Numerical Computation of the Physical Shielding Factor for Different Structures of MOSFET in Gamma Irradiation Field

S. Stanković, R. Ilić, A. Jakšić, D. Nikolić, N. Kržanović

Abstract - In this study conducted numerical experiments aimed to determine the physical shielding factors (PSF) for two different MOSFET structures. The purpose of this paper was to present the new possibilities of the Monte Carlo numerical simulations for interaction of gamma irradiation of ^{60}Co and ^{137}Cs with semiconductor devices that are often located as dosimeters together with complex electronics power systems. The transport of incident photon particles is simulated with Monte Carlo code FOTELP-2014. When kovar is used as a lid in the gamma radiation field, the implemented calculations show that the PSF values for the ESAPMOS RADFET structure are significantly higher than the PSF values for the standard MOSFET structure.

I. Introduction

At a time when the stormy development of technology, the MOSFET as a contemporary type of solid state detector, has been introduced in complex electronics of power systems that can operate in radiation fields of high energy accelerators and applications in the field of nuclear industry, medical applications and space research [1],[2], [3],[4]. The dominant theme in previous research was to examine the electrical characteristics of MOSFET dosimeters in the experiments that were conducted on a gamma irradiation installation [5],[6]. MOSFET components are irradiated by photons of ^{60}Co and then are followed by changes in threshold voltage shift mean values depending on the change of absorbed dose is referred to as D(cGy) was determined in water. Recent conclusions for performance of MOSFET components are more than encouraging in terms of further research to improve the linearity of dosimeter [7]. Monte Carlo simulations of the energy response of a conventionally packed single MOSFET detector were performed with the goal of improving MOSFET energy dependence for personal accident and military dosimetry[8],[9],[10]. One of a major goal of our work was the presentation the Physical Shielding Factor (PSF) which assesses the impact of kovar lid to MOSFET dosimeter response in gamma irradiation field for two different structures of MOSFET.

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II. Physical Shielding Factor

Previous studies regarding the interaction of ionizing radiation with the structure of a MOSFET indicated on specific importance following radiation effects in gate oxide: generate electron-hole pairs in the path of the secondary electrons occurred after penetrating incident ionizing radiation through the material oxide; fast electron recombination of most electron-hole pairs; transport of free charge carriers in the oxide; trap of charge and the formation of positive spatial charge, with the occurrence of recombination centers and the local electric field; and the formation of the charge at the bond interface Si-SiO2 [5],[6],[7]. In doing so, changes in the density of oxide charge and the charge on the surface states affects the characteristics of MOSFET transistors. The sensitive element of the MOSFET detector is the gate oxide, which is defined by a thin silicon oxide layer positioned on top of a thick silicon substrate (see Fig. 1). Radiation creates charge within the thin silicon dioxide layer and this charge and its long term trapping lead to a change of threshold voltage of the MOSFET transistor. In the case of MOSFET, the threshold voltage shift ΔV_T produced by the photon irradiation can be expressed by simple functional dependence of the absorbed dose in the gate oxide SiO_2 [8],[9]. To discover of the influence of MOSFET package effects, it was necessary to define the physical shielding factor (PSF) for different photon energies (E_p) and for kovar as constructional materials of lid as:

$$PSF(E_p) = \frac{D(SiO_2, E_p)_{shield}}{D(SiO_2, E_p)_{bare}} \qquad (1)$$

In this way, factor PSF is defined as the ratio of absorbed dose values in zone SiO_2 when the MOSFET is shielded with protection $D(SiO_2,E_P)_{shield}$, and when the MOSFET without lid $D(SiO_2,E_P)_{bare}$. Absorbed dose is in relation to deposited energy in zone SiO_2 as:

$$D(SiO_2, E_p) = \frac{E_D(SiO_2, E_p)}{\rho_{SiO2} V_{SiO2}} \qquad (2)$$

Where $E_D(SiO_2,E_P)$ is deposited energy, ρ_{SiO_2} and V_{SiO_2} are density and volume of zone SiO_2.

