On the spatio-temporal development of microdischarges
in pulsed driven volume dielectric barrier discharges

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1. Introduction

There is an increasing interest in atmospheric pressure barrier discharges (BDs) for technological applications. In particular BDs are often used for gas purification [1] on industrial sites, e.g. for removal of volatile organic compounds. It is well known that pulsed driven discharges show a better efficiency regarding ozone generation and pollution removal than sinusoidal driven ones [2]. BDs are typical examples of filamentary plasmas, i.e. a multitude of independent and short-lived microdischarges (MDs) is formed. Systematic studies on the MD breakdown were mostly performed on sinusoidal driven BD-MDs in air-like gas mixtures [2-4]. Pulsed driven BDs in N_2/O_2 gas mixtures were studied in [5]. However, there is still a lack of understanding in reactive molecular gas mixtures. The objective of this contribution is to apply simultaneous streak- and ICCD-camera measurements on pulsed driven MDs in order to investigate the breakdown processes with necessary, high spatial and temporal resolution. Differences in the development of MDs in the rising and falling slope of the high voltage pulses are observed.

2. Experimental set-up

The symmetric BD arrangement for the generation of single repetitive MDs is shown in figure 1, it is quite similar to the configuration used in [4]. It consists of a gas cell including alumina (Al_2O_3, $\varepsilon_r \approx 9$, about 0.5 mm thick) covered metal electrodes and quartz glass windows. The electrodes are almost semi-spherical shaped for localization of repetitive MDs. The discharge gap is 1 mm and gas mixture of 0.1 vol.% O_2 in N_2 with total flow of 100 sccm is through the cell. The discharge is driven by application of square wave high voltage pulses (DEI, PVX-411; parameters: 10 kV, frequency 10 kHz, voltage rise 250 V/ns) to one of the electrodes, while the other electrode is grounded. The duty cycle is 10 %, i.e. the pulse width is 10 µs.
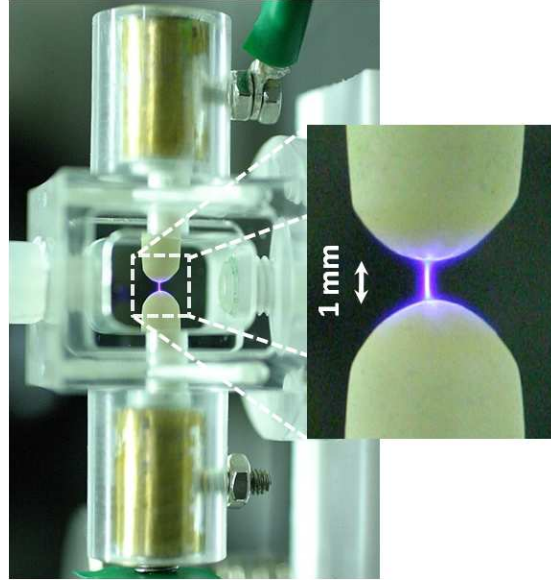
Figure 1: Discharge cell with ceramic covered electrodes and 1 mm long filament.

Electrical measurements are performed with fast current (Tektronix, CT-1) and voltage probes (Tektronix, P6015A) and a storage oscilloscope (Tektronix, TDS 7054). The input power is determined from measured voltage and current slopes. The MDs are observed simultaneously by a fast ICCD camera (Andor, i-Star) and a streak camera system (Hamamatsu, C5680) connected to a far-field microscope. With the ICCD camera high resolution shots of single MDs and their propagation on the electrode surfaces ($\Delta t > 2$ ns, $\Delta x \approx 10$ µm) is investigated, while the streak camera delivers the spatio-temporal MD development along the discharge axis with high temporal (100 ps) and spatial resolution (10 µm). The camera is sensitive in the visible and UV spectral range and the images are not spectrally selective in this case.

3. Results and discussion

Supplying square wave high voltage pulses at the powered electrode two MDs per voltage cycle are generated, namely at the rising slope of the applied voltage and surprisingly at falling slope (i.e. high voltage amplitude breaks down to zero), too. The electrical measurements are shown in figure 2 (left). The displacement current is subtracted from the measured current. In case of falling slope the current maximum is lower but the duration is slightly longer. The transferred charge for a single MD was determined at 1 nC giving an electrical energy per cycle of about 10 µJ for both polarities. The ICCD camera pictures in figure 2 (middle) show single (i.e. individual) MDs generated at the rising and falling slope of the high voltage pulse. The diameter of the MD is about 100 µm, independent on the polarity. The MD channel in the volume branches on the surface of the dielectric electrodes [6]. The

branching is more pronounced at the anode and the accumulation of ICCD photos show a nearly stable structure which blurs just little. Most individual MDs show the same spatio-temporal development and stable localization. Thus the accumulation of lots of single MDs as done for the streak images in figure 2 (right) is reliable for the conditions being considered. The results in figure 2 reveal a quite similar development of MDs as observed for sinusoidal driven BDs in nitrogen-oxygen gas mixtures [3-5, 7]. A cathode directed ionization front (streamer) and an anode glow are indicated and after passage of the streamer a zone of lower light emission ("dark space") is observed. The surface discharge in its temporal development on the electrodes can also be seen from the streak images.

