Characteristics of Atmospheric Helium Dielectric Barrier Discharges Depending on Electric conditions of Nanosecond Pulsed Power

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Abstract: It is well known that dielectric barrier discharges (DBDs) using nanosecond pulsed power show better performance than that of conventional ones in terms of energy efficiency. However, it remains unclear understand the discharge characteristics of pulsed DBDs depending on electrical conditions. In this study, atmospheric-pressure helium plasma is generated by nanosecond pulse DBDs for investigating the dependence of plasma characteristics on the applied voltage, pulse width, and frequency. The plasma characteristics such as electron density and temperature are measured using the optical emission spectroscopy technique. This paper presents the nanosecond pulsed DBDs plasma characteristics depending on the electric conditions of nanosecond pulsed power.

Keywords: Dielectric barrier discharges, Atmospheric nonthermal plasma, Helium plasma, Nanosecond pulsed power, Electron density, Electron temperature, Optical emission spectroscopy

1. Introduction

Dielectric barrier discharges (DBDs) are self-sustaining electrical discharges that occur in electrode arrangements where the discharge channel contains an insulating substance [1]. The functioning of a self-pulsing plasma and the subsequent creation of a nonthermal plasma at normal pressure is caused by this so-called dielectric barrier. They were initially developed in 1857 to produce ozone [2] but have since expanded to include a wide range of other uses, such as surface treatment, plasma medicine, pollutant molecular breakdown in gases, pumping gas lasers, plasma displays, and the production of excimer radiation [1]. When compared to micro or milli-pulsed plasmas, the pulse width of high voltage waveforms is greatly reduced in nanosecond pulsed discharges, which results in lower power consumption [3]. Furthermore, due to the short pulse width of the applied waveforms, nanosecond pulsed discharges can create plasmas while creating less heat in optical emission spectrometry. [4]. The physical and chemical characteristics of plasma are largely governed by electrons. To comprehend the fundamental features of the plasma, the electron density and temperature are crucial plasma parameters. The plasma characteristics such as electron density and temperature are measured using the optical emission spectroscopy (OES) technique. An OES technique combined with a collisional-radiative (CR) model is developed for measuring the electron temperature and density of low temperature helium plasma [5]. Woonwok Lee has developed a Helium CR model for understanding the spectra and kinetics of the Helium plasma [6]. The main wavelengths of Helium plasma are 587.6 nm($3^1\mathrm{D}-2^3\mathrm{P}$), 667.8 nm($3^1\mathrm{D}-2^1\mathrm{P}$), 706.5 nm($3^3\mathrm{S}-2^3\mathrm{P}$), 728.1 nm ($3^1\mathrm{S}-2^1\mathrm{P}$) in this experimental results. This paper presents the plasma characteristics of atmospheric-pressure DBDs depending on the electric conditions of nanosecond pulsed power using OES combined with a CR model.

2. Experimental System

An experimental system was constructed to measure the electron temperature and density of helium plasma generated by dielectric barrier discharges. The experiment was repeated by changing the applied voltage, pulse width, and frequency using a nano-pulsed power supply(NSP-60-20-P-250-TG-H). The applied voltage may be applied up to 20 kV, and the pulse width may be adjusted from 40 to 250 ns. The frequency is adjustable up to 5 kHz. The current and voltage waveforms are measured using a high-voltage probe (PVM-4, North star), current monitor (6585, Pearson Electronics Inc.), and oscilloscope (TDS-5054, Tektronix). The helium spectrum was measured using a spectrometer (HR4000CG-UV-NIR, Ocean optics) and the measurement range is 200 to 1100 nm. Figure 2 shows that the high voltage electrode has a length of 20 cm and square grooves at 3 mm intervals in the central 10 cm part. The dielectric is quartz with an outer diameter of 26 mm and a thickness of 3 mm. Helium gas was injected through the mass flow controller and the flow rate was 4.7 L/min.

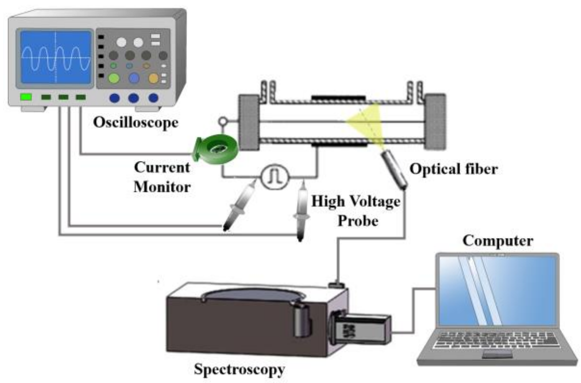

Fig. 1. Schematic diagram of DBDs experimental setup.

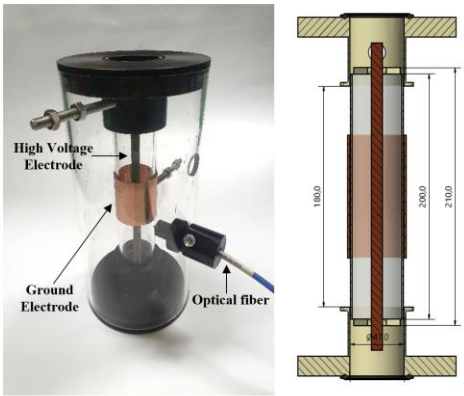

Fig. 2. Photo and diagram of DBDs reactor.