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III. NUMERICAL METHOD

Numerical computation of values deposited energy in zone SiO_2 and factor PSF of radiation sensing MOSFET by Monte Carlo method made with FOTELP-2014 code for incident photons with different energies of radiation sources ^{60}Co and ^{137}Cs. FOTELP-2014 code has great competency in successful resolving of radiation transport problems which review interactions incident photons and secondary electrons and positrons with electronic components and devices, such as MOSFET dosimeters [10],[11]. Physical rigor is maximized by employing the best available cross sections and high speed routines for random values sampling from their distributions, and the most complete physical model for describing the transport and production of the electron cascade from 100 MeV down to 1 keV. FOTELP-2014 is developed for numerical experiments by Monte Carlo techniques for dosimetry and radiation protection, radiation damage in space engineering, radiation therapy and other actual applications of these particles [12]. The condensed history Monte Carlo method is used for the electron transport simulation. During a history the particles lose energy in collisions, and the secondary particles are generated on the step according to the probabilities for their occurrence. Electron energy loss is through inelastic electron-electron (e-, e-) collisions and bremsstrahlung generation. The fluctuation of energy loss (straggling) is included according to the Landau's or Blunk-Westphal distributions with 9 gaussians. With atomic data, the electron Monte Carlo simulation is broadened to treat atomic ion relaxation after impact ionization. Flexibility of the codes permits them to be tailored to specific applications and allows the capabilities of the codes to be extended to more complex applications, especially for calculations of deposited energy and absorbed dose in voxelized geometry using CT data. The actual version of FOTELP-2014 program was expanded by adding new routines of PENGEOM package for geometry modeling. In this way, Monte Carlo simulations were being improved, particularly at themselves energies that are typical for simulations in radiation and nuclear physics and applications on devices with semiconductors in nuclear engineering and space technology.

IV. RESULTS AND DISCUSSION

In this study conducted numerical experiments aimed to determine the physical shielding factors (PSF) for two different MOSFET structures. First considered is the case of gamma ray interaction with the standard structure of the MOSFET (Fig. 1). In order to use numerical methods in this paper, the appropriate geometry form of the MOSFET dosimeter was defined using adequate software. In this case, FOTELP-2014 code uses RFG and PENGEOM software modules for dosimeter geometry description. According to the available data for a very sensitive MOSFET [9], a silicon substrate (1 mm^2 in area, 0.525 mm thick) is contained within a 1 mm thick epoxy bulb (Fig. 1). The silicon substrate and the epoxy bulb are attached to the end of a flexible kapton cable (0.25 mm thick, 2 mm wide) encapsulating two gold wires. The sensitive volume (0.2 mm x 0.2 mm in area) is a 1 μm thick SiO_2 layer. It is sandwiched between the epoxy bulb and the silicon substrate. It is noted that the dimensions of the Monte Carlo dosimeter model are as accurate as the information provided by the manufacturer. The only uncertainty in the geometry is the shape of the epoxy. Although the actual shape may differ from the semi-ellipsoid, as simulated in the Monte Carlo model, its impact on the dose is very small, due to the character of the our numerical experiment based on photon transport. The bare MOSFET is encapsulated in epoxy glue which mechanically protects the chip. Package lid is a 250 μm thick protection shell over 250 μm vacuum layer, which up Epoxy bulb.

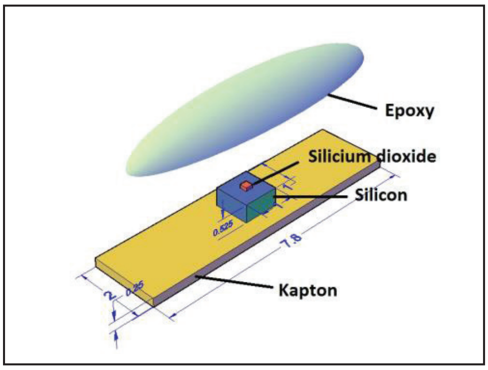

Fig. 1. MOSFET standard structure (sketch of the model).

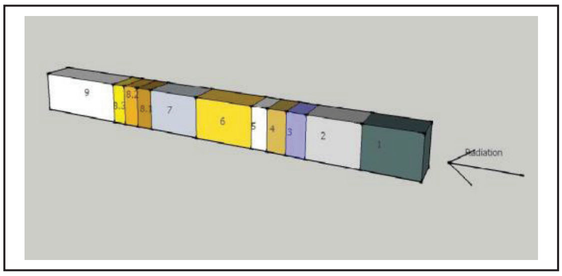

Fig. 2. ESAPMOS RADFET structure – basic configuration (sketch of the model).

In the second case, the basic structure ESAPMOS RADFET consists of the following material zones (Fig. 2): 1. package lid, kovar (29% Ni+17% Co+54% Fe), density is 8,4 g/cm^3, thick is 250 μm; 2. vacuum, 250 μm; 3. passivation, silicon nitride, 3,4 g/cm^3, 0,2 μm; 4. metallisation, aluminium, 2,7 g/cm^3, 1 μm; 5. gate oxide, silicon dioxide, 2,27 g/cm^3, 0,4 μm; 6. substrate, silicon, 2,3 g/cm^3, 500 μm; 7. die attach adhesive, silver glass, 250 μm; 8.1 gold, 19,3 g/cm^3, 1,5 μm; 8.2 nickel, 8,9 g/cm^3, 2 μm; 8.3 alloy (90% W+10% Cu), 17 g/cm^3, 0,25 μm; 9. package base, alumina, 3,6 g/cm^3, 1000 μm .

