INFLUENCE OF PACKAGING CONFIGURATION WITH KOVAR LID ON RADFET RESPONSE TO PROTON IRRADIATION

by

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Radiation sensing MOSFETs (RADFETs) have found numerous applications in space research, as well as in nuclear technology and research, and radiotherapy. Since proton irradiation is an essential part of the space radiation environment, it is important to know RADFET proton response precisely. In this work a numerical simulation of RADFET proton response is performed. To this end the proton transport Monte Carlo software SRNA-2K5, developed by one of the authors, has been adapted to obtain the energy deposited in the RADFET structure and dose distribution within the microscopic dimensions of the dosimeter sensitive volume. Our results show that RADFET response to proton irradiation depends significantly of packaging configurations with kovar lid.

Key words: RADFET, kovar lid, proton irradiation, SRNA-2K5

INTRODUCTION

Radiation sensing MOSFETs (RADFETs) are discrete p-chanel MOS transistors with gate oxides optimized for great radiation sensitivity. RADFETs have found numerous applications in radiation protection studies, radiotherapy, nuclear industry, and space research. Their main advantages over other dosimeters include non-destructive read out, an extremly small size, very low power consumption, compatibility with microprocesors, and a competitive price. The gamma radiation response of RADFETs has been firmly established in calibration work at the ESA ^{60}Co facility [1, 2 and at the standard gamma field at Secondary Standard Dosimetry Laboratory in the Vinča Institute of Nuclear Sciences 3 . The calculation of energy deposited by gamma irradiation in the sensitive volume of a MOSFET dosimeter is of special interest. The Monte Carlo model for MOSFET dosimeter dose simulation has been developed and demonstrated with FOTELP and PENELOPE codes 4 . The proton response of typical RADFETs exhibits energy dependence and deviates from ^{60}Co response 5 . Observations indicate that the RADFET response is dependent on the proton energy as well as varying with the packaging configuration. The packaging effect will be investigated by comparising the total energy deposited in the zones of the RADFET structure. The first aim of this work is to obtain the ratio between the values of the total energy deposited in the sensitive volume (thick SiO_2 layer) for cases of the RADFET structure with and without a package lid. The second goal is dependence identification of the total energy deposited with varying proton energy for the zones of interest.

For the realization of these goals, the proton transport Monte Carlo code SRNA-2K5 6 has been adopted to analyse the influence of the RADFET packaging on its proton response. The numerical experiments performed by the SRNA and GEANT codes gave an aditional confirmation that our proton transport model was consistent 7 . The simulation and measurement of proton beam energy spread using a multi-layer Faraday cup at IUCF 8, 12 , as well as the simulation of positron emiter generation at BNL 9, 10 are evidences that SRNA-2KG has the possibilities as a referent proton transport code. The final stage

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of SRNA-2KG verification was the QUADOS intercomparation of proton transport codes 11, 13 .

RADFET PACKAGING

In order to use numerical methods in this paper, the appropriate geometry form of a MOSFET dosimeter was defined using the adequate software. The SRNA program uses RFG geometry for dosimeter geometry description. According to the available data for a very sensitive MOSFET [4], 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 0.2 mm in area) is a 1 m 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 our numerical experiment based on photon transport. The package lid is a 250 m thick kovar (Ni, Co, Fe) shell over the 250 m vacuum layer, which is up epoxy bulb.

