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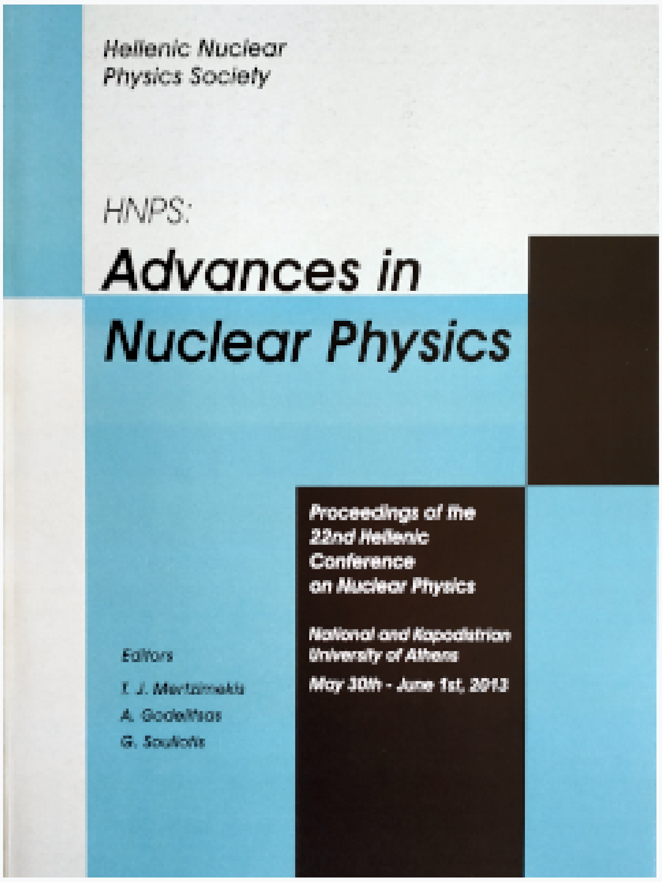

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A STUDY OF THE RESPONSE OF DEPLETED TYPE p-MOSFETs TO ELECTRON DOSE

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Abstract

The p-MOSFET dosimeter studied in this work has been manufactured at LAAS-CNRS Laboratory in Toulouse France, for applications in personal and space dosimetry. They are proposed for proton, heavy ions and electron and photon dose measurements. The current study investigates the sensitivity of this new type of Metal-Oxide-Semiconductor field effect transistor (MOSFET) to electrons. The sensitivity of the new MOSFET based dosemeters to electrons is linear for wide dose ranges. The influence of the electrons energy on the dosemeters response is also investigated.

1. Introduction

Silicon is an active material of radiation detectors and the basic material of electronic devices used in the fabrication and development of electronic circuits. The present technology is evolving towards the creation of faster and less power consuming devices of increasingly small sensitive volume and higher density circuits, achieving new submicron technology with an increase in the number of the memory elements. These devices are then used for applications in several fields including particle physics experiments, reactor physics, nuclear medicine and cosmic rays and trapped particles of various origins in interplanetary space and/or Earth magnetosphere. The continuous evolution of mission requirements and their electronic technologies for spacecraft, combined with the need to meet the space environmental constrains, particularly radiation constitutes challenges for component engineers and designers, especially for space craft dosimetry [1].

In medicine, Diagnostic Radiology often involves the use of ionizing radiation to acquire images for disease diagnosis and treatment. Recent advantages in imaging technology have led to an increase in the use and application of medical imaging. There has been, so, an increase in population radiation dose as a result, related to the exposure of patients during routine examinations.

Among the wide variety of radiation detectors available for dose measurement the most commonly used include Thermoluminescent dosimetry (TLD), Silicon Diodes and Metal-Oxide-Semiconductors Field Effect Transistors (MOSFETs). The MOSFET dosimeter advantages, in comparison with other dosimetric systems include immediate read out (real time measurement) of the dosimetric information while they can be used in passive mode. They have extremely small size of the sensor element, wide dose range, very low power consumption and they present compatibility with microprocessors.

