Effects of Control Parameters on Plasma Bullet Propagation in a Pulsed Atmospheric Pressure Argon Plasma Jet

Sun Ja Kim and Tae Hun Chung

Abstract—**Effects of control parameters (applied voltage, duty cycle, and gas flow rate) on the propagation of plasma bullets are investigated in a pulsed atmospheric pressure argon plasma jet. Images of plasma bullets in the voltage rising and falling phases are presented. The applied voltage, pulse duration, and gas flow rate are observed to influence the bullet propagation characteristics.**

Index Terms—**Atmospheric pressure plasma jet, nonthermal plasma, plasma bullets.**

THE ATMOSPHERIC pressure plasma jet has found various applications for material processing and biomedical treatment due to enhanced plasma chemistry and nonthermal nature. It was found that the plasma jet is constituted of discrete bulletlike plasma clouds moving at a velocity much higher than the gas velocity. Although some recent reports have proposed discharge models to explain the properties of plasma bullets [1], [2], further experimental investigations are needed to advance the understanding of bullet behavior in an atmospheric pressure plasma jet. Fig. 1 shows the jet source driven by pulsed dc voltage with a repetition rate of 50 kHz. At the center of the Pyrex tube (ID is 10 mm and OD is 12 mm) are a tungsten wire with a diameter of 0.6 mm and a pencil-shaped tapered end. The wire shaft is covered with a cone-type Teflon layer tube, leaving a length of 10 mm of the wire exposed to gas. The diameter of the Pyrex tube nozzle is 2 mm. The tip-to-nozzle distance is 10 mm. The argon gas was delivered at a flow rate in the range of 0.5–3 L/min, controlled by a flowmeter (Kofloc RK1600R). A unipolar dc pulse train is applied to the tungsten wire. The current–voltage curve shows two narrow current pulses with a short duration, a positive one as the voltage increased and a negative one as the voltage decreased. To image the plume of the plasma jet on a nanosecond scale, an intensified charge coupled device (ICCD) camera (PI-MAX2, Princeton Instrument) was used with its triggering achieved using a pulse generator. The exposure time of the ICCD camera was 20 ns.

It is observed that the plasma plume is a propagation of bullets rather than a continuous volume of plasma following the trajectory of the gas channel. The propagation velocity of plasma bullet is estimated to be from 0.9×10^4 to 2×10^4 m/s with increasing applied voltage, which indicates that the plasma bullet propagates in the same order of magnitude with the electron drift velocities [2]. The radius of a bullet sphere and the bullet speed increase with the applied voltage [Fig. 2(a)]. In all the cases, the duty cycle was 47%. As the applied voltage is increased to 2.2 kV, the shape of the bullet is elongated along the propagating direction. A further increase in the applied voltage leads to the continuous mode in which excited species are seen to remain within the interelectrode region through the entire cycle of the applied voltage [1]. Fig. 2(b) and (c) shows the sequent images for different duty cycles at the applied voltage of 1.8 kV. For different duty cycles of 47%, 25%, and 8%, the pulsewidths were 10.2, 5.2, and 1.7 μs, respectively. In all the cases, the pulse rise time was 300 ns. With the duty cycle decreasing, the bullet speed increases. Fig. 2(b) shows that, at the duty cycle of 8%, the plasma ignition is easier, and the volume, luminosity, and velocity of the plasma bullet increase. This indicates that the charges accumulated on the dielectric layer have more significant effect on the bullet in the case of a low duty cycle. During the voltage-falling phase, a secondary (weak) discharge due to the negative current pulse is observed, and the bullet propagation is faintly seen [Fig. 2(c)]. In this short duration, electrons accumulated on the dielectric surface depart, and afterward, no electric field is left inside the tube; then, the secondary discharge stops. When the duty cycle is 8%, the secondary discharge becomes brighter, and the ionization channel remains longer. These can be accounted for from that the decrease of duty cycle makes the time span between the primary discharge and the secondary discharge shorter, thus having the effect equivalent to a higher excitation frequency.

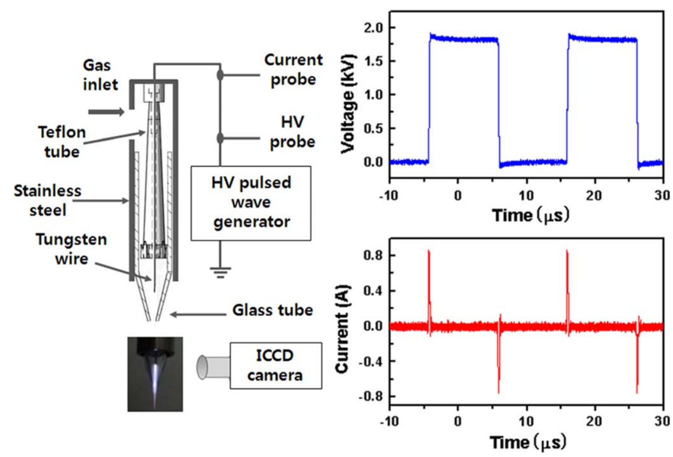

Fig. 1. Pulsed plasma jet and its current–voltage curve.

Manuscript received October 29, 2010; revised February 10, 2011; accepted February 16, 2011. Date of publication March 24, 2011; date of current version November 9, 2011. This work was supported by the Dong-A University.

