Evaluation of Plasma-Wall Interactions Using Material Probes in the Large Helical Device*)

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(Received 22 November 2012 / Accepted 30 September 2013)

Control of plasma-wall interactions (PWIs) and understanding their mechanism are essential issues for realization of fusion reactor. In this study, plasma-wall interactions during FY2010 and FY2011 experiments in the Large Helical Device (LHD) were analyzed by using material probes. We installed material probes at the positions expected to have different deposits of materials such as boron and titanium and investigated the correlation between this impurity deposition and gas retention. The desorption behavior of hydrogen and helium depended on the level of impurity deposition. We observed a new peak for hydrogen desorption at the probe with large boron deposits. The amount of retained hydrogen was large in that probe; however the amount of retained helium was small in the same probe, which is opposite what we observe in the probe with titanium deposits and the probe with a thin deposition layer.

Keywords: material probe, plasma wall interactions, Large Helical Device, boronization, helical system

DOI: 10.1585/pfr.8.2405162

1. Introduction

The accumulation of impurities on the first wall, as well as hydrogen isotope and helium recycling at the boundary plasma significantly influence plasma confinement in fusion devices. These phenomena must be strongly related with radiation loss, a decrease in energy confinement time, and fuel dilution. We must consequently elucidate these PWIs to be able to realize a commercial fusion reactor. For this purpose, it is necessary that we understand conditions at the first wall such as impurity deposits and the retention of hydrogen or helium. Use of a material probe analysis method is a valid way to achieve this. In previous studies [1, 2], we have investigated impurity deposition and gas retention in the LHD's first wall with the material probes. In the LHD, glow discharge cleaning, boronization and Ti-flash as the wall conditionings are closely related with the condition of the first wall. In this study, we installed material probes at positions expected to have different deposition levels of boron and titanium in order to investigate PWIs and determine the correlation between impurity deposition and gas retention behavior in the LHD. In this paper, experimental data was obtained during the FY2010 and FY2011 experiments, which are referred to here as the 13th and 14th campaigns, respectively.

2. Experimental

Figures 1 and 2 show the position of material probes in the toroidal and poloidal directions, respectively. We installed material probes made of stainless steel 316L (SUS 316L), at 1.5 and 6.5 ports near the diborane supply nozzle, and at 5.5 and 9.5 ports near the Ti-ball during the 13th and 14th campaigns in the LHD as shown in Fig. 1. The poloidal position of the probes at 1.5 and 5.5 were on the upper side (1.5U, 5.5U), while those at 6.5 and 9.5 were on the lower side (6.5L, 9.5L). The size of each probe was 10 mm × 10 mm with a thickness of 0.5 mm.

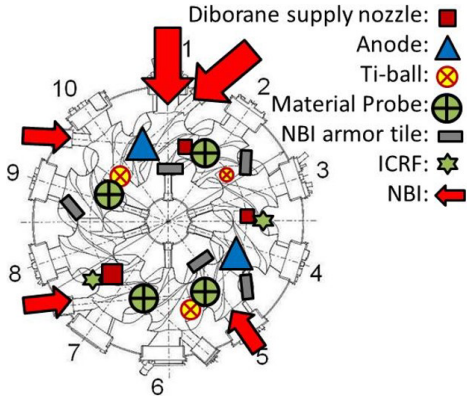

Fig. 1 Toroidal locations of material probes, diborane supply nozzles, anodes, Ti-balls, NBI armor tiles, ICRF heating antennas and NBI direction.

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*) This article is based on the presentation at the 22nd International Toki Conference (ITC22).

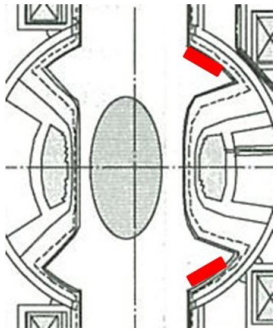

Fig. 2 Poloidal positions of material probes. The positions are shown as red squares.

