SENSITIVITY OF RADFET FOR GAMMA AND X-RAY DOSES USED IN MEDICINE

by

Milić M. PEJOVIĆ [1*], ***Svetlana M. PEJOVIĆ*** [2, 3], ***Dragan STOJANOV*** [3, 4], ***and Olivera F. CIRAJ-BJELAC*** [5]

[1]Faculty of Electronic Engineering, University of Niš, Niš, Serbia
[2]Saarland University Clinic, Homburg, Germany
[3]Faculty of Medicine, University of Niš, Niš, Serbia
[4]Institute of Radiology, University of Niš, Niš, Serbia
[5]Vinča Institute of Nuclear Science, University of Belgrade, Belgrade, Serbia

Scientific paper
DOI: 10.2298/NTRP1403179P

In this paper, the results of radiation sensitive field effect transistors (Al-gate p-channel metal-oxide-semiconductor field effect transistors) sensitivity to gamma and X-ray irradiation are presented. Radiation fields were created using ^{60}Co source for three dose ranges (0-1 Gy, 0-5 Gy, and 0-50 Gy), as well as X-ray unit of 280 kVp spectrum for a single dose range from 0 to 5 Gy. The sensitivity was characterized by the threshold voltage shift, determined from reader circuit measurements, as a function of absorbed radiation dose. It was shown that for the three dose ranges of gamma radiation, as well as for the X-ray range from 0 Gy to 5 Gy there is approximately a linear dependence between threshold voltage shift ΔV_T and radiation dose D. The application of positive bias of +5 V at the RADFET gate during irradiation, for these ranges of gamma radiation, also for X-ray dose range, leads to the increase in ΔV_T and also, approximately a linear dependence between ΔV_T and D, is established. Moreover, it was shown that the sensitivity of RADFET is much higher in the case of X-ray irradiation then in the case of gamma-ray irradiation for the same dose range.

Key words: RADFET, gamma-ray irradiation, X-ray irradiation, threshold voltage shift, radiation dose

INTRODUCTION

P-channel metal-oxide-semiconductor field effect transistors (MOSFET) also known as radiation sensitive field effect transistors (RADFET), or pMOS dosimeters have shown to be a suitable detectors for various applications, ranging from medical applications in diagnostic radiology and radiotherapy to synchrotron radiation and space dosimetry [1-5]. A major advantage of the RADFET as a radiation detector is that the radiation-sensitive region, the oxide film underneath the aluminum transistor gate, is of a small volume [6, 7]. The sensing volume is much smaller compared to integral dose measuring devices such as ionization chamber, semiconductor diode or thermoluminescent dosimeter [8]. Attention is thus being turned to the use of RADFET especially were the detector has to be inserted into a confined space as a catheter [9, 10]. This property of the RADFET also makes it attractive for measuring in the high gradient radiation field where the gradient mostly depends on a single space coordinate, like resolving dose profiles of X-ray micro beams or depth dose distribution. However, the disadvantages of RADFET include the need for calibration in different radiation fields, relatively low resolution (starting from about 0.01 Gy) and non-reusability. On the other hand, the latter property can be considered as an advantage, as it provides a permanent dose record. Some earlier investigations [11] have shown the possibility of RADFET reuse, including our recent investigations [12, 13].

The concept of a RADFET is based on the build-up of positive oxide charge in the gate region when exposed to ionizing radiation. The electrical signal used as a dosimeteric parameter is the threshold voltage. This parameter exhibits a shift when RADFET is irradiated. Threshold voltage is the gate-source voltage (V_{GS}) necessary to induce inversion between the sources and drain terminals, which leads to a flow of constant current between these terminals [14]. The basic mechanisms responsible for threshold voltage shift have been previously discussed elsewhere [15-19]. It is shown that their behavior is a consequence of the following mechanisms: (1) elec-

* Corresponding author; e-mail: milic.pejovic@elfak.ni.ac.rs

tron-hole pair generation, (2) electron-hole recombination, (3) hole transport, (4) deep hole trapping, and (5) radiation-induced interface and oxide traps formation. As for many detectors, they need to be calibrated against an accurate dosimetric reference, such as an ionization chamber traceable to an accepted dosimetry calibration laboratory. Usually a RADFET is operated in integral mode, where the dose is determined from the shift in threshold voltage before and after it is irradiated. In this case, the effect of fading and/or a temperature error can be significant if long time elapses between irradiations, or temperature changes occur between the initial and final readout [20].

