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Tritium distribution measurement of JET Mk II SRP divertor tiles

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Abstract

Tritium surface distribution on the JET Mark II Septum Replacement Plate (Mk II SRP) divertor tiles was measured by imaging plate technique. It was observed that areal tritium concentration was higher at the entrance of inner/outer pumping slots (so called 'shadowed area'). The tritium distribution profiles were similar to those obtained in the Mk IIA divertor which was exposed to a series of D–T plasma operation (DTE1). Tritium concentration of the plasma facing surface was lower compared to that of the shadowed area. Particularly, it was very low at the outer divertor surface. The inner divertor surface also showed low level of tritium retention, though it was covered by the thick carbon deposition on that. This could be caused by tritium release due to the temperature rise when the inner strike point was on the tiles. On the plasma shadowed area like tile gaps, high tritium retention owing to the codeposition was observed.

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Keywords: Tritium; JET; Divertor; Carbon-based materials; Hydrogen retention

1. Introduction

Carbon fibre composite (CFC) and tungsten (W) are primary candidates for high heat flux components in next step fusion devices. W has advantages of a low erosion yield and a low tritium retention. However, some serious issues are remaining such as a strong radiation loss in core plasma, easy melting and cracking under off-normal events, and blistering resulting in subsequent dust formation [1–4]. CFC is presently the best plasma facing material (PFM) withstanding enormous high heat load and avoiding radiation loss in core plasma [5,6]. The major obstacle to the use of CFC as PFM is high erosion yield due to chemical sputtering, which eventually leads to the formation of carbon–tritium codeposited layers as tritium store in the vacuum vessel [7]. In the current ITER divertor design,

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because of those circumstances, W will be used as PFM, except the target area where CFC will be used to tolerate the highest heat load. Therefore, the erosion of CFC and the formation of redeposited layers are critical issues to estimate tritium retention in ITER. In this respect, various modeling and simulations of tritium retention in ITER have been done. However, since the codeposition phenomenon in tokamak is still not perfectly clear, calculated tritium accumulation rate has changed by several orders depending on calculation condition [8–10].

From this point of view, the behaviour of the carbon materials used as divertor armor tile and its contribution to tritium retention has to be investigated carefully for more reliable extrapolation of in-vessel tritium inventory build-up. As one of tritium analysis methods, we have developed and applied tritium imaging plate technique (TIPT) to measure the tritium distribution on the plasma facing wall [11–13]. In this study, we apply TIPT to determine the tritium distribution on the JET Mark II Septum Replacement Plate (Mk II SRP) tiles. From the result, characteristics of tritium retention in Mk II SRP divertor and hint for mitigation of tritium inventory are discussed.

2. Experimental

The imaging plate (IP) is a 2-dimensional radiation detector utilizing a photostimulable phosphor ($BaFBu:Eu^{2+}$), which gives a high-resolution image of tritium distribution on the sample surface. Detailed descriptions about IP have been presented in elsewhere [14–16].

Sample tiles measured here were a poloidal set of Mk II SRP divertor tiles used in 2001–2004 operational period of JET. During this period, no full D–T mixture discharges were made. However, a trace tritium (in deuterium) campaign using a total of 0.5 g tritium was performed [17]. Tritium produced by DD reaction naturally added. The sample tiles were sent to VTT processes in Finland, and their plasma facing surfaces have been analyzed by means of secondary ion mass spectrometry (SIMS) [18,19].

IP analysis was carried out in the radiation-controlled area of VTT processes. IP was placed on the tile surface in a glove box, and exposed to β-rays emitted from tritium retained on the tile surface. IP was fully covered by a thin film made of PPS (poly-phenyl-sulfide) with 1.2 μm thickness in order to avoid the contamination of IP with tritium. This reduces the detection sensitivity about one order of magnitude. Since some of the tiles have curvature on their surfaces, IP was pressed by some weights to ensure the contact to the surface. During the exposure, a number of F-centers are formed due to the generation of the radiation-induced excited electrons in the phosphor crystal. The number and position of F-centers are stored on IP, which makes tritium image. After about 2 h of the exposure, IP was transported to the Laboratory of Radiochemistry, University of Helsinki, and processed by an imaging plate reader in order to obtain the digitized image. Not only plasma facing surfaces but also side surfaces of the tiles were measured.

