§16. Investigation of the Physical Properties of the Mixed-material Deposition Layer Formed on the First Wall Surface of the LHD (2)

Tokitani, M.,
Kasahara, H., Yoshimura, Y., Ueda, Y., Yoshida, N., Masuzaki, S., Motojima, G., Sakamoto, M., Nagasaki, K., Mutoh, T., Yamada, H., Matsunami, N., Ohno, N., Sagara, A., Kajita, S., LHD Experiment Group

The Large helical device (LHD) has an important advantage for steady state operation (SSO). First wall panels and divertor plates of LHD are stainless steel (SUS316L) and graphite, respectively. The former is the major material in LHD, and the graphite area is only about 5% of the total plasma facing area. The temperature of the first wall is almost kept at room temperature (R.T.) during plasma discharges. In the recent SSO experiment, a high-performance ultra-long pulse helium discharge of 48 min with $n_e \sim 1.2\times10^{19}$ m^{-3}, $T_{i,e} \sim 2$ keV was successfully achieved by the higher heating power of 1.2 MW. By using such high performance plasmas, plasma wall interaction (PWI) studies for SSO has been accelerated. At the Beginning of this study, we were trying to focus on the hydrogen retention properties, because hydrogen is included about 10% in the helium long pulse discharge. However, it was revealed that the wall pumping capability of the LHD plasma facing materials (PFMs) is dynamically changed during a helium long pulse discharge by analyzing the 0-dimentional global particle balance model [1]. Such a dynamic change of the wall pumping rate directly affects for controlling a stable steady state discharge. Therefore, this study shifted a focusing point from hydrogen retention to helium retention characteristics.

It is known that mixed-material deposition layers mainly composed by carbon with tiny amount of Fe element are formed on the PFMs surface during a helium long pulse discharge. Such deposition layers would act as an effective trapping site of helium and contribute a wall pumping capability on the long pulse discharges. In this study, microstructural characterization of the mixed-material deposition layer formed on the first-wall surface (SUS316L) during a helium long pulse discharge were performed by using a retractable material probe system. After the material exposure, exposed materials were analyzed by means of focused ion beam (FIB) fabrication technique and transmission electron microscope (TEM) observation.

Fig. 1 shows the cross-sectional BF-TEM images and corresponding electron diffraction (ED) patterns of the SUS316L specimens after exposed to long-pulse discharges for (a) 1000 s, (b) 3389 s, and (c) 9980 s. The thickness of the deposition layer is observed to increase with increasing exposure time. Rutherford backscattering spectrometry (RBS) analysis revealed that this deposition layer was a mixed-material structure composed of C and Fe, and their compositions were ~98% and ~2%, respectively. The former and latter elements originated from the sputtering erosion of the C divertor tiles during the main plasma discharges and the SUS316L first-wall panels during glow discharge cleanings (GDCs), respectively [2]. The diffused ED patterns indicate that the mixed-material deposition layer is porous and comprises a very fine amorphous-like structure. The formation mechanism of such a structure might be because of the mixed feature of C and Fe or co-deposition of helium or hydrogen atoms. Note that by increasing the discharge time of the long-pulse discharge, a certain area of the first-wall surface changes from metal to C. In addition, very fine helium bubbles of 1-2 nm diameter and dislocation loops with a general size of 2-20 nm are clearly observed on the SUS316L substrate even for an exposure time of 1000 s. The size and density of the helium bubbles gradually increased with increasing exposure time toward 9980 s. These types of defects can be formed on not only the clean SUS316L surface but also the SUS316L surface located just beneath the mixed-material deposition layer. However, if the thickness of the mixed-material deposition layer is sufficiently greater than the projection range of the incident helium, the creation of such defects may gradually decrease. Judging from size and depth profiles helium bubbles, injected energy of helium could be around a few keV.

The formation of the mixed-material deposition layer (C: ~98% and Fe: ~2%) and helium bubbles would affect a helium retention on the wall and make a dynamic change of the wall pumping rate during a long pulse discharge.

1) G. Motojima et al., J. Nucl. Mater. in press.
2) M. Tokitani et al., Nucl. Fusion 45 (2005) 1544–1549.

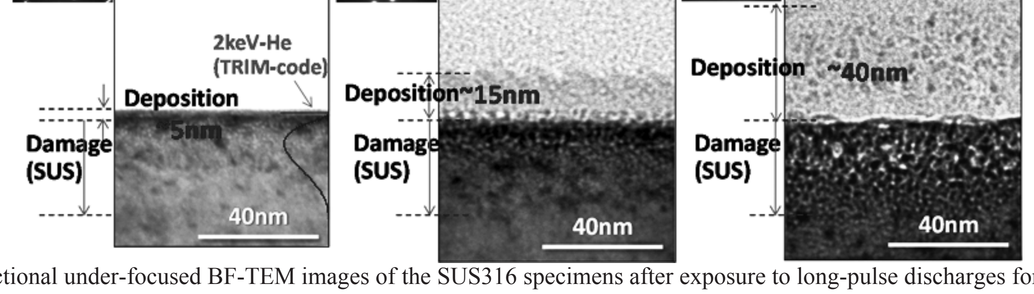

Fig. 1. Cross-sectional under-focused BF-TEM images of the SUS316 specimens after exposure to long-pulse discharges for (a) 1000 s, (b) 3389 s, and (c) 9980 s.