Experimental investigation of streamer affinity for dielectric surfaces

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We have experimentally investigated the affinity of streamers for dielectric surfaces using stroboscopic imaging and stereo photography. Affinity of streamers for dielectric surfaces was found to depend on a wide set of parameters, including pressure, voltage, dielectric material and discharge gap geometry. Our results show that higher relative permittivity, higher pressure, lower voltage, and asymmetrical sample placement increase the chance of the streamer following the dielectric surface.

1. Introduction

Although often observed in experimental studies [1] as well as high and medium voltage applications, the underlying physics of discharges propagating on dielectric surfaces is poorly understood. In order to be able to go from empirical design rules and oversimplified models to knowledge-based design rules, a deeper understanding of the underlying physical mechanisms defining these discharges is an absolute necessity.

We have built a setup that allows us to image streamers stroboscopically. This allows us to study the study the spatial and temporal development of streamers on and in the vicinity of dielectric surfaces [2]. Additionally, we use stereo-photography [3] to be able to study whether a streamer propagates along a dielectric surface and simultaneously study the structure of the streamer.

2. Setup

In order to generate streamers, we apply a positive high voltage pulse to a needle situated 18 cm above a grounded cathode plane. A dielectric sample is also placed in the discharge gap. Dielectric samples are 30 X 150 mm, with variable thickness. The sample is placed in a grounded sample holder, reducing the effective gap distance to ~134 mm. The HV pulse is generated by a capacitor that is discharged after a spark gap is triggered (see FIG. 1). The setup is placed in a vessel that was filled with air at pressures between 30 and 200 mbar.

To image the streamers, we use a LaVision PicoStar HR 12 ICCD camera. By supplying the intensifier of this camera with a train of pulses at a frequency of 50 MHz, we are able to achieve a temporal resolution of 20 ns (see [2] for more details).

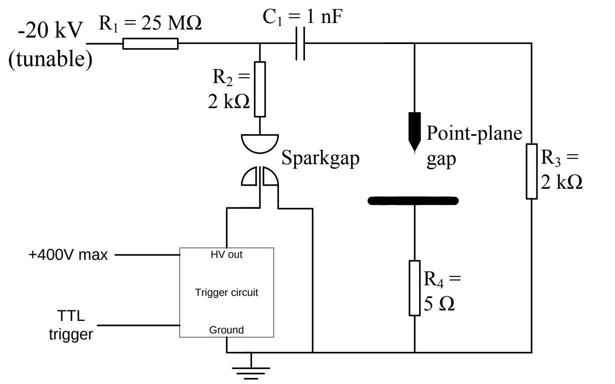

FIG. 1: Schematic drawing of the pulse forming network used in the experiments. In our experiments, a dielectric sample was placed at various positions in the discharge gap.

Using a setup similar to the one described in [3], we are also able to study the propagation of streamers stereoscopically. The dielectric sample is placed perpendicular to one of the image paths in order to study the propagation of the streamer along the surface, where the other image path allows verification of the streamers propagating along the surface. Overlaying the two images clarifies whether or not a streamer propagates along the dielectric surface.

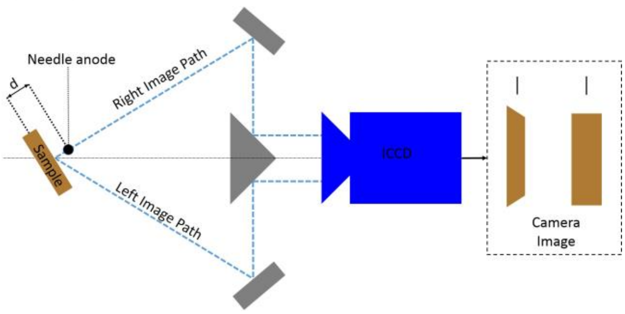

FIG. 2: Schematic drawing of the stereo-photography setup. Using 3 mirrors, the sample is imaged from two angles simultaneously, resulting in the image depicted on the right side. The needle displacement *d* from the centre of the sample is also depicted.

