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

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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 this work, materials positioned in the end-mirror region of GAMMA 10 has been exposed to hydrogen discharges to examine the plasma-material interaction concerning the hydrogen behavior in divertor materials. Here, we report the temperature dependence of metal deposition and the hydrogen transport behavior, particularly the hydrogen trapping at the irradiated surface and the permeation to the back side surface.

The samples used in the study were SiC and W crystals. 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 9 and 27 shots of a typical pulse with 0.4 sec, with ion energy of 200 eV at the sample temperature kept at 370 and 570 K. 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 ion beam analysis technique is also able to detect the permeated hydrogen directly in the material without being affected the molecular recombination process at the back surface, by collecting hydrogen in a storing metal layer on the opposite side of the irradiation. In order to observe the hydrogen permeation, an hydrogen absorbing metal layer of 200 nm Zr was formed on the on the opposite side of the irradiated surface of the sample.

Fig. 1 shows the amounts of displaced Si, retained H and deposited metal atoms in the near surface layer of the single crystal Si sample inserted in the GAMMA10 at the temperatures of 370 K and 570 K. Accumulation of damage and hydrogen retention was nearly saturated at the irradiation fluence of 9 shots, and was not significantly depend on the temperature. On the contrary, the thickness of the deposited metal layer decreased with the temperature. The deposition layer consists of carbon and metal oxides, whose thickness is supposed to be determined by the deposition rate of impurities and decomposition rate by incident hydrogen. Actually, the oxide layer is easily reduced by the hydrogen implantation. According to the analysis of the WO_3 sample exposed simultaneously, the decrease rate of the WO_3 layer was estimated to be about 1.7 nm per a plasma discharge of 0.4 s. The results indicate that the decomposition of the deposition layer was enhanced at higher temperature.

Most of the hydrogen is immediately reemitted from the incident surface of the SiC and W. However, some of incident hydrogen diffuses into the interior to the sample, then transmitted through to the opposite surface. Fig. 2 shows the recoil hydrogen spectra in the Zr/W and Zr/SiC sample irradiated at 570K up to a fluence of 27 shots, clearly indicating hydrogen permeation in SiC. Prior to the GAMMA10 experiments, we confirmed that the hydrogen permeation was found in the same sample of neither SiC nor W under the 5 keV D ion irradiation at the 570 K. In case of the GAMMA10 irradiation, the sites responsible for the molecular recombination rate might be effectively filled with hydrogen incident on the very shallow depth due to much lower ion energy comparing to the 5 keV ion irradiation. As a result of suppressing the reemission process, it is considered that more portion of incident hydrogen diffuse into the interior and permeate to the opposite side of SiC sample.

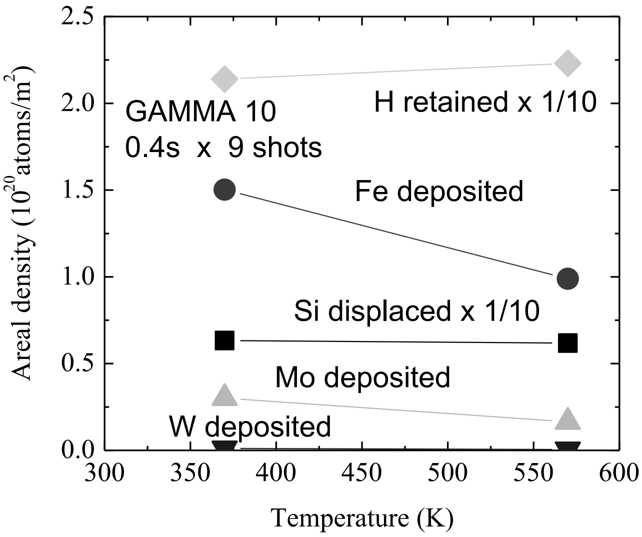

Fig. 1. The recoil hydrogen spectra from the W crystals with and without pre-implantation of 200 keV O ions prior to the plasma irradiation.

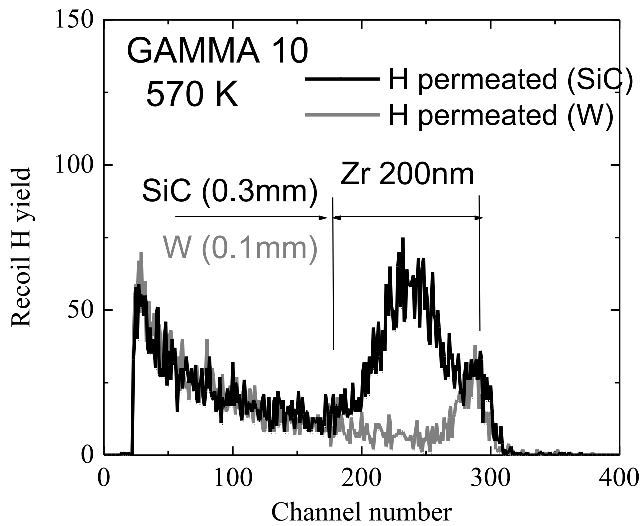

Fig. 2. The recoil hydrogen and helium spectra from the W crystals with pre-implantation of 10 keV He and 200 keV O ions, prior to the plasma irradiation.