For the 13th and 14th campaigns, the number of main discharges was about 6200 and 6500 shots, respectively. Hydrogen and helium glow discharge cleaning (GDC) was conducted for 133 and 35 hours in the 13th campaign and 196 and 84 hours in the 14th campaign, respectively. Boronizations were conducted once before each experimental campaign. Ti-flash was conducted for 27 hours in the 13th campaign and 75 hours in the 14th campaign.

We evaluated deposition on the probes after the two campaigns by means of Auger electron spectroscopy, and hydrogen and helium desorption from the probes and their retention behavior by means of thermal desorption spectroscopy (TDS) [3]. The samples were linearly heated up to 1273 K at a heating rate of 0.5 K/s during the desorption measurement.

3. Results and Discussion

3.1 Characteristics of deposition

Amounts of deposited boron, carbon, titanium and iron in the 13th and the 14th campaign are shown in Fig. 3 and Fig. 4, respectively. Large boron deposition on 6.5L and smaller boron deposition on 1.5U were observed for both campaigns. The smaller boron deposits on 1.5U might result from erosion during the glow discharges. Carbon deposited on all probes mainly originates from neutral beam injection (NBI) armor tiles and divertor plates made of graphite. Carbon deposition at 1.5U was small due to erosion, which might mainly be caused during NBI heated plasma discharge. Conversely, carbon deposition as well as boron deposition was large at 6.5L. This might result from the small erosion near 6.5L because the probe was far from the anode for the glow discharge. Titanium deposition was clearly observed on the probes (5.5U and 9.5L) near the Ti-ball. For all material probes, iron was deposited on the surface, which was due to sputtering and the subsequent re-deposition of the first wall material (SUS 316L) during glow discharge cleanings.

3.2 Hydrogen retention and desorption

The thermal desorption spectra of H_2 in the 13th campaign is shown in Fig. 5. The hydrogen desorption peak

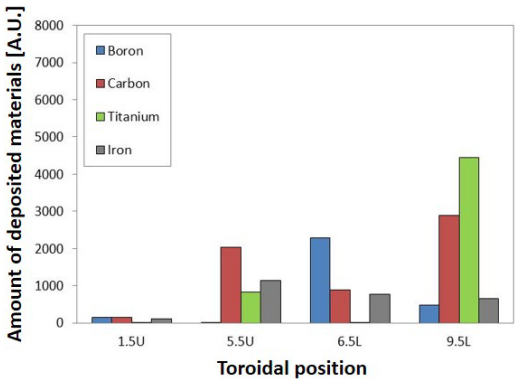

Fig. 3 Amounts of deposited boron, carbon, titanium and iron on the surface of the 4 probes in the 13th campaign.

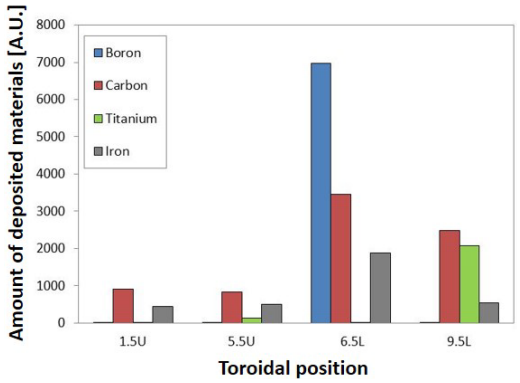

Fig. 4 Amounts of deposited boron, carbon, titanium and iron on the surface of the 4 probes in the 14th campaign.

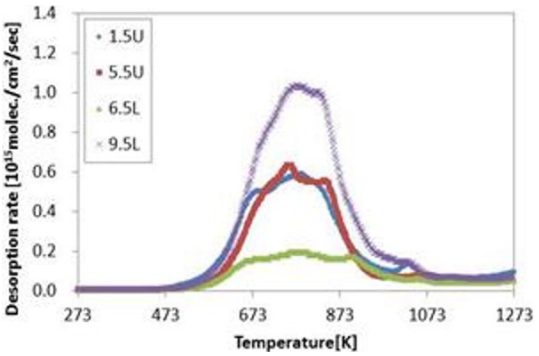

Fig. 5 Thermal desorption spectra of hydrogen of the 4 probes in the 13th campaign.

