§20. Tungsten Coatings Effects on Hydrogen Permeation through the First Wall of a Magnetic Fusion Power Reactor

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1. Introduction

The first wall of a commercial fusion reactor may employ coatings made of refractory metals such as tungsten to protect structural materials chosen from reduced activation ferritic steels. This paper reports on laboratory-scale studies with a steady-state linear plasma device to investigate the hydrogen plasma-driven permeation behavior through vacuum plasma-sprayed tungsten (VPS-W) and sputtering-deposited tungsten (SP-W) coated F82H at ~250-550℃.

2. Results

Shown in Fig. 1 is the hydrogen PDP breakthrough curves for three of the samples tested at ~500℃. The net implantation fluxes are ~2 x 10^{16} H/cm^2/s. Time zero in the figure corresponds to the plasma-on time. The observed steady-state permeation flux through vacuum plasma-sprayed tungsten (VPS-W) coated F82H has been measured to be ~5×10^{12} H/cm^2/s, which is more than one order of magnitude lower than that of bare F82H. In contrast to the permeation rates observed for VPS-W, hydrogen permeation flux through the sputtering-deposited tungsten (SP-W) coated F82H is very high, which is ~2×10^{15} H/cm^2/s, even nearly one order of magnitude higher than that of bare F82H. Fig. 2 shows the temperature dependence of hydrogen PDP fluxes through F82H with/without W coatings at ~250-550℃. It is shown that the VPS-W coatings decrease hydrogen permeation fluxes by more than one order of magnitude compared to bare F82H. However, the SP-W coatings tend to increase the permeability of F82H substrate, and notice that the permeation fluxes decrease as the temperature increases.

3. Discussions

In our previous work, hydrogen GDP through VPS-W coated F82H was studied [1]. It has been found that VPS-W coatings are porous and have connected pores, even a 170 µm thick layer of VPS-W coating has connected pores, which connect the front and rear surfaces of the deposited layer. Therefore, the data obtained for VPS-W coated F82H (Fig. 2) could be attributed mainly to molecular hydrogen permeation through open pores of VPS-W coating combined with permeation in a dissociated form through F82H substrate.

Shown in Fig. 3 is the evaluated recombination coefficient K_r of hydrogen on W and F82H. For W,

$$K_r(\mathrm{W}) = 5.1\ \times 10^{-12}\exp\left(\frac{-1.21\ \mathrm{eV}}{k\mathrm{T}}\right)\mathrm{cm^4 s^{-1}}$$

Notice that the K_r for SP-W coating increases as temperature increases. This explains the data shown in Fig.2 that the permeation fluxes decrease as the temperature increases. Besides, the K_r for SP-W coating is orders of magnitude lower than that of F82H, which leads to increased permeation fluxes through the SP-W coated F82H (Fig. 2).

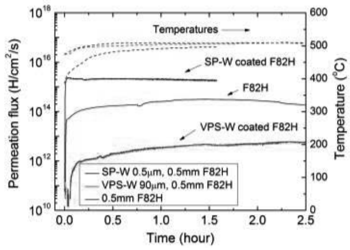

Fig. 1 Hydrogen PDP breakthrough curves for VPS-W and SP-W coated F82H membranes at ~500℃.

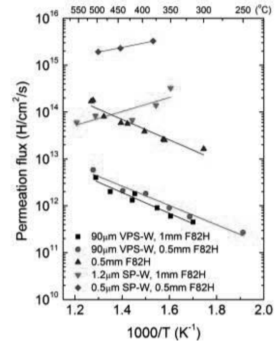

Fig. 2 Temperature dependence of steady-state hydrogen PDP fluxes through W coated F82H and bare F82H under plasma bombardment: net implantation flux ~2 x 10^{16} H/cm^2/s, ion energy 100 eV.

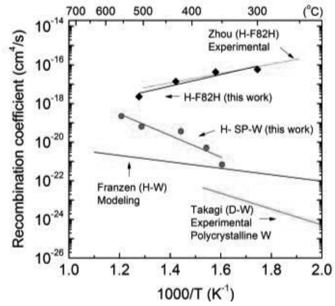

Fig. 3 K_r of hydrogen on W and F82H. Literature data are shown for comparison [2-4].

4. Conclusions

VPS-W coatings reduce hydrogen PDP fluxes by about one order of magnitude, but have been found to be penetrated through connected pores by GDP. SP-W coatings tend to enhance hydrogen PDP fluxes under the given conditions, which is attributed to the lower hydrogen recombination coefficient for SP-W coating compared to that of F82H. The recombination coefficient is a key parameter relating the permeation flux for PDP in the recombination-diffusion regime, suggesting that surface effects on PDP should be further investigated.

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[3] P. Franzen et al., J. Nucl. Mater. 241 (1997) 1082-1086.
[4] I. Takagi et al., J. Nucl. Mater. 417 (2011) 564-567.