Multi-emission Line High-resolution Plasma Spectroscopy on a Micro-hollow Cathode Atmospheric-pressure Helium Discharge

Masahiro Hasuo¹, Shinichi Namba², Keisuke Fuji¹, Taiichi Shikama¹ and Hiromichi Azuma¹

1, Graduate School of Engineering, Kyoto University, Yoshidahonmachi, Sakyo-ku, Kyoto 606-8501, Japan
2, Graduate School of Engineering, Hiroshima University, 1-4-1, Kagamiyama, Higashi-Hiroshima 739-8527, Japan

We have simultaneously observed line profiles of neutral helium 2¹P-3¹D (587.6 nm), 2¹P-3¹D (667.8 nm) and 2¹P-3¹S (706.5 nm) emissions from a 1 mm-diameter hollow cathode plasma at gas pressures from 0.03 to 1 atm. We estimate the Lorentz and Gauss widths from the observed profiles, and then deduce the electron temperature and density and the gas temperature from the widths. The electron density increases as an increase in the gas pressure with the power of about 0.8, and reaches 9.4 x 10²¹ m⁻³ at 1 atm. The electron and gas temperatures are estimated to be about 15000 K and 600 K, respectively, and their pressure dependences are not clearly observed.

1. Introduction

Atmospheric-pressure plasmas gather much notice for many kinds of applications because of their freedom from vacuum enclosure and high particle density [1]. However, since the size of such plasmas is usually small, the plasma diagnostics with an electric probe cannot be applied. Recently, Namba et al. have demonstrated passive emission spectroscopy for the hydrogen Balmer-α and helium 2¹P-3¹D line profiles of a micro-hollow cathode atmospheric-pressure plasma to estimate the electron density, nₑ, and temperature, Tₑ, and the gas temperature, T_g [2]. Here, we propose a method to estimate nₑ, Tₑ and T_g in such a plasma with observing line profiles of helium 2¹P-3¹D (667.8 nm), 2¹P-3¹S (706.5 nm) and 2¹P-3¹D (587.6 nm) emissions simultaneously. For the purpose, we use a multi-wavelength-range fine-resolution (MF) spectrometer developed by ourselves [3].

2. Experiment

Figure 1 shows a schematic illustration of the experimental set-up. A hollow cathode DC plasma is generated between brass cathode and anode separated by a 1 mm-thick ceramic insulator plate, all of which have an 1 mm-diameter discharge hole in the center [2]. The discharge chamber equips an observation window from the cathode side. Emission from the plasma is collected by an achromatic lens and introduced to the entrance slit of the MF spectrometer [2]. The introduced emission is collimated to be a parallel beam by a concave mirror (M; focal length: f = 54 mm). The parallel light beam is incident on a diffraction grating (2400 grooves/mm). The diffracted light beams are focused on a CCD detector (Andor, DV435-BV) by three concave mirrors (M₅₈₇.₆, M₆₆₇.₈, M₇₀₆.₅; f = 54 mm) set at the locations which correspond to the wavelengths of the observed emission lines.

3. Results and discussion

Figure 2 shows examples of the observed spectra at gas pressures of 0.03, 0.14, 0.52 and 1 atm together with the spectra of a low-pressure helium glow discharge. The pressure dependent
broadenings are clearly seen for all the lines, and the magnitudes of the broadening are different from each other. The broadening is caused by electron, ion and atom collisions, which contribute the Lorentz width, $W_L$, and the gas temperature, which contributes the Gauss width, $W_G$. The natural broadening caused by spontaneous emission is negligible in comparison with the observed widths.

Fig. 2. Observed line profiles of the $2^1P-3^1D$ (667.8 nm), $2^3P-3^3D$ (587.6 nm) and $2^3P-3^3S$ (706.5 nm) emissions. + : data points. The lines are the fitted results with a Voigt function convoluted to the instrumental function.

In order to extract $W_L$ and $W_G$ from fitting to the observed spectra, we have to determine the instrumental function of the MF spectrometer. For this purpose, we measured and reproduced respective spectra of a low-pressure helium glow discharge, which have negligible Lorentz widths and a well-determined Gauss widths from the gas temperature. Fig. 3 shows the extracted $W_L$ and $W_G$. The fitted results with convolution of the instrumental function are shown by lines in Fig. 2.

Fig. 3. (a) $W_L$ and (b) $W_G$ as a function of gas pressure. The horizontal lines are the instrumental widths.

At lower pressures, $W_L$ became smaller than the instrumental Lorentz width, $W_L^1$. On the other hand, $W_G$ is smaller than the instrumental Gauss width, $W_G^1$, in almost all the cases. The scatter of $W_G$ increases with an increase in the gas pressure because $W_L$ becomes one order of magnitude larger than $W_G$ at higher pressures, and then the accuracy of the $W_G$ estimation decreases. Therefore, we use $W_L$ at the pressures higher than 0.2 atm in the following analysis.

For the observed emission lines, the Stark broadening coefficients caused by electron and ion collisions have been calculated as a function of $T_e$ [4] and the broadening coefficients due to atom collisions have been measured at several $T_g$ [5-8]. Since these broadening coefficients are different to each other for the emission lines, we numerically solved a simultaneous equation for the measured three $W_L$ to estimate $n_e$, $T_e$ and $T_g$.

Figure 4 shows the results. It is found that $n_e$ increases as an increase in the gas pressure with the power of ~0.8, while the dependence of $T_e$ and $T_g$ are not clearly observed. From $n_e$ and $T_g$, the degree of ionization at 1 atm is estimated to be $7 \times 10^{-4}$.

Fig. 4. (a) $n_e$ and (b) $T_e$ and (c) $T_g$ as a function of gas pressure.

Acknowledgments

This work was partly supported by Grant-in-Aid for Scientific Research (B) (No.21340170).

References


