Spatio-Temporal Images of Single Streamer Propagation in Dielectric Barrier Discharge

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***Abstract*—One-dimensional time-dependent numerical simulations are presented to find the discharge mechanism and illustrate the spatio-temporal images of a single streamer in the dielectric barrier discharge (DBD). Calculated results reveal that the three discharge phases of avalanche, streamer, and decay are distinguished depending on the external voltage applied to the electrodes in the DBD. At different over-voltage conditions, the time evolutions of discharge currents show distinct profiles which adequately explain the spatio-temporal variations of the single streamer in the DBD.**

***Index Terms*—Dielectric barrier discharge, discharge current, discharge phase, numerical modeling, streamer propagation.**

RECENTLY, there have been renewed interests in the diagnostics and numerical modeling of the dielectric barrier discharge (DBD) because of its successful applications to toxic gas decompositions. Most of the DBD diagnostics have difficulties in the measurements due to the limited range and rapid development of the discharge. One of the common measurements is the current evolution varying with time during the discharge in dielectric barrier reactors. Even though such current measurements have been directly used for controlling the DBD plasma process, the physical interpretation of the measured discharge currents is further needed to clarify how these current patterns are linked to the discharge phases, such as avalanche, streamer, and decay. For detailed understanding of the discharge mechanism in the DBD, spatio-temporal variations of a single streamer are investigated in this numerical work by one-dimensional (1-D) time-varying simulations. Specifically, streamer propagations are analyzed to explain the discharge characteristics by comparing the spatio-temporal variations with the temporal discharge current evolutions in different over-voltage conditions.

In this numerical modeling, the motions of electron, positive ion, and negative ion in the DBD are described by a set of continuity equations. A flux corrected transport (FCT) algorithm based on the finite-difference method (FDM) is employed to minimize numerical dissipation, in which upwind and Lax-Wendroff schemes are used as low- and high-order parts, respectively. They are then corrected using a method suggested by Zalesak. Electron impact ionization, secondary emission, electron attachment, and photo-ionization are taken into account in the discharge conditions of atmospheric-pressure dry air [1]. In electric field calculations, an externally applied electric field with no discharge is found from Laplace equation, and an internal electric field generated by space charges in the DBD reactor is solved using the method of disk [2] for a refined description of a highly localized streamer channel. It is assumed that the streamer channel has a radius of 200 μm in this 1-D situation. Secondary electron emissions due to photon impact on the cathode surface are included, and all the incoming electron and ion fluxes are assumed to be accumulated on the barrier surface. Discharge current profiles are obtained from an equation suggested by Sato [3].

In the present numerical DBD model, a dielectric barrier with a relative permittivity of 8 and a thickness of 0.2 cm is covered only on the anode surface, and a discharge gap between the barrier and cathode is 0.2 cm. A spatial mesh of 10^{-3} cm and a time step of 10^{-12} s are taken for the calculations. The seed electrons are initially distributed in front of the cathode in a Gaussian shape with a peak electron density of 10^3 cm^{-3}.

As a result of numerical simulations, Fig. 1 illustrates the temporal evolutions of electron density and electric field between the barrier and cathode in the DBD reactor for the two cases of different voltages applied between the anode and cathode: (a) 45 kV/cm (50% over-voltage case) and (b) 60 kV/cm (100% over-voltage case). Fig. 1 indicates that discharge evolutions are undergone the three phases—avalanche, streamer, and decay—which are more apparent in Fig. 2 as a temporal history of discharge currents. At first, electrons released from the cathode begin to drift toward the anode and multiply themselves as the time elapses. However, in this avalanche phase, there are negligible discharge currents and slightly perturbed initial electric fields due to undeveloped space charges in the reactor. When a streamer occurs at about 18 ns, it is observed that its electric field increases and the discharge current begins to rise. As the streamer approaches the cathode, the electric field gradually increases and reaches its highest value at around 28 ns when the streamer strikes the cathode. Fig. 2 shows a maximum value of the discharge current at this moment. After this streamer phase, the electric field within the streamer channel decreases and the discharge is gradually extinguished. In this decay phase, the discharge current also decreases and finally becomes zero.

When the electric field is applied up to 60 kV/cm, which is a 100% over-voltage condition, the avalanche is turned into an anode-directed streamer midway in the discharge region at 4 ns and its discharge current is slightly increased as depicted in Figs. 1(b) and 2. During the propagation of anode-directed streamer, another cathode-directed streamer is created, and finally the two streamers moving in the opposite directions are observed. In the over-voltage discharge, an earlier transition of avalanche-to-streamer, stronger electric field, and higher dis-

