Two-Dimensional Electron Density Distribution over Positive Primary Streamer Propagating in Atmospheric-Pressure Air

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Elucidating the electron density of streamer discharges propagating in atmospheric-pressure air is critical for achieving a systematic understanding of the production mechanisms of reactive species. Using Shack-Hartmann type laser wavefront sensors with a temporal resolution of 2 ns, we carried out single-shot two-dimensional electron density measurements over positive primary streamers generated in a 13-mm air gap between pin-to-plate electrodes. The electron density over the positive primary streamers decayed in a range of 10^{15} cm^{-3} during the propagation. The decay time constant of the electron density in the primary streamer channels was estimated to be ～2 ns. The distribution widths of the electron density were in good agreement with those of the light emission, typically ranging from 0.8 to 1.5 mm.

1. Introduction

The electron density of streamer discharges propagating in atmospheric-pressure air is crucially important for systematic understanding of the production mechanisms of reactive species utilized in wide ranging applications such as medical treatment, plasma-assisted ignition and combustion, ozone production and environmental pollutant processing. However, electron density measurement during the propagation of the atmospheric-pressure streamers is extremely difficult by using the conventional localized type measurement systems due to the irreproducibility in the discharge paths. In order to overcome the difficulties, single-shot two-dimensional electron density measurement was conducted by using a Shack-Hartmann type laser wavefront sensor. The Shack-Hartmann sensors were applied to pulsed positive primary streamer discharges generated in an air gap.

2. Experimental setup and results

The temporal resolution of the Shack-Hartmann sensors was 2 ns, which was equal to the exposure time of the installed two ICCD cameras. The spatial resolution was determined by the pitch of the microlens arrays, which was 300 μm.

Pulsed positive streamer discharges were generated in a 13-mm gap installed in open air. The air gap was composed of a brass plate cathode and a stainless-steel pin anode, whose tip radius was 80 μm. Figure 1 shows voltage and current waveforms for the streamer discharge in atmospheric-pressure air. The voltage rise-rate was 0.83 kV/ns.

Figure 2 shows that the electron densities at 5 ns after streamer initiation ranged from 5 to 7×10^{15} cm^{-3}, while the electron density at the time of the streamer initiation was 8-9×10^{15} cm^{-3}. In the process of streamer propagation, the electron density decreased with increasing time. On the other hand, the electron density widths distributed uniformly along the *y*-direction at the timing of the streamer occurrence and 5 ns after the streamer initiation. The decay time constant of the electron density in the primary streamer channels was estimated to be ～2 ns from the streamer propagation speed of 9×10^5 m/s. The half-maximum full-widths of the electron density distributions were in good agreement with those of the light emission profiles, typically ranging from 0.8 to 1.5 mm.

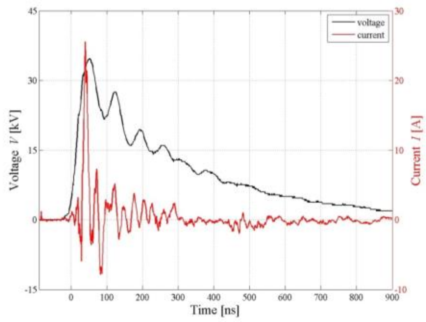

Figure 1. Current and voltage waveforms for air streamer discharge.

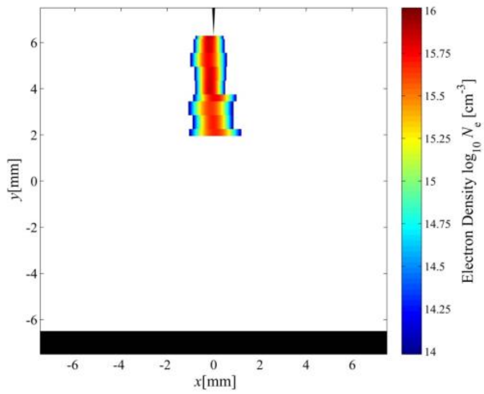

Figure 2. Two-dimensional electron density distribution at 5 ns after air streamer initiation.