Toroidal Distributions of Amounts of Retained Gases and Deposited Impurities during 13th Experimental Campaign in the LHD*)

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(Received 9 December 2011 / Accepted 4 October 2012)

The gas desorption behavior, and the amounts of retained gases and deposited impurities in the first wall during the 13th experimental campaign in the Large Helical Device (LHD) have been evaluated using a material probes technique. The desorption behavior of hydrogen and helium depended on the atomic composition of deposited impurities. The amount of retained hydrogen was large in the vicinity of the anodes used for the glow discharge conditioning (GDC). The amount of retained helium was small near the anodes in this campaign. The toroidal dependence on the amount of retained gas corresponded to the total time for the GDC and the gas species used for glow discharge in the final stage.

Keywords: PWI, LHD, gas retention, impurity deposition

DOI: 10.1585/pfr.7.2402155

1. Introduction

In the fusion devices, the first wall is irradiated by various particles. Numerous plasma wall interactions (PWIs) such as fuel gas recycling and impurity deposition/desorption occur. The confinement of the plasma depends on these PWIs. It is thus important to clarify the PWIs which control the plasma confinement. In previous studies [1, 2], we have investigated fuel gas retention and impurity deposition in the Large Helical Device (LHD) using material probes. Retention and deposition depended on the history of the discharges and the positions of the heating devices and the anodes for glow discharge cleaning (GDC). However, the PWIs in the LHD must change with the improvement of the plasma parameters, and their clarification and control are very useful for the design of helical-type DEMO reactor.

To investigate PWIs during 13th campaign in the LHD, we set some probes on the plasma facing wall. After the campaign, gas retention and impurity deposition at the probes were analyzed.

2. Experimental

316L type stainless steel (Nilaco Inc., Japan), which were similar to the first wall material of the LHD, were used as probes in order to analyze gas retention and desorption behavior. Silicon wafers were also used as the probes to analyze impurity deposition. The size of each probe was 10 mm × 20 mm × 0.5 mmt. Figures 1 show the location of material probes in the toroidal, (a), and poloidal positions, (b). In the LHD, there are #1~#10 sectors, and pairs of the stainless steel and the Si probes were set in each sector. As shown in Fig. 1 (b), the material probes were close to the core plasma. Neutral beam injectors (NBIs) were located at probes #1, #7 and #10 in addition to the #5-O port. Electron cyclotron resonance (ECR) antennas were located at #1.5, #5.5 and #9.5. Anodes for the GDC were located at the #4.5 and #10.5 sectors.

For the 13th experimental campaign, the number of hydrogen and helium main discharge was 3200 and 1200, respectively. Hydrogen and helium glow discharge cleaning as wall conditioning were conducted for 133 hours and 36 hours, respectively. The last discharge of the 13th ex-

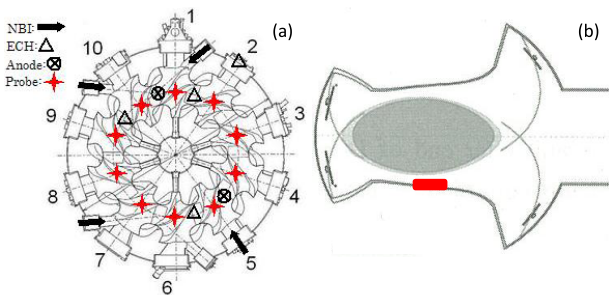

Fig. 1 Locations of the material probes. (a) is upper view and (b) cross sectional view for the LHD.

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*) This article is based on the presentation at the 21st International Toki Conference (ITC21).

perimental campaign was hydrogen glow discharge which was conducted for 23 hours. Boronization was conducted once before the experimental campaign just before starting the main discharge.

After the experimental campaign, the material probes were extracted from the LHD and analyzed. The hydrogen and helium desorption behavior and retention were evaluated by thermal desorption spectroscopy. The sample was linearly heated up to 1273 K with a heating rate of 0.5 K/s. The impurity deposition was evaluated by Auger electron spectroscopy. The surface morphology was observed by scanning electron microscopy (SEM).

