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Investigation of streamer inception and branching conditions using an ultra fast ICCD camera

ICCDカメラを用いた高時間分解計測による ストリーマ放電の開始・分枝条件の研究

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A recently developed ultrafast camera that can acquire 10^8 frames per second was used to investigate streamer discharge. It enabled single-shot evaluation of streamer evolution without the need to consider shot-to-shot reproducibility. This camera was used to investigate streamers in argon. Growing branches, the transition when a streamer forms a return stroke, and related phenomena were clearly observed.

1. Introduction

Discharges are highly transient, probabilistic phenomena and thus ultrafast instruments are required to investigate them. In the past decade, the development of gated intensified CCD (ICCD) cameras has enabled such phenomena to be observed with a temporal resolution on the order of nanoseconds [1]. Streamer tips propagate like tiny spheres in air. Their morphology depends on factors such as the impedance of the high-voltage discharge circuit and the gas species.

In a previous study, we observed branched streamers in argon using an ICCD camera and we investigated the effect of preionization of the background gas on branching phenomena [2]. We found that a background electron density of n_e ~10^5/cm^3 suppresses branching.

In the present study, we used a recently developed ICCD camera with a multi-frame capability (Ultra Neo, NAC Inc.) to investigate such phenomena [3]. The optical system of this ICCD camera is based on a kaleidoscope. It can acquire more than 10^8 frames per second and it has a high spatial resolution. It is a very promising camera for investigating ultrafast probabilistic phenomena such as transient discharges. We chose to investigate the detailed evolution of positive streamers in argon because discharges in argon exhibit very complex branched structures and because it is difficult to determine the velocity of streamers in argon by single-shot measurements. Streamer tracks in argon remain illuminated during the lifetime of the streamer. In contrast, in nitrogen or air only the streamer tip emits light and only for a very brief time. Consequently, the tip velocity can be estimated by measuring the length of the light measured by an ICCD camera with a certain gating time.

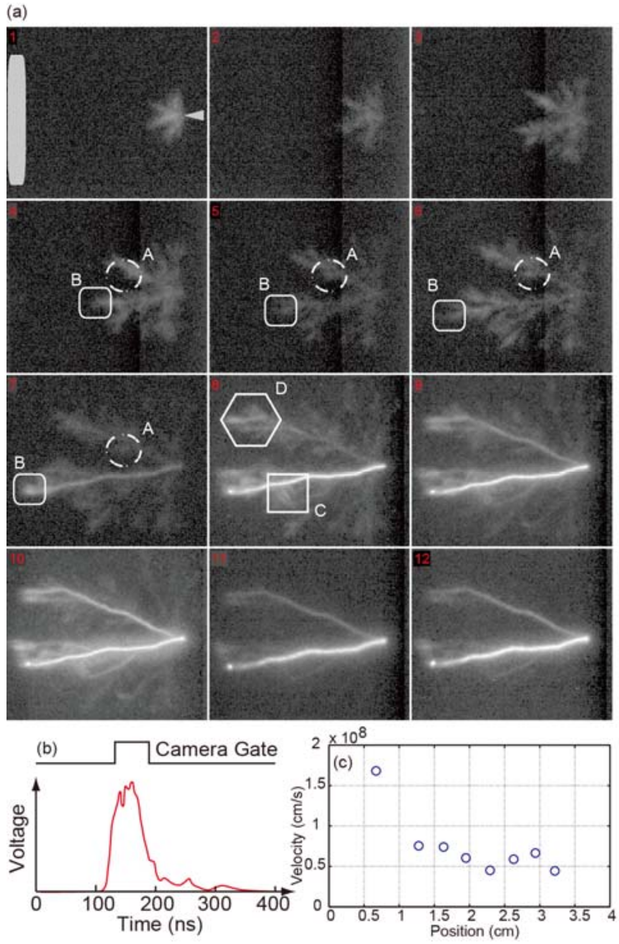

Fig. 1. (a) Growing positive streamer in argon taken by the fast-framing camera. Gate width of each image is 5 ns. Frame number is shown at upper-left of images. Applied voltage and pressure were 21 kV and 1 atm, respectively. Makings show A: stopped tip, B: growing tip, C: reconnecting streamer, D: final jump. (b) Waveform of voltage and gating-duration. 12-pictures were taken in this duration. (c) Velocity distribution of the most elongated streamer tip.

