. Positive and negative currents are observed. Each of the positive peaks in the current spectrum must indicate a discrete population of charge carriers which, in the absence of an applied potential, is able to diffuse at a certain temperature of the matrix with consequent neutralization or deeper trapping. In the presence of a potential the trajectories induced by random thermal motion, and perturbed by the trapped charge in the matrix, are altered to give a component in the direction of + and − charge which is recorded as a current flow. Reduction of the current by blocking electrodes indicates loss of electrons from the sample at the anode and gain at the cathode when they are not blocked. The residual current in the presence of blocked electrodes indicates space-charge build-up competing with neutralization as the sample warms. In the presence of blocking electrodes the average distance of charge movement in the system is about \( \frac{1}{5} \) of that with conducting electrodes.

Resin-carnauba-wax electrets have been irradiated with a Co\(^{60}\) source in a shorted condition. The decrease of the surface charge, measured by an induction plate method, is used for dose determination. Charge decreases exponentially with dose, but the reduction is found to be of temporary duration, the charge recovering within about 2 weeks. It must be concluded that the effect is mainly due to the air gap still existing between dielectric and covering metal foil.

Self-powered neutron detector testing in the Big Rock Point Reactor

H. B. Worsham, Jr. (Saboorock and Willcox)

Measurements are reported for normally incident electron beams in the 1 - 3 keV range. A maximum backscattering to incident number ratio of 0.47 was found for U, and a minimum of 0.1 for Be with 1 keV electrons. The energy relation was also determined, by a calorimetric method.

The suggestion is made that the maximum potential in an electron bombarded dielectric due to the trapped electron charges may exceed the accelerating potential.
TRANSIENT EFFECTS OF INDUCED CURRENT IN POLYMER INSULATION UNDER IRRADIATION OF AN HIGH ENERGY ELECTRON BEAM

K. Yahagi
Waseda Daigaku Rikogaku Kenkyusho Hokoku No.24,49(1963)

Electric conductivity was measured during and after irradiation of polymers (polyethylene and polytetrafluoroethylene) by electrons from a Van de Graaff generator. A space charge field was observed by measuring the global charge of the specimens after irradiation.

INSULATION RESISTANCE IN POLYETHYLENE AND TEFLOM UNDER GAMMA-RAY AND ELECTRON-BEAM IRRADIATION

K. Yahagi, K. Shinohara, K. Mori

Characteristics of teflon change abruptly at about 45°C which is a phase transition point.

GAMMA-RAY INDUCED CONDUCTIVITY IN POLYETHYLENE AND TEFLOM UNDER HIGH DOSE RATE

J. appl. Phys. 34,804(1963)

K. Yahagi, A. Ianno

Measurements with Co^{60} radiation are reported for conductivity as a function of dose rate, temperature, and applied voltage. It is concluded that above 230°C charge carriers are thermal electrons and below that temperature fast electrons.

IRRADIATION OF POLYETHYLENE AND ELECTRICAL CONDUCTIVITY.
THE BEHAVIOR OF CARRIER TRAPS IN POLYETHYLENE UNDER GAMMA IRRADIATIONS.

K. Yahagi, K. Shinohara
HYDROCARBON LIQUIDS


Measurements on n-Hexane are reported. Dark conductivity depended on treatment (filtering and distillation) of the liquid, the untreated liquid giving a conductance of 10⁻¹⁶ ohm⁻¹cm⁻¹ and the treated one a value 10 times lower. Radiaton-induced conductivity using Co gamma rays with a flux of 3x10¹² ev/cm²/sec, was approximately the same for both liquids. This shows that the dark current is due to impurity charge carriers, while the photocurrent is due to carriers produced in the bulk of the liquid by photoionization. Currents showed the typical transient behavior found also in solid dielectrics. A theory is developed taking into account recombination and diffusion. This gives for the current an expression of the form

\[
I = \frac{1}{1 + b_0 e^{-\frac{l}{k \tau}}} \quad \frac{1}{b}
\]

where \(q_0\) is the state-state space-charge density, \(k\) and \(b\) are constants.

ELECTRIC CHARACTERISTICS OF GAMMA-RAY IRRADIATED SHIELDING WINDOW GLASS.

Yamamoto, K., Tsuchiya, M.
J. Appl. Phys., 33, 3016 (1962)

Induced color and electrical resistance of shielding window glass exposed to Co⁶⁰ gamma irradiation are investigated. A high density and a medium density glass are used, with exposure doses between 10⁴ and 10⁶ roentgen. Time-dependent currents are observed. Resistance of medium density glass is lowered by irradiation throughout the whole dose range; resistance of high density glass is first lowered, reaching a minimum for 10⁶ roentgen and increasing afterwards. The quantity of induced space charge by radiation is obtained as a current-time integral. Space charge distribution is also calculated.

