Deuterium Permeation in Tungsten under Simultaneous Deuterium and Carbon Irradiation

Han Yee Peng1, Heun Tae Lee1, Yusuke Ohtsuka1 and Yoshio Ueda1, Masakatsu Fukumoto2

Peng Han Yee1, Lee Heun Tae1, 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

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° 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.

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.

References