24P089-P

Characterization of Tungsten Surface w/wo Nano-Fiber Structure
繊維状ナノ構造He損傷タングステンの表面特性評価

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One of the serious concerns for tungsten materials in fusion devices is the radiation defects caused by helium plasma irradiation since helium is the fusion product. Fiber-formed nanostructure is thought to have a possible weakness against the plasma heat flux and may destroy the reflectivity as an optical mirror in a reactor. On the other hand, characterization of tungsten surface with nano-fiber structure is not fully studied. In this study investigation on the characteristics of nano-fiber structure surface and an interesting method for a recovery of such tungsten surface are shown.

1. Introduction

Divertor materials in fusion devices are exposed to high density and high heat flux plasmas. Tungsten(W) may be employed in the ITER because of its high thermal property, low tritium retention and low sputtering yield. However, it is known to be damaged by helium ion irradiation, and it is called helium defects. We have two kinds of helium defects. One is bubble/holes on the surface [1], the other is fiber-form nanostructure on the surface produced at relatively low temperature, less than 1500K and at the incident ion energy of greater than roughly 10eV [2].

The surface characteristics of nanostructured W would change compared with the flat non-damaged surface, especially the heat conduction. The thin fiber-form nanostructure may be easily melted by plasma heat flux and it is considered that such nanostructured surface may enhance the probability of unipolar arcing than non-damage surface so that recovery of that surface have been tried.

On the other hand, it should be considered that outstanding properties have been found for the wall of fusion reactor.

2. Experimental Set up

The device for the present study is called AIT-PID (Aichi Institute of Technology – Plasma Irradiation Device) which is equipped with three pairs of neodymium permanent magnet bars composing a multi-cusp (azimuthal mode number : 6) magnetic configuration. In addition a solenoidal winding underneath the magnets produces a weak axial magnetic field up to 10mT [3].

3. Characterization

Figure 1 shows the fiber-form nanostructured tungsten made in AIT-PID where we have high density (~10^{18}m^{-3}) helium plasma with the ion bombardment energy of 50eV and the starting surface temperature of 1420K. The helium ion fluence is ~10^{26}m^{-2}. The specimen is a cold worked powder metallurgy tungsten (PM-W). One of the outstanding characteristics of AIT-PID is the presence of hot electron component (T_h ~30eV, α ~5%) where T_h and α are the temperature and the fraction of hot electron component while the bulk electron temperature is around 4eV.

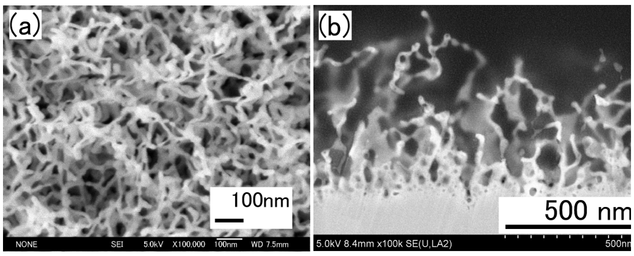

Fig.1 W surface with nano-fiber structure.
(a) : top view (b) : cross-section view

3.1 *Recovery of Tungsten Surface*

The previous experiment of temperature excursion for nanostructured tungsten in the helium plasma [4] has already shown a shortening and a fattening of originally long and thin fibers when the surface temperature increases up to 1600K for a few minutes with an helium ion energy of larger than 6eV. However, the holes and bubbles on the surface are newly created or survived so that a surface roughness may not be removed when the incident helium ion energy is larger than 6eV. It suggests that the recovery would be obtained with non-damaging He plasma whose ion energy is of less than 6eV by biasing to increase the electron heat load on fiber-form nanostructured surface.

Figure 2 shows some typical FE-SEM images of recovered tungsten surface after 60min irradiation of helium plasma with the incident 2aaenergy of less than 6eV and surface temperature 1800K. These images show a substantial diminution of fiber roots which remain on the surface for an incomplete plasma annealing. Therefore, it seems that almost complete recovery of nanostructured tungsten may be possible by a sufficiently long irradiation of helium plasma with a high surface temperature.

