§76. Surface Condition Effects on Hydrogen Plasma-Driven Permeation through the First Wall in QUEST

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In our previous study, first wall particle flux measurements in the QUEST spherical tokamak have been conducted, using a permeation probe that employs a first wall candidate ferritic steel alloy F82H as the membrane and also SUS304 as a comparative reference membrane. The hydrogen diffusion coefficients for F82H estimated from the QUEST data have been found to be lower by a factor of 3 to 4 than those taken in VEHICLE-1, although the sample membranes are essentially the same.[1)] One possible reason for the lower measured diffusivity is that the membrane surface is contaminated during the PDP experiments in QUEST.

Hydrogen concentration profile in a membrane for PDP in RD-regime is schematically shown in Fig. 1(a). The dash line indicates the implantation depth (to be referred to as *d*). Some literature data suggest that the hydrogen PDP flux is enhanced when the plasma-facing surface is contaminated. That is because recombination release is suppressed by the presence of impurity film, as shown in Fig. 1(b). However, it is also true that if the contaminated layer is thick enough to act as a second layer for diffusion, hydrogen PDP will be suppressed (Fig. 1(c)). To verify the surface contamination effects observed in QUEST, the membrane surfaces are analyzed with energy dispersive X-ray spectroscopy (EDX) and X-ray photoelectron spectroscopy (XPS) after permeation experiments in QUEST. The EDX analysis is utilized to check major impurity elements. For XPS analysis, a 4 kV Ar+ gun is used to etch the sample surfaces so that the depth profile can be obtained.

Figure 2(a) shows the XPS analysis result for an F82H membrane after PDP in QUEST. Impurities such as carbon, tungsten and oxygen have been detected on the membrane surface. The thickness of the impurity layer has been found to be tens of nanometers. By comparison, the average depth is only several nanometers predicted by SRIM code for 50 eV H in Fe (Fig. 2(b)). Considering that most of the hydrogen particles near the QUEST first wall are low energy neutrals, the implantation depth will be even shallower. That means H particle implantation cannot penetrate the impurity layer.

A membrane composed of two sheets of thicknesses L_1, L_2 and diffusion coefficients D_1, D_2 has an effective diffusion coefficient D_{eff}, given by [2)]:

$$L_1/D_1 + L_2/D_2 = L/D_{eff}, \qquad (1)$$

where L is the total thickness of the membrane. Using the diffusion coefficient data for F82H from our previous experiments:

$$D = 7.5\times 10^{-4} \exp(-0.14\ \text{eV}/kT), \qquad (2)$$

the hydrogen diffusion coefficient in the impurity layer has been estimated to be $\sim 2\times10^{-10}$ cm^{2}s^{-1}, which is close to the hydrogen diffusion coefficient for tungsten measured in the same temperature range.[3)]

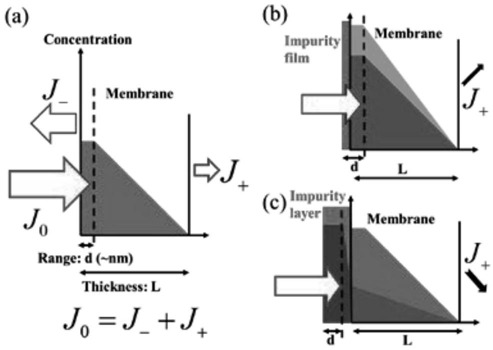

Fig. 1. Plasma-driven permeation takes place in the RD-limited regime for (a) a clean surface, (b) a contaminated surface with thin film and (c) a contaminated surface with thick impurity layer.

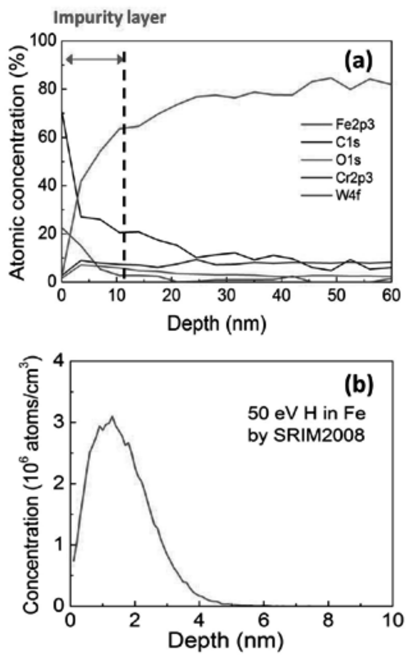

Fig. 2. (a) XPS analysis for an F82H sample after PDP in QUEST and (b) implantation profile for 50 eV H in Fe estimated by SRIM.

1) Zhou, H. et al.: Plasma Fusion Res. **9** (2014) 3405041.
2) Crank, J.: The Mathematics of Diffusion, second ed., Clarendon Press, Oxford, London, 1975.
3) Otsuka, T. et al.: Phys. Scripta **T138** (2010) 014052.