Measurement of plasma temperature in hollow cathode discharge

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Abstract

We report the observation of line shapes in the optogalvanic spectrum, which are different from those of absorption, for transitions origination from the $3P_2$ ($1s_5$ in Paschen notation) metastable level of argon. The OG line shapes resemble those of absorption and be used to diagnose the characteristics of the discharge plasma. The measured plasma temperatures of Ar hollow cathode discharge for several metal cathodes are about 620 ~ 780 K at discharge current of 7 ~ 10 mA.

Key Words : hollow cathode, plasma temperature.

1. INTRODUCTION

A hollow cathode discharge (HCD) plasma [1] is widely used as a atomic vapor or emission source for most elements in the Periodic Table[2]. Because of its high signal-to-noise ratio and relatively simple experimental setup[3,4], the optogalvanic (OG) detection methode in a HCD has been recognized as a powerful technique for several spectroscopic studies and discharge diagnostics[5-7]. Even though this detection method has been used as an alternative to the detection of absorption of fluorescence, it is necessary to take great care in utilizing the OG line shapes for measuring spectroscopic quantities because the OG line shapes may be different from the absorption (Gaussian or Voigt) line shapes[8-11].

In this report, temperatures of HCD plasma are studied for several different Ar/rare-earth metal HCDs by illumination a CW diode laser tuned to the resonant frequency of the Ar metastable transition. A semiconductor diode laser is an appropriate light source for studying the Ar discharge because most lines for 1s-2p transitions of Ar are located in the near-infrared wavelength region[12].

In this experiment, the measurement of plasma temperature of hollow cathode discharge using the OG line shapes as been performed in a 801.479 nm($1s_5$-$2p_8$ metastable transition of Ar).

2. EXPERIMENT

The experimental setup is shown schematically in Fig. 1. Several different commercial HCD tube (Cathodeon Ltd., model 3QQAY/La, 3QQAY/Sm) were used in the experiment. Each one consists of a hollow cylindrical cathode with two-ring anodes and contains argon gas at a pressure of about 5-8 mbar.

The discharge was produced by a high voltage power supply (Bertan Associate, Inc., model series 105). Current limiting resistors of 10 kΩ were used for each anode and the OG signal was detected by blocking the dc voltage using a

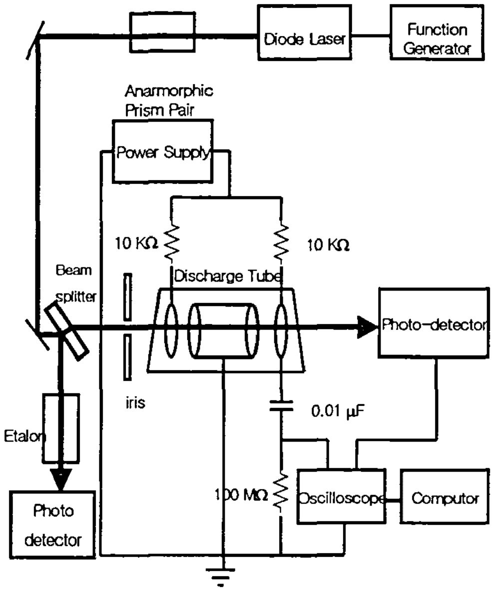

Fig. 1. Experimental setup for plasma diagnosis of hollow cathode discharge.

coupling capacitor of 0.01 μF. We used single-mode diode laser system which have center wavelength of 810 nm(New Focus Inc., 6200 controller with model 6226 laser head). An anarmorphic prism pair and iris diaphragm of 2 mm diameter were used to make an appropriate laser beam shape. A small part of the laser beam was split off by using a thin glass plate and sent to a confocal Fabry-Perot etalon (Tec Optics, model SA-300).

The laser beam path was carefully adjusted to pass through the center of the negative glow region inside the cathode. The measured diameter of the negative glow region for our discharge was larger than the radius of the cathode. The laser beam power in front og the HCD tube was 1 mW and more than 90 % of the input power was transmitted through the HCD tube with the discharge off. With the laser wavelength fixed at the center of a transition line of Ar, the OG signal was obtained with a digitizing oscilloscope (Hewlett Packard, model 54600B).

