Manipulation of helium barrier discharges by laser surface interaction

S. Nemschokmichal, R. Tschiersch, and J. Meichsner

Institute of Physics, University of Greifswald, Felix-Hausdorff-Street 6, 17489 Greifswald, Germany

The influence of a laser beam hitting the dielectric of a helium barrier discharge with a gap distance of 3 mm at a pressure of 500 mbar is investigated. The largest effect occurs when the laser hits the cathodic dielectric in the Townsend-pre-phase of the glow like discharge. Since a current induced by the laser is not measurable, the laser releases only few electrons from the negatively charged dielectric which have large influence on the ionization in the pre-phase of the discharge. This hypothesis is investigated in detail by varying the position of the laser beam with respect to the dielectric and its pulse energy. Furthermore, the measurements are compared with fluid simulations showing the same qualitative behavior.

1. Introduction

Barrier discharges are one of the most common discharge types for industrial applications at atmospheric pressure. Their dielectric barriers between the electrodes cause an accumulation of surface charges extinguishing the discharge by the build-up of an inverted electric field. In the following half period, this electric field enhances the external electrical field and causes an earlier ignition of the following discharge breakdown. Furthermore, the negative surface charges on the dielectric support the electrical breakdown because they are easier to remove by thermal desorption or secondary electron emission than the intrinsic electrons of the dielectric. To investigate this in more detail, one idea is to release these surface charges from the dielectric by laser photons. This artificial removement of surface charges reduces the electrical field before the discharge ignition but provides additional charge carriers in the gap. Hence, it might inhibit or enhance the discharge.

2. Experimental setup

The investigated symmetric barrier discharge configuration is sketched in figure 1. The plane electrodes are made from aluminum and copper, the dielectrics are two 0.7 mm thick glass plates having a relative permittivity of $\varepsilon = 7.6$ and are mounted at a gap distance of 3 mm. The discharge configuration is placed in a cylindrical stainless steel vacuum chamber. The working gas is helium with a purity of 99.999 % operating at a pressure of 500 mbar and a gas flow of 100 sccm. Impurities of up to 100 ppm air must be assumed due to the leakage rate of the chamber. A high voltage with a frequency of 2 kHz and an amplitude from 700 to 1200 V is applied to the upper electrode.

The barrier discharge is characterized by measuring the applied voltage and the transported charge across an external capacitance C_{ext}. The discharge current I_{dis} and the gap voltage U_{gap} are derived from these quantities basing on the electric modeling presented in [1]. For comparison, the external capacitance can be replaced by an external resistance R_{ext} to measure the discharge current directly, and a Rogowski coil is mounted to look for very fast current pulses indicating microdischarges.

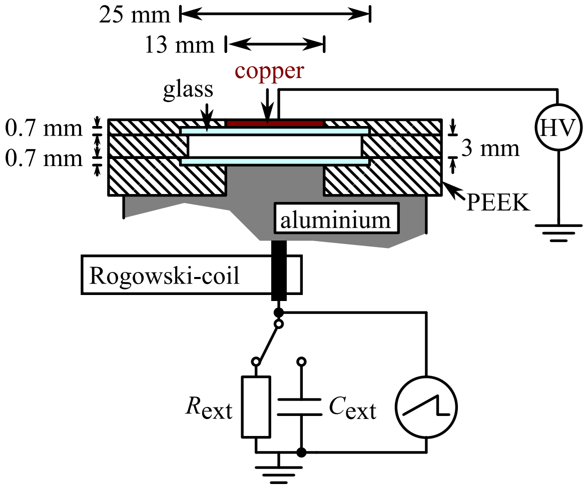

Fig. 1: Sketch of the barrier discharge configuration.

Besides the electrics, the optical emission is measured by a monochromator and a photomultiplier tube. All signals are averaged over 500 laser pulses and are recorded with an oscilloscope at a temporal resolution of 0.4 µs.

The manipulation of the barrier discharge is performed by a Nd:YAG laser at its second harmonic wavelength of 532 nm. The laser beam is focused in the vertical direction by a cylindrical lens to have a vertical extent of about 1 mm in the center of the gap. For the investigation of the laser surface interaction, the laser beam is shifted

