Time Evolution of Pulsed Streamer Discharge in Water

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Abstract—**Pulsed positive streamers in water were observed in the needle-to-plate electrode configuration with a gap of 20 mm. The characteristics of streamer propagation were investigated by using an intensified charge-coupled device camera. A few branching with a channel diameter of $\sim 250\ \mu m$ was observed. The streamers in water did not reach the plate electrode at the stable operation voltage range below the transition to spark. Under the present experimental condition, the propagation velocity of the streamer head was 3×10^4 m/s, which is one order of magnitude lower than that of the streamer in air.**

Index Terms—**Discharge in water, intensified charge-coupled device (ICCD) images, spark gap switch, streamer.**

RECENTLY, streamer, spark, and arc discharges in water have become important for the treatment of polluted water aimed at the removal of dye, odor, and harmful components [1]. Generally, it is known that features of the discharges in water are different from those of the discharges in air. The streamer development in water was investigated with a high-temporal- and high-spatial-resolution optical method using the laser Schlieren method and Mach–Zehnder interferometry [2], [3].

In this paper, we present the results of the time-resolved imaging of streamers in water. A pulsed high-voltage circuit with a self-trigger spark gap switch was used to generate streamers. A needle-to-plate discharge electrode system was inserted into distilled water (conductivity of 12.3 μS/cm), filling an acrylic reactor. A stainless-steel needle (0.14 mm in inner diameter and 0.32 mm in outer diameter) with an insulating cover was used as the stressed electrode, while a brass plate (70 mm in diameter) was used as the grounded electrode. The tip of the needle was protruded 0.5 mm from the insulating cover in order to enhance the electric field at the tip of the needle electrode. An intensified charge-coupled device (ICCD) camera (Andor, i-Star) was used to observe the streamers. In order to synchronize the discharge and the ICCD camera, a p-i-n photodiode detected a light emission from the spark gap switch and sent a signal through a delay generator (Stanford DG535) to trigger the ICCD camera. The time relationship between the voltage pulse, discharge current pulse, and gate opening time of the ICCD camera was monitored with a digital oscilloscope (HP Infinium, 1.5 GHz, 8 GS/s). Hence, although the pulsed high-voltage circuit with the spark gap switch had a jitter, knowing the timing of the high-voltage pulse, discharge current pulse, and exposure time of the ICCD camera, it was possible to determine the phase of streamer evolution.

Fig. 1 shows the typical temporal and spatial evolution of the streamer in water for different ICCD camera exposure times after applying a pulsed high voltage of 27 kV (rise time 70 ns; pulsewidth 15 μs). The ICCD camera was opened for a given time just after the streamer had started. Each image presented in Fig. 1 was selected from a set of different discharge observations at the same conditions to be a representative of the typical time evolution of the streamer. The ICCD camera recorded an image of the streamer head movement from its inception to the moment when the ICCD camera gate was closed. We found that the streamer channel following the streamer head exhibited a weak light emission during the discharge, which lasted about 2 μs. In almost all cases, the streamers extinguished before bridging the electrode gap. Although the streamer propagation length increased with increasing applied voltages, the probability of streamer–spark transition also increased, affecting the stable discharge operation.

The branching pattern of the streamers and their trajectories were different for each discharge pulse. Fig. 1 shows the time evolution of the streamers in distilled water. The diameter of the streamers in water is in the range of 100–250 μm. We observed tiny bubbles that were generated in the vicinity of the needle tip. The bubbles diffused around the stressed electrode. When comparing the streamer discharges in air and in water using the same electrode configuration and pulsed high-voltage supply, brighter and thinner streamers with less branching were generated in water, whereas weaker and relatively thicker ($\sim$900 μm in diameter) streamers with more branching appeared in air.

As said, the trajectory of streamer changed from discharge to discharge. The accumulations of 20 images of the individual streamers for different ICCD camera exposure times are shown in Fig. 2. From the time evolution of the accumulated streamer discharge shown in Fig. 2, an average velocity of the streamer head moving toward the plate electrode was found to be about 3×10^4 m/s. This result is one order of magnitude lower than that of the positive dc streamer head in air [4].

Summarizing, features of the pulsed streamer discharge in water, such as the streamer inception, propagation, and branching, were studied using an ICCD camera. The results showed that within our experimental condition, the streamers in water exhibited less branching and slower propagation velocity when compared with the streamers in air.

