§65. Effects of Surface Mixing Layers of Tungsten on Hydrogen Isotope Behavior

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It is well known that hydrogen retention and permeation in tungsten materials are influenced markedly by surface mixing layers such as a W/C layer and a helium bubble layer near the tungsten surface. For evaluation of tritium behavior in plasma facing materials, quantitative information on tritium diffusion, trapping and release from the mixed surface have to be known. Only qualitative results, however, have been known so far. In the present study, surface mixed layers formed by D/C and D/He ion irradiation with a precise control of impurity concentration and tungsten samples exposed to TEXTOR edge plasmas were used. These samples were exposed to tritium gas. Then surface density of tritium retention was measured by IP (Imaging Plate) and depth profiles were measured by a chemical etching and a liquid scintillator. Surface mixed layers were well characterized by NRA (Nuclear Reaction Analysis), XPS (Xray Photoelectron Spectroscopy), and TEM (Transmission Electron Microscope). By these experimental results, relations between surface conditions (a C/W ratio and a chemical state of C and W) and tritium uptake can be clearly understood.

In the experiments, tungsten samples made by A. L. T. M. Corp. with a purity of 99.99% were exposed to D/T mixed gas (T concentration was 7.2%) at 300 ˚C for 3 hours. Tungsten samples were annealed at 2000 ˚C for 1 hour and polished to a mirror finish. Three types of tungsten samples without plasma exposure, with He plasma exposure to the fluence of 5 x 10^{24} m^{-2}, and with the exposure to TEXTOR edge plasmas. For the TEXTOR plasma exposed samples, C/W mixed layers or carbon deposition layers with the thickness of 100-200 nm were formed.

Tritium surface density after T gas exposure was measure by IP showed clear dependence of T retention on surface mixed layers. Very little T retention on the surface without plasma exposure was observed, while significant amount of T retention was observed on the surface modified layers (either He plasma or TEXTOR plasma). Especially for the He plasma modified surfaces, most T retention was observed even more than that on C deposition layer. Tritium could be trapped in helium bubbles more effectively than carbon deposition layers. Details (temperature dependence, C layer thickness dependence, etc.) need to be investigated. One more note is that tritium retention on (or in) W/C mixed layers is relatively low (higher than non-exposed samples, but lower than C deposition layers). It is believed that surface recombination on W/C mixed layer could be low, which tends to reduce recombination of T on the surface. This might lead to the increase in T retention near the surface. But this theory may not be true. More detailed investigation is necessary.

Tritium diffusion in tungsten was studied by a depth profile measurement with a chemical etching method. Figure 1 shows depth profile of tritium in tungsten with and without He plasma exposure. Since 2000˚C annealed samples used in this experiment had very few defects,

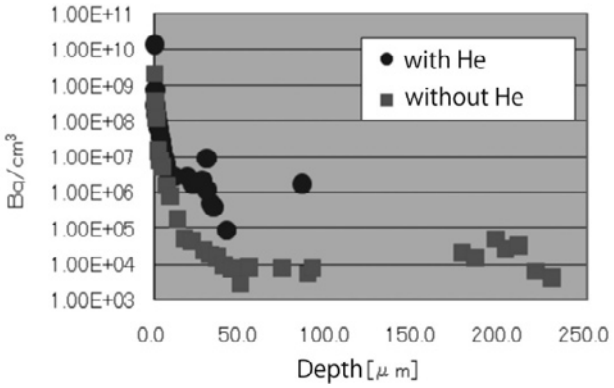

Fig. 1 Depth profiles of Tritium for the samples with and without He plasma exposure.

tritium trapping deep into the bulk (more than 50 μm for the sample without helium plasma exposure) is very small (about D/W = 10^{-9}). On the other hand, near-surface density at the depth less than 50 μm is higher than this value, though tritium exposure did not make any recoil damage. These trapped tritium could be exist at interstitial sites.

To estimate diffusion length by simple 1D diffusion model, it was estimated to be about 2.2 mm with the frauenfelder's diffusivity[1]. This number seems much larger than the experimental one, an order of μm. Even with Zahkarov's diffusivity[2], the diffusion length is about 0.11mm. Therefore, a depth profile of tritium in the non-treated sample cannot be explained by a simple diffusion model. For the He plasma exposed sample, tritium trapping around 20-30 μm in depth is higher. The helium ion implantation range was about 2-3 nm, which is much smaller than this range. At near surface region, helium bubble layers, thickness of which could be a few tens of nm, was formed. One of the theories to understand T trapping around 20-30 μm is that this layer produces internal stress which may induce trapping sites at much deeper area than the helium bubble layer. More investigation will be necessary. We will try these experiments with different tungsten samples and at different exposure conditions.

1) J. Frauenfelder, J .Vac. Sci. Technol. 6 (1968) 388.
2) A.P. Zakharov et al., Fiz. Khim. Mekh. Mater. 9 (1973) 29.