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Spatiotemporal variation of electric field and electron density in atmospheric pressure streamer discharge

大気圧ストリーマ放電における電界・電子密度の空間・時間的変化について

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Spatiotemporal variation of the reduced electric field and electron density in atmospheric pressure streamer discharge is studied by numerical simulation. Results show that streamers appear in strongly non-uniform electric fields near electrodes and produce ionizing waves with high spatial gradients of the electron density and electric field. Although the peak value of the reduced electric field reaches 800 Td at the streamer head, the effective volume for the radical production is very small because the streamer head is very thin and passes through between electrodes very fast.

1. Introduction

A streamer discharge is widely used in many applications such as decomposition of gaseous pollutant, water treatment, ozone production, surface treatment and medical application [1]. However, the understanding of the phenomena involved is still poor. The complete simulation of a streamer discharge may lead to a better understanding of the physicochemical activity and assist in the selection of optimal operation conditions (such as reactor geometry, the flue gas resident time, the applied voltage shape and magnitude) to improve the process efficiency. To perform quantitative analysis of the efficiency of various applications, an insight is needed into the physics of streamer propagation processes.

In these days, the measurements of reactive species such as ozone, hydroxyl radical, and atomic oxygen have been performed by many researchers. The density of the reactive species can be measured by laser-induced fluorescence method [2]. However, because the streamer has the very thin reactive channel (under 1 mm of diameter), it is difficult to measure the spatial distributions of the reactive density accurately. In this situation, the numerical simulation of a streamer discharge can be a powerful tool to know the kinetics of the streamer discharge. In this presentation, the spatial distributions of the reduced electric field and electron density are simulated and their effects on the spatial distributions of the reactive species are discussed.

2. Simulation model

Figure 1(a) shows the configuration of the electrodes and the computation domain. The propagation of a streamer discharge is considered in a point to plane electrode configuration with a gap distance of 13mm. In order to simulate the discharge development, we chose a cylinder domain of 18cm height and 8.0cm radius. The total number of segments is Nz×Nr = 1972×256 with spatial steps from dz = 1 μm (near point and plane) to 10 μm (inter-electrode gap) for z-axis and from dr = 2.5 μm up to 200 μm for r-axis. The point electrode has a revolutionary hyperboloid shape with a radius of 40μm. The model equation used here is a first-order electro-hydrodynamic model for electrons and ions in the framework of the drift-diffusion approximation. We used a reduced

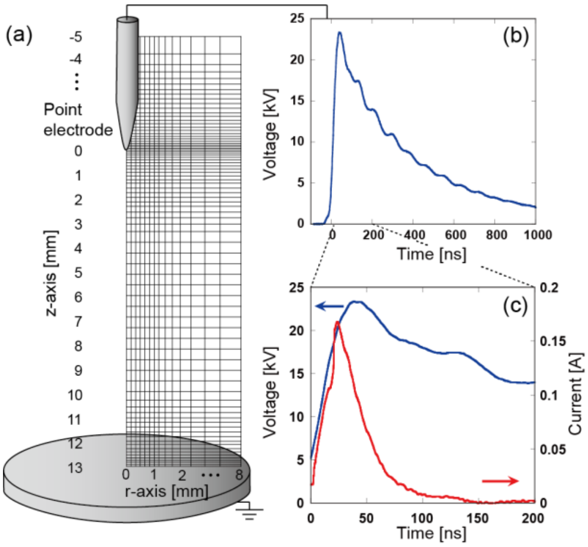
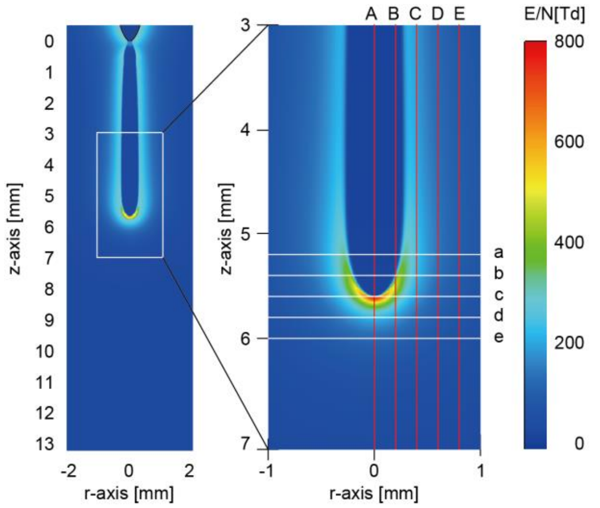
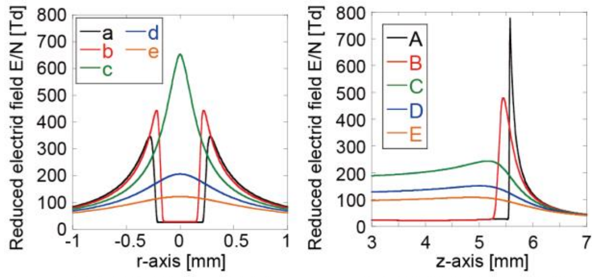


