RADIATION TOLERANCE INVESTIGATION OF A SI DETECTORS AND MICROELECTRONICS USING NSC KIPT LINACS

A.N. Dovbnya, N.I. Maslov, N.A. Dovbnya
NSC KIPT, Kharkov, Ukraine
nikolai.maslov@kipt.kharkov.ua

A possibility of full irradiation tests of semiconductor detectors and microelectronics using electron accelerators are considered in the present work. The techniques for irradiation and for detector tests were described. The data on the efficiency of electron and bremsstrahlung action on the Si bulk material are presented.

PACS numbers: 29.40.Wk

1 INTRODUCTION

Silicon planar detectors (SPD) are used at present widely in physics, its use started in medicine and in different fields of technics. Microelectronics technologies developed during last decades are used for SPD production. Fig. 1 shows the cross-section of the silicon plane detector [1] and Fig. 2 shows the corner of the multichannel microstrip detector [2], which are designed and studied at NSC KIPT.

Fig.1.Cross section of the silicon plane detector: 1 - active zone of the detector, 2 - oxide layer, 3 - Al layers, 4 - p/n transitions of the active zone and of the guard ring, 5 - n+-doped silicon layer, 6 - Al layer of the guard ring.

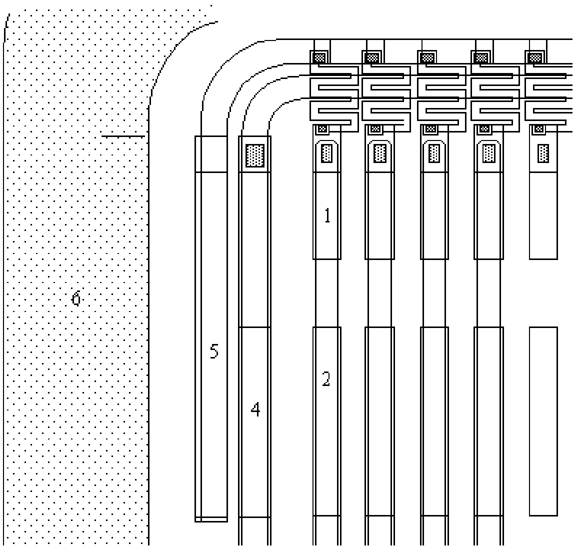

Fig. 2. Corner of the multichannel microstrip detector: 1 - contact pad of the microstrip active zone, 2 - contact pad of the integrated capacitors, 3 - polysilicon resistors, 4 - p^+-guard ring, 5 - basing pad of microstrip active elements, 6 - n^+-guard ring.

Generally, semiconductor detectors are used by the action of high-energy particles of different types and of wide-energy ranges. In high-energy physics experiments, for example, a total equivalent irradiation dose may be up to 10 Mrad and up to 10^{14} n/cm^2 [3].

The action of radiation on semiconductor detectors is implemented, mainly, via two mechanisms. The first mechanism of bulk damaging consists in breaking the crystal symmetry through displacing atoms from their lattice sites. The second mechanism of surface damage consists in changing the charge state of the Si/SiO$_2$ interface through the oxide ionization [4, 5]. In view of this, to simulate the real radiation conditions, it is necessary to irradiate the detector with ionizing radiation and with required neutron fluence. Namely, the neutrons simulate the action of high-energy particles on the bulk of the detector material [4]. Fast simulation of bulk damage for development of detectors may be also, probably, carried out with sources of other particles. These particles would possess certain properties, such as a high penetrating ability and high energy of shifted atoms in interaction.

In the present work a possibility of full irradiation detector and detector microelectronics tests using electron accelerators are considered. The data on the efficiency of electron and bremsstrahlung action on a Si bulk material are compared with the neutron efficiency.

2 INVESTIGATION OF HIGH-ENERGY ELECTRON ACTION ON SI DETECTORS

The energy absorbed by irradiated objects (dose in Gy) is one of the basic parameters characterizing the interaction between ionizing radiation and substance. However, it is not sufficient to measure only the dose if one irradiates semiconductor detectors and microelectronics with high-energy particles. In this case the radiation effects are determined essentially by volume radiation defects arising due to displacements of substance atoms by particles of acting radiation.

