§26. Observation of Hydrogen Permeation in LHD and Evaluation of Wall Leakage for DD Experiments

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Hydrogen permeation through plasma-facing walls in magnetic confinement device has attracted attention from view point of tritium leakage. The main parameter in estimating the permeation is the recombination coefficient, a rate constant for hydrogen atoms to form molecules. The recombination coefficient strongly depends on plasma conditions such as particle flux, ion temperature and impurity amount, so it largely scatters among the laboratory-scale experiments. It is important to observe the permeation in plasma devices of which the plasma conditions are well known and to relate the recombination coefficient with the plasma parameters. For this purpose, a measurement system was installed in a tokamak device QUEST and hydrogen plasma driven permeation during the plasma discharge was observed at 2008. In the present work, the recombination coefficient will be estimated from transient behavior or the permeation flux.

As shown in Fig.1, the system consists of two vacuum systems, upstream and downstream ones, separated by a nickel membrane. The thickness of the membrane is 30 μm. A shutter baffle is located between the membrane and the plasma. Hydrogen permeation through the membrane is observed by a quadrupole mass analyzer (QMA) with magnetic shield, set in the downstream chamber.

Fig. 2 shows transient behaviors of the hydrogen permeation flux, which was observed during and after the plasma discharge. The discharge started at 0 time and continued to 30 s. The plasma was produced using 2.45 GHz RF system under a fixed 4.5 kW RF power. The permeation flux increases and the rise time of permeation decreases with increasing the membrane temperature. This is mainly because the diffusion coefficient increases with the membrane temperature.

The permeation curve can be analyzed with a diffusion model[1)], in which one dimensional diffusion equation is numerically solved with the upstream and downstream boundary conditions of recombination-induced desorption. The numerical calculation has been successfully conducted to fit all the permeation curves under the fixed value of the incident flux.

Temperature dependence of the recombination coefficients of k_u (plasma-side) and k_d (vacuum-side), estimated from the numerical calculation, are shown in Fig. 3. k_d is expressed as

$$k_d = 1.2\times10^{-26}\exp(-0.34[\mathrm{eV}]/kT) \quad [\mathrm{m^4s^{-1}}] \quad (1)$$

The pre-exponential factor agree well with the value estimated with the recombination model[2)], indicating that the recombination process on the vacuum side consists of thermally activated processes. k_u can be expressed as

$$k_u = 4.5\times10^{-29}\exp(-0.08[\mathrm{eV}]/kT) \quad [\mathrm{m^4s^{-1}}] \quad (2)$$

It is nearly equal to k_d at higher temperatures but becomes larger than k_d with decreasing temperature. A plausible explanation is some of the incident hydrogen atoms are reflected by hydrogen absorbed on the upstream surface of the membrane and an effective incident flux becomes smaller at lower temperature. Hydrogen atoms at eV energy are reflected as being atoms by hydrogen-covered surface with high efficiency. This is the reason that hydrogen atoms from the plasma can reach the membrane around the baffle plate.

The above results suggest the suitability of this system for the measurements of atomic flux using a metal membrane with known diffusivity and recombination coefficients.

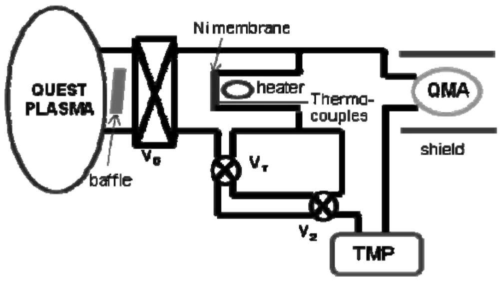

Fig. 1. A measurement system for plasma driven permeation

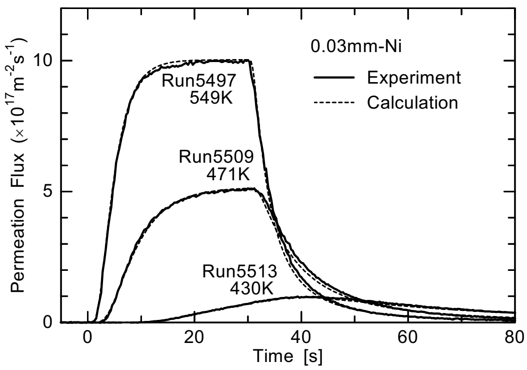

Fig. 2. Transient behavior of the permeation flux during and after 30s plasma discharge.

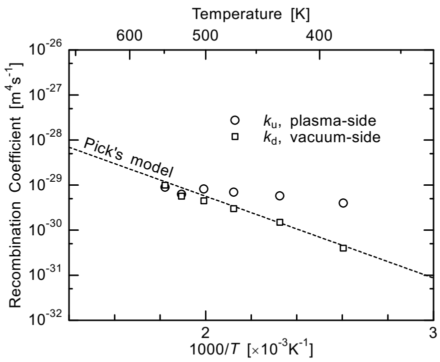

Fig. 3. Temperature dependence of the recombination coefficients on the plasma and vacuum side.

1) I. Takagi, J. Nucl. Sci. Technol. 29 (1992) 947.
2) M. A. Pick, J. Nucl. Mater. 131 (1985) 208.