EsgeeTechnologies Inc.
Analysis and Design through High-Fidelity Simulations

VizGlow Application Note

Nanosecond Pulsed Dielectric Barrier Discharge (DBD) in Atmospheric Air

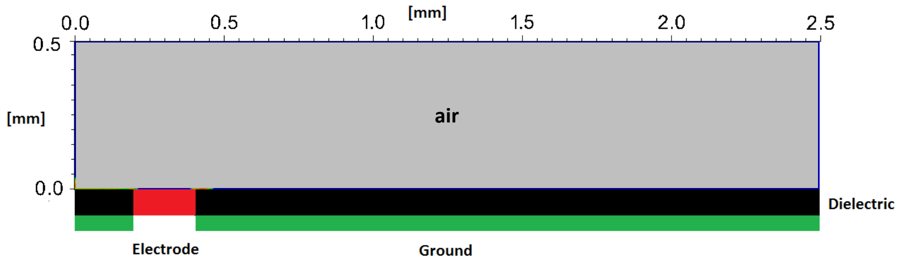

Figure 1: **Geometry for simulation of dielectric barrier discharge (DBD) in air.**

Dielectric Barrier Discharges (DBD) are stable discharges capable of generating reactive non-equilibrium plasmas at high pressures. Operation of these discharges at atmospheric pressure is particularly attractive for a number of applications including vacuum-chamber free materials processing, chemical processing of gas streams, and plasma actuators for aerodynamic flow control. In non-ideal gases such as air, DBD's produce large volume plasmas through the formation of a multitude of thin streamer channels that can fill the available space in the discharge. DBD's are essentially pulsed discharges that are produced by applying a high voltage oscillating waveform or a series of repeated sharp-rising pulses at an electrode in an electrode pair system. One or both of the electrodes must be covered by a dielectric solid layer so as to prevent a direct conducting channel between the electrodes. The dielectric layer traps charge from the plasma which in turn limits a large current density in the plasma. The self-limiting behavior of the dielectric barrier keeps the currents low enough that glow-to-arc (GAT) instabilities are prevented, thereby maintaining a stable non-equilibrium discharge at high pressures. The self-limiting behavior also means that the discharge is necessarily pulsed with the formation of streamer channels that are quenched rapidly during a single pulse. An oscillating excitation is therefore necessary to maintain a semi-continuous discharge. This application note discusses the

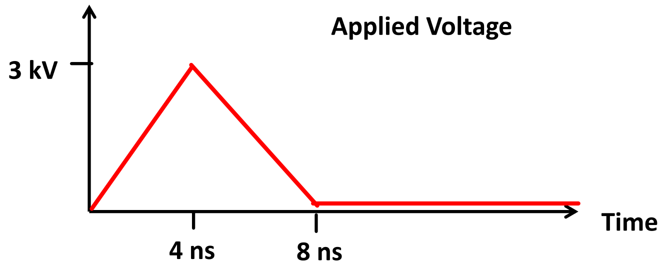

Figure 2: **Single pulse waveform applied at the powered electrode.**

simulation of a prototypical DBD in air. The *VizGlow Plasma Modeling Software Package* is used.

The geometry for the DBD is shown in Fig. 1 and comprises a bare powered electrode (red), a surrounding ground electrode (green) that is covered by a dielectric layer (black). A sharp-rising triangular positive pulse is applied at the electrode as shown in Fig. 2. The pulse duration last about 8 ns and therefore the discharge is called a "nanosecond pulsed DBD". The DBD is generated at atmospheric pressure in air. Since the high pressure imposes a very fine resolution requirement, over 80,000 cells are required in the mesh. The mesh comprises pure quadrilateral cells. Simulation domain is 2.5 mm x 0.5 mm (see Fig. 1). The air is represented by a finite-rate chemistry with 21 gas-phase reactions among 11 species (electrons **E**, oxygen radical **O**, nitrogen molecule **N2**, oxygen molecule **O2**, nitrogen dimer ion **N2+**, oxygen dimer ion **O2+**, nitrogen cluster ion **N4+**, oxygen cluster ion **O4+**, ion complex **O2+N2**, oxygen dimer negative ion **O2-**, oxygen ion **O-**). Since air species comprise radiative states that emit in the ultra-violet, photoionization becomes an important mechanism by which electrons are generated and therefore this mechanism is included in the simulation.