3. Results and Discussion

Figure 3 shows that the applied voltage, current, power, and energy waveforms. This graph represents the result that, among various electric conditions, the charging voltage is 10 kV, the pulse width is 140 ns, and the frequency is 5 kHz. The peak power is measured at 22.9 kW and the input energy per pulse is measured at 3.4 mJ.

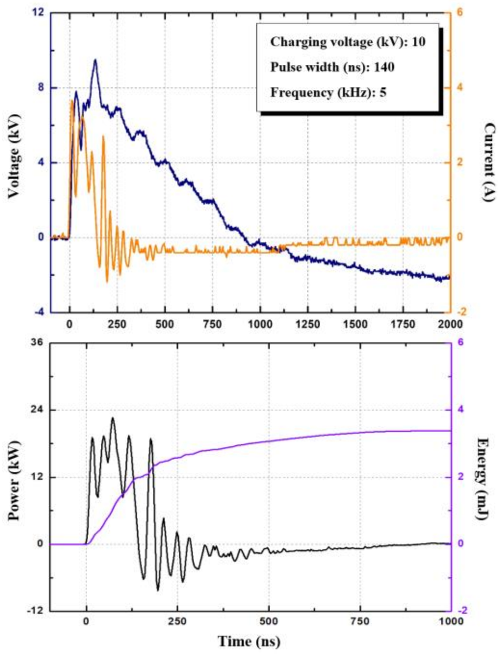

Fig. 3. Electrical diagnostics waveforms

Figures 4 and 5 show electron density and temperature measured by varying applied voltage, frequency, and pulse width at nano-pulsed power. Figure 4 represents input energy, peak power, electron temperature, and density according to frequency and applied voltage. This results from the experiment with the pulse width fixed at 140 ns. As the applied voltage increases at each frequency, input energy and peak power increase. Due to the limit specification of the power supply, the applied energy per pulse was lowered even at the same applied voltage when the frequency was increased. The electron density tends to increase when the frequency is increased, but the electron temperature does not change significantly.

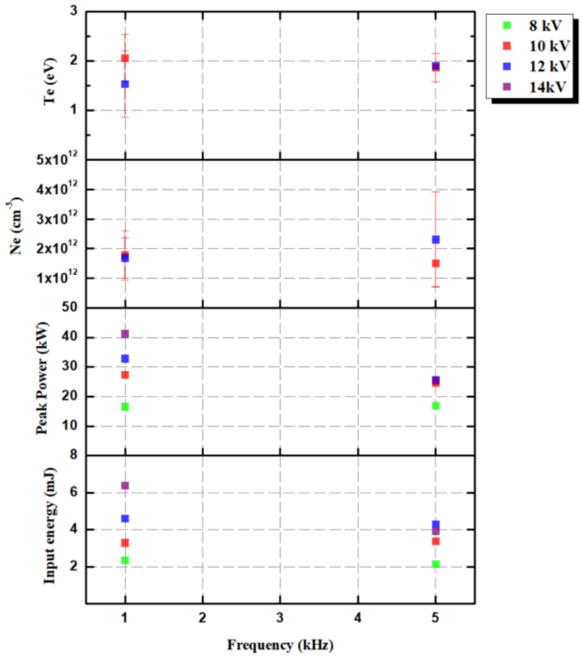

Fig. 4. Helium Plasma characteristics with a fixed pulse width of 140 ns.

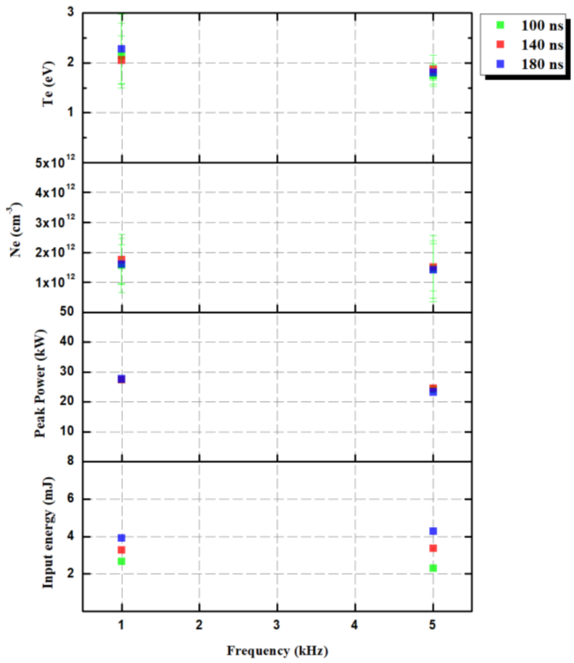

Fig. 5. Helium Plasma characteristics with a fixed applied voltage of 10 kV.

Figure 5 represents input energy, peak power, electron temperature, and density according to frequency and pulse width. This results from the experiment with the applied voltage fixed at 10 kV. As pulse width increases at each frequency, input energy increase and the peak power is not much different. The difference between the electron temperature and density according to the pulse width was not large and tended to decrease when the frequency increased.

4. Conclusions

We study the atmospheric-pressure helium plasma generated by nanosecond pulse DBDs for investigating the dependence of plasma characteristics on the applied voltage, pulse width, and frequency. This paper shows input energy, peak power, electron temperature, and density were measured to study the characteristics of helium plasma.

5. References

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6. Acknowledgement

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