In the part of the numerical simulations of gamma radiation transport trough the complex structure of packaging components MOSFET focus is placed on the determination of the energy deposited in layers that are of interest for the analysis of microscopic processes related to the recombination of radiation-induced electron-hole pairs. Transport incident photons through all the layers of structure MOSFET component was carried out numerical simulations of the Monte Carlo method using the software package FOTELP-2014. On this occasion, were taken into account all the physical processes of interaction of photons with materials given structure. When we carried out the numerical application of mathematical and physical model for determining the value of the absorbed energy as the energy deposited per unit mass in a given layers with different materials, it could be accessed defining physical shielding factor (PSF) for a given structure MOSFET components.

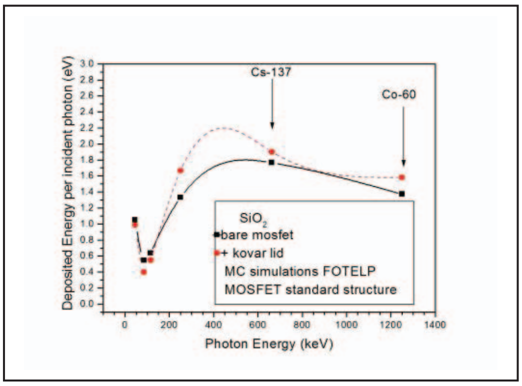

Fig. 3. Results of Monte Carlo calculations for deposited energy in material zone SiO_2 in standard structure.

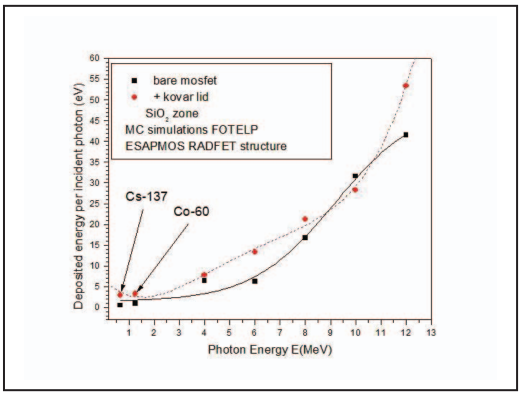

Fig. 4. Results of Monte Carlo calculations for deposited energy in material zone SiO_2 ESAPMOS structure.

Physical shielding factor (PSF) is defined as the ratio of absorbed dose values in zone SiO_2, which in fact means that it is equal to the energy deposited when the MOSFET is shielded with protection, and the MOSFET without lid. Monte Carlo simulations were performed for the transport of incident photons of ^{60}Co and ^{137}Cs gamma sources, as well as on some other photon energies. The results of calculations for deposited energy with Monte Carlo simulations for 10^7 photons per one simulation, presented in Fig. 3 and Fig. 4. In each simulation, the primary photon beam has a direction such that the beam axis is perpendicular to the upper horizontal surface of SiO_2 zone. Calculated values of physical shielding factor for two types of MOSFET structures and for incident photons of ^{60}Co and ^{137}Cs gamma sources are shown in Table 1.

TABLE 1.
RESULTS OF NUMERICAL COMPUTATION FOR PHYSICAL SHIELDING FACTOR (PSF) WHEN KOVAR IS LID FOR MOSFET STRUCTURE IN GAMMA IRRADIATION OF ^{60}CO AND ^{137}CS SOURCE.

Type of model	MOSFET standard structure	ESAPMOS RADFET structure
Photon Energy	PSF_{kovar}	PSF_{kovar}
662 keV (^{137}Cs)	1,077	5,814
1250 keV (^{60}Co)	1,152	3,235

When kovar is used as a lid in the gamma radiation field, the implemented calculations show that the PSF values for the ESAPMOS RADFET structure are significantly higher than the PSF values for the standard MOSFET structure. The analysis of the results shows that for RADFET ESAPMOS there is a significant change in PSF depending on gamma radiation energy, whereby it can be seen that PSF is higher for the source energy of the ^{137}Cs than for the energy of the source ^{60}Co. In addition, when we know the energy dependence of PSF factor for MOSFET with and without armor, can be carried out the analysis for application of method for the required energy compensation on this electronic component.

V. CONCLUSION

It can be concluded that for the different energy of incident photons there is a significant influence of material kovar on the absorbed energy in material zone SiO_2 and other layers of structure MOSFET. In this study confirmed the feasibility of numerical calculations based on Monte Carlo method in the process of designing a MOSFET structure in order to achieve better performances of semiconductor components in the field of radiation. Also, the PSF calculation method gives the possibility that by carefully selecting the material zones in the structure of the electronic component, an increase in the radiation resistance can be achieved. Such research enables the analysis of the obtained results of numerical calculations to consider the possibility of energy compensation for each electronic component individually, which is of great importance in the design of the technical characteristics of electronic devices. Considering that it is of the most importance increasing the packing density of semiconductor devices, and in this way it is possible to make progress by applying calculation method which is demonstrated in this paper.

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