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Tritium retention characteristics in dust particles in JET with ITER-like wall

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Abstract

A tritium imaging plate technique (TIPT) in combination with an electron-probe microscopic analysis (EPMA) were applied to examine tritium (T) retention characteristics in individual dust particles collected in the Joint European Torus with the ITER-like Wall (JET-ILW) after the first campaign in 2011-2012.

A lot of carbon (C)-dominated dust particles were found, which would be pre-existing carbon deposits in the JET-C or produced at the remote area in JET-ILW. Most of T was retained at the surface of and/or in the C-dominated dust particles. The characteristics of T retention in the C-dominated dust particles largely scattered. The retention in tungsten, beryllium and other metal-dominated dust particles is relatively lower by a factor of 10 ~ 100 in comparison with that in the C-dominated particles.

KEYWORDS: JET-ILW, Dust, Tritium, Imaging plate, Electron prove microscopic

analysis

Highlights

- Tritium retention characteristics in individual dust particles collected in the Joint European Torus with the ITER-like Wall after the first campaign in 2011-2012 were successfully examined.
- The retention in tungsten, beryllium and other metal-dominated dust particles is lower by a factor of 10 ~ 100 than that in the C-dominated particles.
- Most of T was retained at the surface of and/or in the C-dominated dust particles.

1. Introduction

Retention of tritium (T) in dust generated in fusion devices with carbon (C) walls will be considered to be one of important issues for safety since T will be hardly removed from C-dust by engineering approach and will be built up gradually at remote areas or gaps during operation, resulting in out of engineering control [1]. To mitigate this issue in ITER, full metals walls are going to be installed as plasma facing walls and inner walls of the vacuum vessel. After the successful experiments of the Joint European Torus with the ITER-like Wall (JET-ILW) [2], fewer generation of metallic dust in mass by a factor of approximately 100 have been reported and varieties of morphologies and compositions of metallic dust particles have been characterized by many method [3-5]. Under the framework of Broader Approach (BA) activity in Japan [6], amounts of T on/in dust generated in JET-ILW have been determined by quantification of T by a liquid scintillation counting method and a thermal desorption method [7]. The results showed that the amount of T per unit mass of the JET-ILW dust was not so small as expected and rather comparable with that per unit mass of dust generated in JET with carbon wall (JET-C). Since various species of metallic and metal oxides dust would be generated in JET-ILW and then ITER, it is important to understand and determine tritium (T) retention and its behavior in individual dust particles with repect to their microstrutures and compositions. In the present study, we have applied a tritium imaging plate technique (TIPT) in combination with an electron-probe microscopic analysis (EPMA) to examine T retention characteristics in individual dust particles collected at the inner diverter region in JET-ILW after the first campaign in 2011-2012 [2].

2. Experimental

Dust particles were collected by a vacuum cleaning method at the surfaces of the tiles at the inner divertor region in JET with ILW after the first campaign 2011-2012 [8]. The total amount was on the level of 0.77 g and a part of them (0.14 g) were sent as a sample to International Fusion Engineering Research Center (IFERC) at Rokkasho in Japan [6, 7]. A tiny amount of dust was taken from that sample and gently mounted on the surface of a disk made of indium (In). The intensity of T retained at a surface of and/or in the dust particles was evaluated by TIPT [9, 10]: emission of β-rays from T to the imaging plate (IP) was measured over a whole surface of the In disk for 1 h at room temperature. A spatial resolution of TIPT was 25 μm. Afterwards, Electron Probe Microscopic Analysis (EPMA) was conducted to determine morphology (composition and structure) of the dust particles in the same surface area where TIPT was conducted.

A whole image of distribution of dust particles in the In disk was observed with a resolution of 20 μm and details of the individual single dust particle was separately observed with a resolution of 1 μm. The obtained maps (images) of the T distribution and elemental compositions were super-imposed to reveal characteristic features of T retention in the individual dust particle with the aid of image analysis software FIZI [11].

