Preliminary Examination of Reflection Coefficient Measurement of RGB Lights on the First Wall in LHD

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An innovative color measurement technique is employed in the Large Helical Device (LHD). This study provides a method for obtaining in broad spatial extent and in great detail the color information of the first wall relating to the thickness of the deposition layer. The RGB (Red, Green, and Blue) value, mainly of the stainless steel plates on the helically twisted coil, is measured by a color analyzer equipped with an integrated sphere light source. On the outer torus side, the colors of almost all stainless steel plates are close to carbon black, which suggests that deposition is dominant. On the inner torus side, all plates except for those neighboring the carbon divertor plates are almost white, as in the case of the stainless steel substrate of the first wall, which suggests that erosion is dominant. The relationship between the color and the distance from the stainless steel plates to the plasma is investigated.

In the Large Helical Device (LHD) the global particle balance analysis shows the dynamic wall retention of fueling particles in the long pulse discharges [1]. Long-term exposed sample analysis reveals that the deposition layer is primarily composed of carbon formed on the first wall, and may be a contributing factor to wall retention [2]. The total amount of the deposition layer formed in the vacuum vessel influences the wall retention rate. Thus, reliable evaluation of the total amount of the deposition layer is crucial. The sample analysis is commonly used to determine the thickness and microscopic structure of the deposition layer. However, it is difficult for the finite specimens to cover an entire area in large fusion devices. Also, the analysis of each specimen is time consuming. The colorimetric measurements for the thickness evaluation of the deposition layer were reported from TEXTOR [3]. The color depends on the composition, the structure, and the thickness of the deposition layer. In LHD, the composition of the deposition layer is primarily carbon. Although the surface roughness on the deposition layer presumably affects the reflection coefficient at each RGB, the color is almost certainly related to the thickness of the deposition layer assuming the same surface structure. In this study, a method

for obtaining in broad spatial extent and in great detail the color information of the first wall is provided using an innovative concept for the color measurement [4]. With a simple three-phase model (ambient, deposition layer, and substrate area), the reflection coefficient depends on the thickness of the deposition layer [5]. Therefore, measurement of the color equivalent to the reflection coefficient can serve as a useful tool for determining the thickness of the deposition layer.

In this study, color measurements are conducted by the handy color analyzer DM-1 developed by Hitachi Kinzoku Corporation. The analyzer is equipped with an integrated sphere light source to measure the material having a metalic gloss, and is convenient as an in-situ measurement in the vacuum vessel. The analyzer is calibrated to ensure measurement accuracy by using a color guide of known RGB (Red, Green, and Blue) values in the range between 0 and 255. The calibration results are shown in Fig. 1. There is an offset of around 400 to the maximum intensity of 1023 in each color. RGB intensity shows the same trend. The intensity sensitivity is higher at higher RGB values. We fit the data and calibrate the RGB values using the polynomial fitting curve.

The first wall plates in the vacuum vessel of LHD are

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stainless steel (SUS316L), while isotropic graphite plates are installed in the divertor section. The former is the main material in LHD (700 m²), while the graphite area (30 m²) constitutes only about 5% of the total plasma facing area. We measure the RGB mainly of the stainless steel plates on the helically twisted coil in one of 10 toroidal sections of the vacuum vessel. The number of measured stainless steel plates totaled 530. Reproducibility is confirmed by repeating each measurement several times. Figure 2 (a) shows the developed view of the measured stainless steel plates. On the outer torus side, the colors of almost all stainless steel plates are close to black. On the inner torus side, all plates are close to white, which indicates the reflection coefficient of around 1, except for those neighboring the divertor plates. These results suggest that the outer torus side is deposition-dominant, while the inner torus side is primarily erosion-dominant. The color measurement results

