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中性子照射タングステンにおけるトリチウムリテンションと透過
Tritium retention and permeation for neutron-damaged W

大矢恭久[1)]、波多野雄治[2)]、片山一成[3)]、山内有二[4)]、信太祐二[4)]、大塚哲平[5)]、近田拓未[1)]、原正憲[2)]、大宅諒[6)]、上田良夫[6)]、外山健[7)]、島田雅[8)]、Dean Buchenauer[9)], Chase Taylor[8)], Bob Pawelko[8)], Brad Merrill[8)], Lee Cadwallader[8)], Rob Kolasinski[9)], David Donovan[10)]
Yasuhisa Oya[1)], Yuji Hatano[2)], Kazunari Katayama[3)], Yuji Yamauchi[4)], Yuji Nobuta[4)], Teppei Otsuka[5)], Takumi Chikada[1)], Masanori Hara[2)], Makoto Ohya[6)], Yoshio Ueda[6)], Takeshi Toyama[7)], Masashi Shimada[8)], Dean Buchenauer[9)], Chase Taylor[8)], Bob Pawelko[8)], Brad Merrill[8)], Lee Cadwallader[8)], Rob Kolasinski[9)], David Donovan[10)]
[1)]静大、[2)]富山大、[3)]九大、[4)]北大、[5)]近大、[6)]阪大、[7)]東北大、[8)]INL、[9)]SNL、[10)]テネシー大
[1)]Shizuoka Univ., [2)]Univ. Toyama, [3)]Kyushu Univ., [14]Hokkaido Univ., [5)]Kindai Univ., [6)]Osaka Univ., [7)]Tohoku Univ., [8)]INL, [9)]SNL, [10)]Univ. Tennessee

Introduction

Elucidation of tritium dynamics is one of the key issues for sustainable D-T fusion. Tungsten will be exposed to high fluxes of tritium (T) accompanied with various energetic particles. Therefore, T retention and its trapping states will be dramatically changed by the accumulation of ion and neutron-induced damage and recovery by heating.

In our previous Japan–US collaboration program, TITAN project, has demonstrated the n-irradiation effect on hydrogen isotope retention in W, where the D retention for 0.025 displacements per atom (dpa) is significantly larger than that for undamaged W. For the design of tritium recycling, hydrogen isotope including tritium permeation study is also mandatory. These facts motivate us to perform extensive hydrogen isotope retention experiments in damaged W under the framework of Japan/US joint project, PHENIX.

Experimental

Disks of stress-relieved W were irradiated using several different methods. As a surrogate for neutron damage, a subset of the samples was irradiated by 6 MeV Fe^{2+} at room temperature in TIARA, QST. A second set of W specimens were exposed to 6.4 MeV Fe^{3+} at higher temperature in DuET, Kyoto University up to 1.0 dpa. All sets of samples were exposed to 1 keV D_2^+ ions up to a fluence of 1.0×10^{22} D m^{-2} at room temperature. In addition, Rabbit irradiation at ORNL was also done with the higher damage concentration of 0.1 dpa and these samples were transferred to INL to perform D plasma exposure using TPE device with the temperature of 673 K with D ion flux of 7.2×10^{21} D $m^{-2}s^{-1}$ up to the fluence of 5.2×10^{25} D m^{-2}. Thereafter, thermal desorption spectroscopy (TDS) was applied with the heating rate of 0.5 K s^{-1} up to 1173 K. The defect concentration and formation of voids were evaluated by positron annihilation spectroscopy (PAS). To complement these results, TEM images of the ion damaged W were also acquired to evaluate the distribution of dislocation loops and voids for Fe-damaged W.

Results and discussion

Fig. 1 shows the D retention behavior for 0.01 dpa and 0.1 dpa Fe ion damaged W with D ion fluence of 1.0×10^{22} D^+ m^{-2} at room temperature. The TDS spectra clearly showed that major D desorption temperature was shifted to 850 K for the higher damaged sample (0.1 dpa), although large D desorption peak for 0.01 dpa is observed at 670 K. It indicates that the major trapping site of hydrogen isotope is changed from vacancies to voids by damage accumulation. For the initial evaluation of

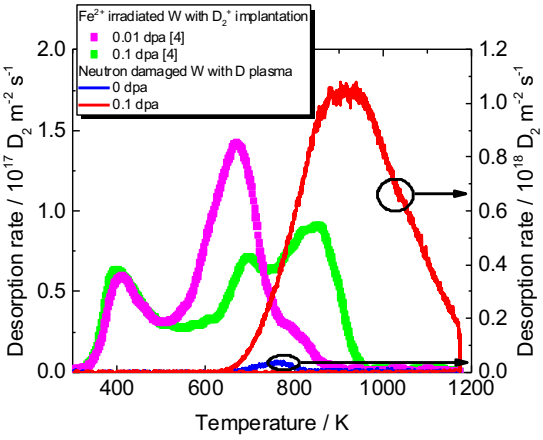

Fig. 1 D_2 TDS spectra for Fe^{2+} damaged W with D_2^+ implantation （D_2^+ fluence： 1×10^{22} D m^{-2} at room temperature）and 0.1 dpa neutron damaged W with D plasma exposure (D fluence: ~ 5×10^{25} D m^{-2} at 673 K) .

