In Vessel Material Migration Study using Toroidal Probe Array in LHD*)

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In order to study migration of sputtered materials and profiles of their re-deposition in the Large Helical Device (LHD), material probes fixed with Si specimens were installed on the private region of the torus outer first-wall in all toroidal sections (10 sections) in the experimental campaign in 2011. The material probes fixed with the Si specimens were exposed to various wall conditionings such as glow discharges cleanings (GDCs), boronization, Ti sublimation and main plasma discharges. After the campaign, the specimens surfaces were investigated with visual observation, Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDS). A type of visual deposition (band) pattern has been observed on the probes at almost all toroidal sections of LHD. The analysis of these patterns on the material probes informs the source and direction of material migration inside the LHD vacuum vessel. The observation and result of the experiment have been presented in this paper.

Keywords: LHD, material migration, erosion, re-deposition, divertor, directional analysis

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1. Introduction

Erosion, transport and re-deposition of plasma facing materials define the topic of material migration in fusion devices [1]. Impurity reduction in plasma is an important issue to avoid dilution and power loss of burning plasma. Thus Plasma wall interaction (PWI) phenomenon in fusion plasma is an integral part of fusion research, and needs to address to recognize the species of impurities and their migration behavior. In particular, PWI leads to the sputtering of the target materials, sputtered materials transported as ions or neutrals throughout the machine and get re-deposited at remote places [2]. The global migration of plasma facing materials in helical devices is considered to be more complex than that of tokamak devices because of the three-dimensional configurations.

First-walls and divertor plates of Large Helical Device (LHD) are frequently exposed to not only main plasma discharges but also many types of wall conditioning processes such as glow discharge cleanings (GDCs), Ti gettering and boronizations. Local positions of subsystems such as existence of GDC anode, diborane nozzles and presence of antennas were found to have significant local effect of erosion and deposition of in vessel materials leading to erosion and deposition dominant zones around the machine [3–8]. This indicates that the erosion and deposition do not occur at the same area and in long term a significant material migration follows. For better understanding of these processes the deposition patterns become increasingly important.

To study migration of sputtered materials and their re-deposition in the LHD, material probes fixed with Si specimens were installed on the LHD first-wall during experimental campaign in 2011. The specimens were exposed to main discharges, glow discharges, boronization and Ti gettering. After the exposure, certain deposition patterns, visible to naked eye has been appeared on the specimens at almost all toroidal sections of LHD. Analyses of these patterns on the specimens were carried out by Scanning Electron Microscope (SEM) and Energy dispersive X-ray spectroscopy (EDS). Following sections explain that analysis of these patterns shows the species, direction and source of deposited materials inside the vacuum vessel of LHD.

2. Experimental Setup

The plasma facing components of LHD are composed by SUS316L first-wall panels and graphite divertor plates having surface areas of 700 and 30 m^2 respectively. Si specimens were used as the sample for the collection of the material depositions. The width and height of these Si specimens were 10 mm and 20 mm respectively. The specimens were fixed between two stainless steel plates, one supporting from back and other holding the specimen from front. Figure 1 shows a set of the specimens in which Si specimen was placed with other specimens (Tungsten and Stainless Steel). The thickness of the supporting plates was 1.5 mm. 10 such sets were installed on the first-wall surface at the torus outboard side each 36° toroidal angle

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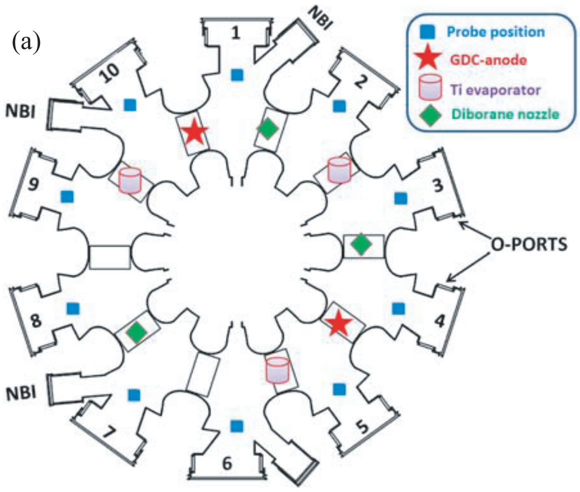
Fig. 1 A set of fresh specimens on the material probe.