3. Results

Initial experiments were performed in air at pressures varying from 30 to 200 mbar. Four different voltages were used, varying from 10 to 21 kV. A dielectric sample was placed in the discharge gap, such that the sample was 4 mm below the needle. A displacement $d = 2$mm was used (see FIG. 2). The sample was placed like this to restrict the discharge to one side of the sample, making it easier to process the images. Epoxy resin samples were used, the filler was changed to vary the relative permittivity of the sample. Sample A had a SiO_2 filler ($\epsilon_r \sim 4$), sample B contained a $BaTiO_3$ filler ($\epsilon_r \sim 10$). We have measured the velocity of streamers using stroboscopic imaging (see FIG. 3), and plotted the results in FIG. 4 and FIG. 5. As can be seen, the velocity was comparable for the two samples described above. This finding seems to indicate that the velocity of surface streamers is not significantly dependent on the relative permittivity.

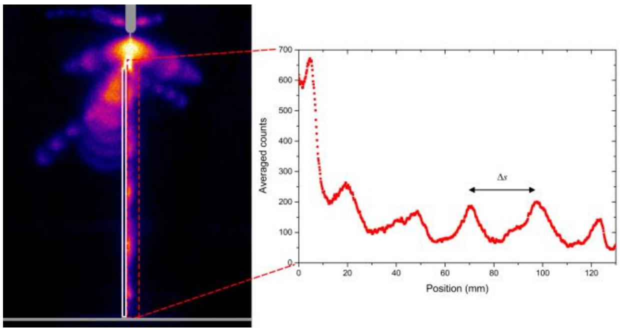

FIG. 3: Example of a velocity measurement. One of the streamer branches travels across the dielectric surface present in the discharge gap. A cross section of this streamer channel is used to determine the distance between two subsequent maxima in counts, and thus the velocity.

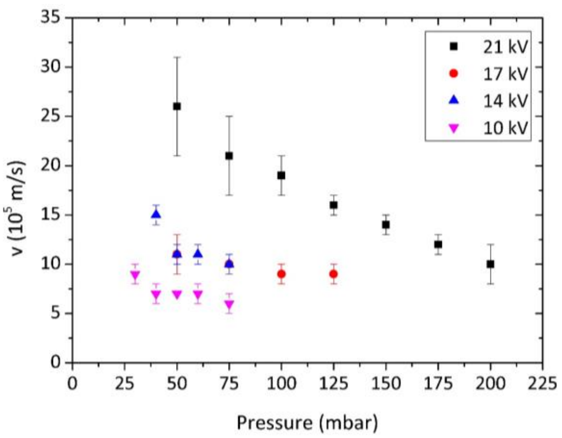

FIG. 4: Velocity of streamers propagating along a SiO_2-filled epoxy resin sample as a function of pressure and pulse voltage.

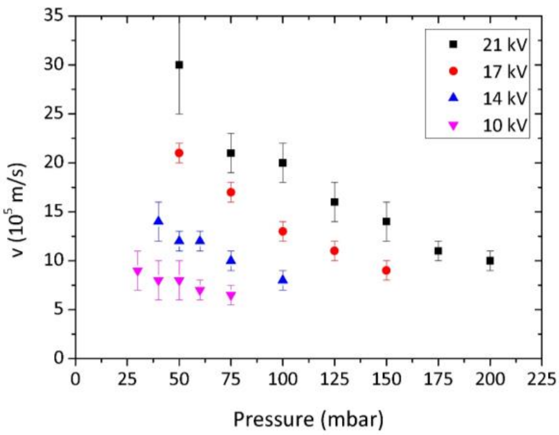

FIG. 5: Velocity of streamers propagating along a $BaTiO_3$-filled epoxy resin sample as a function of pressure and pulse voltage.

Although streamer velocity is comparable for the two aforementioned samples, we found that the affinity of the streamer for the dielectric surface was not. In experiments where the sample was placed directly under the needle, we found that surface streamers did not occur for sample A (SiO_2), whereas surface streamers were observed for sample B ($BaTiO_3$). This can be seen in FIG. 6. Note that not only does streamer affinity depend on the sample, it also depends on the pressure, since surface streamers were only observed for higher pressures (≥90 mbar).

To elaborate on this, three additional samples with varying filler percentages of $BaTiO_3$ were tested as well. Along with the original $BaTiO_3$ and SiO_2 filled samples, this gives us five samples with varying relative permittivity. FIG. 7 shows that surface discharges seem to become more likely for higher relative permittivity and pressure. No surface discharges were observed for the SiO_2 filled sample ($\epsilon_r \sim 4$), suggesting the relative permittivity is not the only important parameter.