The pulsed excitation results in the formation of a positive streamer channel that propagates from the powered electrode to the grounded electrode. However, the presence of the dielectric barrier on the grounded electrode results in the deposition of a positive charge on the dielectric surface. This locally trapped positive charge causes a self-induced electric field that pushes the streamer further down the dielectric surface resulting in a streamer channel that propagates significant distances from away from the powered electrode. Essentially, the dielectric charge trapping is the cause for the large volume filling property of the DBD. Figure 3 shows a series of snap-shots of the electron density in the streamer channel formed by

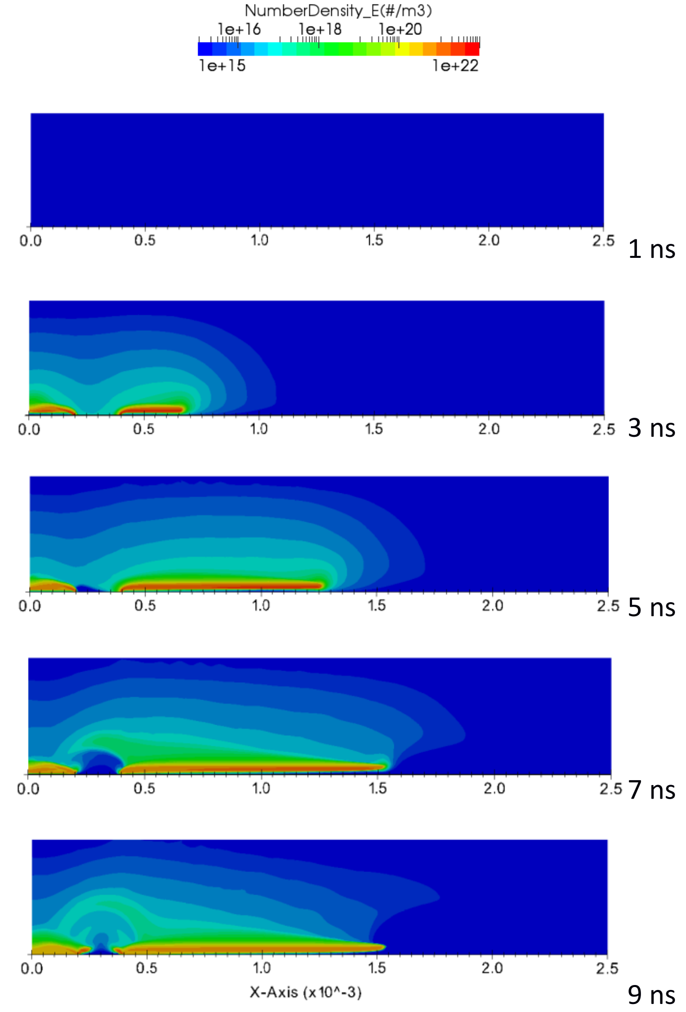

Figure 3: **Electron density transient in air streamer channel formed in the nanosecond pulsed DBD.**

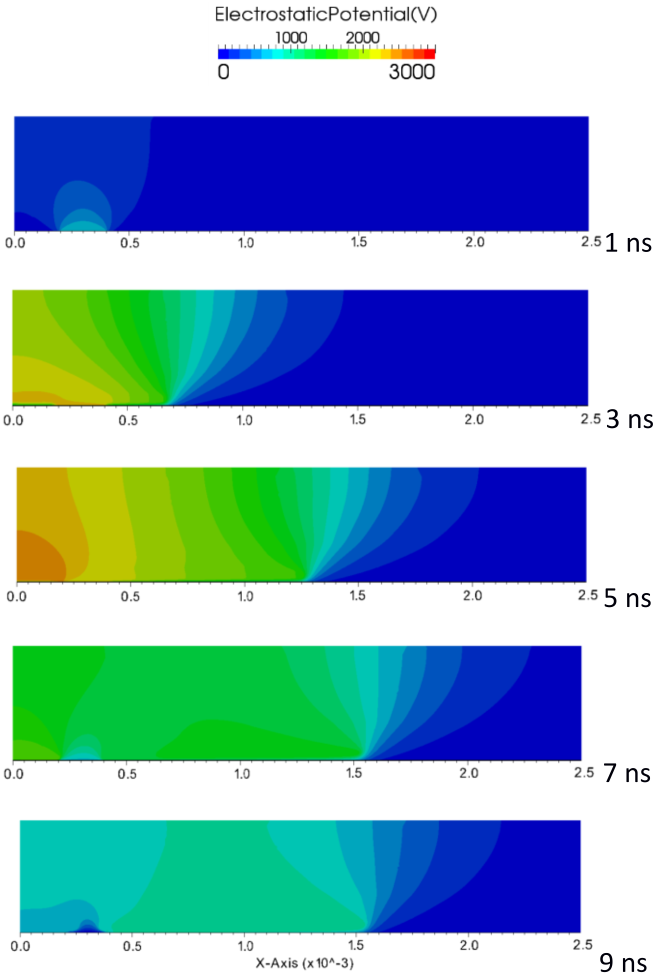

***Figure 4:* Electrostatic potential in the nanosecond pulsed DBD.**

the nanosecond pulsing of the DBD in air. Note that the streamer channel is thin (~ 100 microns). However, a much broader region of electron densities is observed surrounding the streamer. This is essentially a cloud of electrons resulting from photoionization surrounding the streamer. Note that the streamer propagates about 1 mm from the powered electrode in about 7 ns and then extinguishes once the power is turned off.

