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Contribution Parameters for Jet Formation of Atmospheric Pressure Non-Equilibrium Plasma
大気圧非平衡プラズマのジェット形成に寄与するパラメータ

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We have studied atmospheric pressure non-thermal-equilibrium plasma (APP). The plasma is formed by using a quartz tube, helium gas, and electrodes by applying RF high voltage. To define contribution parameters for formation of plasma jet, the relations among jet length, state of gas flow and applied voltage are investigated. It is found that both state of gas flow and applied voltage are influence parameters for formation plasma jet.

1. Introduction

Recently, the atmospheric pressure non-thermal-equilibrium plasma (APP) is much advantageous over low pressure plasma in various aspects [1]. APP has been adopted for industrial, biological, and medical application. Atmospheric pressure plasma such as plasma jets are typically produced using an arc discharge, which produces a high-temperature plasma, whereas dielectric barrier discharge (DBD) produces a low-temperature plasma, which results in less thermal damage to a material surface. As one of applications of DBD, atmospheric pressure plasma jet has been demonstrated using a quartz tube and copper electrodes, to which a low frequency of kHz band and a high voltage are applied. After a plasma plume is produced, the plume indeed resembles a bullet [2]. The formation of plasma jet is related with the state of gas flow and involution ratio of the air and applied voltage [1]. It is necessary to investigate the contribution parameters of plasma jet formation.

In this study, we will describe the experimental results on APP using a quartz tube, helium gas, and copper foil electrodes by applying RF high voltage. We study the relations among plasma jet length, plasma plume current and gas flow rate. The plasma plume current and plasma jet length are investigated by varying the applied voltage.

2. Experimental Setup

Figure 1 shows schematic diagrams of the atmospheric pressure discharge system using a quartz tube and copper electrodes, and measurement systems. The dielectric tube is made of quartz, its diameter about 1.5 mm, its thickness is about 1 mm. The powered and grounded electrodes are made of copper foil of 20 x 20 mm and a thickness of 0.1 mm. The distance between the electrodes is 40mm. The distance between the power electrode and quartz tube edge is 50mm. The helium gas flows in the direction of the powered electrode from the grounded electrode. The helium gas flow is controlled by a gas mass flow controller. The AC power supply (PHF-2KH, Hiden Co.) has a variable voltage from -15 to +15 kV and a variable frequency from 1 to 100 kHz, and the applied voltage waveform is composed some positive and negative pulses. The waveform is controlled using circuit resonance. In the experiment, the frequency of applied voltage is 13 kHz.

The photograph of plasma jet is taken by a digital

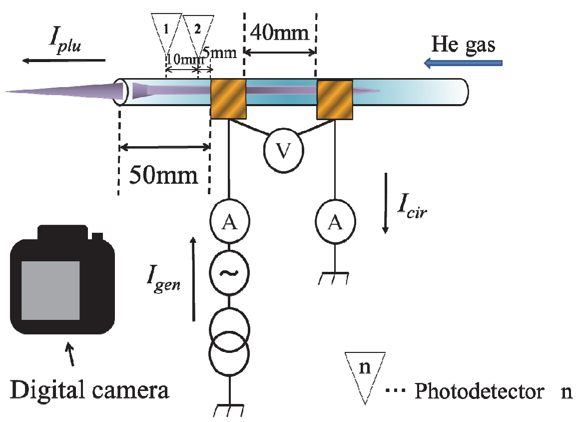

Fig. 1 Schematic drawing of APP device and measurement system.

camera. The plasma jet length is estimated from photograph. The travel length of plasma is observed by emission of plasma jet light integrated on the photograph. The plasma jet length L_p is distance between the tip of plasma jet and the edge of quartz tube.

The applied voltage is measured by high voltage probe (P6015A, Tektronix). The power and ground line currents are measured by the current monitor (model 4100, Pearson Electronics) on the power and ground lines, and former is referred as I_{pow} and the later as I_{gnd}.

