§20. Temperature Impact on Tungsten Surface Exposed to He Plasma in LHD and its Consequences for the Material Properties

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Helium plasma exposure experiments have been carried out under wide temperature range between 65 and 800 °C in 17th and 18th LHD experimental campaign. Cross sectional transmission electron microscope (TEM) observation shows that the helium nano-bubbles are distributed deep inside tungsten (< 70 nm) beyond the range of helium implantation (∼ 15 nm) at any temperature. The bubbles become larger and sparser as temperature increases especially above 500 °C by growing and coalescing small bubbles. These results imply that the bubble nucleation is dominated by the accumulation of helium and the bubbles grow efficiently capturing vacancy at 500 °C and above.

Tungsten is a promising material for the first-wall of fusion devices, hence it is of prime importance to understanding its behavior facing plasma. Produced by the fusion reaction in ITER and DEMO, helium irradiation is known to drastically affect surfaces of exposed tungsten, even at energies below any expected displacement damage. As first-wall materials will reach 500 °C in DEMO, and temperature affects atoms and vacancies mobilities, temperature is a crucial parameter to consider when characterizing the micro-structural changes. In this aim, a new temperature controlled material probe was designed for the exposure of tungsten samples to He plasma in LHD. We saw via TEM that important damages (bubbles and dislocation loops) were created at high temperatures. It is crucial to understand if these micro-structure changes have a global effect on the material behavior in the reactor.

In order to expose tungsten samples to the LHD helium plasmas under the high temperature conditions, two temperature controlled sample holders with micro ceramic heater and a retractive material probe, which is installed at 10.5L port, have been employed. One sample holder can provide multi temperature using temperature gradient between heater (600 °C) and heat sink (65 °C). Another sample holder has reduced thermal loss structure and can achieve to higher temperature up to 800 °C. The tungsten samples, which are keep at high temperature, are exposed to a charge exchange particles from the LHD helium plasma inserting the retractive material probe at the first wall position. The fluence is estimated at $\sim 10^{23}$ $/\mathrm{m}^2$ for a sequence of 100 NBI heated plasma with helium gas puff. Since the energy of the charge exchange particles mainly distribute below the threshold energy of the displacement damage to the tungsten (∼ 550 eV), the vacancy production rate is two order lower than the helium implantation rate.

Cross-sectional observation has been carried out using a TEM after processing a sample with the Focused Ion Beam (FIB). Fig. 1 shows typical damage structure of the helium exposure sample at 800 °C. Helium bubbles are formed not only near surface layer (< 10 nm), where heavily damage is induced by helium implantation, but also deep region beyond the range of helium implantation, although the bubble size become small in the deep region.

Fig. 2 (a) shows depth distribution of the bubble number density at 190, 530, and 800 °C. The bubble formation depth (< 70 nm) is insensitive to temperature, despite the fact that the vacancy migration becomes active at temperature above 500 °C. It seems that vacancies play a lesser role in bubble nucleation, and this provide supporting evidence for bubble nucleation by accumulating helium itself. On the other hand, the bubble becomes larger and sparser under high temperature conditions by growing and coalescing. Large size bubble dominate the total bubble volume at 800 °C (Fig. 2 (b)). This implies that the bubbles grow efficiently capturing vacancy at temperature above 500 °C.

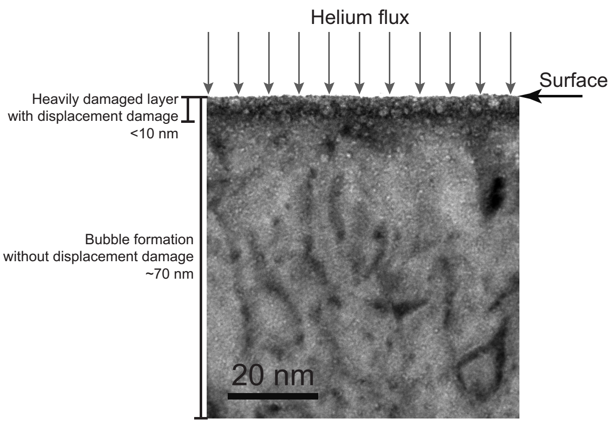

Fig. 1: Cross-sectional TEM image of the helium exposed tungsten at 800 °C

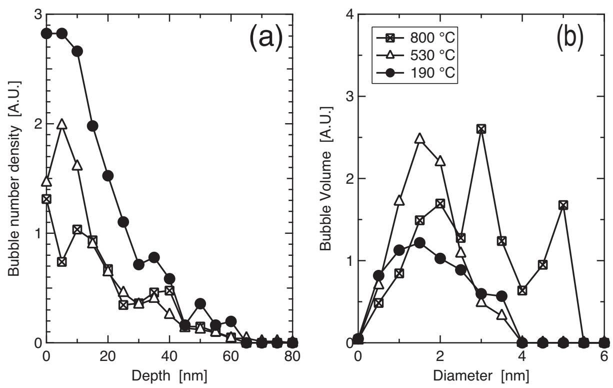

Fig. 2: Temperature dependence of (a) bubble depth distribution, and (b) bubble size distribution.