2.1 Absorbed dose

The dose (Gy or rad) in the specimen irradiated with electrons was determined using the well-known values of ionization energy losses and the measured integral densities of electron fluxes. The dose and its distribution over the detector were also measured with colour film dose meters. The colour film-ref dose meters permits one to perform measurements with an accuracy ≤20% under steady outer conditions and the temperature not exceeding 60ºC. The measurements of the optical density of dose meters were made with micro-photometers.

2.2 Investigation of electrons action on bulk material

The efficiency of electrons action on bulk material of the microstrip detector and readout electronics is determined from the change in the lifetime of charge carriers in silicon specimens-witnesses [6].

The lifetime of nonequilibrium charge carriers (τ) is an electrophysical characteristic of a semiconductor material that is most sensitive to radiation. For example, if one irradiates samples with 10 MeV electrons the changes in the lifetime of nonequilibrium charge carriers can be measured for the integral flux density 10^{10} e^-/cm^2. The change of the inverse lifetime $1/\tau$ satisfies the linear dependence in a broad range of integral flux densities F that is very convenient for determining the damage constant (Fig. 3).

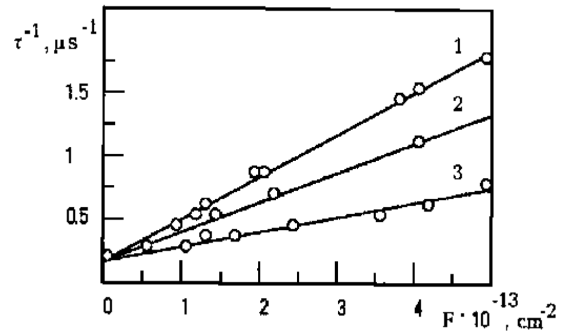

Fig.3. Inverse lifetime plotted against integral flux densities of electrons with energies: 1 – 5 MeV, 2 - 30 MeV, 3 – 120 MeV.

It is known that neglecting the influence of the surface one can determine the leakage current of a semiconductor detector from the relationship [7]

$$j=qn_jWA/2\tau, \quad (1)$$

where q is the electron charge, W is the depth of the detector depletion, A is the active region of the detector, τ is the effective minority carrier lifetime and n_j is the intrinsic carrier concentration. The expression for the change of the leakage current of the detector normalized by one acting particle or one dose unit will have the form

$$\Delta j= 0.5qn_jWA\cdot\Delta\tau^{-1}/D, \quad (2)$$

similar to the well-known expression for the radiation constant K_τ of a semiconductor material [5, 6]

$$K_\tau=\Delta\tau^{-1}/D. \quad (3)$$

Since the leakage current and the radiation constant of the detector material have similar dependencies on the carrier lifetime, then measuring the quantity K_τ for the detector material, one can judge on the efficiency of radiation action on a semiconductor detectors.

3 DAMAGING EFFICIENCY OF HIGH ENERGY ELECTRONS

In Fig .4 plotted is the efficiency of the radiation damage of the detector silicon K_τ.

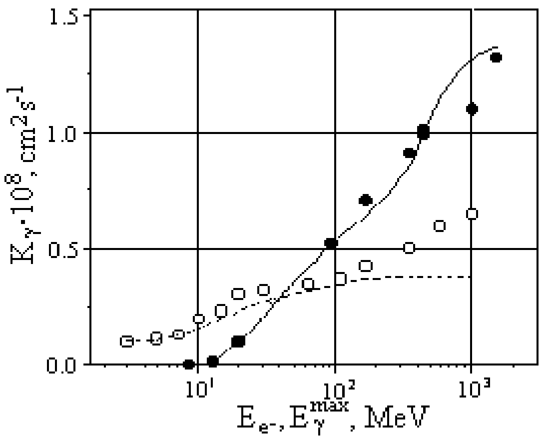

Fig. 4. Efficiency of the radiation damage of the detector silicon under action of accelerated electrons (□) and gamma-quanta of bremsstrahlung spectrum (•).