3. Results

3.1. Plasma facing surface

Fig. 1 shows areal distributions and poloidal line profiles of photo-stimulated luminescence (PSL) intensities (referred as tritium images and tritium line profiles hereafter) obtained for the plasma facing surfaces of the Mk II SRP tiles. The PSL intensity given by TIPT is well proportional to the areal tritium concentration [14–16]. Relative tritium concentrations on the inner divertor tiles were higher than those on the outer divertor tiles by a factor of 2–3. From the visual inspection, thicker carbon deposition was found on the inner divertor tiles, while erosion dominated the outer divertor tiles. Therefore the tritium distribution is correlated to the carbon deposition profiles in the Mk II SRP divertor.

The highest tritium concentration was found in the shadowed area of the base tiles (Tile-4 and -6), of which concentration was about one order of magnitude higher than those on the other plasma facing area. Fig. 2 shows the tritium images and photographs of the plasma facing surface of the inner divertor base tile, together with the poloidal and toroidal sides for Tile-4. The holes on the tile were cored for the SIMS samples. The tritium concentration was higher on the poloidally inner side (closer to the inner louver) corresponding white colored area with some interference pattern in the photograph. Although most of the surface was covered by the redeposited carbon layers of several hundreds micron [19], the thickness of the layers on the white colored area was much thinner than that on the outer side appeared as black.

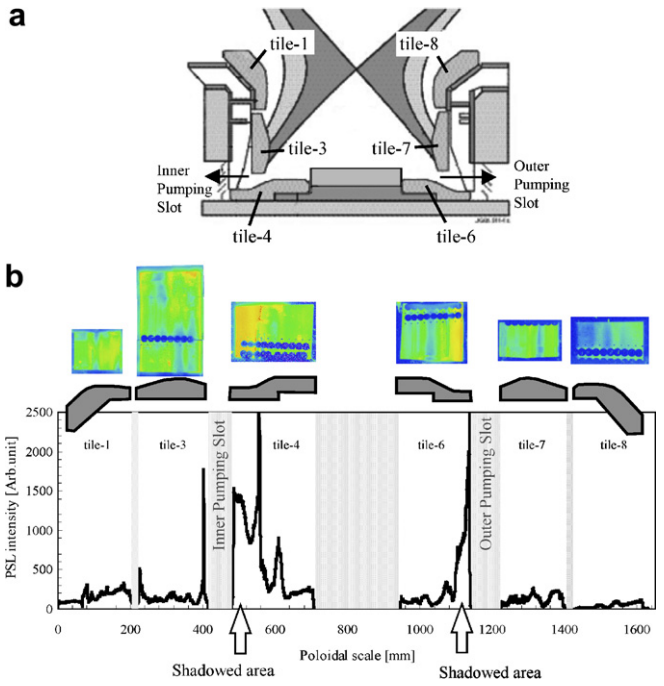

Fig. 1. (a) Schematic cross sectional view of Mk II SRP divertor. (b) IP images of measured tiles and the poloidal line profile obtained from the image analysis. 'PSL intensity' is a special unit used in IP, which is well proportional to the areal tritium concentration. The highest concentration is found in the shadowed area of the divertor.

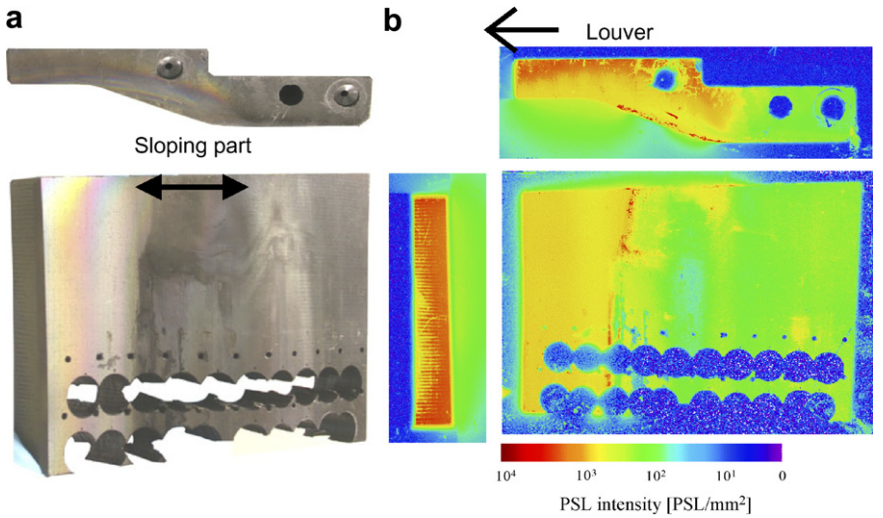

Fig. 2. (a) Photographs and (b) IP images of the plasma facing surface and sides of inner base tile: Tile-4. Thicker deposited layer (several hundreds micron) was found on the 'sloping part' [19]. Tritium concentration is higher in the shadowed area where the interference pattern is seen in the photograph.

