Behavior of Plasma Facing Surfaces in the Large Helical Device

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Abstract. Material probes have been installed at the inner walls along the poloidal direction in LHD from the first experimental campaign. After each campaign, the impurity deposition and the gas retention have been examined to clarify the plasma surface interaction and the degree of wall cleaning. In the 2nd campaign, the entire wall was thoroughly cleaned by helium glow discharge conditioning. For the 3rd and 4th campaigns, graphite tiles were installed over the entire divertor strike region, and then the wall condition was significantly changed compared to the case of a stainless steel wall. Graphite erosion took place during the main discharges and the eroded carbon was deposited on the entire wall. In particular, the deposition thickness was large at the wall far from the plasma. Since the entire wall was well carbonized, the amount of retained discharge gases such as H and He became large. In particular, the helium retention was large at the position close to the anodes used for helium glow discharge cleanings. One characteristic of the LHD wall is a large retention of helium gas since the wall temperature is limited to below 368 K. In order to reduce the recycling of discharge gas, wall heating before the experimental campaign and surface heating between the main discharge shots are planned.

1. Introduction

It is quite important to know the wall conditions of fusion experimental devices and their changes arising from the progress of plasma experiments, by using plasma surface interaction (PSI) techniques. For this purpose, wall-condition data were systematically accumulated as a database and analyzed for the wall characteristics through four experimental campaigns, conducted since 1998 in the Large Helical Device (LHD), whose baking temperature is limited to below 368 K. This paper presents the results obtained in all of these campaigns.

He ECR discharge cleaning was employed in the first campaign for the initial ECH plasma production, and glow discharge cleanings from the 2nd campaign for the production of NBI heated plasmas [1-5]. From the 3rd campaign for ICRF heated plasmas and high-power plasma production, graphite tiles have been installed in the divertor leg region to reduce impurities in the plasma [6,7]. Improved plasma performance was investigated in the 4th campaign, relevant mainly to the magnetic axis position. FIG. 1 shows the stored energies as a function of shot number, representing the progress of LHD plasma performance. The highest values of plasma parameters achieved in these four campaigns are summarized as follows:

(1) T_e of 1.3 keV and n_e of 1.3×10^{19} m^{-3} in the first campaign,
(2) T_e of 2.3 keV, T_i of 2.0 keV, n_e of 7×10^{19} m^{-3} and averaged beta $<\beta>$ of 1% in the 2nd campaign,

(3) T_e of 4.4 keV, T_i of 3.5 keV, n_e of 1.1×10^{20} m^{-3} and $<\beta>$ of 2.4% in the 3rd campaign and (4) n_e of 1.5×10^{19} m^{-3} and $<\beta>$ of 3% in the 4th campaign.

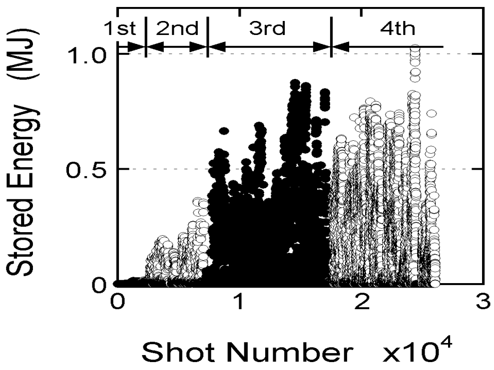

FIG.1. Increase of the plasma stored energy with shot number.

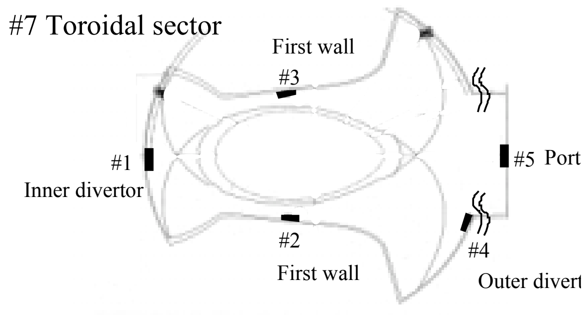

FIG.2. Position of material probes at the inner wall of #7 toroidal sector.

From the first campaign to the 4th campaign, material probes of SS and graphite were placed at several inner wall positions of the same poloidal cross-section (FIG. 2). It is worthwhile, for studying the wall characteristics, to fix the probe positions through the four campaigns. In the 4th campaign, material probes were placed along the toroidal direction in order to clarify the effect of glow discharge cleaning. In addition, material probes were placed at the port, and the probe samples exposed to only main discharges and to only glow discharges were prepared. After each campaign, impurity deposition, change of surface morphology and retention properties of discharge gas and impurity gas were examined, using AES, SEM and TDS, in order to clarify the PSI and degree of wall cleaning.