In Fig. 5 plotted are the inverse lifetimes $1/\tau$ in the silicon specimen and in the Si detector as a function of the irradiation dose. Irradiation by 20 MeV electrons.

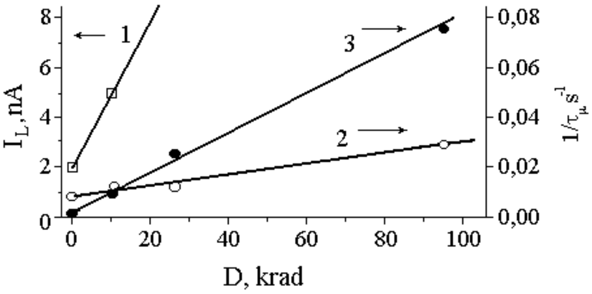

Fig. 5. Leakage current (1), inverse lifetimes (2) in Si detector and inverse lifetime (3) in the silicon specimen as a function of the dose.

The comparison of the values of the slope of $1/\tau$ $=f(D)$ dependences show that the radiation resistance of the detector is higher than that of the initial silicon. Probably, it can be explained by the heterogeneity of the detector surface as well as by the annihilation centers in the material bulk created in the process of technological treatment. Comparison with neutron irradiation (14 MeV) shows the efficiency ratio ~40 for 20 MeV electrons.

So, using the specimen-witness one has the possibility to control the conditions of irradiation by comparing the measured radiation damage constant K_τ with the results obtained previously. The irradiation of the specimen-witness was performed also with the aim to estimate the influence of surface and other effects on the change of the leakage current during irradiation. The 8 mm thickness of the silicon specimen was selected sufficiently high so that the lifetime of minor charge carriers τ_{NCC} can be measured without taking into account the surface influence of the commonly used contactless RF-method. At the same time, the silicon thickness was sufficiently small for neglecting the electron energy losses over the specimen thickness under irradiation.

4 INVERSION OF N-TYPE SILICON BY DETECTORS IRRADIATION

A change in the lifetime of charge carriers in a bulk material leads by irradiation mainly to the decreased signal/noise ratio. One more effect of Si detectors damaging by hard irradiation was displayed and is studied intensively last ten years [8-9]. Radiation damage in Si detectors results in a change of the effective impurity concentration and in conductivity type inversion of Si. Radiation removes shallow impurities by the creation of donor and acceptors and, since acceptor-like states predominate, the n-type Si inverts to the p-type. A detector work possibility is lost, if a detector is not tolerant to type inversion or it takes to increase the depletion voltage after type inversion.

The change of the type inversion may be studied using capacitance voltage (C-V) measurements [8-10]. Fig. 6 shows the bulk Si capacity against the depletion voltage for different irradiation doses.

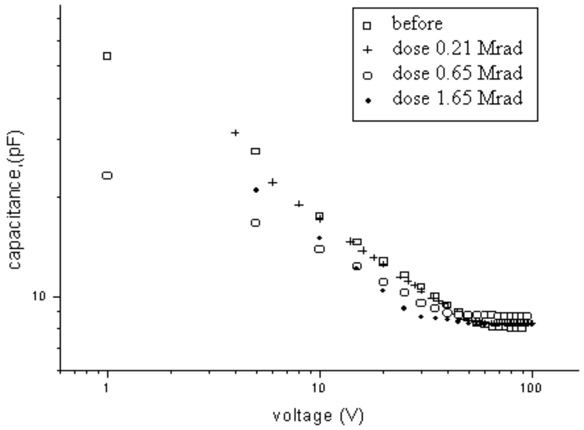

Fig. 6. Bulk capacity against the depletion voltage for different integral doses. Irradiation by 20 MeV electrons.

Fig. 7 shows the full depletion voltage against the irradiation dose.

