Direct Current Glow Discharges in Atmospheric Air

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***Abstract*—A microhollow cathode discharge was used as plasma cathode to sustain a stable direct current glow discharge in atmospheric pressure air. The length of the glow discharge column was varied from 1 mm to 2 cm, with the sustaining voltage increasing linearly with length. For glow discharges with currents on the order of 10 mA, the electron density in the air plasmas exceeded 10^{11} cm^{-3}, with highest values of almost 10^{13} cm^{-3} close to the plasma cathode. When two 8.5-mA discharges were operated in parallel, at a distance of 0.4 cm, the discharge plasmas were found to merge for electrode gaps exceeding 0.5 cm, an effect that can be used to generate large volume, homogenous air plasmas.**

***Index Terms*—Air, atmospheric pressure, direct current, glow discharge.**

RESEARCH on atmospheric pressure glow discharges in air is motivated by applications such as instantly activated reflectors and absorbers for electromagnetic radiation, detoxification of polluted air, and surface treatment. One of the major obstacles in obtaining stable atmospheric pressure glow discharges in air at high electron densities ($>10^{11}$ cm^{-3}) is the glow-to-arc transition. This instability generally develops in the cathode fall, a high field region, which in self-sustained glow discharges is required for the emission of electrons from the cathode through ion impact. By using a microhollow cathode discharge (MHCD) as electron source, the cathode fall can be reduced or even eliminated. Using this concept, stable air discharges between the plasma cathode and a third positively biased electrode, 2-mm apart, could be generated [1]. The electron density in these discharges may reach values as high as 10^{13} cm^{-3} at a gas temperature of approximately 2000 K [1], [2].

We have explored the scaling of these dc atmospheric pressure air glow discharges to larger dimensions, by extending the gap distance up to 2 cm, and by placing two atmospheric pressure air glows in parallel. The MHCD was sustained between molybdenum electrodes, separated by a 130-μm-thick alumina layer, with a 130-μm hole through the sample. The glow discharge between the MHCD and the third electrode was ignited at small gap lengths, in order to keep the ignition voltage low, and then the gap was extended to the desired distance. The current voltage characteristics of both the plasma cathode (MHCD) and the air glow was measured, and photographs of the discharge in the visible were taken with a charge coupled device (CCD) camera. In Fig. 1, photographs of the 5 mm long air glow at three current levels are shown. The microhollow cathode (plasma cathode) current was held at 6 mA. The voltage across the glow discharge was, in all three cases, 840 V.

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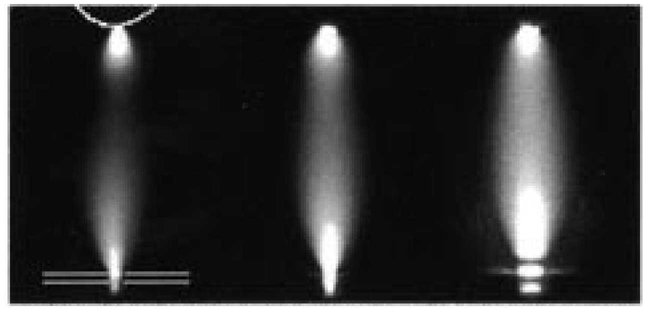

Fig. 1. Photographs of atmospheric pressure air glow discharges at currents of 5.3, 11.1, and 22 mA (from left to right). The electrodes are shown schematically in the photograph on the left.

Fig. 2. Photographs of the air glow discharges with various gap lengths ranging from 0.5 to 2 cm. The current was kept constant at 13 mA. The striations in the photographs are due to the limited resolution of the CCD camera.

Results of such optical measurements and of electrical measurements indicate two stable modes of operation depending on the ratio of glow discharge to MHCD current. For glow discharge currents less than the MHCD current, the center electrode serves as an MHCD anode (Fig. 1, 5.3-mA discharge). For glow discharge currents exceeding the microhollow cathode discharge current, the plasma cathode is not able to provide all the electrons for the glow discharge, and consequently, electron emission from the surface of the center electrode is taking over as electron supply process. The discharge then spreads over the surface of the center electrode, which serves as additional cathode. There is a slight indication of the plasma extending over the center electrode for the 11.1-mA discharge in Fig. 1. The effect is obvious for the 22 mA discharge.