3.2. Poloidal and toroidal sides and rear side

Fig. 3 shows IP images of tile side surfaces together with pictures of the plasma facing surface of the inner divertor tiles. Most of the tile sides were covered by the redeposited layers. The thickness of the carbon deposited layers on the tiles depends on the direction of the side. The tritium concentration

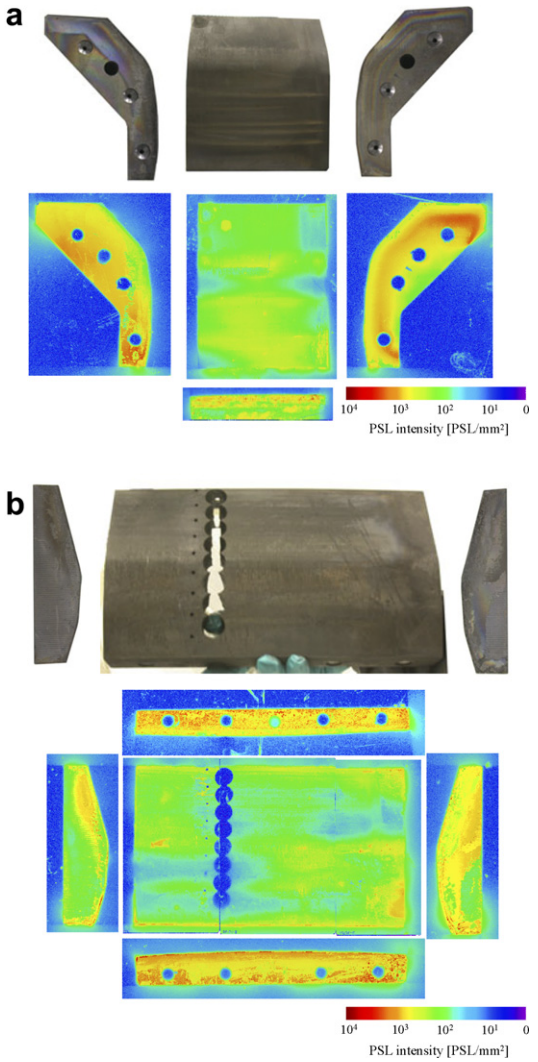

Fig. 3. IP images and photographs of tile sides together with plasma facing surface of (a) Tile-1 and (b) Tile-3.

in these redeposited layers was almost at the same level with that of the shadowed area of the plasma facing surface described above section.

The redeposited layers with high tritium concentration were also found on the rear side of the inner vertical target tile, Tile-3, as shown in Fig. 4(a). The redeposited layers were partly covering the rear side of the inner divertor target tile from the bottom edge to ~30 mm up. Taking the geometry of the divertor into account, carbon deposition was caused by repeating steps of reflections of carbon/hydrocarbon impurities or secondary sputtering of deposition formed in the louver entrance. This observation is very important from the viewpoint of material migration. Above ~30 mm, no deposition was observed as evidenced by the appearance of the lamella structure typical for 2-D CFC tiles. This kind of tritium distribution was already found on the rear sides of the Mk IIA divertor tiles as well, which was attributed to the difference of the retention characteristics of the matrix and the substrate of CFC [20]. It should be noted that tritium concentration on the rear sides was a little higher than that on the plasma facing surface.

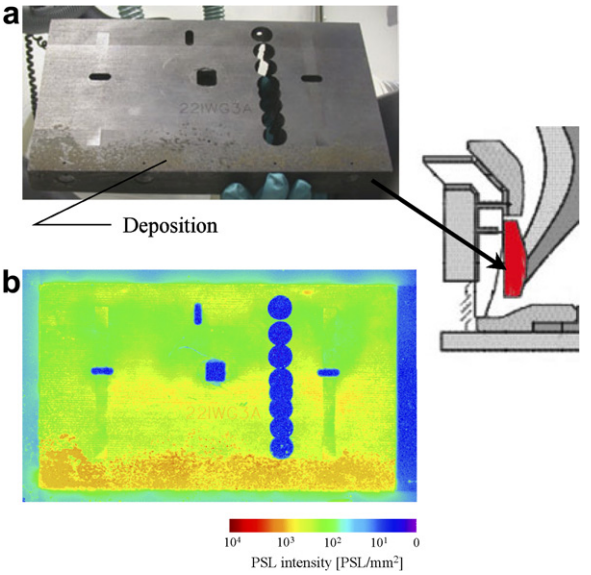

Fig. 4. (a) Photograph and (b) IP images of the backside of Tile-3.

