INFLUENCE OF IRRADIATION ON DEFECTS CREATION IN PIN DIODE STRUCTURE

***V. Sopko*[1]*, B. Sopko*[2]*, D. Chren*[2]*, J. Dammer*[1]**

[1] *Institute of Experimental and Applied Physics, Czech Technical University in Prague,*
Horska 3a/22, CZ 12800 Prague 2, Czech Republic,

[2] *Department of Physics, Faculty of Mechanical Engineering, Czech Technical University in*
Prague, Technicka 4, CZ 16000 Prague 6, Czech Republic Name of Institute
E-mail: vit.sopko@utef.cvut.cz

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1. Introduction

Studies of radiation defects continue to be important and will find increasing application as the radiation doses expected to be measured by semiconductor detectors in future experiments will keep increasing to higher values. An endeavor to capture some of the changes associated with high radiation doses has been the basic motivation for the present work.

2. The long-base Si diode theory

Silicon, like other semiconductor materials, electrical properties strongly depend on distortion of the periodicity of crystal lattice.

The defects introduced into the crystal lattice by radiation can basically be broken down into two groups: the point defects and the clustered defects. These latter defects occurring in clusters, produced e.g. by neutron irradiation, can disrupt considerable volumes of the crystal structure. Irradiation of silicon with fast neutrons produces defect clusters having from 10^{-6} m^{-3} to 17.10^{-6} m^{-3} in size [2].

Interactions of neutrons with the silicon lattice atoms create defects that act primarily as recombination or capture centers, decreasing the lifetime of minority carriers of current. If the damage constant K, which is a function of incident neutron energy and of the material characteristics of semiconductors, is taken into account, then the reduction of lifetime due to irradiation can be described by the relation

$$\frac{1}{\tau} = \frac{1}{\tau_0} + K\Phi, \qquad (2.1)$$

where τ_0 is the pre-irradiation lifetime, τ is the post-irradiation lifetime and Φ is the neutron fluence by which the semiconductor was irradiated. The simplicity of this basic formula, upon which all the theoretical analyses are based, is complicated by difficulties experienced when measuring the lifetime of minority carriers. However, the measurement of lifetime of minority carriers of current is complicated and rather difficult to perform even in specialized centers. Therefore, it is necessary to that an electrical parameter of the semiconductor be chosen such that depends on the lifetime of the carriers and can be measured easily. From this viewpoint, the simplest way is to measure the voltage drop on the diode in the forward direction at a constant current, since this is a parameter that has a minimum dependence on the diode production technology used.

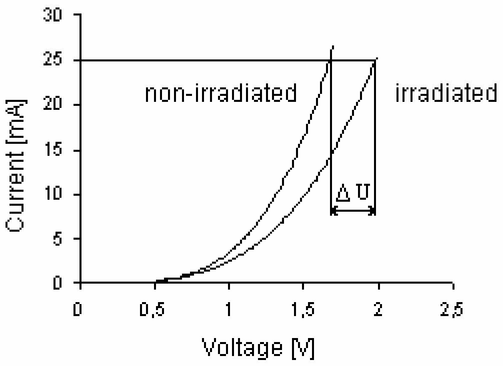

Fig. 2.1*: Changes in the volt-ampere characteristics*
Si diodes with long base before and after irradiation

Irradiation of a diode by fast neutrons is also reflected in a shift of its volt-ampere characteristics – see Figure 2.1. The measure of this exposure is the voltage change in the forward direction of the neutron fluence. For dosimetry purposes, a diode of spherical geometry would be most appropriate; this being not feasible, we use an approximately cubic geometry.

The relationship between the change in forward voltage and the fluence of neutrons which provoked this change can be described as

$$\Delta U = \int_E \frac{\Delta U\left(E\right)}{\Phi(E)} \Phi(E) \mathrm{d}E \,. \tag{2.2}$$

This is integrated over the energy interval E of the neutron spectrum which caused the electrical parameters of the diode to change. The sensitivity of the diodes, defined as the ratio of voltage change to the fluence , can be expressed as

$$\frac{\Delta U}{\Phi} = K.\tau.f\left(\frac{d}{L}\right), \tag{2.3}$$

where K is a damage constant already mentioned, is the lifetime of minority carriers of current and is a complex function of the ratio of base length and the diffusion length of the minority carriers.

