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Conditionings for plasma facing walls of large helical device

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Abstract

The first and second experimental campaigns in large helical device (LHD) were carried out from March to December 1998. Before the each campaign, the material probes were placed at the inner wall of vacuum vessel along the poloidal direction. After each campaign, change of surface morphology, impurity depth profile and gas desorption of the samples were examined. In the first experimental campaign, the ECR discharge cleanings were employed. After the first experimental campaign, the surface was modified by the deposition of sub-micron particles, and the concentrations such as oxygen and carbon were still high. Impurity gas desorption was also large in the sample at the port. In the second experimental campaign, the glow discharge cleanings were employed and the number of main discharge shots increased. After the second experimental campaign, no significant deposition took place except for the position close to the divertor leg, and the oxygen impurity level was reduced. In every sample, the helium was retained by the helium glow discharge. In addition, the amount of gas desorption was considerably reduced even in the sample at the port. In the second experimental campaign, the wall conditionings largely progressed by using the glow discharge cleanings and the increase of main discharge shots with a high heating power.

Keywords: LHD; Wall conditioning; Surface analysis; Impurity; Outgassing

1. Introduction

Large helical device, LHD, has been operated since 31 March 1998. The first cycle and second experimental campaigns were carried out from 31 March 1998 to 13 May 1998 and from 16 September 1998 to 11 December 1998, respectively. The major radius is 3.6 m, the radius of vacuum vessel 1.6 m, plasma radius 0.6 m and volume of the vacuum vessel made by 316L SS 210 m^3 [1]. In the LHD, the temperature of vacuum vessel has to be kept below 100°C since the superconducting helical coils are placed close to the vacuum vessel [2,3]. Therefore, it is necessary to have the wall conditionings based upon main discharge shots and discharge cleanings [4].

In the first experimental campaign, 1800 main discharge shots by 84 GHz electron cyclotron heating (ECH) with power of 300 kW and ECR discharge cleanings with power of 5 kW were conducted. The ECR discharge cleanings were performed in the helical magnetic configuration. In these discharges, hydrogen or helium gas was employed. It was expected that the first wall was cleaned by Frank-Condon neutrals in the H_2 main discharge shot, and the wall around the divertor legs by the plasma bombardment in the H_2 or He main discharge shot and ECR discharge cleanings. Titanium flash with a time period of 1 h was also conducted twice per day in every day. The average deposition rate was approximately 3 monolayers/h. The plasma stored energy in the first experiment campaign was as high as 36 kJ at $B = 1.5$ T, with ECH power of 380 kW. The highest central electron temperature of 2 keV was achieved at the average electron density of 3×10^{18} m^{-3}.

In the second experimental campaign, 5000 main discharge shots with NBI power of 3 MW, ICRF heating power 300 kW and ECH power of 400 kW were

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carried out using hydrogen or helium gas [5,6]. Instead of the ECR discharge cleanings, glow discharge cleanings with power of 6 kW using helium gas was conducted as the wall conditionings [4,5]. It was expected that the entire wall including the wall at the port was cleaned by the glow discharge cleanings. The plasma stored energy significantly increased, and the maximum stored energy of 300 kJ at $B = 1.5$ T (430 kJ at $B = 2.75$ T) was attained near the end of the campaign. In this campaign, the energy confinement time exceeding 0.2 s, $nT\tau_E \sim 1 \times 10^{19}$ keV m^{-3} s at absorption power of 1.5 MW, the maximum central electron temperature of 2.3 keV and average electron density of 6.2×10^{18} m^{-3} were attained.

In order to investigate the wall conditioning effects in the first and second experimental campaigns, the material probes made by 316L SS and graphite (IG-430U) were installed along the poloidal direction at the inner wall of the vacuum vessel. The toroidal position was #7 sector. After the each campaign, these samples were extracted, and impurity deposition, gas retention and surface morphology were examined by Auger electron spectroscopy (AES), thermal desorption spectroscopy (TDS) and scanning electron microscope (SEM), respectively.