3. RESULT AND DISCUSSION

In our experiment, the cylindrical cathode was open-ended in both directions and was placed between two hollow anodes. The use of two anodes ensured that the whole length of the cathode bore was covered with a negative glow in the axial direction. On the other hand, the cathode dark space and negative glow region occupied the HCD mainly in the radial direction[13]. These discharge regions were well defined visually by monitoring the appearance of the plasma emission, as shown in Fig 2. The cathode dark space, which is characterized by a low level of emission intensity and which is represented by the green color, occupied the outer part of the discharge. At the part, the strong emission intensity represented by the red color shows the negative glow region. Between the negative glow and the dark space, an intermediate region existed and is represented by

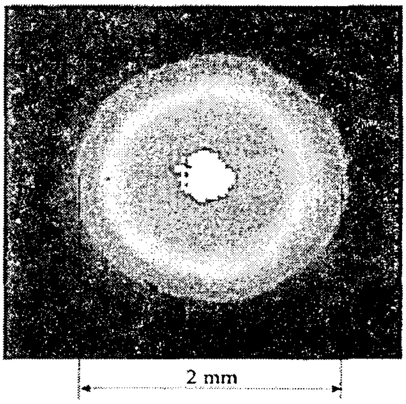

Fig. 2. Plasma emission appearance in the radial direction. The laser beam, represent by the white spot, passed through the central part. The red color occupying the central part corresponds to the strong emission intensities and indicates the negative glow region. The green color corresponding to the weak intensities indicates the dark cathode space. The intermediate is shown as the yellow color.

the yellow color. The laser beam at a diameter of about 2 mm is also shown as the small white spot and the passed through only the negative glow region in the radial direction.

A Schematic diagram of the relevant energy levels [14] is shown in Fig. 3. The lowest excited electronic configuration of Ar consists of four $1s_i$ levels. Two of these are states, $1s_3$ and $1s_5$ are metastable. The $1s_4$ state is quasi-metastable with a slight triple-singlet mixing. The $1s_2$ state is radiatively coupled with the ground state. The next excited configuration consists of the $2p_j$ levels radiatively coupled to the $1s_i$ levels.

In the current range over 3 mA, the OG line shapes resemble those of absorption and be used to diagnose the characteristics of the discharge plasma. A typical line shape of Gd at a current of 8 mA is shown in Fig. 4, and it fits well to a Gaussian line shape. The temperature of the plasma, T(K), is given by

$$\frac{\Delta\nu_D}{\nu_0} = \sqrt{\frac{8kT\ln 2}{Mc^2}}$$

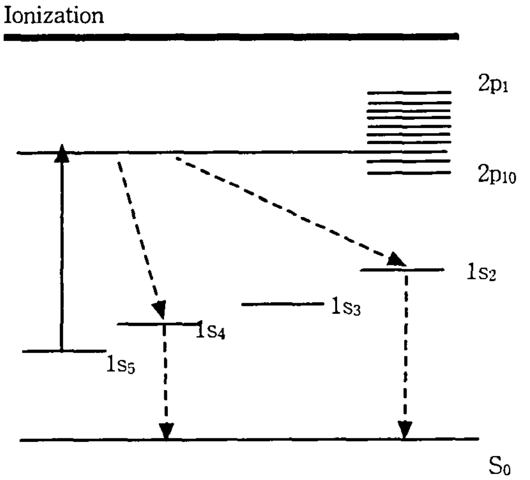

Fig. 3. Energy level diagram for the $1s_i$-$2p_j$ argon transitions studied in this work. Each electronic state is labelled by its Paschen notation.

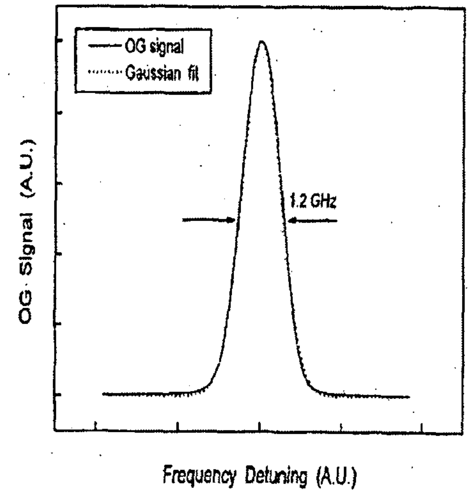

Fig. 4. OG line shape at a current of 8 mA. It agrees with a Gaussian profile having a line width (FWHM) of 1.2 GHz in Sm/Ar HCD

where $\Delta\nu_D$ is the Doppler-broadened line width (FWHM), ν_0 is the center frequency of the transition, M is the mass of the atom, k is the Boltzmann constant, and c is the speed of light. The line width, $\Delta\nu_D$, was estimated from the line profile of the OG spectrum at 801.479 nm for each HCD. The precision of the line width measurement depends on the accuracy of the free spectral range of the frequency marker.

The measured the Doppler width and plasma temperature of the HCD is summarized in Table 1. In this experiments, the error of the measured line width was about ±0.33 GHz corresponding to the error of ±55 K.

Table 1. The plasma temperature of Ar hollow cathode discharge.

Cathode elements	FWHM (GHz)	Temperature (K)
La	1.18	684
Sm	1.20	710
Yb	1.26	780

4. CONCLUSION

The measurement of the optogalvanic line shape is demonstrated as complemental methode to understand the characteristic of HCD plasma.

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