Observation of Plasma-Facing-Wall via High Dynamic Range Imaging*)

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Pictures of plasmas and deposits in a discharge chamber taken by varying shutter speeds have been integrated into high dynamic range (HDR) images. The HDR images of a graphite target surface of a compact planar magnetron (CPM) discharge device have clearly indicated the erosion pattern of the target, which are correlated to the light intensity distribution of plasma during operation. Based upon the HDR image technique coupled to colorimetry, a formation history of dust-like deposits inside of the CPM chamber has been recorded. The obtained HDR images have shown how the patterns of deposits changed in accordance with discharge duration. Results show that deposition takes place near the evacuation ports during the early stage of the plasma discharge. Discoloration of the plasma-facing-walls indicating erosion and redeposition eventually spreads at the periphery after several hours of operation.

Keywords: high dynamic range imaging, plasma dust-like deposit, plasma imaging, carbon sputtering, colorimetry

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1. Introduction

A method of recovering high dynamic range radiance maps from images developed by Debevec and Malik [1] has been utilized in various fields such as characterization of optical components [2]. Multiple photographs of the scene are taken with varying exposure and merged into a single photograph with HDR radiance map. Rosario *et al*. used this method to characterize luminous intensity distribution of a low-pressure steady-state magnetized plasma [3]. Figure 1 shows the low dynamic range (LDR) photos of a sheet plasma taken at various shutter speeds and the HDR image constructed from the LDR pictures. As shown in the figure, HDR gives the structure of the plasma boundary while maintaining the information of luminous intensity distribution in the plasma.

A camera with built-in HDR signal processing can be used as a plasma diagnostic tool like X-ray spectroscopy [4]. On the other hand, the method of constructing multiple photographs does not require large HDR hardwares. It is particularly suited for observation inside of a plasma equipment, which usually has limited number of observation ports. This study extends the HDR imaging applications to internal wall monitoring of a discharge chamber aiming at collecting data related to how dusts are formed and transported inside the chamber. In fusion experiment devices, wall erosion and successive dust formation need observation through sight limited ports. The wall conditions are to be monitored to determine when the walls should be cleaned, modified or replaced. In particular, dusts formed in the fusion device can retain large amount of tritium, and the behavior of dust in the device has to be clarified to minimize tritium retention in the future fusion machines. Thus the effectiveness of HDR imaging utilizing digital camera has been tested with a small magnetron sputter device to observe both carbon target erosion, and successive dust formation in the chamber. Tritium should be injected or contained in the plasma device where dust formation is minimal.

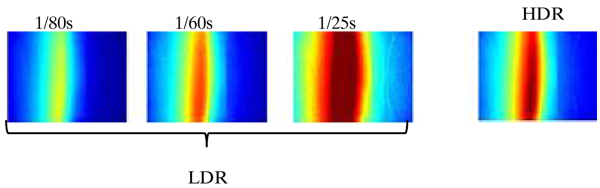

Fig. 1 Contrast stretched LDR images of the sheet plasma at 1/80 s, 1/60 s, 1/25s shutter speeds and the HDR image.

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2. Methodology

2.1 Apparatus

This study used a compact planar magnetron (CPM) device to sputter carbon targets shown in Fig. 2. The device has a 5 cm diameter cathode in a 10.5 cm diameter 12 cm long stainless steel vacuum vessel serving as the anode. A cylindrical and toroidal permanent magnets are mounted inside of the cathode to form a planar magnetron magnetic field geometry. The CPM device is pumped down to 2×10^{-4} Pa with a 50 l/s turbomolecular pump coupled to an oil rotary pump. The viewing port served as the base for the camera stand. A microscope glass slide was attached at the vacuum side of the glass viewport.

2.2 Methods

An 8 cm diameter 0.1 mm thick graphite target was placed on the cathode to be sputtered in an Argon plasma. Pressure inside of the chamber was kept constant at 0.5 Pa and the steady state Argon discharge was maintained at 34 mA discharge current and 523 V discharge voltage. Plasma parameters were measured under this condition using a 1 cm long 0.06 cm diameter tungsten made Langmuir probe. The measured electron density, temperature and potential are 1.8×10^{10} cm^{-3}, 3.5 eV, and −5 V respectively.

