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

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It is well known that surface mixing (modified) layers of tungsten formed by mixed ion irradiation (D/He, D/C, and et al.) strongly affect hydrogen isotope behavior such as T retention, recycling, and permeation. For example, mixed ion irradiation of D and C enhances blister formation on tungsten [1]. Recent study on D/N mixed ion irradiation also enhance blistering and permeation, similar to D/C [2]. D/He mixed ion irradiation greatly reduces D retention in tungsten [3].

Reasons for enhancement or reduction of D release from implanted surfaces are still under discussion. For a helium mixing case, He bubbles formed near surface (within a depth of ~30 nm) could play an important role. Dense He bubbles could make pores reaching the surface by connecting bubbles, which enhances outward diffusion. In this case, effective surface area should increase. For addition of carbon and nitrogen, tungsten carbide or tungsten nitride formed on surface could work as desorption barrier. We need more evidences to understand how these surface mixed (modified layers) affect dynamics of hydrogen isotopes.

In this study, tungsten samples irradiated with D only, D/He, D/N, and D/Ar mixed plasmas were exposed to tritium gas and amount of trapped T in the surface modified layers was measured by IP (Imaging Plate) to know the trap site density in these modified layers. Especially for evaluation of effective surface area, which could be closely related to He bubble dynamics, we first tried to measure tritium adsorption on surface by exposing tungsten at 77 K. At this temperature, hydrogen atoms do not diffuse into the bulk of tungsten at all and exist only on the outermost surface. Therefore, tritium surface density can be directly correlated to an effective surface area.

Fig. 1 shows experimental setup for this experiment. Tungsten samples were exposed to D/T mixed gas (T concentration of 7.2%) at 573 K and 77 K. For 77 K exposure, samples were cooled down by liquid nitrogen.

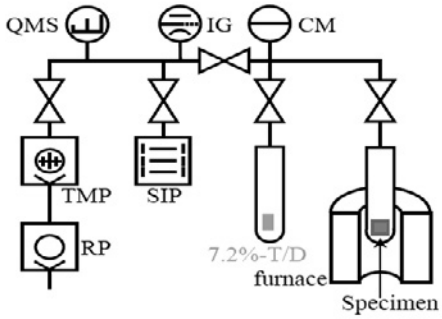

Fig.1 Experimental setup for a T exposure experiment

After exposure to D/T mixed gas, samples were left in vacuum until their temperature became RT. During this process, some of T_2 gas adsorbed at 77 K was released and only T atoms (or molecules) trapped at relatively strong surface trap sites remained. Since surface trap density could be closely related to surface impurity, we always need to pay attention to presence of surface impurities, especially oxygen, which was not deliberately introduced but existed on tungsten surfaces. On the other hand, T_2 gas absorption at 573 K, tritium can diffuse into the bulk and fill most of traps near surfaces.

Intensity of IP signal (PSL, Photo stimulated luminescence) for different plasma exposed samples was shown in Fig. 2. Plasma ion fluence was about 3×10^{24} m^{-2}. Tungsten samples were pre-annealed at 2273 K to remove most of intrinsic defects (dislocations etc.). Therefore, near-surface trap sites after plasma exposure were mostly ion induced ones. Ion bombardment energy was about 50 eV, where only Ar has a non-negligible sputtering yield.

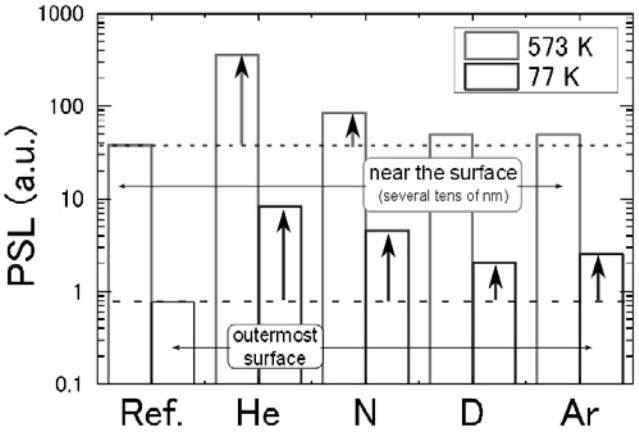

Fig. 2 PSL value after T exposure at 77 K and 573 K. At 77 K, T existed only at outermost surfaces, while at 573 K, T existed in near surface layers with a thickness of several tens of nm.

Among four ions bombardment, He ions made most tritium trap sites both on outermost surfaces (77 K) and near surface layers (573 K) due to He bubbles. Second to He, T trapping on nitrogen modified surface is the largest probably because a tungsten nitride layer became T trapping sites. For D and Ar bombardment, only T adsorption on the outer most surface showed clear increase, while T retention in the bulk (573 K) did not change much by ion irradiation. The reasons could be due to no ion damage for D (less than sputtering threshold energy) and a very short ion range (a few monolayers) for Ar. Both ion bombardments only changed the outermost surfaces such as removal of oxide layer or some other impurities (ex. carbon). For He irradiation, increments in trapping T amount at 77 K and 573 K compared with reference cases is similar, suggesting He bubble growth and increase in inner surface area of He bubbles could play an important role for both cases.

[1] Y. Ueda et al., *Nucl. Fusion* **44** (2004) 62.
[2] H.T.Lee, presented at 14th PFMC (2013).
[3] M. Miyamoto et al., *Nucl. Fusion* **49** 065035.