§6. W-fuzz Formation in Ultra-long Pulse He Discharge in LHD

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Tungsten is one of the potential candidates for the divertor armour material due to its excellent thermal properties, low solubility for hydrogen and low sputtering yield. However, it is known that tungsten is caused serious radiation damage such as He bubbles and dislocation loops by He irradiation [1,2]. One of the ultimate damage structure by He bombardment in tungsten is a fiberform nanostructure (W-fuzz). It is easily formed when the temperature is in the range 1000-2000 K, and the incident ion energy of He is higher than 20 eV [3]. The growth rate of the W-fuzz structure is independent of the ion flux above ~10^{22} He/m^{2}s, and the fiberform structure are initially identified from the dose of over ~10^{25} He/m^2.

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 ultra-long pulse He discharges. Typical parameter of this exposure experiment is summarized in table 1. Then, simultaneous evaluation of the transmission electron microscope (TEM) observation and quantitative analysis of the He distribution on the tungsten surface was carried out.

Input power	1.2~3.0 MW
Total exposure time	10190 s
Surface temperature	1500~2300 K (ε~0.3)
Incident He ion energy	~100 eV
He flux at strike point	~5×10^{21} He/m^{2}s
He fluence at strike point	~5×10^{25} He/m^2

Table 1. Typical parameter of the He exposure experiment at the divertor position of the LHD.

The upper photo of Fig. 1 shows the tungsten specimen exposed to the ultra-long pulse He discharges with the parameters in table 1. Strike point of the divertor plasma was located on the almost central part of the specimen. Color of the whole surface of the specimen seemed to change from metallic color to brown color. Especially, concentration of the brown color was strongest at near the strike point. Energy dispersive X-ray spectroscopy (EDS) analysis showed that there was no impurity depositions. It indicates that some kind of surface morphologies, i.e. formation of He bubbles or surface roughening, would have caused the surface color change. The lower series of Fig. 1 shows the areal density distribution of retained He on the tungsten surface measured by ERD analysis as a function of a coordinate on the sample position. The analyzed points correspond to the dashed line on the tungsten photo. A typical connection length (L_c) profile of magnetic field lines during He long pulse discharges is also plotted in same figure. It is clear that the position of the strong brown color region, namely, strike point and L_c peak are well corresponded. The ERD data showed that the maximum value of the retained He was about 8×10^{21} He/m^2 which is located near the strike point, and it was gradually changed with the position. Fig. 2 and Fig. 3 show the FE-SEM image and corresponding cross-sectional TEM image on the strike point (47 mm position) of the tungsten, respectively. Initial growth phase of the W-fuzz structure was identified. TEM observation revealed that the fine He bubbles with size of 2-20 nm were observed on not only into the fuzzy structure but also in a tungsten matrix just beneath the fuzzy structure. Position of 47 mm corresponds to not only maximum retention of He but also finest W-fuzz growth. On the other hand, magnitude of the W-fuzz structure seems to not have a simple correlation with the areal density of the He in other positions.

This is the first result of the simultaneous evaluation of the nano-scale TEM observation of the W-fuzz structure and quantification of the He areal distribution on the tungsten surface in the large-sized plasma confinement device.

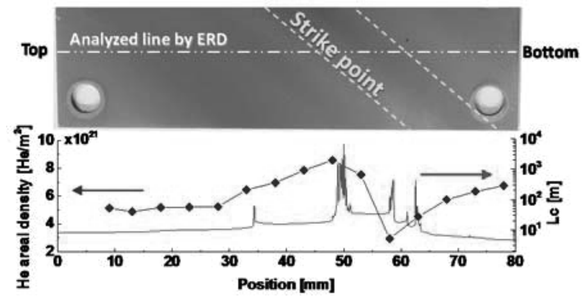

Fig. 1. Upper: photograph of the tungsten exposed to the ultra-long pulse He discharges. Lower: retention profile of He on the tungsten measured by ERD (diamond symbol), and typical connection length (L_c) profile of magnetic field lines during He discharges.

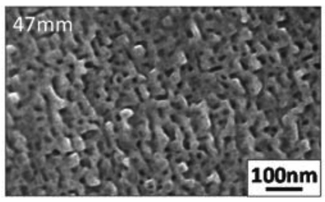

Fig. 2. FE-SEM images on the divertor strike point. Position is indicated on upper left side of the image, and it corresponds to the position on Fig. 1.

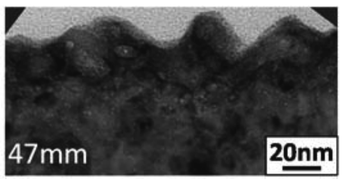

Fig. 3. Cross-sectional TEM images on tungsten specimen at the position corresponding to the FE-SEM image in Fig. 2.

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