Study on the Wall Blackening of a High Intensity Discharge Lamp

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A ceramic metal halide HID lamp was operated with short duration turn-on/turn-off procedure to enhance the effect due to electrode sputtering during lamp ignition. Time dependent change of optical emission spectrum showed that the intensity of W I line spectra were prominent only during the time of lamp ignition. The tested lamp showed more homogeneous blackening compared with a lamp operated with a longer turn-on period. Meanwhile, the lamp operated with a longer turn-on period had shown a blackening thicker toward the direction of gravity. Distributions of light intensities and those of optical emission spectra were measured by producing images of the test discharge tubes through a pinhole. Spatial distributions of the line spectrum intensity of Dy I at 421.18 nm and those of light absorption by Al at 394.40 nm indicated that the densities of these atoms increased toward the direction of gravity.

Keywords: HID lamp, ceramic discharge tube, wall blackening, optical emission spectroscopy, light source

1. Introduction

High intensity discharge (HID) lamps are widely used as energy efficient light sources for various applications. Wide variation of lamps exists, which includes lamps having alumina ceramic discharge tubes. The discharge tube made of light transparent alumina has better durability against high temperature and corrosion compared to quartz glass envelopes.

Wall blackening phenomena are commonly observed for alumina discharge tubes. After operation time of several hundred hours, blackening of a discharge tube leading to light flux reduction is observed. In an alumina ceramic metal halide HID lamp containing DyI_3-TlI-Dy, formation of $3Dy_2O_3 \cdot 5Al_2O_3$ garnet was observed inside the discharge tube after operation [1,2]. The wall blackening proceeds faster toward the direction of gravity [3], and this inhomogeneity has been shown to be caused by convection of plasma in a discharge tube due to gravity [4,5]. The convection of arc in a HID accompanies plasma instability [6], and is also an important factor to cause a severe cracking of the discharge tube [7].

Metallic W is also found on the surface of the inner wall of a used HID lamp [8]. The contamination of the tube wall due to W coverage is probably caused by sputtering during the plasma ignition phase of the lamp startup operation [9]. Thus, we try to clarify the relative contributions from these two mechanisms causing wall blackening of a ceramic metal halide HID lamp. In this paper, the results of investigation on the optical light emissions from W, Dy and Al are reported.

2. Distribution of Wall Blackening

The lamp used in this research is the Panasonic Panabeam, type MT150CE-W-D ceramic metal halide HID lamp. The test lamps were mounted on a socket to align the arc column along the vertical direction. A short duration turn-on/turn-off operation was employed to enhance the effect by W sputtering from the electrode during the lamp startup. Figure 1 shows the schematic diagram of the experimental setup for accelerated testing by short duration turn-on/turn-off operation.

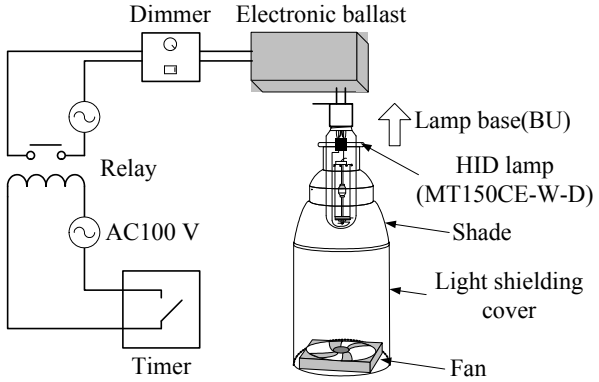

Fig. 1 Schematic diagram of the experimental setup for short duration turn-on/turn-off operation.

A 500 mm long light shielding cover was attached under the shade to reduce stray light around the experimental setup. The cover also served as a conduit of the air flow created by an electric fan attached at the bottom of the light shielding cover to cool the lamp after extinguishing the discharge. The effective cooling of

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the lamp had shortened the time to reignite the discharge from the previous arc. Two time schedules of the lamp tests were employed for short duration turn-on/turn-off operations; one was 2 minutes discharge and 3 minutes cooling, and the other was 10 minutes discharge and 20 minutes cooling. The lamp operated with the former schedule is called sample A, and the other operated with the latter schedule is called sample B in this paper.