EFFECTS OF ELECTRON IRRADIATION ON CONDUCTIVITY IN CdS. Yoshida, Toshio; Kitagawa, Michiharu; Fujino, Takahiro (Radiation Center of Osaka Prefecture, Osaka)

Variations in radiation-induced conductivity of two different types of CdS single crystals near liquid-nitrogen temperature during 5-MeV electron irradiation were investigated. The conductivity of a high-conductivity crystal is increased, and that of a low-conductivity crystal is increased with irradiation. Both conductivities come nearer to each other and seem to approach a limiting value as irradiation is continued. Two possible interpretations for the experimental result are presented. (auth)
In: Radiation Effects in Electronics.ASTI: STP 304 (1966)
( ASTM Special Technical Publication )

Observations on post-irradiation conductivity, thermal charge release, and luminescence are presented. Then electron-irradiated samples are heated, discharge currents are observed. The effects and threshold temperature for onset of currents strongly depend on heating rate. The slower the heating rate, the higher the temperature where effects start. The currents show a series of peaks indicating a band structure for the trapped electrons.

Electron and neutron irradiation generates an electric field mainly by polarization. Assume a dielectric with constant filling the space between two conducting electrodes of radii $r_1, r_2$. The cable is irradiated by gamma from one side, average range of Compton electrons being $d$. A positive ion remains at the site where an electron is knocked out by gamma interaction. On irradiation with neutrons a recoil proton is knocked out. The volume charge density is found to be constant given by $Q = -C \cdot q \cdot A / \Delta s^2$, where $q$ the absolute value of electron charge and $s$ the range of gamma, $J$ their number/cm$^2$, $N$ the number of absorbed gamma necessary to produce 1 Compton electron. Equations are developed for total charge $Q$ per cm of cable length. A formula for the p.d. between the two surfaces is derived. Charge buildup as a function of time is taken into account.

Electron Bombardment of MOS Capacitors
K.H. Zaininger
IRRADIATION OF MIS CAPACITORS WITH HIGH ENERGY ELECTRONS
K.H. Zaininger
MIS capacitors consist of an n- or p-type semiconductor, covered
by a thin insulator film (often oxide) with a metal electrode
on top. Such devices were irradiated with 0.125 to 1 MeV elec-
trons at 25°C. Effects were investigated with C-V measurements.
C-V, and G-V curves were found to be shifted toward more ne-
gative bias indicating the introduction of a positive charge
into the oxide and/or into interface states. Irradiation was
also performed without applied bias, for both uncovered and
metallized SiO₂ films. Above a certain fluence the effect becomes
linear and eventually saturates. The spatial location of the
charge was determined by stepwise removal of a layer of oxide
with a buffered SiO₂ etc., thickness determined by ellipsometry.
It shows almost all positive charge located within 100 Å of the
SiO₂-Si interface which is the region from which radiation-ex-
cited electrons can escape even in the absence of an applied
bias. Situation was different for irradiation under bias, depend-
ing on bias polarity. Dry oxides generate a higher density
of positive charge than steam (or anodic) oxides. Successive
bombardments changed little. Annealing of the charges, which at
room temperature are very stable, takes places between 150°C
and 300°C. Radiation annealing of previously positively biased and irradiated samples takes also place. It
is believed that the radiation-generated holes diffuse in the
insulator and recombine with electrons, but many are captured
into stationary states, giving rise to the observed positive
charge. Holes that are neither trapped nor recombine are neu-
tralized at the metal or the Si. Predominant trapping of holes
has also been observed (for SiO₂) in electron-spin resonance
studies of gamma-irradiated silica, during photo-injection
of holes and electrons into SiO₂ films, and during anodic
oxidation of silicon. If no electric field is present during
irradiation, the major effect will be electron-hole recombi-
ation, only a relatively small number of holes being trapped
and little change being induced. In a bias-bombardment experi-
ment, electrons will readily move out of the insulator under
the field and hole trapping is enhanced.

High-voltage polarization in micas was studied, together with the effect of \( \beta \) radiation on such phenomena. Construction of the apparatus permitted measurements to be made in a vacuum and over the temperature range 20 to 1100°C. The source of \( \beta \) particles was an electrostatic generator operating at 1 MeV and 1 \( \mu \)A. Samples included muscovite, biotite, and phlogopite. It was noted that the emf of high-voltage polarization in micas was quite significant up to 1000°C, a factor to be considered in dc conductivity measurements. Under the influence of \( \beta \) radiation, water was evolved from the mica crystals as a result of radiolysis, and molecular bonds were strengthened. This accounted for a decrease in the emf maximum of high-voltage polarization in the temperature range 850 to 900°C. (K.S.W.)


Short-duration light pulses accompanied by current pulses were observed on warming KDP crystals x-ray irradiated at 77°K. The pulses start a few degrees above the transition temperature \( T_c = 123°K \) and continue until about 200°K. The pulses appear only under ambient gas pressures above about 0.1 torr. Warming of the irradiated crystal to an intermediate temperature between \( T_c \) and 200°K causes only a partial exhaustion of the pulses, and after cooling and reheating pulses appear only above the temperature reached in the former cycle. The pulses originate from discharges into the surrounding atmosphere. A simple model is given to account for the experimental results. (auth)


Effects of low intensity radiation on reversible polarization processes were studied. Both increases and decreases of relaxation and loss were observed.