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

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Charge exchange (CX) neutrals create radiation damages in the subsurface region of Plasma Facing Materials (PFMs) and contribute to the surface modification. Authors have reported that the surface modifications of PFMs caused by CX-neutrals in plasma confinement devices have large impacts on plasma density controlling through recycling and pumping in the wall [1,2]. In the present work, microscopic damage in metals exposed to LHD hydrogen plasma was examined and the energy distribution and the flux of CX-neutrals were evaluated quantitatively.

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, Cu, 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 L-port, and exposed to long discharges for about 150 sec. (Shot No. 58834-58984, hydrogen plasma). Typical plasma parameters were: $T_i \sim 1$ keV, $n_e \sim 3\times10^{19}$ m^{-3}. 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 3 keV.

Fig. 1 shows dark field images of the microstructure in the specimens exposed to LHD hydrogen plasma. The radiation-induced dislocation loops with white contrasts were formed in these specimens. This figure also shows the threshold energies of hydrogen for knock-on damage in each specimen. In general, radiation induced secondary defects are formed as aggregates of point defects produced by knock-on processes. Accordingly, these defects indicate the existence of high energy incident particles. The existence of high energy CX-neutrals was suggested from the depth distribution of dislocation loops in SUS316L exposed to LHD hydrogen plasma as in Fig. 2. The damages are distributed to rather a deep range beyond 100 nm. This widespread depth distribution would be attributed to the high energy components of CX-neutrals with more than 8 keV with a little minor thermal effect.

The flux of CX-neutrals was evaluated from a result of the controlled irradiation experience. Fig. 3 shows fluence dependence of area density of dislocation loops formed in SUS316L under the irradiation with 3 keV hydrogen ions. Compare the defects density with the specimen exposed to the LHD plasma, the fluence of energetic CX-neutrals was roughly estimated to be 2.8×10^{20} atoms/m^2. From this results, the mean flux of CX-neutrals with enough high energy to cause radiation damage (>370 eV) was estimated to be about 2×10^{18} atoms/m^2s. On the other hand, the slightly larger flux ($\sim10^{19}$ atoms/m^2s) was evaluated in similar hydrogen discharges from the point of view of plasma density controlling in LHD [3]. This discrepancy seems to be due to undetectable flux of the low energy CX-neutrals in this experiment.

In this experiment, the flux and energy of CX-neutrals were obtained as just averaged value for varied discharges. Therefore, the flux for individual cases and thermal effect are slate to be evaluated in next experiments with improved sample holder.

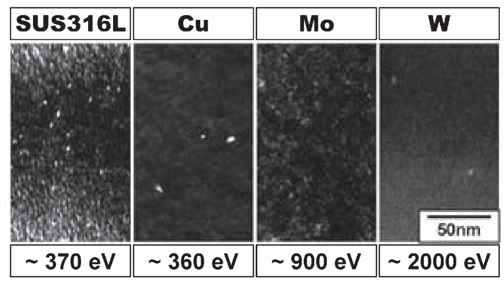

Fig. 1 Dark field images of the microstructures and the threshold energies of hydrogen for displacement damage in each probe specimen.

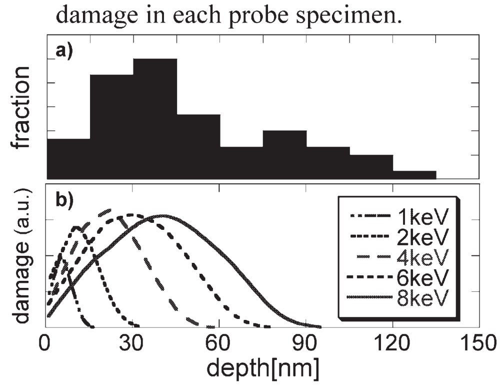

Fig. 2 a) Depth distribution of dislocation loops in SUS316L exposed to LHD hydrogen plasma and b) calculated depth distribution of damage in SUS316L with TRIM-code.

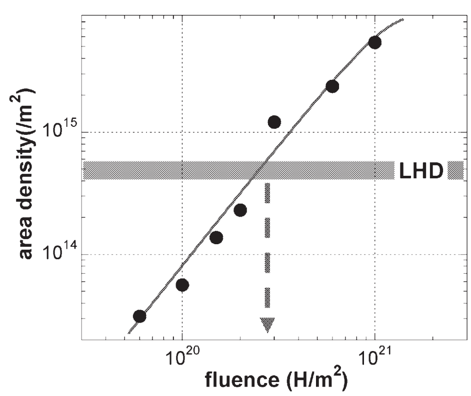

Fig. 3 Comparison of the area density of dislocation loops formed under the irradiation with 3 keV H or LHD plasma.

Reference

1) M. Miyamoto et al., J. Nucl. Mater., 329-333 (2004) 742
2) M. Miyamoto et al., J.Nucl.Mater., 337-339 (2005) 436
3) M. Kobayashi, Annual Report of NIFS, to be published.