The authors are with the Department of Physics, Dong-A University, Busan 604-714, Korea (e-mail: lovey104@hanmail.net; thchung@dau.ac.kr).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TPS.2011.2118767

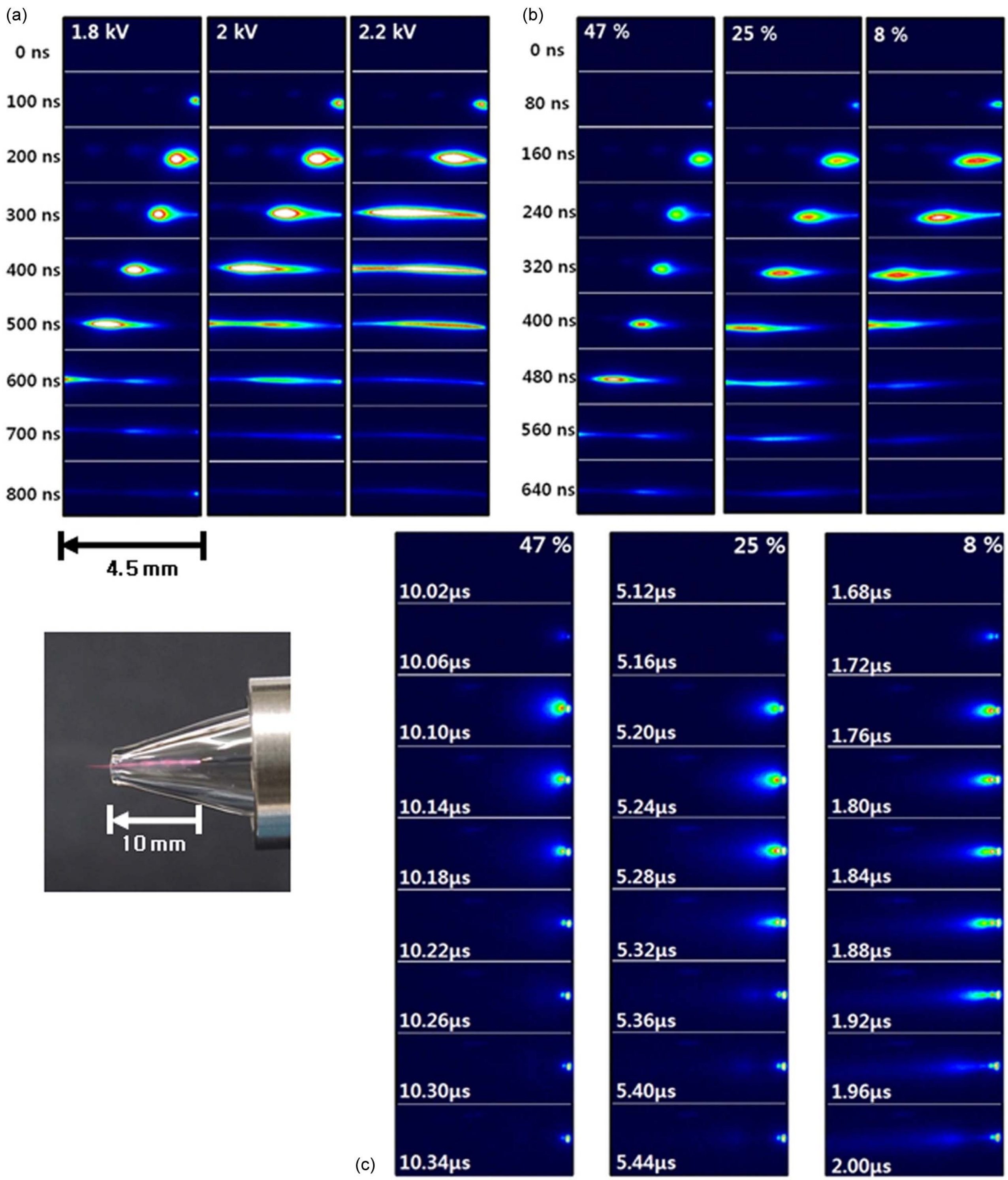

Fig. 2. High-speed photographs of the pulsed Ar plasma plume taken under the gate mode in the voltage rising phase. (a) For different applied voltages (1.8, 2.0, and 2.2 kV) at the duty cycle of 47% and (b) for different duty cycles (47%, 25%, and 8%) at the applied voltage of 1.8 kV. The bullet is propagating to the left. (The position of the anode is at the right side.) (c) Image of plume for various duty cycles in the voltage-falling phase (secondary discharge). The pulse repetition rate is 50 kHz, and the gas flow rate is 2 L/min.

Although not shown in the figure, the gas flow rate does not influence the size of a sphere, but the bullet speed increases slightly with the gas flow rate. These observations provide some insight on the bullet propagation characteristics and additional control over the properties of plasma plume for various applications.

References

[1] J. L. Walsh, F. Iza, N. B. Janson, V. J. Law, and M. G. Kong, “Three distinct modes in a cold atmospheric pressure plasma jet,” *J. Phys. D, Appl. Phys.*, vol. 43, no. 7, pp. 75 201–75 214, Feb. 2010.

[2] E. Karakas and M. Laroussi, “Experimental studies on the plasma bullet propagation and its inhibition,” *J. Appl. Phys.*, vol. 108, no. 6, pp. 063305-1–063305-6, Sep. 2010.