ADS and CDS streamer generation as function of pulsed parameters

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G. J. J. Winands, Z. Liu, E. J. M. van Heesch, A. J. M. Pemen, and K. Yan

***Abstract*—Streamer plasmas can be used to remove pollutants from gases. As a result of the complex mechanisms involved during streamer initiation and propagation, the related knowledge is incomplete. During the last few years, extensive research was performed to determine typical streamer properties (such as velocity and dimensions) as a function of various pulse parameters. During the study, as presented in this paper, typical streamer velocities and diameters in the range of 10^5–10^6 m/s and 0.5–3.0 mm, respectively, were found.**

***Index Terms*—Gas discharges, imaging, pulse power system, velocity measurement.**

STREAMER plasmas have drawn much attention during the last few years. This interest is the result of several aspects. Aside from being challenging fundamental physical phenomena to study, they also exhibit properties that make them useful in industrial applications. The energetic electrons present in the streamer can create radicals during dissociation collisions. These radicals induce chemical reaction pathways that, under the right circumstances, remove the pollutants from the gas [1].

Streamers are channellike discharges that propagate between two or more electrodes, under the influence of their self-induced electric fields. Only since the last few years has it been possible to visualize their generation and propagation, using state-of-the-art camera equipment. Streamers propagate with high velocities in the order of 10^5–10^6 m/s; moreover, they are light-weak phenomena. To obtain time-resolved information, fast-gate-speed intensified cameras can be used.

Streamer appearance greatly depends on the applied voltage characteristic, reactor configuration, and gas conditions. In addition to changes in appearance, the physical streamer properties will also change under the influence of various parameters. Since optimized radical production yields are required for the industrial application, fundamental knowledge regarding the interactions is required.

In [1], extensive research regarding the various interactions is described. Pulse parameters have systematically been varied, streamer generation has been monitored, and the oxygen-radical production yield has been determined. Based on the results, various conclusions regarding optimized streamer generation have been presented. In this paper, some of the results are highlighted. The system used is described in detail in [1]. The power modulator used allows for parameter variation in wide ranges: peak voltage: 40–90 kV, pulse duration: 35–250 ns, voltage rise rate: 0.5–3.0 kV/ns, pulse repetition rate: 10–1000 pulse per second (pps), and voltage polarity: positive and negative. The reactor vessel is a simple wire-plate reactor. Two grounded aluminum plates (22 $\times$ 110 cm) are placed in parallel at a fixed distance away from each other (7.4–15.4 cm). A thin (0.4–15 mm) metal wire with a maximum length of 90 cm is positioned at the center between the plates. The high-voltage pulses are applied to the wire.

A Princeton Instruments 576G/RB intensified charge-coupled device (ICCD) camera is used to obtain the images. The triggering of the camera has been designed in such a way that a temporal resolution of 1 ns can be obtained. The fastest gate time of the camera is 5 ns. The figures show results obtained during the measurements. For all the performed measurements, a separate effect of the pulse repetition rate on the streamer appearance was not found (at least for the experimental range of 1–400 pps with an air flow of 30 m^3/h). The experiments have therefore been performed with a pulse repetition rate of 10 pps.

In Fig. 1, typical examples of the time-resolved development of positive polarity streamers are shown. The time at which the photograph was taken, relative to the voltage pulse, is shown in Fig. 1(i). Typical primary and secondary streamer generation is shown. Starting soon after the voltage increases Fig. 1(a), primary streamers are formed, which transit the complete gap Fig. 1(a)–(f). During their transit, the streamer diameter (determined at 20% of the maximum intensity value) increases from roughly 0.7 mm to a maximum of 3 mm). At the moment the primary streamers reach the cathode Fig. 1(f), secondary streamers are formed. The secondary streamers are always in the same channel as that in which the primary streamers were generated (bright reillumination of the primary streamer channels, as shown in Fig. 2). They only partly travel (20%–40%, depending on the applied electric field) into the interelectrode gap Fig. 1(f)–(h) and always remain attached to the anode. Their diameters are $\sim$1 mm, comparable to the primary streamers at these positions. Similar images, as shown in Fig. 1, have also been obtained for negative polarity streamers. It was found that negative and positive polarity streamers look quite similar. The only striking difference is that the negative polarity secondary streamers protrude much further into the reactor gap (as far as 80%–90% of the gap).