(a)



(b)

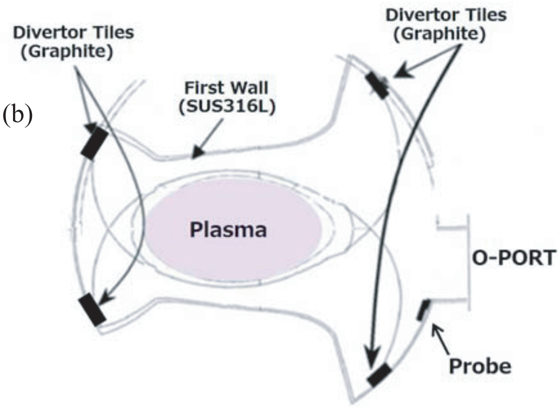


Fig. 2 (a) Torodial and (b) Poloidal location of material probes.

section (#1~#10). Figure 2 shows toroidal and poloidal positions of the material probes. As shown in Fig. 2, GDC anodes are located at toroidal section #4.5, and #10.5-U ports, diborane inlet nozzles in #1.5, 3.5 and 7.5 L ports. Ti sources are at # 2.5, 5.5 and 9.5 L ports. The probes were kept at ground potential.

The plasma shots in the experimental campaign were 7000 in total with each shot duration time lasting about 2 seconds, while total duration of GDC was 325 hr. The probes also have been exposed to Ti sublimation which is periodically conducted in LHD to reduce the hydrogen recycling [9]. After exposure of the probes to above experimental conditions, surface morphology and deposition profiles of the deposited materials, mainly C, B, Fe and Ti were examined by using SEM and EDS using JSM 5600 SEM (JEOL.Ltd). The SEM images and elemental scan of the deposition has been observed at fixed acceleration voltage of 10 keV.

3. Results and Discussion

3.1 Observations of the specimens

The upper series of images of Fig. 3 shows photos of the Si specimens which have been exposed to the above experimental conditions. The lower series of images of Fig. 3 are the corresponding SEM images of the upper series of photos. As shown in Fig. 3, exposure of the Si specimens to full experimental campaign has led to the formation of a visual deposition (band) pattern on left, right and bottom sides of these specimens. The SEM images for all specimens show similar smooth surface condition except specimen #1 and #5. The surfaces of the specimens are rough due to intense erosion. The reason for intense erosion of the specimens is considered to be the presence of GDC anode near the material probe [3,4]. Beside this erosion same visual band pattern appeared on the specimen as the other specimens. All specimens have light brown color bands on their right side. The widths of the bands are around 1.5 mm to 2.5 mm. Some specimens have left side bands of about 1.5 mm. The specimens which have left side band (such as #10) are also accompanied with bottom band of 0.75 mm.

EDS analysis showed that main deposited material was C. Other deposits were B, Ti and components of SUS316. This result is same as previous studies [8].

3.2 Deposits from specific divertor plates

As can be seen right side of visible bands has angle at the top side. It seems that materials deposition on the specimens has followed a particular direction of incidence. To get the direction of incident line, two angles (in plane of the specimen and between specimen and its normal) are needed. Making use of typical dimensions of the top supporting plates which has been used to hold the specimen in position it is possible to calculate two angles of line of incident direction.

The specimens have been exposed to the plasma through the rectangular opening of the holder plates. As shown in Fig. 4 the holder plate has the conic section at top and bottom corner of its rectangular opening. This forms a triangle in plane normal to the specimen. The incident deposited materials have projected top angular section of the holder plate on the specimen plane resulting in the top angular section of deposition band. The line which joins the vertex of these angles (green arrow) forms the hypotenuse of a triangle. This angle gives direction of deposition in plane of the specimen. Another triangle can be formed by joining the left edge of the deposition and top edge of the holder plate (orange arrows). This gives the angle between