NUMERICAL METHOD

SRNA-2K5 performs the Monte Carlo transport simulation of protons in 3-D source and 3-D geometry of arbitrary materials. The proton transport description is based on the condensed history model and on the model of compound nuclei decays that is created in a nonelastic nuclear interaction by proton absorption. The SRNA package has been developed for the time independent simulation of proton transport by the Monte Carlo method for numerical experiments in 3-D geometry with an arbitrary spectrum of protons generated from the source. In proton passage through materials the following processes may occur: the loss of energy in inelastic and elastic scattering with atoms, and the loss of energy in nonelastic nuclear interactions. If a proton trajectory is divided into a great number of steps, proton passage can be simulated according to the Berger's condensed random walk model. The conditions of the angular distribution and the fluctuation of energy loss determinate the step length. The physical picture of these processes is described by the stopping power, Moliere's angular distribution, Vavilov's distribution with Sulek's correction per all electron orbits, and Chadwick's cross-sections for nonelastic nuclear interactions, obtained by his GNASH code. According to the physical picture of proton passage and with probabilities of proton transition from the previous to the next stage, which is prepared by the SRNADAT program, the simulation of proton transport with the SRNA-2K5 program runs according to the usual Monte Carlo scheme: (1) a proton from the input spectrum prepared for random choice of energy, position and space angle is emitted from the source; (2) the proton is loosing average energy in the step; (3) in that step, the proton experiences a great number of collisions and changes direction of movement randomly chosen from angular distribution; (4) random fluctuation is added to the average energy loss; (5) the proton step is corrected with data about the proton position before and after scattering; (6) there is the final probability in the step for nonelastic nuclear interaction to occur, and for the proton to be absorbed. Compound nuclei decay with the emission of protons, neutrons, deuterons, tritons, alpha particles or photons. A particular decay particle is sampled from Poisson's distribution with the appropriate average values of multiplication factor of each particle. The energy and angle of the particle emission and the factors of multiplication are determined from the cross-section that is obtained by the integration of differential cross-section for nonelastic nuclear interaction. The energy and angle of secondary neutron are sampled from the emission spectrum. Neutron and photon transports are not included in the current model.

RESULTS AND DISCUSSION

The general scheme of physical model used in the Monte Carlo simulation previously described is applied to the specific geometrical configuration represented in fig. 1 and for various material layer arrangements. In the numerical experiment monoenergetic beam of protons containing 10^6 particles is incoming perpendicularly to the upper surface of the sensitive volume.

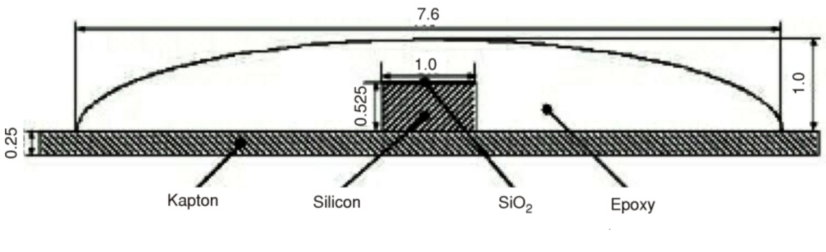

Figure 1. A schematic diagram of the MOSFET dosimeter without the package lid. The sensitive volume (SiO2) is located on the top of the silicon substrate and under the epoxy cover (all units area in mm)

Inspecting the results given in tabs. 1-3 one can conclude that there is a change in the deposited energy within the sensitive volume in cases when the kovar lid is present or absent. This change is the greatest for the energies of proton of around 60 MeV and is caused by the energy dependence of cross-sections describing the proton-layer material interaction.

Table 1. Total deposited energy in the MOSFET material zones for the proton beam $E_p = 10$ MeV, simulation with 10^6 incident particles, for two packaging configuration (without and with the kovar package lid)

Material zone	Deposited energy without package lid [MeV]	Deposited energy with package lid [MeV]	Ratio for influence of package lid
Kapton	0.154 10^7	0.154 10^7	1
Si	0.699 10^7	0.699 10^7	1
SiO_2	0.580 10^3	0.578 10^3	0.997
Epoxy	0.147 10^7	0.147 10^7	1
Kovar	–	–	–

Table 2. Total deposited energy in MOSFET material zones for the proton beam $E_p = 60$ MeV, simulation with 10^6 incident particles, for two packaging configuration (without and with kovar package lid)

Material zone	Deposited energy without package lid [MeV]	Deposited energy with package lid [MeV]	Ratio for influence of package lid
Kapton	0.359 10^6	0.359 10^6	1
Si	0.109 10^7	0.109 10^6	1
SiO_2	0.747 10^2	0.866 10^2	1.16
Epoxy	0.141 10^7	0.141 10^7	1
Kovar	–	0.163 10^7	–

