Affinity of pulsed positive discharges to dielectrics in N_2:O_2 mixtures

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We simulate positive streamer discharges developing in N_2:O_2 near dielectric and conductive materials. This research is important, for example, in the high voltage technology where surface flashovers are to be avoided. We designed an axially symmetric model in which a positive inception cloud develops at the tip of the needle electrode and propagates towards and then along a dielectric rod. We measure the velocity of a positive inception cloud (before the inception cloud is destabilized into filaments) propagating along the dielectric rod and compare it with experiments. We also explain the importance of the fact that the photoionization is shaded by the dielectric rod and therefore positive streamers in air are less sensitive to the electron emission from the dielectric surface.

1. Introduction

Streamer discharges near insulators are notorious for being precursors to surface flashovers, which are detrimental in the high voltage technology. The ultimate goal of our research is to understand how we can avoid surface flashovers. Explaining the mechanisms behind discharge-dielectric interaction is one of the challenges in plasma physics. Dielectric materials tend to attract the discharge due to polarization effects resulting in the modification of the local electric field configuration. Other mechanisms known for influencing streamer discharge propagation include accumulation of surface charge on the dielectrics and secondary electron emission. It has been suggested that photoelectron emission in particular, can play an important role in forcing a positive streamer to propagate along a dielectric surface [1].

We designed a cylindrically symmetric setup, both in experiments and simulations, in which a streamer is ignited from a pin electrode and propagates towards a dielectric rod that is placed directly under the electrode.

2. Modeling

We study the inception stage of positive streamer discharge interaction with dielectric rods using a dedicated fluid streamer model in local field approximation [2]. In the absence of dielectric, the positive inception cloud is studied extensively in [3]. We account for the polarization effects with respect to the dielectric properties of the rods, which is possible due to the implementation of the Ghost Fluid Method in the Poisson solver [4]. Even though the method is not new and was used for streamer simulations before [5], it is still challenging to combine it with accurate transport models, primarily due to the multiscale nature of the streamer.

We calculate the photoelectron emission from the cylindrical surface of the rod by integrating the photon flux produced by the streamer discharge including the shading effect of the rod. We point out the importance of the photoelectron emission for positive streamer propagation along the rod in pure gases, like nitrogen, when the free electrons are scarce and photoionization is insufficient. We show that in air photoionization produces enough free electrons for positive streamers to follow the electric field lines. We perform a further parametric study to determine the mechanisms important for streamer propagation along the rod as opposed to simply following the electric field lines, and we also compare our simulation results with dedicated experiments.

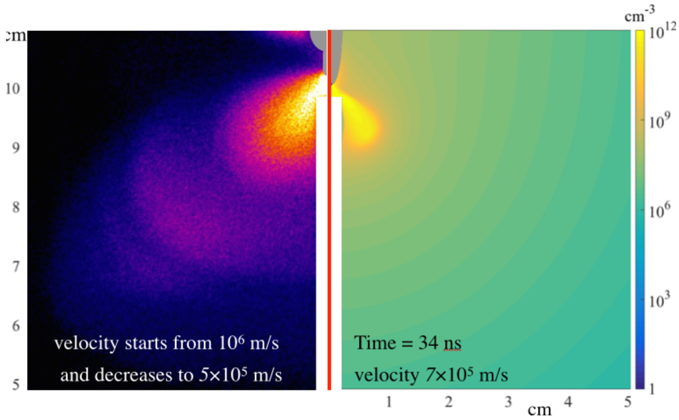

Fig. 1: Stroboscopic image (left panel) and the simulated electron density of the inception cloud after 34 ns (right panel). Air at 75 mbar and 300 K, dielectric permittivity of the rod $\varepsilon = 4$, photoelectron emission yield $\gamma = 10^{-7}$.

3. Experiments

To generate discharges, a positive high voltage pulse between 10 and 17 kV is supplied by a charged capacitor that discharges after a spark gap is triggered to a needle placed above a grounded cathode plane. The voltage rise time is 45 ns. A stainless steel sample holder containing an dielectric rod (4 mm in diameter) is placed on the cathode plane, in such a way that the top of this rod is 2 mm directly below the needle. Our experiments were performed in artificial air and nitrogen-oxygen mixtures, at pressures between 75 and 150 mbar. We use lower pressures in order to get a large cylindrically symmetric inception cloud.

To image the discharge, we use a LaVision PicoStar HR12 camera system. We send a pulse train of tunable length and frequency to the intensifier. This way, we are able to perform stroboscopic imaging of the discharge. By controlling the number of pulses and the frequency, we are able to control the number of gating cycles and the time between these gates.

By measuring the monitor output of the intensifier, we are able to relate the timing of the camera to the voltage pulse. With stroboscopic imaging, we are able to study the spatial and temporal evolution of the discharge in two dimensions. Due to the stochastic behavior of the discharges it is not possible to compare different discharges For the highly nonreproducible discharges that propagate in multiple directions that we are studying, stroboscopic imaging yields the best results [6].

4. Conclusion

Our simulations quantitatively describe the dynamics of positive discharges propagating towards dielectric rods and agree with the dedicated experiments. In air, positive streamers appear to ignore the surface effects due to photoionization that is shaded by the dielectric rod. Therefore, photoionization is localized away from the rod and the surface effects become less important. In pure gases, like nitrogen every source of free electrons is important. In an extreme case of pure nitrogen, photoelectron emission can be the only source of free electrons and thus guide a positive streamer along the dielectric surface.

5. References

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