A Panasonic FA10219ENL planar light source illuminated the tested discharge lamps from the backside of the HID lamp separated by 30 mm. A digital camera (Nikon D80) located 120 mm from the planar light source captured the image of the lamp with the HID lamp in position. After taking the image of the lamp, the lamp was removed to measure the image data of the planar light source. The absorption data of the lamp was deduced from the intensity ratio between two corresponding pictures. Figure 2 shows the results of absorption distributions for the three tested lamps obtained from the green component of the image data.

Absorptions of sample A, which has experienced 3,700 on/off intervals, and that of sample B, which has experienced 1,050 intervals are shown in Figs. 2 (b) and 2 (c), respectively. The data of as-received sample is also shown in Fig. 2 (a). The net durations of the turn-on times of the lamps correspond to 123 hrs for sample A, and 175 hrs for sample B, respectively. Red color in the figure shows the part where the absorption is the highest, while blue color indicates the part where no absorption is present. Both samples A and B exhibited heavier blackening toward gravity. However, the comparison between Figs. 2 (b) and (c) indicates that the sample A experiencing more turn-on/turn-off interval exhibits thicker, and more homogeneous blackening than sample B.

Time dependent optical emission spectra were measured to confirm if the electrodes emitted the composing materials during the ignition phase of the lamp. An optical spectrometer covering the wavelength range from 380 nm to 468 nm was used to measure an optical emission spectra (OES) with 0.03 nm resolution. A prominent line spectrum of W I at 400.9 nm was observed with other line spectra of W and Hg for a short term right after the lamp ignition, as shown in Fig. 3. The spectrum shown in the figure was obtained for 50 ms duration from a time in the first 50 ms from the ignition. The uncertainty of 50 ms for the time data arose from the minimum integration time of the spectrometer signals. Lines of tungsten were observed from 25 to 100 ms from the start of the discharge. Right after the lamp ignition, Hg I line spectra brighter than W I lines were observed. Sharp voltage pulses succeeding to the one ignited the lamp produced line spectrum emissions of WI. These line spectra of WI were not found in the steady state operation of the lamp as can be seen in Fig. 5. Intensities of line spectra had decreased rapidly, and Planck radiation had started to occupy a large part of radiation power after 400 ms from the lamp ignition.

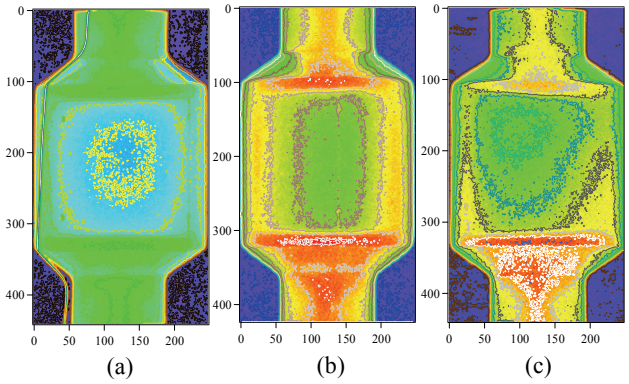

Fig. 2 Absorption of discharge tubes indicated by color. Dark blue or black indicates 0% absorption, and the absorption is larger from green to red. (a) as-received lamp, (b) sample A, and (c) sample B.