3. Experimental Results and Discussion

The L_p tends to increase with increasing the negative pulse number [3]. The negative pulse number is set at 2 pulses. The relations between L_p and positive pulse number in each applied voltage at 2.0 slm on 2 negative pulses is shown in Fig. 2. In all figures averaged value is estimated from three discharges and error bars denote the maximum and minimum values. In Fig. 2 (a), the gas flow rate is set at 2.0 slm which is laminar flow. The L_p tends to increase with the positive pulse. On the other hand, the gas flow rate is set 10.0 slm which is turbulent flow in Fig. 2 (b). The L_p tends to increase with increasing number of positive pulse. The L_p in laminar flow has a long about three times of that in turbulent case except 0 positive pulse case.

The plasma jet length is related with the plasma plume current [3]. When the plasma plume is released into the air, the loss of current is induced by difference between power line and ground line. Thus the plasma plume current I_{plu} is estimated using the subtraction currents $I_{plu} = I_{pow} - I_{gnd}$. The current is time average on the generation period. The relations between I_{plu} and positive pulse number in applied voltage at 2.0 slm on 2 negative pulses are shown in Fig. 3. In the laminar flow, the I_{plu} tends to increase with the positive pulse. In the turbulent flow, I_{plu} tends to increase with the positive pulse. The I_{plu} in laminar flow is higher than that in turbulent flow. The I_{plu} of ±12 kV increase largely compared with the low voltage case.

The L_p and I_{plu} are similar tendency for pulse number. The L_p depends on the plasma plume charge [3]. The plasma plume charge is estimated from the time integration of I_{plu}. In the cases of ±10 and ±11 kV, although the I_{plu} is low, L_p is long. Current is related with plasma density and drift velocity. The drift velocity of plasma increases rapidly more than ±12 kV. The increase of velocity is induced by the increase of electric field. The increase of current is generated with the increase of drift velocity. Thus, the formation of plasma jet would be varied with electric field.

In summary, the dependences of L_p and I_{plu} on positive pulse has a similar tendency. Both the state of gas flow and applied voltage are influence parameters for formation of plasma jet.

References

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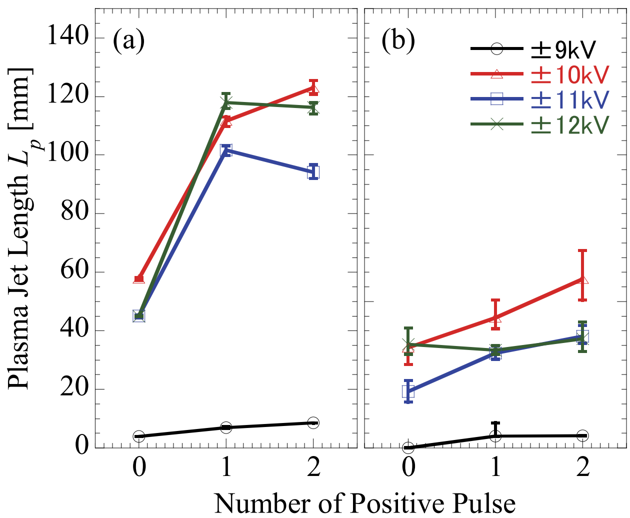

Fig. 2. Relations between L_p and positive pulse number in applying voltage at 2.0 slm on 2 negative pulses. (a): 2.0 slm; and (b): 10.0 slm.

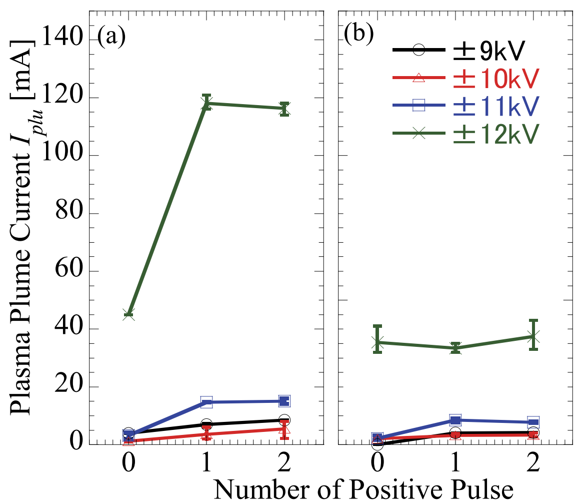

Fig. 3. Relations between I_{plu} and positive pulse number in applying voltage at 2.0 slm on 2 negative pulses. (a): 2.0 slm; and (b): 10.0 slm.