Images of a Nanosecond Repetitively Pulsed Glow Discharge Between Two Point Electrodes in Air at 300 K and at Atmospheric Pressure

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Abstract—For many applications of atmospheric pressure plasmas, a crucial issue is to obtain glow discharges at 300 K. We have generated such plasmas with a nanosecond repetitively pulsed method. We present experimental and simulated optical emission images of the dynamics of the formation of the glow regime at the early stages of its development.

Index Terms—Atmospheric pressure plasmas, corona, glow discharge, spontaneous emission.

In the last years, discharges in air at atmospheric pressure have been studied for an increasing list of applications such as biomedical and surface treatment, chemical and biological decontamination, aerodynamic flow control, and combustion. Some of these applications require diffuse nonthermal (i.e., glow) discharges to simultaneously meet requirements of low power, high chemical reactivity, and low gas temperature. However, at atmospheric pressure, glow discharges in air easily transition into spark discharges that significantly heat the gas. The use of nanosecond repetitively pulsed (NRP) discharges allows to control efficiently the glow-to-spark transition. In these discharges, the application of high-voltage nanosecond-duration pulses generates a strong electric field that accelerates electrons to the high energies required for efficient ionization, whereas the short pulse duration prevents spark formation. The use of NRP made it possible to generate glowlike discharges at atmospheric pressure in air at 2000 K [1] and, recently, at 1000 K [2]. Simulations of the NRP glow regime have been done at 1000 K [3]. In this paper, we present experimental and simulated images of the dynamics of the formation of the NRP glow regime in air at atmospheric pressure and at 300 K.

The setup from [2] is adopted in this paper with two steel point electrodes in a vertical pin–pin configuration with an interelectrode gap of 5 mm. NRP discharges are produced using short-duration (10 ns) high-voltage pulses at a repetition frequency of 1–30 kHz in an atmospheric pressure air flow. In [2], positive polarity pulses were applied to the anode, and the cathode was grounded. In this paper, positive (+9 kV) and negative (−9 kV) pulsed voltages are applied to the anode and cathode, respectively, to avoid perturbations of the Laplacian electric potential from grounded objects around the experiment (i.e., the distribution of the Laplacian electric field at both electrode tips is symmetric). In the experiments, the electrodes can be assumed to be hyperboloids with a radius of curvature of about 50 µm. We present images of discharges for an NRP frequency of 1 kHz in air flowing at 10 m·s⁻¹, at 300 K, and at atmospheric pressure. An ICCD Pimax camera 512 × 512 is used with 50 accumulations. Images are taken every nanosecond with an integration time of 2 ns. In this paper, we have also carried out discharge simulations at 300 K and atmospheric pressure using the 2-D discharge model given in [3] with the model for optical emissions presented in [4]. Hyperboloid electrodes with a radius of curvature of 100 µm are considered. An electric potential difference of 15 kV is applied to electrodes with a voltage risetime of 5 ns to be close to the experimental conditions. As in [3], in this paper, we have simulated a single discharge, and then, to take into account the numerous preceding discharges, we have estimated a density of seed charges on the order of 10⁹ cm⁻³. For air discharges at atmospheric pressure, the emission of the second positive (2P) system of N₂ is known to be the most intense. Then, to compare with experimental images, we have computed the line-of-sight integrated 2P emission time integrated over 2 ns.

Fig. 1 shows the calculated 2P emissions [(a), (c), (e), and (g)] and experimental [(b), (d), (f), and (h)] images of the discharge at different times of the discharge formation. The time t₀ of the first images [(a) and (b)] is adjusted to have the best experimental/simulation agreement. Successive experimental and simulated images are obtained at a time interval of 1 ns. We note that rather good agreement is obtained between simulations and experiments during the entire duration of the discharge formation. At t = t₀, corona discharges are observed on both electrodes with more intense emission on the anode...
side. At \( t = t_0 + 1 \) ns, we observe the connection of both the positive and negative discharges. As both discharges have different radial extents, it is interesting that the connection area is a bottleneck that we observe on images up to \( t = t_0 + 3 \) ns. After the connection \([3],[4]\), the positive discharge rapidly propagates toward the cathode, and then, at \( t = t_0 + 2 \) ns, Fig. 1(e) and (f) shows an intense emission in the bottleneck region due to the contribution of the two discharges, which then extends to the cathode at \( t = t_0 + 3 \) ns [see Fig. 1(g) and (h)]. We note that, at \( t = t_0 + 3 \) ns, the radial extension of the optical emission is larger on the cathode side than on the anode side. A thorough study of the NRP glow discharge at 300 K will be presented in forthcoming publications.

Fig. 1. Spatial distributions of [(a), (c), (e), and (g)] calculated line-of-sight 2P emission time integrated over 2 ns and [(b), (d), (f), and (h)] experimentally measured optical emission. A linear intensity scale is used for experimental and simulation results. The maximum value of the calculated intensity is \( 5 \times 10^{13} \) Rayleigh.

REFERENCES