§30. Effects of Simultaneous Helium Irradiation on Hydrogen Behavior in Plasma Facing Materials

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In fusion reactors, tungsten is a leading candidate for plasma facing materials (PFMs) due to high melting point, low sputtering yield by light ions, and high thermal conductivity. Its brittleness by hydrogen isotope and helium ions, however, is one of the serious concerns. To study this subject in detail, it is important to know hydrogen and helium behavior in tungsten. In fact, quite a few studies have been done on hydrogen or helium behavior in tungsten by mono-species ion irradiation to tungsten. In actual fusion devices, however, hydrogen isotopes (D and T) and helium ions (5~10%) simultaneously impinge on plasma facing materials. Therefore, it is important to study synergistic effects of hydrogen and helium to correctly evaluate tungsten materials response in fusion reactors.

We already showed that the small addition (0.1%) of helium to high flux hydrogen ion beam suppressed blister formation of tungsten. This indicated that helium ion implantation reduces hydrogen influx into the bulk of tungsten. It is known that implanted helium tends to agglomerate at vacancies to form helium bubbles, which could cause internal stress and reduce diffusion. Studies on this issue, however, have been very few, though this effect would be important for hydrogen isotope behavior in first walls.

In this year, simultaneous irradiation of hydrogen and helium beam with different energies to tungsten was made to observe its effect on blistering. In Fig. 1, the ion range distribution of hydrogen and helium in this study. Acceleration voltage was 1.5 keV and the main hydrogen ion component was H_3^+, which meant hydrogen atom energy was 500 eV. By keeping hydrogen ion energy constant, helium ion energies were changed from 0.6 keV to 1.5 keV at 653 K. It was found that no blistering appeared for 1.0 keV and 1.5 keV cases while blistering was enhanced for 0.6 keV cases. According to Fig. 1, blistering took place in the case that the helium ion range was shorter than that of the hydrogen ion. Since helium bubbles were formed around the end of ion range at low temperatures at which helium bubbles were not mobile, it is suggested that helium bubble layer worked as a diffusion barrier of hydrogen.

Helium bubbles observed by TEM were shown in Fig. 2. In the case of no helium addition to the hydrogen beam, bubbles were not observed, while dense helium bubble layer was observed for He:0.1% and He:1.0% cases. Carbon concentration in the beam did not affect helium bubble characteristics. Helium bubble density seemed to increase a little with He concentration in the beam. The volume rate of He bubbles was estimated under the assumption that the shape of He bubbles was sphere and observed sample thickness was 20 nm. It was about 2% for He:0.1 %. This volume rate of He bubbles could affect hydrogen diffusion in tungsten. The mechanism of diffusion reduction could be strain field caused by He bubble layer. Its quantitative analysis, however, must be needed with the help of MD simulation. In addition, more experimental works will give clear pictures on the effects of He bubble layer on T diffusion and bulk retention in tungsten.

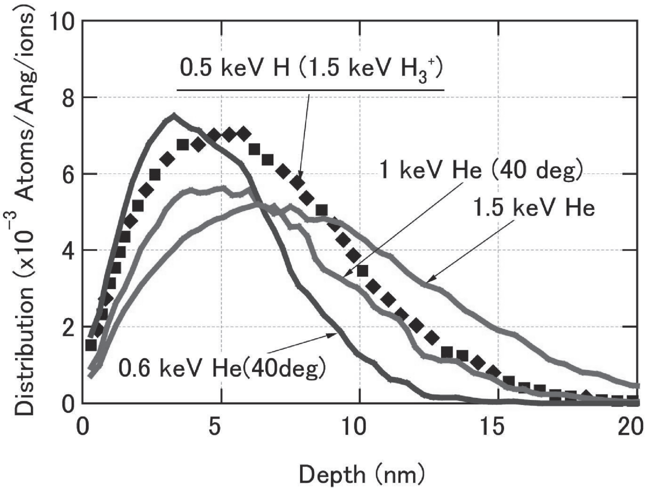

Fig.1 Ion range distribution of hydrogen (0.5 keV, normal incidence, dotted curve), and H ions (0.6 keV (40 deg), 1.0 keV(40 deg), 1.5 keV(normal incidence)).

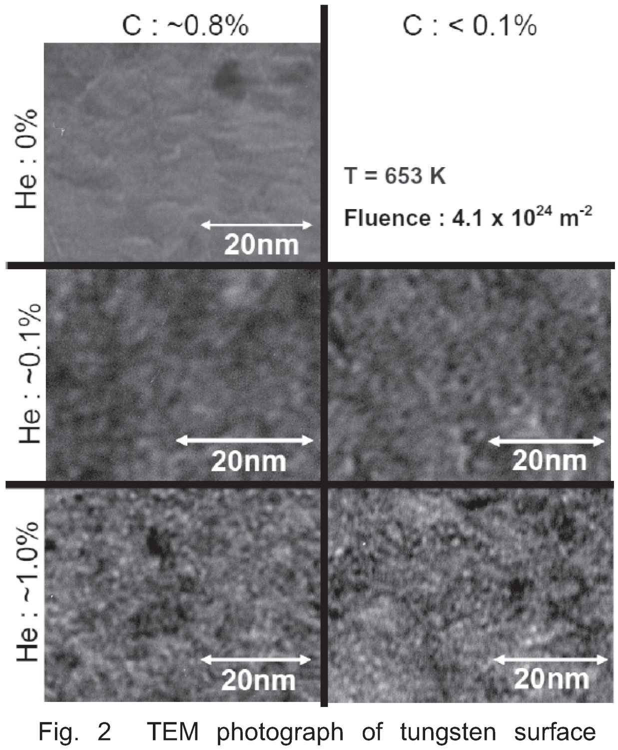

Fig. 2 TEM photograph of tungsten surface layers irradiated by hydrogen, carbon, and helium mixed ion beam.