METHOD OF MEASURING FAST NEUTRON FLUENCE USING THE PLANAR SILICON DETECTORS

A.I. Shafronovskaia, N.I. Zamyatin, A.E. Cheremukhin, LHEP JINR, Dubna, Russia
(on behalf of the QUINTA Collaboration)

Abstract

The technique reported of fast neutron fluence measurements using silicon detectors. One of the main macroscopic effects at radiation damage of silicon detectors by fast neutrons is increase of the reverse current. The increment of the reverse current detector is a linear dependence on fast neutron fluence and is determined by the formula (Eq. 1):

$$\Delta I = \alpha_I \times F \times V, \qquad (1)$$

where $\Delta I = (I_{irrad.} - I_{nonirrad.})$ (A) – the measured increment of the reverse dark current after irradiation of the detector normalized to temperature of +20˚C, $\alpha_I = (5\pm0.5)\times10^{-17}$ (A/cm) – current constant radiation damage of silicon for neutrons with energy 1 MeV, F (cm^{-2}) – equivalent fluence of fast neutrons with energy 1 MeV, $V = d\times S$ (cm^3) – the volume of the detector at the full depletion voltage. The experimental results of measurements of fast neutron fluence with silicon detectors are obtained on the pulsed fast neutrons reactor (IBR-2, channel #3) and on the experimental facility QUINTA JINR, Dubna.

MECHANISM OF RADIATION DAMAGES BY FAST NEUTRONS OF SILICON (SI-DETECTORS)

Fast neutrons with energy of E_n>100 keV are create in volume of silicon radiation damages in the form of violations of a crystal lattice (knocking-out by a neutron of primary atom from lattice site and then created a cascade of defects already beaten out atoms).

Reverse thermogeneration current of the detector grows linearly [1] with increasing fast neutron fluence (see Eq. 1).

The physical meaning of the constant α_I are following: when irradiated silicon detector volume 1cm^3 neutrons with an energy of 1 MeV and a fluence value of 1 n/cm^2 current of the detector is increased due to radiation damage to 5×10^{-17} A at +20˚.

RADIATION DAMAGE OF SILICON DETECTORS UNDER IRRADIATION WITH FAST NEUTRONS (E_N> 100 KEV)

What Happens in Irradiated Silicon

Knocking-out of atom of Si from a crystalline grid with formation of vacancy (V) and interstitial atom Si (I).

V and I to form - electrically active deep centers (VV, VO, VP, IC, I VP, etc.).

Effects of Deep Centres (see Fig. 1)

- Thermal generation / recombination of carriers in volume leads to an increase in reverse (dark) current of the detector, leading to increased noise and power dissipation on the detector.
- Capture (e-h)-pair reduces the primary ionizing charge collection efficiency and, consequently, to reduce the signal from the ionizing particles.
- Compensation impurity results in a change of volume resistivity values of the detector and to change the operating voltage (voltage of full depletion of the detector), respectively.

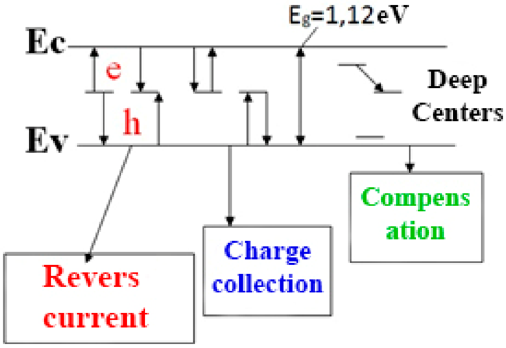

Figure 1: Effects of deep centers.

Fig. 2 shows function of defect formation of D(E) in MeV×mb, (Ougouag) and the function NIEL-FN-522 in keV×cm^2/g, (van Ginneken) [2].

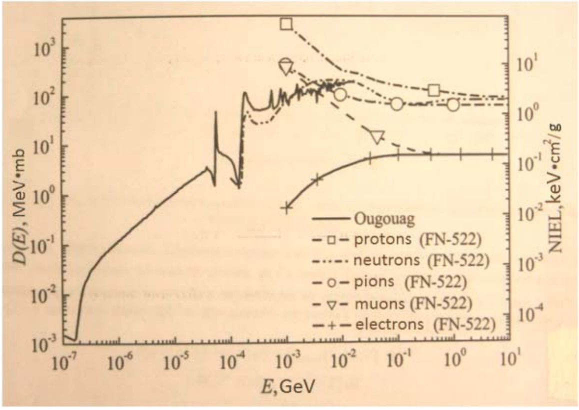

Figure 2: Function of defect formation of D(E) and the function NIEL-FN-522.

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Table 1. Energy of offset of atom of Ed and minimum energy E_0^{min} of electrons and neutrons (protons) necessary for creation of defect of offset.

Semiconductor materials	**Displaceable atom**	**Ed, eV**	**E_0^{min},keV**	
			e	**n (p)**
Ge	Ge	12-20	320-530	0,17-0,29
Si	Si	11-22	115-330	0,18
GaAs	Ga	9,0	230	0,13
	As	9,4	260	0,14
CdTe	Cd	5,6	235	0,13
	Te	7,8	340	0,18
$Cd_{0,8}Zn_{0,2}Te$	Cd	5,6	235	0,13
	Te	7,8	340	0,18
C (diamond)	C	80	530	0,29

WHY IS USEFUL SI-DETECTORS NOT FOR ITS INTENDED PURPOSE (MEASURING OF ENERGY IONIZING PARTICLES), AND FOR MEASUREMENT FAST NEUTRON FLUENCE IN DC MEASUREMENT MODE OF RADIATION DEFECTS

Pin-diode structure with full depletion has strictly fixed sensitive volume (with an electric field) – space charge region (SCR).