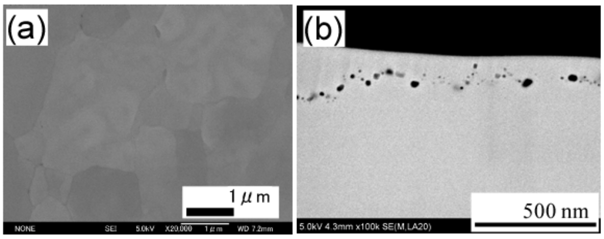

Fig.2 Recovery of W surface with nano-fiber structure. (a) : top view, (b) : cross-section view

3.2 *Cooling and Suppression of Secondary Electron Emission* (*SEE*)

The tungsten surface temperature has been measured with a radiation thermometer assuming a fixed radiation emissivity, for example ε = 0.43 at the wavelength of 0.9μm. However, the surface morphology is substantially changed so that the emissivity approaches to almost unity due to a blacking on the way to fiber-form nanostructured surface formation. Figure 3 shows a cross-check for the cooling with both a radiation thermometer and a thermocouple. At the end the change in emissivity from ε = 0.43 to 1.0 gives almost the same value for both measurement.

Figure 3 also shows a deepening of floating voltage during producing nano-fiber structure. The nano-fiber structure W has a complication on the surface as show Fig.1(b), which decreases SEE so that we have a deepening floating voltage. Thus the plasma power flux decreases with the suppression of SEE.

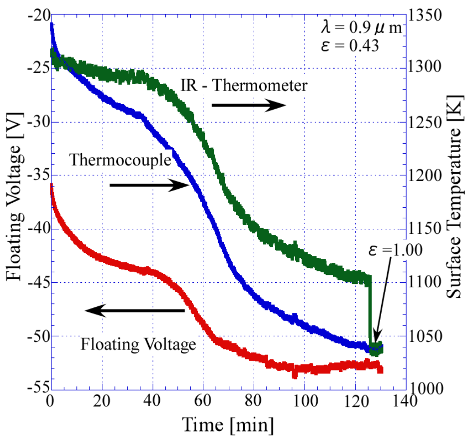

Fig.3 Cooling of Tungsten

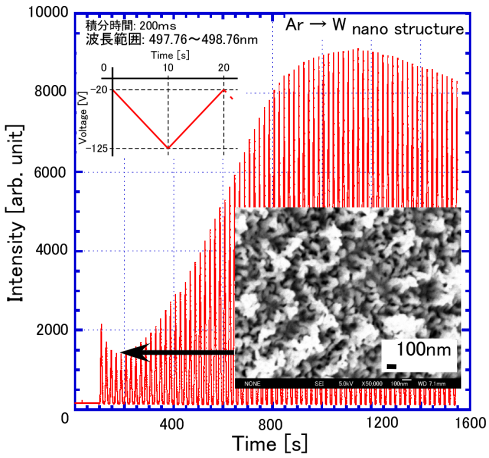

Fig.4 Suppression of Sputtering

3.3 *Reduction of sputtering yield*

The nano-fiber structure on W surface is a kind of jungle for secondary electrons not to be able to go out. This mechanism decreases also physical sputtering yield. We have demonstrated such effects as shown in Fig.4 where the triangular biasing voltage is applied on the target in an argon plasma. The intensity of tungsten atomic line (498.26nm) is plotted as a function of time.

4. Summary

Good properties of nano-fiber structure tungsten surface as a plasma-facing wall in fusion reactor have been demonstrated, that is, a cooling function coming from the increase in radiation emissivity and the suppression of secondary electron emission, a suppressive behavior of sputtering. We can say that nano-fiber subsurface shows the outstanding self-defensive properties for a wall in fusion reactor. On the other hand a recovery technique for nanostructured W is shown. Grain size dependence of plasma annealing was found.

Acknowledgments

The work is supported by a Grant-in-aid for scientific Research (B) (20360414) from JSPS. The authors would like to thank Prof. N. Ohno and Dr. S. Kajita of Nagoya University for their discussions.

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