§30. A Proposal of In-situ Diagnostics Methods for PFMs under Multiple Irradiation

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In the optical diagnostic system, the reflectivity of the first mirror deteriorates by bombardment of energetic plasma particles and deposition of materials sputtered from the plasma facing components and serious concern for the reliability and long term usefulness of spectroscopic system has been represented. On the other hand, diagnostics of plasma facing materials (PFMs) is also a primary issue for maintenance of the high performance plasma in fusion devices. In order to evaluate PFMs conditions, in-situ and real-time diagnostic methods of PFMs are highly desired as an alternative to the existing postmortem methods. In this study, optical reflectivity measurement is proposed as a convenient in-situ diagnostics of the radiation induced microstructure change and its applicability is evaluated.

Solute annealed type 316L stainless steels (SUS316L) and powder metallurgy molybdenum (Mo) and tungsten (W) were mainly used as samples in the present study. Each specimen was cut into a plate of a size of 10×10×0.1 mm^3, and then mechanically mirror polished with alumina powder. Single and simultaneous ion irradiations were performed with 1-5 keV helium and deuterium ions up to a fluence of about 1×10^{23} $/m^2$ using in-situ measurement device that enabled the measurement of reflectivity under the dual ion irradiation. Ex-situ measurements of the ellipsometric angle (Ψ, Δ) and microstructure observation were also carried out by means of a spectroscopic ellipsometer in the range 250-830 nm, and SEM, AFM and TEM, respectively. In addition to these laboratory experiments, the material probe experiment in LHD was performed using material probe samples exposed to LHD plasma during the 14th experimental campaign in 2010, and the change of the optical properties due to plasma-surface interactions was examined.

As results of in-situ measurement of reflectivity under the various ion irradiation conditions, it is found that the reflectivity continues to decrease monotonically up to a rather high fluence of ~10^{23} $/m^2$ without saturation. The single helium irradiation shows the lowest reduction and the moderate reduction is observed for the simultaneous irradiation of deuterium and helium ions. This means that helium irradiation is a crucial factor to determine the degradation behaviors of mirror materials. For the sample irradiated with helium ion, high density fine helium bubbles are observed at near surface region and seem to cause the significant reduction of reflectivity.

The crystal orientation dependence on a surface damage in Mo irradiated with 3 keV helium ion was also investigated in this study as shown in Fig.1. A strong correlation between the surface roughening and the grain orientation is confirmed. It is found that significant surface roughening including crater-like depressions is formed on grains with the direction close to <001>, while relatively smooth surface remains on grains with the other directions, and that the grains which stay smooth surface under the irradiation show rather large erosion than the strongly roughened grains.

Fig.2 shows the wavelength dependence of relative reflectivity in the material probes SUS316L specimens exposed to the LHD plasma. The obvious reductions of reflectivity were confirmed, and give close agreement with the spectra obtained from the samples irradiated under certain conditions. Since the detectable reduction of the reflectivity was clearly observed in the specimens exposed to LHD plasma, the optical reflectivity measurement is considered to be a possible diagnostics method. Especially if the diagnostics is used in-situ, it could be a good tool to detect a real-time change in PFMs. In the next step experiments, the real-time measurement of reflectivity will be performed in LHD. On the other hand, in large plasma confinement devices, the reflectivity is influenced by complex factors including various particle and heat loading and impurity. It is important how to distinguish these factors and estimate the individual influence. Therefore, evaluation of another optical constant, combination of several diagnostics methods and accumulation of comparative basic data are also required.

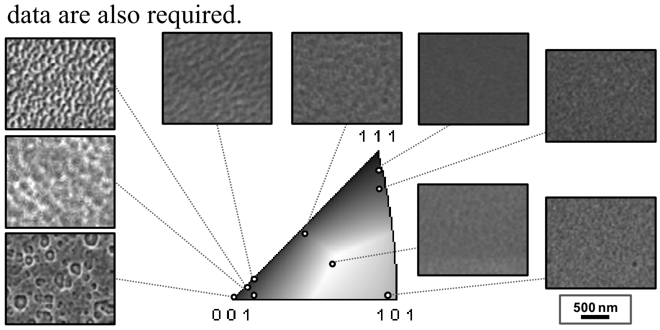

Fig. 1. Typical morphologies observed in each grain with a specific crystal orientation in Mo irradiated with 3 keV-He^+ to a fluence of 1×10^{22} $/m^2$.

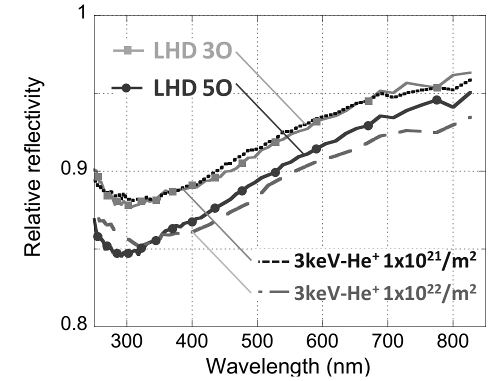

Fig.2 Relative reflectivity in SUS316L exposed to the LHD plasma at the locations of 3O and 5O during the 14th experimental campaign and irradiated with 3 keV-He^+ to a fluence of about 1×10^{21} and 1×10^{22} He/m^2 at R.T.