3. Results and discussion

3-1. Compositions of dust particles

Figure 1(a) is a EPMA image showing a secondary electron image (SEI) with EPMA data for each element at the surface of the In disk. In the image, small dots of blue, green, yellow and red indicate distribution of elements, carbon (C), oxygen (O), tungsten (W) and beryllium (Be), respectively, on the background of black & white grey colors of SEI. Although one dot in the image allows us to recognize as a single individual dust particle at least larger than 20 μm x 20 μm in size, main components of elements in the individual particle and their locations in the disk were clearly identified. All the detailed features or characteristics of the individual dust particles were well summarized in [3-5, 8] and here briefly introduced to categorize which element dominated in each dust particle. Figure 1 (b) shows a dust particle mainly composed of Be with O, which have around 50 μm x 50 μm in size and rather flat surface. This Be-dominated dust particle is likely to be a flake of deposits plausibly oxidized after removal from the JET vessel. Figure 1 (c) shows a W-dominated dust particle, which would be a flake of deposits or agglomerates originated from the W coating. One of them appeared with Be and O indicating a flake of co-deposits as shown in Fig. 1 (d). Two distinct dust particles were identified in Fig. 1 (e) as a Be-dominated dust particle and a C-dominated one, which were close each other by coincidence during the sample preparation. There were many oxides with various elements, iron (Fe), nickel (Ni) and silicon (Si) which might be originated from structure components like steels and Inconels, and diagnostic tools.

Figure 2 (a) clearly indicates locations of C-, Be-, W-dominated dust particles and metals oxide dust particles as small spots with superscriptions (C, Be, W and O) on the whole surface of In disk. Numbers of each dust particles were counted by hand and summarized in Table 1. Very few Be- and W-dominated dust particles were found in comparison with C-dominated and metals oxide dust particles, indicating loose metallic dust particles were hardly generated from the ILW. Note that, since the ILW was full metals plasma-facing walls, too many observation of C-dominated dust particles could be mostly attributed to pre-existing deposits produced in the JET with carbon wall (JET-C) and partly to dust generation at the remote area, e.g. CFC used as louvers, in the JET-ILW.

3.2 Tritium retention of the dust particles

Figure 2 (b) is a IP image showing distribution of intensity of T on the whole surface area of the In disk. Intensity of T becomes larger as the colour changes from green to yellow and red on the background colour of blue. A variety of different colours and sizes of green and red spots indicate different amounts of T retained on surfaces or in bulk of individual dust particles and their locations in the In disk. In order to examine quantitatively what kind of dust particle retained T or not, the images of the elemental compositions (Fig. 2 (a)) and T distribution (Fig. 2 (b)) are super-imposed together as shown in Fig. 3. Two facts were immediately drawn from Fig. 3, (i) all the dust particles did not retain T and (ii) T was found at locations where the dust particles were not recognized in the EPMA image with the resolution of 20 μm. The former was summarized in Table 1 showing that 61% and 88% of the C-dominated and metals oxide dust particles did not retain T. The causes would be attributed to their generation plausibly by inert gas discharges and hydrogen plasma in JET-C or at the remote area in JET-ILW, or possible contamination of artificial or ubiquitous dust from surroundings during the sample collection and the transport. The latter will be discussed later with respect to relationships of T retention characteristics and sizes of dust particles.

Figure 3 and Table 1 clearly shows T retention characteristics of the individual single dust particles. At first, it is important to note again that the number of Be-dominated, W-dominated and metals oxide dust particles retaining T were very small. Consequently, more than 85% of the total dust particles retaining T was the C-dominated ones.

Line profiling of intensities of T and elements for the several dust particles was conducted along white dashed lines depicted in Fig. 3 and summarized in Fig. 4 (a)-(c) for Be-dominated dust particles, (d)-(f) for W-dominated ones and (g)-(i) for C-dominated ones. In the each figure, distribution of T is in good agreement with that of element in the dust particle. Assuming a circular cross-section of the dust particle, a full width of a peak intensity of the element would give a size of the dust particle represented as a diameter of the particle, *d*. Broader width of a peak intensity of T than that of element is caused by T β-ray emission from the surface of the dust particle to the In bed or air in gaps surrounding the dust particle. Such effects would be much smaller for heavier element like W than C and Be due to attenuation of T β-ray in the bulk of dust particle if T was retained in bulk of the dust particle. Except for one particle shown in Fig. 4 (b), T retention on/in the Be-dominated dust particle was low in comparison with the C-dominated dust particle. One unexpected example of Fig. 4 (c) indicates that T was highly retained in the C-dominated dust particles rather than the neighboring Be ones, as seen earlier in Fig. 1 (e). In Fig. 4 (d)-(f) for the W-dominated dust particles, a maximum peak intensity of T was lower by a factor of 100 compared with that for the C-dominated dust particles. Although T retention characteristics of the C-dominated dust particles would be a disturbance to examine T retention behaviour of the metallic dust particles in JET-ILW, it is worth noting that intensities of T in Fig. 4 (g)-(i) are largely scattered.