EXPERIMENTAL DETAILS

RADFET which are an acronym for radiation sensitive field effect transistors [21] with 1 μm thick gate oxide specially designed to measure radiation doses (RADFET Tyndall National Institute, Cork, Ireland) were used. The layout of the single chip is given elsewhere [22]. The chip size is 1 mm 1 mm, and there are two 300/50 and two 690/15 devices on the chip. The numbers 300/50 and 690/15 represent the width and length of RADFET channels, respectively. One 300/50 and one 690/15 devices have four terminals, bulk, drain, gate, and source. The other devices can be treated as two terminal devices because their gates and drains as well as their bulks and sources are joined together. Two terminal devices can be easily used in reader circuit configuration. The transistors oxide was grown at 1000 °C in dry oxygen and annealed for 15 minutes at 1000 °C in nitrogen. The post metallization annealing was performed at 440 °C in forming gas for 60 minutes (for more details see [23]). In the experiment RADFET were divided in eight groups. Two RADFET groups were irradiated by gamma-rays originating from ^{60}Co in the radiation dose ranges from 0 Gy to 1 Gy without gate bias (all terminals were grounded) and with a positive gate bias V_{irr} = +5 V, respectively. Other two RADFET groups were irradiated by gamma-rays originating from ^{60}Co in the radiation dose ranges from 0 to 5 Gy without gate bias and V_{irr} = +5 V, respectively. Two RADFET groups were irradiated by gamma-rays originating from ^{60}Co in the radiation dose ranges from 0 to 50 Gy without gate bias and with a positive gate bias V_{irr} = = +5 V, respectively. Irradiation facility used was a teletherapy cobalt source CIRUS-TS (CIS Alcyon Biointernational, France) with activity of 230 TBq (1.9.1999). The last two MOSFET groups were irradiated with X-rays with mean energy of 140 keV (280 kVp) in the radiation dose range from 0 Gy to 5 Gy, without gate bias and gate bias V_{irr} = +5 V, respectively. In this case, irradiation was performed using an X-ray generator MG 320 (Philips, The Netherlands) with nominal tube voltage of 320 kVp. Beam quality used for irradiation was generated using a tube voltage of 280 kVp, inherent filtration of 4 mm Al and additional filtration of 3.0 mm Cu, which corresponds to the first half-value layer of 18 mm Al or 3.6 mm Cu. Irradiation was performed in the Secondary Standard Dosimetry Laboratory of the Vinča Institute of Nuclear Science, Vinča-Belgrade, Serbia. All measurements were conducted in a climate-controlled laboratory environment with ambient temperature of 20 0.20 °C. The air kerma at the reference point was measured with a calibrated vented 0.6 cm^3 ionization chamber (Model 30012, PTW, Freiburg, Germany) and electrometer Unidos (PTW, Freiburg, Germany). The calibration of the chamber in terms of air kerma for all radiation qualities had been performed at the Secondary Standards Dosimetry Laboratory of the International Atomic Energy Agency (Vienna, Austria), to provide traceability to International Bureau of Weights and Measures (BIPM). Irradiation in cobalt beam quality was performed at dose rate of 192 mGy/min normalized to 1 m form the source, so irradiation time ranging 8 to 42 min was used to achieve doses of 10-50 Gy at irradiation distance of 40 cm, respectively. Similarly, dose rate in X-ray beam quality was 72 mGy/min at 1 m, which corresponds to irradiation time ranging from 14 to 70 min to achieve doses of 1-5 Gy, respectively.

In order to detect threshold voltage shift ΔV_T, threshold voltage before irradiation V_{T0}, and threshold voltage after irradiation V_T were determined, *i. e.*, [24]. The threshold voltage was determined with devices in the so-called reader circuit configuration, whose electric scheme is shown in fig. 1. In this arrangement, a RADFET is treated as two terminal devices. Through the channel a steady current I_D = 10 μA is established and the voltage V_{out} which corresponds to this current

