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Effect of Plasma Excitation Frequency on the Discharge Characteristics of Atmospheric Plasma Jet

大気圧プラズマジェット放電特性に及ぼす励起周波数の効果

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We present discharge phenomena of He atmospheric-pressure RF plasma in frequency region from 13.56 to 100 MHz. Gas-breakdown voltage for discharges decreases with an increase in RF voltage frequency. Discharge characteristics drastically change with increasing RF voltage frequency (f_{RF}); for f_{RF} = 20 MHz, low optical emission of O 777 nm is observed in whole discharge space, while for f_{RF} = 60 MHz, high O 777 nm emission is localized in front of the power and ground electrodes.

1. Introduction

Non-equilibrium atmospheric-pressure discharges have been widely investigated with great attentions to be utilized for a variety of applications from industrial surface processing of materials to advanced medical treatments of biomedical tissues (plasma medicine) to cure diseases including cancer [1,2]. For development of suitable plasma source for plasma medicine, in which the discharge generation at lowered power and with effective production of excited species for the medical treatments, it is considered to be of great significance to investigate the effect of the discharge-voltage frequency on the gas-breakdown voltage and discharge characteristics [3–9].

In this study, atmospheric-pressure gas-breakdown and discharge characteristics have been investigated with RF voltages in the frequency region from 13.56 to 100 MHz. The results showed that the gas-breakdown voltage with RF voltages was considerably lower than that for the DC voltage. The effects of the discharge-voltage frequency on the breakdown phenomena and discharge characteristics are discussed in the study.

2. Experimental

The helium (He) atmospheric RF discharge was investigated in open air. The RF sine voltage was applied to the tungsten wire of 0.5 mm in diameter, where the tungsten power electrode is covered with a ceramic tube and a quartz tube of 1.2 and 3.0 mm in diameter, respectively. The stainless plate was used as a ground electrode, and placed at d = 0.6 mm away from the RF power electrode. He gas was supplied inside the quartz tube with the flow rate of 0.5 slm. Dynamic behavior of atmospheric RF discharge was measured by charge coupled device (CCD) camera with microchannel plate that amplifies the detected light signal. Voltage of RF discharge was measured by a voltage probe, respectively. Optical emission spectra from RF discharge were measured with CCD spectrometer with wavelength range of 300–900 nm.

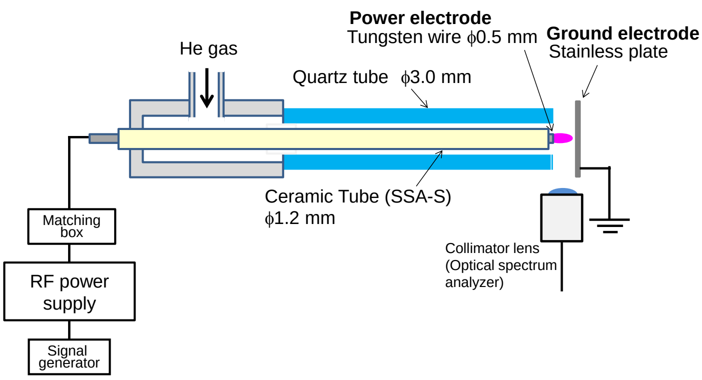

Fig. 1. Experimental setup for atmospheric He RF discharge in open air.

3. Results

Gas-breakdown voltage linearly decreases from 208 to 156 V when RF voltage frequency increases from 13.56 to 60 MHz, and low RF voltage operation of discharge is successfully realized under He atmospheric-pressure condition. It is worth noting that the gas-breakdown voltage for the RF discharge is considerably lower than 600 V for DC discharge.

Then, in order to investigate the effect of RF voltage frequency on discharge characteristics, optical emission spectrum measurements were performed. Figure 2 shows dependence of optical emission intensity of O 777 nm ($I_{O:777\ nm}$) on RF voltage, as a function of RF voltage frequency (f_{RF}). O emission intensity increases with applied RF voltage. In particular, for f_{RF} = 100 MHz, high O emission intensity is obtained at low RF voltage of 100 V. This indicates that highly reactive O species, which are most desired in many plasma material processings, are effectively produced for high RF frequency operation of discharge.

Figure 3 shows CCD camera images of RF discharges at f_{RF} = 20 and 60 MHz. Optical emission signals of O 777 nm are detected by CCD camera through optical bandpass filter. Spatial structure of RF discharge drastically changes with increasing discharge frequency. For f_{RF} = 20 MHz, low optical emission of O 777 nm is observed in whole discharge space, while for f_{RF} = 60 MHz, high O 777 nm emission is localized in front of the power and ground electrodes. Our experiments clearly demonstrated that higher RF frequency operation of discharges is effective for lower gas-breakdown voltage and high rate production of reactive O species.

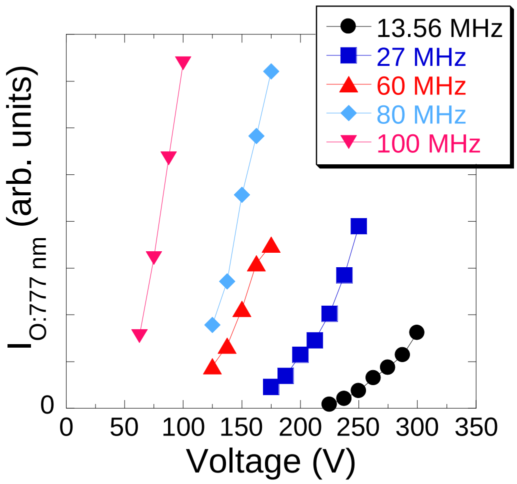

Fig. 2. RF voltage dependence of optical emission intensity of O 777 nm ($I_{O:777\ nm}$), as a function of RF voltage frequency.

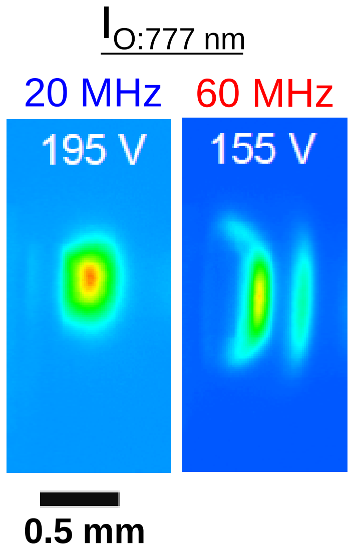

Fig. 3. CCD camera images of RF discharges at RF voltage frequency of 20 and 60 MHz. Optical emission signal of O 777 nm ($I_{O:777\ nm}$) is detected by CCD camera through optical bandpass filter.

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