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Correlation between irradiation defect distribution and deuterium retention behavior in neutron-irradiated tungsten
中性子照射したタングステンにおける照射欠陥分布と重水素滞留挙動の相関

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The deuterium retention behaviors in Fe^{2+} irradiated tungsten with the damage concentration of up to 0.1 dpa and neutron-irradiated tungsten with ~ 10^{-4} dpa were studied. Most of deuterium for Fe^{2+} irradiated tungsten were trapped by both vacancies and voids, although the deuterium trapping by dislocation loops and vacancies were major trapping states for neutron-irradiated tungsten due to lower damage concentration. In addition, neutron energy distribution also made a large impact on deuterium retention and the vacancies would be potential trapping sites for hydrogen isotopes even if the damage concentration is low of ~10^{-6} dpa.

1. Introduction

The usage of tungsten (W) has been considered as a plasma facing material (PFM) in future fusion reactors, because of its higher melting point and lower sputtering rate. It is thought that W will be exposed to 14 MeV neutron produced by D-T fusion reaction during plasma operation. The irradiation defects would be introduced by both energetic ion and neutron irradiation in W, where hydrogen isotopes would be trapped, leading to their retention enhancement. For the development of effective fuel recycling and the safety of fusion reactors operation, it is necessary to clarify the hydrogen isotopes retention behavior in neutron-irradiated W. However, the study of neutron-irradiated W has not been advanced due to formation of higher radioactive products. Therefore, most of previous experiments were done using heavy-ion irradiation to simulate neutron irradiation. The distribution of defects introduced by heavy-ion irradiation is concentrated near the surface, although that by neutron irradiation is expanded uniformly in the bulk [1]. Therefore, it is expected that hydrogen isotope behavior in neutron-irradiated W would be quite different from that in heavy-ion-irradiated W. In this study, irradiation defects were introduced by various implantation methods, namely Fe^{2+} ion irradiation, thermal neutron irradiation and fast neutron irradiation, and their deuterium retention behaviors were evaluated by thermal desorption spectroscopy (TDS). In addition, the simulation of TDS spectra for damaged W was also applied to explain the activation energies of deuterium trapping sites in the damaged W.

2. Experimental

A disk-type polycrystalline W (6 mm$^{\varphi}$×0.5 mm^{t}) purchased from A.L.M.T. Co. Ltd was used. For the pretreatment, the samples were heat-treated at 1173 K under ultrahigh vacuum (<10^{-6} Pa) to remove the impurities and damages introduced during the polishing processes. The Fe^{2+} were implanted into the samples at room temperature with the damage concentration of 0.01 and 0.1 dpa (displacement per atom) by Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) at Japan Atomic Energy Agency (JAEA). The fission neutron irradiation were performed at Kyoto University Research Reactor Institute (KUR) with the damage concentration up to 4.3×10^{-4} dpa. In the case of 14

MeV fast neutron irradiation (fusion neutron irradiation), Fusion Nuclear Source (FNS) at JAEA was used with the maximum damage concentration of 1×10^{-6} dpa. The detail neutron irradiation fluence and energy were summarized in Table I. Thereafter, these samples were transferred to Shizuoka University and the 1.0 keV deuterium ions (D_2^+) implantation was performed with the ion flux of 8.75×10^{17} D^+ m^{-2} s^{-1} up to the ion fluence of 1.0×10^{22} D^+ m^{-2}. The deuterium desorption behavior was evaluated by TDS at the temperature up to 1173 K for Fe^{2+}-irradiated samples and 1273 K for neutron-irradiated samples, respectively.

Table I. Summary of fission and fusion neutron fluence and neutron energy (E_n)

	Neutron fluence (n cm^{-2})	E_n
Fission	3.3×10^{16}	<0.025 eV
	1.3×10^{14}	0.025~0.50 MeV
	7.2×10^{15}	>0.50 MeV
Fusion	1.1×10^{14}-1.1×10^{15}	14 MeV

3. Result & Discussion

Fig.1 shows the D_2 TDS spectra for various damaged tungsten sample. The TDS spectra consisted of three desorption stages. The Peak 1 at 400 K was attributed to the desorption of deuterium adsorbed on the sample surface or trapped by dislocation loops. The Peak 2 at 650 K and Peak 3 at 850 K were corresponded to the desorption of deuterium trapped by vacancies and voids, respectively [2].

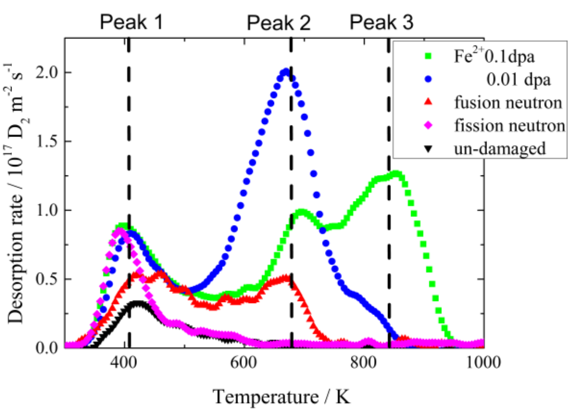

Fig.1 D_2 TDS spectra for various damaged tungsten.

3.1 *Fe^{2+}-irradiated samples*

The deuterium retention for Fe^{2+}-irradiated samples was clearly increased compared to that for un-damaged sample as shown in Fig.1. No large difference for Peak 1 was found among 0.01 and 0.1 dpa Fe^{2+}-irradiated samples, indicating that the retention of deuterium absorbed the sample surface or trapped dislocation loops would be almost saturated. However, the deuterium retention for Peaks 2 and 3 were quite different depending on the damage concentration. The TEM observation indicated that the voids were not produced for 0.01 dpa Fe^{2+}-irradiated samples, leading that most of deuterium was trapped by vacancies. On the other hand, for 0.1 dpa sample, major deuterium desorption stage was shifted toward higher temperature side at 850 K. These facts indicate that voids would become the stable deuterium trapping sites, where deuterium was trapped.

3.2 *neutron-irradiated sample*

To demonstrate the deuterium retention enhancement by neutron irradiation, the neutron fluence was set to be lower damage concentration (10^{-6}-10^{-4} dpa) compared to the actual fusion reactor. Even in these lower damage concentration, it was clear that the deuterium retention was increased, compared to that for un-damaged sample. The D_2 TDS spectrum for fusion neutron irradiated tungsten was extend to both of Peak 1 and Peak 2, indicating the mono vacancies would be one of the deuterium trapping sites. However, that for fission neutron irradiated tungsten was just concentrated on Peak 1, indicating that dislocation loops would act as major trapping sites. The detail mechanism of deuterium trapping for neutron irradiated tungsten is still unclear and further study will be required.

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