Dual Plasma Bullets Colliding Inside a Hollow Electrode of a Multielectrode Helium Plasma Jet

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***Abstract*— The dual plasma bullets colliding inside a hollow electrode of a helium plasma jet are observed for the first time. The jet device has a multielectrode configuration, i.e., several active and grounded electrodes are wrapped one by one on a quartz glass tube. The dual bullets are generated on the both sides of negative electrode. They move toward the central region of the hollow electrode, and finally, collide to each other. Some observations are novel, and may be useful for the further unravel of the underlying mechanism of plasma bullet.**

***Index Terms*— Multielectrode, plasma bullet, plasma jet.**

I. Introduction

THE plasma bullet generated by a plasma jet device has received great attention in the last decade. According to the previous studies, the bullet is a luminopher that typically originates on the edge of plasma channel and then propagates into the free space with a high speed of 10^4–10^5 ms^{-1}. The propagation is due to the generation of free electrons ahead of the streamer (ionization wave) front, but the underlying mechanism is still not clear [1]. In this paper, we report for the first time the colliding of dual plasma bullets in a hollow electrode of a helium plasma jet. Some observations are novel, and may be useful for the further unravel of the underlying mechanism of plasma bullet.

The plasma jet device has a multielectrode configuration, i.e., several active and grounded electrodes (U shape to allow the image taken) are wrapped one by one on a quartz glass tube. Each electrode has a width of 9 mm, and separates from the adjacent electrodes by 6 mm. The inner and outer diameters of the glass tube are 2 and 3.5 mm, respectively. Pure helium (5N) is fed into the glass tube with a flow rate of 3 L/min. A sinusoidal high voltage ($V_{pp} = 8$ kV and $f = 50$ kHz) is applied on the active electrode, and it is measured by an oscilloscope (Tektronix, DPO3000) with a high-voltage probe (Tektronix, P6015A). The discharge current is measured by a noninductive resistance of 30 Ω. The behavior of plasma bullets is recorded by an intensified charge coupled device camera (Andor, DH334T) with an exposure time of 20 ns.

The operating voltage and current in a discharge cycle are plotted in Fig. 1(a), in which the breakdown phases of discharge current are highlighted with red circles marked with N or P for either the negative or positive half-cycles. The voltage and current in such breakdown phases are shown more clearly in Fig. 1(b) and (c), in which the points marked with N1–N6 and P1–P6 are corresponding to the exposure moments for the images shown in Fig. 1(e). The time interval between two adjacent points varies from 200 to 400 ns, due to the velocity variation of plasma bullets. Moreover, the configuration of the jet device and the static electric field lines (without plasma) in the inner space of quartz tube are shown in Fig. 1(d) for readability.

As shown in Fig. 1(e), the plasma bullets are generated on both sides of the negative electrode, and then propagate toward each other. The luminous pattern of each plasma bullet expands when propagation, and it has a conical head and a swallow tail. When the two bullets are very close, they are compressed to have flat shape due to the mutual repulsion of each other. In contrary to the previous studies on the counter-propagating bullets [2]–[4], there are several novel phenomenon: 1) the dual bullets can really collide [see N5 and P5 in Fig. 1(e)] instead of vanishing when apart against each other by $\sim$1 mm; 2) the velocity of each bullet is only $\sim 5 \times 10^3$ms^{-1}, lower than the common cases by one to two orders of magnitude; and 3) no secondary bullet happens. Given that the propagation of plasma bullets happens inside a hollow electrode instead of in the open space [3] or in a dielectric tube [4], these differences may be attributed to: 1) the eigen field of space charge is weakened by the external field of hollow electrode and 2) the electron diffusion in the streamer front is inhibited to some extent by the electrode because it is negatively charged. Moreover, the tail of plasma plume is broom-like and it expands with similar velocity ($\sim 5 \times 10^3$ ms^{-1}) to that of the plasma bullet but toward the opposite direction, this phenomenon has little been studied before. These new observations complement the experimental database of plasma bullets, which can be used for the further check of the theoretical predictions, and consequently, help to elucidate the underlying mechanism.