Assuming that a T retention on/in the dust particle is proportional to the peak intensity of T, T retention characteristics of the dust particles is summarized in Fig. 5 for each element with respect to the size of the particle, i.e. the diameter of the particle, d. 4 of Be-dominated dust particles, 8 of W-dominated ones and 30 of C-dominated ones randomly selected were used. In the figure, T retention in the C-dominated dust particles scattered in three orders of magnitude, which might be categorized into three, high, moderate and low in the order. T retention of the Be-dominated and W-dominated dust particles were lower by a factor of 10-100 than that of the C-dominated ones in the medium T retention category. Dashed lines are eye-lines indicating a square of the diameter, d^2. T retention would increase with the surface area of the dust particles to some degree though deviation and scattering of T retention suggested T trapping near surface region and in bulk of the dust particle as well. The cause of the trapping would be inner walls of either porous, shell or layer structures, or grain boundaries in the dust particles [5]. A trace of T retention not related to the dust particles in Fig. 3 would be attributed to T retention on/in dust particles smaller than several μm or in nm order size since such the dust particles could not be recognized due to a lack of resolution in the present study. Impact of such smaller dust particles and their microstructure on T retention could be clarified by tracing of T distribution with TIPT in combinations with EPMA and transparent electron microscopy (TEM) with the aid of focused ion beam (FIB).

4. Conclusions

The characteristics of T retention for the individual particles in the dust taken at the inner diverter region after the JET-ILW first campaign in 2011-2012 were successfully examined by combination of TIPT and EPMA.

A lot of C-dominated dust particles were found, which would be pre-existing carbon deposits for the JET-C or generated at the remote area in JET-ILW. Most of T was retained at the surface of and/or in the C-dominated dust particles in which T retention characteristic largely scattered. The retention in W, Be and other metal-dominated dust particles is lower by a factor of 10 ~ 100 in comparison with that found for the C-dominated particles.

Acknowledgement

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Table 1 Compositions and numbers of dust particles with/without tritium

Main elements included in dust	Number of dust particle	Number of dust particle with tritium	Number density of dust particles with tritium (%)
C	322	124	85
Metals (Fe, Ni) and Si oxides	93	11	< 7
Be	5	4	< 3
W	11	8	< 6

