Time resolved measurements of streamer inception in air

Time Resolved Measurements of Streamer Inception in Air

T. M. P. Briels, E. M. van Veldhuizen, and U. Ebert

***Abstract*—Images show how an ionization cloud forms at the needle electrode, how the cloud evolves into a shell, and how one or more streamers emerge from this shell and propagate.**

***Index Terms*—Gas discharges, pulsed corona, streamer inception, streamer propagation.**

STREAMERS are narrow rapidly growing ionized channels that generally emerge from sharp tips when a high voltage is applied. Streamers prepare the path of sparks of all sizes. They are used in industry, e.g., in gas and water cleaning [1], [2]. They also can be observed as so-called sprite discharges at low pressure in the atmosphere at 40 to 90 km altitude [3].

As the rapid growth of streamers is dominated by fast two-body-collisions, theory predicts approximate similarity between streamers at different pressures, and experiments confirm it [4]. Similarity implies that time and length scales approximately scale like $1/p$ [2]–[4]; therefore, one can zoom into the streamer evolution by lowering the pressure p.

In Fig. 1, we image/illustrate the early stages of evolution of positive streamers at pressures of 100 and 400 mbar, with applied voltage ranging from 7.5 to 25 kV. The discharges start with an ionization cloud at the anode tip and evolve downwards toward the cathode plate at a distance of 40 mm. The discharges are driven by single high-voltage pulses with a short rise time of 25 ns. These pulses are created with a capacitor supply (the C-supply described in [5]) using a semiconductor switch. One picture is taken per discharge pulse using a digital Andor iCCD-camera. The false colors in the images indicate the intensity of the light; in each panel, they are adjusted to resolve the structure optimally. The time T below each panel in the figure is the delay between the start of the corona current and the opening of the camera. T has a jitter of about 30 ns which is visible when comparing panels Ia and Ib or IIIc and IIId. The exposure duration is given by Δt.

The figures show the formation of an initial ionization cloud at the anode tip (panels Ia, IIa, IIIa). The cloud expands and forms a shell (Ib, IIIb), i.e., the maximal light intensity moves away from the tip. The shell destabilizes and forms one or more streamers (e.g., Ic, IIb, IIIb) that propagate toward the plate electrode (e.g., Id, IIc, IIIc, IIId). Panel IId shows the reillumination of the streamers close to the tip. A tiny anode glow is also visible in IIId. Positive and negative discharges generally evolve in the same way. However, in the present electrode configuration and at 1 bar, positive discharges emerge above a voltage of 5 kV, while negative discharges emerge only above 40 kV (which is about the dc-breakdown voltage of our 40 mm gap) [6]. Future theory should try relating these different inception voltages to the different nucleation processes of the ionization cloud at the anode or cathode tip.

The first and the second column show discharges at the same pressure of 100 mbar, but at a voltage of 10 kV in column I versus 7.5 kV in column II. At 10 kV, the initial ionization cloud has a reduced height of $p \cdot h = 1.9 \pm 0.4$ mm $\cdot$ bar, while for the lower voltage of 7.5 kV, it is $p \cdot h = 0.9 \pm 0.4$mm $\cdot$ bar, i.e., only half as high. For 10 kV, only one streamer with reduced diameter $p \cdot d \approx 0.25$ mm $\cdot$ bar (panel Id) hardly emerges from the cloud before reaching the electrode, while for 7.5 kV, four streamers with $p \cdot d \approx 0.16$ mm $\cdot$ bar (IIb) emerge and propagate. They are all thin streamers of type 3 in the classification of [4], where the streamer diameter was discussed as a function of voltage and voltage rise time.

The second and the third column look similar, but the pressure in column III is as high as 400 mbar and the voltage is 25 kV. The reduced height of the cloud $p \cdot h = 3.8 \pm 1.6$ mm $\cdot$ bar is actually twice as large as in column I. The reduced streamer diameter is $p \cdot d \approx 0.6 \pm 0.1$ mm $\cdot$ bar (IIIc, IIId), four times thicker than the streamers in column II. This diameter was classified as type 2 in [4]. Comparable measurements in synthetic air [7] show that for $U = 40$ kV, $p = 613$ mbar, a discharge gap length of 30 mm, and a voltage rise time of 11 ns, a single streamer as thick as the cloud propagates toward the plate.