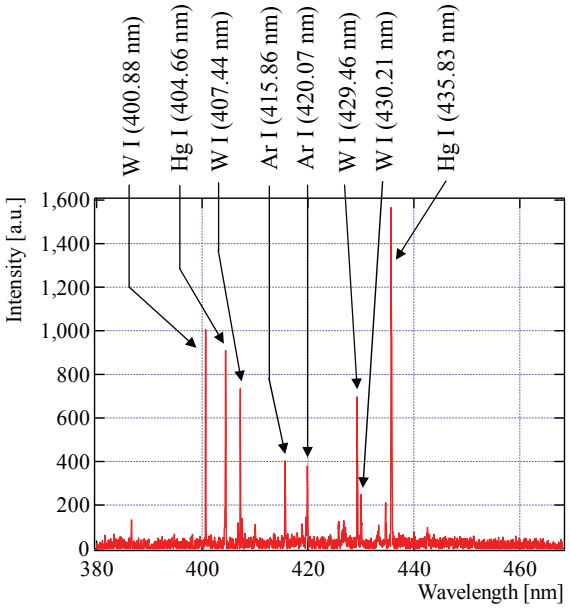

Fig. 3 Optical spectrum of light from HID plasma during lamp ignition. (About 100 ms from the ignition.)

3. Spatial distributions of spectral intensities

Spatial distributions of OES were investigated so as to see their correlations to the blackening patterns on the lamp tubes. Pinhole imaging was employed to reduce light intensity with maintaining the spatial resolution. The experimental setup is schematically illustrated in Fig. 4. A 0.3 mm diameter pinhole was opened through the wall of the Panasonic NK07613 lamp shade. A screen to observe pinhole image was placed at 40 mm from the pinhole, while the distance from the pinhole to the center of the discharge lamp was 40 mm. Thus, an inverted image of the same size of the discharge tube appeared on the screen. A light input of an optical fiber

was located at the position specified on the screen to deliver light signal to an optical spectrometer. Screen was removed during the period to measure the optical spectrum distributions.

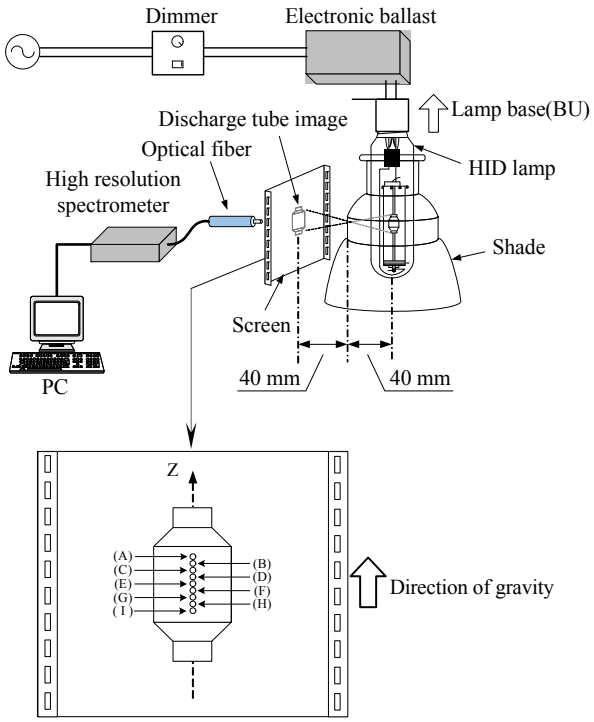

Fig. 4 Schematic diagram of the experimental setup for measuring spatial distributions of OES. Points A through I indicate the positions where the inlet of the optical fiber connected to the spectrometer was located.

Observed OES at positions A, E, and I are shown in Fig. 5. In the figures, the ordinates are normalized to the light intensity integrated over the entire range of observed wavelength in order to compare the relative contributions from line spectra. Line spectrum emissions of HgI at 404.66 nm and 435.83 nm, that of Tm I at 451.19 nm, and that of Tm II at 424.68 nm were prominent. Relative intensities of mercury lines from the lamp ends were more prominent than those at the lamp center.

Lamp center had shown OES with line spectra due to transitions from excited atoms at higher initial energies. Namely, the temperature of the plasma at the lamp center appears higher than those at the lamp edges. When the line spectra from the lower lamp edge were compared with the corresponding ones from the upper edge, the local temperature of the upper edge seemed a little lower than the upper edge.

