Deposition layer studies in LHD with directional material probe method

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“Directionality” is a key parameter to understand the mechanism of deposition layer formation in fusion devices. To study directionality of deposition layer, a simple new tool, a directional material probe, was proposed [1]. The probe consists of a flat disk and pin. If deposits come to the probe with directionality, a shadow of the pin is formed on the deposition layer on the disk. If no shadow appears on the deposition layer, it suggests that the deposition layer was formed isotropically. The directional material probe method has been applied to deposition layer studies in the Large Helical Device (LHD), and the results of the analysis of the probes are shown in this contribution.

In fusion devices, plasma facing components are eroded by the interactions with plasma. The eroded materials migrate and deposit on elsewhere, and they form deposition layer. Understandings of the properties of deposition layer and mechanism of the formation are very important for considering future fusion reactors operation. Because such deposition layer can be a source of dusts by peel-off of the layer, and can be a large sink of fueling particles, i.e. deuterium and tritium [2]. Especially, tritium retention in plasma facing components is serious problem in fusion reactors because tritium breeding rate will be limited to be a little bit larger than 1 [3]. From the point of view of safety, reduction of dusts is so important [4].

Directionalities have been observed in the deposition layer in fusion devices. For example, in JT-60U, carbon deposition layer was formed on the divertor tile in the inner divertor with directionality [5]. Deposition layer with directionality was also observed on the first wall in LHD [6]. These directionalities showed the incident angle of the deposits, and the transport mechanism was deduced from the angle. The mechanism is considered to have the position dependence in devices. Therefore, the directionality data should be taken at various positions in the vacuum vessel in fusion devices to understand the in-vessel material migration. In the examples described above, the directionalities were analyzed by scanning electron microscopy (SEM) in JT-60U and transmission electron microscopy (TEM) in LHD, respectively. The observations take time not only for the observation itself but also for the fabrication of samples, such as focused ion beam fabrication [5]. Therefore, they are not necessarily suitable for many sample analyses focusing on directionality. On the other hand, visible shadows on the deposition layer are frequently observed on plasma-facing components after plasma experiments. These shadows are cast by ledges onto the plasma-facing components. At times, the incident direction of the deposits can be determined by analyzing the shadows. However, it is difficult to remove plasma-facing components easily for detailed analysis with surface analysis devices.

The concept of the directional material probe (DMP) is depicted in Fig. 1. The DMP consists of a flat disk and shading pin. If deposits arrive at the DMP from a particular direction, a shadow of the pin is formed on the deposition layer on the disk. If deposits arrive isotropically, no shadow is formed. Thus, the directionality can be analyzed much more easily and quickly by visual observation and direct measurement than by SEM and/or TEM. Thus, many DMPs installed at various positions in the vacuum vessel of a fusion device can be analyzed to reveal material migration in the vacuum vessel. In addition to simple analysis with eyes and rulers, the DMP can be analyzed in detail using SEM, TEM, and other surface analysis methods, yielding a further understanding of the mechanism of the deposition layer formation.

The DMPs were installed on the plasma facing surfaces in the LHD vacuum vessel before the experiment campaign in 2010, 2011 and 2012. In the LHD vacuum vessel, there are two major plasma facing materials. The first wall panels are made of stainless steel (SUS316L), and the divertor plates are made of isotropic graphite. In reference [1], results of the visual observations of two of the DMPs are shown. In Fig. 2, the two DMPs are shown. One of them (DMP1) was installed on the first wall near the divertor plates in the torus-inboard side, and the other (DMP2) was installed on the first wall in a vertically elongated poloidal cross-section on the mid-plane in the torus-outboard side. The diameter of the disk and the shading pin of the

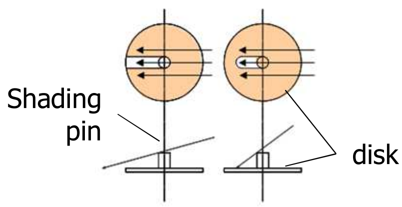

Fig. 1. Schematic of the directional material probe concept. The hatched parts represent the deposition layer. The arrows show the incident angles and directions of deposits. The two images show different incident angles of deposits.

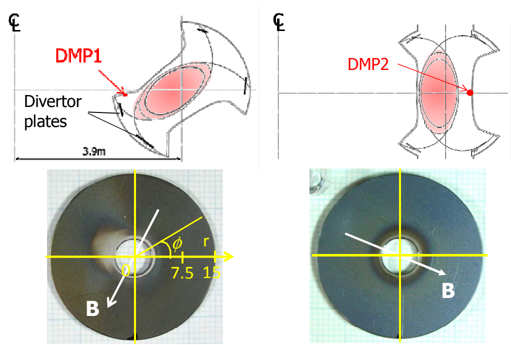

Fig. 2. Positions and photos of the surfaces of DMP1 and DMP2 after the experimental campaign in 2010. The white arrows indicate the direction of magnetic field lines at each DMP's position.

DMP were 30 mm and 5 mm, respectively, and they were made of titanium.

