§74. Erosion of Plasma Facing Materials by Charge Exchange Neutrals

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PSI (Plasma Surface Interaction) is one of the serious problems related to not only control of plasma but also deterioration of materials. Authors have reported that the surface modifications of PFM (Plasma Facing Material) in plasma confinement devices such as TRIAM-1M and LHD has large impacts on plasma density controlling().
On the other hand, charge exchange (CX) neutrals create radiation damages in the subsurface region of vessel walls and greatly contribute to the surface modification. In the present work, therefore, microscopic damage in metals exposed to hydrogen plasma in LHD was examined and the impact of CX neutrals on surface modification was quantitatively evaluated.

To examine the surface modification caused by CX-neutrals, a materials probe experiment was carried out. Pre-thinned vacuum-annealed disks of 3 mmϕ made of SUS316L, W and Mo were used as specimens. These specimens mounted on the material probe system were placed at the similar position of the first wall surface through the 4.5 low port (4.5L), and exposed to long discharges for about 50 sec. (Shot No. 50834~50853, hydrogen plasma). Typical plasma parameters were: T_i ~ 1.5 keV, n_e ~ 3×10^{19} m^{-3}. The temperature of the specimen holder during the discharges stayed almost constant at room temperature. After exposing the discharges, the microstructure of specimens was observed by means of transmission electron microscopy (TEM). In addition, irradiation experiments were carried out with hydrogen ions of 2 keV.

Fig. 1 shows dark field images of the microstructure in the W specimen and the SUS316L specimen. The radiation-induced dislocation loops with white contrast were formed in these specimens. In general, radiation induced secondary defects are formed as aggregates of point defects produced by knock-on processes. Since the threshold energies of hydrogen for displacement damage in Mo and SUS316 are about 2.0 keV and 0.36 keV, respectively, these defects indicate the existence of high energy incident particles. By comparison with material damages of the 2 keV hydrogen ion irradiation experiments, the fluence of energetic CX neutrals was roughly estimated to be of order 10^{21} atoms/m^2. On the other hand, any defect was not observed in the specimens placed in deep holes directing to several directions. This means that the fluence of energetic CX neutrals was less than 10^{22} atoms/m^2 because the solid angle open to the plasma is rather small. From these results, the mean flux of CX-neutrals with energy high enough to cause radiation damage was estimated to be about 2×10^{19} atoms/m^{2}s.

The depth distribution of the dislocation loops formed in SUS316L is plotted in Fig. 2. As shown in this figure, damages are distributed to rather a deep range, which also indicates the existence of high energy incident particles. Fig. 3 shows the damage distribution calculated by TRIM91-code for H^+ of several energy (a) and the energy with Maxwellian distribution at 1.5 keV (b). Since the calculated depth distribution give close agreement with the damage distribution in SUS316L, this widespread depth distribution would be attributed to the high energy components of CX-neutrals with 6-8 keV.

In this materials probe experiment, the incident direction dependence of CX-neutrals was not estimated because any defect was not observed in the specimens placed in deep holes directing to several directions. The detail evaluation of the effects of CX-neutrals on modifications of PFM would be done by increasing the exposure time.

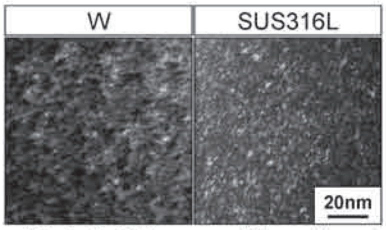

Fig. 1. Dark field images of the microstructures in W and SUS316L.

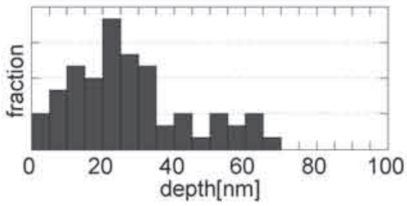

Fig. 2. Depth distribution of dislocation loops in SUS316L.

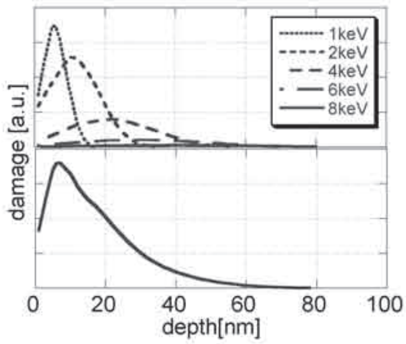

Fig. 3. Calculated depth distribution of damage in SUS316L with TRIM-code. (a)Energy dependence and (b)damage by particles of incident energy with Maxwellian distribution at T_i=1.5keV.

Reference

1) M. Miyamoto et al., J. Nucl. Mater., 313-316 (2003) 82
2) M. Miyamoto et al., J. Nucl. Mater., 329-333 (2004) 742
3) M. Miyamoto et al., J.Nucl.Mater., 337-339 (2005) 436