Effect of E-Field on the Length of a Plasma Jet

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Effect of E-Field on the Length of a Plasma Jet

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***Abstract*—Plasma jet device, which generates plasma in open space rather than in a confined electrode gap only, attracts lots of attention recently. The generation of a plasma jet could be a gas flow phenomenon, an electrical phenomenon, or both. In this paper, the effect of electric field on the length of a special designed plasma jet is investigated. The plasma jet is driven by a pulsed direct current (DC) power supply. Simulation of the electric potential along the plasma jet shows that the electric potential difference along the 4 cm plasma jet is about 400 volts for applied voltage of 4 kV. This is consistent with the measured electric potential along the plasma jet. Besides, the experiment results also show that the length of the plasma jet reaches its maximum when the pulse width is about 1 μs. According to the measured current-voltage curves, it could be concluded that the effect of pulse width on the length of the plasma jet is solely due to the electric field effect.**

***Index Terms*—Atmospheric pressure plasma, dielectric barrier disharge, non-equilibrium plasma, plasma jet, pulsed DC voltage.**

LOW-PRESSURE plasmas have been widely used for thin film deposition, plasma etching, surface modification and cleaning, improving biocompatibility, plasma chemistry and synthesis of nano materials [1]–[5]. However, at low-pressure, one of the major disadvantages is that a vacuum system is unavoidable. This limits the low-pressure plasmas to high-cost, vacuum-compatible applications.

Recently Laroussi and Lu reported an atmospheric pressure cold plasma jet [6], [7] having a plasma plume of several centimeters long. Fig. 1(a) is the schematic of the plasma jet setup. The diameter of the quartz tube is 25 mm. The center hole of the quartz disk is 3 mm. The gap distance is 5 mm. When helium gas is injected from one end of the quartz tube and the high voltage pulses are applied to the two ring electrodes, a homogeneous discharge is created in the gap and a room temperature plasma plume is generated in the surrounding air.

Previous experiments of high-speed photography [7] have shown that the plasma plume consists of a plasma bullet, propagating with a velocity up to 1.5×10^5 m/s. This is more than 10^4 times higher than the gas speed, which is 8 m/s. So the generation of the plasma jet should be an electrical phenomenon rather than pure gas flow phenomenon. However, up till now, how the applied electric field affects the length of the plasma jet has not been clearly understood. In this paper, the effect of the applied electric field on the length of the plasma plume is studied.

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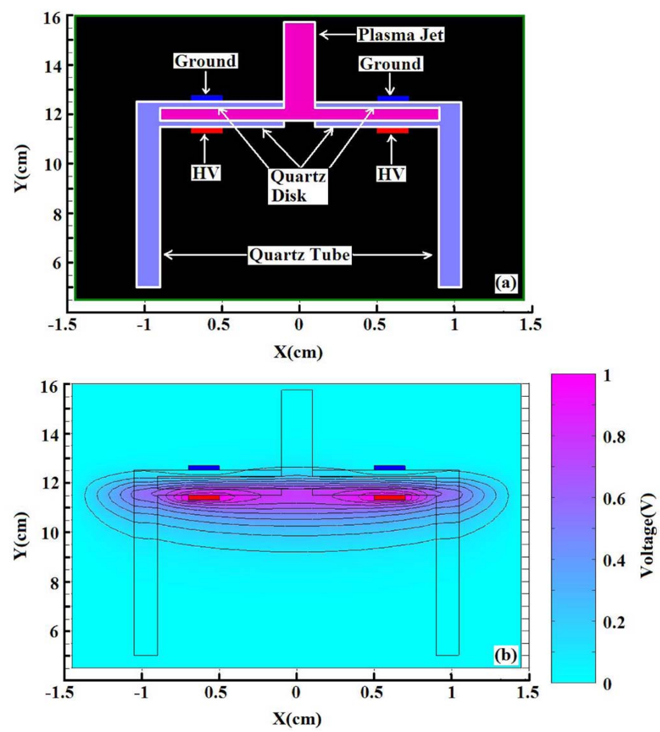

Fig. 1. (a) Schematic of the plasma jet, (b) electric potential simulation results of the plasma jet.

