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Effects of neutron irradiation on silicon semiconductor detectors using D-T fusion-produced neutrons in the JET tokamak and the Fusion Neutronics Source

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Introduction

The effects of fusion-produced neutrons due to deuterium (D) and tritium (T) reactions on the energy responses of semiconductor x-ray detectors are investigated under the international fusion-research cooperation among the Joint European Torus (JET) tokamak in the European Union, the Fusion Neutronics Source (FNS) at Japan Atomic Energy Research Institute (JAERI), and the GAMMA 10 tandem mirror in Japan.

Recent fusion experiments using D-T reactions make a serious problem of semiconductor damage from fusion-produced neutrons. In particular, damage to silicon materials including such semiconductor plasma-monitoring detectors, glass fibers, optical-communication devices should be widely investigated for their applications under the future fusion environment.

Experimental Apparatus

X rays monochromatized with a double-crystal [Si(111)] monochromator (BL-15C) in the energy range of 6 to 15 keV are incident on *p-i-n* photodiode arrays employed for x-ray tomography in the JET tokamak. Each detector array consists of 35 channels with anodes 4.5 mm by 0.96 mm at 0.99 mm spacing with common cathodes. These detectors are fabricated using a 300-μm-thick n-type-silicon wafer.

Experimental Results

In Fig. 1, we show the ratio of the energy response η/E of the JET detector arrays after to before neutron exposure at a 6-V reversed bias voltage V_b. The degradation ratios in η/E with a neutron fluence of 4.6×10^{13} and 1.5×10^{14} neutrons·cm^{-2} are plotted in Fig. 1 using the open triangles and filled circles, respectively. In the FNS facility, D-T fusion-produced 14-MeV neutrons are irradiated into the detectors. On the other hand, in the JET tokamak, fusion-plasma experiments using D-T reactions (14-MeV neutron exposure of 1.1×10^{14} neutrons·cm^{-2}) as well as D-D reactions (2.45-MeV neutrons of 0.4×10^{14} neutrons·cm^{-2}) are carried out during the period of the use of the present detector for x-ray tomography. The data on the x-ray-energy responses in Fig. 1 are obtained using several machine times of synchrotron radiation experiments before and after these neutron irradiation experiments.

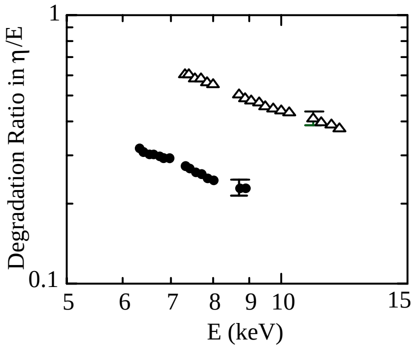

Fig. 1 The degradation ratios in η/E at V_b of 6 V with a neutron fluence of 4.6×10^{13} and 1.5×10^{14} neutrons·cm^{-2} are plotted using the open triangles and filled circles, respectively.

In Fig. 1, we show the degradation effects on η/E. The degraded response is within one order-of-magnitude less than the response before neutron irradiation under the exposure of 1.5×10^{14} neutrons·cm^{-2} in JET. The reduction of η/E due to neutron damage is explained using our theory on the x-ray response in terms of the reduction of a total sensitive depth ~ $d_{dep}+L$, where d_{dep} and L denote the depletion layer thickness and the minority-carrier diffusion length, respectively (for more detail, see Refs. [1]-[3]). The functional dependence of d_{dep} and L on neutron fluence is planned to be solved through these step-to-step researches. An important finding in Fig. 1 is a neutron degradation effect having x-ray-energy dependence; that is, the degradation ratio in Fig. 1 decreases with increasing x-ray energy.

References

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