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Retention and depth profile of hydrogen isotopes in gaps of the first wall in JT-60U

Y. Nobuta [a,*], T. Arai [b], J. Yagyu [b], K. Masaki [b], M. Satoh [b], T. Tanabe [c], Y. Yamauchi [a], T. Hino [a]

[a] Laboratory of Plasma Physics and Engineering, Hokkaido University, Kita-13, Nishi-8, Kita-ku, Sapporo 060-8628, Japan
[b] Japan Atomic Energy Agency, 801-1 Mukaiyama, Naka-shi, Ibaraki 311-0193, Japan
[c] Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, Fukuoka 812-8581, Japan

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ABSTRACT

Hydrogen (H) and deuterium (D) retention in gap side surfaces of the first wall tiles exposed to DD and HH discharges in JT-60U were examined. On the sides of outboard tile, the H and D retention and the deposited amount of boron increased with the gap width. On the sides of inboard tile, thick carbon deposition layer (~10 μm) was observed. The deposited layers retained rather large amount of hydrogen with ~0.15 in (H + D)/C atomic ratio compared to that found in the deposited layers on the divertor tiles, most likely due to the lower temperature. The H + D retention on the sides analyzed here was comparable to that of the plasma facing surface.

1. Introduction

Tritium retention in plasma facing materials (PFMs) is a primary issue for next step fusion devices, such as ITER, fuelled with mixture of deuterium and tritium because it greatly affects on its safety and operational schedule [1]. For this reason, it is important to investigate retention behavior of hydrogen isotopes in present tokomaks for prediction of tritium retention in ITER. In tokamaks, hydrogen (H) and deuterium (D) retention and carbon erosion/deposition in the divertor area has been intensively investigated so far [2–12]. In JT-60U, it was found that the H + D retention in the plasma facing surface and the side surface of the graphite tile in the divertor area is of the order of about 10^{22}–10^{23} atoms/m^2.

On the other hand, the hydrogen isotopes retention in the first wall area has not been examined well. Hydrogen isotopes retention of first walls could become large due to its huge surface area and relatively lower temperature. In particular, tritium accumulation in the plasma shadowed area like gaps between plasma facing tiles is a serious concern for controlling the in-vessel tritium inventory because tritium retained in gaps is difficult to remove by ordinary discharge cleanings. Recent results of JT-60U show that the H + D amount in the plasma facing surface of the first wall could be fairy large [13]. In this study, we focused on the retention of hydrogen and deuterium in gap side surfaces of the first wall tiles, which were investigated by means of thermal desorption spectroscopy (TDS). Deposits in gaps were also analyzed by secondary ion mass spectroscopy (SIMS) and scanning electron microscope (SEM).

2. Experimental

Fig. 1(a) shows a cross sectional view of the vacuum vessel of JT-60U and poloidal locations of analyzed two graphite tiles. Two tiles investigated here were located at outer mid-plane (10Ga6) and inboard wall (8Lb3) and were toroidaly 40° apart each other. Fig. 1(b) shows sampling positions in the tiles. Gap widths of tiles sides are also shown in Fig. 1(b). The graphite tile located at the outer mid-plane (10Ga6) had different gap widths (1–20 mm) on each side. The tiles were exposed to a total of 18000 DD and 2700 HH tokomak discharges, keeping the temperature of the vacuum vessel at ~570 K, in the operation periods from July 1992 to November 2004. Just before venting the vacuum vessel, hydrogen discharges were carried out to remove tritium produced by DD reaction. During this operational period, boronization by glow discharge using helium and decaborane ($B_{10}D_{14}$) mixture gas was conducted occasionally.

For analysis, sample plates (8 × 8 × 0.5 mm) were cut from a tile side surface, one including the front edge (referred as front side samples) and the other the rear edge (rear side samples) as shown in the inset of Fig. 3. The depth profile of hydrogen (H), deuterium (D), boron (B) and carbon (C) of the samples was analyzed with secondary ion mass spectroscopy (SIMS), using cesium ion (Cs^+) as a primary ion with an energy of 11 keV and a beam current of 200 nA at 60° to the surface normal. The Cs^+ beam size was approximately 32 μm and the rastering size area was set at 400 × 400 μm^2. In order to eliminate the effect of crater edges, the secondary ion signal was collected only from the center of the rastered area. In the SIMS analysis, the secondary ion intensities of hydrogen, deuterium and boron were normalized by that of carbon for comparison. After the SIMS analysis, the crater depth was measured by a surface profile meter and the etching rate was

* Corresponding author.
E-mail address: y-nobuta@eng.hokudai.ac.jp (Y. Nobuta).