On DMP1, deposition layer with a shadow was formed. Comparison of this result and the previous material probe analysis results suggests that the source of deposits is the divertor plates near the probes, and deposits directly came to the probes without ionization. [1, 6, 7]. On the other hand, no clear shadow can be observed on the surface of DMP2. It suggests the deposits came to DMP2 isotropically.

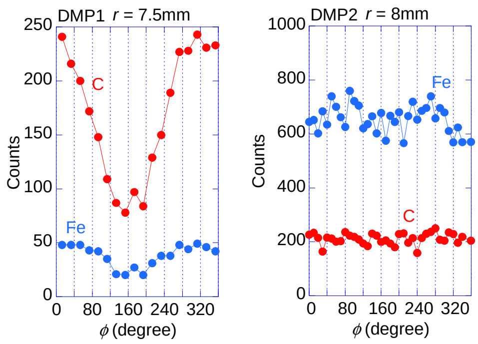

Fig. 3. Angular distributions of carbon and iron on DMP1 and DMP2. The vertical axis is total counts of the signal from carbon and iron, respectively. The definition of the horizontal axis, ϕ, and r is shown in Fig. 2.

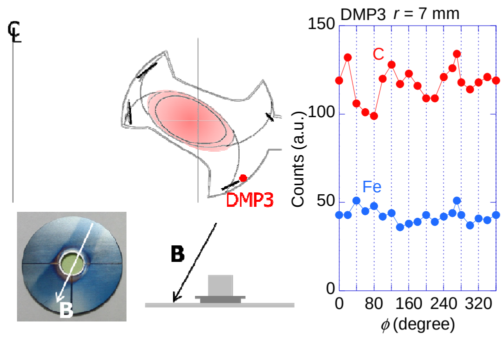

Fig. 4. Positions and photos of the surfaces of DMP3 after the experimental campaign in 2011. The white arrows indicate the direction of magnetic field lines at the DMP's position. The graph is the angular distributions of carbon and iron on DMP3. The definition of the horizontal axis, ϕ, and r is shown in Fig. 2.

Deposits components distributions on the DMPs were analysed by using Energy-dispersive X-ray spectroscopy (EDX). Figure 3 shows the angular distributions of carbon and iron on DMP1 and DMP2. The vertical axis is total counts of the signal from carbon and iron, respectively. In the DMP2 case, both distributions of carbon and iron are almost flat as same as visual observation, and that suggests carbon and iron came to the DMP isotropically. In the DMP1 case, both distributions are similar. They have their minimum around $\phi = 160^{\circ}$, and the angle is almost same as the visible shadow direction. In the visual observation, the shape of the shadow seems to be sharp. But the EDX analysis revealed that the shape is broad. Also the angular distributions suggest that the source and transport of carbon and iron from their sources to the DMP are same. This result is interesting because the divertor plates and the first wall were considered to be the source of carbon and iron, respectively, and their angular distributions on DMP should be different. The mechanism of that is considered as below: During glow discharge cleaning, iron atoms were sputtered from the first wall and were deposited on the divertor plates, and they formed the mixed-material deposition layer with carbon [8]. During confined plasma experiments, the deposition layer including both carbon and iron was sputtered by the bombardment of the ions in the divertor plasma. At last, carbon and iron deposited with similar angular distribution on the DMP.

On the DMP installed in the torus outboard private region, two shadows were formed as shown in Fig. 4. The ends of the shadows were outside the DMP, and it suggests the incident angle of deposits were shallow. The angle of the magnetic field lines across the DMP is much steeper than the incident angles of deposits. Therefore the shadow is considered to be not related to the magnetic field lines, thus to the plasma flow. On the DMP3, angular distributions of carbon and iron are different. The distribution of carbon has negative peaks at the angle of the shadows. Therefore carbon deposition caused the shadows. But the mechanism of the two shadows formation has not understood at this stage.

Summary of this contribution is as below:

- A simple new tool for deposition layer studies focused on the directionality, a Directional Material Probe (DMP), was proposed and was applied to PWI studies in LHD.
- DMPs were installed on several positions on the first wall in recent experimental campaigns in LHD, and both macro- and micro-scopic analyses of the DMPs were carried out.
- Position-dependent variations in the directionality of deposition layer formation were found. Directionality of each deposit element was analyzed.
- Mapping of the directionality of deposition layer in the LHD vacuum vessel is in progress.

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References

[1] S. Masuzaki, Plasma and Fus. Res., to be published.

[2] M. Shimada *et al.*, J. Nucl. Mater., **438**, S996 (2013).

[3] M. Nishikawa, Fusion Sci. Tech. **59**, 350 (2011).

[4] J. Roth, J. Nucl. Mater. **390-391**, 1 (2009).

[5] Y. Gotoh *et al.*, J. Nucl. Maer. **313-316**, 370 (2003).

[6] M. Tokitani *et al.*, J. Nucl. Mater. **417**, 668 (2011).

[7] G. Kawamura *et al.*, Contrib. Plasma Phys. **50**, 451 (2010).

[8] M. Tokitani *et al.*, J. Nucl. Mater. **438**, S818 (2013).