4. Discussion

One should note that the tritium retention on the plasma facing surface of the inner divertor tiles was rather low in spite of the existence of the thicker redeposited layers on them. The most probable reason is temperature elevation of the tile surface during a discharge. According to the thermodynamics for the carbon and hydrogen system, the saturation concentration of hydrogen retention in carbon above 500 K decreases exponentially with temperature. In JET, fast 2-D camera was used to measure the power flux to the divertor tiles [21]. One of the results showed that the surface temperature around the strike points rose up to 700 K during a discharge. In addition, if type-I ELM occurred, the surface temperature escalated to above 1800 K [22]. Hence, such high heat load to the tile surface could reduce the tritium concentration of the redeposited layers on the plasma facing surface.

Since the impurity carbon flux would be less than a few % of the total hydrogen impinging flux to the plasma facing surface, most of the impinging hydrogen must be reemitted. In addition the temperature escalation at the plasma facing surface during the shot could easily result in the hydrogen saturation. Hence isotope ratios of H, D and T in the near surface layers would be the same as those for the impinging flux avoiding tritium accumulation. At the plasma shadowed area, on the other hand, no isotope replacement could be possible until the saturation is attained. Since the temperature rise at the shadowed area must be very small, its saturation concentration is very high and tritium would be piled up in the redeposited layers on the plasma shadowed area.

Actually, the redeposited layers formed in the inner and the outer shadowed areas and in the tile gaps showed higher tritium concentration than that for the plasma facing surface. Since those area were not exposed to the plasma directly, the temperature increase would be much less comparing to that for the plasma facing surfaces, namely, it would remain an operating temperature: 473 K (the temperature of the divertor base structure might be lower than this temperature because of the water-cooling). Around this temperature region, the hydrogen saturation level in carbon is still high, up to H/C $\sim$ 0.4. The tritium profile on the tile sides clearly shows less tritium retention near surface edge of the plasma facing side, which confirms the high temperature escalation only at the plasma facing side.

In the Mk II SRP divertor, however, the thickness of the redeposited layer was less than those observed on Mk IIA divertor tiles, in which the thick redeposited layers were flaky with very high tritium concentration. During the operational phase using Mk IIA divertor configuration, the inner strike point was mainly on the horizontal target tiles (corresponding to Tile-4 and -6). However, following phases of Mk II GB and Mk II SRP divertor configurations, the vertical divertor tiles (Tile-3 and -7) were main target tiles. As already noted in JT-60U, carbon deposition is dominated to the inner side from the eroded area [23], the reduction of the deposition in the Mk II GB and Mk II SRP divertor configurations is quite reasonable. The significant tritium retention at the inner side surface of the horizontal tile (Tile-4) well corresponds to the carbon transport in the inner side. Hence, such the inner divertor configuration with the pumping slot located below the inner divertor strike point seems good for the reduction of the carbon codeposition and dust formation in the louver entrance area [24,25].

5. Conclusion

Tritium distributions on the plasma facing surface and shadowed area of the JET Mk II SRP divertor were measured by tritium imaging plate technique.

On the plasma facing surface, tritium concentration on the inner divertor was higher than that on the outer divertor. However, the concentration on the plasma facing surface was still at a low level, which was about one order of magnitude lower than that on the shadow area and even lower than that for the rear side. Such difference was probably caused by difference of surface temperatures. The surface temperatures around the divertor strike points were easily raised to more than 500 K due to plasma heat load. On the other hand, the temperature of the shadowed area might remain the operating temperature $<$500 K even during a discharge.

The amount of carbon deposition in the shadowed area of Mk II SRP divertor decreased as compared to that of Mk IIA divertor. Since codeposition in the shadowed area will be a major concern for in-vessel tritium inventory, such reduction directly means mitigation of tritium retention. CFC is presently the favorable candidate as PFM against ELMs and/or uncontrolled disruptions. Thus, CFC is preferable as PFM until stable plasma operation becomes possible. In this respect, less tritium incorporation in codeposition in plasma facing surface and reduction of amount of codeposition in the shadowed area are good news for ITER tritium inventory under using CFC divertor target.

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