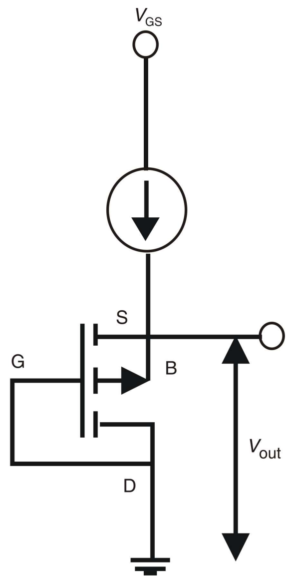

Figure 1. Electronic scheme of the RADFET threshold voltage measurements

is then measured. This voltage represents threshold voltage. Reader circuit configuration provides fast and accurate readout of RADFET threshold voltage without any complex electronic or logic circuits around the detectors of the RADFET ([23] for more details). This value of the current was selected because it was close to the zero temperature coefficients for our devices. Namely, when reader circuit characteristics are measured at different temperatures, all of them intersect for the current value of approximately 10 μA. Thus, the V_T readout at 10 μA is temperature independent. RADFET were read out immediately after each irradiation, *i. e.*, the time interval between each successive irradiation was less than a minute.

Reader circuit measurements were performed by Keithley 4200 semiconductor characterization system (SCS). The system is equipped with three medium-power source measuring units (4200 SMU). The source measuring units have four voltage ranges (200 mV, 2 V, 20 V, and 200 V) and three current regions (100 A, 100 mA, and 1 A). One of the source-measuring units is equipped with a preamplifier for measuring very small currents (in the order of 1 pA).

RESULTS

Figure 2 shows the dependence of threshold voltage shift ΔV_T on gamma-radiation dose D in the 0 Gy to 1 Gy range for $V_{irr} = 0$ V and $V_{irr} = +5$ V. It can be seen that gate bias of +5 V leads to larger change in ΔV_T with the dose increase then in the case when there is no bias on the gate.

Dependence between ΔV_T and D can be expressed as $\Delta V_T = AD^n$ [24], where A is the constant and n is the degree of linearity depending on the electric field, oxide thickness, and absorbed radiation dose. Ideally, this dependence is linear, *i. e.*, $n = 1$, where A represents the sensitivity $\Delta V_T / D$. Symbols in fig. 2 represent ΔV_T values from RADFET reader circuit measurements while the solid lines are determined by fitting the data with expression $\Delta V_T = AD^n$ for $n = 1$. It was shown that the values of correlation coefficients r^2 are 0.99 for both $V_{irr} = 0$ V and $V_{irr} = +5$ V, respectively. Having that the correlation coefficients are very close to one, it can be assumed that there is a linear dependence between ΔV_T and D, so that the sensitivity $\Delta V_T / D$ is the same in the whole interval.

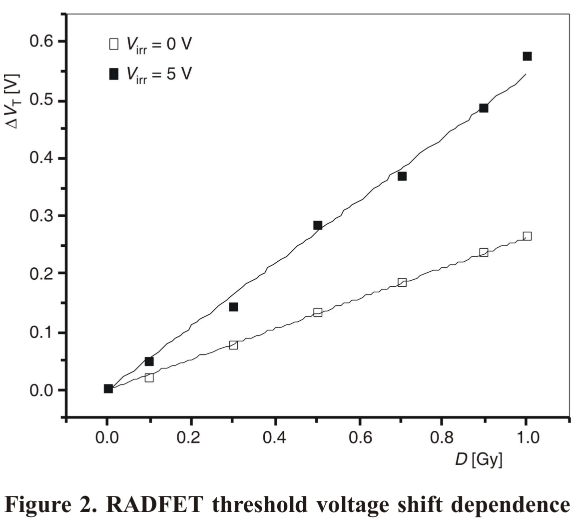

Figure 2. RADFET threshold voltage shift dependence on gamma-ray irradiation dose in 0-1 Gy range without gate bias and with gate bias V_{irr} = +5 V

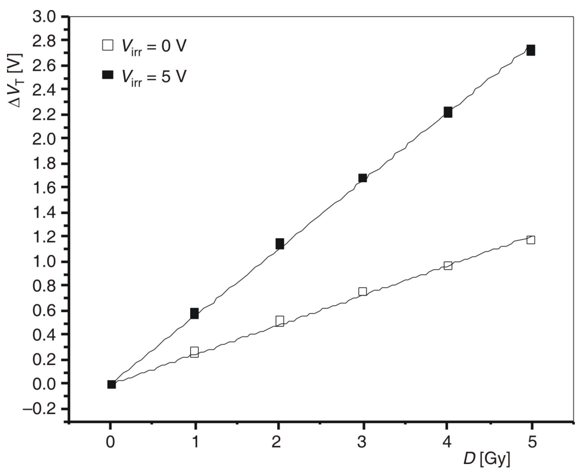

Figure 3. RADFET threshold voltage shift dependence on gamma-ray irradiation in 0-5 Gy range without gate bias and with gate bias V_{irr} = +5 V

