Blister Formation on Tungsten Irradiated by 4 MeV Helium Ion Beam in Ordinary Temperature

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Blistering was observed on surface of polycrystalline tungsten samples irradiated by helium ion beams with 4 MeV kinetic energy in a fluence of 10^{22} m^{-2}. The helium ion beam was used as the damage source to the tungsten plate, and the surface temperature of tungsten sample was increased up to 345 K by the ion beam irradiation. The surface was modified by the ion beam irradiation, and its maximum height was about 20 μm.

Keywords: high energy helium ion beam, plasma facing material, tungsten, blister

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Tungsten is one of the candidates of plasma-facing materials (PFMs) in the nuclear fusion system. In this system, low-energy helium ions (<keV) are irradiated to divertor plates along with magnetic flux lines. Surface modification of tungsten, such as helium bubbles [1] and fibrous nanostructure [2], was generated due to the low-energy helium irradiation, and these properties have been investigated.

Irradiation of high-energy helium ions (~MeV) on the first wall by toroidal ripple loss was numerically calculated in the tokamak-type fusion reactor [3]. High-energy helium ions deposit the kinetic energy locally inside the wall in comparison with low-energy ions. A defect layer along with depth direction was created by the irradiation. In previous studies, the effect of high-energy helium irradiation in order of MeV has been reported [4–6]. Moreover, the tungsten samples were controlled in a high-temperature condition. At a material temperature of 473 K, vacancies inside tungsten move [7] and a vacancy cluster is created. Helium bubbles and blisters may be created by ion beam irradiation with a large fluence even in low-temperature condition. In this study, we investigated the damage on a tungsten surface irradiated by 4 MeV helium ion without external heating except the ion beam irradiation.

The helium beam irradiation experiment was carried out using an electrostatic tandem accelerator (Tandetron broch (4117-MC*-358): High voltage engineering) at Nagaoka University of Technology [8]. The kinetic energy of helium ion (He^{2+}) was 4 MeV. Using TRIM code [9], the projectile range of 4 MeV helium ions in tungsten was estimated to be 6.1 μm. The helium ion beam was collimated by a squared aperture of 2 × 2 mm. Figure 1 shows the photograph of the irradiation target in the vacuum chamber. The tungsten sample was mounted on the ion collector with thermo labels and a thermocouple in a vacuum chamber. The pressure in the vacuum chamber was set as 1.6×10^{-4} Pa. The beam current was measured using the ion collector during the irradiation. In addition, the surface temperature of the sample was measured by the K-type thermocouple with a data logger (midi LOGGER GL10-TH: GRAPHTEC Corporation). The surface temperature of the ion collector around the tungsten sample was also measured by the thermo labels (Temp plate P/N 101-6V: Palmer Wahl Instruments, Inc.). The sample was a polycrystalline tungsten plate (Nilaco corporation), which was fabricated by powder metallurgy in a purity of 99.95%. The size of the sample is a 10 × 10 × 0.2 mm. In this study,

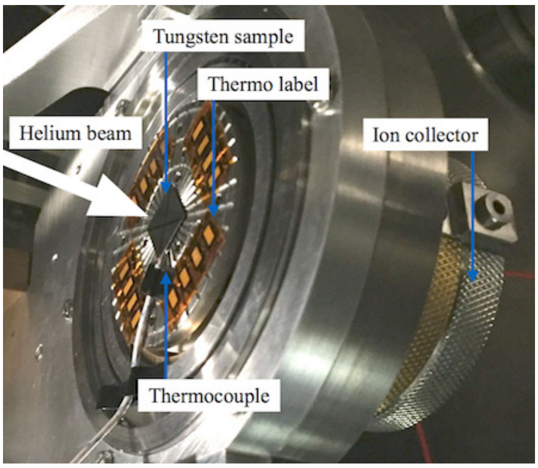

Fig. 1 Photograph of the irradiation target in the vacuum chamber. The tungsten sample was mounted on the ion collector with thermo labels and a thermocouple.

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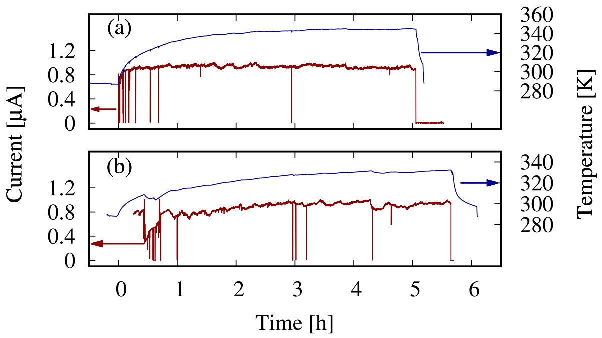

Fig. 2 Time evolution of beam current and surface temperature of tungsten implanted with 4 MeV He^{2+}. (a) Sample A. (b) Sample B.