This work refers to the study of electron's dosimetry by p-MOSFETs. The dosimeter has been used to neutron measurements with appropriate converters [2]. The interest of electrons to measure radiation dose from electrons is mainly due to their application in medicine and space activities. The first application referred to the fact that small superficial cancerous lesions are typically treated with electrons. Accurate dosimetry of such small electron fields requires dose measurements with small area detectors, as the MOSFETs detectors. The performance of such detectors is crucial, [1,3]. The second application of MOSFETs to space dosimetry concern to the possible biological effects induced by electrons. Electrons have a considerable contribution in the outer radiation belt of Van Allen belts region inside the Earth magnetosphere having energies distributed up to 10 MeV. In the inner radiation belt there are fewer electrons, of lower energy, up to 0.5 MeV. Although the radiation weight factor is low, they release radiation dose mainly for missions of long duration and during extra vehicular applications.

2. Experimental

The p-MOSFETs used in the present study are of depleted type and were fabricated at LAAS-CNRS, Toulouse, France, following a process designed for improving both sensitivity to radiation dose and stability [4]. The sensitivity of the dosimetric system is one of the main objectives when designing MOSFETs for radiation dosimetry purposes. One of the possible ways to enhance the sensitivity is by increasing the gate oxide thickness [4,5]. For this reason the MOSFETs used in this study they have fabricated with thick gate insulator of 1.6 μm. They have 3 μm of LiF deposited on the surface of the MOS gate as they have been studied for neutron dosimetry [1,6]. The devices can operate as a real time as well as passive dosemeter with high performance. A compact automated configuration based on a microcontroller, a memory, A/D converters and a custom designed chip to implement all other needed functions has been designed. The high sensitivity system is being able to measure the threshold voltage shift due to radiation dose with precision of the order of 100 μV.

A block diagram of the complete system is shown in figure 1. A number of circuits have been integrated in one chip. The chip has been fabricated with an appropriate technology offered by EUROPRACTICE organization and tested experimentally at the Electronics and Computer Laboratory of the University of Thessaloniki.

The p-MOSFET devices were irradiated with electrons at the Linac of Anticancer Theageneio Hospital of Thessaloniki. The beam was collimated in circular shape of 4cm in diameter and was oriented perpendicular to the SiO_2 surface. The irradiations were performed at the isocentre. The response of the device was studied at 6, 8, 10, 12 and 15 MeV electrons with a dose rate of 1 Gy/min. Measurements were taken with the device operated in real time mode.

An automated instrumentation configuration based on a microcontroller [7] retained the time of the run as well as the threshold voltage V_T at each time of measurement. The storage of measurements was set to every second. The dose induced in SiO_2 was calculated according to the time recorded and the dose rate given, at the same time, by the accelerator monitor.

3. Results and discussion

Radiation creates electron-hole pairs in the gate oxide, electrons are swept of the gate oxide, but the holes drift towards oxide/Silicon interface and get trapped near the interface, giving rise to oxide charge and interface traps. The trapped charges affect the gate voltage by reordering of charges. The measurement of the shift of the threshold voltage is proportional to the absorbed dose [1,5,6,8]. The threshold voltage shift, ΔV_T, which is the measured quantity, depends upon: a) the incident particle type and energy (dE/dx) b) the ionizing particle penetration into the oxide c) the absorbed dose, D, d) the gate bias during irradiation and e) the gate insulator thickness.

