# Stabilization and pattern formation of microdischarges in surface barrier discharge arrangements in air at atmospheric pressure

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## 1. Introduction

Surface barrier discharges (SBDs) offer a simple design for the generation of non-thermal plasmas at atmospheric pressure. A (dielectric) barrier fills the entire gap between two electrodes, the gas discharge occurs at the electrode edges on and close to the surface of the isolating material. Since the complete electrode arrangement can be incorporated in a single component, SBDs gain more and more attention in plasma technology (ozone generation, cleaning of exhaust gases, surface treatment, gas flow control and biomedical applications). SBDs form filamentary plasmas, consisting of single microdischarges (MDs) visible as discharge filaments. The MDs in air have a duration of about 20 ns, a length of about 1 mm and are about 0.2 mm thick, which is a challenge for diagnostics. In order to investigate the MD development cross-correlation spectroscopy (CCS) is a powerful tool. The CCS method provides high sensitivity and resolution. It has been already successfully applied to corona, volume and coplanar barrier discharges [1, 2]. Since CCS is a single photon counting and thus time consuming technique, it requires a time-stable localization of repetitive generated MDs. The stability of the MDs must be provided for the complete data accumulation cycle which appeared much more challenging than for the other above mentioned discharge types. In the contribution the difficulties and useful strategies of MD stabilization in SD arrangements are reported. Furthermore, the formation of MD patterns on dielectric barrier was studied.

## 2. Experimental set-up

The electrode arrangement (see section 3) is mounted in a moveable discharge cell. It is connected with gas flow system (dry air flow of 300 sccm, 1 atm) and power supply (sinusoidal voltage, amplitude several $kV_{pp}$; frequency about 60 kHz, period T= 16.6 µs). Short exposure time photos are used to observe discharge formation and stabilization. Therefore, by means of an iCCD camera (PCO imaging DiCAM Pro), enhanced by a far-field microscope (Questar QM-100), highly resolved pictures (spatial resolution about 4 µm) of the discharge can be taken.

## 3. Results and discussion

For the generation of MDs, it was necessary to test different SD electrode arrangements. Three conditions must be fulfilled: (i) generation of repetitive, well-localized single MDs; (ii) thermal and chemical stable electrode material to ensure stable discharge geometry and operation; (iii) mechanical stability of the arrangement for the movement for foreseen spectroscopic studies (e.g. realization of spatial resolution). The fist attempt was an arrangement consisting of an isolated wire (grounded) and a bare wire (driven at high voltage). The thin bare wire was arranged to tip the isolated wire only at one point. Although in this arrangement single MDs could be observed at low overvoltage, the configuration failed because of mechanical instability. For more robust arrangements solid plates of dielectric material (alumina $Al_2O_3$; 96% purity, $\varepsilon_r$= 10, thickness 0.6 mm) were used. Different discharge configurations can be realized as shown in Fig. 1 (a-d).

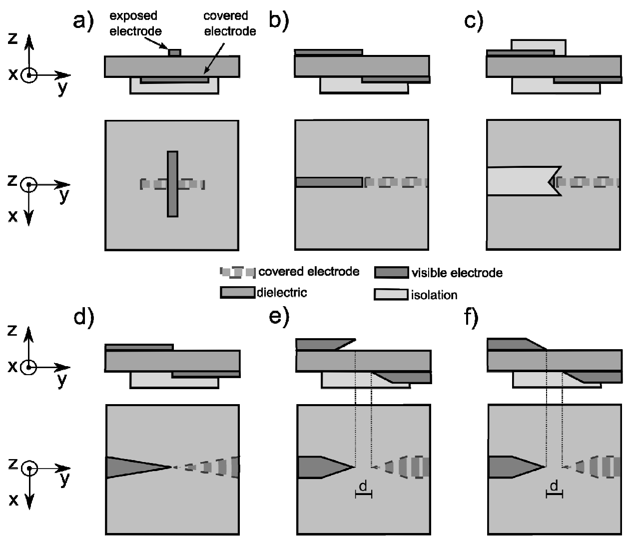


Fig. 1: Different electrode arrangements for the generation of SBDs with well-localized MDs.

