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Serious Modification of Plasma Facing Surfaces in LHD by Glow Discharge Cleaning at Start-up Phase

LHD における初期グロー放電洗浄におけるプラズマ対向面の変質

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In case of LHD, intensive glow discharge cleanings using Ne, He and H are carried out successively at the start-up phase of each experimental campaign. Though the amount of the adsorbed gas at the internal surfaces of the torus decreases enough, its structure and character are changed seriously, and their features, especially at the sputtering dominant area, were maintained through the experimental campaign. Mixing with co-deposited metallic elements, C, O and He at the surface, which was induced by the plasma bombardment, changed the character of the surface to that with very high ability for H retention.

1. Introduction

In order to improve plasma performance, especially to achieve very long duration discharges, active control of hydrogen recycling will be indispensable. One of the key processes controlling the recycling is retention and desorption of hydrogen through the plasma facing surfaces under the operation. We have been studying modification of plasma facing surfaces of LHD continuously since 2008 (Cycle 12) by paying special attention to the change of physical and chemical properties of the surface such as ability of hydrogen retention and its nano-structure. As reported so far, it became clear that even if the plasma facing surface placed at the sputtering dominant area its ability for hydrogen retention is unexpectedly high due to the formation of a mixing layer on the surface. Though its thickness is only about 10nm, very complicated defective structure of the mixing layer results in very high hydrogen retention.

In LHD, many different types of plasma discharges are performed day by day. Not only main plasma discharges with H or He but also glow discharge cleaning (GDC) are carried out time to time by using H, He or Ne. We have reported that each type of discharges have their own interaction with wall materials. In order to control hydrogen recycling process actively, it is important to know what type of discharges play major role to determine the nature of the plasma facing surface. In the present work, therefore, modification of plasma facing surfaces under the glow discharge cleaning at the start-up phase of the Cycle 14 (2010) were examined by inserting probe materials at the wall position, because vigorous modification of the plasma facing surface under the GDC can be expected from the relevant fundamental studies performed so far.

2. Experimental Procedures

Three sets of material probe samples consisting of thin platelet samples and pre-thinned TEM samples made of SUS316L, W and Mo were exposed to GDC at the start-up phase, following hydrogen main discharges (106 shots, #98201~98306) and both of them, respectively, by using the retractable material prove transfer system installed at the 4.5L port. GDC was performed with Ne gas for 12h, H gas for 122h and He gas for 24h successively. Energy of the plasma bombarding the surfaces was estimated about 200eV. The samples were quickly taken out from LHD after finishing the plasma exposures and then modification of the surface and its ability for hydrogen retention were examined by means of TEM, XPS, GD-OES and TDS.

3. Experimental Results and Discussion

3.1 Modification of surface by GDC

As shown by a TEM micrograph and the

corresponding electron diffraction pattern of a pre-thinned Mo in Fig.1, the surface is covered by heavily modified layer consisting of fine crystals with nano-size of Mo and oxide of Fe and Mo. Chemical analysis using XPS and GD-OES indicated that not only metallic elements of the substrate (Mo in this case) and the wall (SUS316L), but also large amount of C and O exist. These results indicate that physically sputtered Mo atoms under GDC with Ne and He returned to the surface near-by and deposit together with Fe, Cr, O and C sputtered form the wall and the divertor made of graphite. In case of SUS316L substrate, the surface was covered by thick modified layer consist of fine crystals of Fe and Fe-oxide together with C. As reported so far, co-deposition of metallic atoms together with O and C leads to pronounced refinement of crystal grains and, as a result, the deposited layer get very high ability for H trapping. Decreasing of O and C is effective to keep the ability of the metallic deposition at low level.

Another important feature of the modified layer is effects of He bombardment. A large number of fine He bubbles (white dot images in Fig.1a) are formed together with dislocation loops in the substrate. As shown in Fig.2, a cross-sectional view of a W sample exposed to the GDC, the He bubbles are mainly formed in the modified layer of about 8nm-thick. It is noteworthy that nanoscopic structure and chemical state of the modified layer formed by the GDC performed during the start-up phase are quite similar to those of the samples exposed to the whole plasmas in the experimental campaign. It is considered that heavy GDC at the start-up phase plays very important role to determine the nature of the plasma facing surfaces located at the sputtering dominant area.

It was also observed that deposition of carbon on "shadowed" area, where sputtering by Ne and He was difficult, was very remarkable, because the sputtered C can drift in the torus by forming C-H complexes. This phenomenon also affects optical properties of first mirrors for plasma diagnostics.

3.2 Modification by the following H plasma discharges

It was observed that the ratio of metallic oxides, which have been formed in the GDC phase, decreased. It means that the oxides were deoxidized by reacting chemically with bombarding H plasma. It was also remarkable that the surface was covered by C deposition. In LHD, chemical sputtering of C and it re-deposition under the H main discharges is also important PWI process.

4. Conclusions

At present, structure and character of the plasma facing surfaces of LHD, especially at the sputtering dominant area, are almost formed by the plasma bombardments under the GDC in the start-up phase. The present work indicates that minimizing the GDC and reduction of C and O is necessary to reduce ability for hydrogen retention, which will be effective to improve the plasma performance of long duration discharges. It is considered that replacing the present graphite divertors by W ones would be very effective to reduce contents of C and O and would promote reactor-relevant studies with LHD furthermore.

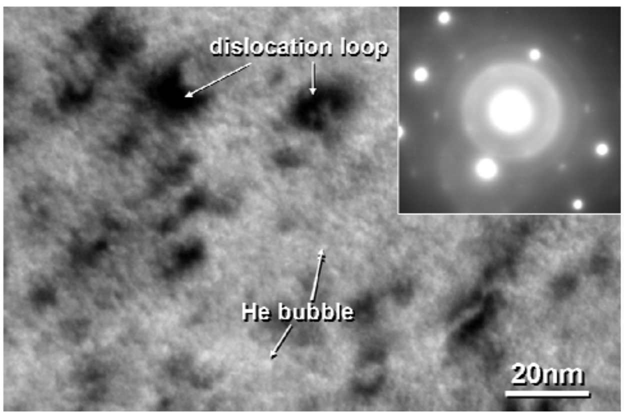

Fig.1 Microstructure of Mo exposed to GDC at the start-up phase

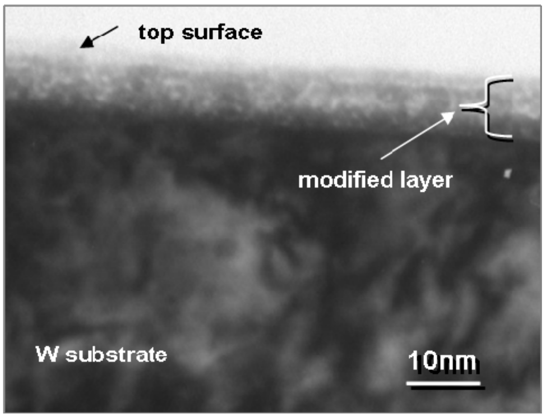

Fig. 2 Cross sectional view of W exposed to GDC at the start-up phase