Deflection of Streamer Path in DC Electric Potential
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Abstract—Nonequilibrium atmospheric plasma jets are associated with sequence of streamer breakdowns developing in helium-air mixture. In this paper, propagation of the streamer in plane capacitor is photographed, and deflection toward the positive capacitor plate is analyzed.

Index Terms—Atmospheric-pressure plasmas, plasma sources.

I. INTRODUCTION

RECENTLY nonequilibrium atmospheric plasma jets (NEAPJs) are widely used in biomedicine for treatments of cancer, cellular modifications, bacteria killing, wound healing, and so forth [1]. The phenomenon of the NEAPJ is associated with the sequence of streamer breakdowns developing in helium stream flowing out from a discharge tube into an ambient air. Interaction of the NEAPJ streamer with the externally created electric potentials was studied in [2] and [3]. A streamer stopping by external electrostatic potential was demonstrated and used for measuring the electrical potential of the streamer head [2]. However, deflection of the positively charged streamer head toward the positive plate of capacitor has not received solid explanation yet [3]. In this paper, we present temporarily resolved photographs of the NEAPJ streamer inside the plane capacitor and explain its attraction to the positive electrode.

We utilized discharge tube with diameter of 4 mm equipped with central noninsulated electrode mounted on the tube axis and grounded ring electrode mounted downward the tube. Helium (He) flow through the tube was \( \sim 11-12 \ \text{L/min} \). A capacitor was formed by two plane copper electrodes (plates size: 1.1 cm \( \times \) 3.5 cm, gap = 1.8 cm) mounted as schematically shown in Fig. 1(b). The electrode shown at the bottom of Fig. 1(b) was at dc potential \( U_{\text{cap}} = 3.2 \ \text{kV} \), whereas the top electrode was grounded. More details on the NEAPJ setup can be found elsewhere [1], [2].

Photographs of the streamer propagation are presented in Fig. 1(a) and (b) without and with the capacitor respectively. Waveforms of discharge voltage and current are shown in Fig. 1(c). It was observed that the plasma jet is about twice shorter when the capacitor is in place. In addition one can see that streamer propagates along the straight line without the capacitor, whereas deflects toward the positive plate if the capacitor presents.

In order to understand behavior of the streamer in the external electrical potential, the perturbation of the electrical field created in vicinity of the streamer’s head (\( E_h \)) should be considered. Indeed, \( E_h \) is critical for streamer propagation since this field directly affects the electron avalanches developing in front of the streamer head. First, \( E_h \) should exceed threshold value corresponding to balance between ionization of ambient gas (primarily He) and attachment to oxygen in order to support streamer propagation [4]. Second, direction of \( E_h \) affects avalanche trajectory and thus governs the entire streamer path.

Taking into account, that electrical potential of high voltage discharge electrode (\( U_d \)) is transferred to the streamer head without significant drop, the electric field \( E_h \) around the streamer head can be estimated as

\[
E_h = \frac{U_d - U_0}{2r_s} \cdot \frac{E_{\text{ambient}}}{E_{\text{ambient}} - E_d},
\]

where \( U_0 \) is space potential created at current head location by sources other than streamer head, \( r_s \)-streamer channel radius [2], [4].

Let us now estimate perturbation of \( E_h \) introduced by capacitor used in current experiment. Space potential is \( U_0 \approx 0 \ \text{V} \) and 1.6 kV without and with the capacitor, respectively. The average potential of streamer tip is \( U_d \approx 2.2 \ \text{kV} \) during the time interval when streamer develops \( (t = 2.5-5.5 \ \mu s; \text{pink bar on the Fig. 1(c)} \) and visual streamer radius is \( r_s = 0.015 \ \text{cm} \). This finally yields \( E_h \approx 73 \) and 27 kV/cm without and with the capacitor, respectively.

Therefore, insertion of the capacitor decreases electric field in the streamer head vicinity about three times. This significant reduction of the field causes stopping of the following streamer propagation observed in experiment. In addition, insertion of capacitor perturbs the direction of the field around the head. This causes the electrons from the avalanches initiated in front of the streamer head to follow direction of the perturbed field, which finally changes the entire streamer path. Indeed, the strongest avalanches develop along the axis due to minimal presence of the oxygen. In the case of free streamer propagation (without the capacitor), the electrons of these avalanches are attracted solely by positive streamer head and, as result, move directly toward it along the axis. In contrast, when the capacitor is in place, the electrons of the avalanches are attracted simultaneously by the positive streamer head and by the positive capacitor’s plate [Fig. 1(d)]. Therefore, the resultant drift direction of the avalanche electrons (and, therefore, the entire avalanche path) deflects from the axis toward the positive capacitor plate as shown schematically in Fig. 1(d). Streamer propagation in the direction of the positive capacitor plate perpendicular to the jet axis stops shortly.

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due to increased presence of the ambient air and elevated attachment to oxygen that quenches further development of the avalanches.

REFERENCES