Value of volume of the space charge region is determined by the thickness of the detector and area (p-n)-junction.

Thickness detector (crystal) measured with high accuracy (2%), and the square of transition is known from topology of detector with micron accuracy.

Modern technology of planar Si-detectors allows you to receive extremely low reverse current, defined the charge carrier lifetime in detector's volume (surface leakage to neglect).

Increment the reverse current of detector by fast neutron irradiation will be determined only by radiation defects in sensitive volume of the detector (SCR), which is known with high accuracy.

Si-detector as a detector for DC measurement, caused by radiation defects (without preamplifier, see Fig. 3).

METHOD OF MEASUREMENT OF THE EQUIVALENT 1 MEV FAST NEUTRON FLUENCE USING SI-DETECTORS

- Measurement of the thickness of detectors, visual inspection.
- Before irradiation screening detectors with good parameters to measure IV and CV characteristics of the detectors (U_{bd}>2×U_{fd}; I_d=a×$U_d^{1/2}$, i.e. there is no surface currents).
- Packaging, labels, entry into the database.
- The location and fixation detectors in specified positions on the physical installation and irradiation with astronomical time recording the start and end of irradiation.
- Removal of detectors after irradiation and storage in a freezer at t = –15°.
- Measurement of IV and CV after irradiation, detectors put into storage in the freezer.
- Correction of the measured currents to t = +20°.
- Calculation of the value of the equivalent 1 MeV neutron fluence by Eq. 1, tabulation and graphing.

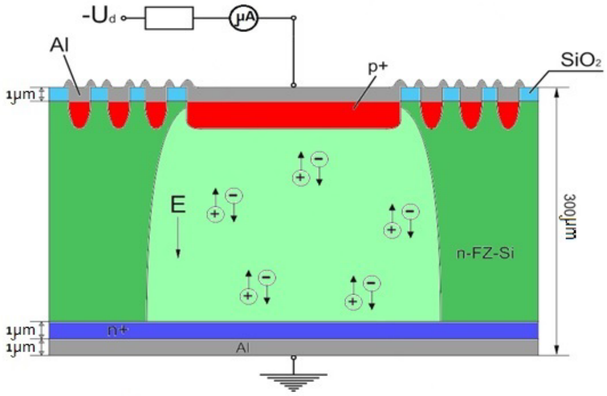

Figure 3: Si-detector without preamplifier.

Figure 4 shows the experimental IV characteristics for the detector before- and after- irradiation by fast neutrons. From the measured IV characteristics (+20°) obtained the value of the equivalent fluence of 1 MeV neutrons equal to $\Phi = 2{,}86\times10^{10}cm^{-2}$.

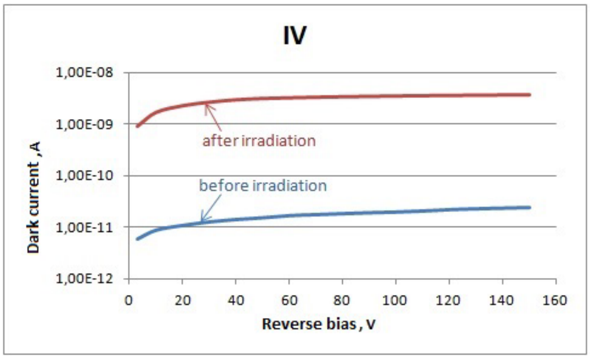

Figure 4: IV characteristic of the detector active area 13 mm^2 and a thickness of 300 μm before- and after-irradiation by fast neutron on QUINTA (as an example).

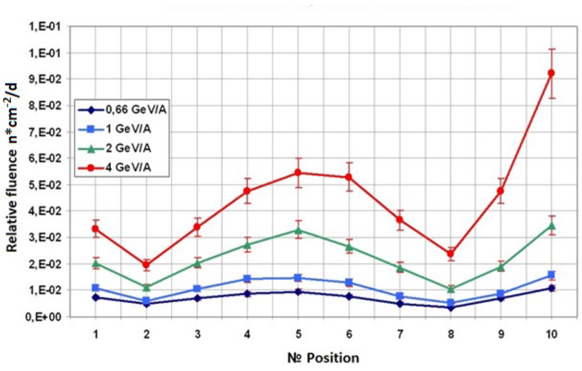

Figure 5: Corrected to 1 MeV neutron fluence (1 deuteron) on the surface of the “QUINTA” for different Ed.

CONCLUSION

- Experiments show that the value of radiation damage by fast neutron Si-detectors can measure equivalent fluence 1 MeV neutron for the unknown spectrum.
- Linear dependence of volume current of detector from fluence fast neutron allows you to measure fluence in the range from 10^8 cm^{-2} to 10^{16} cm^{-2}, the sensitivity of the method depends on the volume of the detector (the higher volume, the higher sensitivity).
- This way of measuring the fluence allows you to get the experimental result within 2-3 hours after extraction of detectors out of zone irradiation.
- Accuracy of method defined by accuracy current constant damages $\alpha_I=5\times10^{-17}\pm10\%$ ($A\times cm^{-1}$), at 20˚.
- To improve the accuracy of the measurement is necessary for calibration of detectors on the mono energy neutrons.

REFERENCES

[1] I.A.Golutvin et al., “Radiation hardness of silicon detectors for collider experiments”, preprint E14-95-97, Dubna (1995).

[2] Van Ginneken A. Non ionizing energy deposition in silicon for radiation damage studies: Fermi Nat. Accelerator Lab. Report FN-522, (1989).