For this exposure mode, usually called **zero bias mode**, the expected response of the voltage shift ΔVT can be expressed in the form [1,6,8]:

$$\Delta V_T = aD^b$$

The quantity ΔV_T indicate the difference V_T-V_{To}, where V_T and V_{To} are the pre and post irradiation threshold voltage respectively. The power **b** is connected to the degree of linearity. Parameter **b** depends on the oxide thickness, the electric field and absorbed dose [9]. In the case where parameter b is close to the unity, the behavior of ΔV_T relative to the absorbed dose is linear thus the parameter **a** represents the sensitivity of the MOSFET dosemeter. Parameters a and b have to be determined experimentally. In table 1 parameters a and b corresponding to the conditions of the present experiment are given. The values of the parameters are derived by fitting the experimental points, for each energy of electrons, as there are shown in figure 2.

Table 1. The values of the p-MOSFETs response and their degree of linearity versus electron dose.

E, MeV	**a, mVolt/Gy**	**b**
6	66.20 ± 0.11	0.96 ± 0.01
8	91.36 ± 0.08	0.95 ± 0.01
10	101.93 ± 0.08	0.95 ± 0.01
12	124.43 ± 0.76	1.03± 0.02
15	177.36 ± 0.76	1.02 ± 0.03

The depleted type of p-MOSFET dosemeters presents a similar response to photons and electrons of few MeV [10]. The results can be understund considering the interactions of photons with matter, finally be absorbed via electron energy loss. The response of these dosemeters is about 2 times higher than the response of the MOSFETs dosemeters presented in literature, which are enhancement type MOSFETs [11]. This response can be increased even more, about one order of magnitude, if a biased applied in the source of the dosemeters during the irradiation. Although the response to electron dose is higher than published in literature, an increase with electron energy is observed, Fig 3. This effect presented in thick detectors, relative to the electron range, is connected to the stopping power of electrons. Indeed as it can be shown in figure 4 presenting the stopping power of electrons as a function of the electron energy [12], the response of the p-MOSFETs follow the increase of the stopping power curve above about 10 MeV. For lower energies, 1-10 MeV, the response is presented flat according to the stopping power curve. However, a flat response which is not connected to the electron/particle energy is preferable for dose measurements especially in poly energetic field of electrons. In medical applications the energy of electrons is defined with accuracy so the knowledge of the response in that energy overcome the energy dependence of the response and the increase of detector thickness presented as an advantage of the device giving the possibility for increasing the response.

4. Conclusion

The response of the depleted type of p-MOSFET dosemeters is about 2 times higher than the response of the MOSFETs dosemeters presented in literature, which are enhancement type MOSFETs. This response can be increased even more, about one order of magnitude, if a biased applied in the source of the dosemeters during the irradiation. Their sensitivity as a function of the dose is linear for wide range of doses. Additionally presents a linear behavior as a function of electron energy. This result is in contradiction with the results presented in literature obtained with MOSFET dosemeters of enhancement type and without any converter. This effect is connected to the stopping power of electrons.

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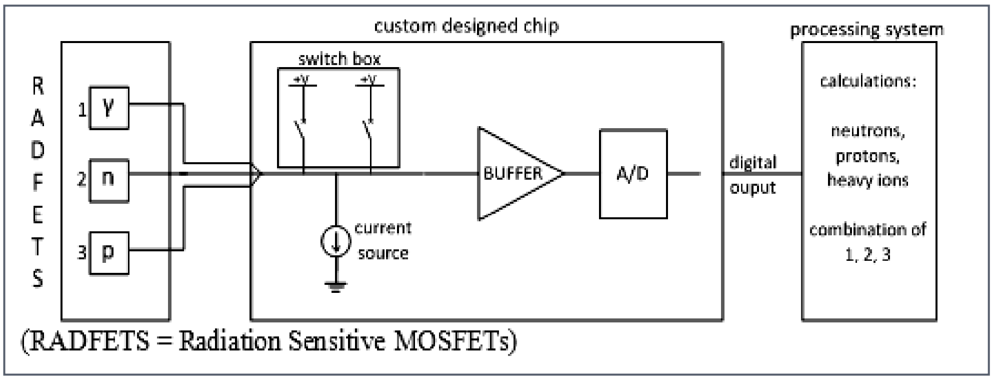