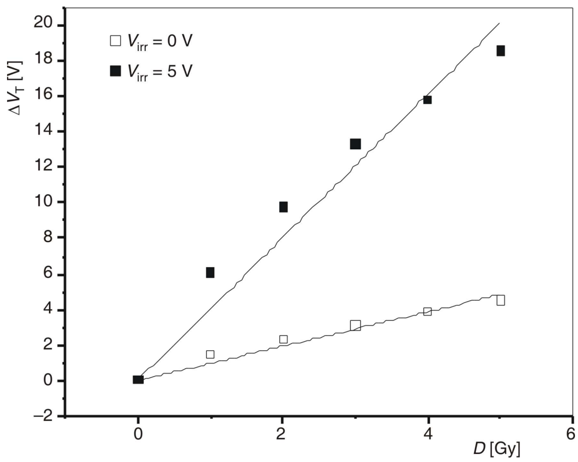

Figure 4. MOSFET threshold voltage shift dependence on X-ray irradiation in 0-5 Gy range without gate bias and with gate bias V_{irr} = +5 V

Threshold voltage shift ΔV_T for gamma and X-ray irradiation dose D in the 0 Gy to 5 Gy range for $V_{irr} = 0$ V and $V_{irr} = +5$ V is presented in figs. 3 and 4, respectively.

It can be seen that ΔV_T increase is much higher in the case when RADFET are irradiated with X-rays then in the case of gamma-rays irradiation and this is a consequence of different photon energies. Namely, X-rays beam quality used was generated with tube voltage of

280 kVp with corresponding half value layer of 18 mm Al, mean energy of 140 keV, while gamma-rays photons originated from ^{60}Co. It is known that ^{60}Co in each disintegration emits β^- particles and two photons of energy 1.17 MeV (99.86%) and 1.33 MeV (99.98%), transforming itself into ^{60}Ni. These two photons with different energies are usually considered as average, with photon energy of 1.25 MeV. Due to different photon energies of X and gamma rays, different interaction mechanisms dominantly occur in the RADFET gate oxide, which further lead to radiation-induced interface and oxide traps formation. On the basis of the atomic number as a function of photon energy [25] it can be concluded that both photoelectric effect and Compton scattering are occurring, however their contribution to the total interaction coefficient is different, as photoelectric effect contributes more at lower energies, whereas Compton scattering dominates at higher energies. Therefore, for cobalt photons (1.25 MeV) the primary ionizing mechanism is Compton effect, but in the area of low and medium-photon energy of X-rays there is a mixed influence of Compton scattering and photo-effect.

Fitting of experimental data for gamma radiation dose range from 0 Gy to 5 Gy (fig. 3) gives correlation coefficients of 0.99 for both V_{irr} = 0 and V_{irr} = +5 V. Correlation coefficients for the case when MOSFET are irradiated with X-rays in the 0 Gy to 5 Gy range (fig. 4) are 0.96 and 0.95 for V_{irr} = 0 V and V_{irr} = +5 V, respectively, so it shows that the linearity between ΔV_T and D is satisfactory for practical applications.

Figure 5 shows $\Delta V_T = f(D)$ dependence for dose range from 0 Gy to 50 Gy for V_{irr} = 0 V and V_{irr} = +5 V. Fitting of experimental data gives the linear correlation coefficients of 0.98 and 0.97 for V_{irr} = 0 V and V_{irr} = +5 V, respectively. It can be concluded that in this dose range there is also an approximately linear dependence between ΔV_T and D.

