JP0450230

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Development of RISA (Radiation Induced Surface Activation) Detectors for Onsite Sensing and Microdosimetry

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Abstract

We investigate a new technique for radiation detection using radiation induced surface activation (RISA) phenomenon which is found in oxide materials (with high resistivity) causing current conduction through the irradiation of gamma or beta rays. The RISA current has been observed typically in Rutile-type TiO_2. We have performed a Monte Carlo simulation of gamma ray photons in TiO_2 and backing layers to make clear carrier generation processes leading to the conduction and to develop new type detectors for onsite sensing and microdosimetry. Results show that the dominant process to generate electron-hole pairs in thin TiO_2 layer is collisional interaction of electrons generated in backing layer, which suggest the RISA detector can be used for estimating the absorbed dose in bio-materials.

KEY WORDS: Radiation induced surface activation, TiO_2, Backing layer, Onsite sensing, Dosimetry

1. Introduction

Radiation induced surface activation (RISA) is a phenomenon observed in oxide materials of high resistivity, which causes current conduction through the irradiation of gamma or beta rays. One of the authors found the RISA current induced in Rutile-type TiO_2 film for the first time [1], and the conduction current has been detected also in some other oxide materials [2,3]. However, the mechanism leading to the conductivity has not been understood yet. Figure 1 shows a typical configuration of RISA detector. Radiation is normally incident on TiO_2 surface backed by Al_2O_3 layer. As is reported by Ref. [1], conductance of TiO_2 films reaches several pS (pico-siemens) with gamma ray irradiation of kGy/h intensity. This conduction may arise from electron-hole production and the carrier flow in TiO_2 layer. However, direct excitation of the layer by gamma ray irradiation is not feasible because the TiO_2 layer is so thin that gamma ray photons can penetrate without any interactions. Major possibility of producing electron-hole pairs may be attributable to the excitation by electrons generated in Al_2O_3 layer.

In this study, we simulate gamma ray interactions in the RISA detectors by a Monte Carlo method of photons to investigate the carrier generation processes. Then we seek appropriate conditions to design new type detectors using RISA for onsite sensing and dosimetry.

2. Methods

To examine the processes occurring in the RISA detector, we perform a Monte Carlo simulation of ^{60}Co gamma ray photons and estimate the production rate of secondary electrons in the layers. In the Monte Carlo simulation, we consider three interaction processes: coherent scattering, incoherent scattering and photoelectric effect. The collision interaction cross sections for these processes are taken from Storm and Israel (1970) [4], and the scattering factor for incoherent scattering and the atomic form factor for coherent scattering by Hubbell et al. (1975) [5] are incorporated in the simulation code. A large number of photons (> 2000000) is followed in the Monte Carlo method until the photon energy comes down below a cutoff value (typically 1keV).

In addition to the simulation with TiO_2 and Al_2O_3 layers, we also take TiO_2 and $C_5H_8O_2$ (Lucite) substrate into account. $C_5H_8O_2$ is a typical tissue equivalent (TE) plastic, and if the conduction of TiO_2 is associated with the physical process in backing material, $C_5H_8O_2$ can be a bio-tissue substitute for sensing the absorbed dose. We evaluate the possibility for a dosimetric use of RISA detector by this model analysis.

3. Results & Discussion

Figure 2 shows energy distribution of electrons generated by photon processes in the 4×4cm TiO_2 and Al_2O_3 layers. The thickness of TiO_2 layer was set to be 0.25μm and three cases of the thickness for Al_2O_3 backing substrate, 0.05, 0.1 and 0.15cm, were adopted in the simulation. As was expected, the frequency of ^{60}Co gamma ray interaction with TiO_2 layer was extremely low compared to that with Al_2O_3 layer. It was also found that the electron generation is mainly caused by the Compton scattering (>99%). In regard to the distribution in Fig.2, it should be pointed out that the maximum energy of electrons (i.e., the Compton edge) is given by

$$K_{max} = \frac{2\alpha}{1+2\alpha}E_0 \quad \left(\text{where } \alpha = \frac{h\nu}{0.511}\right) \qquad (1)$$

for the incident photon energy $E_0(=h\nu)$ in MeV (1.33MeV and 1.17MeV for ^{60}Co gamma ray). The electron energy distribution for TiO_2 and $C_5H_8O_2$ layers is given in Fig.3 as well. We can see that the production rate of electrons in this combination of layers is almost one third of that in TiO_2 and Al_2O_3 layers. This ratio may be originated by the difference of mass density between $C_5H_8O_2$ and Al_2O_3, $1.18g/cm^3$ and $3.80g/cm^3$, since the interaction cross sections for both the materials are almost same in quantity.

