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Deuterium Permeation in Tungsten under Simultaneous Deuterium and Carbon Irradiation
重水素・炭素同時照射下でのタングステン中の重水素透過特性

Han Yee Peng[1], Heun Tae Lee[1], Yusuke Ohtsuka[1] and Yoshio Ueda[1], Masakatsu Fukumoto[2]
Peng Han Yee[1], Lee Heun Tae[1], 大塚 裕介[1], 上田 良夫[1], 福本 正勝[2]

[1] *Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan*
[2] *Japan Atomic Energy Agency, 801-1 Mukoyama, Naka, Ibaraki 311-0193, Japan*
[1]大阪大学大学院工学研究科 〒565-0871 大阪府吹田市山田丘2-1
[2]日本原子力研究開発機構 〒311-0193 茨城県那珂市向山801-1

Ion driven permeation of D through W under simultaneous D+C irradiation at 1 keV ion energy and 10^{20} $m^{-2}s^{-1}$ irradiation flux was studied as a function of specimen temperature (550 K < T_w < 1050 K) and C fraction in the incident flux (0.1% < f_C < 3%). A prominent feature of the D permeation under simultaneous D+C irradiation is the temperature dependent increase in steady state D permeation flux with a maximum at 700-800 K. W/C mixed surface layer was observed from XPS analysis. This W/C mixed layer formation was interpreted to reduce the recombination coefficient or/and diffusivity, resulting in the observed increase in permeation flux.

1. General

Tungsten (W) is a leading candidate for plasma facing material in future fusion reactors and will be used in divertor region of ITER. Although W has lower hydrogen retention under hydrogen isotopes (H, D, T) irradiation, there still remain important issues under fusion environment such as release and diffusion processes of H isotopes in W. At present, a tungsten divertor with carbon-fibre composite as the strike plate is planned for the initial stages of ITER. Carbon (C) impurities resulting from erosion, transport, and deposition processes will result in simultaneous irradiation of W by H and C species. The resulting interaction will modify the tungsten material forming a W-C “mixed-material” with properties different from a pure W material. This change will affect both H release and diffusion processes in W, with corresponding impact on fuel recycling and retention. Therefore, a clear understanding of the impact of C on H diffusion in W is desirable.

The diffusion behavior of hydrogen isotopes in W can be evaluated by studying the permeation of deuterium (D) in W. Previous studies of H retention in mixed W-C materials indicate that the presence of C on the W surface increases the inward transport of H into W bulk [1]. However, the data on the effect C on hydrogen ion driven permeation in tungsten is very limited with only one previous study having examined single D ion driven permeation in carbon film coated W [2]. In this study, we present experimental results of ion driven permeation of D through W under simultaneous D+C irradiation, and show the effect of C on D transport in W.

2. Experimental

Permeation experiments were performed using a high flux ion beam test device (HiFIT) [3], where the incident energy of the ions was 1 keV at a flux of 10^{20} $m^{-2}s^{-1}$. The specimens used were stress-relieved 99.99% pure polycrystalline W with diameter of 34.8 mm and thickness of 30 μm [4]. The W specimen was isolated from the permeation side by sealing it between two standard conflat flanges and a copper gasket [4]. The specimen was irradiated at incident angle of 15^{o} through an 8 mm diameter aperture. The D permeation flux was measured by using a high resolution quadrupole mass-spectrometer (MKS microvision plus) with a mass range of 1-6 amu. The main experimental parameters varied were the specimen temperature (550 K < T_w < 1050 K) and the C fraction in the incident flux (0.1% < f_C < 3%). Following D+C permeation experiments, the irradiated specimen surfaces were observed under an optical microscope and a scanning electron microscopy (SEM). Also, the surface atomic compositions and the depth profiles of the implanted C at the front surface following irradiation were analyzed by X-ray photoelectron spectroscopy (XPS) at Osaka University and Japan Atomic Energy Agency (JAEA).

3. Results and Discussion

Temperature dependent increase in the D permeation flux under simultaneous D+C irradiation was observed in comparison to D-only irradiation case, with a value of 200 times larger at 700-800 K, as shown in Fig. 2. XPS analysis showed that the surface was a mixed composition of C and W. Hence, the increase in D permeation flux can be interpreted as a reduction in recombination coefficient or/and diffusivity due to tungsten carbide formation at the incident surface. In addition, temperature dependent increase in blister size on W surface was observed. This indicates that the enhanced D diffusion by the C/W layer causes blistering on the W surface, since the diffusion of D into the W bulk is necessary for blistering [5]. However, the measured C/W surface composition was temperature independent, indicating that the C on the W surface was not directly correlated to the temperature dependent increase in D permeation flux.

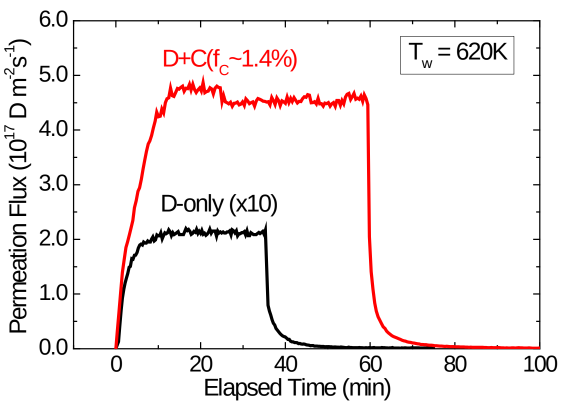

Fig.1. Comparison of beam-on transient curves during D-only and simultaneous D+C irradiation. The origin corresponds to beam on time, and the D-only curve is scaled up by a factor of 10 for comparison. (Taken from Ref. [6])

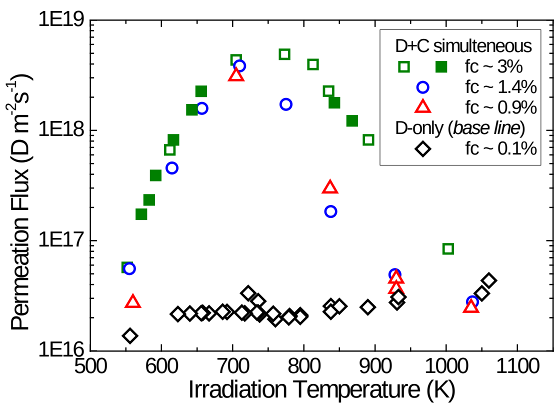

Figure 2: Steady state D permeation flux plotted as a function of temperature at different C fractions in the incident flux (0.1% < f_C < 3%). (Taken from Ref. [6])

We present permeation flux data under various experimental conditions to discuss the temperature dependency and C fraction dependency of D permeation in W. Furthermore, we discuss the modification of the W surface and correlate the modified surface with changes in the permeation flux data. Finally, we compare our result to the simple diffusion theory of Doyle and Brice [7] which describes the steady state H transport in W to understand the C effect on D diffusion.

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