Formation of Nanostructured Tungsten with Arborescent Shape due to Helium Plasma Irradiation

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Deeply nanostructured tungsten with an arborescent shape was found for the first time to be formed on tungsten-coated graphite by a high-flux helium plasma irradiation at surface temperatures of 1250 and 1600 K, an incident ion energy of 12 eV (well below the physical sputtering threshold) and a helium ion fluence of $3.5 \times 10^{27}\,\mathrm{m}^{-2}$.

Keywords: plasma-material interaction, nanostructured tungsten, helium bombardment

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Tungsten (W) is one of the most important materials for plasma-facing components such as the first wall, the divertor plate and so on, as well as for the optical mirrors in the next step fusion devices, because of its very useful material properties such as high melting point, high threshold energy for physical sputtering, and low retention of hydrogen isotopes. However, recent laboratory experiments have shown that helium ions, which are important fusion product in burning plasmas, produce holes and bubbles on the surface of bulk W at an incident energy below the threshold value of physical sputtering. Tungsten holes and bubbles are generated under the condition of W surface temperatures higher than 1600 K and a helium ion fluence of greater than 10^{25}-$10^{26}\,\mathrm{m}^{-2}$ [1–6]. The optical reflectivity becomes almost zero. In comparison with higher surface temperatures, a low W surface temperature, such as 1200 K, still alters the material surface resulting in decreased optical reflectivity, that is, producing blacking. It is apparent that in this surface modification the surface shapes changed from micron-size to submicron-size, which should be further investigated in surface temperatures in a lower range.

The tungsten-coated graphite (W-C) may be a promising material for plasma-facing components in fusion devices because of W-C's substantial weight reduction compared with bulk tungsten materials. The difference of surface morphology between W-C and bulk W would make a difference in surface modification due to high flux helium ion irradiation, which despite its importance has not so far been reported.

The W-C used in the present investigation was fabricated by Plansee Co. by using a fine-grained graphite IG-430U (TOYO Tanso Co.) substrate, $20 \times 20 \times 10\,\mathrm{mm}^3$, coated with W using the plasma spray technique (PS-W). The thickness of the PS-W layer is 1 mm. Rhenium layers were inserted between the PS-W layer and the fine-grained graphite as a diffusion barrier layer. The experiments were carried out in the NAGDIS-II (NAGoya university DIvertor Simulator-II), which generates high density helium plasmas in a steady state [7]. The surface temperature of the W-C was adjusted to either 1250 or 1600 K.

Figures 1 (a)~(c) and (a′)~(c′) are SEM photographs of the W-C surface after and before helium plasma irradiation, respectively, while Figs. 1 (d) and (e) show photographs taken by a field emission scanning electron microscope (FE-SEM) with high spatial resolution. The sample was exposed to a helium plasma at a surface temperature of 1250 K, a fluence of $3.5 \times 10^{27}\,\mathrm{m}^{-2}$, and an ion incident energy of 12 eV. The surface modification is characterized by the following two features: an enhancement of micron-size roughness and a deep nanostructured arborescent shape. Especially, the surface was deeply covered by a submicron fine structure, resulting in optical blacking of the surface. A huge number of rods were found to be connected to each other in a disordered manner. The typical diameter of the rods is about 20~30 nm. Such a nanostructure leads to a substantial enlargement of the effective surface area. Surface atomic element analysis using an energy dispersive X-ray fluorescence spectrometer (EDX) is shown in Fig. 2, indicating that the nanostructures are made of W element, although we do not know small composition of light elements such as carbon and oxygen, which could be retained in the PS-W layer before irradiation, because EDX analysis has low sensitivity to such light elements. Detailed analysis of the nanostructure is the focus of future study. The sample with a high surface temperature, say 1600 K, shows similar features to the