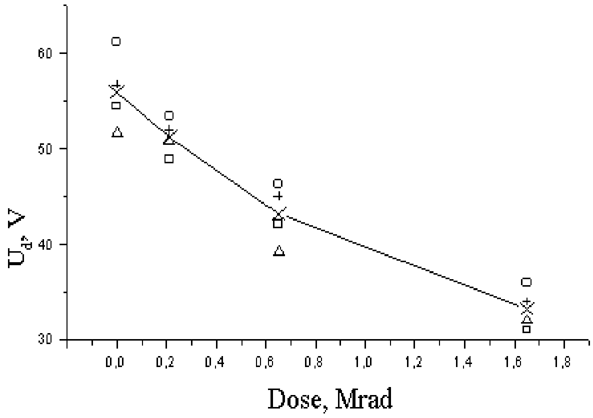

Fig.7. Full depletion voltage for different irradiation dose. O, , Δ, +– are here the data for four different detectors. Irradiation by 20 MeV electrons.

The voltage of total depletion is determined from the point where the strong and weak variations of capacity against voltage in log-log coordinates intersect.

5 CONCLUSIONS

The possibility of full irradiation tests of semiconductor detectors and microelectronics in NSC KIPT were presented. The techniques for irradiation [11] and for detector tests [12] were created and developed last years. Required Quality Assurance plan for tests was registered by the accredited body ISO 9000.

REFERENCES

1. G.Bochek, V.Kulibaba, N.Maslov, S.Naumov, A.Starodubtsev. Silicon pad detectors for a simple tracking system and multiplicity detectors creation // *Problems of Atomic Science and Technology. Issue: Nuclear-Physics Research* (37). 2001, v. 1, p. 36-39.
2. N.Maslov, V.Kulibaba, S.Potin, A.Starodubtsev, P.Kuijer, A.P. de Haas, V.Perevertailo. Radiation tolerance of single-sided microstrip detector with Si3N4 insulator *// Nuclear Physics B* (Proc. Suppl.). 1999, #78, p. 689-694.
3. *Proc. of the Workshop on LHC Backgrounds*, CERN, 2 March 1996.
4. Holmes-Siedle, M.Robbins, S.Watts et al. Radiation tolerance of single-sided silicon microstrips // *Nucl. Instrum. Meth. in Phys. Res.* 1993, A 326, p. 511-523.
5. H.W. Kraner // *Nucl. Instr. and Meth.* 1984, A 225, p. 616-618.
6. N.I.Maslov, G.D.Pugachev, M.I.Heifets // *Physics and Technics of Semiconductors.* 1982, v. 16, No 3, p. 513-515 (in Russian).
7. A.S. Grove. *Physics and Technics of Semiconductor Devices.* New York: Wiley, 1967. (Ch. 6, p. 176-177).
8. D.Pitzl, N.Cartiglia, B.Hubbard et al. Type inversion in silicon detectors // *Nucl. Instrum. Meth. in Phys. Res.* 1992, A 311, p. 98-104.
9. E.Fretwurst, N.Claussen, N.Croitoru et al. Radiation hardness of silicon detectors for future colliders // *Nucl. Instrum. Meth. in Phys. Res.* 1994, A 339, p. 357-364.
10. A.P. de Haas, P.Kuijer, V.I.Kulibaba, N.I.Maslov, V.L.Perevertailo, V.D.Ovchinnik, S.M.Potin, A.F.Starodubtsev. Characteristics and radiation tolerance of a double-sided microstrip detector with polysilicon biasing resistors // *Problems of Atomic Science and Technology. Issue: Nuclear-Physics Research* (36). 2000, v. 2, p. 26-33.
11. K.I.Antipov, M.I.Ayzatsky, Yu.I.Akchurin et al. Electron linacs in NSC KIPT: R&D and application // *Problems of Atomic Science and Technology. Issue: Nuclear-Physics Research* (37). 2001, v. 1, p. 40-47.
12. P.Kuijer, A.Kaplij, V.Kulibaba, N.Maslov, V.Ovchinnik, S.Potin, A.Starodubtsev. Control complex for a double-sided microstrip detector production and tests // *Problems of Atomic Science and Technology. Issue: Nuclear-Physics Research* (36). 2000, v. 2, p. 41-45.