§15. Surface Analysis of Nuclear Fusion Materials Irradiated by Gamma-10 Plasma

Nagata, S., Zhao, M., Hoshi, K., Shikama, M. (Tohoku Univ.),
Nakashima, Y., Sakamoto, M., Hosoi, K., Takada, S. (Tsukuba Univ.)

The aim of this study is to obtain fundamental knowledge of the interaction between diverter materials and the plasma confined by a tandem-mirror-type device. We made an attempt to insert a material probe to examine the irradiation effects on the probe exposed in Gamma-10 at Plasma Research Center, Tsukuba University, by post irradiation experiments using ion-beam analysis techniques. To investigate the plasma-wall interaction, so far, silicon and carbon substrates have been preferably used as passive collector probes for analyzing fluxes of metal impurities and hydrogen to the plasma facing materials. For the present experiment, we selected a silicon carbide sample as the probe material. Silicon carbide composites are attractive for fusion applications because of their excellent high temperature properties, high heat flux resistance, and low activation characteristics. It is also promising to evaluate quantitatively particles impinging on the surface. Moreover, a single crystal sample allows us to observe the irradiation induced lattice damage by using ion-channeling experiments.

The sample was a piece of 10 x 10 x 0.5 mm cut from commercially available 4H-SiC single crystal wafers, and was placed on a sample holder made of Mo. The sample holder was attached on a transfer rod, which can be adjusted to locate at 0.6 m from the end of the mirror exit of Gamma-10 during the plasma operation. The size of the entrance slit of the sample holder was about 5 mm diameter for the incident plasma particles. The irradiation was performed in typical hot-ion-mode plasmas ($n_{e0} \sim 2 \times 10^{18} m^{-3}$, $T_i \sim 5$ keV) with 28 shots of each pulse with 0.39 sec. After the plasma exposure, the sample was analyzed by Rutherford backscattering (RBS) and the elastic recoil detection (ERD) methods for deposited metal impurities and retained hydrogen atoms in the surface layer of it, respectively. The ion beam measurements were carried out using a tandem accelerator at Institute for Materials research, Tohoku University.

Fig. 1 shows backscattering spectra of the SiC single crystal sample, obtained under <0001> axial channeling condition of the incident 2 MeV He^{++} analyzing beam. Characteristic peaks of Fe, Cr, Ni, Mo and W clearly appeared in the sample after the irradiation, and the integrated number of metal atoms was estimated to be 1.2 x 10^{20} m^{-2}. The composition analysis of these elements in the deposited layer indicates that those metal elements were originated from the vacuum vessel of the Gamma-10. Additionally, backscattering yields of C and Si atoms increased after the irradiation due to the lattice damage caused by the incident particles. Fig. 2 shows concentration depth profiles of hydrogen atoms retained in the near surface layer of the same sample obtained by the ERD analysis. When the depth resolution is took into account, hydrogen atoms of 1 x 10^{21} m^{-2} were accumulated within 20 ~ 30 nm of the top layer, corresponding to an average concentration of 0.4~0.5 H/host-atom which is comparable to the saturation concentration of ion-implanted hydrogen in a SiC crystal at room temperature. Both the hydrogen retention and its depth distribution were consistent with the number of displaced atoms and its damage profile evaluated from the RBS spectrum. The calculated fluence, based on the plasma parameters for the operating condition, however, was an order of higher than the observed hydrogen retention in the SiC sample. The large discrepancy can be explained by the saturation phenomenon at the implanted surface layer, where the impinging hydrogen is immediately released after attaining the saturation concentration. The observed depth distribution of the hydrogen and the damage spreads far beyond projected ranges of the incident hydrogen with several hundred eV. This might be attributed to the instantaneous saturation of hydrogen in the surface layer owing to the high flux (~1 x 10^{21} $m^{-2}s^{-1}$) exposition of the plasma.

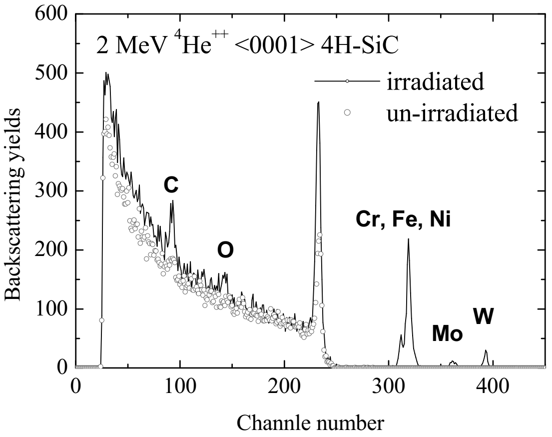

Fig. 1. Backscattering spectra of the SiC single crystal irradiated at the end of the mirror exit of Gamma-10.

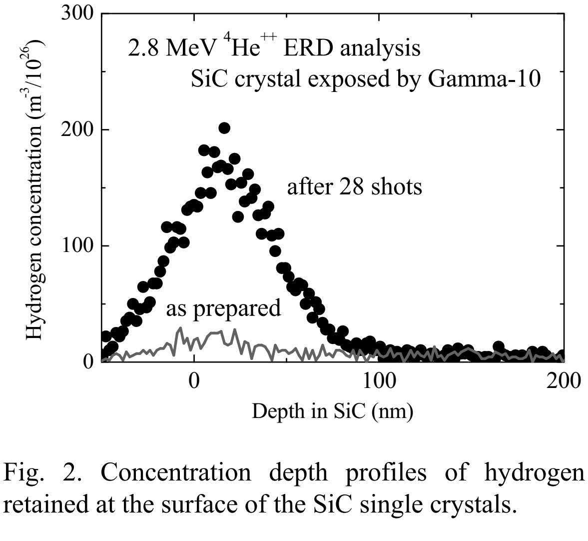

Fig. 2. Concentration depth profiles of hydrogen retained at the surface of the SiC single crystals.