§22. Bi-directional Hydrogen Isotope Permeation through the First Wall of a DEMO Reactor

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Reduced activation ferritic steels (RAFSs) such as F82H are the candidate materials for the first wall of a helical DEMO reactor: FFHR. From the viewpoint of thermal stress, the optimum thickness of the first wall is ~5 mm [1] in which case the first wall will be subjected to bi-directional hydrogen permeation by the two mechanisms: one is plasma-driven and the other is gas-driven, the latter of which is due to the dissociation pressure of bred tritium. Despite their importance, there are virtually no experimental data available on the plasma- and gas-driven permeation through RAFSs. In the present work, as the first step to investigate bi-directional hydrogen permeation, plasma-driven permeation (PDP) behavior through a reduced ferritic steel alloy has been studied.

A plasma-driven permeation experimental setup has been installed on the linear plasma generator, VEHICLE-1 [2], which is equipped with a 1 kW ECR plasma source. As shown in Fig.1, the central 35 mm diameter area of a 70 mm conflat flange made of F82H or SUS304 is machined down to a thickness of 0.65-1.1 mm to serve as a permeation membrane. The stainless steel is used as a reference material because SUS304 has been widely investigated. These flange type samples are mounted on the permeation setup and exposed to plasmas in VEHICLE-1. The permeation chamber is installed with a quadrupole mass spectrometer (QMS) to measure the partial pressure of H_2 permeating through the membrane. The membrane sample is electrically isolated from the chamber, so that a negative bias voltage can be applied to control the ion bombarding energy. Two thermocouples (one in the upstream and the other in the downstream side) and an IR pyrometer are used to measure the membrane temperature. Prior to a hydrogen PDP experiment, the membrane surface is pre-conditioned by argon plasma bombardment at -100V for 15 min. Then, hydrogen plasma bombardment is performed at an ECR power of 250 W and a hydrogen pressure of 2×10^{-3} Torr. The plasma density is ~1.4×10^{10} cm^{-3} and the electron temperature is ~4 eV. Using the zero-dimensional model [3], the hydrogen ion species composition is calculated to be $H^+:H_2^+:H_3^+ \approx 0.2:0.4:0.4$ under this typical plasma discharge condition, and the implantation ion flux is then estimated to be ~1.1×10^{16} $H\cdot cm^{-2}\cdot s^{-1}$.

Data taken for 1.1 mm-thick F82H and SUS304 at a bias of -100V have indicated that the steady-state permeation fluxes are 2.2×10^{13} $H\cdot cm^{-2}\cdot s^{-1}$ and 4.2×10^{12} $H\cdot cm^{-2}\cdot s^{-1}$, respectively, the former of which agrees with a one-dimensional diffusion model: DIFFUSE [4], however, the latter of which turns out to be several orders of magnitude larger than the model prediction. The diffusion coefficient of α-Fe (D=1.1×10^{-4} $cm^2\cdot s^{-1}$), which approximates F82H, is several orders of magnitude higher than that of stainless steel (D=4.8×10^{-9} $cm^2\cdot s^{-1}$) at a temperature around 200 ℃ [5], which should be the main reason for the higher PDP flux of F82H.

Figure 2 shows the time evolution of the hydrogen PDP fluxes through 1.1 mm thick membranes of F82H and SUS304. Only for F82H, a transient peak has been observed, reaching a peak PDP flux of 7.7×10^{13} $H\cdot cm^{-2}\cdot s^{-1}$. One possible explanation for the transient peak is that hydrogen atoms absorbed on the downstream surface are released together with permeating hydrogen atoms. This process will lead to a gradual decrease of the PDP flux when the initial downstream hydrogen atoms are depleted.

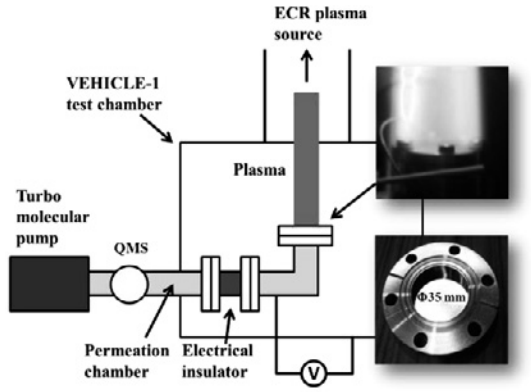

Fig.1 The plasma-driven permeation experimental setup in Vehicle-1.

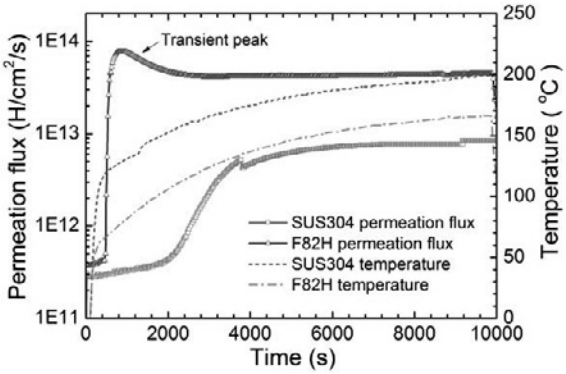

Fig.2 Time evolution of hydrogen PDP fluxes through 1.1 mm F82H and SUS304 membranes.

1) Sagara, A. et al.: Fusion Technol. **39** (2001) 753.
2) Hirooka, Y. et al.: J. Nucl. Mater. **337-339** (2005) 585.
3) Hollmann, E. M. et al.: Phys. Plasmas **9** (2002) 4330.
4) Baskes, M. I.: "DIFFUSE83" Sandia Rep. SAND83-8231
5) Doyle, B. L. et al.: J. Nucl. Mater. **122&123** (1984) 1523