2. Experimental

Before the first experimental campaign, five 316L SS samples same as the vacuum vessel material were placed along the poloidal direction at the #7 toroidal sector (Fig. 1). The size of each sample was $10 \times 20 \times 1$ mm^3. Before the installation, the samples were cleaned in acid, water and ethyl alcohol. The sample positions #2–#3 were close to the plasma, #1 and #4 near the divertor leg and #5 at the port. Two graphite sheets were placed at the divertor leg positions in order to observe the deposition of metal impurities. After the campaign, these samples were extracted, and change of the surface morphology, depth profile of impurity at the surface and desorption of gas species retained were examined by SEM, AES and TDS, respectively. Before the second experimental campaign, the samples were similarly installed, and similar evaluation was performed after the extraction of the samples.

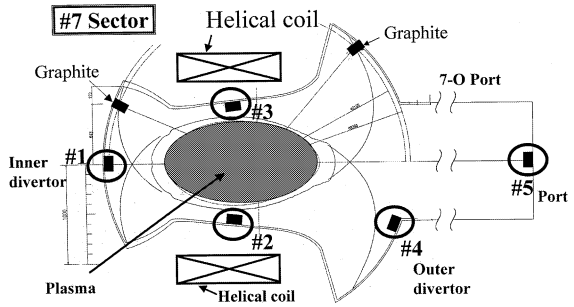

Fig. 1. Schematic diagram of poloidal cross-section at #7 port and the positions of sample placed.

3. Results

3.1. After the first experimental campaign

After the campaign, the surface morphologies of the samples were modified. In every sample, small particles with a size of sub-micron deposited on the surface. The deposition at #1–#4 was large, and at #5 small. Fig. 2 shows the SEM photographs of as-received sample, and samples at #1 and #5 after the exposure. Since the major contents at the surface were iron and oxygen as shown later, it is presumed that the deposited material is Fe–O.

The depth atomic compositions of as-received sample, and the samples at #2 and #5 are shown in Fig. 3. Compared with the case of as-received sample, the oxygen concentration increased at the position of inner divertor, #1 and the position close to the plasma, #2.

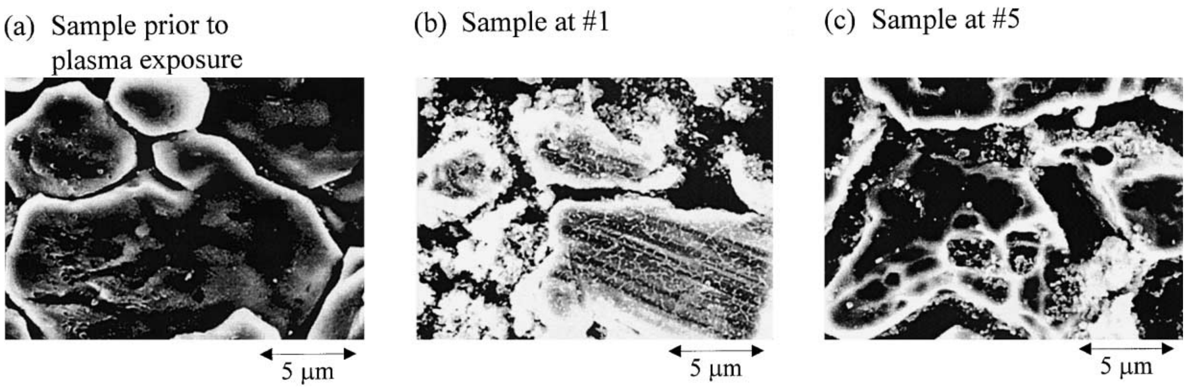

Fig. 2. Surface morphologies of as-received sample (a) and samples placed at #1 (b) and #5 (c).