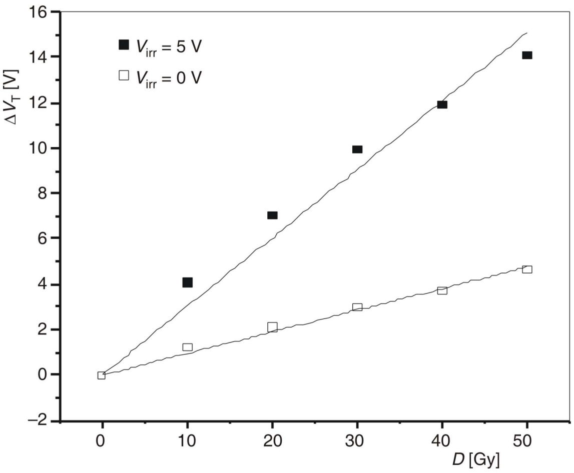

Figure 5. RADFET threshold voltage shift dependence on gamma-ray irradiation dose in 0-50 Gy range without gate bias and with gate bias V_{irr} = +5 V

Comparing results between gamma-ray irradiation for dose range from 0 Gy to 50 Gy (fig. 5) with results for X-ray irradiation for dose range from 0 Gy to 5 Gy (fig. 4) shows that ΔV_T for gamma-ray irradiation dose of 50 Gy and X-ray irradiation dose of 5 Gy are approximately the same for V_{irr} = 0 V. For V_{irr} = + 5 V, ΔV_T for X-ray irradiation is about 4 V higher than in the gamma-ray irradiation case. It can be concluded that RADFET are much more sensitive to X-ray irradiation.

DISCUSSIONS

Many investigations [17-19, 26-33] have shown that the exposure of MOS components to gamma and X-ray irradiation leads to the increase of electrical charge in the insulating gate oxide (net positive oxide trapped charge) and interface charge (interface traps). The dosimetry of ionizing radiation using MOS transistor is based on the measurement of positive oxide trapped charge in the gate oxide Q_{ox} and interface traps Q_{it}. Q_{ox} leads to the shift of I_D-V_G curve towards more negative voltage. The interface charge Q_{it} also contributes to this shift and in addition, reduces the slope of the linear part of the curve due to degradation of the carrier mobility in the transistors channel [21].

The threshold voltage V_T given by [34]

$$V_T \quad V_{T0} \quad \frac{Q_{ox} \quad Q_{it}}{C_{ox}} \quad V_{T0} \quad \Delta V_T$$

where C_{ox} is the oxide capacitance per area unit. In the case of p-channel MOSFET (RADFET) both Q_{ox} and Q_{it} are positive and add to define ΔV_T, *i. e.*, both effects result in a negative shift of the threshold voltage.

The physical mechanisms leading to the creation of positive oxide trapped charge and interface traps during irradiation have been studied for many years [20, 35, 36] and here we will discuss only the main features required for their understanding. Namely, gamma and X-ray irradiation generates electron-hole pairs in the oxide, and the fraction of them which escape initial recombination is accelerated toward the electrodes. Under positive gate bias, electrons migrate toward the gate and holes being slower migrate toward SiO_2/Si interface. During the migration some holes can be captured in defects in SiO_2 structure, which are mainly located near SiO_2/Si interface, and behave as hole traps. The result is a buildup of a relatively stable positive oxide trapped charge density. Probably as a result of the liberation of hydrogen ions in oxide during irradiation, interface traps are also created [25].

Our earlier investigations [24] have shown that the irradiation of RADFET with gamma-ray irradiation leads to the formation of positive oxide trapped charge which is ten times greater than interface traps density. Because of that, the influence of interface traps can be neglected in threshold voltage shift change. It is known that the number of created positive oxide trapped charge rises with the number of holes which avoid the recombination with the electrons and this process depends on gate polarization during irradiation, V_{irr}. For V_{irr} = 0 (figs. 2 to 5), the electric field in the oxide is only a consequence of the work function difference between the gate and substrate (the zero-bias conditions are equal to the gate bias of 0.3 V), so the probability for electron-hole recombination is higher than in the case when V_{irr} = 5 V. Namely, for V_{irr} = 5 V the large number of holes will escape the initial recombination, which increases the probability for the creation of positive oxide trapped charge. Such increase is manifested through the increase of threshold voltage shift for the same value of irradiation dose, which can be clearly seen in figs. 2 to 5.