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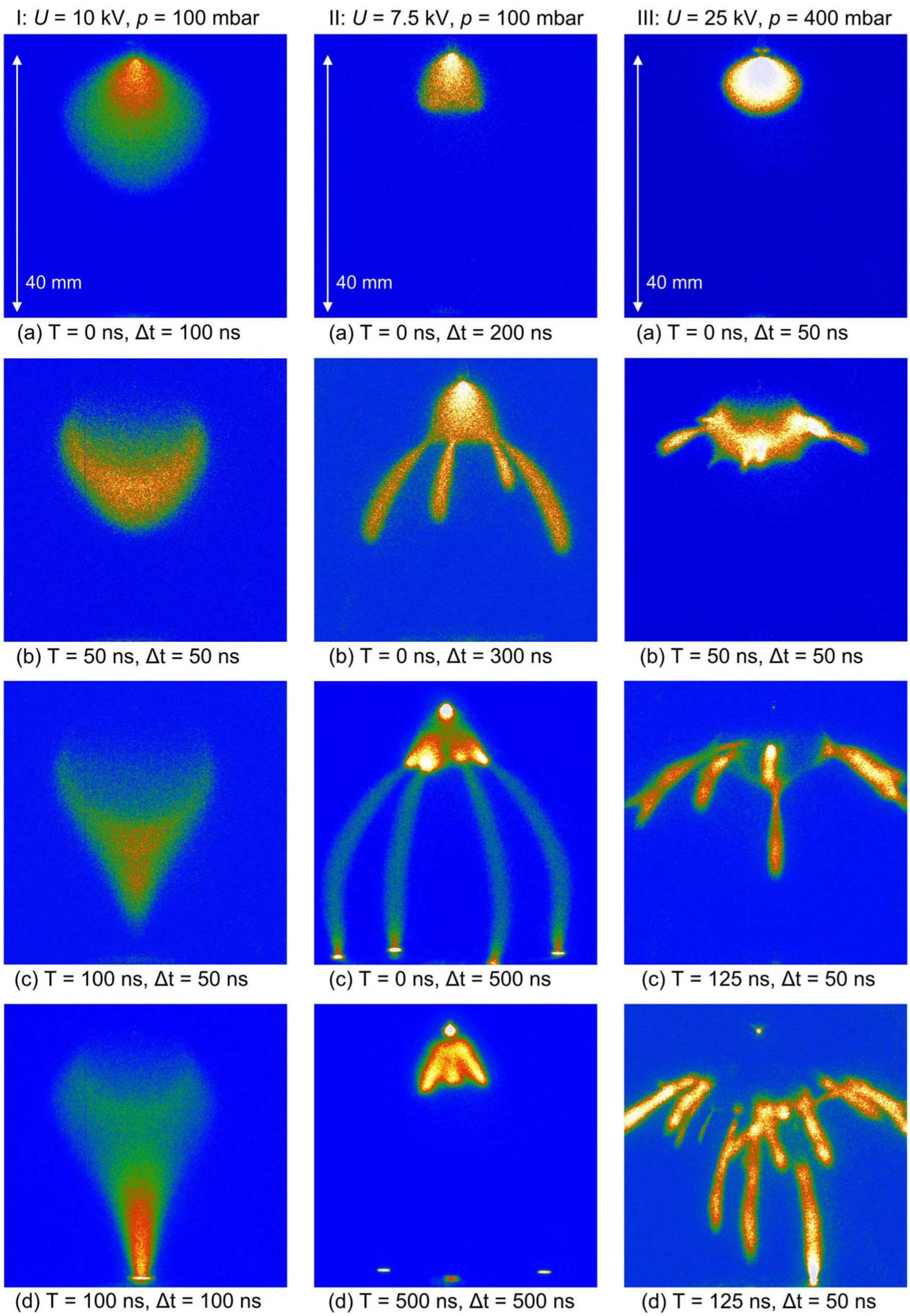

Fig. 1. Series of time resolved photographs showing stages of evolution of positive discharges in air. The electrodes are (above) point to (below) plane with a distance of 40 mm. Columns I and II show the same pressure of $p = 100$ mbar, but different applied voltages (I: 10 kV, II: 7.5 kV), column III is at higher pressure $p = 400$ mbar and an applied voltage of 25 kV. The exposure times are indicated with T for the start and Δt for the duration.