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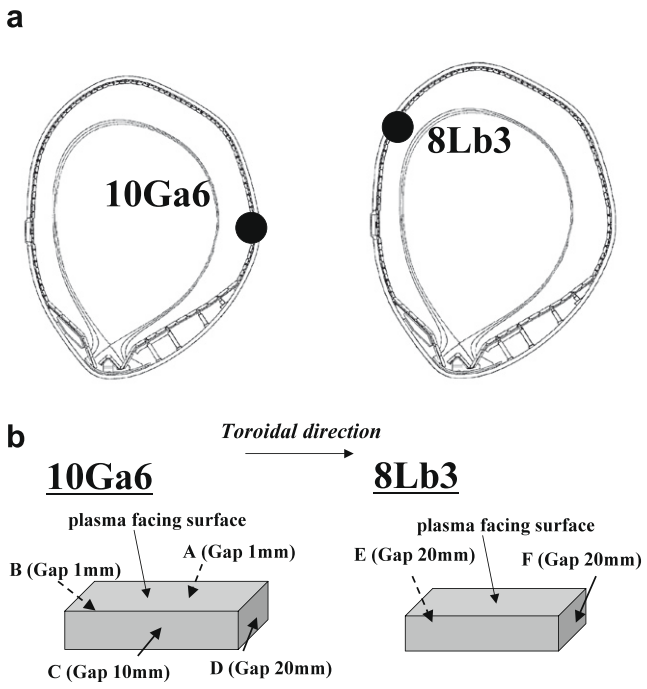

Fig. 1. (a) Cross-sectional view of the vacuum vessel of JT-60U and poloidal locations of analyzed two graphite tiles. (b) Sampling positions of each graphite tile.

estimated to be 0.96 μm/h. Retained amounts of hydrogen and deuterium were obtained with thermal desorption spectroscopy (TDS) with a constant heating rate of 0.42 K/s from room temperature to 1273 K. Thickness of re-deposition layers was investigated by using scanning electron microscope (SEM).

3. Results

Fig. 2 shows the depth profiles of D/C, H/C and B/C signal intensity ratios for (a) 10Ga6-B, (b) 10Ga6-D and (c) 8Lb3-F, which were obtained with SIMS. One can note that the deposition on the narrow gap was quite small compared with those for the wider gap. In 10Ga6-B (Fig. 1(a)) with a narrow gap width of 1 mm, all signal intensity ratios were very small. In 10Ga6-D (Fig. 1(b)) and 8Lb3-F (Fig. 1(c)), which had a wide gap width of 20 mm, the intensity ratio of D/C increased with that of B/C.

Fig. 3 shows the retained amounts of hydrogen and deuterium and the integrated signal intensity ratio of B/C within the thickness of 2.0 μm. For all samples analyzed here, the total amounts of retained hydrogen and deuterium in front side samples were larger than that in rear side samples. In 10Ga6, one can see that the retained amounts of H + D and the amount of deposited boron increased with the width of gaps. Although the 8Lb3 tile located at inboard wall had the same gap width (20 mm), the H + D retention of side E was roughly a factor of two larger than that of side F. This would be due to large carbon deposition on side E, as discussed below.

Fig. 4 shows SEM image of re-deposited layer of side E in 8Lb3. On this side surface, re-deposited layer was uniformly deposited from front side to rear side. From the SEM observation, the thickness of the re-deposited layer was measured to be 10 μm on average. In the SIMS analysis, it was found boron concentration in the re-deposited layer was very low. From the results, the re-deposited layer consists mainly of carbon. Since ions are trapped by line of magnetic force and could hardly reach deep into gap, the carbon deposition must be mainly due to neutral carbon atoms or molecules. Although first walls are generally thought to be erosion

