§15. Bulk Tungsten Exposure Experiment on the Helium Long Pulse Discharge in LHD for Creating the Tungsten Fiberform Nanostructure

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Tungsten is one of the candidate for the divertor armor material due to its excellent thermal properties, low solubility for hydrogen and low sputtering yield. However, serious radiation effects, due to helium irradiation, formation of dislocation loops and helium bubbles have been reported in the laboratory experiment [1,2]. In particular, growth of a nanometer-size fiberform nanostructure (W-fuzz) which is easily formed when the temperature is in the range 1000-2000 K and the incident ion energy of helium is higher than 20 eV [3]. It has been reported that the growth rate of the W-fuzz structure is independent of the ion flux above ~10^{22} He/m^{2}s, and fiberform nanostructures are initially identified from the dose of over ~10^{25} He/m^{2}s.

Once such porous structures are formed, retention properties of hydrogen isotopes and thermal conductivity would be changed drastically. As such, formation of the W-fuzz structure and their negative effects in fusion devices have been concerned. However, formation of the W-fuzz in the large sized fusion devices has been scarcely demonstrated. In this study, therefore, demonstration of formation of the W-fuzz was carried out by exposing the bulk tungsten specimen with size of 80×30×1.5 mm^3 to the LHD divertor plasma during helium long pulse discharges.

Fig. 1 shows the schematic view of the experimental set up of the tungsten exposed to helium divertor plasma. Selected discharges for exposure are the long pulse helium discharges with the parameters n_e ~1.2×10^{19} m^{-3}, $T_{i,e}$ ~2 keV. Main component of T_e and T_i of divertor plasma to the specimens were expected to be $T_{i,e}$ ~10-20 eV. Taking into account the sheath potential, the actual incidence energy of the plasma bombarding the specimens is considered to be about 100-200 eV. Unfortunately, absolute value of the divertor plasma flux could not be measured, but judging from previous diagnostics of the divertor plasma flux, it would be expected to be over ~10^{22} He/m^{2}s. Since total exposing time is 10190 s in total with 22 discharges, total fluence is estimated to be over ~10^{25} He/m^2. Temperature of the tungsten surface was measured by infrared camera (FLIR, SC2500). If we assume the emissivity of the tungsten surface to 0.4, surface temperature was reached to be around 1900-2000 K. These exposure conditions are sufficiently satisfied with the creation condition of the W-fuzz on the laboratory experiment [1].

Fig. 2 shows the surface photo of the tungsten specimen (a) before and (b) after exposure. Although some part of the surface color was changed from metallic color to brown or dark brown, clear evidence of formation of the W-fuzz did not show clearly. Detail analysis of the surface structure will be performed by using a field-emission type scanning electron microscope (FE-SEM). Oxygen probe bean elastic recoil detection (ERD) analysis was performed by tandem accelerator. Fig. 3-(a) shows the geometry of the ERD analysis and Fig. 3-(b) shows the quantitative result of the surface profile of the retained helium on the tungsten surface. Quantitative analysis of the surface profile of helium with few mm resolution is difficult, but Oxygen probe beam ERD technique has large advantage for obtaining its profile. Peak of the helium retention can be identified on almost center of the specimen (~5×10^{21} He/m^2), and it is decreased toward the left hand side (0 mm side). This means that strike point of the divertor plasma was located on the tungsten specimen, and sufficient flux of the helium would be injected on the surface. More detailed analysis comparing between surface observation and ERD results will be performed for clarify the formation mechanism of the W- fuzz in the large sized plasma confinement devices.

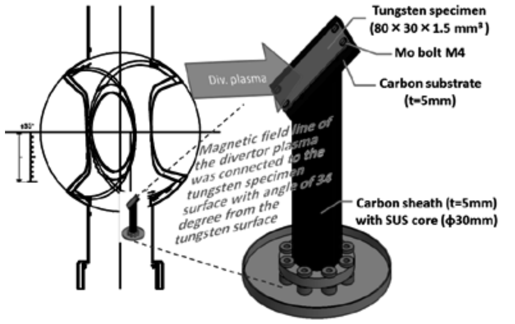

Fig. 1. Experimental set up of the plasma irradiation at divertor position in LHD.

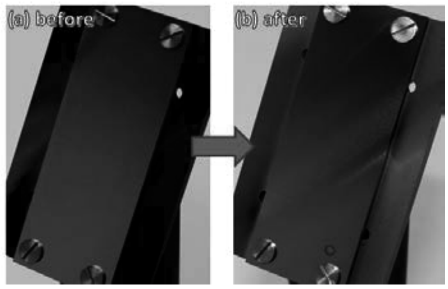

Fig. 2. Surface photo of the tungsten surface (a) before and (b) after exposure to the helium long pulse discharges.

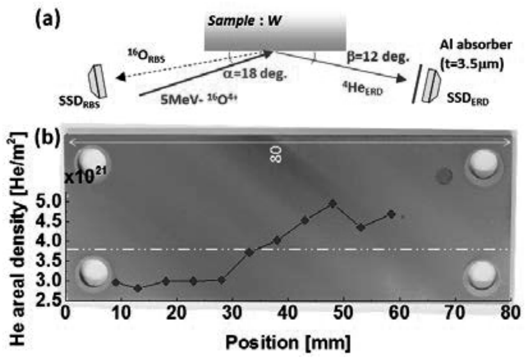

Fig. 3. (a) Geometry of the Oxygen probe beam ERD analysis and (b) Surface profile of the retained helium on the tungsten.

1) H. Iwakiri et al., J. Nucl. Mater. 283-287 (2000) 1134-1138.
2) N. Yoshida et al., J. Nucl. Mater. 337-339 (2005) 946-950
3) S. Kajita et al., Nucl. Fusion 49 (2009) 095005