§73. Mechanism Underlying Trapping of Hydrogen Isotopes in Neutron-Irradiated Plasma Facing Materials

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Understanding of tritium behavior (diffusion, trapping, desorption, etc.) in neutron-irradiated plasma facing materials (PFMs) is indispensable to(for) evaluation of tritium balance and safety assessment of fusion reactors. Tungsten (W) has been recognized as a primary candidate of PFMs, but effects of neutron irradiation on tritium behavior have been scarcely examined. The objective of this work is to understand the mechanisms underlying hydrogen isotope trapping by radiation defects in W through microstructural analysis and defect characterization. Neutron-irradiated specimens were prepared in Japan-US joint project TITAN. Ion implantation was also carried out to investigate the correlation between dpa values and hydrogen isotope retention.

Disk-type specimens (6 or 3 mm diameter, 0.2 mm thickness) were prepared by cutting rods of pure W (99.99%). The rods were manufactured by A. L. M. T. Co., Japan by powder metallurgy and supplied under stress-relieved conditions. After polishing the surfaces by diamond powder and colloidal silica suspension, the disk-type specimens were annealed in vacuum at 1173 K for 30 min to relieve the stress induced in the surface region by the polishing. Neutron irradiation was carried out in High Flux Isotope Reactor (HFIR) in Oak Ridge National Laboratory (ORNL) under the framework of TITAN project. The 6 mm disks irradiated at coolant temperature (50 ^{o}C) up to 0.025 dpa were transported from ORNL to Idaho National Laboratory (INL), and retention of deuterium was examined by a thermal desorption technique after exposure to deuterium plasma in a linear plasma machine (Tritium Plasma Experiment, TPE). Detailed experimental procedure has been described elsewhere.[1)] Specimens damaged by 2.8 MeV Fe^{2+} ions were also examined for comparison. Flux and fluence of deuterium were ~10^{22} D $m^{-2}s^{-1}$ and ~10^{26} D m^{-2}, respectively, and specimen temperature was 473 K.

The thermal desorption spectra of deuterium thus obtained are shown in Fig. 1. Deuterium retention in the unirradiated specimen (0 dpa) was small, and desorption was observed in a temperature range from 420 to 700 K. In the case of specimens damaged by Fe ions, deuterium retention increased with increasing dpa value. Such increase in deuterium retention was ascribed to trapping effects by defects formed by Fe ion implantation. At 3 dpa, two distinct desorption peaks were observed at 470 and 590 K, indicating that at least 2 types of defects contributed to the trapping effects. In the case of neutron-irradiated specimen, desorption of deuterium continued up to high temperature (1020 K). In addition, the amount of retained deuterium was clearly larger than the case of Fe ion implantation up to the same dpa value (0.025). One of possible reasons for such difference is different distribution of defects. Ion implantation can create defects only in the region near the surface (less than 1 μm under the present conditions), while neutron irradiation forms defects uniformly throughout the specimen thickness. Therefore, number of defects in the specimen can be larger in the latter case at comparable dpa values. In addition, diffusion length of desorbing deuterium can be also larger. It is, however, also necessary to consider differences in the energy spectrum of primary-knock on atoms and damage rate (dpa/s). Hence, further investigation is still required to derive the final conclusion.

Shipping of the small disks (3 mm diameter) from ORNL to International Research Center for Nuclear Materials Science, Institute for Materials Research, Tohoku University was scheduled for microstructural observation with transmission and scanning electron microscopes and characterization of vacancy-type defects by positron annihilation techniques. Casks for shipping were sent from Japan to ORNL, and packing was completed. However, shipping from ORNL to Japan was postponed due to the Great East Japan Earthquake. The small disks will be shipped as soon as possible to start microstructural observation and defect characterization.

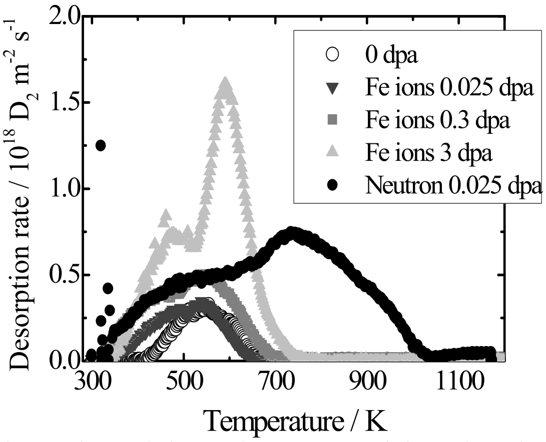

Fig. 1 Thermal desorption spectra of deuterium from W damaged by neutron irradiation and Fe ion implantation after exposure to deuterium plasma at 473 K up to ~10^{26} D m^{-2}.

1) Shimada M. et al., Journal of Nuclear Materials, in press, doi:10.1016/j.jnucmat.2010.11.050.