As well as emission line spectra, absorption lines were also found in the optical spectra. These include Dy at 404.60 nm and 421.18 nm, together with Al at 394.40 nm and 396.15 nm. Figure 6 shows the Dy absorption lines observed for sample B and those for as-received lamp. As clearly indicated in the figure, Dy lines have changed from emission lines to absorption lines by arc operations. The reduction of optical thickness of Dy leading to an enhancement of absorption corresponds to an increase of Dy density due to disintegration of DyI_3-TlI-Dy in the lamp tube.

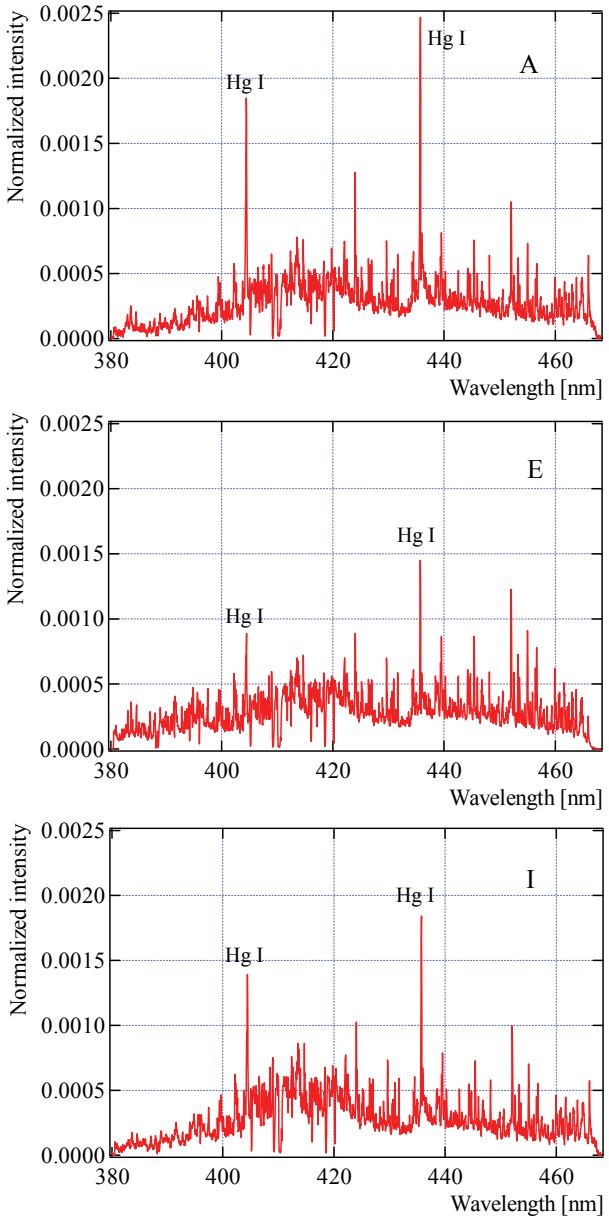

Fig. 5 Optical emission spectra taken at lamp locations indicated by A (tube bottom), E (tube center), and I (tube top) in Fig. 4.

The intensity of the emission spectrum of Dy at 421.18 nm for an as-received lamp is plotted as a function of the distance from the tube center in Fig. 7. The height of the line spectrum emission was normalized to the integrated light intensity in the wavelength range from 380 to 468 nm. As shown in the figure, the line spectrum is more prominent at the bottom of the lamp, indicating a higher concentration of Dy at the bottom. This agrees with the result reported by Flikweert *et al.* [5], which has explained the higher Dy density at the tube bottom due to the effect of convection.

