§9. Sputtering of Plasma Facing Materials by Irradiation with CW High Flux Ion Beam

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We have developed a new ion source device with triode spherical electrodes (HiFIT, High Flux Irradiation Test device) for ion irradiation experiments to plasma facing materials. Details of HiFIT were already described in Ref. 1. This year, H ion irradiation experiments to tungsten were started.

For tungsten irradiation experiments, all results were obtained using sinterd poly-crystalline tungsten samples (20 x 10 x 0.5^t mm) with mirror-polished surfaces. To limit the irradiation area, a 3 mm diameter aperture was set in front of the samples. Beam energy, flux, and fluence were mainly 1.0 keV H_3^+, ~ 4.0 x 10^{20} H/m^{2}s, and 10^{24} ~ 10^{25} H/m^2, respectively. Samples were heated from 388 K to 873 K by means of an IR heater.

In this experiment, carbon was deliberately introduced into the irradiation beam to investigate the effect of carbon impurity on erosion and surface modification of tungsten. The carbon concentration (extracted as hydrocarbon) in the beam were determined by a magnetic ion mass analyzer. It can be controlled from 0.10 % to roughly 10 % by changing the amount and size of graphite plates put inside of the source plasma chamber and changing the flow rate of puffed methane gas. Oxygen impurity concentration was always less than 0.10 %. The other impurity concentration is less than the detection limit (0.01 %).

Figure 1 shows irradiated part of tungsten samples with the beam energy of 1.0 keV and sample temperature of 653 K. Carbon concentration of more than 0.35 %, a large number of blisters with various sizes were formed on the surface, see Fig.1 (b) and (c). According to the observation of the cross section of the samples, the thickness of the blister skins were an order of μm, which is much deeper than ion range of hydrogen. Surface erosion by physical sputtering mainly by carbon was also confirmed. In the case of carbon concentration of 0.95 %, the surface was eroded by about 200 nm measured by a surface profilometer. Blisters appeared on the surface with the fluence more than 1.0 x 10^{24} H/m^2. As the beam fluence was increased, the number and the size of blisters became large. Blisters were formed even in the case of the beam energy of 300 eV with carbon concentration of 0.80 % and beam fluence of 3.4 x 10^{24} H/m^2. The size and the number of blisters, however, were smaller than those of 1.0 keV cases.

In the case of carbon concentration of 0.11 %, irradiated part was only eroded by a little amount of carbon and oxygen impurity and blisters were not observed on the surface, see Fig.1 (a). In the case of carbon concentration of 2.35%, carbon impurity deposited on the tungsten surface with the thickness of 220 nm and blisters were not observed either. For mixed ion bema of hydrogen (0.33 keV) and carbon (1.0 keV), the critical carbon concentration over which carbon deposition takes place is 1.50 % according to the calculation evaluating erosion of tungsten, and deposition and re-erosion of carbon referring to Krieger et al.[2]. Our experimental results roughly agreed with the calculation.

The following reason could account for the mechanism of the carbon effect on blister formation. The implantation range of hydrogen is about 3~8 nm, which is larger than that of carbon (2~4 nm). So a significant amount of hydrogen atoms implanted deeper than carbon diffuse deep inside of bulk materials due to low diffusivity of hydrogen atom in tungsten carbide layer formed in the very surface of tungsten. As the fluence increases, the carbon atoms implanted in the very surface also diffuse into the bulk, which could complicate the hydrogen behavior. If the hydrogen atoms diffusing deep inside the bulk are trapped and these trap sites grow to high pressure voids, these voids would grow to form blisters.

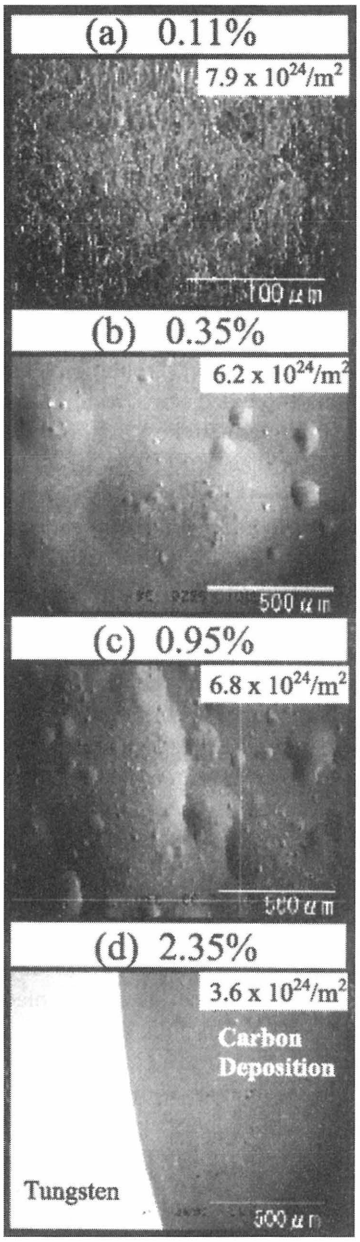

Fig. 1 SEM photograph of the tungsten target after irradiation by carbon and hydrogen mixed ion beam with the beam energy of 1.0 keV.

References

1) T. Shimada, et al., Rev. Sci. Instrum. 73 (2002) 1741.
2) K. Krieger et al., J. Nucl. Mater. 290-293 (2001) 107.