§15. Radiation Damage and Deuterium Trapping Property in Ion Irradiated Ferritic Steel

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The behavior of hydrogen isotopes in the first wall is one of the key issues in understanding the recycling process for fuel hydrogen isotopes in fusion reactors as well as the radiation damage of plasma facing materials.

In the present work, therefore, we studied the formation of defects in model alloy of reduced activation ferritic/martensitic steels (Fe-9Cr) under deuterium ion irradiation at elevated temperatures and their role in the trapping and desorption of deuterium by using complementary TEM and TDS. Because migration and reaction hydrogen isotopes and lattice defects are thermal activation processes, it is expected that the defect formation and gas trapping depend strongly on the irradiation temperature.

Fe-9Cr specimens used in the present work were prepared by arc melting method. Irradiation with 8keV-D_2^+ ions were carried out in an ultra-high vacuum evacuation apparatus equipped with a small duo-plasmatron type ion gun. Deuterium irradiated specimens were transferred into the TDS apparatus, where the thermally desorbed deuterium gas was measured with a quadruple mass spectrometer.

Pre-thinned samples for transmission electron microscope observation were obtained by twin-jet electro-polishing. The in-situ observation under D_2^+ ion irradiation was conducted using a 200 kV transmission electron microscope equipped with a low energy ion accelerator.

Fig. 1 shows changes in microstructures in Fe-9Cr formed by the irradiation at 573 K to a dose of $3.0\text{x}10^{22}$ D_2/m^2, followed by isochronal annealing (100 K step, 30 min). The cavities were shrunk with increasing annealing temperature, and it became unobservable at 873 K.

Fig. 2 shows thermal desorption spectra of deuterium from Fe-9Cr irradiated with 8 keV-D_2^+ ions at 300 K, 573 K and 673 K. In the case of deuterium irradiation at 300 K, deuterium desorption stage were formed below 550 K. Total amount of the trapped deuterium for irradiations of $3.0\text{x}10^{22}$ D_2^+/m^2 is $1.1\text{x}10^{17}$ D_2^+/m^2. For case of 573K and 673 K irradiation, no desorption stage were formed at lower fluencies (<$3.0\text{x}10^{21}$ D_2^+/m^2), and new desorption stage formed between 650 K and 1100 K at higher fluencies (>$1.0\text{x}10^{22}$ D_2^+/m^2). Total amount of the trapped deuterium for irradiations of $3.0\text{x}10^{22}$ D_2^+/m^2 at 573 K is $6.8\text{x}10^{17}$ D_2/m^2.

These results indicate that the cavities act as responsible trapping site of deuterium under such irradiation conditions. Some authors showed that two large desorption stages were formed in Be under deuterium ion irradiation and they suggest the higher temperature side is related to cavities filled with D_2 molecules. By using SIMS and RGA, the existence of D_2 molecules in irradiation Be was confirmed by Alimov et. al.. Since Fe-9Cr is a transition metal alloy, on the other hand, it is supposed that deuterium recombination reaction does not occur readily at the void surface. Therefore, deuterium desorption stage in this case can be interpreted as follows; most of deuterium atoms getting into the cavities may return to the matrix quickly, because the trapping energy of deuterium in cavity is small and mobility is high. As a rare case, however, deuterium atoms recombination and form D_2 in the voids. Due to its strong chemical binding, D_2 cannot get out from the voids. At higher temperature (>773K), void shrink thermally until they become stable. Their size depends on the number of D_2 in it. Therefore, though it cannot be observed by TEM, very fine cavities which filled the D_2 molecules still remain in the specimen at 873 K. At much higher temperature (>873K), the bubbles become mobile. Once they reach the surface, they disappear and D_2 are released simultaneously and form desorption stage.

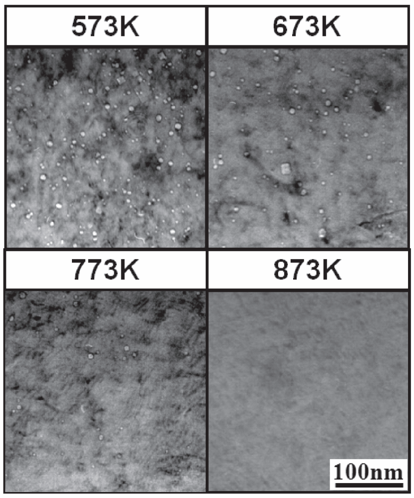

Fig. 1. Isochronal annealing (100 K-step, 30 min) of microstructure in Fe-9Ce formed by 573 K irradiation to a dose of 3×10^{22} D_2^+/m^2.

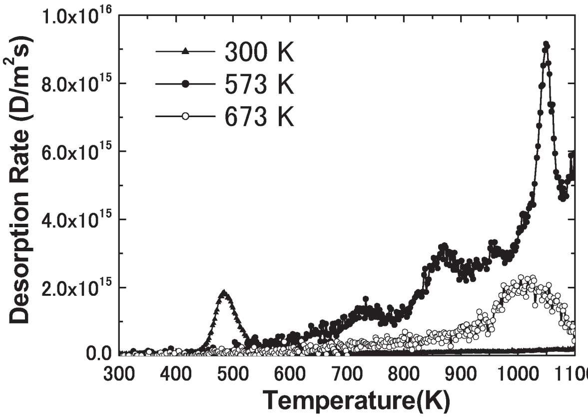

Fig. 2. Thermal desorption spectra of deuterium released from Fe-9Cr irradiated to 3×10^{22} D_2^+/m^2 at 300 K, 573 K and 673 K.