Optical Properties of Fiberform Nanostructured Tungsten in the Infrared Wavelength Range

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Fiberform nanostructured tungsten (FN-W) samples were synthesized by helium plasma irradiation with different irradiation times. It is shown that the optical reflectivity decreases significantly with the increase of the irradiation time, even in a long-wavelength infrared range up to several dozen μm. These experimental results are of importance for the usage of retroflectors and will offer a promising direction for other practical applications.

Keywords: fiberform nanostructure, reflectivity, helium plasma

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With the development of new technologies, the demand for nanostructured materials has rapidly grown. The increasing interest in nanostructured materials has prompted intense investigations into appropriate fabrication techniques. The growth of nanostructured materials using the plasma technique has proved to be one of the most promising approaches for the construction of precisely tailored nanostructure. Since the discovery of fiberform nanostructures (FN) on tungsten (W) surface irradiated by helium (He) plasma [1], the unique properties of FN have stirred the interest of researchers trying to utilize it in advanced new applications. The nanostructured black surface gives rise to extreme interest in the optical properties of FN. Kajita et al. demonstrated that FN exhibited the optical absorptivity of almost 100% from the visible to near-infrared wavelength range (200 - 1550 nm) [2]. At the same time, degradation of optical properties of the retroreflectors for plasma diagnostics using the laser in fusion devices is becoming a concern [3]. The use of retroflectors is envisaged in ITER for poloidal polarimeters and toroidal interferometers/polarimeters operating at 118.8 and 10.6 μm, respectively [4]. Since the impact of helium plasma irradiation on the reduction of reflectivity is still unknown, it is also important to evaluate the dependence of the reduction of optical reflectivity on the wavelength and irradiation condition. In this work, the optical reflectivity in the infrared wavelength range from the unirradiated to the formation of a homogeneous nanostructured layer on the W surface is shown.

The FN W samples at different helium fluences were made using the W plates ($10\times10\times0.2\,\mathrm{mm}^3$) in the NAGDIS-II device. The irradiation time was 5, 10, 15, 30, 60, and 120 min. The helium flux was $\sim1.2\times10^{22}\,\mathrm{m}^{-2}\mathrm{s}^{-1}$, and the helium fluence was equal to the product of the helium flux and the irradiation time. The details of the preparation process were reported previously [5]. The nanostructured layer thickness can be estimated from the helium fluence and was increased from 0 to 1.3 μm as the irradiation time was increased from 5 to 120 min [6]. The surface morphologies were investigated by a field emission scanning electron microscope (FE-SEM, JSM-7100F, JEOL). The optical reflectivities for different helium fluences were carried out using Fourier transform infrared spectroscopy (FT-IR, FTIR-8400, Shimadzu).

Figures 1 (a-c) show FE-SEM images of the samples synthesized at the irradiation times of 5, 15, and 30 min,

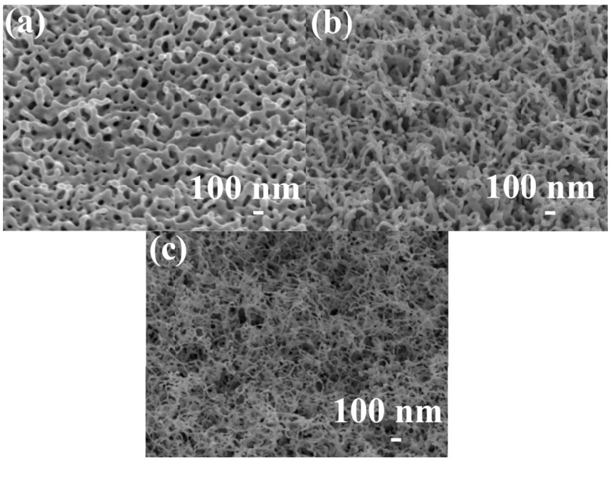

Fig. 1 FE-SEM images of FN W samples irradiated by helium plasma for (a) t = 5 min, (b) t = 15 min, and (c) t = 30 min.