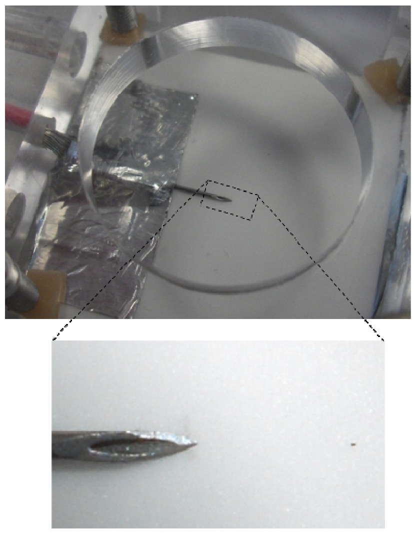

Fig. 2: Photo of arrangement 1(f) (exposed electrode view)

Electrodes made of silver (0.5 mm wide) can be vapour deposited on alumina. The plasma was generated at the nearest points of the electrodes. To generate the plasma only at one electrode tip and at one side of the dielectric surface (at the so-called exposed electrode), the other electrode was embedded in further isolation (silicone glue, so-called covered electrode). The arrangement 1 (a) represents so-called symmetric SBD. The other arrangements (b)-(f) are called asymmetric, since the discharge appears only at one edge of the exposed electrode [3]. In the configuration (c) the exposed electrode was isolated, too. The isolation was notched to guide the MD channel. However, in the arrangements (a)-(c) more than one filament at the exposed electrode was generated, even at voltages close to the extinction value. Using sharp electrode geometry (Fig. 1 (d)) a single filament was observed, but the silver electrodes were oxidised and eroded by the plasma during operation. Thus the discharge geometry changed during operation and MDs became instable.

Highly stable filaments were investigated by using two needle electrodes (syringe hollow needles) made of a chrome-nickel-steel alloy (0.4 mm diameter) instead of silver evaporated electrode (Fig. 1(f) and 2). The needles were laid parallel on the opposite sides of the aluminium oxide plate and the tip of the electrodes faced each other with a gap d= 1.15 mm. This arrangement provided well-localized MDs for 60 to 100 hours of discharge operation which is suitable for CCS studies. In this electrode arrangement the MDs develop directly on the dielectric surface as shown in Fig. 3. The MDs start at the triple point (electrode-dielectric-gas) and bridge the complete path to the mirrored position of the covered electrode. Comparing the MD formation with the calculated initial electric field (i.e. volume space and surface charges are not considered) recalls, that the MD channels follow the field lines, i.e. the electrode geometry determines the MD formation even when the discharge was already running for a certain time with considerable deposition of residual charges on the dielectric.

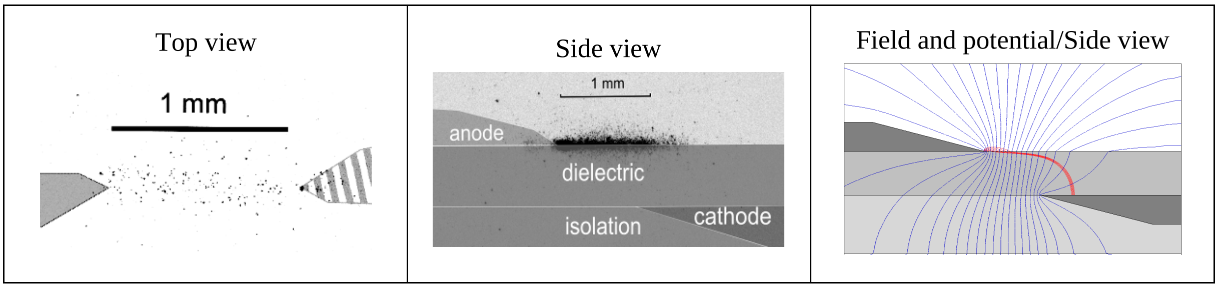


Fig. 3: Top view (left) and side view (middle) iCCD-camera photos of MDs (negatives with reworked electrode shapes, iCCD gate= 8,5 µs = T/2, 100 cycles of accumulation) with the calculated initial electric field (right, potential lines in dark blue and streamlines of electrical charges in red) in configuration 1(f).

If the needle is not completely laid on the dielectric (configuration 1 (e)), the MDs start at the needle point, too. If the MDs hit the dielectric surface they propagate along the surface towards into the cathode region, similar as in configuration 1 (f). Again the MD channels follow the field lines of the initial electric field (Fig. 4 d). Increasing the voltage amplitude more MDs per T/2 of the applied voltage occur. These MD take completely different paths, e.g. below the electrode edge (Fig. 4 b) or into the volume (Fig. 4 c).