of all probes was observed at around 773 K. The peak for 9.5L was larger than that of the other three probes, which might be attributed to large titanium deposits. The thermal desorption spectra of H_2 in the 14th campaign is shown in Fig. 6. The peak at around 773 K was observed in all probes similar to the 13th campaign. In addition, the signal for 6.5L appeared around 500 K. According to previous studies, the peak observed from 500 K to 800 K was associated with B-H-B and B-H [4, 5] and the one observed from

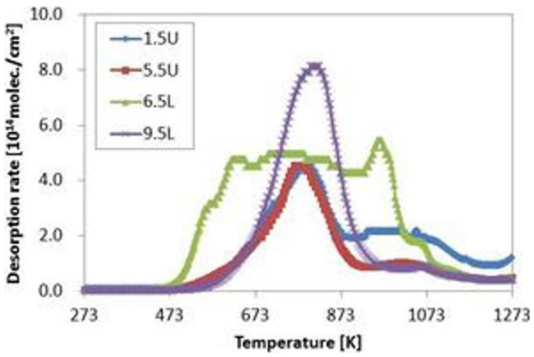

Fig. 6 Thermal desorption spectra of hydrogen of the 4 probes in the 14th campaign.

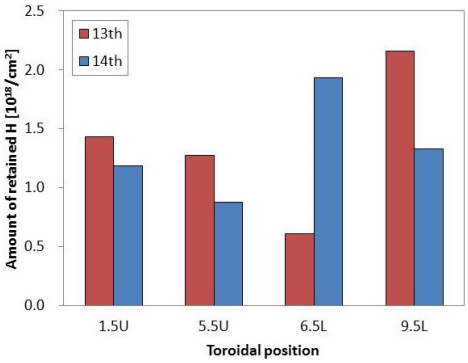

Fig. 7 Comparison of the retained amounts of hydrogen in SUS316L samples in the 13th and 14th campaign.

800 K to 1000 K was associated with graphite [4]. The increase in boron deposition might be responsible for the peaks of B-H-B and B-H from around 500 K which were clearly observed in the 14th campaign, compared with the 13th campaign. According to the other reports [6, 7], deuterium in deposited boron/carbon film was desorbed at around 950 K, which was originated from B-C-D bonds. Therefore, the peak at 6.5L at around 900 K might be associated with B-C-H.

The quantities of retained hydrogen in the 13th and 14th campaign are shown in Fig. 7. Hydrogen retention at 6.5L far from the anode was large in the 14th campaign, while the probes near the anode (1.5U, 5.5U and 9.5L) had large retention in the 13th campaign. These results were associated with large boron deposition because hydrogen is originally contained in boron film deposited by boronization and is easily retained in boron film [8, 9]. Therefore, hydrogen recycling might be larger at around 6.5L for the 14th campaign. With respect to three probes near the anode, hydrogen retention at 9.5L was larger than those at 1.5U and 5.5U. This result was associated with large titanium deposition because it is well known that titanium is chemically active and reacts easily with hydrogen.

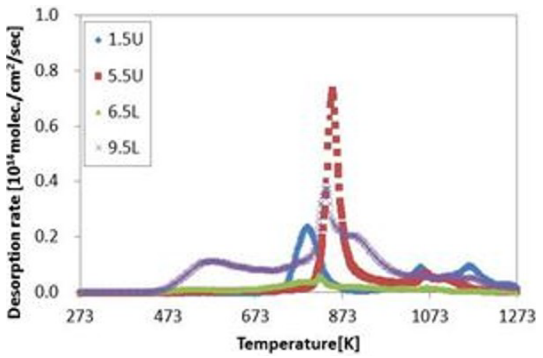

Fig. 8 Thermal desorption spectra of helium of the 4 probes without ICRF heating antennas in the 13th campaign.

