§25. Kinetics of Hydrogen Isotopes at Surfaces and Bulks of Plasma Facing Materials Based on Group 5 Metals

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Group 5 metals including V are candidate materials of superpermeable membranes for pumping fuel particles in divertor region. In addition, V alloys have attractive mechanical and nuclear properties as structural materials of fusion blankets. From these viewpoints, the interactions of hydrogen isotopes including tritium with V and V alloy were investigated by different experimental techniques.

Nakamura et al. [1] have examined the absorption of hydrogen atoms by Nb panel and observed sufficient pumping speed at specimen temperatures, *T*, above 200 ºC. In the lower *T* region, however, the pumping speed dropped sharply with decreasing *T*. Such reduction in pumping speed at low *T* poses a serious problem in performance tests in existing fusion devices including LHD. The reduction in pumping speed can be caused by (1) saturation of surface by hydrogen adsorbed from gas phase or segregated from the bulk, (2) contamination by adsorbed impurities such as water vapor, and/or (3) surface oxidation. In the present study, absorption of atomic hydrogen by V panel near room temperature was examined as functions of incident flux, bulk hydrogen concentration and chemical surface state to understand the mechanism underlying the reduction in pumping speed observed at low *T*.

The atom-driven hydrogen absorption by V panel was examined near room temperature in an UHV chamber equipped with Ta filament serving as an atomizer (*T* increased from 30 to 70 ºC during experiment due to radiation from atomizer). A Nb ribbon which was kept at 400 ºC was used as a reference sample providing constant pumping speed. The chemical surface state was analyzed by means of X-ray photoelectron spectroscopy (XPS).

Fig. 1 shows the flux dependence of the absorption coefficient of atomic hydrogen by V panel. No significant change in absorption rate was observed in a wide range of incident flux (10^{17} – 10^{21} $H \cdot m^{-2} \cdot s^{-1}$). In addition, the absorption rate was almost independent of the bulk hydrogen concentration in a range from 10^{23} to 10^{26} $H \cdot m^{-3}$. Hence, it was concluded that the reduction in pumping speed was not due to the surface saturation by hydrogen.

The influence of impurity gases on absorption coefficient of atomic hydrogen is shown in Fig. 2. No noticeable change was induced by exposure to CO. On the other hand, the absorption coefficient sharply dropped by exposure to O_2. Exposure to H_2O, however, led to reduction in the absorption rate only at very large extent of exposure corresponding to 10^4 monolayers. Namely, the reduction in pumping speed could not be ascribed to the surface contamination by water vapor adsorption.

The surface analyses by XPS showed that oxide films (mainly V_2O_3) were formed by the exposure to O_2 and the extended exposure to H_2O. These observations indicate that the formation of oxide layer is the dominant mechanism underlying the reduction in pumping speed observed at low *T*. In other words, performance tests of membrane/panel at low *T* are possible if the growth of oxide layer could be avoided by reduction of oxygen partial pressure and/or periodical surface conditioning.

Diffusion of tritium is also important issue for the application to structural materials of blankets. Hence, the diffusion coefficient *D* of tritium in recrystallized specimen of V-4Cr-4Ti alloy (NIFS-HEAT-2) was measured by glow discharge implantation method [2] in a temperature range from 100 to 300 ºC. The temperature dependence of *D* thus obtained was described as

$$D\ (m^2 \cdot s^{-1}) = 7.5 \times 10^{-8} \exp(-0.13\ (eV) / kT).$$

This value was noticeably smaller than that for pure V and comparable with the value for binary V-4Ti alloy, indicating the trapping effect by Ti. The observations of tritium distributions in several specimens having different microstructures indicated that the spatial distribution of trapping sites depended on the conditions of rolling and heat treatments.

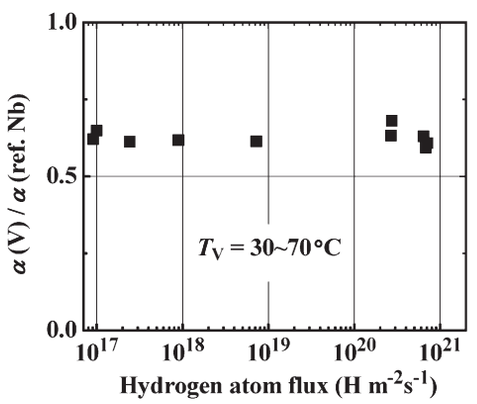

Fig. 1 Correlation between absorption coefficient of hydrogen atoms on V surface and incident flux.

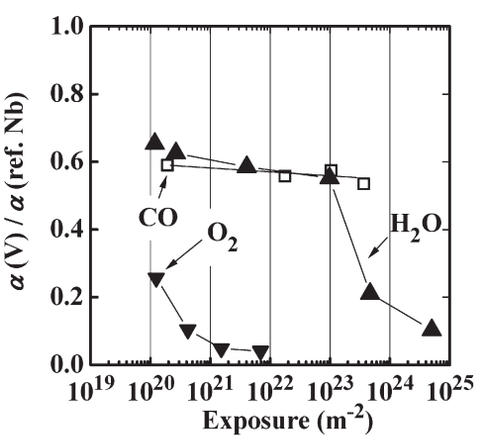

Fig. 2 Change in H atom absorption coefficient by exposure to impurity gases.

References
1) Nakamura Y., et al.: J. Nucl. Mater. **337-339** (2005) 461.
2) Hashizume K., et al.: Fusion Technol. **28** (1995) 1175.