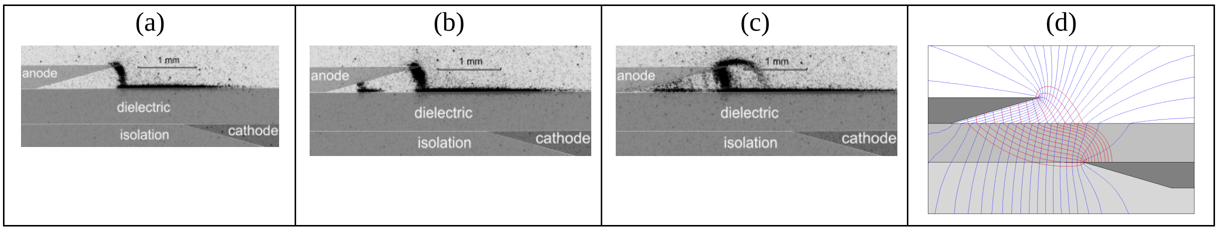


Fig. 4: MD formation in configuration 1 (e) at different high voltage amplitudes (iCCD-negatives with reworked electrode shapes; side view; (a) 6.6 kVpp, (b) 8.2 kVpp, (c) 10.7 kVpp; (iCCD gate = 8,5 µs = T/2, 100 cycles accumulation) and calculated initial electric field (d)

In case of configuration 1 (f) the pattern formation is investigated on the dielectric barrier if the arrangement is driven in such a way that several MDs per T/2 appear. The first MD channel bridges directly between the exposed electrode and the position of opposite electrode. The channels of the subsequent MD evade this area and propagate around it. Increasing the voltage amplitude and thus the number of MD per T/2, patterns as shown in Fig. 5 (right) are observed. The MD inception point changes and longer and longer MD channels occur around the area of foregoing MD activity. Obviously, surface charges which are deposited on the dielectric in the foregoing MD interferes the MD propagation in such a way, that the discharge channels develop along an alternative way on an uncharged surface area [4, 5].

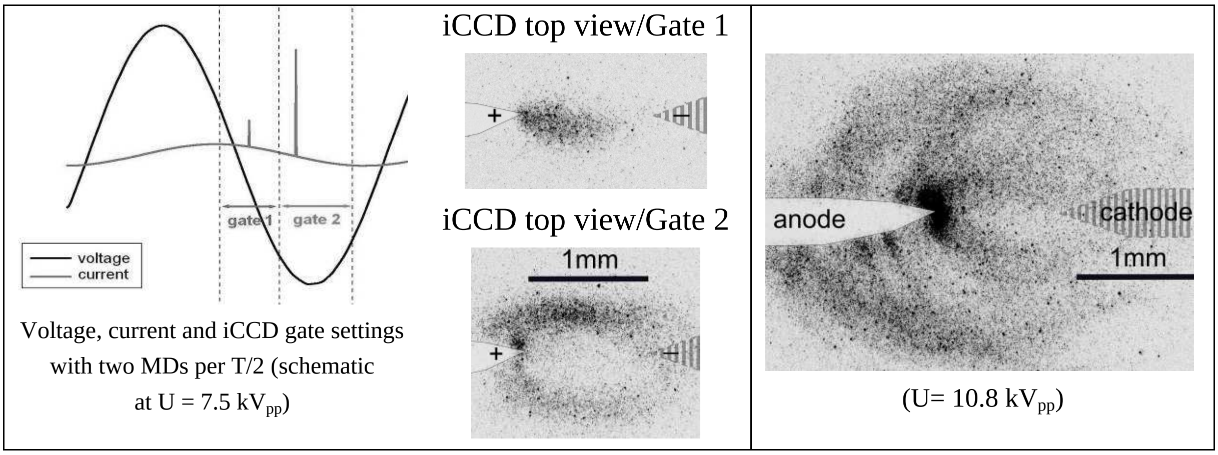


Fig. 5: MD pattern formation caused by overvoltage in the SBD configuration 1(f) with 2 MD per T/2 (left and middle; iCCD photos taken over 20 cycles with gate of 1500 ns) and with more than 6 MDs per T/2 (right)

## 4. Conclusion and Outlook

Several SD arrangements were investigated in order to provide time-stable and well localized MDs for further investigation. The SBD arrangement consisting of two needle electrodes in an asymmetric set-up on opposite sides of a 0.6 mm thick alumina plate (i.e. one exposed and one embedded electrode) was carried out to provide the needed performance. This configuration (Fig. 1 (f)) was used in order to conduct a CCS data which are presented elsewhere [6]. The MD propagation path is determined by the initial electric field and the residual surface charges affect the propagation along the dielectric leading to specific pattern formation. The surface charges may have an influence on the discharge uniformity and plasma parameters in large electrode configurations for technological applications, too. Therefore, the knowledge on the elementary processes between the plasma and charged isolating surfaces are of great concern and needs further investigation.

## References

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