Figure captions

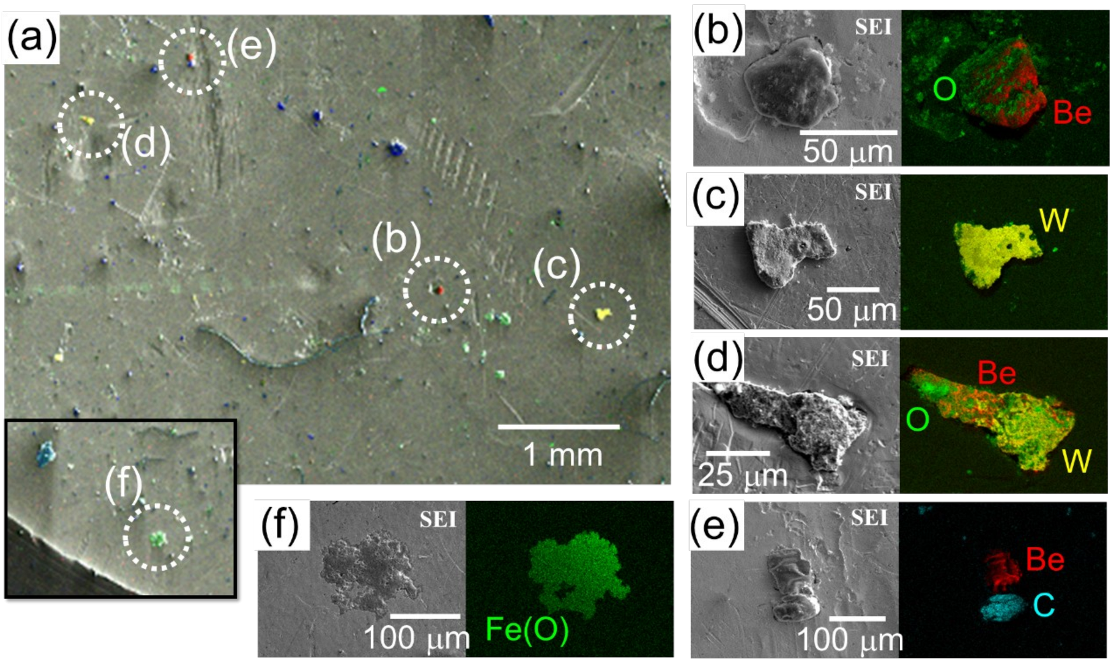
Fig. 1. Secondary electron image of (a) a whole surface area of In disk with EPMA image of C, Be, O and W, and magnified EPMA image of (b) a Be-dominated dust particle, (c) a W-dominated particle, (b) a W-dominated particle codeposited with Be, (e) a Be-dominated dust particle neighboring a C-dominated particle and (f) an Fe oxide dust particle.

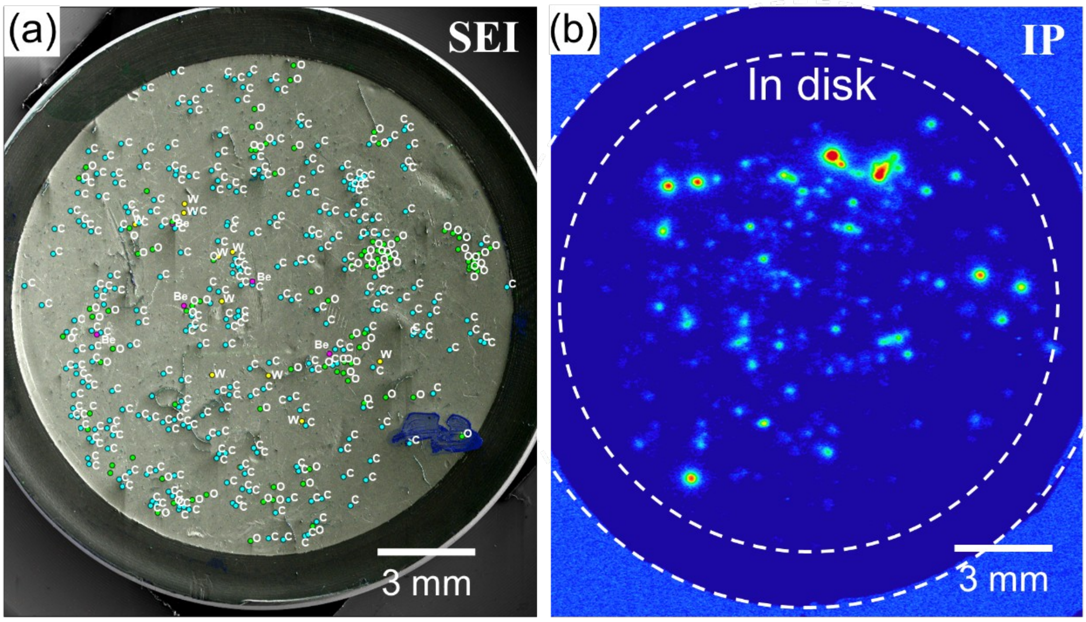
Fig. 2. (a) EPMA image with identification of composition in the dust particles. Small circles with superscriptions indicate locations of the dust particle and compositions, C, O, Be and W. (b) IP image showing T distribution in the In disk.