3. Results and Discussion

3.1 Desorption behavior and impurity deposition for each probe

Figure 2 shows the thermal desorption spectra of H_2 for the #3, #5 and #10 probes. The different feature of the hydrogen desorption were observed for the each probes. Figure 3 (a) shows depth profile for the #3 probe. Thin carbon dominant film was deposited on the #3 probe. The thermal desorption spectra of hydrogen for #3 had a peak at around 950 K in addition to a low temperature region as shown in Fig. 2. In the previous study, it had been reported that hydrogen retained in graphite desorbed around 1000 K [3]. The peak at 950 K for the #3 probe corresponded to the desorption temperature, and might be associated with the graphite on the probe. The low temperature peaks might be owing to hydrogen desorption from the stainless substrate, because the deposition thickness was small for the #3 Si probe, as shown in Fig. 3 (a).

Figure 3 (b) shows the depth profile for the #5 probe. Impurity deposition on the probe was almost the same as the #3 probe. In spite of the similar deposition, the hydrogen desorption behavior of the #5 probe was not similar to the #3 probe namely some peaks in the low temperature region were comparably large and a peak at 950 K was absent.

Figure 3 (c) shows the depth profile at the #10 probe. Boron deposition in the deep region and carbon deposition in the shallow region were observed for this probe. For the #10 probe, the hydrogen desorption had peaks in the range of 650 - 750 K with a shoulder at 950 K. According to a previous report [3, 4], peaks associated with boron content appeared at 500 - 800 K. The hydrogen desorption of the #10 probe was consistent with these reports, considering the fact that the large boron deposition on the probe was observed. A peak at 950 K corresponds to that of #3 So this peak might be also associated with graphite on the probe.

Figure 4 shows the thermal desorption spectrum of helium for the #1, #3 and #5 probes. For the #3 probe, the desorption peak appeared at 800 K, 1050 K and 1200 K The peak at 1050 K was the largest. In the previous study [2], it has been found that stainless steel with irradiation of higher helium energy had desorbed in the higher temperature region. The high temperature peaks for the #3 probe might be associated with helium implanted into the stainless steel during the main discharges. On the other hand, the low temperature peaks might be associated with helium

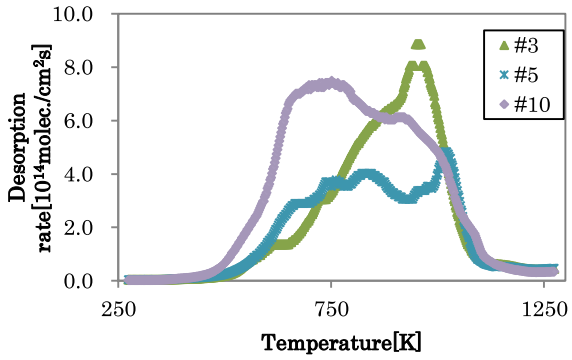

Fig. 2 Thermal desorption spectra of H_2 for #3, #5 and #10.