Next, we investigated possible processes to induce a current conduction of TiO_2 through the reaction associated with electrons produced in the photon process. Rutile-type TiO_2 possesses the energy band structure for electrons with gap energy of 3.0eV, and there are supposedly two courses to generate electron-hole pairs in TiO_2 layer: collisional excitation by electrons and optical pumping by bremsstrahlung photons arising from the straggling motion of electrons. Figure 4 shows range of electrons taken from Ref.[6]. The range for several hundreds keV electrons is roughly from 0.01cm to 0.5cm, which is comparable to the thickness of backing layer. This means that a large number of electrons can reach TiO_2 layer to activate it. Especially the electron range in $C_5H_8O_2$ is several times larger than that in Al_2O_3, which may be advantageous for activating TiO_2. On the other hand, the energy transfer to bremsstrahlung emission can be estimated by bremsstrahlung yield. We determined the ratio of bremsstrahlung radiation energy to total energy of electrons using the following equation:

$$R = \frac{E_{rad.total}}{E_{elec.total}} = \frac{\int E \cdot Y(E) \cdot N_e(E)dE}{\int E \cdot N_e(E)dE} \qquad (2)$$

where E is the electron energy, $N_e(E)dE$ represents the number of electrons between E and E+dE, and Y(E) is the bremsstrahlung yield. In the present study, $N_e(E)dE$ was taken from the energy distribution in Figs.2 and 3, and Y(E) from Ref.[6]. The result is given in table 1 to show that the energy ratio transferring to bremsstrahlung is 10^{-3} order of magnitude. This number seems to be slight, but is sufficient to give a portion of energy for making photons contribute to optical pumping of TiO_2 layer (e.g., several hundreds eV of total energy is given by bremsstrahlung radiation per electron with 100keV kinetic energy).

4. Conclusions

As the provisional conclusion, we summarize the results that RISA phenomenon is primarily caused by the behavior of electrons generated by the Compton scattering in substrate layer. It is likely that the Compton electrons can activate TiO_2 layer though the collisonal excitation and the bremsstrahlung emission. Accordingly, it should be emphasized that substrate (backing) layer is essential in the RISA detector and if the layer is made of tissue equivalent (TE) plastic we can use this for dosimetric monitors in radiology. Natural modification of the detector geometry would be favorably made into a spherical shape for measuring the fluence and the absorbed dose of radiation.

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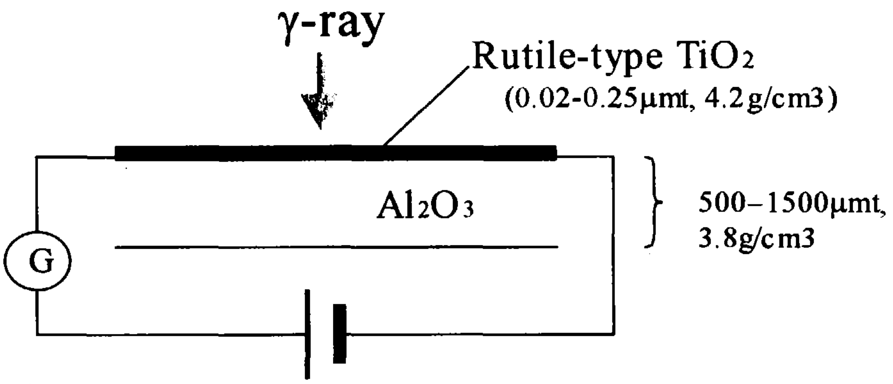