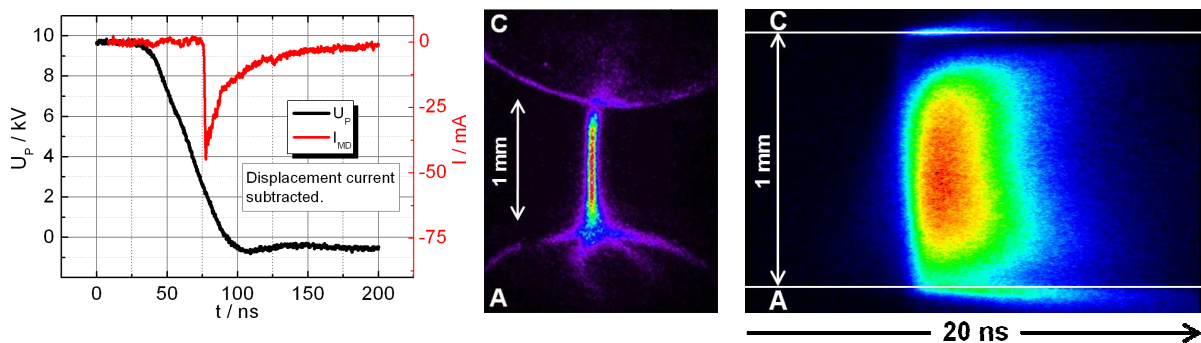(a) Rising voltage slope
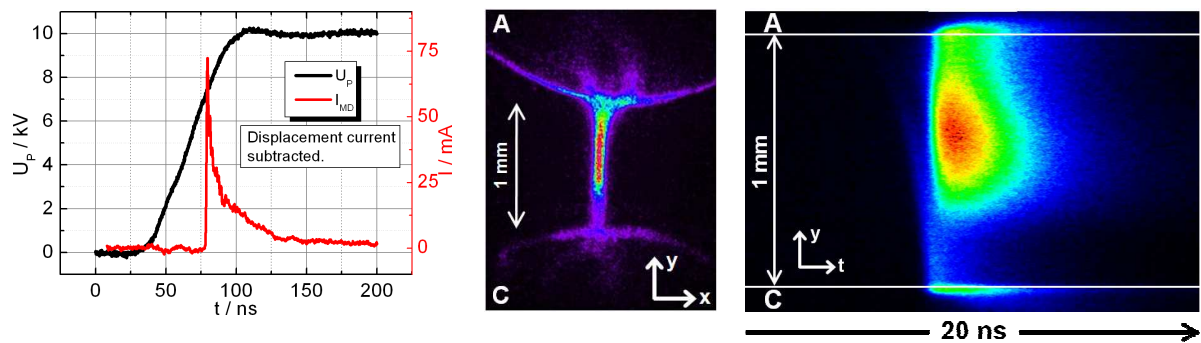
(b) Falling voltage slope

Figure 2: Left: Applied voltage (U_P) and discharge current without capacitive displacement current (I_{MD}) during rising slope; middle: ICCD pictures of individual MDs (left); right: Streak camera image of MDs (accumulation of 1000 events, right) in the rising (top, a) and falling slope (bottom, b) of a 10-kV-pulse (A - anode, C - cathode; red color – highest, black – lowest intensity).

In contrast to sinusoidal driven BDs there are significant differences in the MD development and structure for the two different polarities. MDs generated in the falling slope show an anode glow that appears more or less uniform in the whole gap (except wall regions), while for the rising slope there is a local maximum about 400 µm in front of the anode.

Consequently, the dark space region after the streamer phase is larger in case of the rising slope (250 µm vs. 100 µm), which is also seen in the ICCD images. The analysis of the streak images further reveals a higher velocity of the cathode directed front for the rising slope ($v_{rise} \approx 1.3 \ 10^6$ m/s vs. $v_{fall} \approx 0.6 \ 10^6$ m/s). The propagation velocities in sinusoidal driven BD-MDs determined from cross-correlation spectroscopy measurements [4] are lower than in case of pulsed driven BDs. The dominant excitation process of the emitting states (excited N_2 molecules) is direct electron collision [1, 3]. Thus the observed structure must be interpreted as a convolution of the local electron density and the reduced electric field strength.

4. Summary and Outlook

Simultaneous streak and ICCD images of single individual MDs in a pulsed driven dielectric barrier microdischarge with 1 mm gap in a gas mixture of 0.1 vol.% O_2 in N_2 have been recorded. The breakdown and MD formation is quite similar as in sinusoidal driven BDs (i.e. consisting of a cathode directed streamer and an anode glow), but significant differences in the rising and the falling slope of the high voltage pulses are observed for a duty cycle of 10% ($t_{pulse} = 10 \ \mu s$).

There is a higher current maximum at the rising slope. The spatial structure differs between both slopes. The dark space in front of the cathode is larger during the rising than the falling slope and the intensity distribution differs. The discharge lasts longer during the falling slope and the cathode directed ionising front velocity is faster in the rising slope. The time between the microdischarges has an effect on the discharge physics. Thus, further investigations will include a variation of the duty cycle and will be performed spectrally selective to gain access to the electron density and to the reduced electric field by means of a kinetic model [7].

References

[1]   U. Kogelschatz, Plasma Chem. Plasma Process. 23 1 (2003)
[2]   B.M. Penetrante, S.E. Schultheiss (Eds.), Non-thermal Plasma Techniques for Pollution Control, Springer-Verlag Berlin Heidelberg (1993)
[3]   R. Brandenburg, H.-E. Wagner, A.M. Morozov, K.V. Kozlov, J. Phys. D: Appl. Phys. 38, 11 (2005) 1649
[4]   T. Hoder, R. Brandenburg, R. Basner, K.-D. Weltmann, K.V. Kozlov, H.-E. Wagner, J. Phys. D: Appl. Phys. 43 (2010) 124009
[5]   D. Braun, U. Küchler, G. Pietsch, J. Phys. D: Appl. Phys. 24 (1991) 564
[6]   A. Kumada, S. Okabe, K. Hidaka, J. Phys. D: Appl. Phys. 42 (2009) 095209
[7]   K.V. Kozlov, H.-E. Wagner, R. Brandenburg, P. Michel, J. Phys. D: Appl. Phys. 34 (2001) 3164