Imaging of Radial and Axial Profiles During the Formation of Atmospheric Pressure Nanosecond Pulsed Discharges in Ar, N_2 and Air

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Abstract: This work reports on the imaging of the radial and axial dynamics of atmospheric pressure repetitively pulsed nanosecond discharges. Simultaneous streak and time-gated sCMOS imaging are conducted. We achieve a 100 ps time resolution and directly resolve the different discharge regimes in Ar, N_2 and synthetic air in single-shot measurements.

1. Introduction

Atmospheric pressure plasmas offer a variety of applications such as chemical conversion, flow control, surface treatment, and nanomaterials synthesis [1]. Nonequilibrium atmospheric pressure plasmas feature predominant coupling of electrical energy into the generation of free electrons, excited species, and radicals with only moderate heating of the surrounding gas.

Nanosecond pulsed pin-pin discharges in air have been extensively studied. Ultrafast gas heating mechanisms featuring temperature increase up to 1000 K/ns and involving O_2 dissociation into O atoms from collisions with N_2(A,B,C) species have been demonstrated [2]. Recently, new mechanisms have been proposed to explain the observed sub-nanosecond characteristic transition time of these discharges from non-equilibrium low-temperature plasmas to fully-ionized, thermal spark discharges. Our work focuses on the validation of these mechanisms. To this end, leveraging simultaneous single-shot streak and sCMOS imaging, our study resolves the radial constriction and expansion of these discharges, as well as their axial propagation between the two metal pin electrodes.

2. Methods

Discharges are generated in Ar at 1 atm, between two sharpened tungsten pin electrodes separated by a 1 mm gap distance. +7 kV, 200 ns long, high-voltage pulses produced by a DC power supply (Spellman SL150) and pulser (PVX-4110) are supplied to the top electrode (anode). A 1 kΩ resistor inserted between the HV pulser output and the tip of the anode limits the current in the electrical circuit. The bottom electrode is grounded. Current and voltage waveforms are measured before and after the resistor, respectively and recorded with each image. A Hamamatsu C13410 streak camera captures single-shot images of the radial or axial discharge dynamics, while an iStar sCMOS camera simultaneously records a snapshot of the discharge morphology (3 ns gate).

3. Results and Discussion

Figure 1 displays two streak images of 50 ns and 10 ns sweeps, respectively. These images depict the initial radial evolution of the discharge in the mid-gap. It is observed that it takes about 2-3 ns for the streamer to reach mid-gap. Then, an initial radial expansion is evidenced from t~2-5 ns. Subsequently a radial constriction occurs between t ~5-6 ns. This is followed by another expansion phase lasting up to t~15 ns. Later, a second constriction phase is

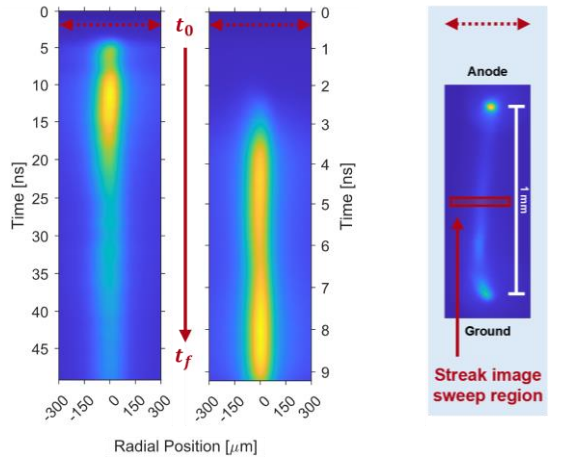

Fig. 1. *Left:* 50 ns streak image of radial evolution of plasma. *Middle:* 10 ns streak image of radial evolution of plasma. *Right:* sCMOS image of the full plasma; the red box shows the imaged region for the streak images.

observed, and soon after the size of the discharge appears to reach a quasi-steady state around t~20 ns. This constriction and expansion dynamics relates to streamer to spark transition. We will report on streamer propagation features and timescales of regime transitions.

4. Conclusion

This work reports 100 ps time-resolved single-shot streak images of radial and axial dynamics of atmospheric pressure nanosecond repetitively pulsed discharges in Ar. The full conference contribution will provide similar results in N_2 and synthetic air. These results, paired with energy measurements from the recorded electrical waveforms, as well as with a 0-D kinetic mechanism will enable us to validate different hypotheses from the literature regarding the kinetic mechanisms underpinning transitions during different discharge regimes.

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