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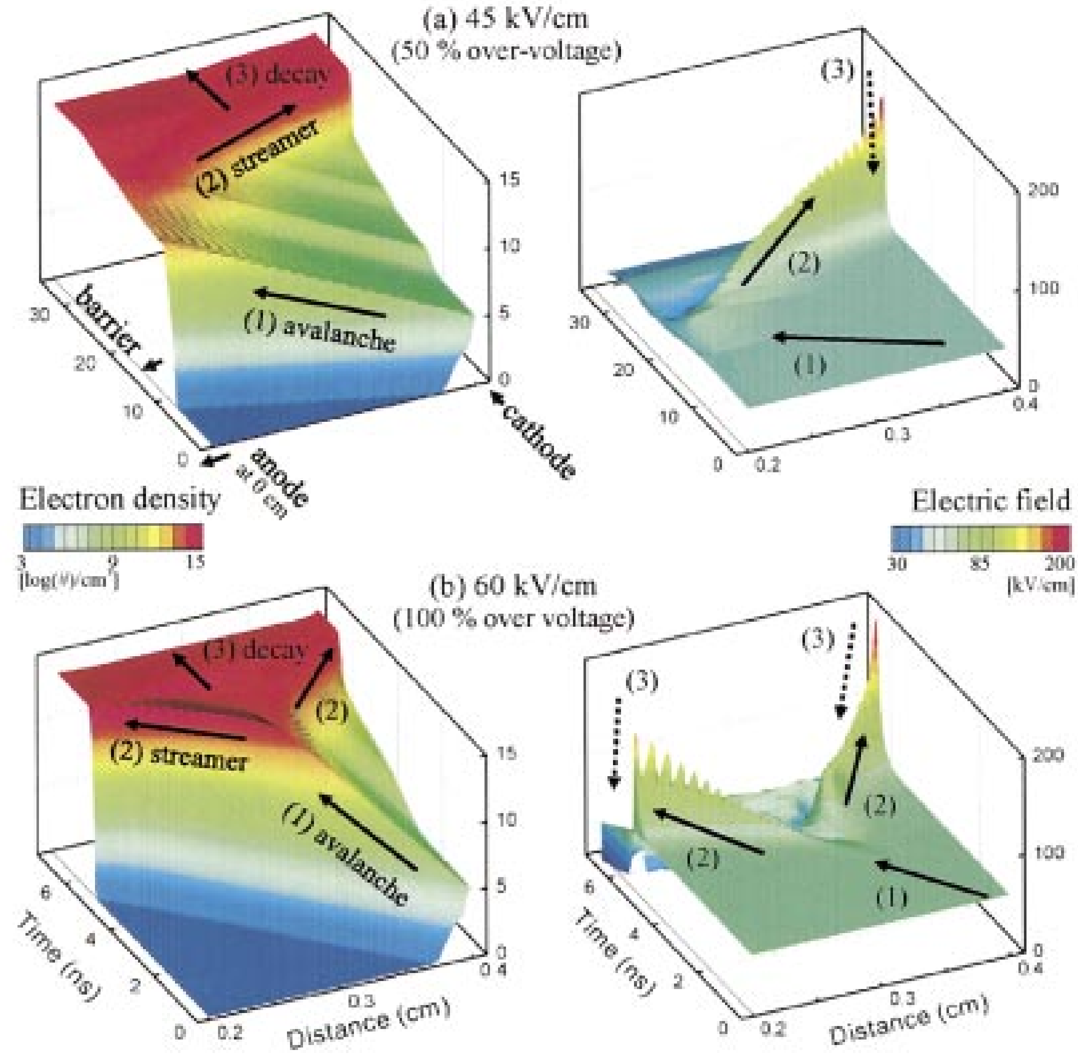

Fig. 1. Spatio-temporal evolutions of electron density (left) and electric field (right) in DBD for the two different applied voltages: (a) 45 kV/cm (50% over-voltage case) and (b) 60 kV/cm (100% over-voltage case).

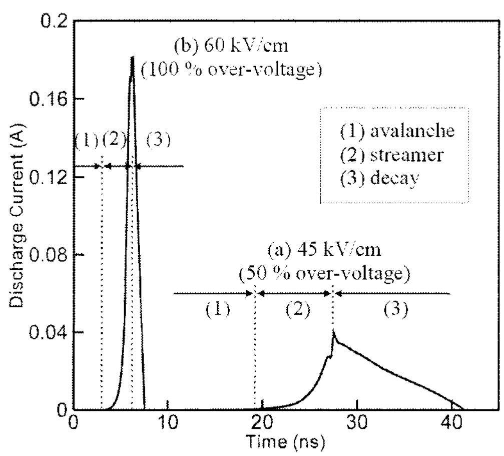

Fig. 2. Temporal histories of discharge currents relevant to Figs. 1(a) and (b).

charge current with a narrower width are found compared with the 50% over-voltage case. Since the discharge mechanism in the DBD reactor illustrated by the spatio-temporal variations of the DBD characteristics in Fig. 1 can be inferred from the temporal evolutions of current profiles shown in Fig. 2, the simulation images obtained in this numerical work will be useful for the analysis of measured DBD currents.

References

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