2. Impurity Deposition and Gas Retention

After the first campaign, on the entire wall surface there were deposited many sub-micron particles, which were identified as Fe-O particles. Oxygen concentration and the deposition thickness were large, 60 at.% and 200 nm, respectively. The amount of retained gas was large at the wall far from the plasma. The temperature rise during the discharge was very small in the entire wall. Thus these results suggest that the ECR discharge cleaning was effective for the wall near the plasma but not for the wall far from the plasma.

After the 2nd campaign, the deposition of Fe-O sub-micron particles disappeared at the wall except in the inner divertor leg region. In addition, both the oxygen concentration and the deposition thickness became low, 40 at.% and 20 nm, respectively. The total gas retention also decreased by 30%; in particular, the decrease was largest at the wall far from the plasma. The retention of He, the gas species used for main discharges and glow discharges, was observed at the entire wall. The retained amount is not negligible, compared with that of hydrogen. These results suggest that both the glow discharge cleaning and the large increase of main discharge shots were quite effective for the wall conditioning.

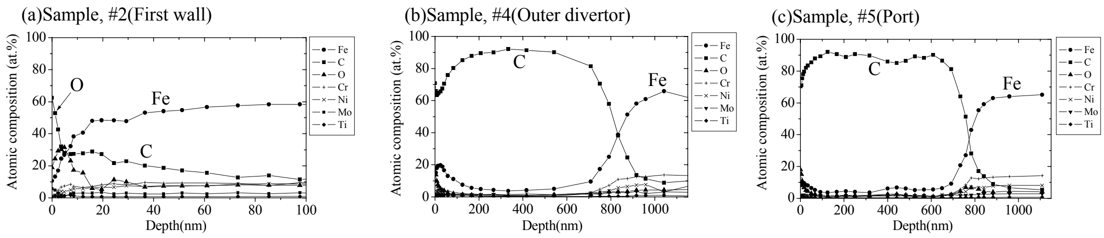

FIG.3. Depth profiles of atomic composition at the first wall (a), near the outer divertor (b) and the port (c).

From the 3rd campaign, the wall surface was substantially changed by the installation of graphite tiles at the divertor leg region. FIG. 3 shows the depth profiles of atomic composition in the samples at the first wall (a), near the outer divertor leg regions (b) and at the port (c). The entire wall was covered by carbon, and hence, a large reduction of Fe impurities in the plasma was observed. FIG. 4 shows the amounts of gas retained in samples after the 3rd campaign. The amount of retained gas was doubled compared with the case of the 2nd campaign. The increase of the gas retention is due to the deposition of carbon. In particular, the retained amount at the wall far from the main plasma increased greatly owing to the thick deposition of carbon. FIG. 5 shows the amount of retained helium for the positions shown in FIG.2. The helium gas was employed for half of the main discharge shots and helium glow discharge cleanings. The helium retention was clearly observed at the entire wall in this campaign. The helium retention was large at the wall close to the plasma. It is presumed that the helium retention took place owing to implantation of charge exchanged helium during the main discharge and helium ions during the helium glow discharge.

The toroidal sector of the sample shown in FIG. 5 is #7, which is far from the anode used for the helium glow discharge. In the 4th campaign, material probes were installed along the toroidal direction. The sample close to the anode retained a very large amount of helium, one order larger than the amount shown in FIG. 5. This large retention is due to the ion implantation during the helium glow discharge. It was also observed that the deposition of impurities such as Fe was dominant in the vicinity of the anode. It is presumed that the impurities emitted during the glow discharge were ionized in the high density plasma near the anode and deposited on the cathode, the wall close to the anode.

The sample exposed to only main discharge shots or glow discharge cleaning was prepared using a rotating shutter, in addition to the samples along the poloidal and toroidal directions. FIG. 6 shows depth profiles of atomic composition for a stainless steel (SS) sample exposed to only main discharges (a) and a graphite sample exposed to only helium glow discharges (b). In the SS sample exposed to only main discharges, carbon deposition was dominant owing mainly to erosion of the divertor tiles. On the other hand, in the graphite sample exposed to only the glow discharges, dominant Fe deposition was observed. These results clearly show that major PSIs take place at the graphite divertor in the main discharge and at the first wall in the glow discharge. FIG.7 shows the desorption spectra of retained helium from SS samples exposed to only glow discharges and to only main discharges. The helium retained in the glow discharges and the main discharges desorbed in the temperature ranges below and higher than approximately 800 K, respectively. A large amount of helium was implanted during the He

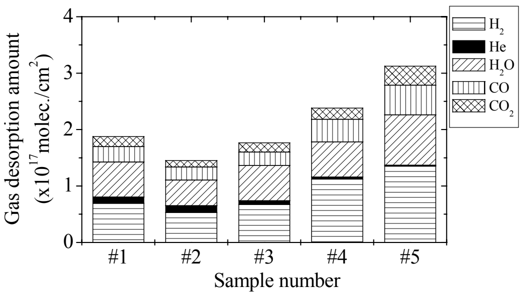

FIG.4. Amounts of gas retained in the samples after the 3rd campaign.