Fig.1 Schematic description of typical RISA detector

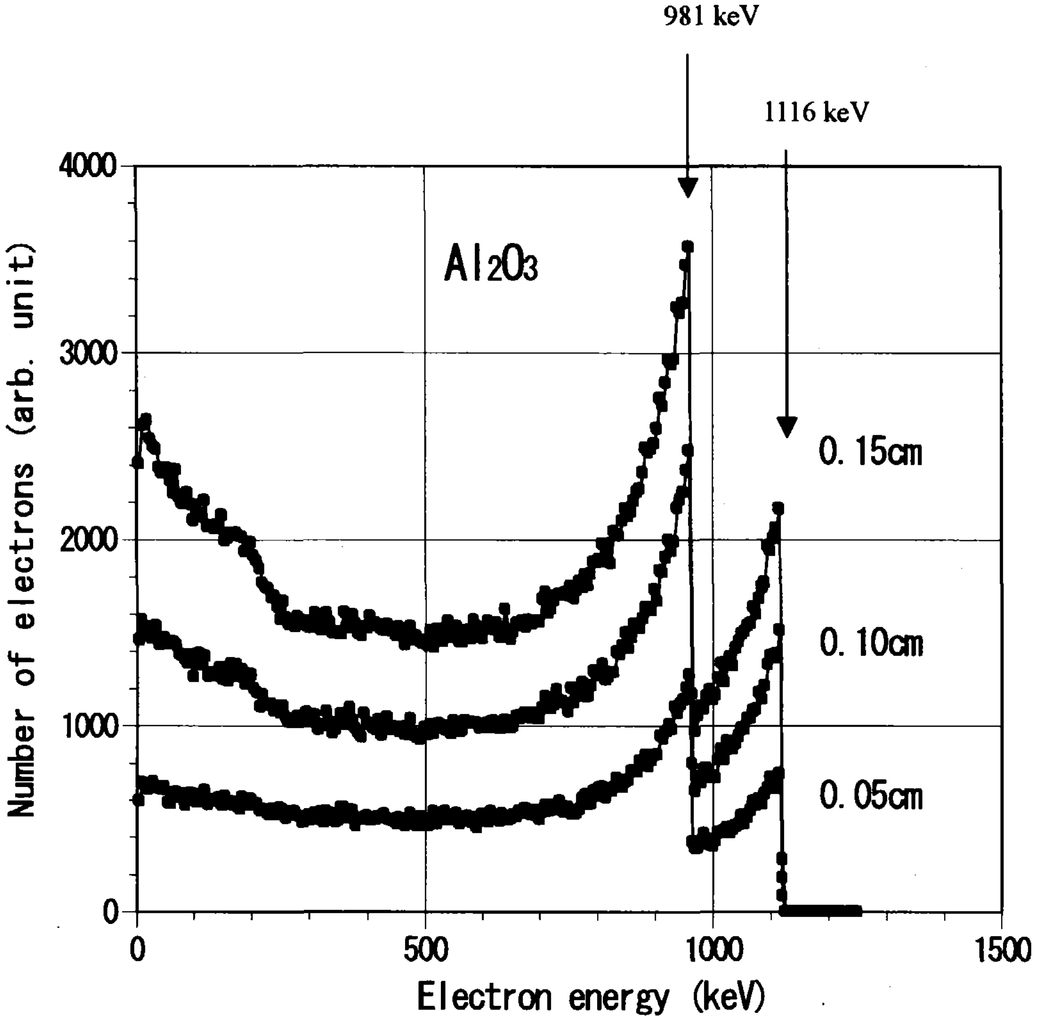

Fig.2 Energy distribution of electrons generated by photon processes in TiO_2 and Al_2O_3 layers