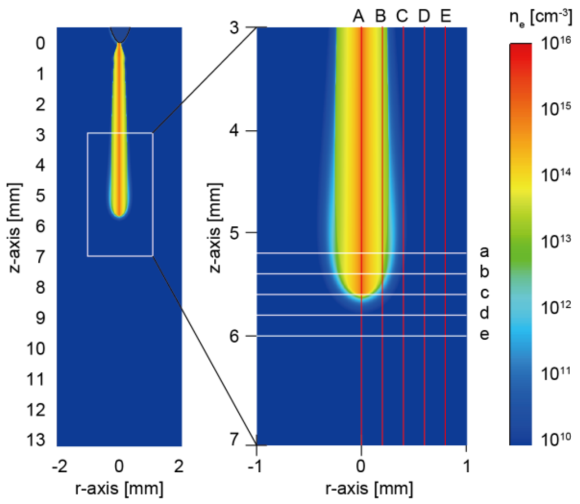
Fig. 1. (a) Schematic view of the calculation domain and mesh, (b) waveform of the applied pulsed voltage, and (c) enlarged view of the applied and calculated discharge current [3]. The applied voltage is 24 kV.



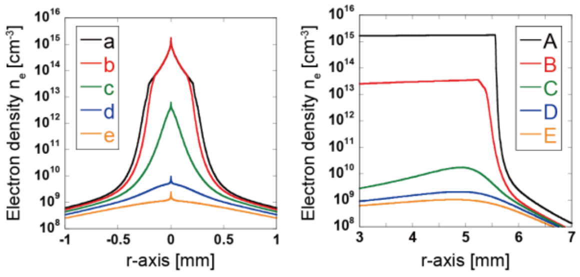
(a) 2D distribution of E/N (b) Enlarged view of (a)



(c) Radial distribution of E/N (d) Axial distribution of E/N



(a) 2D distribution of n_e (b) Enlarged view of (a)



(c) Radial distribution of n_e (d) Axial distribution of n_e

Fig. 2. (a) Cross sectional view of reduced electric field *E/N* of streamer discharge at time *t* = 12 ns, (b) enlarged view of (a), (c) radical distribution of *E/N*, and (d) axial distribution of *E/N*.

Fig. 3. (a) Cross sectional view of the electron density n_e of streamer discharge at time *t* = 12 ns, (b) enlarged view of (a), (c) radical distribution of n_e, and (d) axial distribution of n_e.

reaction model including electron impact reactions (excitation, ionization, dissociation, recombination, attachment, and detachment), ion recombination, and the reactions of neutrals. A detailed description of the chemical reaction model is given in our previous report [3]. Figure 1(b) shows the waveform of the applied pulsed voltage and Fig. 1 (c) shows an enlarged view of Fig. 1 (b) and the discharge current. In this simulation, the actual pulsed voltage, which is measured from our experiments [4], is applied to the conduction anode tip.

3. Results

Figures 2(a) and (b) show the spatial distribution of reduced electric field E/N at time t = 12 ns. The streamer has the high spatial gradient around the streamer head. Figures 2 (c) and (d) show the radial and axial distributions of E/N along the lines drawn in Fig. 2 (b), respectively. The E/N at the streamer head is about 800 Td, and the thickness of the streamer head is about 0.2 mm, which is defined by the FWHM of the axial distribution. Figures 3(a) and (b) show the spatial distribution of electron density n_e at time t = 12 ns, and (c) and (d) show the radial and axial distributions of the lines drawn in Fig. 3(b). The radial distributions of n_e do not have the Gaussian distributions. The n_e at the center of the streamer is about 10 times larger than that at the edge of the streamer. From these radial distributions of *E/N* and n_e, we can estimate that radial distributions of reactive species could not have the Gaussian distributions too. In this presentation, we show the simulated spatial distributions of some reactive species and compare them with the spatial distributions of *E/N* and n_e.

References

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