

§19. Formation Mechanism of Material Mixing Layers on First Walls and their Effect on Hydrogen Isotope Retention

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To use different wall materials in fusion reactors mixed material layers and deposition layers are formed through erosion, transport in mainly edge plasmas, and redeposition of wall materials. These layers greatly affect hydrogen isotopes behavior by providing trapping sites and modifying diffusion characteristics and recombination. In addition, helium ions, reaction product of DT fusion reaction, also greatly modifies surface characteristics of tungsten through the formation of He bubbles. Systematic study of these effects, however, has not been performed and basic data of mixed materials necessary for the estimation of tritium behavior in wall materials are not sufficient.

In this study, material mixing of tungsten and helium, and its effects on hydrogen isotope behavior have been investigated by mixed ion beam irradiation device HiFIT with a new equipment for deuterium permeation. Deuterium and helium mixed ions were irradiated to pure tungsten material with the HiFIT device. These gases were mixed in an ion source to be ionized and were extracted with an acceleration voltage of 1 keV. Since there was no mass separation in the HiFIT device, several deuterium molecular ions such as D^+ , D_2^+ and D_3^+ together with small amount of impurities (mainly 0.1~0.2% C) were irradiated. Pure tungsten samples with the thicknesses of 30 μm and 75 μm were used. Heat treatment with 1300 $^\circ\text{C}$ for 1 hour in a hydrogen atmosphere was done for stress relief and recrystallization. Most of intrinsic defects are removed by this heat treatment. We tested 2000 $^\circ\text{C}$ annealed tungsten and it also showed similar diffusion behavior, which indicated that a trapping site effect is not significant.

A new permeation device, named POD-HD, was installed to HiFIT. Tungsten samples can be heated up to about 1000 K by an infrared heater with a quartz rod. This temperature range almost corresponds to that of blanket first walls. Therefore, POD-HD is a useful device to take permeation data relevant to estimation of tritium behavior in blankets. A base pressure of the permeation chamber was about 3×10^{-9} Torr after 24 hour 400 K baking. Most of permeated deuterium atoms appeared as D_2 molecules, which indicated that residual hydrogen did not affect much about release of deuterium from the permeation side of W samples. Ion beam flux and residual D_2 pressure were $1 \times 10^{20} \text{ m}^{-2}$ and $\sim 10^{-5}$ Torr.

Evolution of permeation flux of deuterium was measured with 2% of He. Permeation fluxes after saturation depended on temperature. At 1000 K and 800 K, addition of 2% He to D ion beam reduced permeation fluxes by about 50%. On the other hand, permeation fluxes significantly reduced (by more than two orders of magnitude, which was less than the detection level). In the

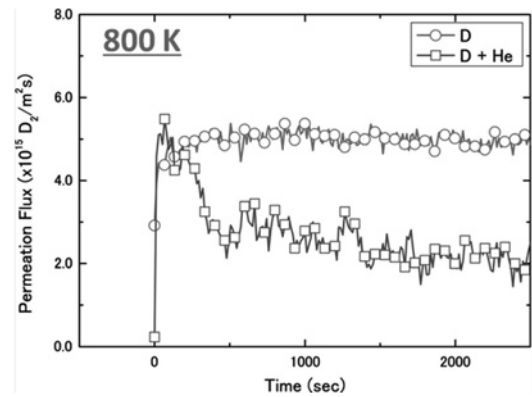


Fig.1 Evolution of permeation flux with and without He (2%). Ion energy and W thickness were 1 keV and 75 μm .

case of pure D ion implantation, dependence of steady-state permeation flux on impinging D flux ϕ was about $\phi^{1.0}$, indicating characteristics of permeation was in DD regime, which meant deuterium release from a front side and a back side was controlled by diffusion. On the other hand, in the case of D and He mixed ion irradiation, flux dependence was changed to about $\phi^{0.5}$, indicating permeation regime changed to RD. Therefore, D release mechanism at the front surface decorated by He ion implantation could change from diffusion-limited to recombination-limited.

This hypothesis seems in good agreement with He bubble connection model, which has been suggested by D and He mixed plasma exposure experiments to tungsten, which showed addition of He greatly reduced D retention in tungsten[1]. As He ions are injected into near surface region, He bubbles were formed with its sizes dependent on temperature. At low temperatures less than about 800 K, nano-sized He bubbles were densely formed. Eventually, these bubbles were connected to produce open pores to the surface. Implanted D atoms diffuse to the inner surface of these pores and recombine to form D molecules. These molecules easily move in the pores and finally escape from the surface. In this process, diffusion length of implanted D is very short. Then, surface recombination could become a controlling process. This experimental result does not contradict with our permeation result.

For pure D implantation at 1050 K, permeation flux slowly increased without showing saturation up to 6,000 sec. One of the possibility is the effect of carbon ions existed in ion beam in a small amount. This carbon could segregated on the surface and prohibit D atoms from desorption. This will be clarified in further permeation study with D and C mixed ion beam irradiation.

[1] M. Miyamoto, et al., Nucl. Fusion 49 (2009) 065035 (7pp).