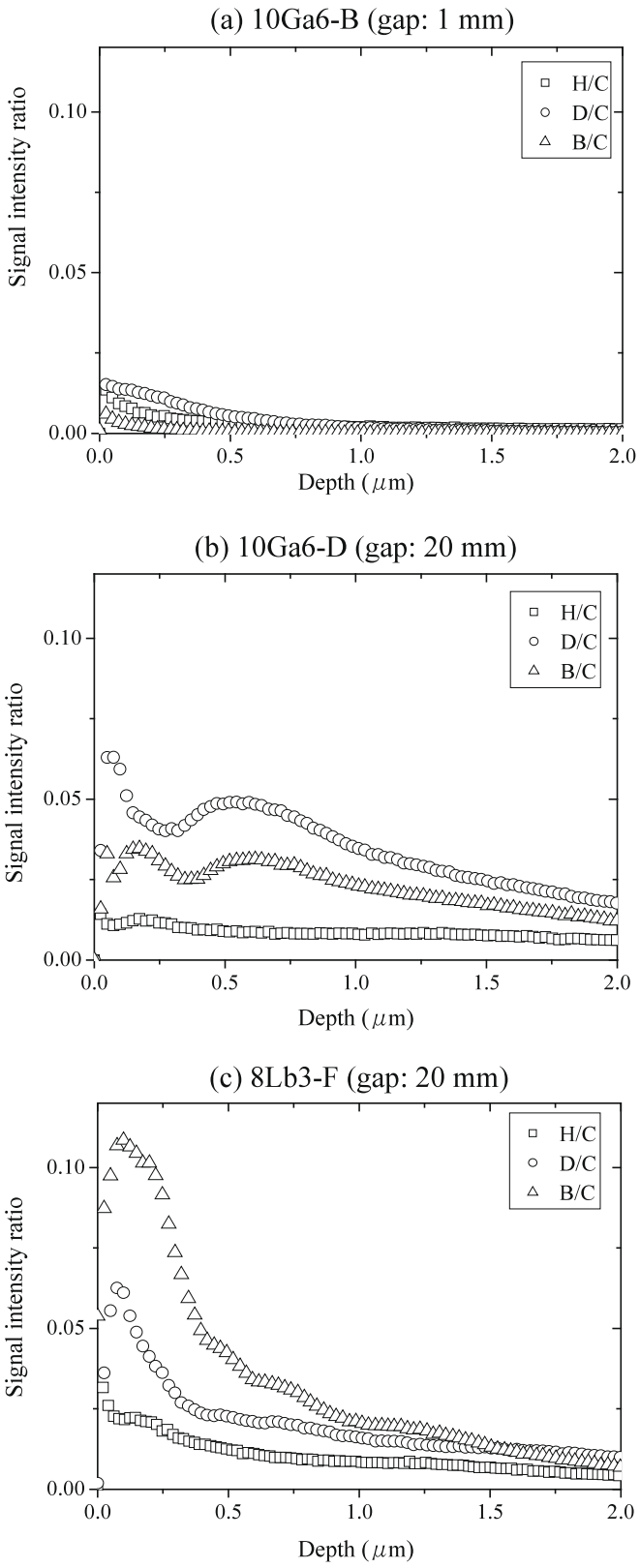

Fig. 2. Depth profiles of D/C, H/C and B/C signal intensity ratios measured with SIMS for (a) 10Ga6-D, (b) 10Ga6-B and (c) 8Lb3-F.

dominated area, the results show that deposition could occur in gap side surface even in first wall area. Assuming the density of the carbon deposition layer was 0.91 g/cm^3 [14] and all hydrogen and deuterium were retained in the carbon deposition layer, the

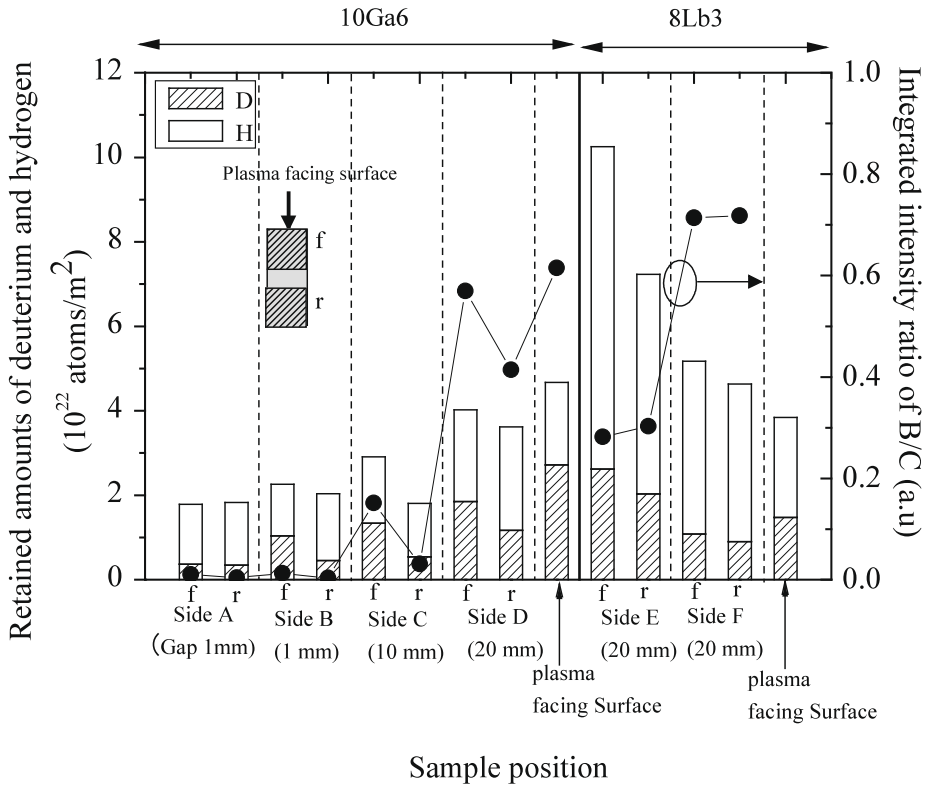

Fig. 3. Retained amounts of hydrogen and deuterium measured with TDS, and the integrated signal intensity ratios of B/C within the thickness of 2.0 μm in SIMS analysis.

