§10. Plasma Irradiation Effects on Hydrogen Behavior in Nuclear Fusion Materials

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The GAMMA 10 tandem mirror, equipped with various heating system such as radio-frequency wave, microwave and neutral injection systems, produces high temperature plasmas. It is a promising approach to study the plasma-wall interactions in divertor regions by utilizing the high heat-flux of ions and electrons in the linear device. In the present work, materials positioned in the end-mirror region of GAMMA 10 has been exposed to hydrogen discharges with various plasma parameters to examine the plasma-material interaction concerning the hydrogen behavior, by the depth profiling of the hydrogen and helium, as well as irradiation induced damages.

The samples used in the present study were SiC and W. The SiC plates were commercially available 6H-SiC single crystals. The W disks were cut from single crystal rods prepared by the floating zone melting method. Poly crystalline plates were by the heat treatment at 1373K for 1h in high vacuum. The sample holder made of Mo was attached on a transfer rod, which can be adjusted to locate at 0.3 m from the end of the mirror exit. The irradiation was performed in hot-ion-mode plasmas with 10~40 shots of a typical pulse with 0.4 sec, varying parameters of ion energy (150-350 eV). After the plasma irradiation, each sample was analyzed by Rutherford backscattering spectrometry (RBS) and by the elastic recoil detection (ERD) methods for deposited metal impurities and retained hydrogen atoms in the surface layer of it, using a 1.7 MeV tandem accelerator. The He and O ion implantation to the samples prior to the plasma exposure was also performed to study the pre-damaged effects on the hydrogen retention.

The average projected ranges of the 10 keV He and 200 keV O ions were roughly estimated to be about 30 and 130 nm, respectively. The hydrogen plasma of 350 eV can penetrate only about 5 nm, shallower than the damaged region created by the ion implantation. No difference was found between the hydrogen recoil spectra of the W samples with and without the oxygen pre-implantation, as shown in Fig. 1. The oxygen implantation induced defects would be formed in the depth far beyond the projected ranges of plasma ions. It indicates that the incident hydrogen does not diffuse into the interior of the W, immediately being released by the molecular recombination process at the irradiated surface. On the other hand, hydrogen retention was clearly increased in the He pre-implanted layer as shown in Fig. 2. The incident hydrogen diffused into the interior to be trapped in the He pre-implantation induced damages. Comparing to the 200 keV O implantation, the He induced damage profile would be more overlapped with the incident hydrogen, and implanted He atoms were also trapped in the damaged layer. The enlargement of hydrogen retention in the He implanted layer is attributed to the enhancement of diffusion and the suppression of the recombination of hydrogen.

Significant differences of the impurity deposition and the defect formation were observed between the W and SiC crystals. The plasma irradiation induced deposition and the displacements in the W surface were much less than those in the SiC. The ineffective damage formation observed in the W crystal can be quantitatively explained by the lower energy transfer by the nuclear collisions and the lower particle reflection rate for incident hydrogen.

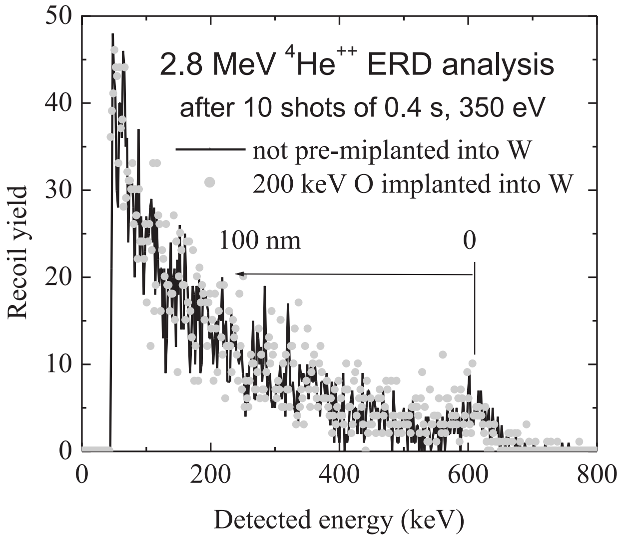

Fig. 1. The recoil hydrogen spectra from the W crystals with and without pre-implantation of 200 keV O ions prior to the plasma irradiation.

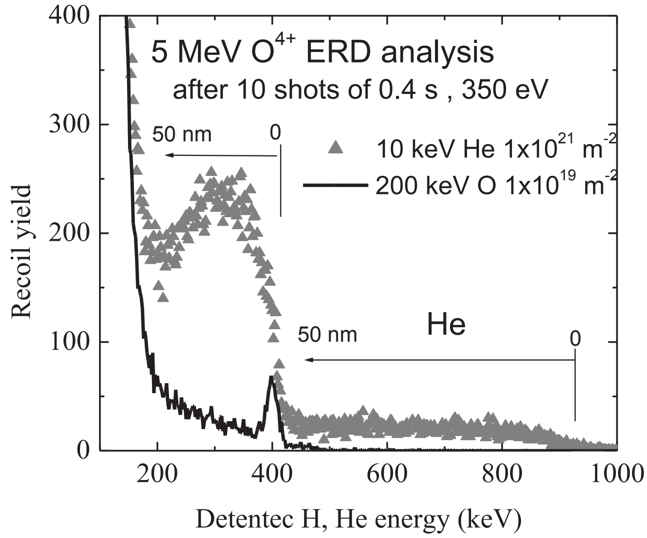

Fig. 2. The recoil hydrogen and helium spectra from the W crystals with pre-implantation of 10 keV He and 200 keV O ions, prior to the plasma irradiation