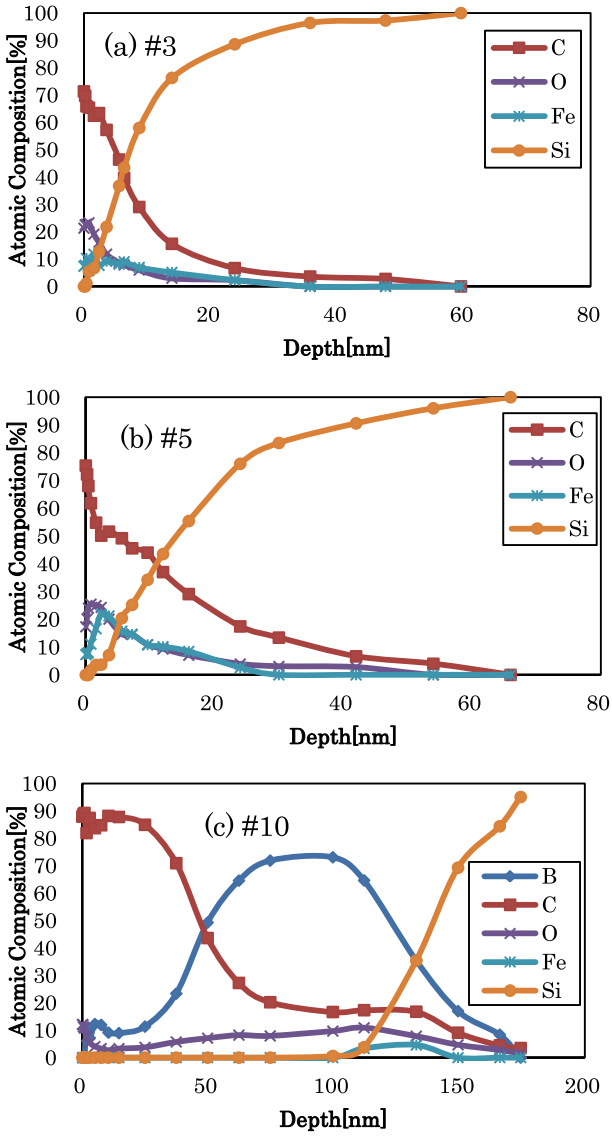

Fig. 3 Depth profile of atomic composition for (a) #3, (b) #5 and (c) #10 probe.

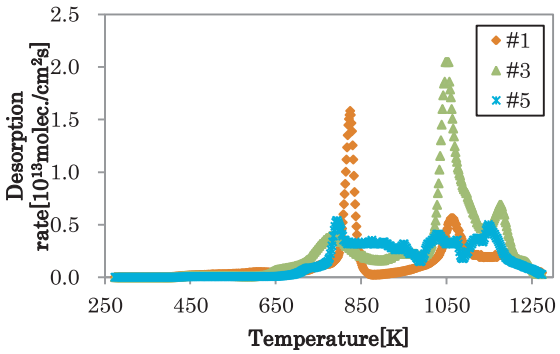

Fig. 4 Thermal desorption spectra of helium for #1, #3 and #5.

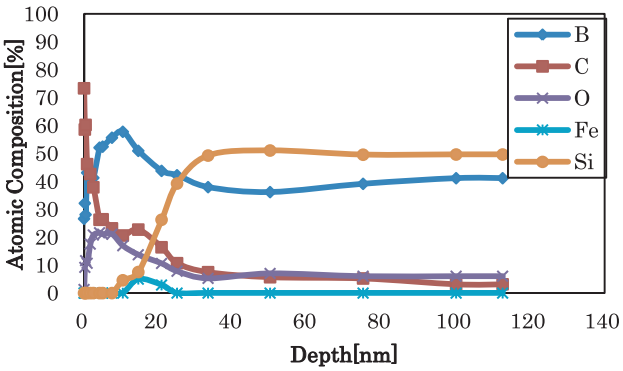

Fig. 5 Depth profile of atomic composition for #1 probe.

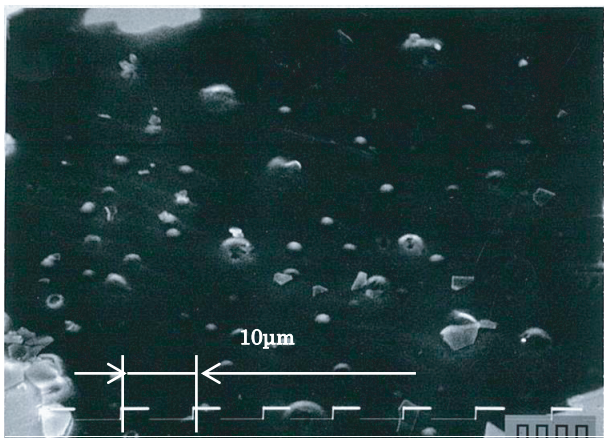

Fig. 6 Surface morphology at #1.

implanted during the GDC into the stainless steel.

For the helium desorption of the #5 probe, some peaks appeared in the range of 800 - 1050 K. This was quite a different result from the #3 probe.