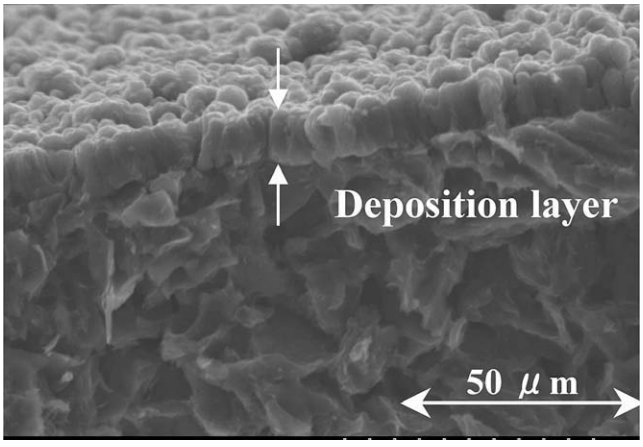

Fig. 4. Cross-sectional SEM image of re-deposited layer of 8Lb3-E.

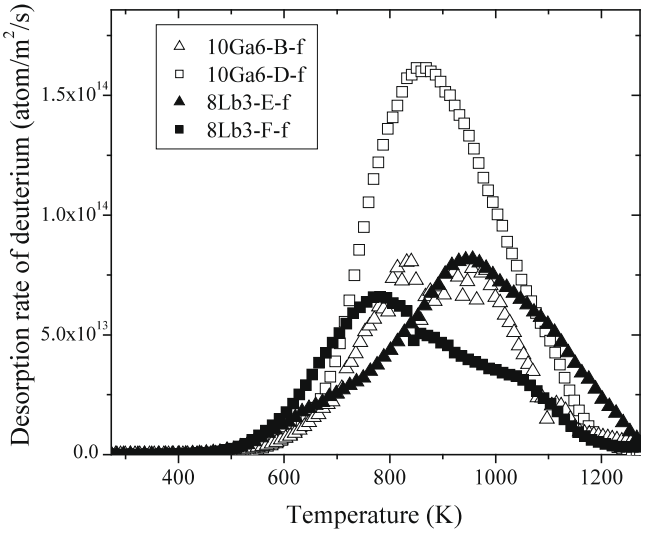

Fig. 5. TDS spectra of deuterium for 10Ga6-B, 10Ga6-D, 8Lb3-E and 8Lb3-F.

atomic ratio of (H + D)/C was estimated to be approximately 0.15. This value is higher than that of re-deposited layer observed in the inner divertor region of JT-60U [12], probably due to the lower temperature of the first wall.

Fig. 5 shows TDS spectra of deuterium for 10Ga6-B, 10Ga6-D, 8Lb3-E and 8Lb3-F. Deuterium retained in 10Ga6-D-f and 8Lb3-F-f desorbed at lower temperatures compared with those in 10Ga6-B-f and 8Lb3-E-f, respectively. As shown in Fig. 3, 10 Ga6-D-f and 8Lb3-F-f had larger deposits of boron on its surface. As reported in other papers [15–17], deuterium trapped in carbon materials containing boron desorbs at temperatures lower than that in pure carbon materials. The boron deposition on the side surfaces might have caused the difference in desorption temperatures.

4. Summary

The hydrogen and deuterium retention in gap side surfaces of the first wall tiles exposed to DD and HH discharges in JT-60U were investigated with TDS and SIMS. On the sides of outboard tile analyzed here (10Ga6), the hydrogen and deuterium retention and boron deposition increased with the gap width. The depth profile of deuterium was very similar to that of boron. Deuterium retained in the gap side with a large boron deposit desorbed at relatively low temperature.

On the side of inboard tile (8Lb3), thick carbon deposition layer (~10 μm) was observed and the atomic ratio in (H + D)/C

in the carbon layer was estimated to be approximately 0.15. This value is higher than that observed in the divertor region, probably due to the lower temperature of the first wall. Such the deposition in gap side would be serious in ITER because it is hard to remove.

The H + D amount in gap side surfaces of the first wall measured here was of the order of $(2–10) \times 10^{22}\,m^{-2}$. Normalized by integrated NBI time (6×10^4 s), this value corresponds to approximately $(0.3–1.5) \times 10^{18}\,m^{-2}\,s^{-1}$. Although this value is smaller than that of the inner divertor with heavy deposition of carbon [10], the results suggest that the hydrogen isotopes retention in gaps of the whole first wall area could be significantly large.

Since carbon deposition on the tile sides quite depends on poloidal and toroidal locations we need further measurements for accurate evaluation of tritium inventory.

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