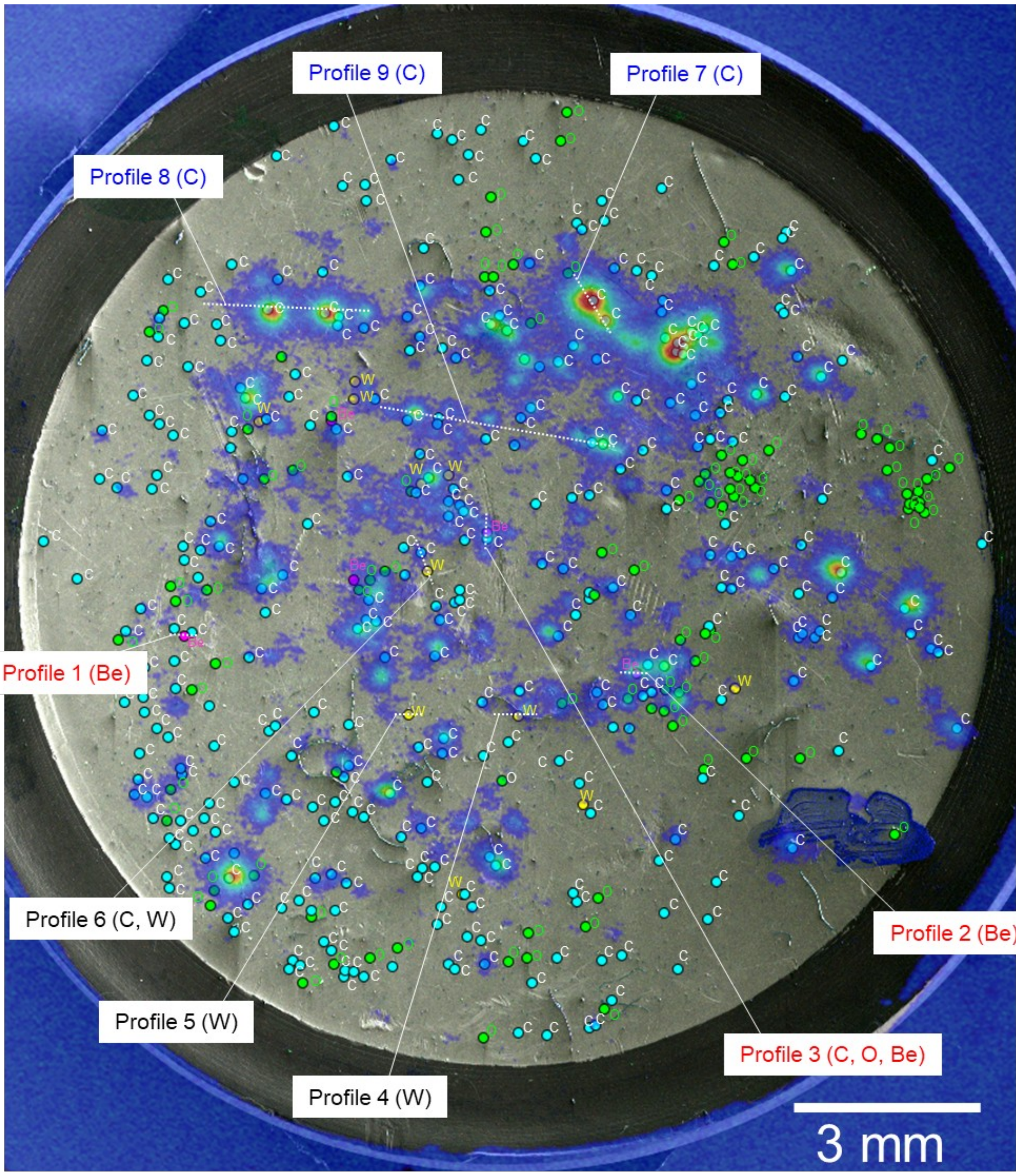
Fig. 3. Super-imposing image of Fig. 2 (a) EPMA image and (b) IP image. Line profiling show in Figs. 4 was conducted along white dashed lines.