2. Observation of growing streamer and similarity of streamer and other surface growth phenomena

Examples of growing streamer in argon observed by the fast-framing camera are shown in Fig. 1 and 2. Needle-to-plane electrode was used. The distance between the electrodes was 3 cm. Positive high-voltage pulses were applied to the needle electrode for the case of positive streamer.

As noted on the figure 1, one of the tip was stopped growing (region A) while another tip closer to cathode kept on growing (region B). Immediately after the first streamer reached to cathode, it turns into arc mode. Remaining streamers closer to the arc channel were attracted to it and reconnected (region C). Final acceleration of the streamer propagation was observed at region D [4]. The velocity reaches almost 3 times faster than before (Fig.1 (c)). The formation of short circuit observed at 7-th frame, this corresponds to the voltage drop in the Fig. 1(b).

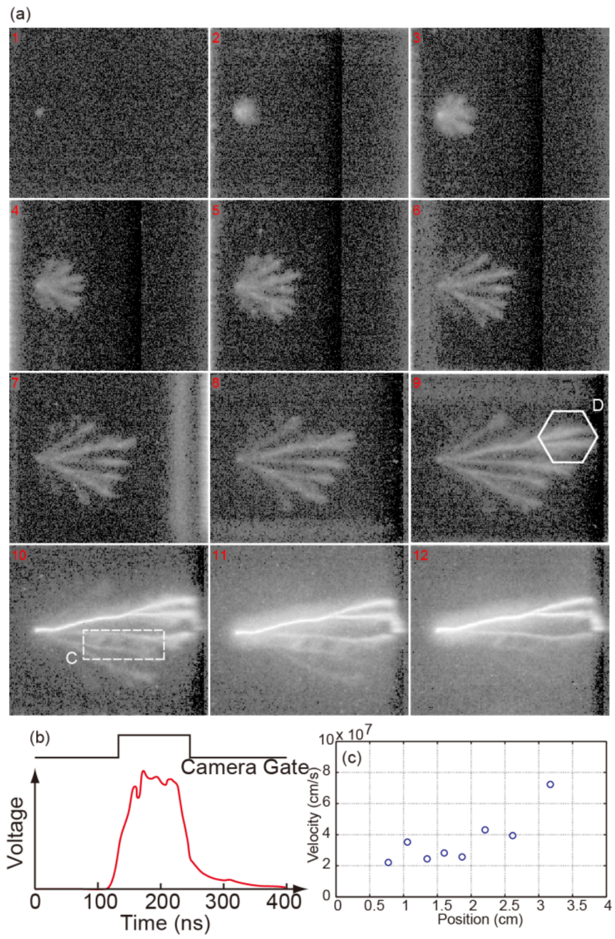

Fig.2. Growing negative streamer in argon. Gate width was 10 ns. Other experimental conditions were same for Fig.1.

The negative streamer in Fig.2 shows different behavior. The negative streamer has more extending branches while the positive streamer in argon shows very detailed branched structure. The shape of the positive streamer is closer to DLA phenomena [5]. The shape of the negative streamer is rather similar to viscous fingers [6]. The propagation velocity is almost half compared to the velocity of positive streamer. The reconnection and final jumps are also observed for negative streamer.

The observed shielding effect in the positive streamer is one of the features of the DLA. However the observed reconnection behavior is not observed in the DLA. The reconnection can be explained by the model proposed by Dawson [7]: the model assumed that the streamer tips are insulated from the anode and that tips can propagate in zero-field strength by transferring electrostatic energy to the next avalanche.

The origin of the self-similar structure in streamer was discussed by some authors. The similarity of dielectric barrier discharge on surface to DLA was pointed out by Niemeyer [8]. They showed that the discharge structure has a Hausdorff dimension of 1.7 which is closer value for the DLA phenomena. The possibility of Laplacian instability was also shown by ref [8]. However, the theory to explain the very diverse morphology of the discharge has not been built yet.

6. Summary

The temporal evolution of streamers in argon was investigated by performing single-shot measurements using a recently developed ultrafast framing camera. The morphology is discussed by comparing with the other surface growing phenomena.

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