Tritium distributions on W-coated divertor tiles used in the third JET ITER-like wall campaign


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1. Introduction

The Joint European Torus (JET) performed three ITER-like Wall (ILW) campaigns with beryllium (Be) main chamber walls and divertor region made of bulk W and W-coated carbon-fiber composite (CFC) tiles in 2011–2012 (ILW-1), 2013–2014 (ILW-2) and 2015–2016 (ILW-3) [1,2]. The characteristics of ILW-3 in comparison with ILW-1 and -2 are its longer period and more high power deuterium (D) discharges [3]; the input energy in ILW-1, -2 and -3 is 150, 201 and 245 GJ, respectively [4]. The inner strike point was predominantly on the surface of inner vertical tile (Tile 3) for ILW-1 and the corner of inner floor tile (Tile 4) for ILW-2, while the outer strike point was predominantly on bulk W Tile 5 for ILW-1 and the corner of outer floor tile (Tile 6) for ILW-2. The distribution of the strike point in ILW-3 was similar to that in ILW-2 [2].

Tritium (T) formed by DD fusion reactions (D + D → 1.01 MeV T + 3.03 MeV p where p is proton) is present in the JET vacuum vessel. A part of T is expected to be thermalized in the plasma, while remaining part could be implanted into walls at high energy. Hatano et al. [5,6] have examined the T distribution on the divertor tiles retrieved after ILW-1 by measuring β-rays from T using an imaging plate (IP) technique. Strong enrichment of T in beryllium (Be) deposition layers was observed after the second campaign. In contrast, T distributions after the third campaign was more uniform though Be deposition layers were visually recognized. The one of the possible explanations is enhanced desorption of T from Be deposition layers due to higher tile temperatures caused by higher energy input in the third campaign.

2. Experimental procedures

The cross-sectional view of JET divertor region and tile locations are...
The intensity of Ar(Kα) x-rays (2.958 keV), atmosphere for disk specimens taken by coring from the ILW-2 and were exposed to the plasma in JET in both ILW-1 and -2, though Tiles 1 redeposition of W [9]. Note that the majority of ILW-2 tiles examined were covered with IP to leave the other parts of surfaces for different types of analyses. The IP measurements for ILW-2 tiles described in [9] were conducted in August–September 2015 at the VTT. The surface of examined Tile 4 was covered by Mo layer instead of W layer to study redeposition of W [9]. Note that the majority of ILW-2 tiles examined were exposed to the plasma in JET in both ILW-1 and -2, though Tiles 1 and 4 were used solely in ILW-2 [9].

Energy spectra of β-ray induced x-rays were measured under Ar gas atmosphere for disk specimens taken by coring from the ILW-2 and ILW-3 tiles. The intensity of Ar(Kα) x-rays (2.958 keV), I_{Ar(Kα)}, indicates the concentration of T at the surface and the subsurface region within the escape depth of β-rays, and the intensity ratio of W(Lα) x-rays (8.398 keV) to W(Mα) x-rays (1.775 keV), I_{W(Lα)}/I_{W(Mα)}, increases with penetration depth of T into W layers due to larger escape depth of W (Lα) x-rays [9]. A silicon drift detector (SDD) with 8 µm-thick Be window (X-123SDD, Amptek Co., USA) was used. The Be window has negligible transmittance for x-rays below 0.6 keV [10]. Hence, characteristic x-rays of low atomic number elements such as Be, C and O were not able to be detected. More detailed measurement procedures are described elsewhere [9]. The spectra for the ILW-2 Tiles were obtained in January–April 2017 and those for ILW-3 tiles were acquired in January–February 2018 at the VTT.

3. Results and discussion

In Fig. 1, the IP images for the ILW-3 tiles are compared with those for the ILW-2 tiles. In this figure, “ILW-1 & 2” means the tiles were exposed to the plasma during ILW-1 and ILW-2 and retrieved after ILW-2, and “ILW-2 only” indicates the tiles were installed in the vacuum chamber after ILW-1 and then retrieved after ILW-2. The colors indicate the PSL intensity in ascending order from blue (lowest), green, yellow and red (highest). Blue contrasts in a circle shape correspond to the places from where disk specimens were taken out. In the case of the ILW-2 tiles, the band-like regions shown by yellow-red colors were observed at the apron of Tile 1, Tile 4 and Tile 6, as indicated by black arrows. The colors of these regions suggest strong enrichment of T. Similar band-like regions extended in the poloidal direction was also found for the ILW-1 tiles [5], and those regions corresponded to the areas covered with deposition layers of Be and other impurities such as C and O. Hence, the enrichment of T at these positions was ascribed to codeposition of thermalized T with Be and other impurities. However, such strong T enrichment was not observed for the ILW-3 tiles. In other words, T distribution was more uniform in the case of the ILW-3 tiles. Photos of the ILW-3 Tiles 4 and 6 are also shown in Fig. 1. The formation of deposition layers could be visually recognized as change in color from gray-silver to dark gray.

