20PB-111

Spectroscopic Measurement of Atomic Hydrogen Impurity in a Microhollow Cathode Helium Plasma

マイクロホローカソードヘリウムプラズマ中の不純物水素原子の分光計測

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We observed spatially resolved Stark-split spectra of Balmer-β line of atomic hydrogen impurity in a microhollow cathode helium plasma. Each polarization component of the spectra observed was fitted by using theoretical intensities calculated with analytical hydrogen wavefunctions on parabolic coordinate. The electric field strengths of 6-10 kV/cm were derived from the fitting of the Stark-split spectra, however, the line width of each spectrum was much broader than the value expected from the temperature of the microhollow plasma. By comparing line widths between each polarization component, the line broadening was found to come from the lack of spatial resolution owing to spherical aberration of lens.

1. Introduction

Microhollow cathode discharge (MHCD) is one of the efficient methods to generate an atmospheric pressure plasma and relevant reactive species for many applications. For further utilization of the atmospheric pressure plasma by MHCD, the relation between plasma parameter and reaction dynamics should be made clear. Spatial distribution of an electric field strength is one of the most important parameters to characterize internal dynamics of MHCD plasmas, however, highly resolved spatial distribution of electric field in the microhollow cathode has not been reported. Such a field distribution is essential to discussion of the effect of sheathe region.

Recently, we have reported a measurement of electric field formed in sub-atmospheric microhollow cathode plasma by using Balmer-β line of hydrogen atom [1]. In the present study, we complement our previous report especially from the viewpoint of line widths of Stark-split spectra.

2. Theory

Stark splitting of atomic hydrogen lines was discussed in detail by Bethe and Salpeter [2]. In particular, analytical treatment of the relative intensities among each Stark-split line has seldom been discussed in other publications. The shift of line λ_{shift} [cm^{-1}] is represented by

Table I. Principal spectral lines of Stark-split H_β line calculated by analytical formulae.

	d_L	Relative Intensity
π component	± 6	0.1233
	± 8	0.5846
	± 10	0.5496
σ component	± 2	0.2192
	± 4	1.3885
	± 6	0.8952

$$\lambda_{\text{shift}} = \frac{F}{15621.6}\, d_L, \tag{1}$$

where F [kV/cm] is the electric field strength and d_L is an integer being composed of quantum numbers on parabolic coordinate. We calculated theoretical relative intensities of each split-line by using analytical formulae and relevant statistical weights. Calculated results on each polarization component are shown in Table I. The transitions whose intensities are less than 0.03 were omitted.

3. Experiment

The MHCD assembly was placed in a vacuum chamber. Both cathode and anode are made of brass, and the insulators are ceramics MACOR®. The cathode disk has an inner-hole diameter of 1.0 mm and a length of 2.0 mm [3]. The helium gas was fed into the chamber at a flow rate of 0.5 L/min through the cathode hole. The discharge was operated at a

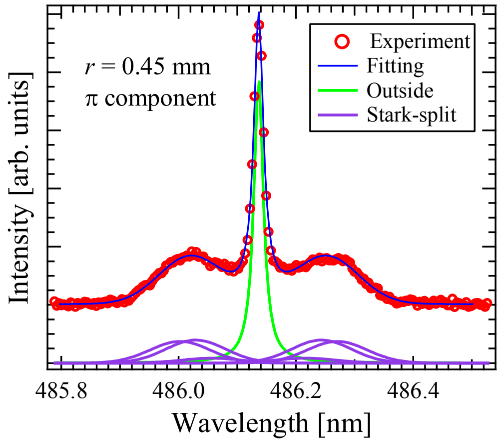

Fig.1. Stark-split H_β spectrum of π polarization component, curve reproduced by using theoretical relative intensities, and each component obtained by fitting procedure [r=0.45 mm].

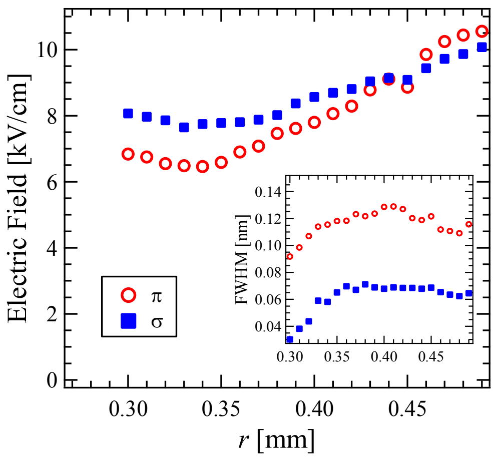

Fig.2. Electric field distribution derived by the analysis of the Stark splitting on each polarization. Inset shows line width fitted for each Stark-split transition component.

20 mA with a discharge voltage of 200 V and the gas pressure of 1 kPa. The plasma emission was measured by a high-resolution visible spectrometer (HR 1000, Jovin Yvon, 2400 grooves/mm) from the axial direction of the cathode. The plasma image was magnified by 7 times by a spherical lens (f=350mm). The spectral resolution of the spectrometer was estimated to be 8.9 pm (FWHM) by measuring a HeNe laser line at 632.8 nm.

4. Results and Discussion

An example of obtained H_β spectrum is shown in Fig. 1. The source of atomic hydrogen would be MACOR® as the insulator or water in the helium gas. The most intense peak was observed in the center of the spectrum. The center peak would come from the hydrogen atoms that exist outside the microhollow cathode (outside component).

The spectra observed were fitted to derive electric field strengths. We assumed that the outside component was fitted by the lorentzian curve, whereas the stark-split components were fitted by six gaussian having the same line widths and calculated relative intensities.

Spatial distribution of the electric field strength is shown in Fig. 2. The field strength derived from each polarization component should be the same, however, the difference was observed especially in the region far from the electrode surface. The large signal from atoms outside microhollow cathode might be hindering the measurement of weak electric field.

The inset of Fig. 2 shows the line widths of Stark-split spectra determined by the fitting. The line width for π component corresponds to 10-eV Doppler broadening, which was much higher than a practical temperature of the plasma in MHCD. Moreover, the line widths were significantly different between π and σ components. We found that the ratio of line widths of π to σ component (~1.8) agrees with the value of weight average of d_L on each component (~1.85). This indicates that the broadening of line width is coming from the deviation of the electric field strength in single spectrum by the lack of spatial resolution in observation due to spherical aberration (FWHM: ~0.13 mm) of the lens.

5. Conclusion

We obtained spatial distribution of electric field strength by fitting H_β Stark-split spectrum. Because of the steep change of the electric field on radial position, the lack of spatial resolution probably induce further broadening of the line width, resulting in significant error of the electric field strength.

Acknowledgments

We thank Mizuki Nakai for his contribution to ray-tracing simulation.

References

[1] L. Mastuoka, D. Maki, K. Yanagiya, S. Namba: The Papers of Technical Meeting on Plasma Science and Technology, IEE Japan, PST-14-21, pp. 13-17 (2014) [in Japanese].

[2] H. A. Bethe and E. E. Salpeter: "Quantum Mechanics of One- and Two-Electron Atoms", Dover Publications, New York (2008).

[3] S. Namba, T. Yamasaki, Y. Hane, D. Fukuhara, K. Kozue, and K. Takiyama: J. Appl. Phys., **110**, 073307 (2011).