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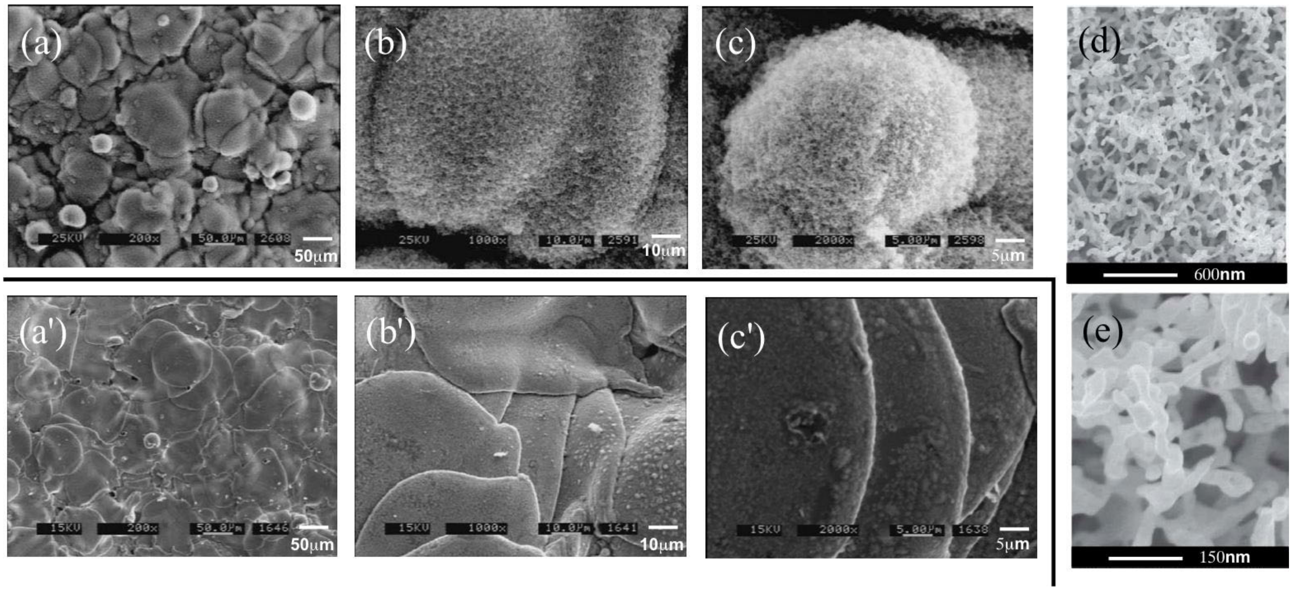

Fig. 1 (a)~(c): SEM photographs of W-C surface after and (a′)~(c′) before helium plasma irradiation at a surface temperature of 1250 K, a fluence of 3.5×10^{27} m^{-2} and an ion incident energy of 12 eV. (d) and (e): photographs taken by FE-SEM with a high spatial resolution. The line of sight is normal to the samples.

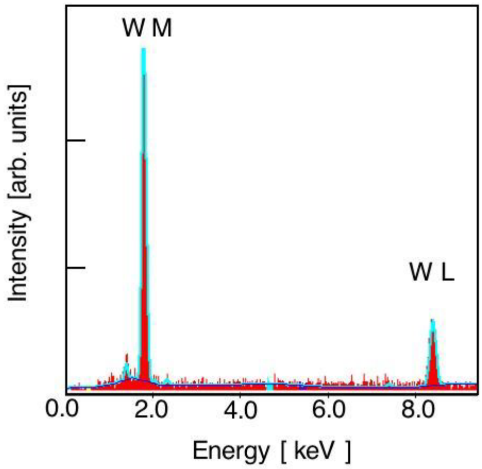

Fig. 2 Surface element analysis using an energy dispersive X-ray fluorescence spectrometer.

above mentioned one.

The observed surface modification would seriously alter the properties of hydrogen retention as well as the material's thermal resistance to heat pulses such as Edge Localized Modes (ELMs), another subject for future study. On the other hand, such surface modification would constitute a new innovative fabrication process of nanostructured tungsten for industrial applications because the nanostructured materials express quite different chemical and physical properties from those of bulk ones. The nanostructured W materials are formed by thermal evaporation and chemical vapor deposition using WF_6 gases; however, the fabrication process is difficult compared with those for carbon nanostructures. Examples of applications of nanostructured W materials include an electron emitter [8] and a catalyst [9] for nitrogen oxide, hydrocarbon, and other chemical applications.

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