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Absorption Spectra Measurement of Helium Atoms in Micro-Hollow Cathode Atmospheric-Pressure Plasmas by a Diode Laser

マイクロホローカソード大気圧プラズマ中ヘリウム原子の
半導体レーザー吸収スペクトル計測

Shota Yamawaki, Daisuke Morita, Koichi Katayama, Taiichi Shikama and Masahiro Hasuo
山脇翔太，森田大輔，片山光一，四竈泰一，蓮尾昌裕

Graduate School of Engineering, Kyoto University
Yoshida-Honmachi, Sakyo-ku, Kyoto 606-8501, Japan
京都大学大学院工学研究科　〒606-8501　京都市左京区吉田本町

We have measured absorption spectra of the He I 2^1P-3^1D (667.8 nm) transition in a micro-hollow cathode helium plasma at gas pressures from 0.04 to 1 atm with a vertical-cavity surface-emitting laser diode. From a fit with a Voigt function we estimated Lorentz and Doppler widths. The Lorentz width increases as an increase in the gas pressure, while the Doppler width gradually decreases below 0.2 atm. It is found that the Lorentz width at the gas pressure lower than 0.2 atm is mainly due to the pressure broadening.

1. Introduction

Recently, micro-plasmas attract much attention due to their possibility of many applications such as a UV radiation source, pollutant removal and surface cleaning [1,2]. Micro-plasmas can be generated even at an atmospheric pressure [3].

Line profile analysis with atomic emission spectroscopy is one of the characterization methods for such a small plasma [4]. Laser absorption spectroscopy has advantage in the spectral resolution because its instrumental function can be usually neglected. However, since the line profile broadens largely due to atom, ion and electron collisions in a high pressure plasma, a large range of light frequency scan is necessary.

It is known that a vertical-cavity surface-emitting laser (VCSEL) diode offers this feature [5]. Here, we apply it to high-resolution absorption spectroscopy for a micro-hollow cathode helium plasma.

2. Experiment

Figure 1 shows a schematic diagram of the experimental set-up. The light source is a VCSEL (vixar, V670S-002-0001). We scan a light frequency over the He I 2^1P-3^1D transition by sweeping an injection current to the laser diode using a function generator (IWATSU ELECTRIC, FG-330) at a repetition rate of 5 Hz. The swept light frequency range is about 230 GHz.

A collimated laser beam passes through an optical isolator (ISOWAVE, I-6070-CM), and then is split into two beams by a half mirror (SURUGA SEIKI, F56-30). One of the beam enters a confocal Fabry-Perot interferometer (TecOptics, SA-300, free spectral range=1.89 GHz) used as a frequency marker. The other beam passes through a discharge chamber. In the chamber, 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 [4]. The discharge chamber is filled with a pure helium gas at pressure from 0.04 to 1.0 atm. The light intensity transmitted through the plasma is detected by a photo-detector placed behind the chamber. The signals from the function generator, the photo-detector and the Fabry-Perot interferometer are simultaneously recorded by a personal computer via an AD convertor (KEYENCE, NR-2000).

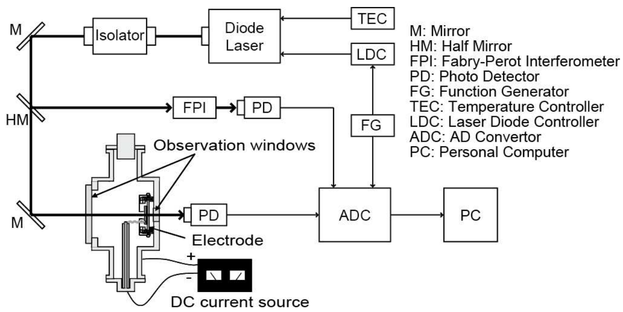

Fig. 1. The experimental set-up.

3. Result and Discussion

Figure 2 shows an example of raw data at the gas pressure of 0.04 atm. Fig. 2(a) shows the injection current and the frequency marker signal. Fig. 2(b) shows the photo-detector signals recorded for the following three cases; (1) both the laser and discharge on, $I^{(1)}$, (2) only the laser on, $I^{(2)}$, and (3) only the discharge on, $I^{(3)}$. The absorption spectrum can be calculated as -ln ($I^{(1)}$ - $I^{(3)}$)/ $I^{(2)}$.