Several 22 bit LDR photos were taken at various shutter speeds using a digital camera (Pentax K10D) at the same aperture opening of f/5.6. All the automatic settings of the camera such as auto gain and auto white balance were turned off. The LDR photos were converted to HDR via Photoshop® software. Pictures taken by the digital camera were stored with jpeg format, and pixel data were converted into 32 bits resolution. The HDR image was reconstructed with the same interval in tonal values, which are proportional to the actual brightness. The procedure is schematically illustrated in Fig. 3, showing the line scans of image data taken at different shutter speeds.

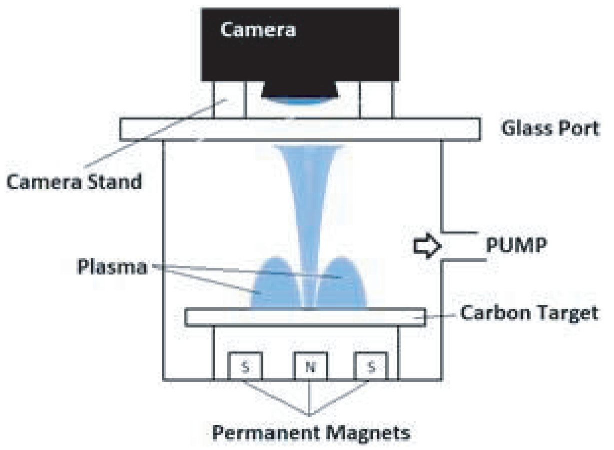

Fig. 2 The Compact Planar Magnetron device used for the experiment.

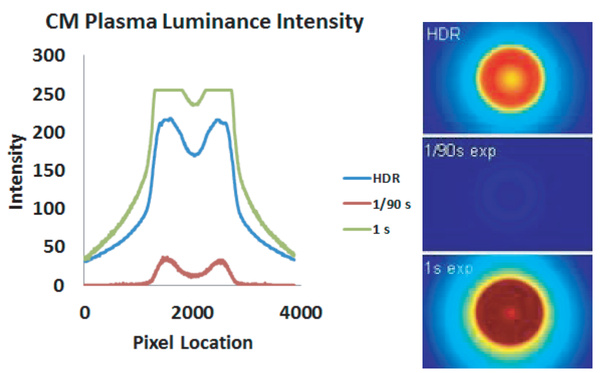

Fig. 3 Line plot and false-color maps of the LDRs and HDR images of the circular plasma.

3. Results

3.1 Plasma glow with carbon redeposition

Plasma glow can be rendered via HDR. In Figs. 4 (a)-(c), false color images of the CPM plasma are shown in HDR pictures. At fast shutter speed, the intensity signal of the image is weak. At slow shutter speed, the intensity

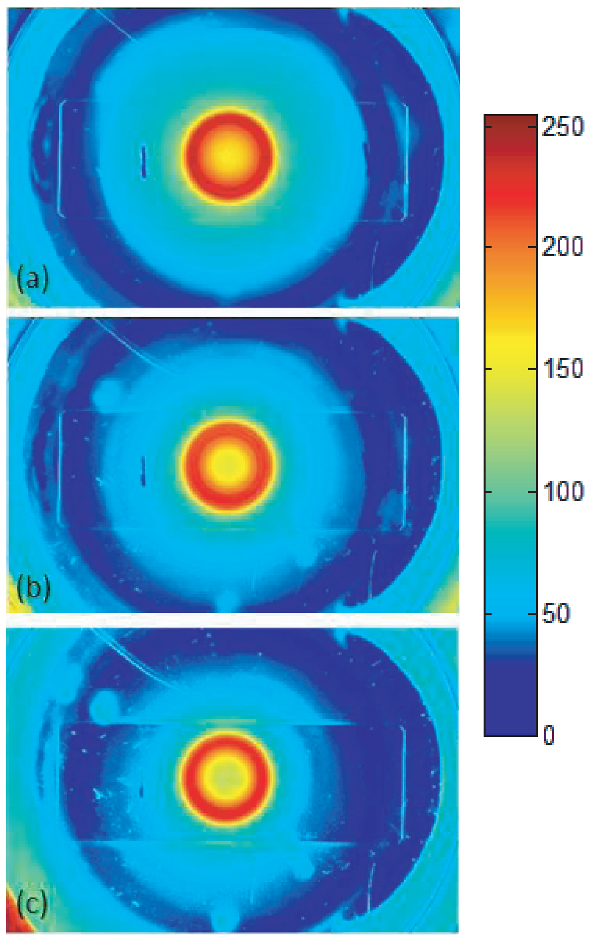

Fig. 4 False color HDR images of the plasma at the (a) start, at (b) ~2 hr, and (c) ~5 hr, of the graphite sputtering. The slide glass highlights the difference in the refractive index due to the deposits.