Larger values of ΔV_T when RADFET were irradiated by X-rays (fig. 4) then in the case when they were irradiated by gamma-rays (fig. 3) are a consequence of different formation of positive oxide trapped charge density. During gamma irradiation the primary ionizing mechanism is Compton's effect and its influence on formation of oxide trapped charge density is considerably smaller than in the case of X-rays irradiation when there is a mixed influence of Compton's effect and photo-effect. It should be emphasized that our results (figs. 3 and 4) are in agreement with earlier investigations of clinical semiconductor dosimetry system (CSDS) MOSFET irradiated by X-rays whose photon energies were 36 keV, 123 keV, and 1.4 Mev [36]. It was shown that the decrease of X-rays irradiation energy leads to the increase of threshold voltage, so it can be concluded that the photo-effect contribution to the positive oxide trapped charge formation is much bigger than the contribution of Compton's effect. Such conclusion is in agreement with the results presented in figs. 4 and 5, where it can be seen that threshold voltage shift for gamma-rays irradiation up to 50 Gy dose and X-rays irradiation dose of 5 Gy are approximately the same for V_{irr} = 0 V, while for V_{irr} = 5 V threshold voltage shift for X-rays irradiation is about 4 V higher than in the case of gamma-ray irradiation.

CONCLUSIONS

The sensitivity of RADFET manufactured in Tyndall National Institute, Cork, Ireland with 1 μm thick gate oxide to gamma-ray irradiation for radiation dose ranges 0-1 Gy, 0-5 Gy, and 0-50 Gy as well as for X-ray irradiation for radiation dose range 0-5 Gy has been investigated. Because average photon energy is 1.25 MeV the primary ionization mechanism is Compton's scattering. The photon energy of X-ray irradiation used in our experiments was 140 keV, so there was a mixed influence of Compton's scattering and photo-effect. The sensitivity of studied devices was based on threshold voltage shift determined from reader circuit measurements. These results show that for considered dose ranges of gamma and X-rays there is approximately a linear dependence between threshold voltage shift and absorbed dose, which shows that the sensitivity for considered radiation dose ranges can be expressed as a ratio between threshold voltage shift and radiation dose. The application of positive bias on the gate, V_{irr} = +5 V, leads to the sensitivity increase of these devices. The results have also shown that the sensitivity is greater when RADFET are irradiated by X-rays than by gamma-rays for the same dose range. The explanation for such behavior can be found in the fact that mixed influence of Compton's scattering and photo-effect leads to the formation of greater density of positive oxide trapped charge than in the case when only Compton's effect exists.

Due to the high sensitivity of considered components to X-rays irradiation it can be expected their satisfactory sensitivity for lower radiation doses than the ones used in this paper. Our further investigations will be focused to lower doses of X-rays irradiation, below 1 cGy in order to investigate the RADFET application in dose range used in radiology.

ACKNOWLEDGEMENTS

The Ministry of Education, Science and Technological Development of the Republic of Serbia, supported this work financially through the project No. 171007.

AUTHOR CONTRIBUTIONS

Theoretical analysis was carried out by M. M. Pejović, experiments were carried out by M. M. Pejović, S. M. Pejović, and O. F. Ciraj-Bjelac. All of the authors have analyzed and discussed the results. The manuscript was written by M. M. Pejović, S. M. Pejović, and O. F. Ciraj-Bjelac. The figures were prepared by M. M. Pejović.

REFERENCES

[1] Bower, M. W., Hintenlang, D. E., The Characterization of a Commercial MOSFET Dosimeter System for Use in Diagnostic X-Ray, *Health Phys., 75* (1998), 2, pp. 197-204
[2] Kron, T., *et al.*, Dose Response of Various Radiation Detectors to Synchrotron Radiation, *Phys. Med. Biol., 43* (1998), 11, pp. 3235-3259
[3] Peet, D. J., Pryor, M. D., Evaluation of a MOSFET Radiation Sensor for the Measurement of Entrance Surface Dose in Diagnostic Radiology, *Br. J. Radiol., 72* (1999), 858, pp. 562-568
[4] Dong, S. L., *et al.*, Characterization of High- Sensitivity Metal Oxide Semiconductor Field Effect Transistor Dosimetric System and LiF: Mg, Cu, P

Thermoluminescence Dosimeters for use in Diagnostic Radiology, *Appl. Radiat. Isot., 57* (2002), 6, pp. 883-891

[5] Marcie, S., *et al*., *In vivo* Measurements with MOSFETS Detectrors in Oropharynx and Nanopharynx Intesity-Modulated Radiation Therapy, *Int. J. Radiat. Oncol. Biol. Phys., 61* (2005), 5, pp. 1603-1606