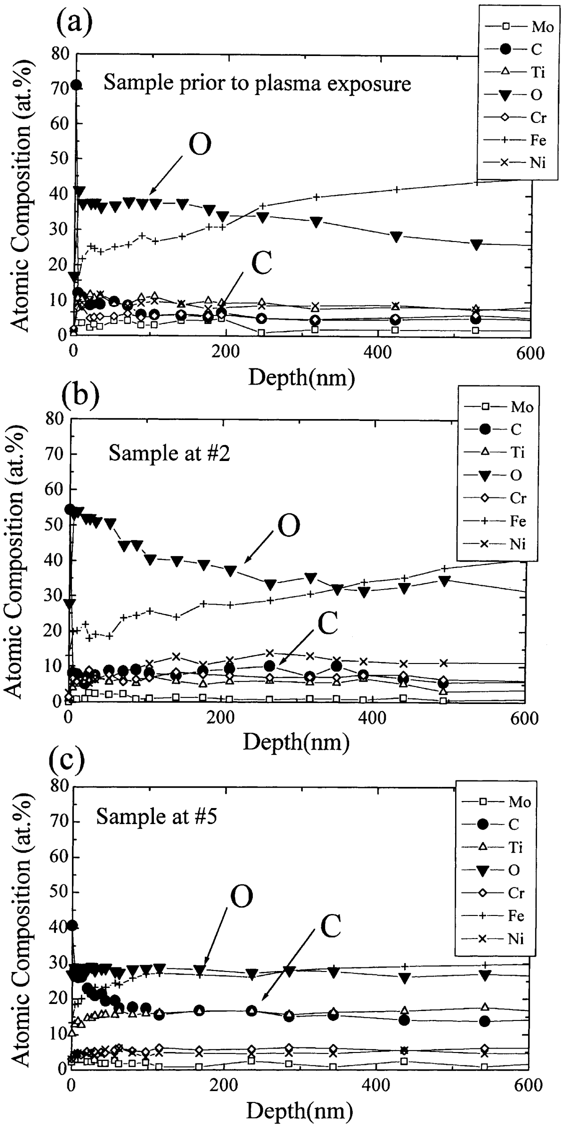

Fig. 3. Depth profiles of atomic composition for the samples at #1, #2 and #5.

The oxygen concentration at the top surface was as high as 55 at.%, 15 at.% higher than that of the as-received sample. At the other positions, the oxygen concentration was comparable with that of the as-received sample. The carbon concentration increased at the position of outer divertor, #4, and at the port, #5. In 316L SS samples, the deposition of metal impurities on 316L SS samples was not clearly observed, since the metals are contents of the sample. However, the analysis for the graphite samples showed the deposition of Fe and O [7]. The deposition amounts of Fe and O obtained by RBS analysis were 10^{15-16} atoms/cm^2, and the thickness of the deposition was several tens nm.

For samples at #1–#5, the thermal desorption spectroscopy was conducted, and the amount of gas retained was obtained. The sample temperature increased from RT to 600°C with a heating rate of 30°C/min. Most of the gas retained in the sample desorbed in the temperature range below 600°C. The amount of gas retained was obtained by deducting the amount of as-received sample from that of the sample exposed. Thus, this amount gives a net trapping or detrapping gas amount during the first campaign. Fig. 4 shows the amounts of gas retained for the samples at #1–#5. Major gas species were H_2O, H_2, CO, CO_2, CH_4 and He. The total gas amounts at #5 and #4 were large although those at #1–#3 were small. The desorption of He was clearly observed at the position of outer divertor, #4. The desorption of impurity gas was large at #5.

3.2. After the second experimental campaign

After the first experimental campaign, the impurity level at the inner wall was still high and the plasma reached little to the wall at the port. So, the glow discharge cleanings was employed instead of the ECR discharge cleanings in the second experimental campaign.

The surface morphology of the samples at #2–#5 after the campaign was very similar with that before the installation. In particular, no significant particle depo-

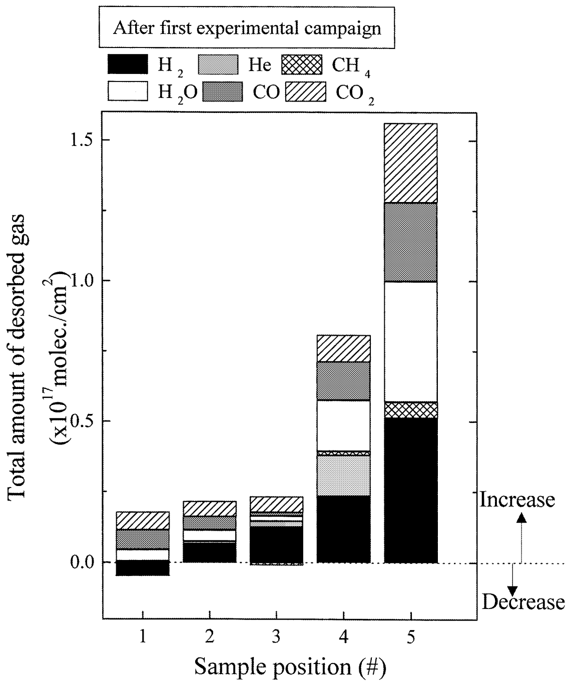

Fig. 4. Total amount of gas retained for the samples at #1–#5, after the first experimental campaign.

