Deepening of Floating Potential for Tungsten Target Plate on the way to Nanostructure Formation

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Deepening of floating potential has been observed on the tungsten target plate immersed in high-density helium plasma with hot electron component on the way to nanostructure formation. The physical mechanism is thought to be a reduction of secondary electron emission from such a complex nano fiber-form structure on the tungsten surface.

Keywords: plasma-facing material, tungsten surface, nanostructure, secondary electron emission, deepening of floating potential

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Tungsten material is very important in terms of fusion reactors, especially plasma-facing component. Helium defects are the concerns when employing the tungsten for the divertor target and/or the first wall since helium is the fusion product and would be contained by around 10% of scrape-off layer plasmas in fusion devices. Recently the nano fiber-form structures have been identified on a variety of tungsten surface irradiated by helium or helium/deuterium mixture plasmas [1, 2].

The surface characteristics of thus formed tungsten plate would change compared with the flat non-damaged surface, for example, the radiation emissivity [3], the sputtering yield [4], the heat conduction [5], the discharge property [6] and so on. In this report the secondary electron emission (SEE) property will be discussed in relation to the floating potential which is important with respect to the impurity releases through physical sputtering and plasma heat flux.

Nano fiber-form structured tungsten surfaces have been formed in a newly developed linear plasma generator AIT-PID [3, 7] as shown in Fig. 1. In this device the high density helium plasmas have been produced with a hot electron component. The plasma density exceeds $1 \times 10^{18}\,\mathrm{m^{-3}}$ and the bulk electron temperature (T_c) is about 4 eV, while the hot electron component with the fraction of roughly 8% has a temperature (T_h) of up to 40 eV. Such a two electron temperature plasma gives a deep floating potential ensuring a high ion impact energy which is important to form nanostructured tungsten surface. The floating potential is around −40 V with respect to the vacuum chamber, and the ion incident energy to the tungsten is 45 eV considering the plasma potential of around +5 V which is unchanged during the exposure. Such a high sheath voltage can be explained by the numerical analysis on the floating condition that the electron flux balances with the ion one, as shown in Fig. 2, which indicates that the value of 45 V is a little smaller than the theoretical prediction assuming a complete Maxwellian distribution for both electrons.

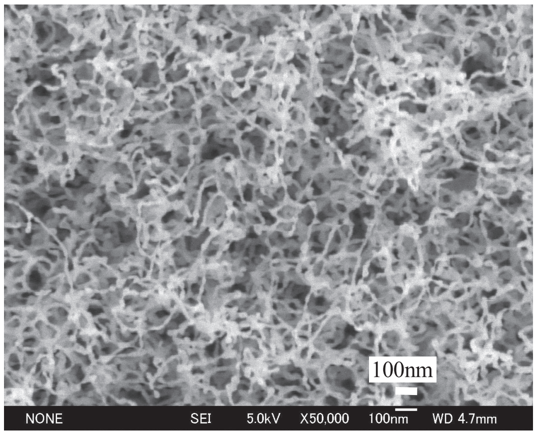

Fig. 1 Surface morphology of well-developed tungsten surface irradiated by He plasma under the floating condition. Ion flux is $8.6 \times 10^{21}\,\mathrm{m^{-2}s^{-1}}$ with the energy of 45 eV and the ion fluence of $7.7 \times 10^{25}\,\mathrm{m^{-2}}$.

Figure 3 shows the time evolutions of the floating potential and the tungsten surface temperature observed with a radiation thermometer with a fixed emissivity of 0.43. The drop of surface temperature comes from an increase of radiation emissivity and associated target cooling assuming a constant plasma heat flux onto the target, which was discussed in [3]. The floating potential changes rapidly from −40.0 down to −48.5 V during the period of large change in surface temperature, meaning a certain correlation with nanostructure formation.

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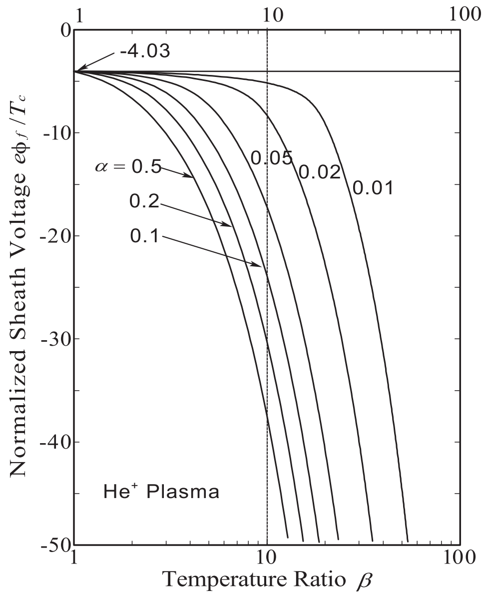

Fig. 2 Normalized sheath voltage as a function of temperature ratio $\beta = T_h/T_c$ for two electron temperature helium plasma, taking the hot electron abundance α as a parameter. The electron energy distributions are assumed to be Maxwellian. The SEE is not considered here.

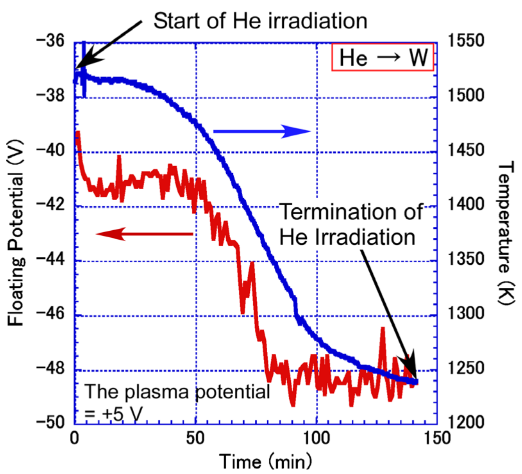

Fig. 3 Time histories of floating potential of tungsten plate and its surface temperature observed with radiation thermometer with the fixed emissivity of 0.43.

Tungsten has a fairly high SEE coefficient. The Maxwellian electrons with the temperature of 40 eV gives almost 1.0 for SEE yield [8]. Therefore, the floating potential for the normal flat tungsten surface seemed to be influenced by the electron emission in the presence of hot electrons which have an apparent electron temperature of 40 eV with a possible cut-off energy around 100 eV since the discharge voltage is less than 100 V. The electron emission from the surface is known to make the floating potential shallow in the initial stage.

Deepening of floating potential on the way to nanostructure formation has been thought to come from the reduction of electron yield. It is quite reasonable since the secondary electrons cannot come out to the sheath region through a forest of nano fiber-form complex. A similar situation was already analyzed by K. Ohya's group, in which a deep trough prevents the emission of secondary electrons [9]. Moreover, 50% increase in He gas pressure makes the drop of floating potential about 5 V compared with about 9 V for the previous case since the fraction and temperature of hot electrons decrease with an increase in gas pressure. But we do not know to what extent the secondary electrons cannot go out.

A completely different idea could explain the reduction of SEE as follows: tungsten nanostructure is composed of thin skin with many helium cavities [5] so that the tungsten skin could be too thin for the primary electrons to pass through it. However, the electron range for the energy of less than 100 eV is less than 1 nm [10, 11] so that the above idea is not the case.

In conclusion, the observed deepening of floating potential for nanostructured tungsten may come from the reduction of effective SEE yield due to thick forest made from nano fibers.

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