First, the electric potential distribution along the plasma plume is simulated by 2-D electrostatic method. It is noticed that the length of the quartz tube has no effect on the plasma plume. So it is chosen to be 7.5 cm as shown in Fig. 1(a). It has been found that the plasma plume can be touched by a bare hand without any electrical shock feeling. So it is reasonable to assume that the outer boundary (the outer rectangle) has electric potential of zero, even though the top edge of the boundary is only 2.5 mm away from the tip of the plasma. The ground ring electrode has zero electrical potential and the high voltage ring electrode has electrical potential of 1 V. The dielectric constant of the quartz tube and two quartz disks is 3.8. The plasma jet is assumed to be 4 cm long. Regarding the dielectric constant of the plasma, it is a spatially and temporally dependent complex number. To simplify the problem, it is assumed to be equal to vacuum dielectric constant in this paper.

The 2-D simulation result is shown in Fig. 1(b). Ten electric potential contours are shown in this figure, so the potential difference between two successive lines is one tenth of the applied voltage. Therefore, according to Fig. 1(b), the electric potential

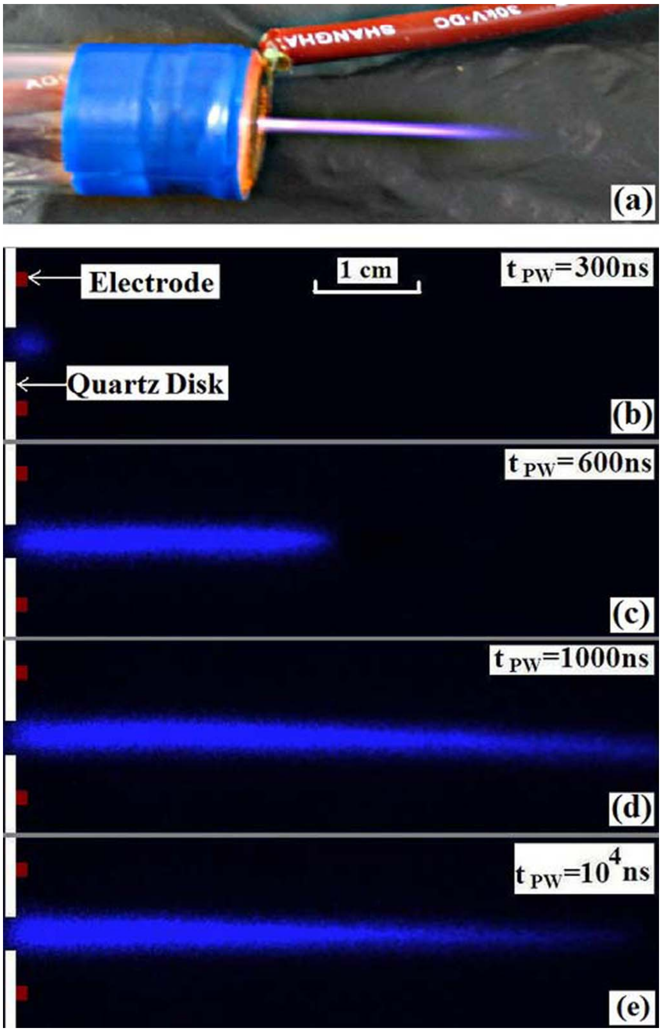

Fig. 2. (a) Typical photo of the plasma jet, (b)–(e) photos of the plasma jet for different pulse width with fixed applied voltage of 4.7 kV and frequency of 500 Hz.

difference along the 4 cm long plasma jet is about 400 V for the applied voltage of 4 kV.

Secondly, the effect of the pulse width on the length of the plasma jet is studied. Fig. 2(a) shows a typical photo of the plasma jet and photos Fig. 2(b)–(e) show the plasma jet photos for different pulse widths with applied voltage and pulse frequency fixed at 4.7 kV and 500 Hz, respectively. With the increase of the pulse width, the length of the plasma plume increases dramatically. The length of the plasma plume reaches its maximum when the pulse width reaches around 1 μs. Then it actually becomes slightly shorter when the pulse width is further increased to 10 μs.

It has been noticed that, as long as the pulse width is longer than 500 ns, the adjustment of the pulse width does not affect the shape and peak value of the discharge current pulses. In other words, when the pulse width is increased to more than 500 ns, it has no more effect on the discharge current except changing the zero current duration. Therefore, the increasing of the plasma plume length with the increasing of the pulse width from 500 ns to 1 μs can only be attributed to the electric field effect. However, when the pulse width is further increased from 1 μs to 10 μs, the length of the plasma plume actually decreases slightly. This is still not well understood. On the other hand, it has been noticed that, if the pulse width is increased to more than 20 μs, arcing discharge is occurring between the anode and the ground electrode directly. And the plasma plume disappears. Therefore, the decreasing of the plasma plume length at 10 μs may be indication of discharge mode transition.

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