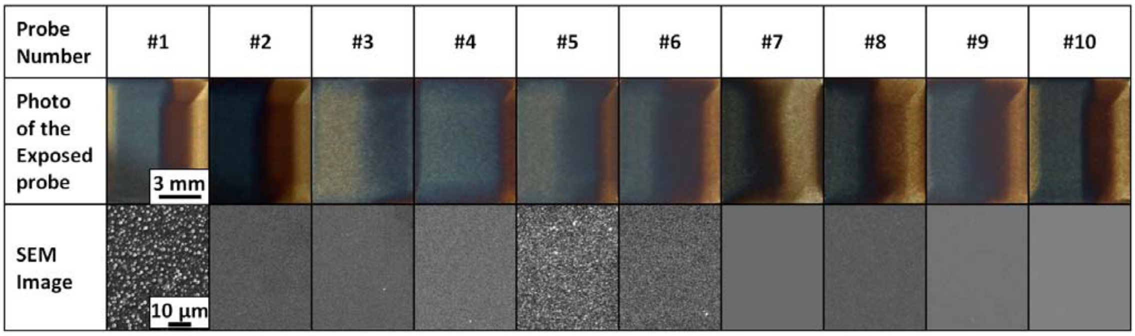


Fig. 3 Photos of exposed probes and corresponding SEM images. On right side of the probes deposition patterns are clearly visible.

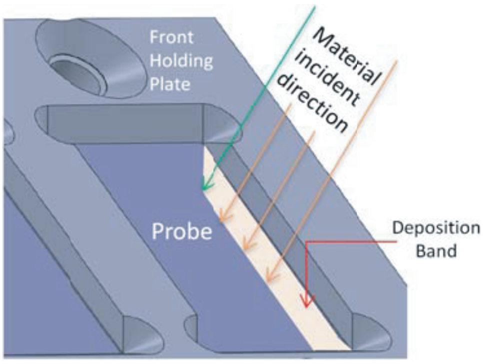


Fig. 4 The deposition pattern has been formed by incident deposited materials across the probe holder in a particular direction.

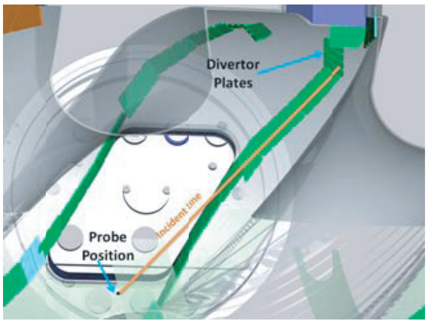


Fig. 5 Source of deposited materials from specific divertor plates from right side.

deposited materials incident line and the specimen plane.

After getting the incident line of deposited material it was traced in CAD. As shown in Fig. 5, direction of materials deposition points (line-of-sight) to the specific divertor plates. It suggests that eroded materials from divertor plates directly reached to the specimen. It is not clear when the materials came from the divertor plates whether during GDC or main plasma operation.

3.3 Incoming direction of the deposited Ti

SEM image of left side band on the specimen in Fig. 6 shows a clear boundary of the contrast. In same figure,

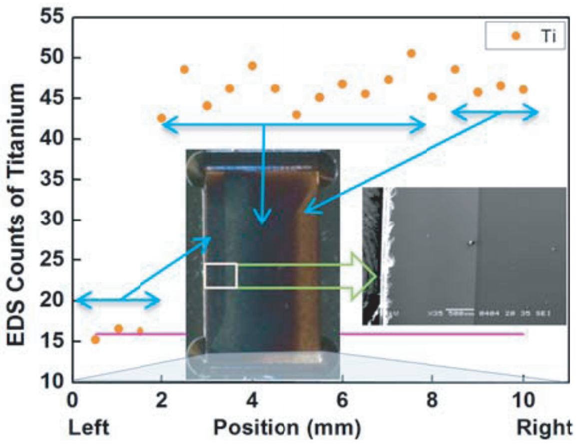


Fig. 6 Horizontal EDS scan of Ti. Horizontal pink line shows the EDS counts of Ti on fresh Si. On the graph also shown SEM scan on left band of the specimen.