We also found that sample placement is very important with respect to streamer affinity for dielectric surfaces. To illustrate this, FIG. 8 shows the chance of a discharge having surface as well as gas components P(SG) as a function of pressure and sample placement. This result clearly shows surface streamers become more likely for higher pressure and asymmetrical sample placement. For a given sample placement, surface streamer probability went from zero to one in a relatively narrow pressure regime.

Pulse voltage also plays a role, as can be seen in FIG. 9, where higher pulse voltage leads to less surface discharges for otherwise equal conditions.

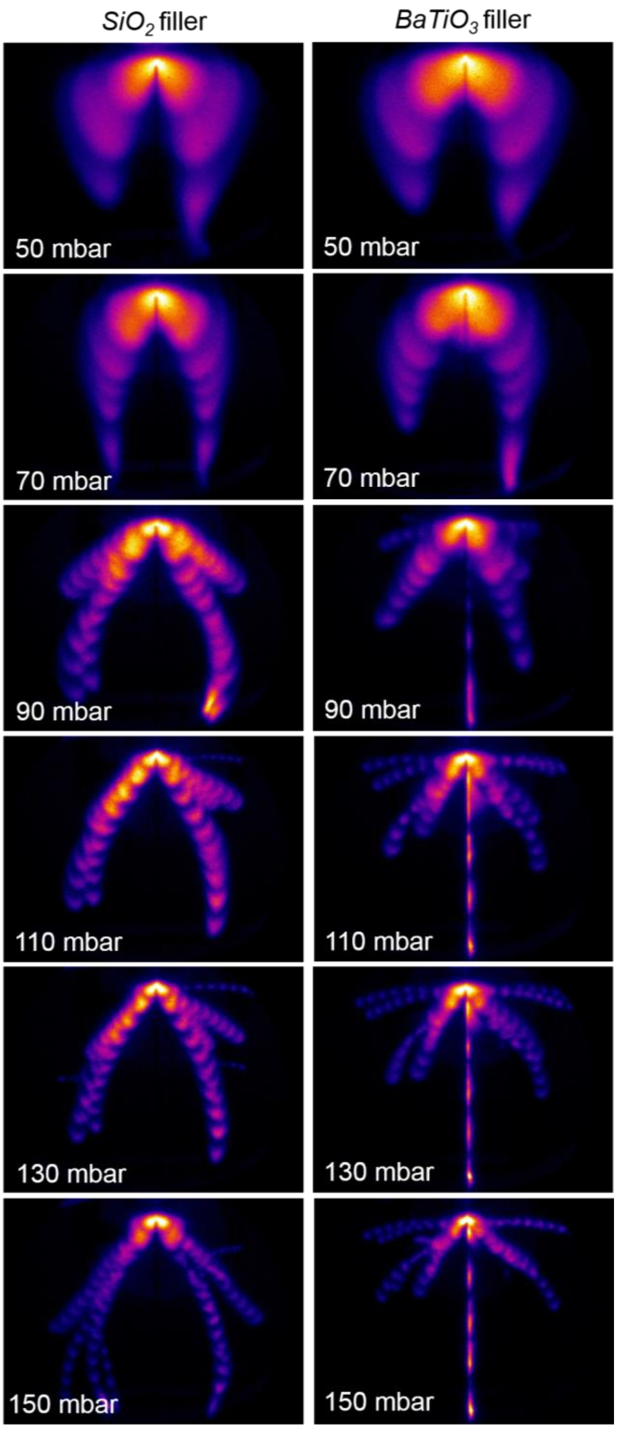

FIG. 6: Typically obtained images when the samples were placed directly underneath the needle anode. Experiments were performed at 21 kV with a repetition rate of 1 Hz.

We found that pulse voltage, pressure, sample material and sample placement all influenced streamer affinity for dielectric surfaces. A small parameter window would often change behaviour from no surface streamers to all surface streamers. This seems to indicate two mechanisms are competing.

Although conclusive evidence has not yet been obtained, we can speculate about the cause of this behaviour. When the discharge is not travelling along the dielectric sample, it is travelling mostly parallel to the electric field lines. This means that either the dielectric sample modifies the electric field (through polarization or negative surface charges) to favour surface discharges, or it provides the discharge with an additional source of electrons.

Electric field modification would explain why higher relative permittivity leads to higher affinity for dielectric surfaces: field lines will be bended more towards the sample, favouring propagation along the surface. Also, placing the sample further away from the needle decreases the angle streamers would have to deviate from the electric field lines to propagate along the surface.