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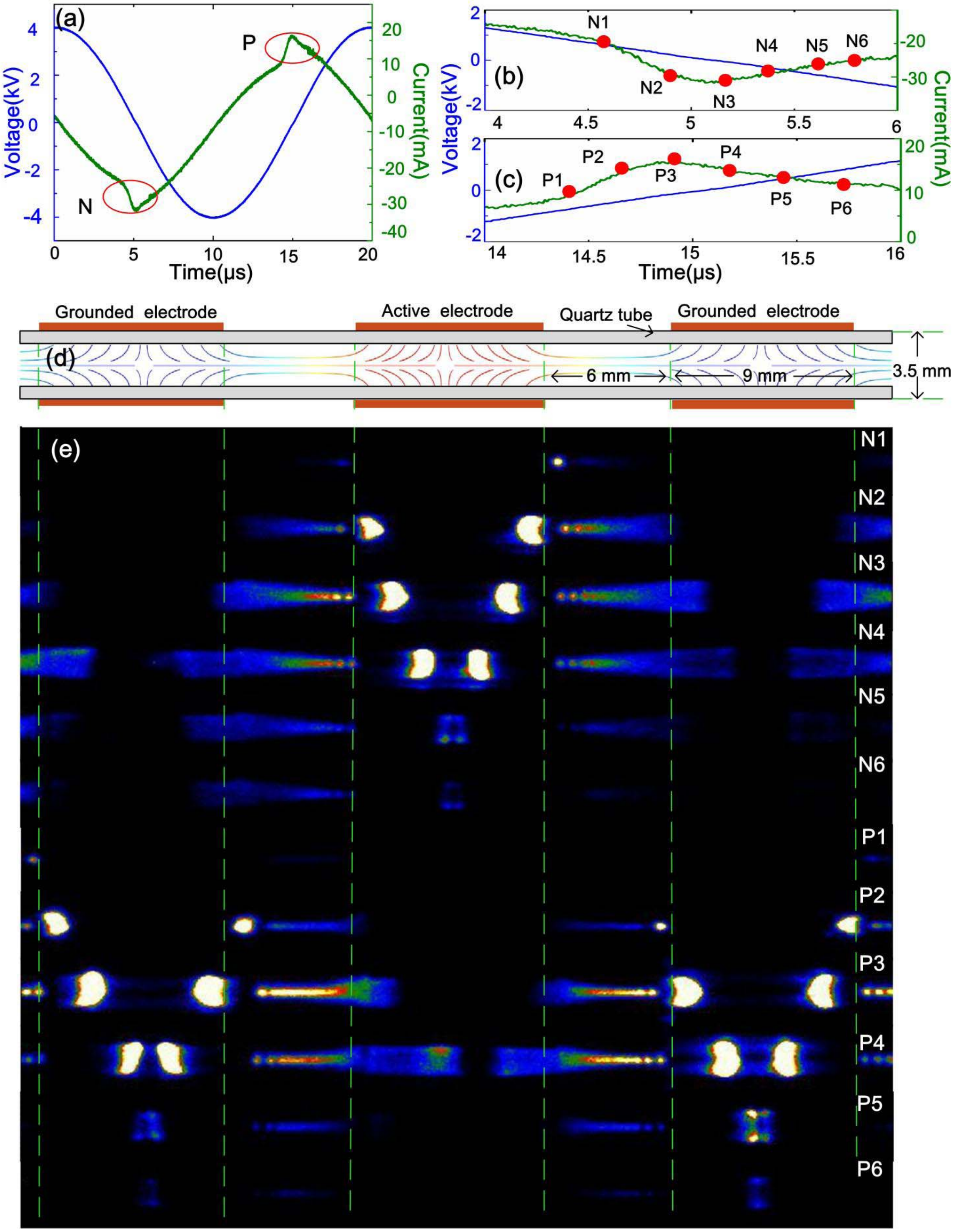

Fig. 1. Counter propagation of dual plasma bullets inside a hollow electrode of a multielectrode plasma jet. (a) Discharge voltage and current in one cycle. (b) and (c) Breakdown phases in negative and positive half cycles that are marked in (a) with N and P, respectively. (d) Static electric field lines in the inner space of quartz tube. (e) Counter propagation of plasma bullets taken by an ICCD camera at the moments of N1–N6 and P1–P6. These moments are given in detail in (b) and (c).

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