§92. Effects of Microstructure and Additional Elements of Tungsten on Bulk Diffusion and Retention

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Recent experimental and theoretical works suggest that microstructure and additional elements greatly affect hydrogen isotope behavior in tungsten. It is believed that hydrogen atom diffusion along grain boundary and inside of grains is not the same. Probably diffusion along grain boundary is more pronounced. It is also suggested that high flux and high fluence hydrogen ion implantation could cause a high density layer of solute hydrogen near the surface, which would result in oversaturation and defect creation [1]. The mechanism of this defect creation is not cleared yet but it closely relates to hydrogen precipitation from oversaturation layers.

Additional elements could improve tungsten mechanical properties. Tungsten is well known for its brittleness at low temperatures, after recrystallization, and by neutron irradiation. To improve these deficiencies, new tungsten materials (TFGR-W) have been developed by Prof. Kurishita [2]. These materials include TiC or TaC dispersoids at grain boundaries, which increase ductility near room temperature, prevent recrystallization, and alleviate radiation embrittlement. But one remaining concern is retention enhanced by addition of dispersoids. It was already known that hydrogen isotope retention in TFGR-W is higher than pure tungsten. But more database are necessary to understand the role of additional dispersoids on retention and to optimize TFGR-W materials in terms of mechanical properties and tritium retention.

In this study, we used tritium (T) gas for measurements of hydrogen isotope retention and its depth profile. Tritium is very useful to correctly measure T distribution with very large dynamic range (more than 10^5) by chemical etching technique. W samples used are conventional powder metallurgy, hot rolled ones with the purity of 4N. Annealing was made at 1173 K for stress-relief. T exposure with D/T mixed gas (7.2% T) was done at 573 K for an hour to 5 hours at the pressure of 1.2 kPa. After exposure to D/T mixed gas, samples were left in vacuum until their temperature became RT.

T retention up to 50 μm for various tungsten materials is shown in Fig. 1. It was found that annealing at 1173 K clearly reduced T retention by about one thirds by comparing similar exposure conditions (1 hour and 5 hours) of annealing and no annealing. Since ITER Grade tungsten (ITER GW) was annealed at similar annealing temperature, ITER GW shows similar T retention to annealed ones.

Depth profiles of these exposure and materials conditions are shown in Fig. 2. It is interesting to note that for any types of tungsten, quite high D/T concentration near top surface was observed. Then the concentration decreases steeply to the bulk. Except for the top surface concentration, bulk concentration of D/T is higher by an order of magnitude for the no-annealing cases than for the annealing cases, which could be due to higher trap sites concentration. But the density is decreasing to the bulk, which suggests that D/T diffusion to the bulk would proceed as D/T gas exposure time increased. It is necessary to model these phenomena and make acceptable models for evolution of D/T retention for lifetime of fusion reactors.

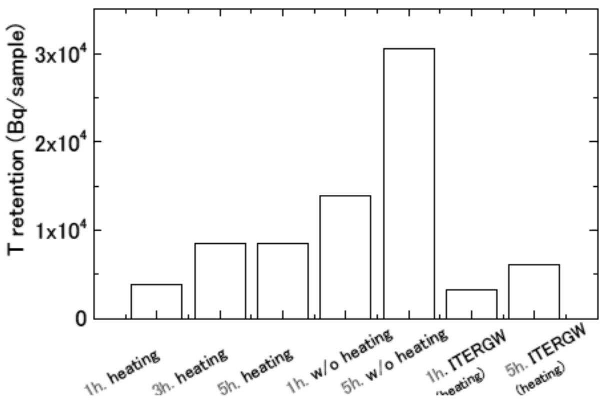

Fig.1 T retention up to 50 μm for each experimental conditions. Sample heating (annealing) was made at 1173 K. ITERGW has perpendicular grain boundary orientation to surfaces.

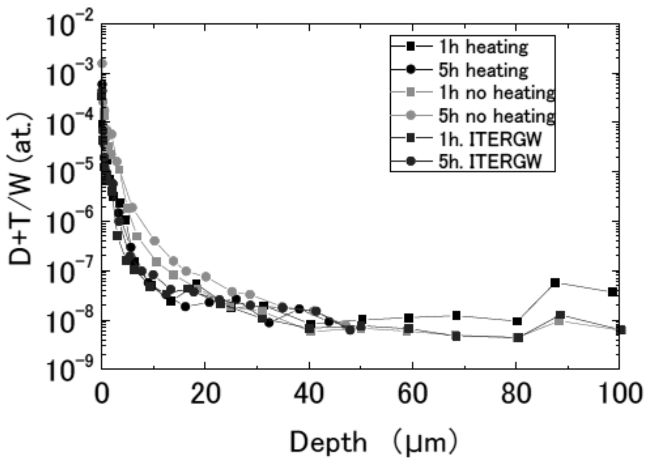

Fig. 2 Depth profile of hydrogen isotopes (D and T) exposed to D/T mixture gases at 573 K for 1 to 5 hours.

In future, we plan to expose tungsten with different microstructures and additional impurities to understand D/T behavior in the bulk, which eventually determines total retention in tungsten plasma facing materials. In addition, we will employ IP (Imaging Plate) to measure 2D surface T profile in combination with etching technique, which enable us to obtain 3 D hydrogen isotope distribution in tungsten materials.

[1] O. V. Ogorodnikova, J. Roth, and M. Mayer, J. APPL. PHYS. 103, 034902 (2008).
[2] H. Kurishita, et al., J. Nucl. Mater., 398 (2010) 87-92.