§20. In Situ Measurement of Surface Modification of Plasma-facing Material during the Long Duration Discharge

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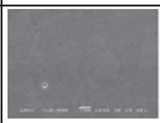
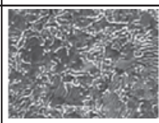
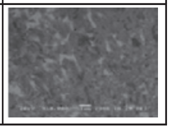
A new plasma-wall interaction (PWI) simulator APSEDAS (Advanced PWI Simulation Experimental Device and Analysis System) has been developed in order to investigate surface modification of plasma facing material. In order to study the surface modification due to the PWI, in situ and real-time measurement of the surface modification is necessary.

In this study, two tungsten (W) samples were irradiated by He plasma at low (< 710 K) and high (~1400 K) surface temperatures, respectively. The typical parameters during the irradiation were n_e ~1.1 x 10^{19} m^{-3} and T_e ~ 7 eV. The ion flux and space potential are estimated from n_e, T_e and floating potential to be ~8.7 x 10^{22} ions m^{-2} s^{-1} and ~28 V below the threshold for physical sputtering. The samples were polycristalline W of which diameter, thickness and purity were 20mm, 1.0 mm and 99.99 %, respectively. It was annealed at 1127 K for 1 hour. The surface of the sample was mechanically polished to a mirror finish and its roughness was less than 0.01 μm. In situ measurement of the optical reflectivity of the W sample during plasma irradiation was made by using a Xe lamp and a visible spectrometer. The incident and reflected angles were ~75 degree, which is the vicinity of pseudo-Brewster angle of W.

Table I shows irradiation parameters and micrographs of a scanning electron microscope (SEM) of the irradiated W samples as well as unirradiated one. There is no distinctive change in the surface morphology in the low temperature sample (W-1) of which fluence was ~1.6 x 10^{26} He^+ m^{-2} and surface temperature (T_s) was in the range from < 473 K (i.e. lower limit of a detectable level) without plasma to 710 K with plasma due to pulsed plasma production and good cooling capability. On the other hand, the He plasma is found to induce remarkable fine irregularities of a few μm on the surface of the high temperature sample W-2 of which fluence was ~6.5 x 10^{25} He^+ m^{-2} and T_s was constant of 1400 K during the exposure. This surface morphology seems to be caused by He bubble formation and its growth due to higher T_s as observed in other experiments. Figure 1 shows the fluence dependence of the relative reflectivity (R_{rel}) of W-1. The R_{rel} changed as a function of the He fluence. This means that the optical constant (i. e. refractive index (n) and extinction coefficient (k)) of the modification layer should be changed due to the exposure to the He plasma, because the surface morphology did not change as shown by the SEM micrograph in Table I.

Figure 2 shows optical reflectivity at λ = 555nm as a function of the depth of the modification layer, which was estimated by using a multiple-beam interference model. A candidate of the reason why the R_{rel} increased twice may be that at first the surface modification layer grows deeper than 70 nm from the surface like the arrow A in Fig.2 probably due to fine bubble formation, and then the modification layer is modified more (e.g. growth of the bubble size) leading to change in the optical constant like the arrow B in Fig.2.

Table I Parameters of the He plasma for exposure and the SEM micrographs.

Sample No.	W-1	W-2	W-3 (unirradiated)
ne, Te, Vs	1.1 x 10^{19} m^{-3}, 7 eV, 28 V		--
Flux	8.7 x 10^{22} He m^{-2} s^{-1}		--
Exposure time	1800 s	730 s	--
Fluence	1.6 x 10^{26} He m^{-2}	6.5 x 10^{25} He m^{-2}	--
Temperature	<473* ~ 710 K	1400 K	--
SEM micrograph			

*: lower limit of the detectable level

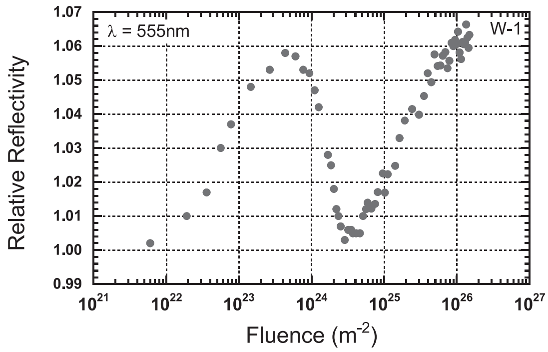


Fig.1 Relative reflectivity at λ=555 nm as a function of the fluence of the exposure of the W-1 sample to the He plasma.

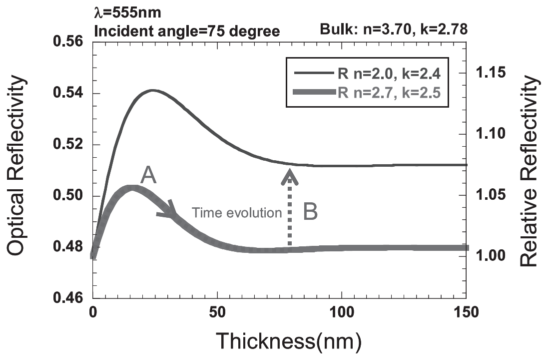


Fig.2 Optical reflectivity at λ = 555nm as a function of the depth of the modification layer. The final value of the optical constant of the W-1 sample and a value intermediate between the final one and the initial one (i. e. n = 2.7 and k = 2.5) are used for the calculation of the thin line and the thick line, respectively.