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Neutron fluence dependence of x-ray energy responses for tomography detector arrays

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Introduction

Degradation in responses of semiconductor x-ray detectors after fusion-produced neutron exposure still remains one of the serious problems in recent fusion experiments. For the purpose of investigating neutron effects on semiconductor x-ray detectors, detection characteristics of n-type silicon semiconductor detectors which are similar to those utilized for x-ray-tomography detectors in the Joint European Torus (JET) tokamak, are studied.

Experimental Apparatus

X rays monochromatized with a double-crystal [Si(111)] monochromator (BL-15C) are incident on a semiconductor detector array irradiated with the neutron fluence of 10^{13}-10^{15} n/cm^2 by the use of the fusion neutronics source (FNS) of Japan Atomic Energy Research Institute. The detector array consists of 35 channels with anodes 4.5 mm by 0.96 mm at 0.99 mm spacing with common cathodes.

Experimental Results

In Fig. 1, the x-ray energy responses η/E of the JET detector arrays measured after neutron irradiation experiments are shown by the filled circles as a function of the D-T fusion-produced neutron fluence. Here, the open circle plotted at fluence of 5×10^{12} n/cm^2 represents the x-ray energy response before neutron irradiation for reference. The incident x-ray energy of 7.6 keV is applied. In Fig. 1, the first finding is made; that is, the recovery of the degraded response is found after the neutron exposure beyond around 10^{13} n/cm^2 into the detectors [1]. A further novel finding is followed as a "re-degradation" by a neutron irradiation level over about 10^{14} n/cm^2. Such a "non-linear" response behavior serves as a response survival of 30% at 7.6 keV even for 5×10^{14} n/cm^2 as compared to the response without the neutron exposure.

This non-linear response may be physically interpreted in terms of a type inversion from n- to p-type silicon in the detector. The increase in depletion layer thickness d_{dep} at a bias voltage V_b below its fully depleted voltage for n-type semiconductor detectors is found with increasing the neutron fluence. This increase in d_{dep} for n-type detectors has already been reported as an increase in post-neutron resistivity. It is generally believed that the dependence of d_{dep} on neutron fluence occurs due to a reduction in the effective impurity concentration which is equal to donor minus acceptor concentrations, for n-type material, in the extreme case leading to conversion to p-type silicon. The new findings of the "non-linear" response behavior due to neutron exposure is consistently explained by using our theory on the x-ray responses [2,3] in terms of the above described increase in d_{dep} and the reduction of the diffusion length L in a silicon substrate region located behind a depletion layer. The signal contribution from the substrate region to the total x-ray response for the detector dominates over the signal from the depletion layer particularly for low-bias operations as shown in reference [1]. Neutron irradiation produces damages to silicon substrate, and then the damages caused by neutron exposure creates deep levels in the silicon bandgap leading to reduction in the minority-carrier lifetime.

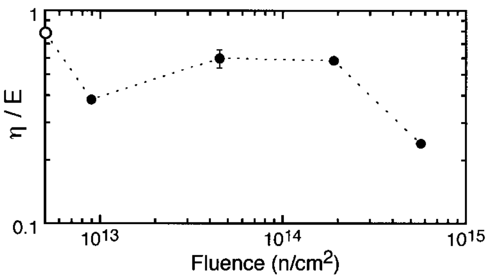

Fig. 1 Neutron fluence dependence of the x-ray energy responses for the JET detector arrays before irradiation (the open circle plotted at fluence of 5×10^{12} neutrons/cm^2 for convenience) and after irradiation with 14 MeV neutrons (the filled circles).

References

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