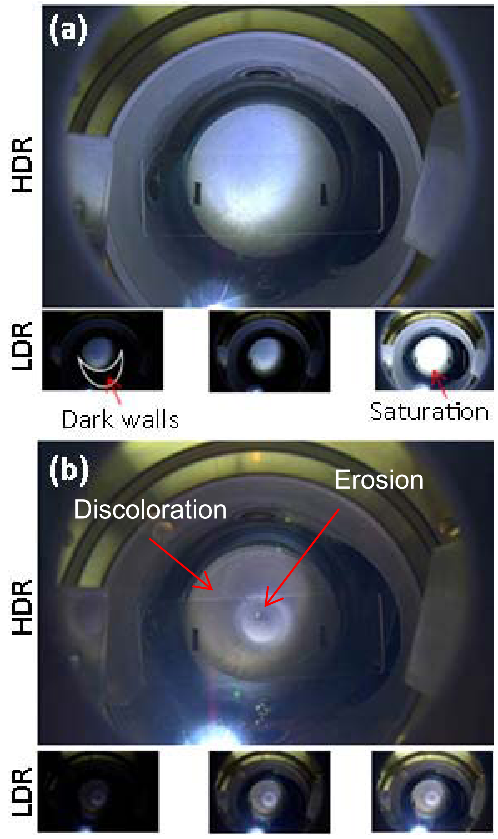

Fig. 5 HDR photos of the plasma device interior chamber and its LDR photos (a) before and (b) after discharge operation.

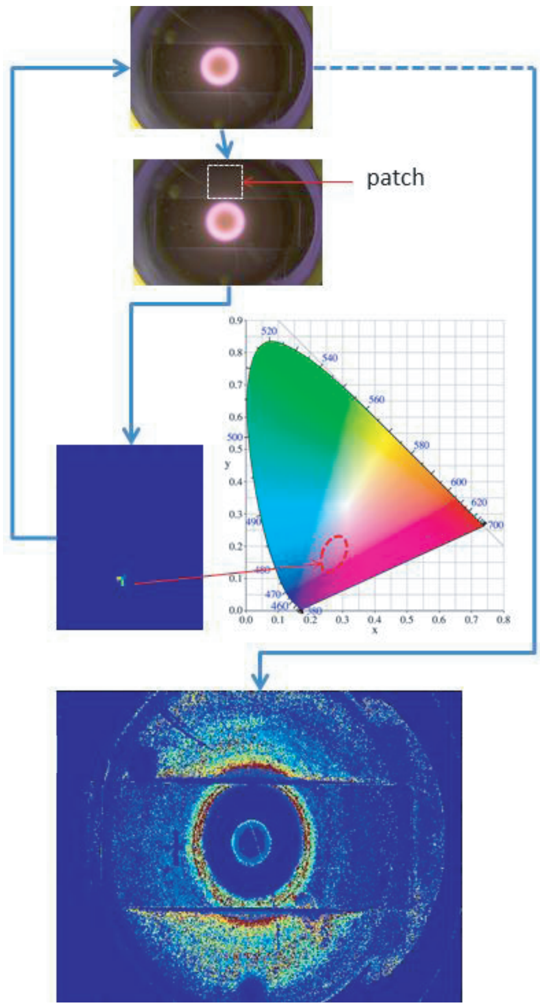

Fig. 6 The HDR photo of the plasma at ~5 hr sputtering and its chamber walls as the source of the patch. The HDR photo is then scanned to find matching pixel colors from the patch. If the pixel color values match, then this pixel takes a non-zero value in the false color map. (Color map CIE 1931 2°)

is saturated. Pictures shown in Fig. 4 clearly indicates the change in light intensity distribution of the plasma glow. The most definitive advantage of HDR image representation is that Figs. 4 (a)-(c) show the advancement of carbon deposition onto the viewing port and the attached slide glass.