Table 3. Total deposited energy in MOSFET material zones for the proton beam $E_p = 100$ MeV, simulation with 10^6 incident particles, for two packaging configuration (without and with kovar package lid)

Material zone	Deposited energy without package lid [MeV]	Deposited energy with package lid [MeV]	Ratio for influence of package lid
Kapton	0.248 10^6	0.248 10^6	1
Si	0.783 10^6	0.784 10^6	1.001
SiO_2	0.288 10^2	0.286 10^2	0.993
Epoxy	0.107 10^7	0.106 10^7	0.991
Kovar	–	0.111 10^7	–

For higher energies there is a significant amount of deposited energy in the kovar lid, indicating the direct dependence between layer material presence and the decrease in the deposited energy in the dosimetricaly sensitive volume of SiO_2. This trend of the decrease of the deposited energy with the increase of the proton energy is also present in the case without the kovar lid.

Figure 2 shows the deposited energy-incident proton energy dependence in the dosimetricaly sensitive volume when the RADFET contains the kovar lid. One can see that for the change of the incident proton energy from 10 MeV to 100 MeV, the deposited energy in SiO_2 layers changes for around 20 times. This means that the efficiency of proton detection decreases with the incident proton energy increase.

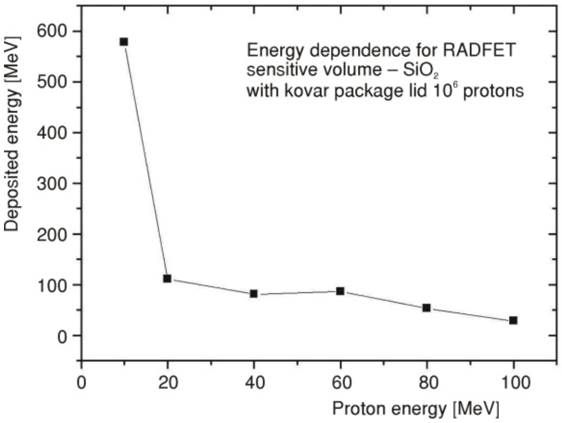

Figure 2. The dependence of deposited energy relative to different proton energy

CONCLUSIONS

Our intention in this paper was, among other things, to initiate the ideas on how to set up appropriate experiments, which would meet the conditions imposed by numerical simulations. However, the problem of the electrical measurements of properties in a medium that has microscopic (or even less) dimensions are well known. Thus, the purpose of this paper is to present the possibilities of the numerical simulations for the deposited energy distribution on microscopic or submicroscopic levels, primarily in a qualitative sense. Further investigations in other areas of interest, related to the study of electrical and technological characteristics of components necessary in the semiconductor technique and material physics, are planned.

Comparing the deposited energies in the dosimetricaly sensitive volume for cases when the kovar lid is present and absent in the RADFET structure one can conclude:

(1) the presence of the kovar lid essentially modifies the amount of deposited energy and this influence is especially pronounced for the energies around 60 MeV; and

(2) with the increase of incident proton energy, the RADFET detection efficiency decreases substantially.

REFERENCES

[1] Keating, A., Mohammadzadeh, A., Nickson, B., Jakšić, A., Hajdas, W., Modelling Packaging Effects on Proton Irradiation Response of NMRC RadFETs, 2003, http://escies.org/GetFile?rscid=907

[2] Tylka, A. J., Dietrich, W. F., Boberg, P. R., Brownstein, B., Flueckiger, E. O., Petersen, E. L., Shea, M. A., Smart, D. F., Smith, E. C., CREME96, A Revision of the Cosmic Ray Effects on Micro-Electronics Code, December, *IEEE Trans.Nucl.Sci., 44* (1997), 6, pp. 2150-2160

[3] Savić, Z., Stanković, S., Kovačević, M., Petrović, M., Energy Dependence of PMOS Dosimeters, *Rad. Prot. Dos., 64* (1996), 3, pp. 205-211

