Degradation behaviors for high-temperature irradiated Si photodiodes

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1. Introduction

For several reasons, an interest in high-temperature electronics develops fast and the knowledge about their degradation under high-temperature irradiation conditions is highly desirable. This paper presents the results of a detailed study of the effects of high-temperature 4-MeV neutrons, γ-rays and 2-MeV electron irradiation, on the performance of silicon pin photodiodes.

2. Experiment

p+n Si pin photodiodes were fabricated on floating-zone (FZ) n-type (111) Si substrates doped by phosphorus to a resistivity of 2-4 kΩ cm. The sample temperature during irradiation was fixed ranging from 20 to 300 °C and was controlled by a panel heater, mounted in a chamber. In order to compare the radiation source dependence of radiation damage, the diodes were irradiated by 4-MeV neutrons produced by a 241Am-Be neutron source, 2-MeV electrons and by 8150.1 TBq 60Co. Before and after irradiation, the device performance was measured with the deep levels in the n-type Si substrate studied using DLTS methods.

3. Result and discussion

Figure 1 shows the typical current/voltage (I/V) characteristics after different high temperature neutron irradiation for a fluence of 1.0 x 10¹¹ n/cm². From this figure, it can be found that after irradiation the dark current increases, and that the degradation of the device performance decreases with increasing sample temperature during irradiation. To investigate the degradation behavior by room and high-temperature irradiation, one can calculate the damage coefficient (K) of the dark current by the following equation.

\[ K = \frac{\partial I_D}{\partial \Phi} \]  

where \( \Phi \) is the fluence. Based on equation 1, K value at room temperature of the neutron, γ-ray and the 2-MeV electron irradiation is calculated to be 7.2 x 10⁻²¹ n⁻¹Acm², 3.2 x 10⁻²⁴ e⁻¹Acm² and 1.1 x 10⁻²² e⁻¹Acm², respectively. It is clear that the difference of irradiation damage for different radiation sources is due to the different number of knock-on atoms (in other words: in non-ionizing energy loss), which is attributed to the difference of mass and the possibility of nuclear collisions [1]. Figure 2 shows the corresponding Arrhenius plot K versus 1/T_{irr} for neutron, electron and gamma ray irradiation. From this figure, one can calculate activation energy 0.09–0.03 eV, for different radiation source. The activation energy is nearly the same for neutrons and γ s, while it is slightly higher for the electron exposures. This means that irradiation at elevated temperatures has a stronger impact for the latter compared with neutrons and γ s, and that the cluster damage is somehow more thermally stable than the simple point defects like the V-O and V-V centers.
After a $1.1 \times 10^{11}$ n/cm$^2$ at room temperature neutron irradiation, two electron capture levels ($E_{111}$ and $E_{112}$) with ($E_c - 0.22$ eV) and ($E_c - 0.40$ eV) were induced in the n-Si substrate, while one minority hole trap ($H_{111}$) at ($E_v + 0.37$ eV) was found. In principle, it is expected that the $E_c - 0.22$ peak is associated with the A-center or V-O combined with the CiCs peak, while the $E_c - 0.40$ eV level contains the single acceptor charge state of the di-vacancy. In agreement with the behavior of the device performance, both electron traps decrease with increasing sample temperature during irradiation.

4. Conclusions

The degradation of the device performance and the introduction rate of the lattice defects decrease with increasing irradiation temperature. This result suggests that the creation and recovery of the radiation damage proceeds simultaneously at high temperatures.

Acknowledgements

Part of this work was supported by Giant-in-Aid for Scientific Research (No.14550660) from Ministry of Education, Culture, Sports, Science and Technology, and by Inter-University Laboratory for the Joint Use of JAERI Facilities.

References