§105. Effects of Alloying Elements on Hydrogen Isotope Retention in Neutron-irradiated Tungsten

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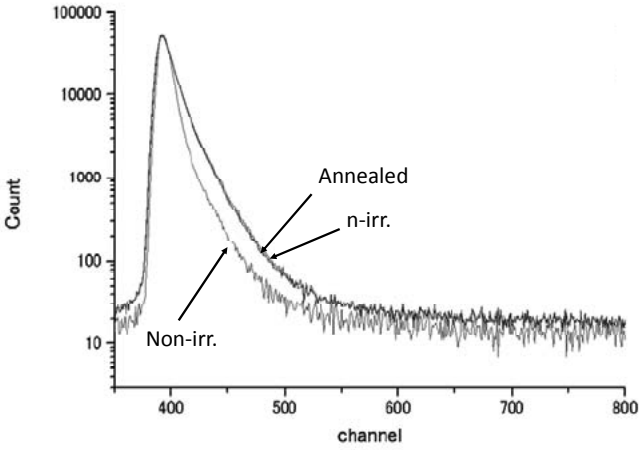
Effects of neutron irradiation on hydrogen isotope retention in tungsten (W), which is a leading candidate of plasma-facing material (PFM) of future fusion reactors, have been examined in the Japan–US joint research project TITAN.[1–3] In this project, W specimens were irradiated with neutrons in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL), and the retention of deuterium (D) was examined in Idaho National Laboratory (INL) using a linear plasma machine called Tritium Plasma Experiment (TPE).[1-3] D retention increased by neutron irradiation by orders of magnitude due to trapping effects of radiation-induced defects, and it reached 0.8 at.% at 0.3 dpa (displacement per atom) after the plasma exposure at 200 °C and 0.3–0.4 at.% at 500 °C. These observations suggested that tritium inventory in vacuum vessels of fusion reactors using W as PFM significantly increases by neutron irradiation. It is, therefore, necessary to understand the trapping mechanisms by radiation-induced defects and develop methods to mitigate trapping effects. The objectives of this study are to examine the type of radiation-induced defects playing dominant roles in trapping and the effects of alloying on the density and hydrogen trapping energy of those defects. In 2013, positron lifetime measurements were performed for neutron-irradiated pure W to study the nature of vacancy-type defects induced by the irradiation.

Specimens used were disks (2 mm diameter, 0.2 mm thickness) prepared from a rod of pure W supplied by A. L. M. T. Co. Japan under stress-relieved conditions. These specimens were mechanically polished using abrasive papers, diamond powders and colloidal silica suspension, and then annealed in vacuum at 900 °C to remove impurity hydrogen and damaged layers induced by polishing. Neutron irradiation was performed at around 300 °C in HFIR at ORNL to 0.3 dpa. After the specimens were shipped to International Research Center for Nuclear Materials Science, the lifetime of positrons was examined using ^{22}Na positron source. Here, a source of ^{22}Na was sandwiched by two specimens, and time difference between emission of γ-rays in ^{22}Na source due to β^+ decay and that of annihilation γ-rays in the specimens was measured. The measurements were repeated after annealing the specimens in vacuum at 500 °C for 10.8 ks (3 hours) to examine microstructure change during the plasma exposure in TPE at 500 °C. Non-irradiated specimens were also subjected to the measurements for comparison.

Fig. 1 shows positron lifetime spectrum of non-irradiated (Non-irr.), neutron-irradiated (n-irr.) and annealed (Annealed) specimens. The horizontal axis of this figure is channel number corresponding to the time difference between the γ-ray emissions and the vertical axis shows the γ-ray intensity. The neutron-irradiated and annealed specimens showed gradual slope in the high channel number side in comparison with non-irradiated specimen because of the formation of defects with longer positron lifetime than the matrix. No significant difference was observed between neutron-irradiated and annealed specimens; the positron lifetime was 149.0 ± 0.2 ps for the former and 148.5 ± 0.2 ps for the latter. These values of positron lifetime correspond to monovacancies, divacancies and dislocations. [4]. It is appropriate to consider that D atoms introduced into the specimens by the plasma exposure in TPE were trapped in those types of defects. In TITAN project, the specimens irradiated with neutrons to 0.025 dpa was exposed to plasma at 200 and 500 °C, and then thermal desorption spectra of D were measured. The desorption spectra were sensitively dependent on temperature of plasma exposure, and D desorption was observed at 170–900 °C and 470–900 °C after exposure at 200 and 500 °C, respectively. The influence of annealing at 500 °C on positron lifetime was negligibly small, as described above. Hence, the difference in desorption spectra obtained at different exposure temperatures was ascribed to not the change in defect structure but the lower occupation probability of weak traps by D at higher temperature.



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2) Hatano Y. et al.: Nucl. Fusion **53** (2013) 073006.
3) Hatano Y. et al.: J. Nucl. Mater., **438** (2013) S114–S119.
4) Zhu S. et al., J. Nucl. Mater., **343** (2005) 330.