

§86. Isotope Effects on Trapping and Release of Hydrogen Isotopes in Fusion Reactor Materials

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Tritium (T) retention in fusion reactor materials is an important problem for safety assessment and T economy of fusion reactors because it raises T inventory in a system and dead storage of T. Trapping of T at defects and impurities dominates T inventory in materials with low hydrogen isotope solubility such as steels and W materials being candidates of structural and plasma-facing materials of fusion reactors. A majority of T retention studies have been performed using deuterium (D) as a surrogate of T. Detailed understanding of isotope effects on trapping/detrapping is necessary to evaluate T retention from the data obtained with D. Information on isotope effects is indispensable also in the evaluation of efficiency of T removal using an isotope exchange technique.

The isotope exchange between H and D can cause a problem in the evaluation of trap concentration from D concentration. This is because, in principle, D in a specimen can be replaced by H from the environment. Hydrogen isotopes in materials can be divided into diffusive and non-diffusive hydrogen. The latter means a hydrogen atom strongly trapped at an imperfection and immobile at around ambient temperature. The release of “diffusive D” before analysis is carefully considered in most studies. However, even “non-diffusive D” can be released before analysis if H enters in a specimen from the environment and the activation energy for H-D isotope exchange is significantly lower than that for detrapping.

From these viewpoints, the penetration of hydrogen isotopes from the environment into reduced activation ferritic/martensitic steel F82H was examined in this year. The specimens used were plates of F82H irradiated with 20 MeV W ions to 0.54 dpa at the damage peak situated at a depth of $\sim 2 \mu\text{m}$ from the surface.

In the first experiment, the irradiated F82H specimen was exposed to D_2O vapor at room temperature for 1 year. Heavy water was put into the bottom of stainless steel vessel and the specimen was hanged in the open volume. After freezing heavy water by cooling from the outside using liquid nitrogen, the vessel was evacuated and sealed by closing the valves attached. Then, the vessel temperature was returned to room temperature and kept for a year. The vapor pressure at room temperature ($\sim 300 \text{ K}$) is around 3 kPa.

In the second experiment, the irradiated F82H specimen was exposed to D_2 gas at 0.1 MPa and 473 K for 5 h. Retention of hydrogen isotopes was measured using thermal desorption spectroscopy (TDS) several months after the D_2 gas exposure.

The depth profile of D in the F82H specimen exposed to D_2O vapor is shown in Fig. 1 together with damage profile calculated using SRIM program [1]. The

concentration of D in the specimen was far higher than the detection limit, and D was concentrated in the near-surface region damaged with W ions. It is therefore clear that D penetrated into the F82H steel specimen via the reaction $x\text{D}_2\text{O} + \text{Fe} \rightarrow \text{FeO}_x + 2\text{D}$ and got trapped at radiation-induced defects. These observations indicated that, if steel specimens are kept in air, H penetrate into the samples via oxidation with H_2O vapor in air.

Fig. 2 shows TDS spectra of hydrogen isotopes from the F82H steel specimen damaged with W ions and exposed to D_2 gas. As previously mentioned, the measurement was performed several months after the D_2 gas exposure. Although no H was intentionally introduced into the specimen, the amount of desorbed H was far larger than that of D. In addition, the desorption peaks of H_2 , HD and D_2 appeared at the same temperature. These results suggested that H from air via the above-mentioned reaction and/or that present in the specimen as an impurity occupied the defects together with D.

In most studies, the profile of H and desorption spectrum of H_2 are not given due to high background of H and H_2 . The observations in this study clearly showed that the necessity of measurements of H and H_2 for accurate evaluation of trap concentration.

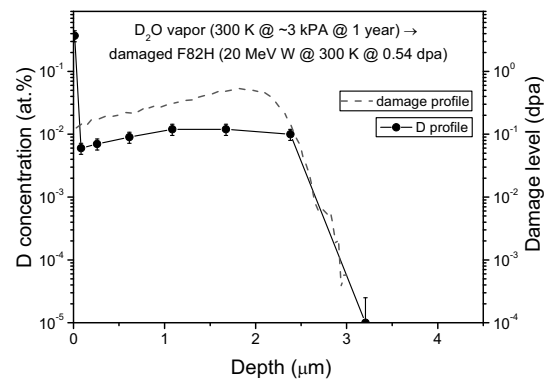


Fig. 1. Depth profile of D in F82H specimen damaged with 20 MeV W ions and then exposed to D_2O vapor at around 300 K for 1 year.

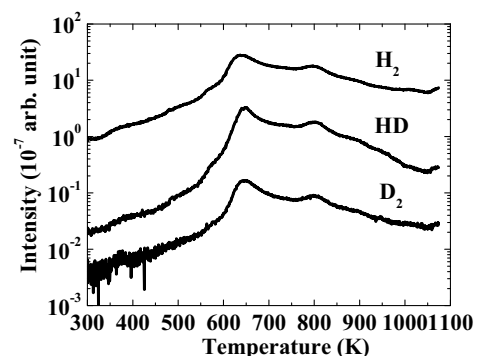


Fig. 2. Thermal desorption spectra of hydrogen isotopes from F82H steel damaged with 20 MeV W ions and exposed to D_2 gas at 473 K for 5 h.

- 1) Ziegler, J.F.: SRIM - The Stopping and Range of Ions in Matter, ver. SRIM-2008.3, <http://srim.org>.