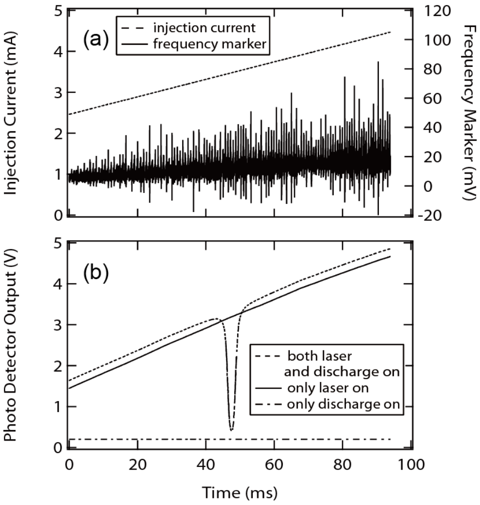

Fig. 2. An example of raw data. (a) The injection current to the laser diode and the frequency marker signal. (b) The photo-detector signals.

Figure 3(a) shows thus calculated absorption spectra at gas pressures of 0.04, 0.13, 0.39 and 1 atm as a function of the light frequency detuning from the absorption peak. The light frequency is calibrated by the frequency marker signal. In Fig. 3(b), the absorption is normalized by the peak value for the purpose of comparing the line shapes. The pressure dependent broadenings are clearly seen.

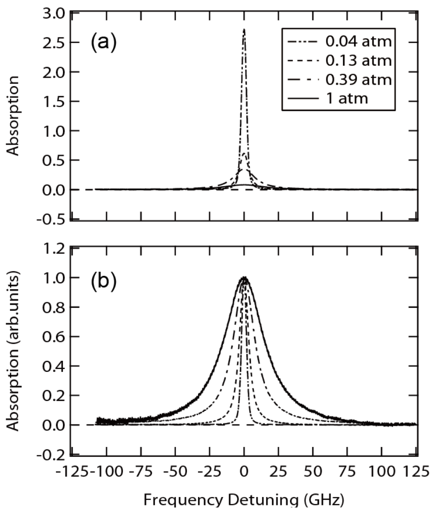

Fig. 3. (a) Absorption spectra at gas pressures at 0.04, 0.13, 0.40, 1 atm. (b)Normalized absorption spectra.

It is known that there are two kinds of broadenings; the Doppler and Lorentz broadenings. The former is caused by the atomic motions reflecting the gas temperature and the latter is caused by atom, ion and electron collisions.

We fit the absorption spectra with a Voigt function having five adjustable parameters of the Doppler and Lorentz widths (FWHM), the vertical and horizontal offsets and the area. Fig. 4 shows the estimated Doppler and Lorentz widths as a function of the gas pressure. The Lorentz width increases as an increase in the gas pressure. Since the Lorentz width becomes very large at the gas pressures higher than 0.2 atm, it becomes hard to estimate the Doppler width. Therefore, we plot the Doppler width at the pressures below 0.2 atm.

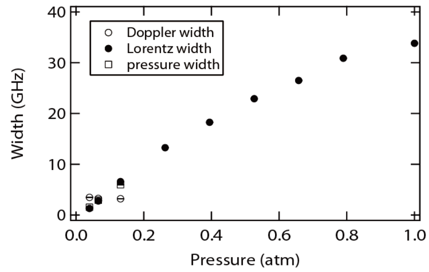

Fig. 4. Pressure dependence of the Doppler, Lorentz and pressure widths.

We calculate the gas temperature from the Doppler width to be 470.4 ± 0.7, 414.4 ± 0.6 and 402.6 ± 1.5 K at 0.04, 0.06 and 0.13 atm, respectively. From these gas temperatures and pressures, we estimate the pressure width, which is caused by atom collisions, using its broadening coefficient [6]. The result is shown in Fig. 4. The difference between the observed Lorentz width and the pressure width may give the Stark width, which is caused by ion and electron collisions. However, the difference is not clearly detected.

Acknowledgments

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