Line profiles of PSL intensity shown in Fig. 2 were generated by taking slices from 2-dimensional images along poloidal trajectory; a narrow band (2 mm width) extending in the poloidal direction was set on a plasma-facing surface of each tile, and the PSL intensity distributions in narrow bands along the poloidal direction were plotted against S-coordinate. The profile for the ILW-1 tiles [6] is also shown. The peaks of PSL intensity were observed at S = 162–173 mm (Tile 1), 712–790 mm (Tile 4) and 1363–1500 mm (Tile 6) for the ILW-1 and -2 tiles. In contrast, the ILW-3 tiles showed no clear peak and more uniform T distribution, as mentioned above. In the case of the ILW-1 and -2 tiles, the shadowed region of Tile 4 showed higher T concentration than the apron of Tile 1 though the deposition at the former was thinner than that at the latter [8]. The high T concentration at the shadowed region of Tile 4 was ascribed to high carbon to Be ratio in the deposition layer [8,11,12].

Fig. 3(a) and (b) show typical energy spectra of β-ray induced x-rays from areas with and without deposition layers, respectively. The specimens corresponding to these spectra were taken from the poloidal...
The characteristics of spectral distributions of x-rays in Fig. 3(a) and (b) indicate the presence of strong bremsstrahlung x-rays and Ar(Kα) x-rays, as well as negligible W(Lα) x-rays. The intensity of Ar(Kα) x-rays in Fig. 3(b) is very weak compared with that of W(Mα) x-rays. The comparison of Fig. 3(a) and (b) indicates the dominant factor of the intensity of Ar(Kα) x-rays is the presence of Be deposition layer and T concentrations in the deposition layer.

The absence of Be(Kα) x-rays was due to absorption by the detector window, as described earlier. A large peak of W(Mα) x-rays shown in Fig. 3(b) together with relatively intense W(Lα) x-rays and bremsstrahlung x-rays at 4–10 keV indicate deep penetration of T into W layers (up to several micrometers) [9]. The intensity of Ar(Kα) x-rays in Fig. 3(b) is very weak compared with that of W(Mα) x-rays. The comparison of Fig. 3(a) and (b) indicates the dominant factor of the intensity of Ar(Kα) x-rays is the presence or absence of Be deposition layer and T concentrations in the deposition layer.

The intensity of Ar(Kα) x-rays is plotted against S-coordinate in Fig. 4. Relatively high intensity was observed at Tile 0, Tile 1, the shadowed region of Tile 4 (S = 740–780) and Tile 6. These regions are covered by Be deposition layers [8]. The difference between ILW-2 and ILW-3 was most significant at the shadowed region of Tile 4 and Tile 6, and the intensity for the ILW-3 tiles in these regions was smaller than that for the ILW-2 tiles by a factor of 2–6. These observations are consistent with the results of IP measurements (Fig. 2), and they also suggest lower T concentrations in the deposition layers formed in ILW-3 than the case of ILW-2.

Because of the longer period of operation and higher input power, it is hardly expected that the amount of T produced in ILW-3 was smaller than that in ILW-2. For the same reasons, it is improbable that the amount of Be deposited on the divertor tiles during ILW-3 was far smaller than that during ILW-2. Heinola et al. [8] compared D retention in the ILW-1 and -2 tiles and found an increase in D desorption during ILW-2 plasma operation due to higher energy depositions on the tiles. Therefore, it is appropriate to consider that the lower T concentration in the deposition layers observed after ILW-3 was due to enhanced T desorption caused by higher input power than ILW-2.

Likon et al. [13] have examined thermal desorption of D from the positions indicated by red arrows in Fig. 1. The characteristics of the spectra given in Fig. 3(a) (the upper flat part of Tile 6, S = 1398) are strong bremsstrahlung x-rays (the broad peak at 1–4 keV), strong Ar (Kα) and W(Mα) x-rays, and negligibly weak W(Lα) x-rays. The Ar(Kα) x-rays were induced by β-rays from T present at the surface and sub-surface layers within the escape depth of β-rays, as previously mentioned. These characteristics suggest codeposition of T with Be and other impurities. The strong bremsstrahlung and Ar(Kα) x-rays relative to W(Mα) x-rays are explained by the generation of bremsstrahlung x-rays in Be deposition layers and larger escape depth of β-rays in Be than in W. The absence of Be(Kα) x-rays was due to absorption by the detector window, as described earlier. A large peak of W(Mα) x-rays shown in Fig. 3(b) (the horizontal part of Tile 8, S = 2063) together with relatively intense W(Lα) x-rays and bremsstrahlung x-rays at
specimens taken from Tiles 0, 1, 3, 4 and 6 retrieved after ILW-2 and ILW-3 and reported that the desorption of HD and D₂ from ILW-3 specimens occurred at higher temperatures than that from ILW-2 specimens in most cases. Their observations indicate that the low binding energy traps were emptied during the plasma operations in ILW-3. Depth profiling of D and other elements performed in [13] using nuclear reaction analysis and secondary ion mass spectrometry showed that the amounts of impurities and the thickness of the deposition layers were comparable between ILW-2 and ILW-3 so these do not explain the differences in the release temperatures. Hence, they concluded that higher release temperatures for the ILW-3 specimens than for the corresponding ILW-2 specimens could be due to higher absorbed energies [13]. The observations for D in [13] are consistent with those for T in the present study.

4. Conclusions

The distributions of T on W-coated CFC divertor tiles used in ILW-3 were measured using an IP technique and BIXS, and compared with the distributions after ILW-2. Both techniques consistently showed that the concentration of T in Be deposition layers formed on the divertor tiles during ILW-3 was significantly lower than that after ILW-2. The lower T concentration after ILW-3 was ascribed to enhanced T desorption caused by higher energy depositions on the tiles.

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Supplementary materials

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References