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Hydrogen retention in the first wall tiles of JT-60U

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Tritium retention in plasma facing materials is one of the most important safety concerns for a fusion reactor. We have investigated detailed hydrogen isotopes retention in the first wall carbon tiles of JT-60U in terms of poloidal/ toroidal distributions, erosion/ deposition, and tile temperatures by means of scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), thermal desorption spectroscopy (TDS) and secondary ion mass spectroscopy (SIMS). SEM observation showed that the first wall was mostly eroded. The amount of hydrogen isotopes retained at the eroded area of the first wall carbon tiles was similar to that of the divertor eroded region, but much smaller than that of the co-deposited layers in the divertor region. The integrated retention over the whole first wall becomes similar level to that of the whole divertor area and could be significant part of the tritium inventory of a fusion reactor. Different from the divertor region, D retention in deeper region was appreciable owing to the direct injection of high energetic deuterons and neutrals originated from NBI. Such D retention in the deeper region seems difficult to remove, compared to that retained in near surface layers which is easily replaced by the isotopic exchange.

Keywords: hydrogen retention, carbon, plasma facing material, first wall, JT-60U

1. Introduction

Erosion and re-deposition of plasma facing carbon materials and tritium incorporation in the re-deposited carbon layers are major concerns for tritium safety, wall cleaning and their life time in a fusion reactor. For divertor area, extensive studies have been done and significant amounts of redeposited layers retaining very high concentration of hydrogen were found on the inner divertor tiles, which is believed to dominate the total hydrogen retention in ITER. On the other hand, little has been studied on the first wall region, where hydrogen retention is believed to be small because the first wall is mostly eroded [1-4].

In this work, we have examined the first wall carbon tiles of JT-60U to clarify the erosion/ deposition and retention characteristics of the hydrogen isotopes by means of SEM, XPS, TDS and SIMS. The results were compared with a previous study for the divertor tile [3].

2. Experiments

Horizontal and vertical cross sectional views of the vacuum vessel of JT-60U were shown in Fig.1 (a) and (b), respectively. The first wall of JT-60U was covered by isotropic graphite tiles. The tiles analyzed here were located at the outboard and were exposed to D-NBI (neutral beam injection) and H-NBI of ~18000 shots and 2800 shots, respectively, during the experimental campaign of July 1992- November 2004. The total NBI time was ~6.0×10^4s, with which the amount of hydrogen retained in each tile was normalized. JT-60U was operated at ~573K. Hence, the temperature of the first wall tiles must be a little increased owing to the plasma heat load, though the tile temperature was not measured. During the experimental campaign, boronization was occasionally made and some of the first wall tiles retained Boron (B).

The plasma facing surface of the tiles was analyzed by SEM and XPS. The retention of hydrogen isotopes (H and D) within 10 x10 x 1 mm^3 of the plasma facing surface was determined by TDS [3]. Depth profiles of the hydrogen isotopes (H and D) in the tiles were investigated by SIMS.

3. Results & Discussion

The cross-sectional SEM image of the outboard first wall tiles clearly shows that the tile surface was eroded without any traces of deposition as shown in Fig.2. Nevertheless some tiles retained boron showing two different types of depth profiles. One is rather constant B concentration (a few %) in depths, probably owing to repeating processes of erosion and deposition. The other is a sharp B concentration decay from the surface indicating that the boronized layers made by the boronization were remained escaping from the full erosion. Compared with the inboard tiles previously analyzed [5], which was fully covered by the thick boron layers, the total B amount retained in the outboard first wall was much smaller. Hence hydrogen retention in the outboard tiles was not likely influenced by B.

TDS spectra for the first wall tile were shown in Fig.3. Those for the eroded divertor tiles previously obtained were also given for comparison [3]. The peak

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temperatures for H_2, HD and D_2 desorption appeared at 900-1000K, which are clearly lower than those observed for the divertor tiles of above 1000K. This is attributed to lower temperature of the first wall tiles than that of the divertor tiles, which is above 1400K during the discharges [4].

Retained amounts of hydrogen in the analyzed tiles are compared with the separation of H and D in Fig.4. The results of the eroded and redeposited divertor tiles (OuDV and InDV, respectively) are also given for comparison. The H+D retentions of the first wall tiles are clearly smaller than that of the redeposited divertor tiles and similar to that of the eroded divertor tile. The different retention characteristics among the tiles compared here could be attributed to the tile temperatures and impinging fluxes. In the previous work [4], we have shown that the hydrogen retention in the eroded divertor tiles was quite low due to temperature rise owing to plasma heating, in spite of the large particle flux. Although the lower temperature of the first wall tiles should result in higher retention compared with the eroded divertor tile, the lower particle flux at the first wall could lead to the similar total retention to that of the eroded divertor tiles.

In the depth profile by SIMS in Fig. 5 (b), deep implantation of D in the eroded area is appreciable and has large contribution on the total retention. For the eroded divertor tiles, D once retained near surface regions was completely replaced by H during HH discharges, resulting in very high H/C as seen in Fig.5 (a). On the other hand, D retained in the deeper region is not likely replaced. The lower tile temperature of the first wall would also depress the isotope exchange. Such retention in the deeper region is attributed to the injection of high energy deuterium (both neutrals and ions) originating from D-NBI analogous to the high energy T implantation in the first wall tiles observed in the previous work [4]. The integrated amount of the hydrogen injected in the rather deep region, even though the concentration was small, could have larger contribution on the overall tritium retention in a reactor.