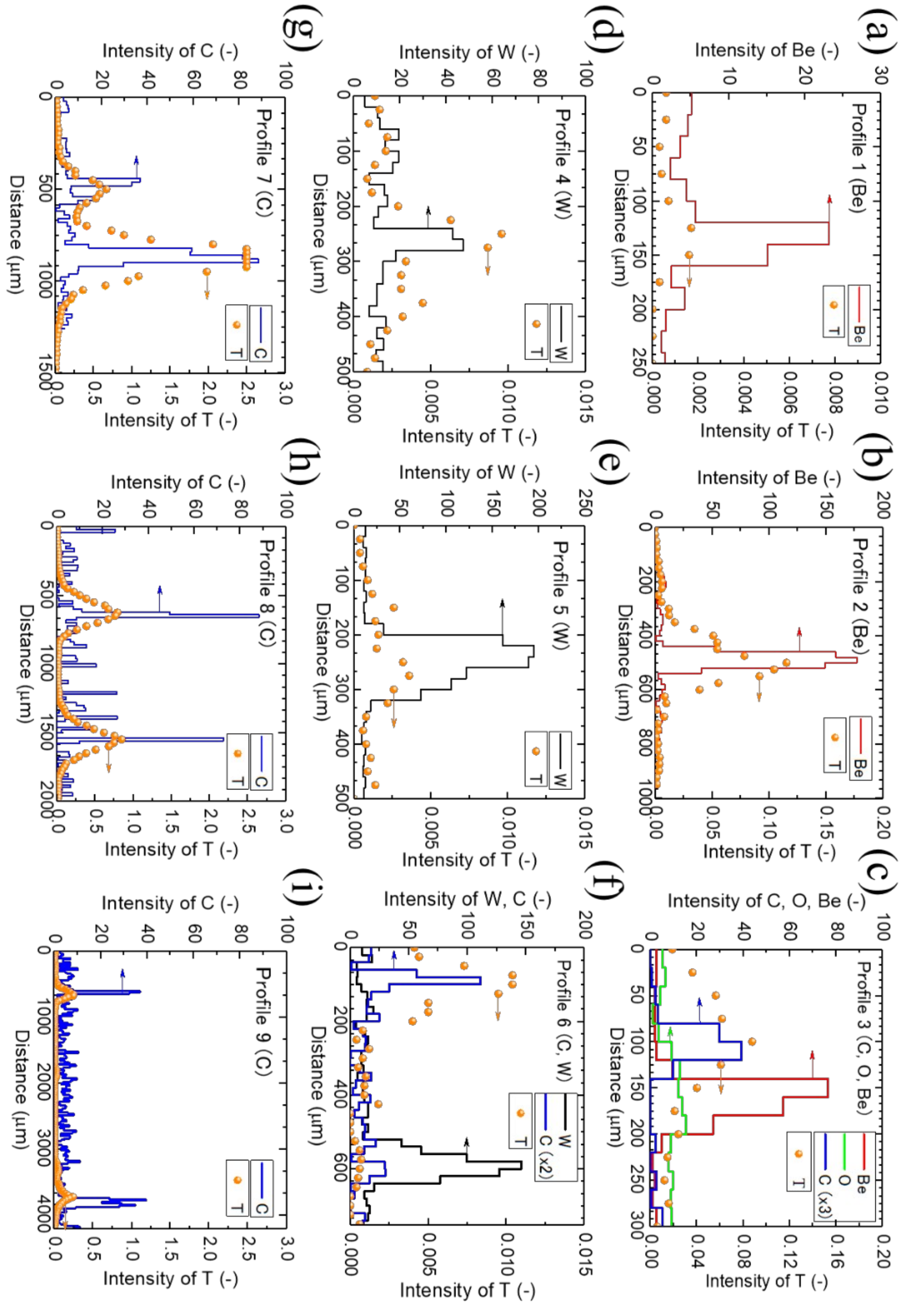
Fig. 4. Line profiles of intensity of T and elements, (a)-(c) for Be-dominated dust particles, (d)-(f) for W-dominated ones and (g)-(i) for C-dominated ones.

