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Deuterium Ion Driven Permeation through Tungsten

タングステン中の重水素透過特性に関する研究

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Tungsten is the present material choice for the ITER divertor, as well as candidate armour material for DEMO. It is important to understand hydrogen interaction with tungsten to estimate recycling and permeation behavior, as well as in-vessel tritium inventory. To study hydrogen diffusion, surface recombination, and trapping processes in tungsten, ion driven permeation experiments have been performed. Specifically, permeation experiments under mixed ion irradiation with helium and carbon species were done to determine the effects of impurities in the plasma. In addition, the effect of different tungsten microstructure was examined.

1. Introduction

Tungsten (W) is the present material choice for the ITER divertor, as well as candidate armour material for DEMO. To assess the safety and operational cycle of future fusion devices a detailed understanding of hydrogen (H, D, T) transport in tungsten is required. We have performed deuterium ion driven permeation experiments through tungsten to determine how changes in plasma and material parameters will impact the hydrogen transport in tungsten. On the plasma side, we have introduced helium and carbon impurities and studied their effects. On the material side we have examined the effect of different tungsten microstructure. This poster presentation will provide an overview summary of these experimental results.

2. Experimental

Details of the irradiation device, HiFIT, can be found in previous publication [1] and a brief description follows. A microwave plasma discharge was extracted and focused into a beam composed of both D atoms and ions. Typical ion flux was ~1.5 x 10^{20} D m^2 s^{-1}. For He/D mixed irradiation, He gas was introduced into the source resulting in 2 % He in the incident flux. For C/D mixed irradiation, C impurities in the beam were introduced by placing graphite plates or rings inside the ion source. Details of determining the carbon fraction in the incident beam can be found in Ref. [1].

The permeation setup [2] consists of a W specimen sealed by placing it between two standard conflat flanges and a copper gasket. The specimen was irradiated at incident angle of 15 degrees through an 8 mm diameter aperture. A high resolution quadrupole mass spectrometer (MKS microvision plus) with a mass range 1-6 amu was used to monitor changes in the mass 3 (HD or H_3) and mass 4 (D_2) signals at the permeation side. The signals were calibrated using a standard D_2 calibration leak. Typical pressures during experiments were 10^{-4} and 10^{-6} Pascal in the irradiation and permeation chambers, respectively.

The specimen was heated from the rear side by an infrared heater and the temperature measured by a spot welded thermocouple at the irradiation surface. Temperature uncertainty was ±10 K for D/He experiments and ±5 K for pure D and D/C experiments.

Three different types of W specimens were investigated. Two polycrystalline specimens of 99.99 % purity manufactured by ALMT corp, Japan with different grain sizes were obtained by annealing at 1573 K (W1) and re-crystallization at 2273 K (W2). Following the annealing process, the specimens were mechanically polished to the desired thicknesses of 25 μm, 50 μm, and 75 μm. 50 μm thick polycrystalline specimens annealed at 1203 K (W3) were provided by IPP, Garching. Details of the microstructure for this W3 specimen have been previously discussed in Ref [3].

3. Results and Discussion

3.2 *D-only irradiation*

The principal aim of this work was to determine the effect of W microstructure on D permeation and diffusion [4]. From Figure 1, the difference in the steady state permeation flux between tungsten specimens with different grain sizes was in agreement within a factor of two. The largest difference was observed at the limits of both high and low temperature. We tentatively concluded that steady state permeation flux was independent of microstructure and estimate that grain boundary effects will not contribute significantly to steady state permeation in tungsten in the temperature region of interest for ITER operation or future blanket conditions.

3.2 *He or C mixed ion irradiation*

Under mixed He/D irradiation, a clear decrease in the permeation flux was observed in comparison to D-only case; see Figure 2. In addition, the permeation flux was observed to obey a square root dependence to the incident flux. This was in direct contrast to D-only case, where the permeation flux was linearly proportional to the incident flux over a temperature range 550 K < T < 1050 K [2]. Such a shift could be modeled by changes to the front diffusivity which could be attributed to He bubbles formed near the surface. It was further determined that hydrogen does not diffuse according to Frauenfelder's [5] values in the implantation zone.

Under mixed C/D irradiation, an opposite trend of increased permeation was observed [6]. Mixed C/D irradiation resulted in the formation of W/C mixed layers near the surface, which could reduce hydrogen diffusivity and/or recombination. A more detailed treatment is presented in poster presentation **24P078-P**.

4. Summary

From D-only irradiation experiments with various W specimens with different grain sizes, it was determined that diffusion through grain boundaries appear limited and will not affect permeation behavior significantly. However, they will have an impact on tritium inventory if they are preferential sites for precipitation due to large buildup of solute concentration within the lattice. Such conditions are expected under mixed carbon-hydrogen irradiation.

Mixed ion (He/D and C/D) driven permeation in tungsten was studied. Mixed material formation and modification of the front surface could vary the steady state permeation by factor ranging from 10^{-2} to 10^{2}. Significant finding was the modification in the near surface by formation of He bubbles or C/W mixed layers can significantly vary the steady-state permeation flux. For He/D mixed ion irradiation, more than an order of magnitude reduction in permeation flux was observed. In contrast, for mixed C/D mixed ion irradiation, more than two orders of magnitude enhancement of permeation flux was observed. These reduction (He/D) and enhancement (C/D) are strongly temperature dependent, and is most significant at 800 K; corresponding to the expected blanket first wall temperature in future fusion devices.

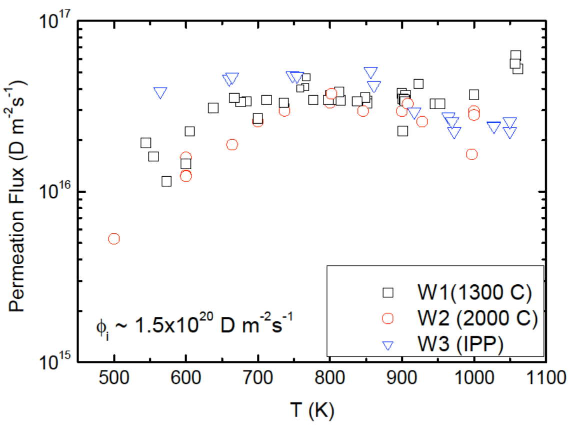

Fig.1. Steady state permeation for three specimens with different grain sizes. The thickness of W1 and W2 specimen was 25μm. The permeation flux for 50 μm W3 specimen has been multiplied by 2. Taken from Ref. [4].

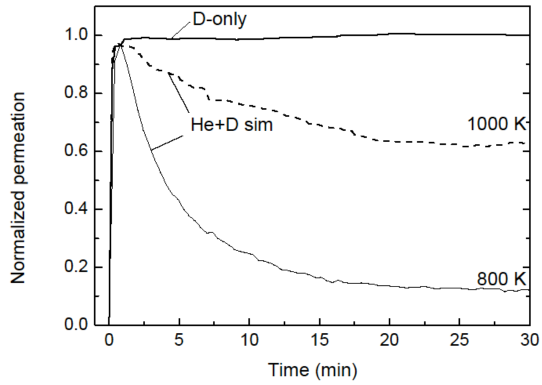

Fig.2. Comparison of beam-on transient curves during Pure D and He/D mixed irradiation. From Ref. [2].

Acknowledgments

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