Nonelectrode Streamers in Deionized Water

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***Abstract*—In this paper, the study results of nonelectrode streamers initiated by microparticles of sizes less than 50 μm are presented. The used method is anode screening with the help of a preliminarily prepared conductive layer close to an electrode surface. A microparticle initiates multiple simultaneous streamers, both fast cathode and slow anode directed.**

***Index Terms*—Breakdown voltage, charge carrier processes, dielectrics, liquids, measurement by laser beam, space charge.**

USUALLY, breakdown initiates on electrodes. There are several reasons for this: The point of maximum field intensity is close to the electrodes, a lot of heterogeneities (bubbles, adsorbed ions, asperities, etc.) are on electrodes, and electrodes could provide power supply for growing plasma structures. Electrode screening due to charge emission or creation of conductive layers close to the electrode (e.g., "diffusion electrodes") can provide electrode field decrease. In this case, discharge initiation can take place inside the bulk of liquid. The small spots of proper discharge glow initiated inside the bulk of water have been already recorded [1], [2]. The goal of this paper is to present the images of double streamer structures initiated in the bulk of liquid.

The methods of generation and registration of streamers are the same as those described in earlier works [1], [3]. The conductive layer was created near the anode. Panoramic kerrograms and shadow images were obtained with the help of a semiconductor laser with a pulse duration of 3 ns. The spatial resolution was 10 μm. Both images show several streamers initiated both in the bulk of liquid and on the cathode. Each of the bulk-initiated streamers consists of negative-cathode bushlike structure (streamer) and anode filamentary ones. In Fig. 1, the length of the cathode part of streamer 1 is 100 μm, and the length of the anode part of the streamer is 400 μm. The width of the cathode part of the streamer is 150 μm, and the width of the anode part of the streamer is approximately 400 μm. As for the bulk-initiated streamer shown in Fig. 2, the longitudinal lengths of the cathode and anode parts of the streamer are 1 and 2 mm, respectively; the diametrical dimensions for both parts have the same value of $\sim$1.3 mm. One can see from the images that the cathode streamers from the electrode and cathode parts of nonelectrode streamers have the same bushlike shape. When the structure of cathode streamer could be seen in detail, the branch diameter was estimated as 100 μm.

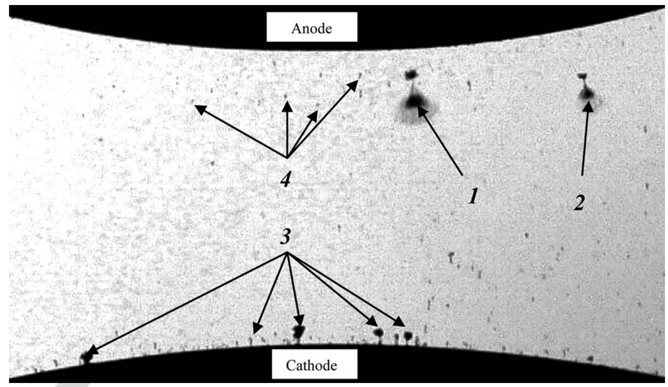

Fig. 1. (3) Cathode and (1 and 2) nonelectrode streamers. Gap space $d =$ 4 mm; pulse voltage amplitude $U = 160$ kV. (4) Dark dots are small particles.

The peculiarity of bulk-initiated streamers is a simultaneous growth of both anode and cathode parts of streamers from a single point. The evolutions of both parts of the streamer are interdependent. It occurs due to a simple principle that streamer currents must have the same value. Therefore, streamer propagations depend on each other. It should be underlined that the charges of anode and cathode parts of these streamers are equal to one another.

The careful image study (see Fig. 1) allows one to find out a lot of dark points there. In our opinion, they are conductive products of previous breakdowns. Their sizes are less than 50 μm.

The initiation of ionization processes in the bulk of liquid is probably caused by small microparticles (see Fig. 1). If their form is spherical, the electric field in two opposite points close to microparticles is three times more than mean field intensity. The point from the side of anode electrode can be considered as small cathode, and the point from the side of cathode electrode can be considered as small anode. The intensified field must provide cathode streamer initiation from the cathode point of particle surface. It is well known that initiation of slow cathode streamers requires less electric field intensity in comparison with anode streamers. Due to the current inside the cathode streamer, the electric field close to the anode point of the particle leads to further field increase until the moment when anode streamer initiation comes. Charge separation inside this double streamer structure provides the propagation of both streamers. As for streamer velocity, the cathode streamer obviously has subsonic speed at a mean field intensity of 400–500 kV/cm. The estimation of anode streamer velocities gives the values two to four times more according to the present data. In our opinion,

