§32. Microscopic Damage and Particle Retention on Metallic Walls in LHD

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First walls and divertor plates of LHD are made of stainless steels and isotropic graphite, respectively. They are frequently exposed to not only main plasma discharges but also many type of wall conditioning processes such as glow discharge cleanings (GDCs). Thus, surface conditions of plasma facing components (PFCs) are different from place to place. In addition to radiation damages, mix-material re-deposition layer composed by Fe, Cr, C and O are formed on PFCs [1,2]. If such deposition layers were emitted from the surfaces, they may act as the effective metal impurities for plasma. Therefore, change of the microscopic characteristics of PFCs is important for steady state plasma operations. To clarify the microscopic modification of first walls after exposed to LHD plasmas, material probe experiment through the single experimental campaign was conducted.

Pre-thinned and bulk Mo plates were mounted on the special sample stage of outer-port of the LHD which is located at about 2500mm from Last Closed Flux Surface, and then, exposed to the plasma discharges through the 2006FY campaign. Three types of exposure were selected in this experiment; (1): only main plasma discharges, (2): only GDCs, (1)+(2): both main plasma and GDCs. In the case of (1), the total fluence through this campaign were roughly estimated to be 1.5×10^{23}H/m^2, 2.4×10^{23}He/m^2, respectively. In the case of main plasma discharges, main component of incidence particles to the specimens is charge-exchanged neutrals (CX-neutrals). From our previous study, incidence flux and energy of CX-neutrals to the first wall during main plasma discharge was estimated to be $\sim1\times10^{19}$ions/m^{2}s and ~1keV, respectively [3]. If the average discharges time was assumed to be 2s, total fluence on this experiment is roughly estimated to be about 9.0×10^{22}H/m^2, 3.2×10^{22}He/m^2, respectively.

Fig. 1 shows scanning electron microscopy (SEM) and atomic forth microscopy (AFM) images of Mo after exposed to the case of (1), (2) and (1)+(2). The upper series of micrograph shows that in the case of (2) and (1)+(2), large blisters with size of over 20μm were formed on the surface. The number of them is more remarkable in the case of (1)+(2).The lower series shows AFM images of boundary area. It was clear that exposed area of (2) and (1)+(2) suffered strong sputtering erosion over 200nm. In contrast, exposed area of (1), some erosion was observed, but intensive modification such as blisters and dusts were not identified. The results indicate that GDCs has a major role for surface modification and sputtering erosion than that of main plasma discharges.

Fig. 2 shows a cross-sectional TEM image of large blister in the case of (1)+(2) fabricated by FIB technique. It should be noted that thickness of the blister's lid was estimated at about 2μm, and fracture and upheaval of it has been occurring along grain boundaries. It is considered that injected H atoms during main plasma discharges and GDCs diffused up to 2μm, and were accumulated at the grain boundaries which may act as effective trapping site of H atoms. Newly injected H atoms were continuously trapped along the grain boundaries one after another, and formed the highly pressurized and expanding fields at the grain boundaries. Finally, they caused intergranular fractures.

In order to know depth distribution of internal damage, cross-sectional TEM observations in all exposure cases were also performed. The results are shown in Fig. 3. In the case of (1)+(2), very heavy damages such as bubbles and surface roughening were simultaneously occurred in the sub-surface region about 30nm thick. In contrast, for the case of (1), although small bubbles were observed in about 30-40nm thick, size and density of them were not so remarkable than that of (2) and (1)+(2). In the case of (2), small bubbles were densely observed on sub-surface layer about 10nm thick which may be mainly caused by He GDC.

According to the other researches[4], although estimated total fluence of H in the case of (2) and (1)+(2) was much lower than that of critical fluence of blister formation, large size blisters were clearly confirmed. The possible formation mechanism was proposed as following. He bubbles and dislocation loops near the surface produced strong stress field around them, and the bubbles and stress fields may act as the diffusion barrier for H atoms. Particularly, high energy H e.g. CX-neutrals, has longer range than the thickness of such strongly damaged layer, and they can be retained effectively. Thus, the injected H atoms were difficult to be released from the surface, and were accumulated in grain boundaries, and finally, they formed large size blisters.

Present results indicate that formation of bubbles and blisters must be lead to the undesired impurity generations in LHD even at the bottom port of the torus.

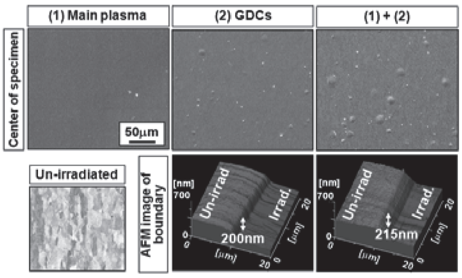

Fig. 1. Upper series; SEM images of exposed specimen. Lower series; AFM images of boundary area.

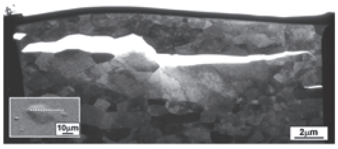

Fig. 2. Cross-sectional TEM image of large blister at the case of (1)+(2) .

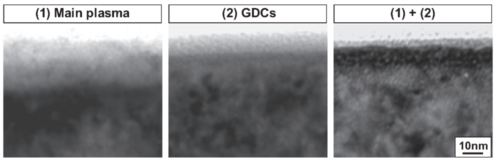

Fig. 3. Cross- sectional TEM images of three exposure cases.

[1] T. Hino et al., Nucl. Fusion 44 (2004) 496
[2] Y. Nobuta et al., Fusion Eng. and Des. vol.81 1-7 (2006) 187
[3] M. Tokitani et al., J. Nucl. Mater. to be published
[4] M.Y. Ye et al., J. Nucl. Mater. 313-316 (2003) 72