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タングステンと炭素の表面混合層の形成による
タングステン中の重水素透過への影響

Effect of Tungsten and Carbon Surface Mixed Layer Formation on Deuterium Permeation in Tungsten

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In ITER, tungsten (W) will be used as a plasma facing material in the divertor with carbon-fiber composite at the strike plate. However, erosion and transport of sputtered carbon (C) materials will result in the simultaneous irradiation of W by hydrogen isotopes (H, D, T) and C impurities, leading to formation of a W-C mixed surface layer. In case of all metal devices, C impurities will always be present as impurities as observed in ASDEX-Upgrade [1].

The influence of such W-C mixed layer on hydrogen permeation through W has been scarcely investigated. In our previous study, C/D mixed irradiation resulted in higher steady state permeation flux in comparison to D-only irradiation [2]. However, whether the formation of W-C surface mixed layer resulted in changes to diffusive or release properties remained unclear. According to H transport theory of Doyle and Brice [3], the dependence of permeation flux on incident flux indicates certain transport regimes. In this study, we have varied the incident flux and specimen thickness to determine the transport regime during C/D mixed irradiation, providing a more detailed understanding of the impact of C on D permeation.

Permeation experiments were performed using a high flux ion beam test device (HiFIT) coupled with a permeation device [4, 5]. The W specimens used were thickness of 30 and 50 μm, with purity of 99.99%. The D permeation flux was measured using a quadrupole mass-spectrometer. The incident flux varied from 10^{19} – 10^{20} $m^{-2}s^{-1}$, and incident energy was 1 keV. The specimen temperature range was 550 – 1050 K, and the C fraction in the incident flux was below 3%.

Previously, a peak enhancement factor of about 200 at 700 K was observed during C/D mixed irradiation in comparison to pure D irradiation [2]. Therefore, we measured the permeation flux dependence on incident flux at 610, 710, and 850 K; see Figure 1 At 850 K, the steady state D permeation flux was proportional to the incident flux (n=1), and at 710 K the steady state D permeation flux was nearly proportional to the square root of incident flux (n=0.59); where n indicates the exponent of the power fit in Figure 1. These can be interpreted as diffusion limited (DD) and surface recombination limited (RD) transport at 850 K and 710 K respectively [3]. However, physically unreasonable values of front diffusivities are required to fit the observed increase in permeation flux at this temperature At 610 K, no incident flux dependence was observed, which cannot be explained by Doyle and Brice model.

We discuss further the effect of mixed W-C surface on D permeation by considering the incident flux dependency with new experiments on specimen thickness dependence. We consider effects of changes in diffusivity and the surface recombination coefficient of W-C surface mixed layer. This work contributes towards quantifying the effect of mixed W-C material formation on hydrogen transport and is valuable for estimating tritium permeation and safety in fusion devices.

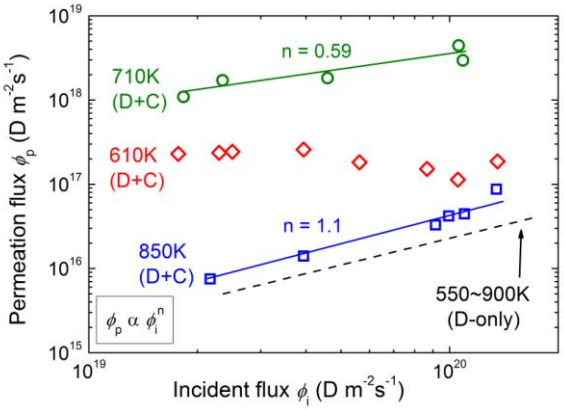

Figure 1: Steady-state D permeation flux plotted as a function of incident flux at three temperatures. The dash line corresponds to D-only result from Ref. [5].

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