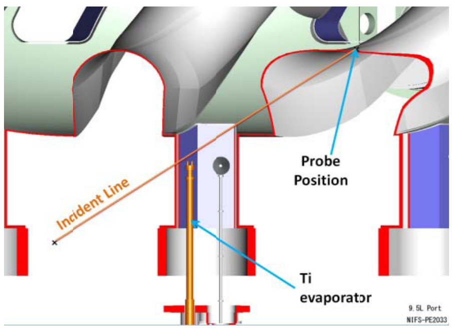


Fig. 7 Schematic view of the position of the Ti evaporator in the LHD vacuum vessel and expected incident line of the deposited Ti particles to the material probe (orange line).

EDS scan of Ti shows that deposition is much lower than that of at the middle and at right band of the specimen. It indicates that the left side band was formed by Ti deposition during Ti sublimation done for wall conditioning.

For left side band on the specimen #10, similar analysis as that applied to the right side band was performed. Figure 7 shows schematic view of the position of the Ti evaporator in the LHD vacuum vessel and expected inci-

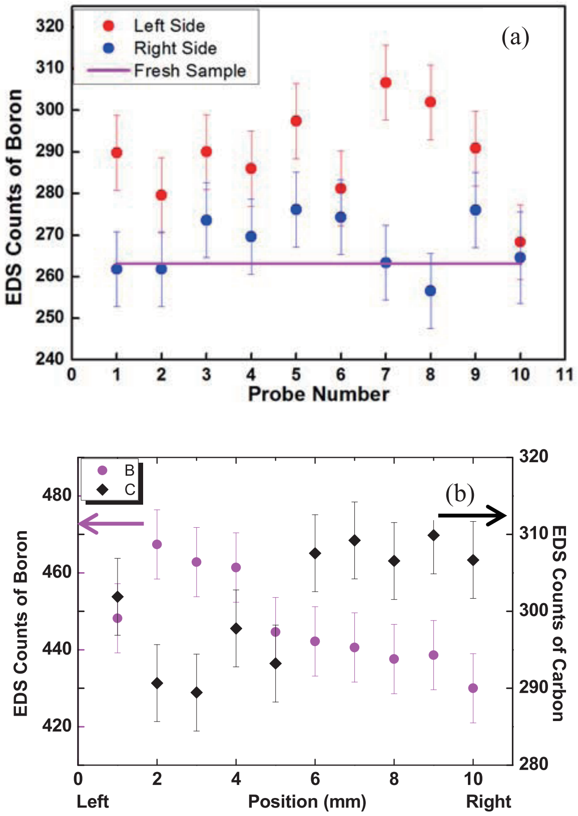


Fig. 8 (a) Comparison of the left/right side of the EDS counts of the B on all probes (toroidal sections). Analysis points of left/right sides are inside of the band [1 minute EDS scan] (b) Positional dependence of the EDS counts of B and C on #3 Si specimen [2 minutes EDS scan].

dent line of the deposited Ti particles to the material probe. It points to the Ti sublimation system which is located at the bottom port of toroidal section 9.5.

3.4 Asymmetric depositions of B and C

Asymmetric deposition of B and C were found by EDS analysis of all the specimens. Figure 8 (a) shows comparison of the left/right side of the EDS counts of the B on all troidal sections (probe number). Analysis points of left/right sides are inside of the bands area of the specimen. It is clearly indicated that B is higher on left band side of the specimen than that of in the right band side for all specimens. Figure 8 (b) shows the positional dependence of the EDS counts of B and C from left to right side on the Si specimen (#3). Their profiles are asymmetric, and their peak positions locate opposite side. It suggests that the incident directions of C and B were different, and that means the mechanism or source position was different from one another.

The reason why these asymmetric depositions occurred is not clear at this stage.

4. Summary

Exposures of the material probes fixed with Si specimen to the main plasma and wall conditionings have been lead to the formation of some visible deposition patterns on the specimen area. That means more than one mechanism caused the formation of deposition patterns on the specimens.

By analyzing of the patterns, we found some sources of the deposited materials such as the specific divertor plates and Ti sublimation source. This suggests that during main plasma or wall conditionings, materials are originated from different directions. They migrate from their source and ends on the vessel wall forming an oblique angle with walls depending on their birth place.

Detailed study to clarify the spatial variation of deposited materials on the specimens, underlying mechanism of generation and transport of the in-vessel materials is the subject of future investigation.

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