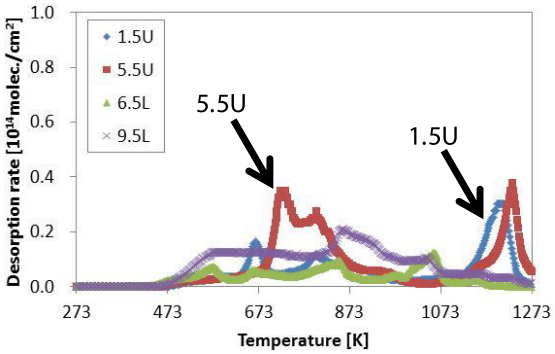

Fig. 9 Thermal desorption spectra of helium of the 4 probes with ICRF heating antennas in the 14th campaign.

3.3 Helium retention and desorption

The thermal desorption spectra of helium in the 13th campaign are shown in Fig. 8. In a previous study, it was found that stainless steel irradiated with higher energy helium had desorbed at a higher temperature [2]. The 900 K high temperature peaks might be associated with helium implanted into the stainless steel substrate during main discharges. On the other hand, low temperature peaks under 900 K might be associated with helium implanted into the stainless steel substrate during GDC.

The thermal desorption spectra of helium in the 14th campaign is shown in Fig. 9. The helium desorption peaks around 1200 K in the 14th campaign became notably large in probes with little deposition such as at 1.5U and 5.5U near the Ion Cyclotron Range of Frequencies (ICRF) heating antenna. Previously, it was found that plenty of helium was desorbed from 900 K to 1300 K in probes near the heating antenna in the campaign with ICRF heating because of the high energy helium it produced [10]. It was therefore speculated that the peaks around 1200 K were associated with the new installation of ICRF antenna in the 14th campaign. However, at 6.5L which was located near the antennas, there was no peak from 900 K to 1300 K in the 14th campaign. This result suggests that high energy helium is less likely to be retained in boron film than stainless steel. The desorption spectrum at 9.5L in the 14th

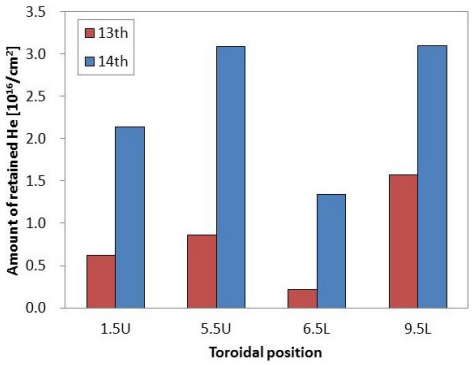

Fig. 10 Comparison of the retained amounts of helium in SUS316L samples in the 13th and 14th campaign.

campaign was similar to that in the 13th campaign. This result confirmed previous observation that the deposition at 9.5L is similar in each campaign.

Amounts of retained helium in the 13th and 14th campaign are shown in Fig. 10. Compared with the 13th campaign, the amounts of retained helium in all probes increased in the 14th campaign. This might result from an increase in the duration of the helium glow discharge. In both the 13th and 14th campaigns, helium retention was large at 5.5U and 9.5L, while small at 6.5L. These results indicate that helium was retained more easily in the stainless steel substrate and titanium film than in boron film.

4. Summary

In this paper, we installed material probes at the positions expected to have different deposits of materials such as boron and titanium in the LHD during the 13th and 14th campaigns to investigate PWIs. Afterwards, we extracted them from the LHD and determined the correlation between impurity deposition and gas retention behavior. The elements deposited were boron, carbon, titanium and iron. Deposition distributions were closely correlated with probe positions. For probes far from the anode, large boron deposition was observed due to small erosion. The desorption and retention behavior of hydrogen and helium depended on the impurity of the deposition. In the case of a large boron deposition probe, a new peak of hydrogen at around 900 K might be associated with B-C-H. Hydrogen retention was highest for probes far from the anode in the 14th campaign, while it was large for probes near the anode in the 13th campaign. Thus, hydrogen might be retained at locations having large boron deposition more than near the anode. In addition, hydrogen recycling might be higher in locations with large boron deposits. On the other hand, helium retention was large in probes with no boron deposits. Helium is considered more easily retained in stainless steel and titanium film than boron film. Hydrogen retention was larger than helium retention by two orders of magnitude. Therefore, it was found that hydrogen was more easily retained than helium.

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