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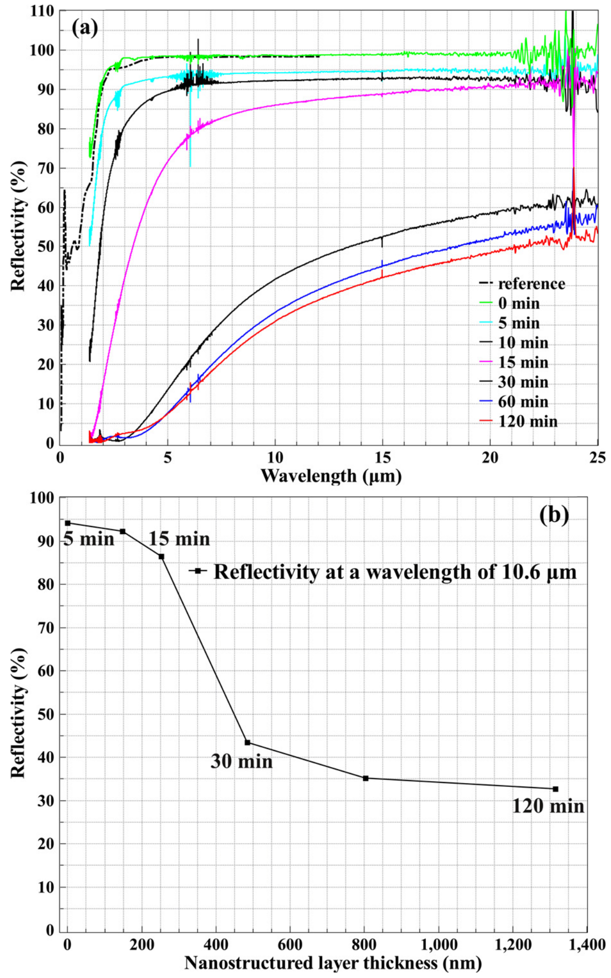

Fig. 2 a) FT-IR reflectivity vs. wavelength for the FN W samples under different irradiation times (solid line) and smooth W metal (dotted line) from Ref. [7], b) estimated nanostructured layer thickness dependence of reflectivity at a wavelength of 10.6 μm (toroidal interferometry/polarimetry system operating wavelength).

respectively. From Fig. 1 (a), there are pinholes and protrusions on the W surface, as the helium fluence was lower than the fluence threshold for the fuzz growth (4×10^{24} m^{-2}) [6]. As the irradiation time was increased from 5 to 15 min, fuzz were produced on the W surface. Finer nanostructures were formed when increasing the irradiation time, as shown in Fig. 1 (c).

Figure 2 (a) shows FT-IR reflectance spectra of the nanostructured W synthesized by the helium plasma irradiation. The FT-IR spectra of a W plate not treated by plasma irradiation and smooth W metal from Ref. [7] are also presented as a reference in Fig. 2 (a). Change of reflectivity with the irradiation time (or, equivalently, nanostructured layer thickness) depends on the wavelength. The sharp decrease of reflectivity in the 1.5 - 3 μm range is caused by strong absorption by multiple reflections, while the flat decrease in the reflectivity intensity at a wavelength greater than 3 μm is that as the wavelength increases the impact of absorption effect becomes gradually weaker. The results in the 1.5 - 3 μm range are in good agreement with the previous research results [2], while the results at a wavelength larger than 3 μm have not yet been reported. Figure 2 (b) shows the reflectivity at wavelength of 10.6 μ as a function of nanostructured layer thickness. Here the wavelength of 10.6 μm will be used for one of the polarimeters in ITER, and the nanostructured layer thickness was estimated from the helium fluence according to Ref. [2]. In Fig. 2 (b), by increasing the irradiation time from 15 to 120 min, the reflectivity decreased sharply at first, but it did not change much after 30 min irradiation. This observation can be explained by the higher aspect ratio of a 30 min irradiation sample compared to a 15 min irradiation sample (see Figs. 1 (b) and (c)). Here the aspect ratio is defined as the ratio of height to the radius (H/R). And the reason why it subsequently slows down is that although the thickness increases, the shape of fuzz on the surface basically remains unchanged, that is, the aspect ratio is basically the same.

For 0, 5, 10, and 15 min irradiation samples, the reflectivity increases with wavelength close to 100%. Therefore, it is speculated that such a trend can also result for 30, 60, and 120 min irradiation samples. In other words, the formation of fuzz would have little influence on reflectivity at 118 μm.

In this study, we measured the reflectivities of FN W samples in an infrared wavelength range. A thorough understanding of the relation between the plasma nanofabrication process and the optical properties of nanomaterials is needed to provide a reference for the fabrication of FN W optical components. This can be also viewed as an important step toward creating long-lived retroflectors in fusion devices.

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