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

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Hydrogen isotope retention in plasma facing materials is one of the important issues in safety assessment of fusion reactors. Recent report shows that neutron irradiation significantly increases deuterium (D) retention in W due to trapping effects of radiation-induced defects.[1,2] However, detailed trapping mechanisms have not been clarified. For better understanding of defect-hydrogen isotope interactions in W, in this study, disk-type specimens of W were irradiated with high energy electrons to induce Frenkel pairs uniformly throughout the bulk, and clustering of vacancy-type defects and D trapping were examined using positron annihilation spectroscopy (PAS) and thermal desorption spectroscopy (TDS). In addition, neutron irradiation of pure W and various W alloys were performed at 290 ºC in the BR2 reactor through the irradiation program of the International Research Center for Nuclear Reactor Materials, Institute of Materials Research, Tohoku University.

The samples subjected to neutron irradiated in the BR2 reactor were disks being 6 mm in diameter and 0.5 mm in thickness. Those samples were prepared from rods and sheets of pure W, W-5%Re alloy, K-doped W and K-doped 3%Re alloy fabricated by A. L. M. T. Co., Japan. Disks prepared from a sheet of pure W purchased from Goodfellow Co., UK were also irradiated for comparison. The neutron irradiation has been completed, and hydrogen isotope retention will be measured using a new compact divertor plasma simulator (C-DPS) and gas exposure system currently under construction in the radiation controlled area of the International Research Center for Nuclear Reactor Materials. The size of vacancy-type defects and trapping-detrapping in/from the defects will be examined using PAS. Microstructure will be studied using a transmission electron microscope (TEM).

The electron irradiation was performed for the disks of recrystallized W (RC-W) and stress-relieved W (SR-W) at 8.5 MeV and around 100 ºC to 10^{-3} dpa in the Research Reactor Institute, Kyoto University. Then those specimens were subjected to exposure to D_2 gas (0.1 MPa) or annealing in vacuum at 300 ºC for 100 h. Size distributions of vacancy-type defects were examined using PAS, and D retention was measured using TDS.

Positron lifetime for RC-W before the irradiation was 118.1 ps. It clearly increased to 169.7 ps by the electron irradiation due to formation of mono- or divacancies. Long lifetime components appeared after D_2 gas exposure and annealing in vacuum at 100 ºC due to clustering of vacancies. Interestingly, the positron lifetime after D_2 gas exposure (278.9 ps) was significantly shorter than that after annealing in vacuum (341.8 ps). The positron lifetime in SR-W before electron irradiation was slightly longer than that in RC-W due to the presence of defects formed during fabrication processes. Nevertheless, similar change in the lifetime was observed after the irradiation and heat-treatment in D_2 gas and in vacuum. The shorter positron life time observed after D_2 gas exposure than that after annealing in vacuum can be explained by retardation of clustering of vacancies by D in W and/or decrease in the effective open-volume in vacancy clusters due to D trapping. Occupation of traps by D was confirmed by using coincident Doppler broadening spectroscopy. The size of vacancy clusters will be examined using TEM. TDS spectra of RC-W are shown in Fig. 1 as examples. D concentration in RC-W increased from [D]/[W] = 1.1×10^{-6} to 8.6×10^{-6} by electron irradiation. The main desorption peak from the irradiated sample appeared at ~575 ºC and the shoulder at ~700 ºC. These two peaks were assigned to the detrapping of D from vacancies and vacancy clusters. Detailed analysis of spectra are in progress.

Table 1 Positron lifetime in recrystallized (RC) and stress-relieved (SR) W under as-prepared conditions (Non-irr.), after electron beam irradiation (e-irr.) and subsequent heat treatments at 300 ºC for 100 h in D_2 gas (D_2 exp.) and in vacuum (Vac. Ann.).

Sample	RC Non-irr.	RC e-irr.	RC e-irr. D_2 exp.	RC e-irr. Vac. Ann.
Pos. LT (ps)	118.1	169.7	133.7 278.9	129.7 341.8
Sample	SR Non-irr.	SR e-irr.	SR Non-irr. D_2 exp.	SR Non-irr. Vac. Ann.
Pos. LT (ps)	127.7	168.8	153.6 299.7	133.0 312.1

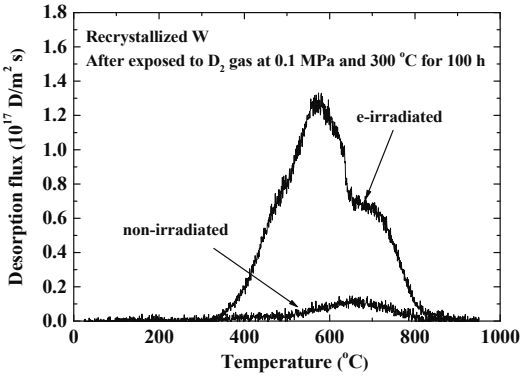

Fig. 1. TDS spectra from RC-W under as-prepared conditions and after irradiation of 8.5 MeV electrons to 10^{-3} dpa.

1) Hatano, Y. et al..: J. Nucl. Mater. **438** (2013) S114.
2) Hatano, Y. et al.: Nucl. Fusion **53** (2013) 073006.