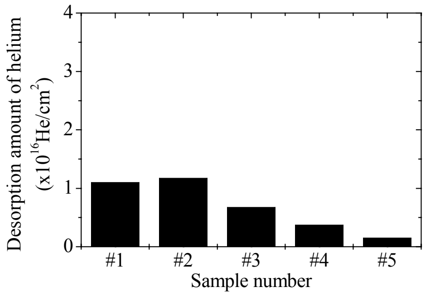

FIG.5. Amount of helium retained in the samples installed along poloidal direction at toroidal sector #7.5 after the 3rd experimental campaign.

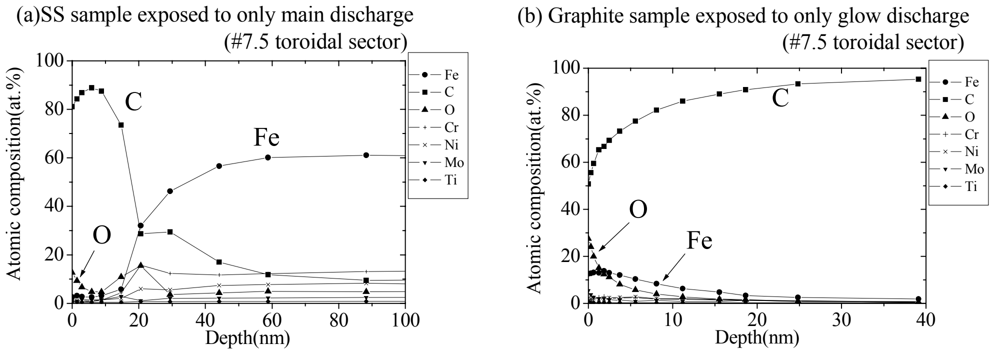

FIG.6. Depth profiles of atomic composition for the SS sample exposed to only main discharges and the graphite sample exposed to only helium glow discharges.

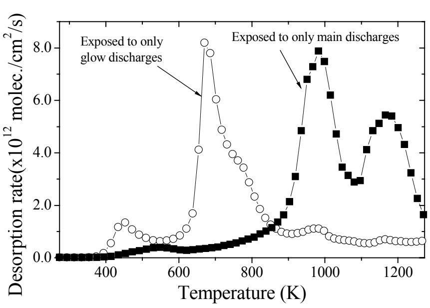

FIG.7. Desorption spectra of helium in the SS samples exposed to only glow discharges and main discharges.

glow discharges. In particular, in the sample close to the anode, the retained amount was one order of magnitude larger than that of FIG.7. In order to reduce the helium recycling, baking with a temperature higher than 800 K is required.

One of the major characteristics of the LHD wall is a large retention of discharge gases such as helium and impurity gas. In order to reduce the oxygen concentration in the plasma, boronization was conducted in the 5th campaign, and the oxygen concentration was reduced to approximately half that of the 4th campaign. For reduction of helium or hydrogen recycling, baking of the wall before the 6th campaign will be conducted. In addition, surface heating between the main discharge shots is planned. Thus, it is expected that the plasma confinement will be further improved.

3. Summary and Conclusion

The wall behavior in LHD was characterized, corresponding to the progress of plasma performance with the increase of heating power and the installation of graphite tiles for the divertor. It was found that the He glow discharge and charge exchange particles during the main shots contributed greatly to the wall cleaning in the first and 2nd campaigns. In the 3rd and 4th campaigns, the graphite tiles were installed over the entire region of the divertor trace, and then wall condition was significantly changed compared with the case of the previous SS wall. The entire wall was well carbonized, after which a large reduction of the Fe impurity level in the plasma was observed. However, the gas retention was increased by the deposition of carbon.

The retention of discharge gases such as helium was observed to be large, and this is one of the characteristics of the LHD wall. One method of reducing the gas retention is baking the wall before the cooling down of the superconductor coils. This procedure will be conducted in the 6th campaign. Surface heating using a scanning laser flash between the main discharge shots is also useful. For reduction of oxygen impurities, boronization was observed to be effective in the 5th campaign. In the 6th experimental campaign, boronization will also be conducted. Both the wall heating and the boronization will lead to further improvement of the LHD plasma.

References

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