In experiments where a laser was used to create a local pre-ionization [4], it was shown earlier that streamers can move perpendicularly to the electric field if a locally higher electron density is present there. It should be noted however that guiding in these experiments was only observed in high-purity nitrogen, and not in air, where photo-ionization serves as a local source of electrons. Nevertheless, these results show that streamers may deviate from the electric field lines if more electrons are available elsewhere. A dielectric surface may act as a (local) electron source. According to Jorgenson et al., photoemission may [5] serve as a local electron source, especially when a surface is pre-charged negatively, keeping electrons from colliding and attaching to it.

At higher pressure or lower pulse voltage, the lower reduced electric field may lead to higher dielectric surface affinity, because the lower Townsend multiplication increases the importance of additional electrons introduced by the surface.

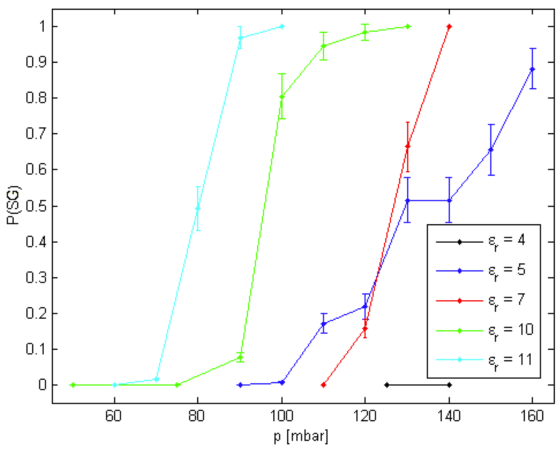

FIG. 7: Chance of the discharge having a surface component P(SG) as a function of pressure for epoxy samples with five different fillers.

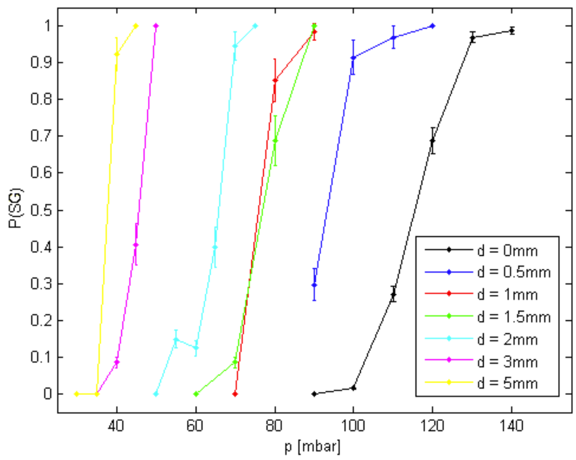

FIG. 8: Chance of the discharge having a surface component P(SG) as a function of sample placement and pressure for the $BaTiO_3$ filled epoxy sample.

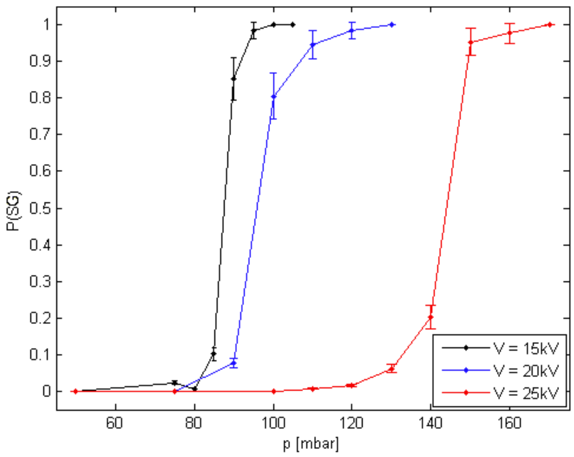

FIG. 9: Chance of the discharge having a surface component P(SG) as a function of pressure for the original $BaTiO_3$ filled sample for three different pulse voltages.

4. Conclusions

We have experimentally investigated the affinity of streamers for dielectric surfaces and found that affinity depends on sample material and position, pressure, and voltage. Our results show that surface streamers become more likely for samples with higher relative permittivity, higher pressure, lower voltage, and asymmetrical sample placement.

We expect that additional electrons created by photoemission from the dielectric surface will under some circumstances allow streamers to deviate from the electric field lines. Additionally, surface charges and polarization will change the electric field lines, bending them towards the sample.

5. Acknowledgements

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6. References

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