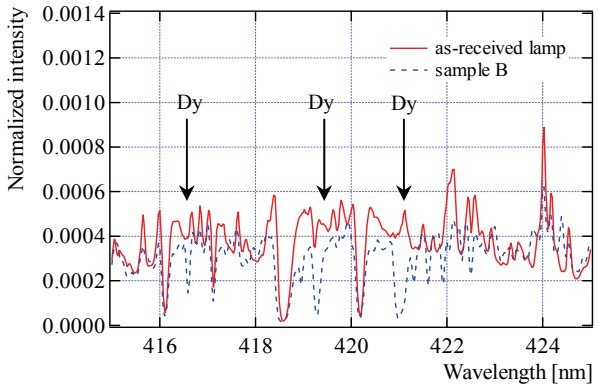

Fig. 6 The optical emission and absorption of Dy.

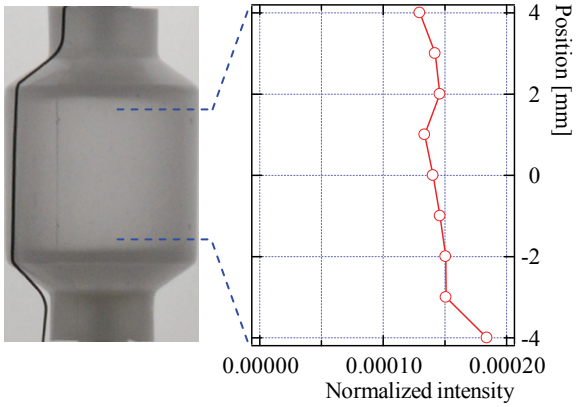

Fig. 7 Spatial distribution of line spectrum emission of Dy at 421.18 nm.

Another characteristic absorption spectral line is Al at 394.40 nm wavelength. The absorption was obtained through dividing the depth of the dip in the spectrum at the absorption wavelength by the averaged light intensity obtained from the intensities of both edges of the dip. The spatial distributions of absorption by Al at this wavelength are plotted in Fig. 8 for an as-received sample, for sample A and for sample B. The observed spatial distributions show the smaller optical absorption by Al at lamp edges as shown in Fig. 7. The reason for observing smaller absorptions of Al at the lamp edges can be due to Al density distribution caused by the temperature distribution and the corresponding convection.

The comparison among the as-received sample, sample A, and sample B indicates that curves of as-received sample and that of sample A are similar, while that of sample B exhibit more homogeneous profile in the vertical direction. The comparison between the Al absorption distribution and the corresponding light absorption distribution measured from light transmission experiments suggests the existence of a direct correlation between the wall blackening of discharge tube and the local Al density.

4. Summary

Spatial distributions of light intensities of alumina ceramic metal halide HID lamps had shown two characteristic patterns of wall blackening. One progresses homogeneously with the number of times of lamp ignition, while the other advances preferentially toward the lamp bottom with the integrated lamp operation time. The latter is considered related with precipitation of metallic elements transported in the lamp due to convection, which has been partly confirmed by spatial distributions of emission/absorption spectra. The former can be related with sputtering of electrode materials, which has been confirmed by W emission spectra observed during lamp ignition.

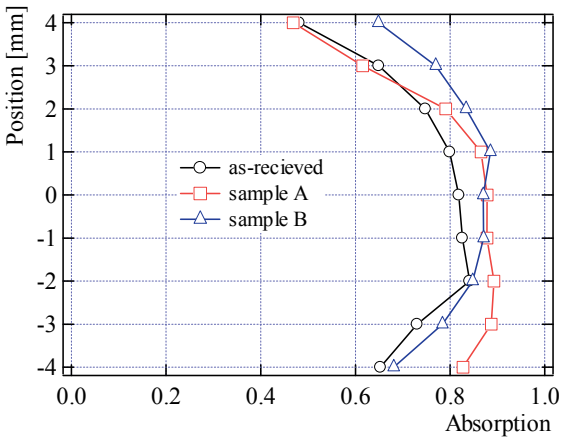

Fig. 8 Absorption by Al spectral line at 394.40 nm plotted as functions of vertical position for as received sample, sample A, and sample B.

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