§77. 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 in evaluation of tritium balance and safety assessment of fusion reactors. Tungsten (W) has been recognized as a primary candidate of PFMs, and the effects of neutron irradiation on tritium behaviors have been examined under the framework of the Japan-US joint research project TITAN. In this project, W specimens are irradiated with neutrons in the High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory (ORNL), and retention of hydrogen isotopes is examined in Idaho National Laboratory (INL) using a linear plasma machine called Tritium Plasma Experiment (TPE).[1-4] The objective of this work is to understand the mechanisms underlying hydrogen isotope trapping in radiation defects through characterizations of defects in the W specimens prepared in the TITAN project. In addition, because of a small damage rate by neutron irradiation, tritium behaviors at high damage levels are studied using ion-irradiation techniques. In the case of ion-irradiation, however, defects are localized in a region near a specimen surface, whereas neutron irradiation induces defects uniformly in the bulk. It is known that exposure to intense hydrogen isotope plasma also modifies microstructures of W, and it is necessary to distinguish the effects of radiation damages from those of plasma exposure. Therefore, in 2011, techniques to load hydrogen isotopes into ion-irradiated W specimens without significant modification of microstructure were developed.

Disk-type specimens ($\phi 6 \times 0.2$ mm) 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 regions by the polishing. The specimens thus prepared were damaged by 2.8 MeV Fe^{2+} ions to 3 dpa at room temperatures. The thickness of damaged zone was evaluated with SRIM2008 program to be ca. 1 μm. Deuterium was loaded into the irradiated specimens with three different techniques: (1) exposure to high flux D plasma at 473 K (flux ~10^{22} D $m^{-2}s^{-1}$, fluence ~10^{26} D m^{-2}), (2) exposure to low energy, low flux D atoms at 403 K (flux 1.9×10^{18} D $m^{-2}s^{-1}$, fluence 6.2×10^{22} D m^{-2}), and (3) exposure to D_2 gas at 673 K and 0.1 MPa. The retention of D was measured by using techniques of thermal desorption spectroscopy (TDS) and nuclear reaction analysis (NRA).

After the exposure to D atoms and D_2 gas, the concentration of D in the damaged zone was ca. 0.5 at. % corresponding to D retention of 4×10^{20} D m^{-2}. On the other hand, significantly larger D retention (3×10^{21} D m^{-2}) was observed after the exposure to plasma. It is known that density of traps induced by ion irradiations cease to increase at ca. 0.5 dpa and ca. 1 at.%.[5] The accumulation of D up to 1 at.% in 1 μm-thick damaged zone corresponds to the retention of 8.2×10^{20} D m^{-2}. The D retention observed after the plasma exposure was significantly larger than this value. Fig. 1 shows TDS spectra after exposure to the plasma and atoms. The desorption of D from the plasma-exposed specimen was completed at 800 K, whereas that from the specimen exposed to atoms continued up to 1100 K as observed for neutron-irradiated specimen.[1-4] In addition, many small burst-like peaks were observed in TDS spectrum of the plasma-exposed specimen. These observations indicated that a majority of D retained in the plasma-exposed specimen was present in bubbles and/or blisters, while that in the specimens exposed D atoms and D_2 gas was trapped in radiation defects. In other words, exposure to low energy, low flux D atoms or D_2 gas is an appropriate method to examine trapping effects of defects created by ion irradiations.

The first batch of small neutron-irradiated disks ($\phi 3 \times 0.2$ mm) has been shipped from ORNL to International Research Center for Nuclear Materials Science, Institute for Materials Research, Tohoku University. The defect characterization will be started in 2012.

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2) Y. Oya et al.: Phys. Scr. **T145** (2011) 014050.
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4) M. Shimada et al.: Fusion Eng. Design, in press, doi:10.1016/j.fusengdes.2012.02.103.
5) J. Roth, K. Schmid, Phys. Scr. **T145** (2011) 014031.

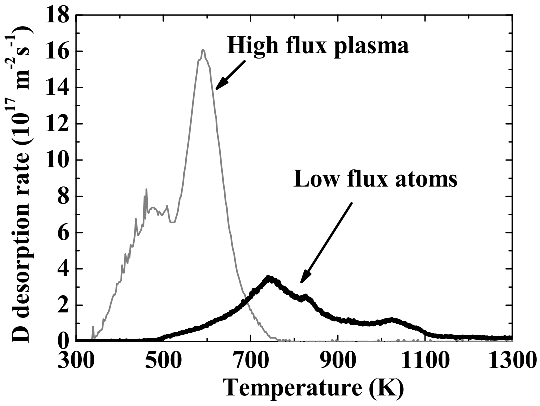

Fig. 1 Thermal desorption spectra of deuterium from W damaged by 2.8 MeV Fe ion irradiations after exposure to deuterium plasma at 473 K and deuterium atoms at 403 K.