Figure 4 shows the evolution of electrostatic potential in the discharge. The potential starts out looking like a vacuum potential profile during the early part of the transient (~ 1 ns). However as the streamer develops the self-consistent nature of the electric field induced by the streamer channel becomes evident. The streamer head (leading edge of the propagating streamer) is electronegative due to an excess of electrons that distorts the potential imposed by the powered electrode. At the end of the transient the potential collapses with the quenching of the plasma.

Finally, a comparison is made of the streamer propagation with the photoionization and without the photoionization. Figure 5 shows propagation of the streamer for the two cases at three different times during the transient. Note that the case without the photoionization results in a much weaker streamer that propagates a very short distance away from the powered electrode before being quenched at the end of the pulse. Also note that the absence of photoionization results in a strongly confined electron density profile without the cloud of electrons that surrounds that streamer in the case with photoionization. This direct comparison emphasizes the role of photoionization in streamer propagation in air DBD’s.

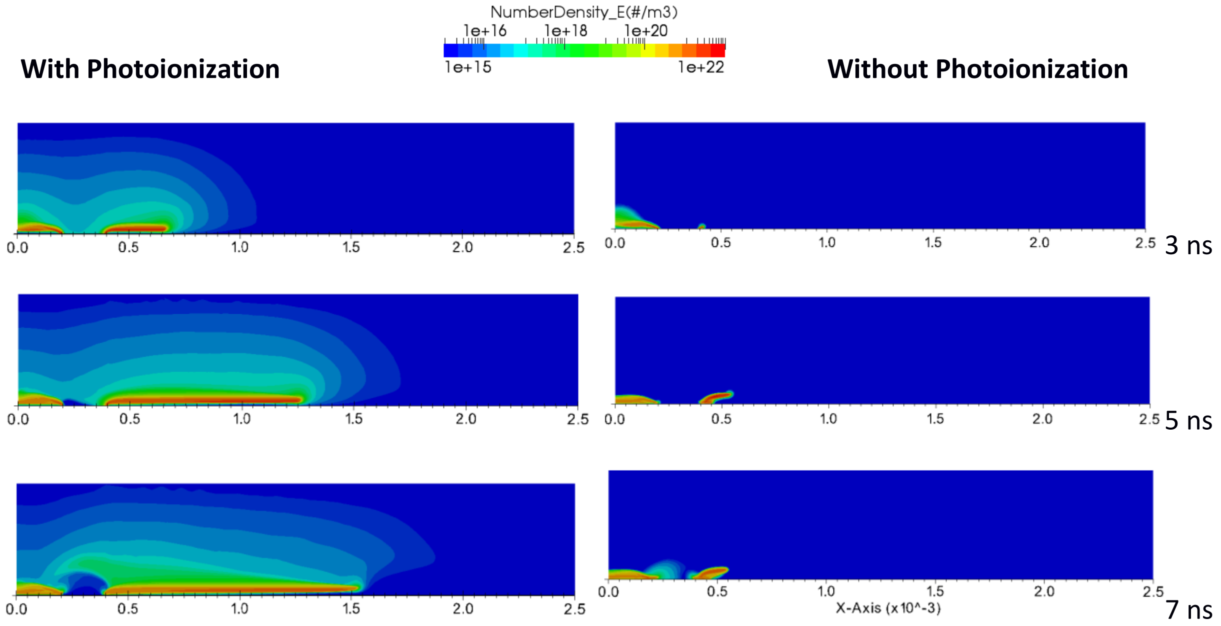

Figure 5: **Comparison of streamer propagation with and without including the photoionization model.**

In summary, the *VizGlow Plasma Modeling Software Package* provides robust capability for the high-fidelity simulation of high-pressure non-equilibrium discharges such as DBD's. Simulation of DBD's is a particularly challenging problem because of the highly disparate time scales involved in the problem and the potentially wide range of length scales imposed by the small region of discharge formation in the context of a larger application domain. Furthermore, the high pressure results in very restrictive resolution requirements since the thin propagating streamer must be resolved accurately in order to model the DBD discharge. This kind of modeling is very much the state-of-the-art in plasma computational modeling community.

In closing we note that *VizGlow Plasma Modeling Software Package* is part of the *Overviz* framework suite which provides an intuitive interface to set-up a project to be solved using *VizGlow*, manipulate multiple projects for parametric studies. *VizGlow* is provably fast, robust, and easy-to-use software and currently a leading industrial plasma simulation tool.

For further information on this application note or details about the *VizGlow* and other software packages you may contact us at

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