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

マイクロホローカソード大気圧ヘリウム放電の複数発光線同時高分解プラズマ計測

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We have simultaneously observed line profiles of neutral helium 2^3P-3^3D (587.6 nm), 2^1P-3^1D (667.8 nm) and 2^3P-3^3S (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 10^{21} 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 2^1P-3^1D line profiles of a micro-hollow cathode atmospheric-pressure plasma to estimate the electron density, n_e, and temperature, T_e, and the gas temperature, T_g [2]. Here, we propose a method to estimate n_e, T_e and T_g in such a plasma with observing line profiles of helium 2^1P-3^1D (667.8 nm), 2^3P-3^3S (706.5 nm) and 2^3P-3^3D (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_c; 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 ($M_{587.6}$, $M_{667.8}$, $M_{706.5}$; f = 54 mm) set at the locations which correspond to the wavelengths of the observed emission lines.

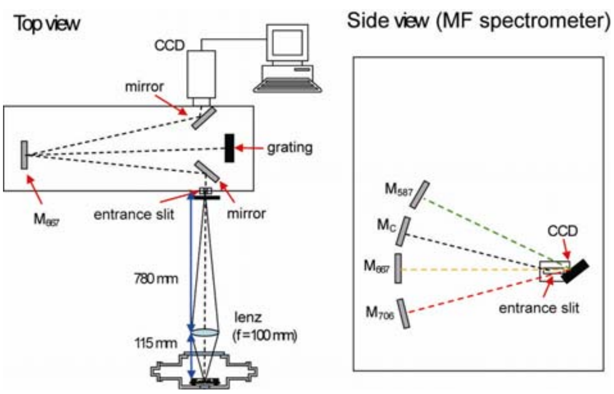

Fig. 1. A schematic illustration of the experimental set-up and MF spectrometer.

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.

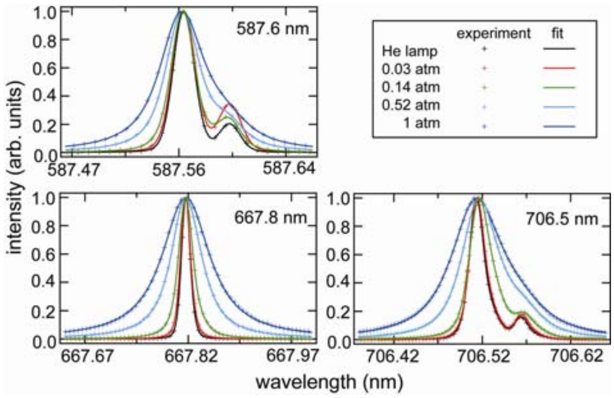

Fig. 2. Observed line profiles of the 2^1P-3^1D (667.8 nm), 2^3P-3^3D (587.6 nm) and 2^3P-3^3S (706.5 nm) emissions. + : data points. The lines are the fitted results with a Voigt function convoluted to the instrumental function.

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.

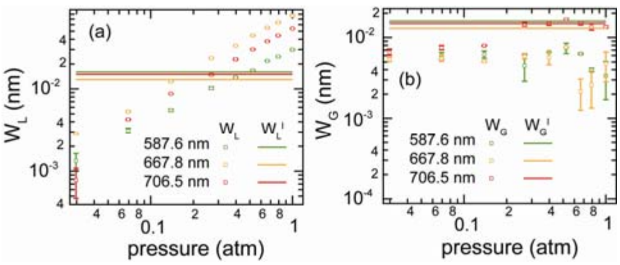

Fig. 3. (a) W_L and (b) W_G as a function of gas pressure. The horizontal lines are the instrumental widths.

At lower pressures, W_L became smaller than the instrumental Lorentz width, W_L^I. On the other hand, W_G is smaller than the instrumental Gauss width, W_G^I, 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 x 10^{-4}.

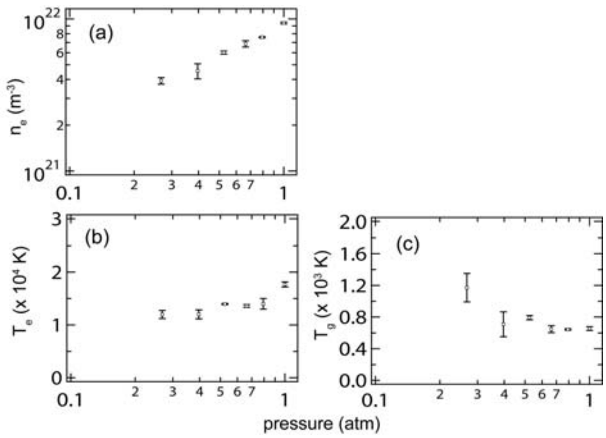

Fig. 4. (a) n_e and (b) T_e and (c) T_g as a function of gas pressure.

Acknowledgments

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