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IONIZING RADIATION EFFECTS ON IMPLANTED PACEMAKERS

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1. Introduction

The medical treatment of patients having cancer requires in more than 50 % of the cases radiotherapy. Some of these Patients have implanted pacemakers; every year approximately 30 patients with implanted multi-programmable pacemakers are treated in Vienna University Hospital.

Since most pacemakers are implanted in the „fossa infraclavicularis", special care has to be taken when irradiating this region. A high percentage of these patients are women with carcinomia of the mamma. Some scientific papers report functional disorder or complete destruction of pacemakers due to the accumulated absorbed dose, whereas the clinically administered dose should still be much higher for adequate radiation therapy of this kind of cancer. Functional disorders were already observed at doses of 2 Gy !! (Marbach [1]).

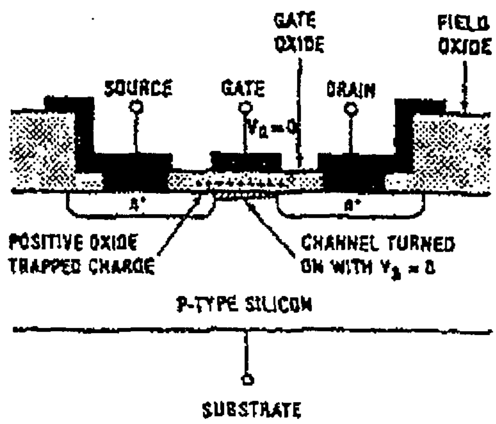
2. Theory

From the historical and technological point of view, three kinds of pacemakers were developed and sold on the market: The first type of pacemaker to be designed was equipped with bipolar technology, while the second type combined the bipolar and CMOS-technology (complementary metal oxide semiconductor) and the third type was a monolithic CMOS pacemaker. The main components of the electronical circuits are transistors which are designed in the classical bipolar technique (emitter, collector, base) or in more advanced field effect technique (MOSFE-transistors).

The advantages of the first type mentioned are the following: Pacemakers incorporating bipolar components only were very resistant against ionizing radiation (up to 1400 Gy accumulated dose Vencelaar [2]).

The following characteristics are to mentioned about the second type: Pacemakers based only on CMOS-devices were cheaper and needed less electrical energy. First generation equipped with CMOS-devices had an 8μm isolating gap (gate oxide), while the following generations had gaps with 5 and 3μm. Investigations carried out by McGarrity [3] showed, that this gap is responsible for permanent malfunctions of MOSFETs when irradiated with ionizing radiation, self-repairing effects are not significant and can be neglected. Functional disorder during irradiation is not expected and was never reported. The reason for this is the respectably low doserate in radiotherapy.

Figure 1. Charge distribution within the MOSFET after irradiation



Within the isolating Si- or Ge-Oxide-Layer, electron-hole pairs are produced during irradiation. Some holes are transported through the oxide layer by means of „hoping transport" without recombination with electrons, while few holes are permanently trapped near the metallic gate contact, known as deep-hole-trapping. This trapped charge induces a voltage between the metallic contact and the inversion channel on the other side of the oxide layer. This mechanism is similar to that of a capacitor, where the space between the two contacts is filled with isolating material. Assuming that the charge on the capacitor is kept constant, the voltage has to increase in accordance with the increasing distance.

The characteristics of the whole device is influenced by the permanently trapped charge in the MOS-FET. In the worst case a n-channel-MOSFET is permanently in conducting state even without gate voltage.

The comparison with the capacitor explains the following findings: Cardiac pacemakers based on 8μm technology are more radiation sensitive than 5μm CMOS pacemakers, and these are more sensitive than 3μm based pacemakers. The same charge in a grater distance to the inversion channel produces more voltage thus increases the possibility of pacemaker failure.

3. Experiments

14 multiprogramable pacemakers and 2 intercardial defibrilators were exposed to Co-60 radiation (Theratron 780C), to 9 MeV electrons and to 6 and 10 MV photon radiation (GE Saturne 43 LINAC). The pacemakers were placed into a water phantom, 0.5 cm under watersurface and with 25 cm of water below to allow for backscatter. The irradiation was carried out similar to patient treatment. The dose was given in fractions of 0.5 Gy in time intervals of 120 seconds, based on the conclusion of McGarrity's investigations on relaxation time of MOSFET's receiving short irradiation pulses.

Pacemaker	Maximum Dose [Gy]
CO-NEOS	80
CO-RELA	12,5
CO-MICD	80
CO-META	90
CO-SENS	100
X6-DROM	> 25
X6-MINI	100
X6-SENS	100
X6-AURO	100
X10-NEOS	100
X10-MICD	60
X10-META	80
X10-VITA	12,5
E9-TRIO	12,5
E9-ACTI	17,5
E9-SENS	100

The following parameters of the pacemakers were checked: telemetry, battery, pulse frequency, pulse amplitude and period at an accumulated dose of 2, 5, 7.5, 10, 12.5, 15, 17.5, 20, 25, 30, 35, 40, 45, 50, 55, 60, 70, 80 and 100 Gy.

Each one of the following facts entailed the failure of the pacemaker: 20% deviation from the set data; complete breakdown of telemetry; 10% deviation from adjusted pulls frequency; low battery after irradiation. 10 pacemakers functioned satisfactorily up to 80 Gy, 3 reached 15 Gy and 3 could not stand much more than 10 Gy.

4. Conclusion

According to our measurements and the literature the following conclusions can be drawn: Pacemakers in CMOS / Bipolar technology should not be exposed to an absorbed dose of more than 5 Gy, the same dose limit applies to pacemakers in 8μ CMOS technology, the latest generation of pacemakers in the 3μm technology will function satisfactorily to an absorbed dose of up to 70 Gy (Holzer [4]).

5. References

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