The gap length, which in Fig. 1 is 5 mm, can easily be extended to larger values (Fig. 2). The discharge voltage increases linearly with gap length for constant discharge current. The plasma cross-section increases with increasing distance from the electrodes. For gaps of less than 1 cm, the widest cross-section is at midpoint, for larger gaps it shifts closer to the anode.

Information on the electric field distribution along the glow discharge axis was obtained by varying the gap distance and recording the voltage at constant current. The electric field E decreases initially with increasing distance from the cathode, but approaches a constant value at a distance of approximately 0.5 cm from the plasma cathode. In the plasma region where E is independent of position, E increases with decreasing discharge current. It was measured as 1.2 kV/cm for a discharge current of 13 mA, and increased to 2 kV/cm for 5-mA currents. Values of the cathode fall voltage were obtained by extrapolating the voltage versus gap distance curve to zero gap distance, and by recording the residual voltage. The cathode fall was found to be dependent on glow discharge current, varying from 40 V at 5 mA, to 22 V at 13 mA.

The electron density n_e was obtained from the plasma conductivity by using the information on the electric field distribution and the average current density, j (discharge current divided by plasma cross section)

$$n_e = j/(ev(E)) \tag{1}$$

where values for the drift velocity $v(E)$ were obtained from [3]. The electron density decreases for discharges with a current of 13 mA from values of 10^{13} cm^{-3} close to the plasma cathode to a constant value of approximately 10^{11} cm^{-3} at a distance from the cathode which corresponds to the largest plasma diameter.

The MHCD sustained air glow discharge has a negative differential resistance. Parallel operation of the high-pressure glow discharges, therefore, requires the use of ballast resistors for individual discharges. Two discharges were operated side by side, each carrying a current of 8.5 mA, with their axes 0.4 cm apart. It was found that for this configuration, the discharge formed individual plasmas up to a gap distance of approximately 0.5 cm. For larger distances, the plasmas merge (Fig. 3, top), and eventually, with increasing gap a homogeneous plasma layer is formed (Fig. 3, bottom). Using arrays of microhollow plasma sustained glow discharges allows us, therefore, to generate large volume, homogeneous atmospheric pressure air plasmas with electron densities exceeding 10^{11} cm^{-3}.

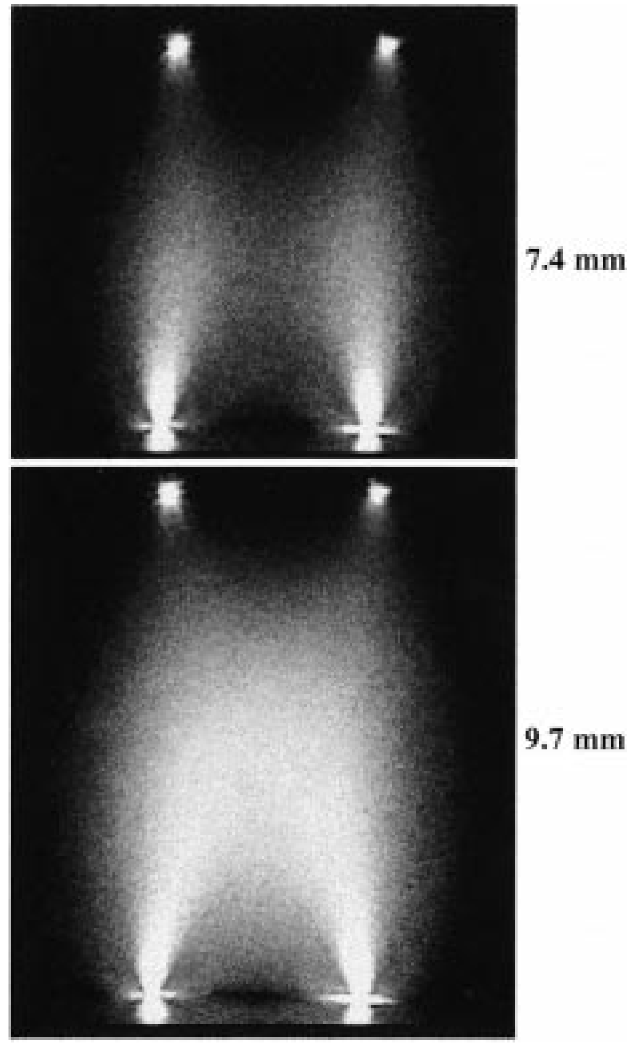

Fig. 3. Parallel operation of two air glow discharges. The individual discharges carry a current of 8.5 mA.

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