Comparison of pulsed and sinusoidal operated barrier discharges

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The paper presents experiments on the spatial and temporal structure of the breakdown process of microdischarges. Simultaneous streak and iCCD images of individual microdischarges in a pulsed driven dielectric barrier discharge with 1 mm gap in a gas mixture of 0.1 Vol.-% O_2 in N_2 at atmospheric pressure are recorded. For temporal symmetric square wave pulses there are no significant differences between the microdischarges at rising and falling slopes which is in accordance with the sinusoidal dielectric barrier discharge operation. For asymmetric pulses there is a significant difference in the spatial structure as well as in the temporal behavior of the microdischarges between the rising and the falling slopes of the high voltage pulse.

There is an increasing interest in atmospheric pressure discharges for technological applications. Due to their low gas temperature, high electron energy and the presence of active species these discharges have a high potential for plasma chemistry e.g. for ozone production as well as gas and water purification [1]. Besides corona discharges and micro hollow cathode discharges, dielectric barrier discharges (DBDs) are often used in this field of application. Here, sinusoidal driven ones are basically used in practice [2]. In last years however, there are applications where pulsed driven discharges show a better efficiency in pollution removal than sinusoidal driven ones.

The aim of this work is to extend the understanding of the basic processes of filamentary pulsed DBDs with precise measurements. The paper presents experiments on the electrical characteristics as well as the spatial and temporal structure of the breakdown process in a nitrogen-oxygen-mixture at atmospheric pressure as model system. The comparison of pulsed operation with sinusoidal operation of the DBD will give deeper insight in the physical processes.

A symmetric dielectric barrier microdischarge arrangement is used to investigate single microdischarges (MDs). It consists of a gas cell made of plexiglas, including alumina covered half sphere metal electrodes and quartz glass windows to allow the observation of the MDs. The dielectric barrier thickness is about 0.5 mm and the gap of the electrodes is 1 mm. The N_2/O_2 gas mixture (0.1 Vol.-% O_2 in N_2) at 1 atm with a total flow of 100 sccm is flushed through the cell.

For sinusoidal operation of the DBD a set of an arbitrary waveform generator, power amplifier and high frequency high voltage transformer is used as power supply. The discharge is operated at 20 kHz with $U_{pp} = 14$ kV. At this amplitude and geometry one MD per half-period is generated. For pulsed operation of the DBD a pulse generator is used which is supplied by a high voltage power supply. In this case, the discharge is driven by unipolar square wave pulses of 10 kV amplitude at a repetition rate of 10 kHz. The duty cycle is chosen to 50%. The voltage rise of the pulse is approximately 250 V/ns. Thus, the voltage rise time for pulsed mode is three orders of magnitude higher than for sinusoidal operation. Electrical measurements are performed with fast probes and recorded with a 5 GS/s digital sampling oscilloscope to estimate the electrical power of the discharge. The MDs are observed with a high temporal and spatial resolution simultaneously by a fast iCCD camera and a streak camera system connected to a far-field microscope.

The results for sinusoidal operation of the DBD are presented in figure 1. In this case, there is one discharge per half-cycle. Here, current pulse shape and amplitude are identical for both half-periods. Also, the same spatial structures of the discharge are observed. The general discharge development is the same at both half-periods. The discharge process starts with the accumulation of positive space charges in the pre-breakdown phase and the subsequent propagation of a cathode directed ionizing front followed by a short lasting transient glow discharge [3]. Surface discharges in their temporal development can also be seen on the electrodes. The ionizing front velocity is determined from the streak images. It is equal for both half-periods and approx. $0.5 \cdot 10^6$ m/s in front of the cathode. This is in accordance with the pulsed symmetrical DBD in which the MDs show the same behavior at both slopes. But, the ionizing front velocity for sinusoidal operation is a little smaller than for the pulsed one. For temporal symmetric pulses there are no significant differences between the MDs at rising and falling slope (not shown here). Here, current pulse shape and amplitude are identical for both slopes. Also, the same spatial structures are observed as well as the equal ionizing front velocity. This changes if asymmetric pulses are applied [4].

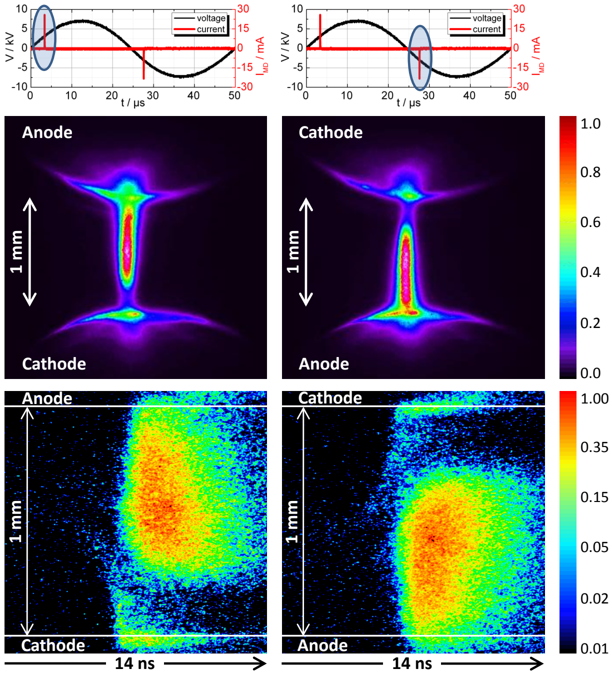

Fig. 1: ICCD pictures and streak images in both half-periods (indicated on top) of a sinusoidal driven DBD with $U_{pp} = 14\,\mathrm{kV}$ and $f = 20\,\mathrm{kHz}$ for 0.1 Vol.-% O_2 in N_2 in pseudocolor intensity scale.
Top: ICCD pictures accumulated of 10000 MDs (linear intensity scale).
Bottom: Streak images accumulated of 64 single MDs with jitter correction (logarithmic intensity scale).

The similar behavior of sinusoidal driven DBDs and DBDs operated by a symmetrical pulse is due to the same time delay between the MDs. The MD characteristic depends essentially on the charge deposition at the dielectric surfaces, so these processes take place on a $\sim 10\,\mu s$ time scale. Also the lifetime of the metastable N_2 for 0.1 Vol.-% O_2 in N_2 at atmospheric pressure is in this order of magnitude, so it could influence the MD properties. This behavior changes markedly when the time between two MDs is reduced to the ion drift time ($\sim 1\,\mu s$ for 1 mm gap) [5].

References

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