22E09

Diagnostics of a Slot-antenna Excited Atmospheric-pressure Microwave Plasma by Space- and Time-Resolved Optical Emission Spectroscopy

時空間発光分光によるスロットアンテナ励起大気圧マイクロ波プラズマの診断

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Ar/H_2 atmospheric pressure plasma excited by a pulsed microwave in a slot antenna was investigated to understand an electric field influence on hydrogen Balmer-β (H_β) spectral profile using space- and time-resolved optical emission spectroscopy. Strong optical emission intensity from the plasma was observed in the vicinity of electrode. At the early stage of plasma ignition, especially in the vicinity of the slot antenna, clear difference between parallel- and perpendicular-polarized H_β emission line profiles with respect to the microwave electric field direction was observed by a polarization spectroscopy technique, suggesting influence of the microwave electric field on H_β line profiles.

1. Introduction

Atmospheric pressure non-equilibrium plasmas have been given much attention due to its high chemical reactivity with low process temperatures in the atmosphere. Generally, to produce non-equilibrium plasma, pulsed high voltage is applied to electrodes so as to suppress arc discharges. Accordingly, to understand pulsed atmospheric pressure plasma, not only time-averaged plasma parameters but also temporal dependence of plasma parameters is very important.

Optical emission spectroscopy (OES) has been used for diagnostics of atmospheric pressure plasmas as an intrusive technique. As one of OES measurement techniques, electron density, one of typical and important plasma parameters, has been evaluated from hydrogen Balmer-β (H_β) line width [1,2]. This measurement is based on Stark broadening of the H_β line width due to micro electric fields in the vicinity of excited H atoms. However, there is a possibility that the line profile is also influenced by externally-applied electric fields.

In this study, time-resolved OES with a high spatial resolution is applied to investigate the production process of pulsed atmospheric pressure microwave plasma. Influence of applied electric field on the plasma density measurement is discussed from the difference of line widths between parallel and perpendicular polarization with respect to the microwave electric field direction. Spatial variation of emission from the plasma is also investigated, varying the electrode distance.

2. Experimental

Figure 1 shows schematic of experimental apparatus. Ar and small amount of H_2 are introduced into a waveguide line through independent mass flow controllers at fixed flow rates of 1000 sccm and 16 sccm, respectively. A non-equilibrium atmospheric pressure microplasma is produced inside a slot antenna at the end of the waveguide line, using pulsed 2.45 GHz microwave

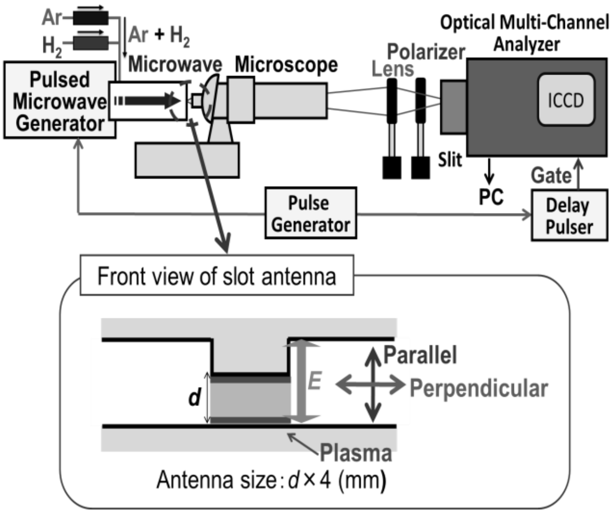

Fig. 1. Schematic of experimental apparatus.

(pulse width: 70 μs, repetition frequency: 10 kHz, peak power: 150 W). The length of the slot antenna is 4 mm and the slot antenna gap (d) is varied from 0.2 to 0.8 mm. Emission image from the plasma is focused on an entrance slit of an optical multi-channel analyzer (OMA) and also on a CCD detector of the OMA through a relay lens of 5 cm diameter and a microscope. This enables us to measure spatial profile of the emission across the slot gap. To evaluate a microwave electric field from H_β spectral profile, a polarizing filter is placed in front of the OMA entrance slit. Here, direction of the polarization is defined as "parallel" and "perpendicular" with respect to the direction of the microwave electric field across the slot antenna gap, as shown in Fig.1. In this study, T=0 is defined at a time of microwave power injection an x-axis is defined as a direction across the slot antenna with the origin at the center of the slot gap.

