§14. Surface Analysis of Nuclear Fusion Materials Irradiated by GAMMA 10 Plasma

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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 comparable to the SOL parameter of tokamaks. It is a promising approach to study the plasma-wall interactions in divertor regions in tokamaks by utilizing the high heat-flux of ions and electrons in the linear device. However, little is known about the edge plasma behavior in the linear device. In the present work, a material probe 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 in GAMMA 10, by the quantitative analysis of the deposited layer and retained hydrogen, oxygen, and other metal impurities, as well as irradiation induced damages.

The samples used as the material probe were mainly SiC and W single crystals. 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. 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 RBS analysis combined with a channeling condition was also performed to evaluate the plasma induced damage profiles in the crystals. The H 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.

After the plasma irradiation, an oxide layer consisting of Fe, Cr, Ni, Mo and W was formed on the SiC crystal. The the hydrogen was retained in both the oxide layer and the substrate. The integrated number of the metal elements and hydrogen was estimated to be the order of 10^{19}~10^{20} m^{-2} and 10^{21} m^{-2}, respectively. On the irradiated SiC sample, colored area was clearly visible as concentric circles. According to the ion beam analysis sweeping across the diameter of the irradiated area with an interval of 1mm, the integrated amount of the deposited metal atoms showed a maximum at the center of the circle and decreased toward the edge as shown in Fig. 1. On the other hand, relatively flat distribution was found in the whole irradiated area for displaced Si atoms, and even higher at the edge where little deposited metal atoms was observed.

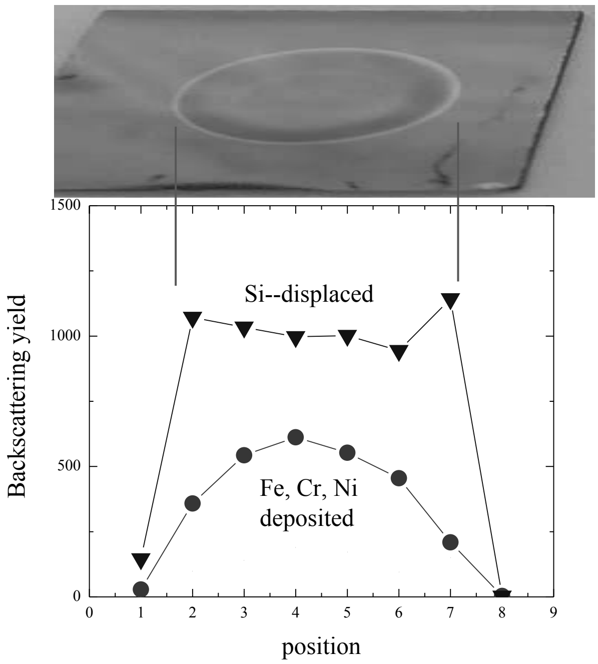

Fig. 1. The irradiated spot on SiC crystal (upper). the amount of the deposited metal atoms and displaced Si atoms obtained by RBS scanning across the diameter of the circular area of the irradiated SiC surface.

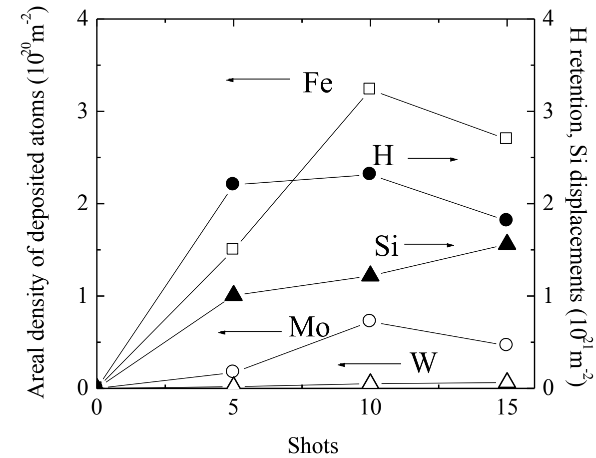

Fig. 2. The deposition of metal, H retention and damage plotted as a function of the number of discharges with 0.4 s.

The areal density of the deposited metal atoms and retained H atoms saturated and slightly diminished after 10 shots of 0.4 s discharges as shown in Fig. 2. The decrease of the oxide layer is attributed to the reductive reaction. The incident hydrogen ions were totally stopped in the deposited layer whose thickness was comparable to the projected ranges of them. On the contrary, the number of damaged Si atoms increased up to 15 shots. When the deposited layer reduced, incident hydrogen reached to the SiC substrate over again, creating displacements. The hydrogen retention was strongly enhanced in W crystals when the pre-damaged layer was formed in the near surface. The pre-damaged layer far beyond the ranges of the plasma ions did not influence the trapping behavior of the hydrogen in both W and SiC crystals.