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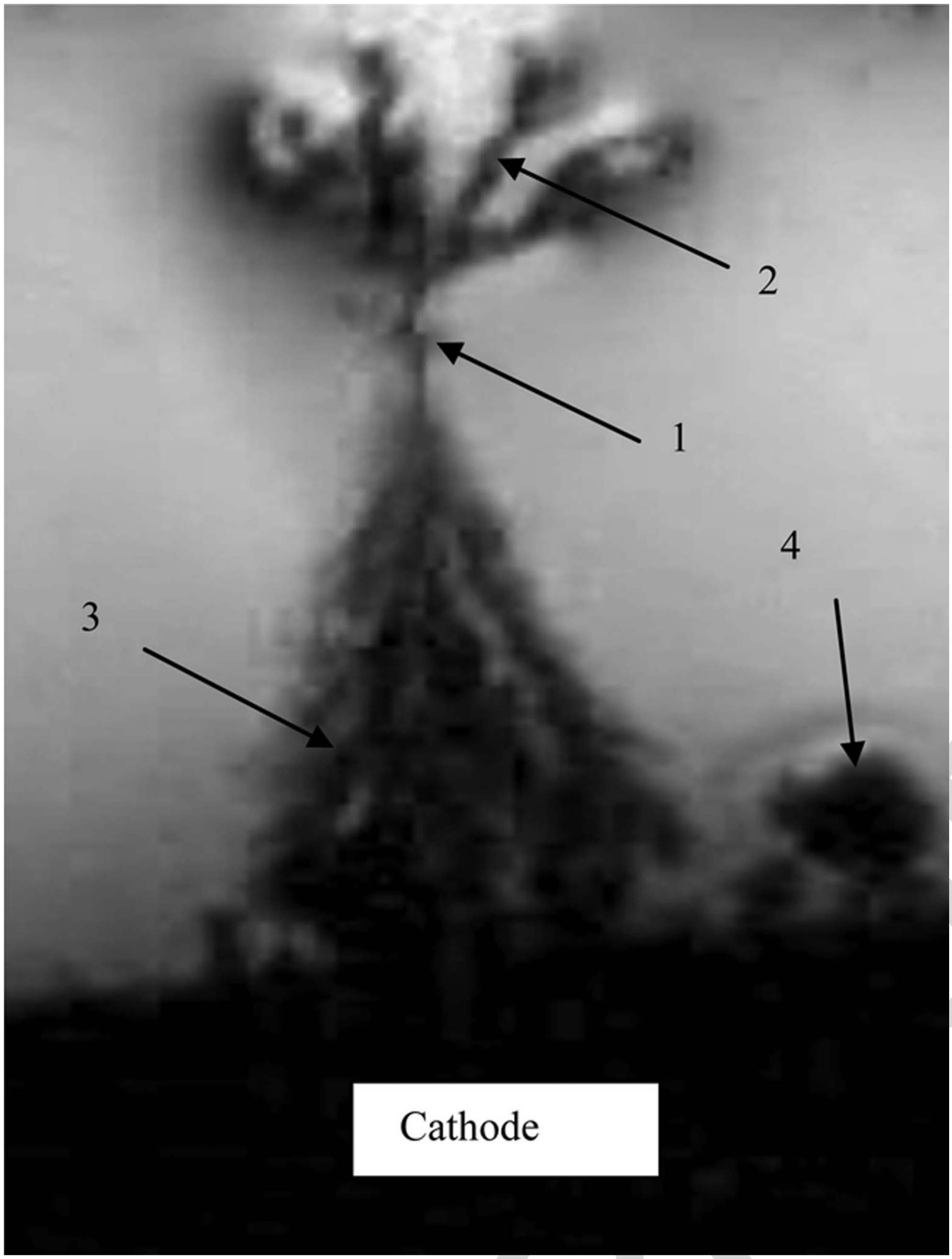

Fig. 2. Fragment of a twofold nonelectrode streamer. (1) Original point of streamers. (2) Cathode bushlike streamer. (3) Anode more filament streamer. (4) Usual cathode streamer. Peak value $U = 164$ kV, the instantaneous voltage is roughly 100 kV, and $d = 4$ mm. The total length of both cathode and anode streamers is 2.9 mm. The anode streamer reaches the cathode. All experiments were performed by using voltage pulses with a total rise time of $\approx 2\ \mu$s and a U of up to 200 kV. The total fall time of pulse was 0.2 μs. The first and second pictures were taken at the moment 100 ns after the moment of voltage maximum.

the anode streamer has a supersonic speed, and then, its velocity decreases and acquires a subsonic value. The reason of this behavior is due to the fact that the slow movement of cathode streamer cannot provide enough current for the fast movement of anode streamer.

In conclusion, the images of nonelectrode streamers formed in deionized water at pulse strength have been presented. These structures are provided by electric field screening near the anode and the presence of small particles inside the gap space.

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