3. Results and Discussions

To understand spatial and temporal variation of the plasma, emission intensity profile is obtained along x-axis. In this measurement, zeroth order light from the grating is focused on the CCD and images for 30 pulsed discharges are accumulated. Figure 2(a) and (b) show optical emission profiles along x axis for two slot widths d=0.2 and 0.8 mm, respectively, at T=0.3 and 40.1 μs. The emission intensity profiles are symmetric, indicating the production of symmetric plasma. Furthermore, strong emission intensity is observed in the vicinity of electrodes, irrespective of the measurement time and the slot gap distance.

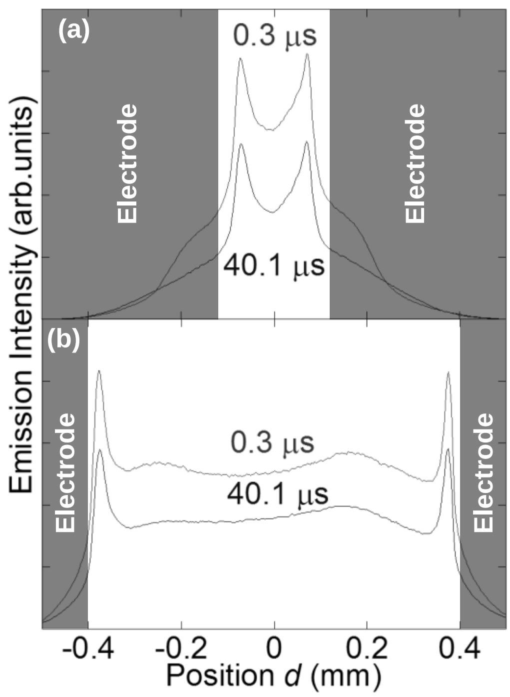

Fig. 2. Optical emission profiles of (a) d=0.2 mm and (b) d=0.8 mm.

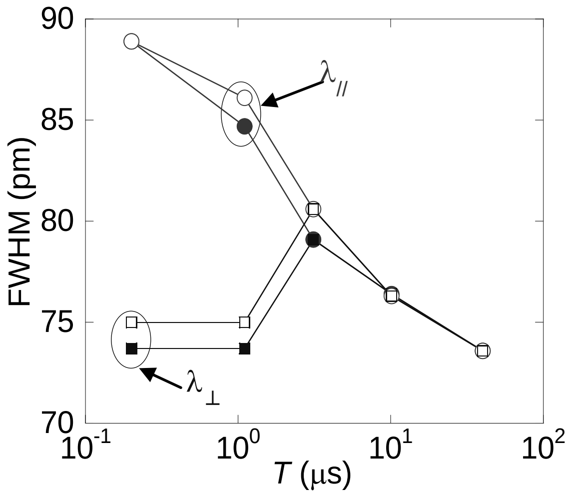

Fig. 3. $\Delta\lambda_{//}$ and $\Delta\lambda_{\perp}$, as a function of T. Open and closed symbols denote measurements in the vicinities of lower and upper slot electrodes, respectively. Slot width is 0.8 mm.

To give an insight into the plasma structure, temporal variations of the full-width at half-maximum (FWHM) line widths of H_β spectra are measured in the vicinities of two slot edges as a function of time. Here, $\Delta\lambda$ denotes the FWHM line width of H_β, and subscripts of // and $\perp$ denote parallel and perpendicular polarizations, respectively. Clear differences between $\Delta\lambda_{//}$ and $\Delta\lambda_{\perp}$ are observed at T<1 μs, indicating influence of strong electric field on H_β spectral profiles at the beginning of the plasma ignition. It should be also pointed out that almost same $\Delta\lambda_{//}$ and $\Delta\lambda_{\perp}$ are obtained both in the vicinities of two slot antenna edges during the discharge, suggesting the symmetrical plasma production in the slot antenna.

4. Conclusions

Influence of the microwave electric field across the slot antenna gap was discussed from the difference of line widths. From space-resolved emission intensity measurements, symmetric discharge across the slot antenna was confirmed. From time- and space-resolved H_β line width measurements, symmetric and strong electric field in the vicinity of the slot antenna was suggested at the early stage of plasma production.

Acknowledgement

This work was supported by Grant-in-Aid for Scientific Research (C) 21540509 by MEXT.

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