[6] Holmes-Siedle, A., The Space-Charge Dosimeter – General Principles of a New Method of Radiation Detection, *Nucl. Instr. Methods, 121* (1974), 1, pp. 169-179

[7] Rosenfeld, A. B., *et al*., MOSFET Dosimeters: Role of Encapsulation of Dosimetric Characteristics in Mixed Gamma-Neutron and Megavoltage X-Ray Field, *IEEE Trtans. Nucl. Sci., 42* (1995), 6, pp. 1870-1877

[8] Kaplan, G. I., *et al*., Improved Spatial Resolution by MOSFET Dosimetry of an X-Ray Microbeam, *Med. Phys., 27* (2000), 1, pp. 239-244

[9] Hughes, R. C., *et al*., Miniature Radiation Dosimeter for *in vivo* Radiation Measurements, *Int. J. Radiat. Oncol. Biol. Phys., 14* (1988), 5, pp. 936-967

[10] Gladstone, D. J., *et al*., A Miniature MOSFET Radiation Dosimeter Probe, *Med. Phys., 21* (1994), 11, pp. 1721-1728

[11] Kelleher, A., *et al*., Investigation Into the Reuse of pMOS Dosimeters, *IEEE Trans. Nucl. Sci., 41* (1994), 3, pp. 445-451

[12] Pejović, M. M., *et al*., Successive Gamma-Ray Irradiation and Corresponding Post-Irradiation Annealing of pMOS Dosimeters, *Nucl Technol Radiat, 27* (2012), 4, pp. 341-345

[13] Pejović, M. M., Pejović, M. M., Jaksić, A. B., Response of pMOS Dosimeters on Gamma-Ray Irradiation During its Re-Use, *Radiation Protection Dosimetry, 155* (2013), 4, pp. 394-403

[14] Carvajal, M. A., *et al*., Thermal Drift Reduction with Multiple Bias Current for MOSFET Dosimeters, *Phys. in Med. and Biol., 56* (2011), 12, pp. 3535-3550

[15] Soubra, M., Cygler, J., Mackay, G., Evaluation of a Dual Bias Metal-Oxide-Silicon-Semiconductor Field Effect Transistor Detector as Radiation Dosimeter, *Med. Phys., 21* (1994), 1, pp. 567-572

[16] Thomson, I., Thomson, R. E., Berndt, L. P., Radiation Dosimetry with MOS Sensor, *Nucl. Appl. Technol., 6* (1984), 1, pp. 121-124

[17] Benedetto, J. M., Boesch, H. E., McLean, F. B., Dose Energy Dependence of Interface Trap Formation in ^{60}Co and X-Ray Environments, *IEEE Trans. Nucl. Sci., 35* (1988), 6, pp. 1260-1264

[18] Shaneyfelt, M. R., Fleetwood, D. M., Hughes, K. L., Charge Yield for Cobalt-60 and 10 keV X-Ray Irradiation of MOS Devices, *IEEE Trans. Nucl. Sci., 38* (1991), 6, pp. 1187-1193

[19] Oldham, T. R., McLean, F. B., Total Ionizing Dose Effect in Mos Oxides and Devices, *IEEE Trans. Nucl. Sci., 50* (2003), 3, pp. 483-499

[20] Rosenfeld, A. B., *et al*., Feasibility Study of Online High-Spatial-Resolution MOSFETS Dosimetry in Static Pulsed X-Ray Radiation Fields, *IEEE Trans. Nucl. Sci., 48* (2001), 6, pp. 2061-2068

[21] Hughes, R., Theory of Response of Radiation Sensing Field Effect Transistors, *J. Appl. Phys., 58* (1985), 3, pp. 1375-1380

[22] Pejović, S., *et al*., Characteristics of MOSFET Suitable for Use in Radiotherapy, *Appl. Radiat. and Isotopes, 77* (2013), pp. 44-49

[23] Jaksić, A., *et al*., Gamma-Ray Irradiation and Post-Irradiation Response of High Dose Range RADFET, *IEEE Trans. Nucl. Sci., 49* (2002), 3, pp. 1356-1363

[24] Pejović, M. M., Pejović, M. M., Jaksić, A. B., Contribution of Fixed Oxide Traps to Sensitivy of pMOS Dosimeters During Gamma Ray Irradiation and Annealing at Room and Elevated Temperature, *Sensors and Actuators, A 174* (2012), pp. 85-90