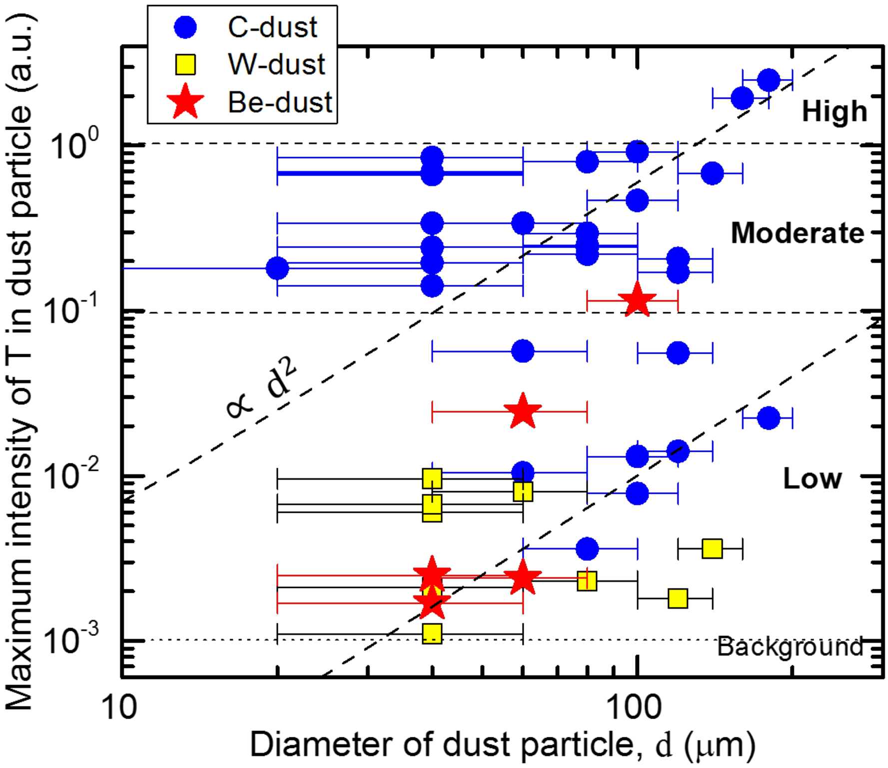
Fig. 5. T retention characteristics of the dust particles summarized for each element with respect to the size of the particle.


(a)
(e)
(d)
(b)
(c)
1 mm
(f)
(b)
SEI
50 μm
O
Be
(c)
SEI
50 μm
W
(d)
SEI
25 μm
Be
O
W
(f)
SEI
100 μm
Fe(O)
(e)
SEI
100 μm
Be
C


(a)
SEI
3 mm
(b)
IP
In disk
3 mm


Profile 9 (C)
Profile 7 (C)
Profile 8 (C)
Profile 1 (Be)
Profile 6 (C, W)
Profile 5 (W)
Profile 4 (W)
Profile 3 (C, O, Be)
Profile 2 (Be)
3 mm


(a)
Profile 1 (Be)
Intensity of Be (-)
Distance (μm)
Intensity of T (-)
Be
T
(b)
Profile 2 (Be)
Intensity of Be (-)
Distance (μm)
Intensity of T (-)
Be
T
(c)
Profile 3 (C, O, Be)
Intensity of C, O, Be (-)
Distance (μm)
Intensity of T (-)
Be
O
C (x3)
T
(d)
Profile 4 (W)
Intensity of W (-)
Distance (μm)
Intensity of T (-)
W
T
(e)
Profile 5 (W)
Intensity of W (-)
Distance (μm)
Intensity of T (-)
W
T
(f)
Profile 6 (C, W)
Intensity of W, C (-)
Distance (μm)
Intensity of T (-)
W
C (x2)
T
(g)
Profile 7 (C)
Intensity of C (-)
Distance (μm)
Intensity of T (-)
C
T
(h)
Profile 8 (C)
Intensity of C (-)
Distance (μm)
Intensity of T (-)
C
T
(i)
Profile 9 (C)
Intensity of C (-)
Distance (μm)
Intensity of T (-)
C
T


C-dust
W-dust
Be-dust
High
Moderate
Low
Background
∝ d²
10⁰
10⁻¹
10⁻²
10⁻³
10
100
Maximum intensity of T in dust particle (a.u.)
Diameter of dust particle, d (μm)