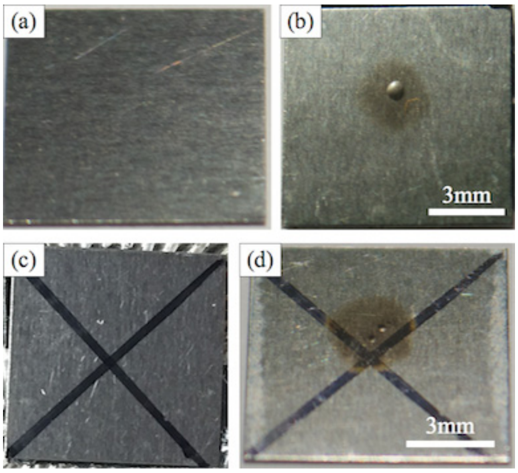

Fig. 3 Photographs of tungsten surface before and after irradiation. (a) Nonirradiated sample. (b) Irradiated sample (sample A). (c) Before irradiation for sample B. (d) After irradiation for sample B. The black lines on (c) and (d) show traces by a marker pen.

the irradiation experiment was carried out for two samples (i.e., samples A and B) without heaters to control the sample temperature. Here, two samples were prepared in the same irradiation condition to confirm reproducibility.

Figure 2 shows the time evolution of beam current and surface temperature of tungsten. Here, the red line denotes the beam current. The blue line denotes the surface temperature. The figure also shows the quasi-steady state helium ion beam current of 0.8 - 1 μA. The particle fluence and flux were 10^{22} m^{-2} and 10^{17} m^{-2} s^{-1}, respectively, calculated from the time evolution of beam current. It corresponds to helium concentration of 40 at.% (4,000 appm) and the maximum number of displacement of 53 dpa around the projectile range, estimated by TRIM code. From these results of both thermocouple and thermo labels, the maximum temperatures on the surface of samples A and B were obtained as 345 K and 332 K.

Figure 3 shows the photographs of tungsten surface before and after irradiation. The color of the irradiation

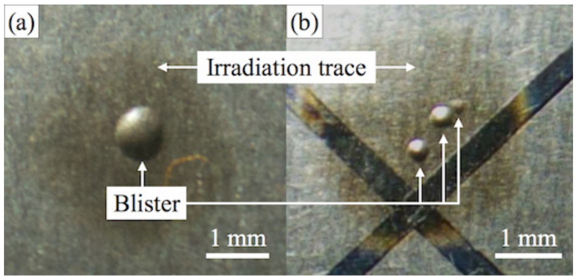

Fig. 4 Enlarged image around blisters in Fig. 3 (b) and Fig. 3 (d). (a) Sample A. (b) Sample B.

surface changed at the irradiated trace. In addition, the blisters were observed on the sample surface. Figure 4 shows the enlarged image around the blisters as shown in Fig. 3. Figure 4 (a) indicates the blister formation on sample A, and three blisters were observed on sample B, as shown in Fig. 4 (b). The height of the blisters was measured using a stylus profilometer (Dektak 6M: Bruker Corporation). The height of the largest blister was about 20 μm.

The results show the blister formation at a temperature less than 473 K, as reported in Ref. [7]. In this study, the helium ion beam had monochromatic kinetic energy of 4 MeV. High-energy helium ion deposits the energy and stops inside the tungsten sample locally because it has a Bragg peak. Thus, helium concentration becomes high around the penetration depth of the helium ion (4,000 appm). These results suggest the possibility of blistering inside the tungsten irradiated by the helium ion beam even in ordinary temperature condition.

In summary, a 4 MeV helium ion beam was irradiated on the tungsten sample using a tandem accelerator in order to study the radiation damages. The particle fluence and flux corresponded to 10^{22} m^{-2} and 10^{17} m^{-2} s^{-1}, respectively. The surface temperature on tungsten was increased up to 345 K during the irradiation. Blister formation was observed on the surface of the tungsten samples irradiated by the helium ion beams. The height of the blister was measured as 20 μm. The blisters were formed owing to the high-energy helium ion beam irradiation without heating except ion beam irradiation.

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