[4] Stanković, S., Ilić, R., Osmokrović, P., Lončar, B., Vasić, A., Computer Simulation of Gamma Irradiation Energy Deposition in MOSFET Dosimeters, *IEEE Trans. Plas. Sci., 34* (2006), 5, pp. 1715-1718

[5] Pease, R. L., Simons, M., Marshall, P., Comparison of pMOSFET Total Dose Response for Co-60 Gammas and High Energy Protons, *IEEE Trans.Nucl.Sci., 48* (2001), 3, pp. 908-912

[6] Ilić, R. D., SRNA-2K5, Proton Transport Using 3D by Monte Carlo Techniques, OECD NEA Data bank, IAEA-1382, March, 2005, http://www.nea.fr/dprog

[7] Ilić, R. D., Lalić, D., Stanković, S. J., SRNA-Monte Carlo Code for Proton Transport Simulation in Combined and Voxelized Geometries, *Nuclear Technology & Radiation Protection, 17* (2002), 1-2, pp. 27-36

[8] Mascia, E. A., Schreuder, N., Anferov, V., Characterizing of Proton Therapy Beam Using a Multi-Layer Faradey Cup, Internal Report, Indiana University Cyclotron Facility, Bloomington, Ind., USA, August 10, 2001, Internal Report

[9] Beebe-Wang, J. J., Dilmanion, F. A., Peggs, S. G., Schlyer, D. J., Vaska, P., Feasibility of Positron Emission Tomography of Dose Distribution in Proton-Beam Cancer Therapy, EPAC, Paris, 2002

[10] Beebe-Wang, J. J., Dilmanion, F. A., Peggs, S. G., Schlyer, D. J., Vaska, P., PET Imaging of Dose Distribution in Proton-Beam Cancer Therapy, *Nuclear Technology & Radiation Protection, 20* (2005), 1, pp. 23-26

[11] Agosteo, S., QUADOS Problem P3, 2003, www.nea.fr/download/quados/Prezentazioni%20Web/P3_web/

[12] Mascia, A., Schreuder, N., Ilić, R. D., First Joint Meeting of the Nuclear Physicists of the American and Japanese Physical Society, Maui, Hawai, USA, Arhives of the Bulletin of the American Physical Society, 2001, http://flux.ops.org/MEETNGS/YR01/HAW01/ABS/S420.html#SMS.058

[13] Ilić, R. D., Pešić, M., Pavlović, R., Distribution of Proton Absorbed Dose in Human Eye Simulated by SRNA-2KG Computer Code, International Intercomparison of the Usage of Computer Codes in Radiation Dosimetry, *Proceedings*, Final Workshop, Bologna, Italy, 2003

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УТИЦАЈ КОНФИГУРАЦИЈЕ ПАКОВАЊА СА ПОКЛОПЦЕМ ОД КОВАРА НА ОДЗИВ РАДФЕТА НА ПРОТОНСКО ЗРАЧЕЊЕ

Полупроводничке компоненте које су осетљиве на радијацију као што су МОСФЕТ (РАДФЕТ) имају бројне примене у космичким истраживањима, у нуклеарној технологији и истраживањима, и радиотерапији. Пошто је протонско зрачење основни део космичког зрачења у природном окружењу, важно је прецизније познавати одзив РАДФЕТ-а на протонско зрачење. У овом раду спроведена је нумеричка симулација одзива РАДФЕТ-а на протоне. За праћење транспорта протона Монте Карло методом, софтвер СРНА-2К5 је развијен и прилагођен да прорачунава депоновану енергију у сваком делу структуре РАДФЕТ-а и расподелу апсорбоване дозе унутар осетљиве запремине дозиметра која има микроскопске димензије. Резултати прорачуна показују да одзив РАДФЕТ-а на протонско зрачење значајно зависи од конфигурације паковања са поклопцем од ковара.

Кључне речи: РАДФЕТ, ковар поклопац, протонско зрачење, СРНА-2К5