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

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Increase in tritium (T) retention in tungsten (W) due to trapping at neutron-induced defects is an important problem for safety assessments of fusion reactors. Positron annihilation spectroscopy (PAS) provides information on the types and densities of defects together with number of hydrogen atoms in a defect [1], and therefore it has potential to be a powerful tool to examine interactions between radiation-induced defects and hydrogen isotopes. In this study, positron lifetime and coincidence-Doppler broadening (CDB) were measured for W irradiated with high energy neutrons or 8.5 MeV electrons with and without D doping to examine the applicability of PAS to the analysis of hydrogen isotope trapping at defects in W.

Disk-type W specimens were irradiated with high energy neutrons in the High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory (ORNL) at around 573 K for 48 days or 8.5 MeV electrons to 10^{-3} dpa at around 373 K using a linear accelerator in Kyoto University. The neutron irradiation was performed under the Japan-US collaboration research program TITAN. The damage level reached 0.3 dpa. These specimens were heated at 573 K under vacuum or D_2 gas atmosphere (0.1 MPa) for 100–400 h. Positron lifetime and CDB were measured using ^{22}Na source. Thermal desorption of D was also examined.

Results of positron lifetime measurements for neutron-irradiated specimens are summarized in Table 1. The positron lifetime of non-irradiated specimens was 118 ps. This value corresponds to the annihilation of positron in the matrix of W [1]. After the neutron irradiation to 0.3 dpa at 573 K, short and long life components appeared. The life times for short and long life components were evaluated to be 268 and 453 ps. These values are comparable with those evaluated for vacancy (V) clusters with 5V and >37 V [1]. It is clear that relatively small and large V clusters were formed by displacement damages and vacancy diffusion under fast neutron irradiation. The average positron lifetime was evaluated to be 332 ps. No significant change in positron life time was observed after annealing in vacuum for 100 and 400 h because the specimen had been already kept at 573 K for 48 days in the HFIR.

In contrast, significant reduction in positron lifetime was observed after annealing under D_2 gas atmosphere; the life times for short and long life components were evaluated to be 174 and 442 ps. The shorter positron lifetimes were ascribed to the reduction of open volumes in V clusters due to accommodation of D atoms. The observations clearly showed that D atoms were trapped at both small and large V clusters. The CDB ratio curves showed lower intensity of annihilation γ-rays in the low momentum region and higher intensity in the high momentum region compared with non-irradiated W. These difference are also good evidences for the occupation of vacancy clusters by D atoms in W.

The positron lifetime after irradiation of 8.5 MeV electrons was 170 ps and smaller than that after the neutron irradiation due to lower irradiation temperature (373 K) and damage levels (10^{-3} dpa). The value (170 ps) indicates the formation of single vacancies, as expected. The heating at 573 K for 100 h under vacuum led to increase in the lifetime to ~200 ps due to clustering of vacancies. As observed for neutron-irradiated specimens, the value of positron lifetime after heating under D_2 gas atmosphere was smaller than that after heating under vacuum due to occupation of vacancy clusters by D atoms.

Fig. 1 shows thermal desorption spectrum of D from the neutron irradiated specimen after exposure to D_2 gas for 400 h. The main peak appeared at 835 K and smaller peak was observed at 1103 K. The ratio of peak areas between the main and the high temperature peaks was about 2:1. The main peak was assigned to the desorption from the small V clusters and the high temperature peak to that from large V clusters.

Table 1 Positron lifetime in W under as-prepared conditions (non-irr.), after neutron irradiation at 573 K to 0.3 dpa (n-irr.) and subsequent annealing at 573 K for 100 h in vacuum (n-irr. vac. anneal.) and in 0.1 MPa D_2 gas (n-irr. D_2 exp.).

Sample		non-irr.	n-irr.	n-irr. vac. anneal.	n-irr. D_2 exp.
Positron life time (ps)	Average	118	332	334	253
	Short life component	-	268	266	174
	Long life component	-	453	456	442

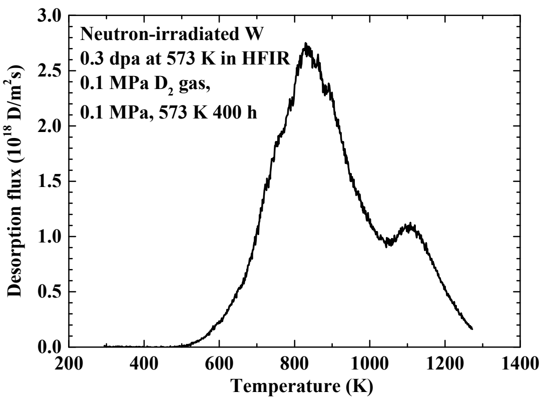

Fig. 1. TDS spectrum of D from neutron-irradiated W after exposure to D_2 gas at 0.1 MPa and 573 K for 400 h.

1) Troev, T. et al.: Nucl. Inst. Meth. Phys. Res. B. **267** (2009) 535.