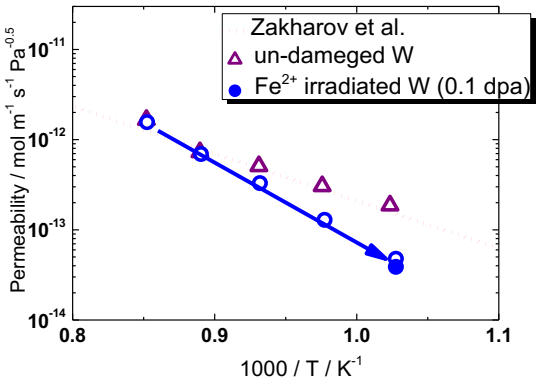

Fig. 2 D permeability for 0.1 dpa Fe^{2+} irradiated W.

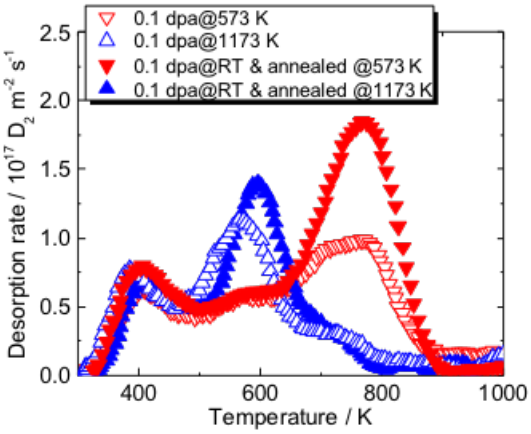

Fig. 3 Comparison of D_2 TDS spectra for damaged W with high temperature irradiation and that with annealing after room temperature irradiation.

neutron irradiation effect, small W single crystal specimen with the size of 4 mm × 4 mm, which is picked up from tab of tensile specimen (0.1 dpa neutron irradiation at 673 K), is used. Fig. 1 also shows D_2 TDS spectra for 0.1-dpa-neutron-damaged W and un-damaged W with TPE D plasma exposure. It is clear that the D retention is clearly enhanced by the neutron irradiation and the desorption temperature is shifted toward higher temperature side. Comparing to D ion irradiation, the TDS spectrum is broadened and extended toward higher temperature side, leading that D was migrated into W bulk region due to damage introduction throughout the sample by neutron irradiation and D migration by high temperature and high flux irradiation.

In order to elucidate how D diffuses through damaged W, D permeability through Fe^{2+} damaged specimen were measured. We hypothesize that trapping of D by defects affects the number of available D diffusion pathways through the lattice. This would be manifested by a reduction in D permeability for damaged W, which we confirmed experimentally as shown in Fig. 2. Furthermore, by heating above 1100 K, D permeability was completely consistent with that for undamaged W, suggesting that irradiation-induced defects had been recovered. It can be said that the nature of the defects is critical, and their stability will strongly influence D permeability. We observed no experimental conditions that led to the enhancement of D permeability due to damage introduction.

Furthermore, we note that thermal annealing is quite important to determine the recovery condition of irradiation damage and two sets of experiments were performed. Consider Fig. 3, which shows D_2 TDS spectra for 0.1 dpa Fe^{2+} damaged W. Here we examine the effect of heating both during the irradiation process and afterward; temperatures of 573 K and 1173 K are considered. A clear reduction of D desorption at ~ 800 K due to higher temperature irradiation was found in comparison with post-annealed W at the same temperature, which also causes the desorption peak to shift to lower temperature at 573 K and 873 K. In particular, post-mortem PAS results showed that the recovery of voids was remarkable at 873 K and the trap density was clearly small. These results show that dynamic recovery of defects is enhanced by higher temperature irradiation, and the formation of vacancies reduces the D trapping energy.

Summary

This paper presents recent results, including an analysis of D retention by various methods over a range of defect concentrations. The accumulation of defects resulted in the formation of stable trapping sites which, based on our TDS results, are consistent with voids. We propose that D trapping by defects reduces the number of available D diffusion pathways through the lattice, a mechanism that could lead to a reduction of D permeability. Finally, we note that dynamic recovery of damages is enhanced by high temperature irradiation.

Acknowledgement

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