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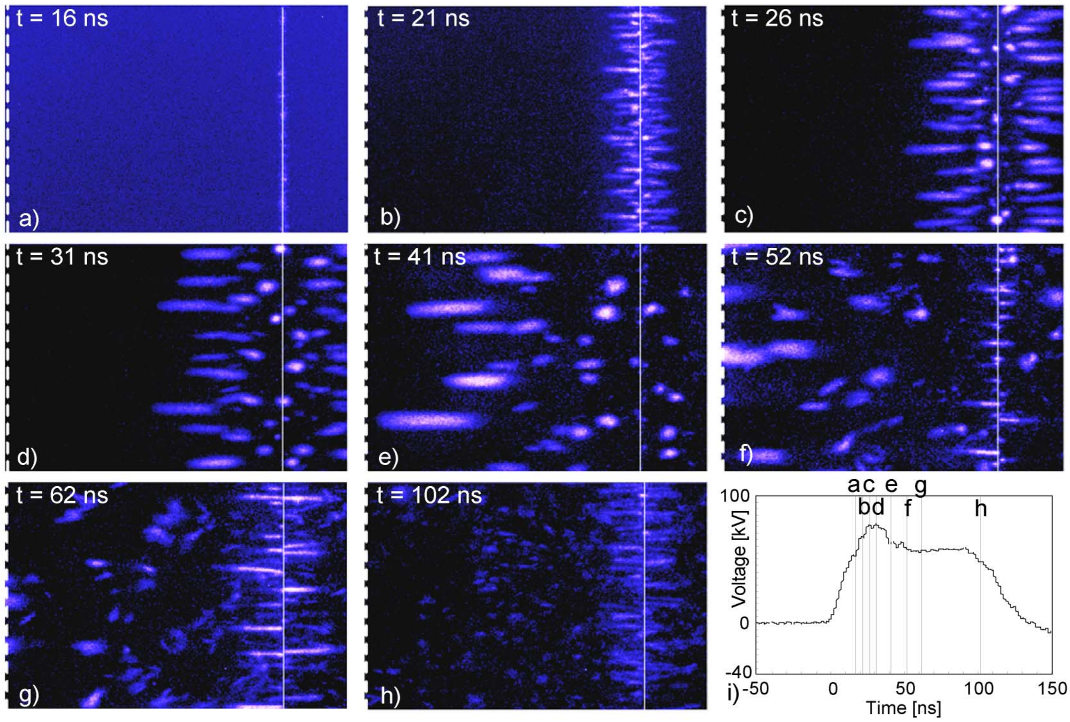

Fig. 1. (a)–(h)Time-resolved (5 ns) ICCD images (white line: reactor wire, dotted line: reactor wall, image size: ∼7 × 5 cm, pulse voltage: +74 kV, rise rate: 2.7 kV/ns, pulsewidth: 110 ns). (i) Voltage waveform together with the moments the images are taken.

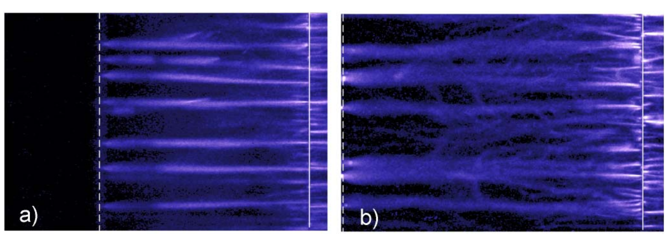

Fig. 2. Time-integrated (400 ns) ICCD images (pulsewidth: 100 ns, rise rate: 2.8 kV/ns) with (a) −75 kV, 1.3 J/pulse, and a wire-plate distance of 37 mm and (b) +82 kV, 1.9 J/pulse, and a wire-plate distance of 57 mm.

Images similar to those shown in Fig. 1 are useful in determining the streamer head position (relative to the wire), the streamer diameter, and the average light intensity as a function of time. By plotting these parameters as a function of time, several interesting streamer characteristics can be determined like the propagation velocity. It was observed that, during propagation, the velocity is almost constant, with a value depending on the amplitude and rise rate of the pulse. Only near the plate electrode do the streamers slightly accelerate. Typical velocities (for both positive and negative polarities) obtained were in the range of 10^5–10^6 m/s, similar to the values obtained by other researchers [2], [3]. The streamer diameter was found to linearly increase during streamer transit with the velocity $(\sim 10^4$–10^5 m/s$)$ again depending on the voltage amplitude and rise rate. Typical diameters ranged from 0.5 mm (near the wire) to as high as 3.0 mm (near the plate). The thickest streamers were always observed for the high-amplitude voltage pulses. Again, no large differences between both voltage polarities could be observed.

To determine the number of streamers, their spatial distribution, branching, etc., the images, as shown in Fig. 1, are not optimal. For these measurements, it is preferable to use the images with longer (400 ns) gate time, as shown in Fig. 2. With these, the complete paths of the streamers can be observed. Numerous streamers do not reach the plate electrode but only partly cross the gap. At the position were those primary streamers that do cross the complete gap connect to the plate electrode, a small bright spot can be observed. The secondary streamers are visible as bright reillumination of the primary streamer filaments near the reactor wire. In addition to the individual streamers, the interaction between adjacent streamers also becomes visible. Branching can be observed, and sometimes, interconnecting streamers (two streamers merging into a single channel) are visible.

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