Figure 1. A block diagram of the complete system

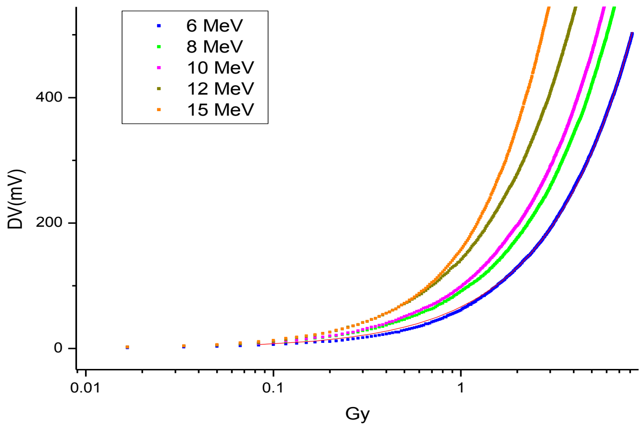

Figure 2. The response of the dosemeters as a function of the dose for various electron beam energies.

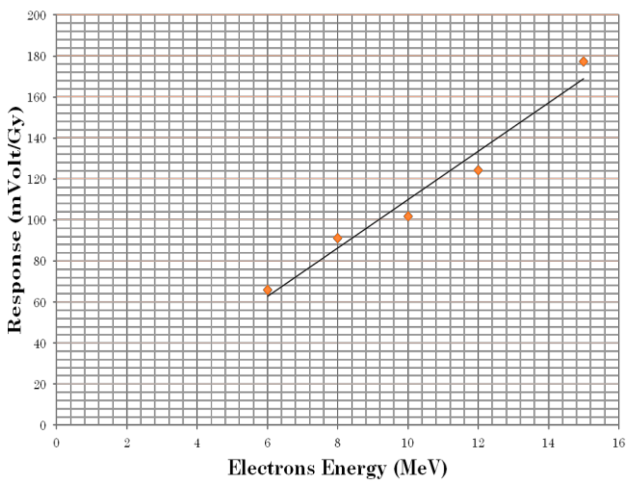

Figure 3. The Linearity of the dose response as a function of the energy of the electron beam.

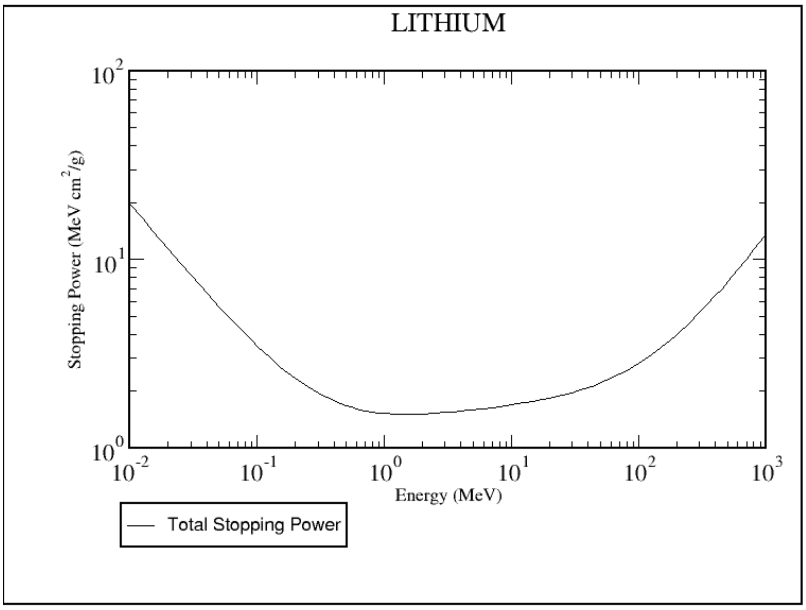

Figure 4. The stopping power of electrons in Lithium.