Figure 5 shows the depth profile of the atomic composition of the #1 probe. This profile was boron deposition in the deep region and carbon deposition in the shallow region. For helium desorption at the #1 probe, peaks appeared at 800 K and 1050 K and the peak at 800 K was larger than that of 1050 K. Figure 6 shows an SEM image

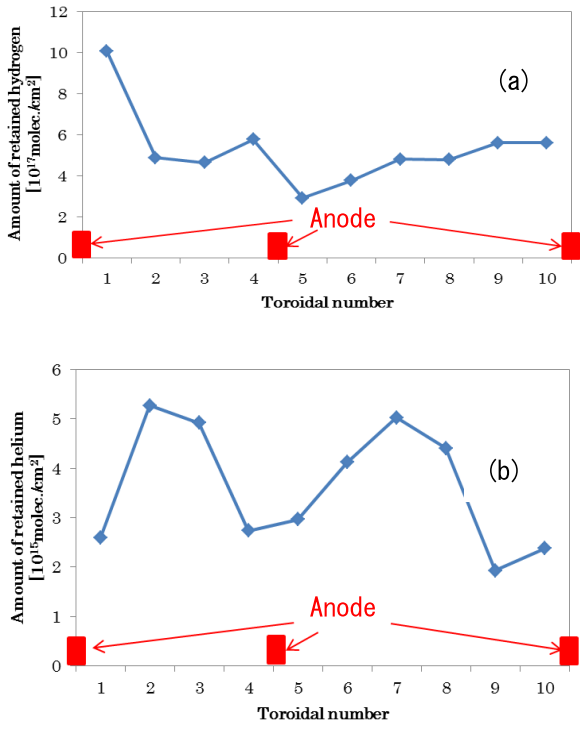

Fig. 7 Toroidal distribution of (a) hydrogen and (b) helium.

of the #1 stainless steel probe. Many blisters and exfoliation of the deposited film were observed. It was found that helium contained in blisters in boron film [5]. So, the low temperature peak might be associated with the blisters. The high temperature peak might be associated with stainless steel irradiated with high energy helium during the main discharges, since the stainless steel substrate was directly exposed to the plasma after the exfoliation.

As mentioned above, hydrogen and helium desorption behavior on the first wall were strongly connected to impurity deposition.

3.2 Toroidal distribution of gas retention

Figure 7 (a) shows the toroidal distribution of amount of the retained hydrogen which was large near the anodes for GDC. In the previous study, mainly hydrogen was retained during GDC [5]. For the 13th experimental campaign, hydrogen GDC had been conducted for 133 hours and the probe near the anodes suffered large hydrogen flux during the GDC. In addition, the last discharge was hydrogen GDC (for 23 hours) so that hydrogen retention near the anodes increased by the last discharge.

Figure 7 (b) shows the toroidal distribution of amount of the retained helium. The amounts were two orders of magnitude smaller than those of hydrogen. This resulted from the difference in the GDC duration. Helium retention near the anodes was small. Helium fluence near the anodes was small due to the short helium GDC duration. In addition, the last hydrogen GDC might result in a reduction in the amount of retained helium near the anodes.

4. Summary

In this paper, we set material probes in the LHD during the 13th experimental campaign. Afterwards, the material probes were extracted from the LHD and gas desorption behavior, gas retention, impurity deposition and surface morphology were analyzed. The different features of hydrogen and helium desorption as well as impurity deposition were observed. The kinds of deposited impurities were carbon, boron and iron and desorbed hydrogen had some peaks associated with each impurity. Desorbed helium had two main peaks at around 800 K and 1050 K. This is considered to be caused by its energy of incidence. The peak intensity changed with the deposited impurity. In the case of not much deposition and where carbon was dominant, the peak at 1050 K was larger than that of 800 K. On the other hand, in the case of a large deposition and where boron and carbon deposition was observed, the peak at 800 K was larger than that of 1050 K. The toroidal distribution of the amount of retained hydrogen was large near the anodes due to hydrogen's GDC duration and the last discharge of the 13th experimental campaign. On the other hand, the amount of retained helium was small near the anodes. This is also considered to be a result of helium's GDC duration and the last discharge of the experimental campaign.

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