3.2 Observation of target erosion

Figures 5 (a) and (b) show HDR and LDR images of graphite target surface before and after the discharge operation. The HDR image shown in Fig. 5 (b) depicts erosion and dark layer (discoloration) on the surface of the target edge region as seen on the viewing port.

3.3 Colorimetry

The experimental results show the HDR pictures can be utilized to see subtle change in condition inside the discharge chamber. In discharge devices having carbon wall, emission of dust often becomes a problem. Colorimetry has been utilized to characterize plasma material interaction such as thickness of deposits [5]. Here we try to use colorimetry to analyze dust-like settlement inside the experimental device chamber. The technique was based on Soriano *et al.*'s study [6] that used colorimetry for color-based tracking of faces and hands. In Figs. 6 and 7, non-zero values of the false color image indicates dust-like deposition. In Fig. 6, glass region with dust-like deposits is used as a patch to filter in same color pixels of the HDR photo of the plasma chamber. If the image pixel has the same color from the patch pixels, the image pixel is highlighted. This HDR photo has been taken towards the end of carbon sputtering .The same patch was used to analyze HDR photos at the start and for every hour of sputtering. In Fig. 7, dust-like deposits are observed to settle near the evacuation port then at the interior walls.

4. Conclusion

Target erosion and material deposition onto a viewing port have been monitored by merging the low dynamic range photos to construct high dynamic range pictures. Dust-like deposits on the wall can be monitored successfully during plasma operation via HDR images. Color-based measurement was attempted in order to monitor dust

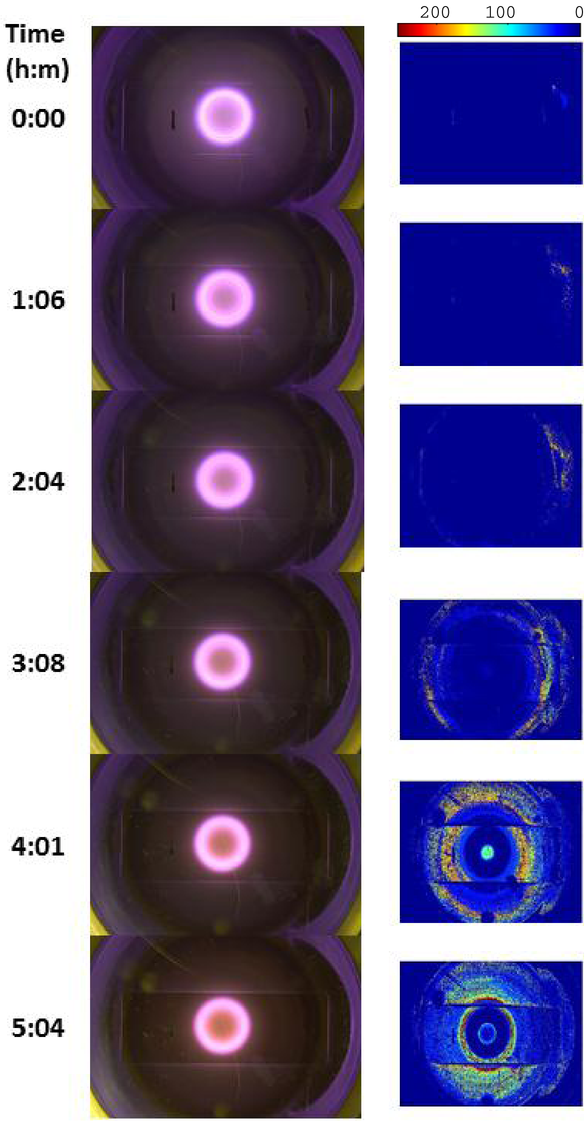

Fig. 7 The actual HDR photos of the plasma at about 1 hr intervals and their color-filtered images.

settlement in accordance with time advancement. The method has exhibited how dust-like deposits are distributed on the chamber wall. As the method is simple and a small camera can be installed conveniently to a device, monitoring of plasma experiment device can be made easily without major modification.

Acknowledgement

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