

## Hydrogen plasma-driven permeation through vacuum plasma sprayed tungsten coated F82H

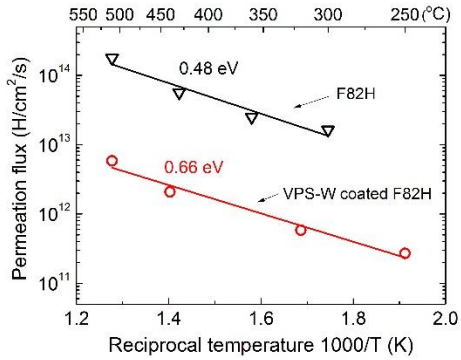
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The first wall of a commercial fusion reactor will employ coatings made of refractory metals such as tungsten to protect structural materials chosen from reduced activation ferritic steels or vanadium alloys. This work reports on laboratory-scale studies with a steady state linear plasma device to investigate the hydrogen plasma-driven permeation (PDP) behavior in vacuum plasma sprayed tungsten (VPS-W) coatings on substrate of F82H. It has been found that the VPS-W coating decreased the hydrogen PDP fluxes by more than one order of magnitude at a temperature range of 250-500°C. The analysis of hydrogen permeation through such a multi-layer membrane in the diffusion-limited regime has been carried out, suggesting that the ratio of hydrogen concentrations at the interface is equal to that of the hydrogen equilibrium solubilities in these materials. It is shown that the calculation results correlate well with experimental ones.

From the Arrhenius plots (fig. 1), the activation energies are estimated to be 0.66 eV and 0.48 eV, respectively. The tungsten coating decreases the hydrogen PDP fluxes by more than one order of magnitude from 250-500°C. At ~500°C, the permeation reduction ratio is evaluated to be 0.036.



**Fig. 1** Temperature dependence of hydrogen permeation fluxes through bare F82H and VPS-W coated F82H under plasma bombardment: net implantation flux  $\sim 10^{16}$  H/cm<sup>2</sup>/s, ion energy 100 eV. The thicknesses of W coating and F82H membrane are 0.09 mm and 0.5 mm, respectively.

Let us consider the process of hydrogen permeation through a two-layer membrane (fig. 2). In the diffusion-limited regime, according to the Fick's First Law [1]

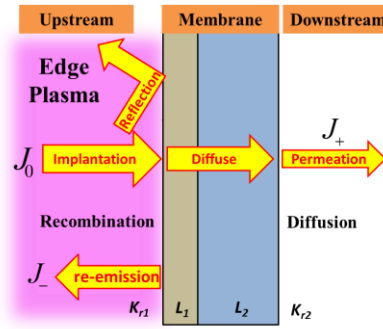
$$J_+ = \frac{D_1(C_1 - C_2)}{L_1} = \frac{D_2(C_3 - C_4)}{L_2}, \quad (1)$$

Usually one suppose that the ratio of hydrogen concentrations at the interface  $C_2$  and  $C_3$  is equal to the ratio of hydrogen solubilities  $K_{s1}$  and  $K_{s2}$  in these materials [2]:

$$\frac{C_2}{C_3} = \frac{K_{s1}}{K_{s2}}. \quad (2)$$

$$J_- = K_{r1} C_1^2 \quad (3)$$

$$J_0 = J_- + J_+ \quad (J_+ \ll J_-), \quad (4)$$



**Fig. 2** Sketch of hydrogen PDP process.

$J_+$  can be presented as:

$$J_+ = \frac{D_1 \sqrt{J_0 / K_{r1}}}{L_1} \cdot \left(1 + \frac{\phi_1 L_2}{\phi_2 L_1}\right)^{-1}. \quad (5)$$

In the limiting cases of  $\frac{\phi_1 L_2}{\phi_2 L_1} \ll 1$ , i.e. the hydrogen permeability of the coating is much lower than that of the substrate. In this case,

$$J_+ = \frac{D_1 \sqrt{J_0 / K_{r1}}}{L_1}. \quad (6)$$

Here,  $\varepsilon$  is defined as a ratio of  $J_+$  of the membrane with coating to that without coating.

$$\varepsilon = \sqrt{\frac{K_{r2}}{K_{r1}} \cdot \frac{D_1 L_2}{D_2 L_1}}, \quad (7)$$

Based on literature [3-4],  $\varepsilon=0.012$  is obtained, which correlates well with experiments.

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