are shown visually in the CAD rendering in Fig. 2 (b). It can be seen that the color is close to white for the stainless steel plates located near the plasma and close to black for those located far from the plasma. This suggests that there is a correlation between the plate color and the plate distance from the plasma. Figure 3 shows the RGB values as a function of the shortest distance of the stainless steel plates to the last closed flux surface (LCFS) for a typical magnetic configuration (R_{ax} = 3.6 m). It can be seen that the RGB is high for stainless steel plates located near the LCFS. In some stainless steel plates at the center of the saddle portion, the RGB is still high even in areas far from the LCFS, and the RGB of the plates near the carbon divertor plates is low even near the plasma. The color of a stainless steel plate, which is identified by the competition between the deposition and erosion processes, will depend on such parameters as the distance to the plasma and the angle of view of the divertor plates.
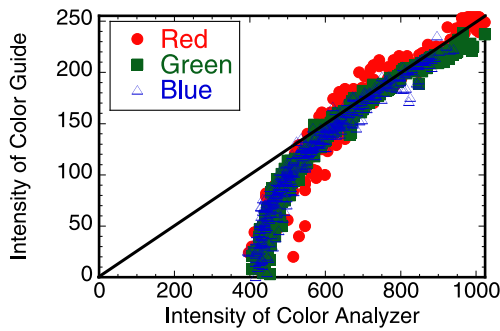

Fig. 1   Calibration results of the color analyzer obtained using a color guide.
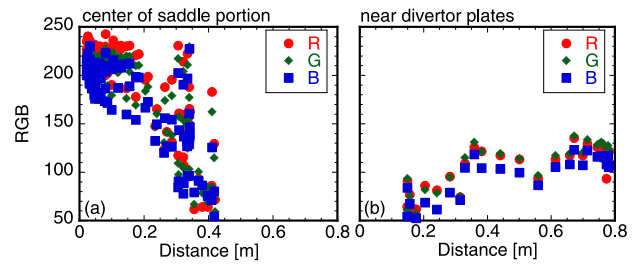

Fig. 3   Relationship between the RGB and the distance from the stainless plates to the LCFS at (a) center of saddle portion and (b) near divertor plates.
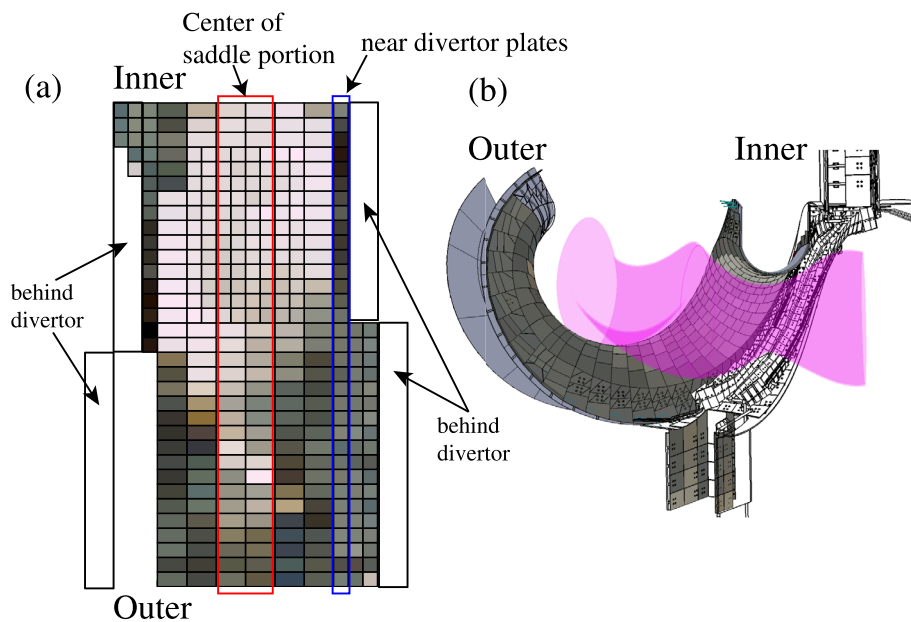

Fig. 2   (a) Developed view and (b) CAD showing the color distribution of the measured stainless steel plates. A typical plasma shape is drawn in (b).

Characterization of the deposition layer by this study is qualitatively consistent with the previous results from the direct specimen analysis [6, 7]. In the future, the thickness of the deposition layer will be determined from samples mounted on the same toroidal section with color measurements as part of the long-term exposed sample analysis, using a focused ion beam system. If the relationship between the thickness and the color is revealed, the measured stainless steel plates can be distinguished as belonging to deposition-dominant areas, erosion-dominant areas, or in-between areas. Thus, estimation of the amount deposited on the entire vacuum vessel would become possible.

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