3. Manufacture of type S1 PIN diodes

Wafers of N-type silicon single crystals, of resistivity ranging from 0.7 to 2 Ohm.m, have a final thickness of 1.2 mm after polishing and etching. Application of new single crystal production technologies developed during the last decade (dislocation-free single crystals, in combination with an alloying technology by nuclear transmutation doping) introduced considerable quality improvements of the silicon materials, thanks especially to reduced scatter of their electrical parameters and to their improved stability when subjected to further processing, etc. The diffusion processes came to be replaced by modern technologies such as ion implantation, allowing precision doping at low temperatures during very short time periods. Magnetron sputtering technology brought about an increase in quality and, thus, durability of metallic contacts, both in terms of their contact resistance and in terms of improved assembling of the measuring outlets (pin soldering). Thanks to all these methods, it is guaranteed that the silicon material will be exposed to thermal stressing for only very brief periods, thus reducing the amount of change of the electrical parameters of silicon. Then the plates are subdivided into different systems of a size of 1.2 by l.8 by l.8 mm^3, having previously removed the surface oxide and applied nickel-titanium contacts. Subsequently, the diodes thus made are fitted with soldered wire leads and encapsulated.

The main benefit due to the new technologies has been the stabilization of the parameters of dosimetric diodes. In type S1 diodes, the variance of initial voltage determined at the current of 25 mA was reduced to 1%. All these measures have contributed to the unification and standardization of the dosimetric characteristics of the diodes.

4. Results of the experiments

Measurements of the energy levels by DLTS were performed using type S1 dosimetric diodes (samples 1-10) irradiated by a ^{252}Cf source at the CMI (Czech Metrological Institute). On the as-irradiated diodes, the radiation dose received was determined by measuring the forward voltage at a constant current of 25 mA for 40 ms. Using a calibration curve [7] for type S1 diodes expressing voltage as a function of dose received, the doses actually received by the test diodes were computed from the difference in voltage before and after irradiation. The energy levels of defects were measured using a DLTS apparatus designed and built at the CTU. The energy levels determined from the experimental data are listed in a synoptic fashion in Table 1. For both the experimental and the calculated levels, the available literature was scanned for corresponding energy levels. The comparisons reveal that the levels comprise the following components: vacancies, vacancy complexes, or complexes with interstitial atoms i.e., impurities: boron, phosphorus, oxygen, carbon. The results show that at higher doses, the energy levels of traps will change; in the case of the diodes 6 and 10, which received a dose of nearly 8 Gy and more than 8 Gy, respectively, the levels for traps were 0.5792 eV and 0.5982 eV, different compared to the levels found for the diodes 1 to 5 and 7 to 9.

Tab. 1. *Energy levels in irradiated PIN diode.*

Diode	**Dose [Gy]**	**Measured energy trap [eV]**	**Energy trap [eV] [1]**	**Energy trap [eV] [2]**	**Energy trap [eV] [3]**	**Energy trap [eV] [4]**	**Energy trap [eV] [5]**	**Energy trap [eV] [6]**
1	1.42±0.28	0.3759 0.4550		0.44-0.47			0.36	0.37
2	3.09±0.62	0.3442 0.4372					0.36 0.41-0.47	0.36 0.42
3	1.36±0.27	0.2712 0.3341	0.26	0.34	0.26		0.28	
4	1.45±0.29	0.2198 0.4490		0.22 0.44-0.47	0.45	0.21	0.23 0.41-0.47	0.225
5	1.78±0.35	0.1685 0.3704	0.17 0.36	0.39	0.17	0.17	0.36	0.17 0.37
6	7.53±1.51	0.2460 0.3029 0.5792		0.29	0.26	0.25 0.30		0.58
7	1.37±0.27	0.222 0.2892 0.4312	0.23	0.22 0.29	0.23 0.44		0.23 0.41-0.47	0.225
8	1.77±0.35	0.2575 0.2585 0.3845	0.26 0.26	0.39	0.26 0.26			
9	1.40±0.28	0.1514 0.2598 0.3549	0.26 0.36	0.16	0.26	0.16	0.36	0.36
10	> 8 Gy	0.1778 0.3371 0.5982				0.18	0.17	0.17

5. Conclusion

A shift from VV^- to VV (neutral) is observed in neutron irradiated diodes. From the results obtained, an explanation that clearly offers itself is that the nature of the defects produced by irradiation of material exhibiting N type conductivity is different from those for type P material. Given that the experiments were conducted with the same material, i.e., the dopant present in the material remained unchanged, it can be stated that simply by changing the type of conductivity with increasing dose [8], a different kind of defects is produced, having different activation energies in the forbidden band.

All these results are consistent with the ongoing RD 50 experiments at CERN.

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