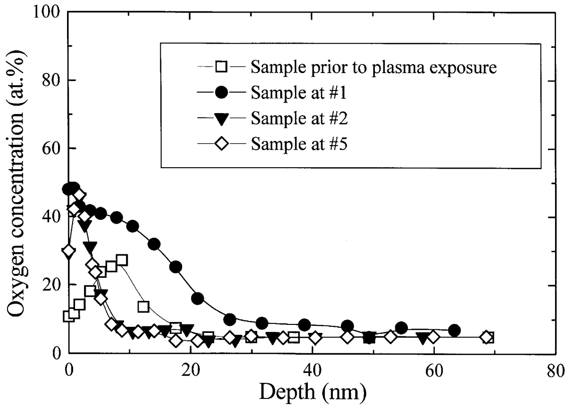

Fig. 5. Depth profiles of oxygen atomic composition for the samples at #1, #2 and #5.

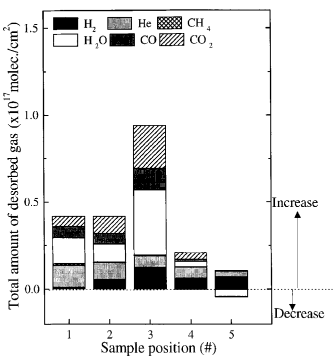

Fig. 6. Total amount of gas retained for the samples at #1–#5, after the second experimental campaign.

sition was observed in these samples. Only at the position of inner divertor, #1, the deposition of particles with a size of sub-micron was observed. Since this position is closed to the divertor leg, the sputtered materials may have deposited on the sample.

Major impurity observed on the surface of samples was oxygen. Fig. 5 shows the depth profiles of oxygen of as-received sample and samples at #1, #2 and #5. In the sample at #1, the oxygen content at the surface was large, which corresponds to the particle deposition. The oxygen concentration at the top surface was as high as 40 at.%, and the depth was less than 20 nm. Compared with the case after the first experimental campaign, the oxygen concentration was reduced. In the graphite sample, the deposition of O and Fe was observed. The thickness of the deposited layer was less than $\sim$10 nm.

Fig. 6 shows amount of gas retained. The desorption of He was clearly observed in every position. This result is the effect of the He glow discharge cleanings. The total amounts of gas retained at #4 and #5 largely decreased. The impurity level at the surface and the desorption of impurity gas after the second experimental campaign was reduced by the glow discharge cleanings and the increase of main discharge shots with higher heating power.

4. Summary

After the first and the second experimental campaigns, the 316L SS and the graphite samples placed at the inner wall of LHD vacuum vessel were extracted, and the change of surface morphology, impurity deposition and gas desorption were examined.

After the first experimental campaign, the wall surface was modified by the deposition of particles with a size of sub-micron. The impurity concentrations of oxygen and carbon were observed to be high. The retention of the discharge gas, He, was observed at the position of outer divertor. The amount of gas desorption of the sample at the port was large.

After the second experimental campaign, significant deposition was not observed in most of the samples. Only at the position of inner divertor close to the divertor leg, the deposition of sub-micron particles was observed. Major impurity at the surface was oxygen, but the concentration was reduced compared with the first experimental campaign. In the every sample, the helium was retained by the effect of He glow discharge. The desorption of gas at the port position was largely reduced. Then, the wall conditionings entirely progressed. The use of glow discharge cleanings and the increase of main discharge shot in the second experimental campaign contributed to the wall conditionings.

The samples were also placed in the third experimental campaign. These will be also analyzed to examine the improvement of the wall conditionings.

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