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Estimation of Xenon Filling Pressure in Mercury-free Metal Halide Lamp by Optical Emission Line Broadening

発光スペクトルの広がりを利用した無水銀メタルハライドランプのXe封入圧推定

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In the environmental point of view, non-toxic and environmentally friendly products are demanded. In the field of light sources, various mercury-free lamps have been studied. For automotive headlamps, mercury-free metal halide lamps have been developed. However, deviation of the xenon filling pressure affects lamp performance and a non-destructive method to estimate the xenon filling pressure is required. The authors measured the emission spectra of mercury-free metal halide lamps for several kinds of filling pressure. By calculating Van der Waals broadening of measured spectra, it is shown that the xenon filling pressure can be estimated.

1. Introduction

Nowadays, non-toxic and environmentally friendly products are demanded. In the field of light sources, various mercury-free lamps have been studied. For automotive headlamps, considerable research and development of mercury-free metal halide lamps (MHLs) has been performed [1–8] and commercial lamps are already available in the market. In conventional MHLs, mercury vapor has several important roles; one of them is to maintain the plasma impedance high. In the mercury-free MHLs, substitute metal vapors, such as zinc, are employed instead of mercury. Moreover, filling pressure of the buffer gas (xenon) is increased compared to conventional MHLs, up to or more than 10 atm. The working pressures of the metal vapors are determined by working pressure. On the other hand, xenon working pressure is determined by the filling pressure. Therefore, deviation of the xenon filling pressure affects lamp performance. Thus, a non-destructive and simple method to estimate the xenon filling pressure in automotive mercury-free MHLs which is applicable in the manufacturing process is required.

Previously, the authors proposed a pressure estimation method from the plasma impedance (lamp voltage and current) measurement in the lamp ignition phase [9]. Although it has a good estimation accuracy (~0.1 atm), it requires accumulation measurement of unstable current value in the ignition phase. In this paper, the authors propose a pressure estimation method from the optical emission line broadening in the steady working phase.

2. Experimental Procedure

D4 type mercury-free MHLs were used in this study. The lamps with four different filling pressures, 10.0, 12.1, 13.5, 15.4 atm, were prepared. All the lamps have passed the manufacturer’s inspection about the electrical characteristics such as voltage, current, power consumption and the optical characteristics such as total flux and color coordinate. This means the deviation of filling pressure from the above setting values is small, i.e. less than 0.1 atm. At the steady state working of the lamps, emission spectra were measured with a monochromator (Bentham, DTMc300, wavelength resolution was set at 0.05 nm) and a PMT (Hamamatsu, R955).

3. Results and Discussion

At the steady state working, the lamps showed strong emission of metal vapors at the near IR (infrared) region. Measured emission spectrum at near IR region at 10 atm is shown as circles in Fig. 1. The spectra in this region had four main peaks, which are assigned to Na I (818.325 nm, $^2P^\circ_{1/2}$–$^2D_{3/2}$), Na I (819.479 nm, $^2P^\circ_{3/2}$–$^2D_{3/2}$), Na I (819.482 nm, $^2P^\circ_{1/2}$–$^2D_{5/2}$), Zn I (820.380 nm, $^3P^\circ_2$–$^3G_3$). In the high pressure plasma (several tens atm), the shape of line spectra becomes asymmetric because of Van der Waals broadening in the quasi-static approximation, whose profile is

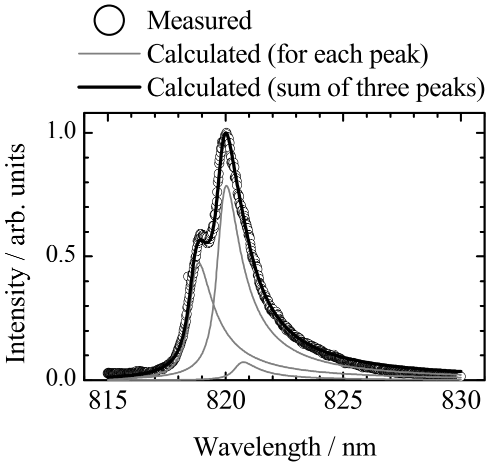

Fig. 1. Measured (circles) and calculated (lines) emission spectra of the mercury-free metal halide lamp at near IR region at the xenon filling pressure of 10 atm

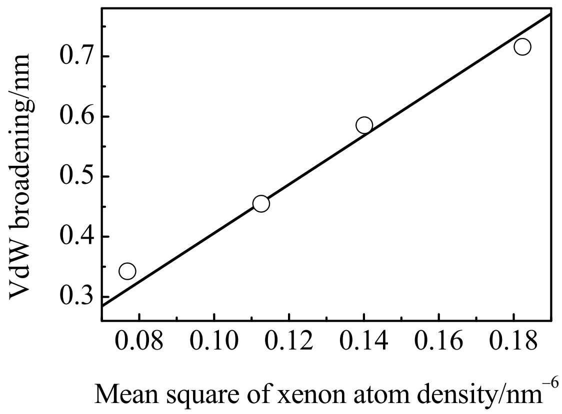

Fig. 2. Calculated Van der Waals broadening value for each lamp as a function of mean square of xenon atom density.

shown as,

$$P_{qs}(\lambda) = \begin{cases} \dfrac{\sqrt{\Delta\lambda_{qs}}}{2(\lambda-\lambda_0)^{3/2}} \exp\left[-\dfrac{\pi\Delta\lambda_{qs}}{4(\lambda-\lambda_0)}\right] & (\lambda > \lambda_0), \\ 0 & (\lambda \le \lambda_0). \end{cases} \quad (1)$$

Symmetric contribution to the spectral broadening, i.e. pressure broadening, Stark broadening, etc., were considered as Lorentz profile, as shown in Eq. (2).

$$P_i(\lambda) = \frac{\Delta\lambda_i}{\pi} \frac{1}{(\lambda-\lambda_0-s)^2 + (\Delta\lambda_i)^2}. \quad (2)$$

Calculated spectra for each peak (two peaks near 819.4 nm were combined) by convoluting Eqs. (1) and (2) are shown as gray lines, and the sum of three peaks is shown as the black thick line, in Fig. 1. It is found that the calculated profile fits to the measured spectrum well.

The Van der Waals broadening in quasi-static approximation, $\Delta\lambda_{qs}$, is proportional to square of number density of the neutral atom which collides with the radiating atom. In these lamps, xenon partial pressure is dominant compared to those of metal vapors (less than 1 atm). Figure 2 shows calculated Van der Waals broadening value for each lamp as a function of mean square of xenon atom density. The xenon density in the steady state was calculated with assumption of parabolic temperature profile with 5500 K at the center [10] and 1000 K at the lamp edge. It is found that the calculated Van der Waals broadening values are almost proportional to the mean square of xenon atom density. It is shown that the xenon filling pressure can be estimated by asymmetric line broadening of emission spectra.

4. Conclusion

The emission spectra for D4 type mercury-free MHLs were measured and analyzed with xenon filling pressure of 10.0, 12.1, 13.5, 15.4 atm. By calculating Van der Waals broadening of measured spectra, it is shown that the xenon filling pressure can be estimated.

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