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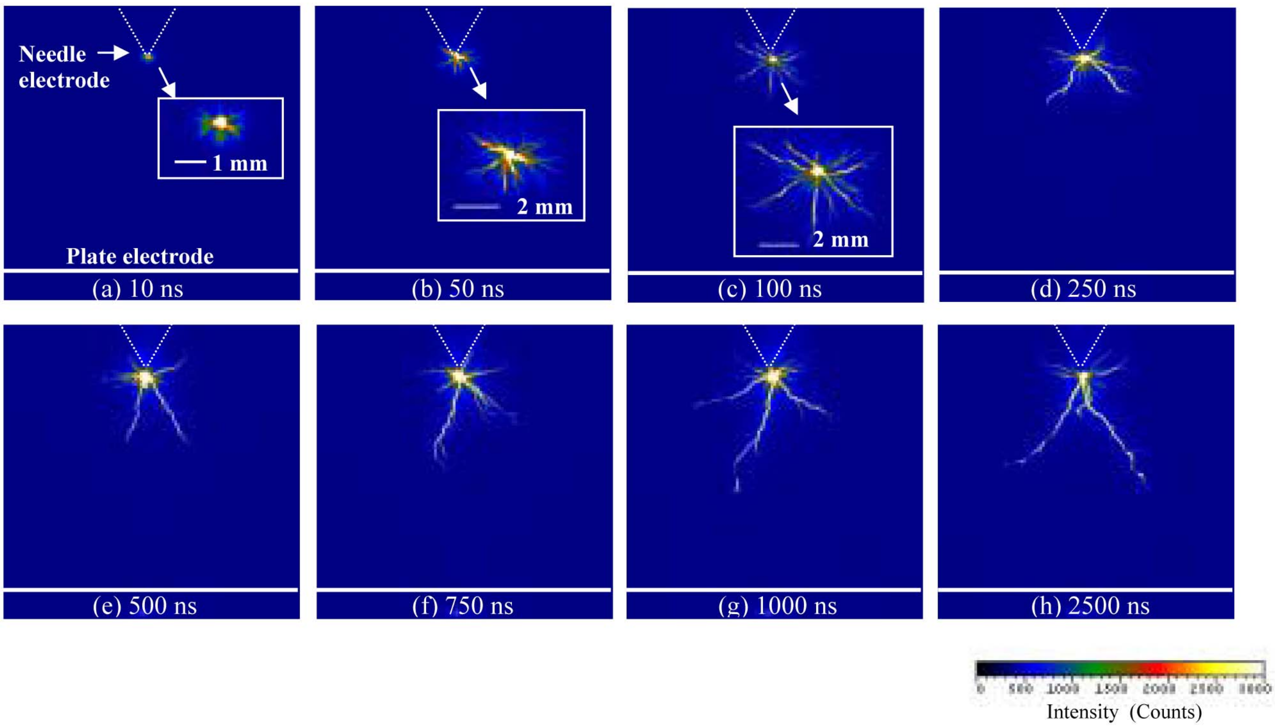

Fig. 1. Time evolution of pulsed streamers generated by a single discharge in distilled water (applied voltage: 27 kV; discharge current: 4–6 A; and gap: 20 mm). Each image is plotted with the same intensity scale: (a) 10 ns; (b) 50 ns; (c) 100 ns; (d) 250 ns; (e) 500 ns; (f) 750 ns; (g) 1000 ns; and (h) 2500 ns.

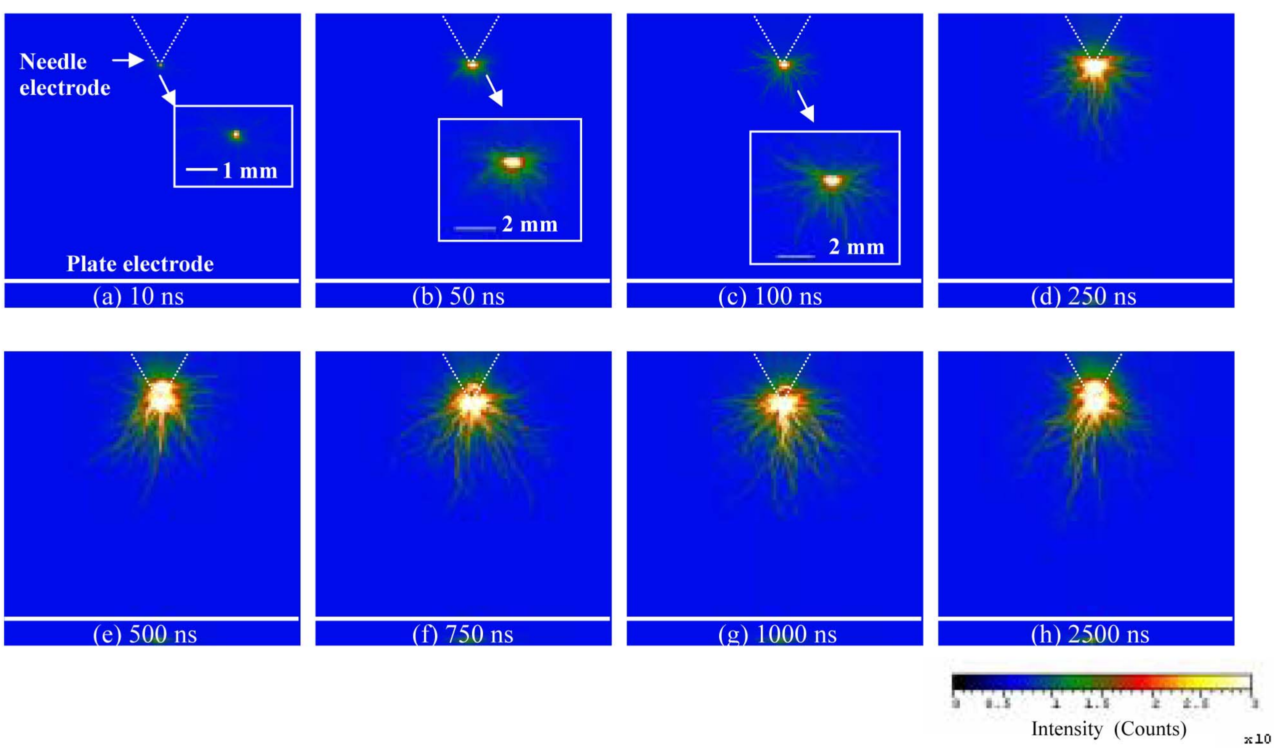

Fig. 2. Accumulated images of 20 streamers in distilled water (applied voltage: 27 kV; discharge current: 4–6 A; and gap: 20 mm). Each image is plotted with the same intensity scale: (a) 10 ns; (b) 50 ns; (c) 100 ns; (d) 250 ns; (e) 500 ns; (f) 750 ns; (g) 1000 ns; and (h) 2500 ns.

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