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Long-term observations of x-ray energy responses of semiconductor detectors after neutron irradiation

Junko KOHAGURA*[1], Teruji CHO[1], Mafumi HIRATA[1], Tomoharu NUMAKURA[1], Noboru YOKOYAMA[1], Yamato TOMII[1], Serina KIMINAMI[1], Suguru TOKIOKA[1], Yasuhiro MIYAKE[1], Kiyoaki SHIMIZU[1], Makoto NAKAO[2], Takashi KONDOH[2], Takeo NISHITANI[2], Keiichi HIRANO[3], Hideki MAEZAWA[3], Syoichi MIYOSHI[1]

[1]Plasma Research Center, University of Tsukuba, Ibaraki 305-8577, Japan

[2]Japan Atomic Energy Research Institute, Ibaraki 319-1195, Japan

[3]KEK-PF, Tsukuba, Ibaraki 305-0801, Japan

Introduction

X-ray tomographically reconstructed data analyses by the use of silicon semiconductor detectors play an important role in controlled thermonuclear fusion research in order to investigate plasma electron behavior [1]. However, recent harsh radiation environments in fusion experiments by using deuterium-tritium and/or deuterium-deuterium reactions pose the serious problem of radiation-induced degradation in X-ray detection characteristics of semiconductor detectors. In this article, the effects of fusion produced neutron irradiation on X-ray energy responses of silicon semiconductor detectors are investigated in terms of dependence on time after the end of neutron irradiation process [2].

Experimental Apparatus

X rays monochromatized with a double-crystal [Si(111)] monochromator (BL-15C) are incident on semiconductor detectors 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. Semiconductor detectors investigated in the present work are similarly designed *pin* photodiode arrays (n-type wafer) for position-sensitive X-ray tomography diagnostics in the Joint European Torus (JET) tokamak. Each detector array consists of 35 elements with an individual anode of 4.5 mm by 0.96 mm.

Experimental Results

It is well known that detectors show radiation-induced degraded performance after irradiation such as an increase of leakage current, and changes in effective doping concentration. It is also known that the observed degraded characteristics of the detectors change gradually with time even after the end of the irradiation process. The effects are known as “annealing effect” and “reverse annealing effect”.

Figure 1 shows the long-term observations of X-ray energy responses of the JET detector arrays as a function of time kept at room temperature after the neutron irradiation experiments. X-ray energy responses η/E of the detectors with neutron fluences of 8.9×10^{12} n/cm^2 and 4.5×10^{13} n/cm^2 are plotted by the circles and the squares in Fig. 1, respectively. Here, open symbols and closed symbols represent the data with a detector bias V_b of 1.5 V and 6.0 V, respectively. The incident X-ray energy of 8.0 keV is applied by the use of the synchrotron radiation at the Photon Factory.

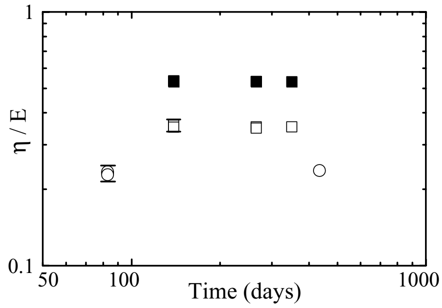

Fig.1 Long term changes in X-ray energy responses η/E as a function of time after irradiation with fluences of 8.9×10^{12} n/cm^2 and 4.5×10^{13} n/cm^2.

The result that the differences between the data in each data set are only less than 4% is consistent with the results obtained for other characteristic properties [3]; that is, the annealing behavior of effective doping and volume-generated current drastically changes within a period of roughly one week after irradiation, and after that changes with time become moderate. This is interpreted as follows: Various kinds of defects and defect complexes produced by irradiation affect the detector performance and have different annealing time constants. After some period of time the annealing effect of detects having longer annealing time constant remains dominantly, which makes the annealing changes with time moderate.

References

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*kohagura@prc.tsukuba.ac.jp