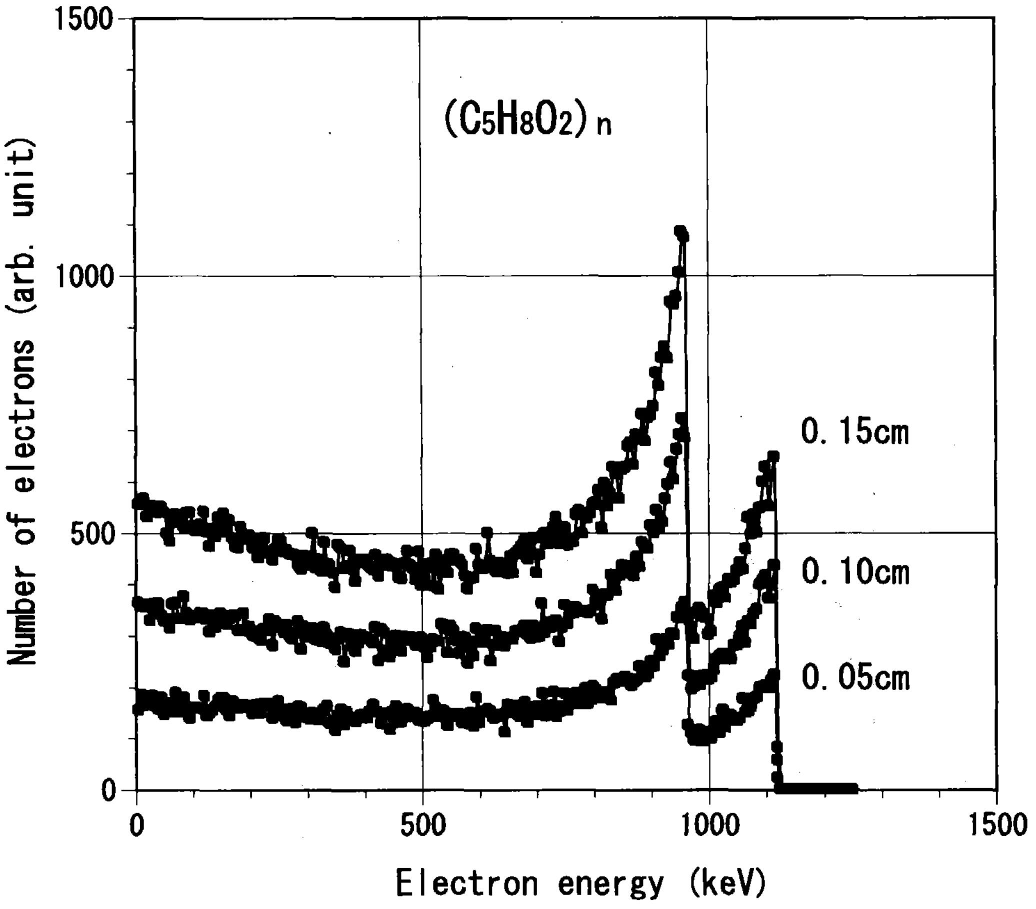

Fig.3 Energy distribution of electrons generated by photon processes in TiO_2 and $C_5H_8O_2$ layers

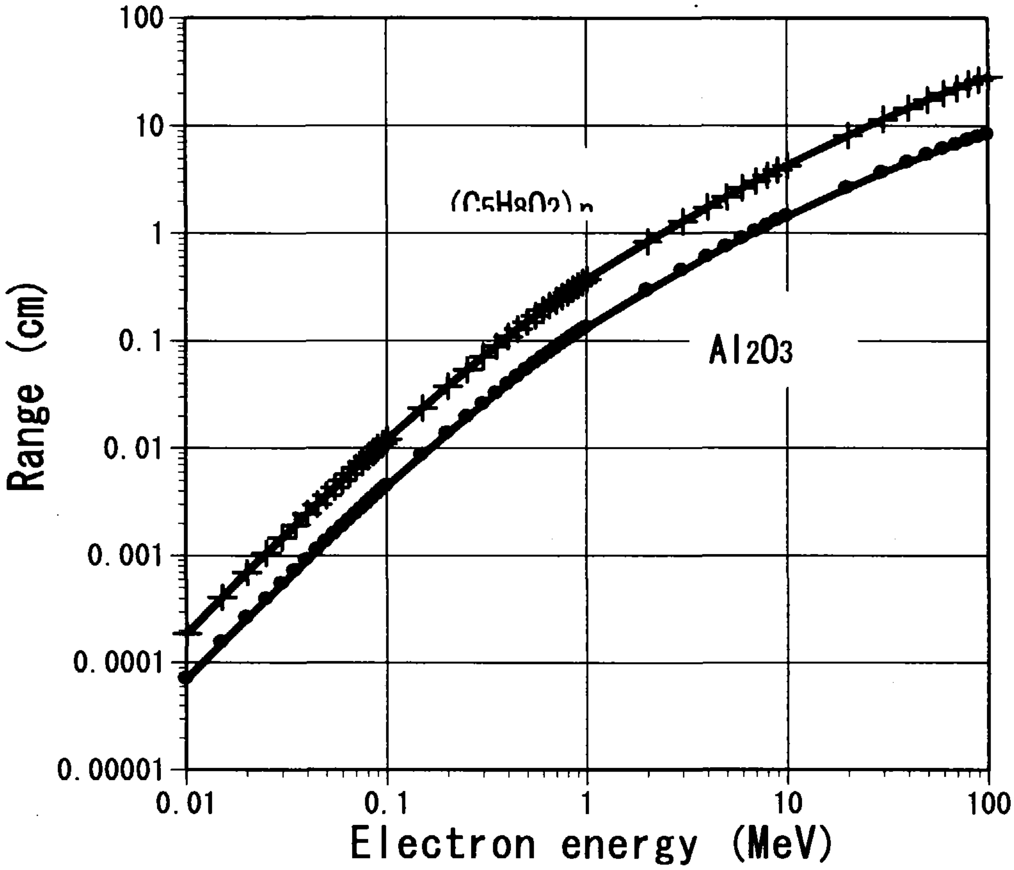

Fig.4 Range of electrons in $(C_5H_8O_2)_n$ and Al_2O_3 (Ref.[6])

Table 1. Ratio of bremsstrahlung radiation energy to total kinetic energy of electrons

	Al_2O_3		
Thickness (cm)	0.05	0.10	0.15
R	6.82E-03	6.78E-03	6.77E-03

	$(C_5H_8O_2)_n$		
Thickness (cm)	0.05	0.10	0.15
R	3.54E-03	3.53E-03	3.53E-03