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Experiment and measurement with high-energy helium irradiation to tungsten using tandem accelerator for divertor in magnetic confinement fusion system

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Abstract

An experimental system for irradiating high-energy (4 MeV) helium beam was developed to investigate irradiation damage of tungsten by using tandem accelerator. In this system, particle fluence to a tungsten thin plate was achieved to 10^{22} ions/m^2. Electron diffraction images were acquired for damaged tungsten using a transmission electron microscope (TEM) to measure the particle loading by helium irradiation. Crystal structure was qualitatively changed between helium irradiated area and non-irradiated area from diffraction patterns.

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Keywords: Magnetic confinement fusion; Tungsten; Divertor; Helium bubble; Tandem accelerator

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1. Introduction

A divertor is equipped in magnetic confinement fusion devices to remove helium ion generated by nuclear fusion reaction. As a divertor material, tungsten is used for ITER [1]. By irradiation of low energy helium ions (<keV), bubble structure [2] and filament structure (W-fuzz) [3] were observed inside and on the surface of the tungsten, respectively. In addition, high-energy helium was irradiated experimentally to demonstrate the damage of displacement by neutron [4]. These particle loadings cause erosions, for example, increasing retention of hydrogen isotopes, decreasing heat conductance, and so on. Especially, the irradiation of the high-energy helium ions may cause the recrystallization of the tungsten in the depth direction. Thus, it is important to estimate the irradiation damages by high-energy helium ions in the order of mega electron volts, because the mechanical property of divertor decreases due to the embrittlement effect. In this study, to reveal an irradiation effect on tungsten in the depth direction of the target material by high-energy helium ions, an experimental system for helium beam irradiation was developed. Furthermore, the measurement system was discussed to observe the damages in the depth direction of the target material.

2. Experiment and results

Figure 1 represents overall scheme of the experimental setup in this study. Tungsten thin plates (purity 99.95%: Nilaco) of 10 × 10 mm^2 in size and 0.2 mm in thickness are prepared. First, irradiation experiment was carried out with a tandem accelerator to generate the damage in tungsten. Then, thin-film processing experiment using a focused ion beam (FIB) system was measured the effect of the irradiation in the depth direction by a transmission electron microscope (TEM). Finally, measurement experiment by using TEM was observed the effect of the irradiation in the depth direction.

The tandem accelerator (Tandetron broch (4117-MC*-358): High voltage engineering) was used to generate the damages in tungsten. By using the system, He^{2+} ion beam at energy of 4 MeV was irradiated to the thin tungsten plate. Irradiated area to the center of the tungsten sample was collimated in 2×2 mm^2. Then, the beam current on the tungsten was detected by using an ion collector. The particle fluence was calculated from experimental result, and was achieved to 10^{22} ions/m^2. In addition, this is a rough standard for the helium bubble creation in energy region of < keV [5].

After the irradiation experiment, FIB system (FB2200: Hitachi high-technologies) and TEM (HT7700: Hitachi high-technologies) was used to observe the irradiation damages in the depth direction. Using FIB system, the tungsten sample was processed to enough thickness (177 nm) that is observable by TEM. As gallium ions were irradiated to a sample in the FIB processing, the surface damage might be generated due to the irradiation of gallium ions. The accelerating voltage and the beam current of gallium ions were controlled to reduce the damages. Figure 2 represents a FIB image for processing tungsten. TEM images were observed between helium irradiated area and non-irradiated area by TEM. Figure 3 represents bright-field images in comparison with irradiated area and non-irradiate area. In Fig. 3, it is difficult to determine whether presence of the particle loading such as helium bubbles by irradiating helium beam. Thus, electron diffraction images were acquired by TEM. Figure 4 represents the diffraction images for these areas. From Fig. 4 (b), Debye-Scherrer rings rendered as typical diffraction pattern of polycrystalline materials were observed for the diffraction pattern of helium non-irradiated area. On the other hand, from Fig. 4 (a), the diffraction pattern was changed from Debye-Scherrer rings to sparse diffraction spots. This result shows that the grain size for the irradiated tungsten sample was increased. As a result, the recrystallization was caused by irradiation of the helium ion. It is implied that the inside of the tungsten sample becomes friable due to the irradiation of high-energy helium ions.

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