[25] Ristić, G. S., Influence of Ionizing Radiation and Hot Carried Injection on Metal-Oxide-Semiconductor Transistors, *J. Phys. D: Appl. Phys., 41* (2008), 2, 023001

[26] Sarrabayrouse, G., Gessinn, F., Thick Oxide MIOS Transistors for Ionizing Radiation Dose Measurement, *Radioprotection, 29* (1994), 4, pp. 557-572

[27] Oldham, T., Ionizing Radiation Effects in MOS Oxides, Advances in Solid State Electronics and Technology Series, Springer; World Scientific, 1999

[28] Huges, H. L., Benedent, J. M., Radiation Effects and Hardening of MOS Technology: Devices and Circuits, *IEEE Trans.Nucl. Sci., 50* (2003), 3, pp. 500-520

[29] Johnston, A. H., Super Recovery of the Dose Damage in MOS Devices, *IEEE Trans. Nucl. Sci., 31* (1984), 6, pp. 1427-1433

[30] Benedetto, J. M., Boesh, H. E., The Relationship Between ^{60}Co and 10 keV X-Ray Damage in MOS Devices, *IEEE Trans. Nucl. Sci., 33* (1986), 6, pp. 1318-1323

[31] Dozier, C. M., *et al*., An Evaluation of Low-Energy X-Ray and Cobalt-60 Irradiations of MOS Transistors, *IEEE Trans. Nucl. Sci., 34* (1987), 6, pp. 1535-1539

[32] Beutler, D. E., *et al*., Variations in Semiconductor Device Response in a Medium Energy X-Ray Dose-Enhancing Environment, *IEEE Trans. Nucl. Sci., 34* (1987), 6, pp. 1544-1550

[33] Vukić, V. Dj., Osmokrović, P. V., Failure of Negative Voltage Regulator in Medium-Photon-Energy x Radiation Fields, *Microelectronics Reliability, 54* (2014), 1, pp. 79-89

[34] Dasgupta, A., *et al*., Dose enhancement and Reduction in SiO_2 and High-k MOS Insulators, *IEEE Trans. Nucl. Sci., 57* (2010), 6, pp. 3463-3469

[35] Fleetwood, D. M., *et al*., Comparison of Enhanced Device Response and Predicted X-Ray Dose Enhancement Effects on MOS Oxides, *IEEE Trans. Nucl. Sci., 35* (1988), 6, pp. 1265-1271

[36] Cheung, T., Butson, M. J., Yu, P. K. N., Energy Dependence Corrections to MOSFET Dosimetric Sensitivity, *Austras. Phys. Eng. Sci. in Med., 32* (2009), 1, pp. 16-20

Received on March 30, 2014
Accepted on September 5, 2014

**Милић М. ПЕЈОВИЋ, Светлана М. ПЕЈОВИЋ,
Драган СТОЈАНОВ, Оливера Ф. ЦИРАЈ-БЈЕЛАЦ**

ОСЕТЉИВОСТ РАДФЕТ ТРАНЗИСТОРА ЗА ДОЗЕ ГАМА И X-ЗРАЧЕЊА КОЈЕ СЕ КОРИСТЕ У МЕДИЦИНИ

У овом раду приказани су резултати везани за осетљивост РАДФЕТ-ова на гама и X-зрачење. Као извор гама зрачења коришћен је ^{60}Co и озрачивање је урађено за три опсега доза (0-1 Gy, 0-5 Gy, и 0-50 Gy) као и извор X-зрачења 280 kVp за опсег доза од 0-5 Gy. Карактеризација осетљивости је вршена на основу помераја напона прага ΔV_T, одређена из мерења напона прага у једној тачки струјно-напонске карактеристике, као функције апсорбоване дозе *D*. Показано је да за три опсега дозе гама зрачења као и за опсег дозе X-зрачења од 0 до 5 Gy постоји приближно линеарна зависност између ΔV_T и *D*. Примена позитивне поларизације на гејту од +5 V РАДФЕТ-ова доводи до пораста вредности ΔV_T и такође постоји приближно линерна зависност између ΔV_T и *D*. Осим тога је показано да је осетљивост РАДФЕТ-ова знатно већа у случају озрачивања X-зрацима него гама зрацима за исти опсег дозе.

Кључне речи: РАДФЕТ, гама зрачење, X-зрачење, промена напона прага, доза зрачења