4. Summary

The hydrogen retention in the outboard first wall tiles of JT-60U has been examined at first time in detail. It is confirmed that the outboard first wall tiles are mostly eroded and retained much smaller hydrogen compared to the divertor tiles. Some tiles retained boron (B) originating from the boronization. However, their B contents were quite small compared to the inboard tiles mostly covered by B layers and had little influence on hydrogen retention.

Hydrogen retention in near surface region is dominated by H, most probably because D retained in the surface layers during DD discharges is replaced by H during HH discharges subsequently made for T removal.

Although the H+D retention in each first wall tile is very small, the integrated hydrogen (H+D) retention for the whole first wall tiles becomes comparable or larger than that for the whole divertor tiles.

It should be mentioned that D retention in the deeper region of the eroded first wall tiles is appreciable. This is attributed to the injection of high energetic deuterons and neutrals originating from NBI. This type of tritium retention, i.e. direct injection of energetic tritium, is a concern for metallic wall, because faster hydrogen diffusion in the metal should increase the retention in the deeper region, which could not be replaced by the isotopic exchange.

More detailed measurements of the first wall tiles located wider area are needed to make the estimation of tritium retention in a whole tokamak reliable.

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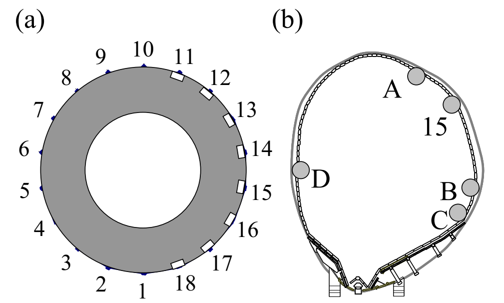

Fig.1 (a) Toroidal and (b) poloidal schematic view of the JT-60U vacuum vessel. Sample locations are indicated in (a) and (b).

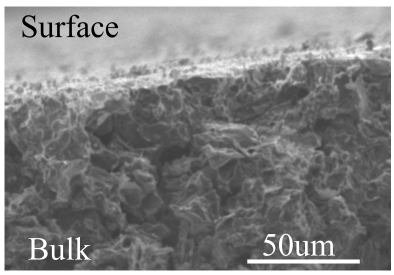

Fig.2 The cross sectional view of the surface by SEM.

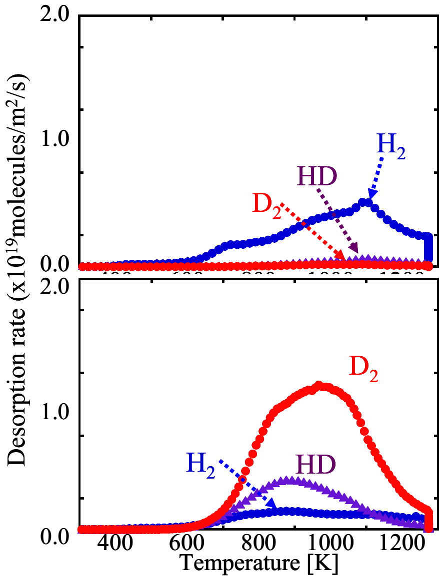

Fig.3 TDS spectra of (a) the eroded divertor tile and (b) the first wall tile

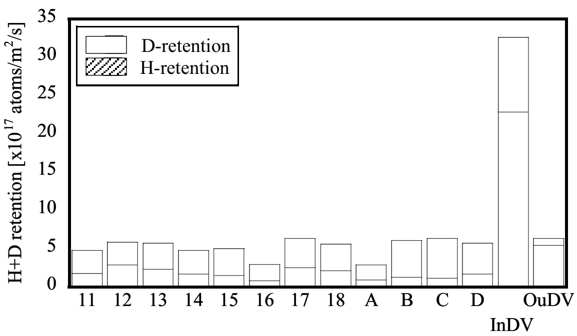

Fig.4 H+D retention of the first wall tiles and eroded divertor tile (OuDV) and re-deposited divertor tile (InDV).

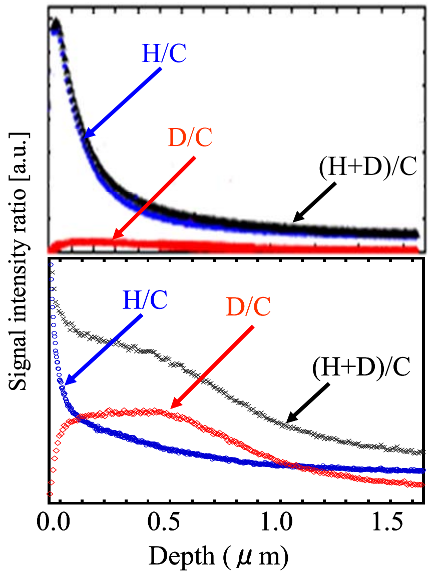

Fig.5 Depth profile of (a) the eroded divertor tile and (b) the first wall tile