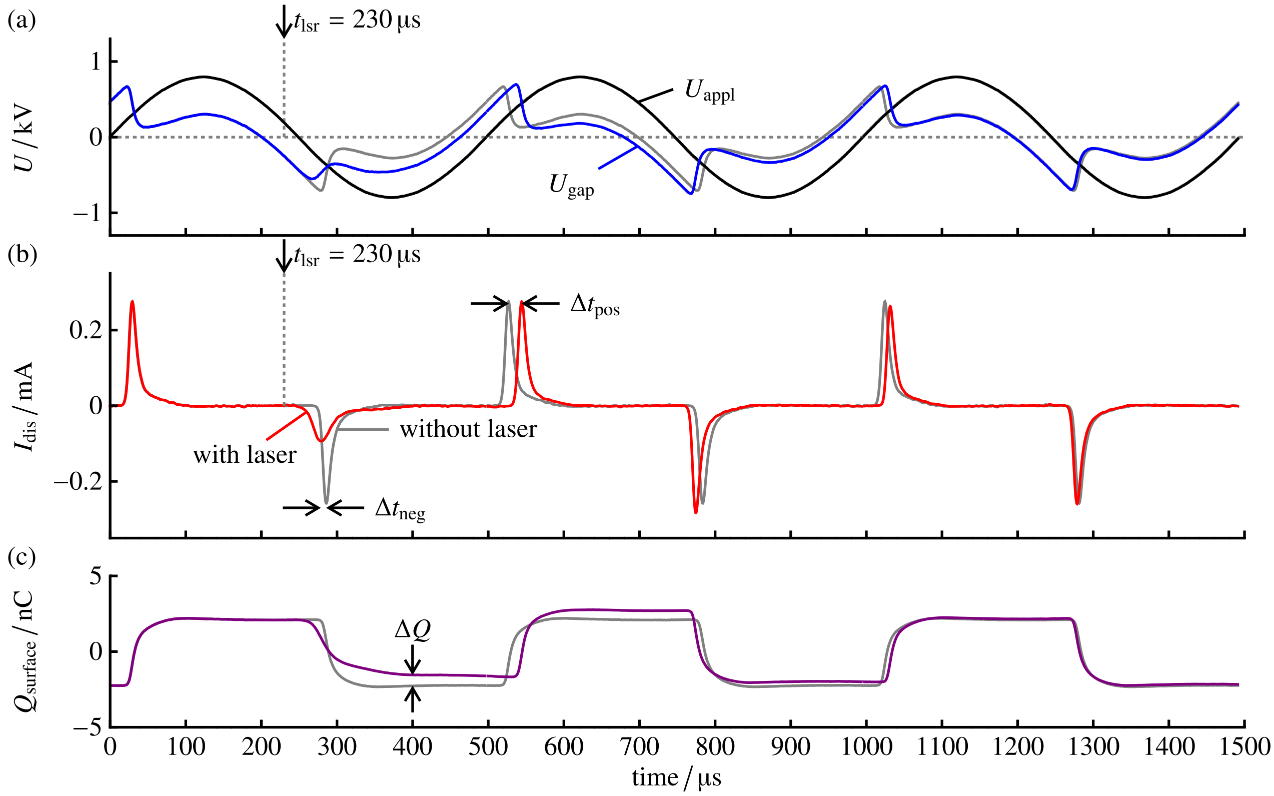

Fig. 2: (a) Applied and gap voltage, (b) discharge current and (c) surface charge for the discharge periods disturbed by the laser pulse in comparison with the undisturbed discharge (gray lines). The arrow marks the laser firing time.

carefully to one of the dielectrics until a strong effect is observable. For the comparison with the undisturbed discharge, usually four discharge periods are recorded and the laser is fired in the second period.

3. Results

3.1. Laser-disturbed discharge

A measurement showing the general behavior of the laser disturbed discharge is presented in figure 2. The figure shows the applied and gap voltage in (a), the discharge current in (b) and the surface charge in (c) for the disturbed discharge period and the two subsequent discharge periods. In comparison, the undisturbed discharge is plotted by gray lines. It is measured just before the disturbed discharge period to guarantee the same operating conditions.

For the conditions presented, the laser beam hits the negatively charged cathodic dielectric during the pre-phase of the discharge. This is the situation with the maximal effect. It is visible that the laser surface interaction does not induce a remarkable discharge current, but it has a remarkable effect on the following negative discharge pulse. This discharge ignites earlier and at a lower gap voltage. Hence, the laser surface interaction results in an enhanced pre-ionization during the pre-phase of the discharge, probably because of an additional release of electrons from the negatively charged dielectric by the laser photons.

The earlier discharge ignition has several consequences. First of all, the current maximum is shifted to earlier times by Δt_{neg}. Secondly, the voltage drop during the discharge pulse is smaller. Thirdly, the transported charge is reduced by ΔQ. Besides the influence on the subsequent negative current pulse, there is also a remarkable effect on the following discharge pulses. E. g., the first positive current pulse after the laser disturbance ignites later. This is caused by the less transported charge during the negative current pulse, wherefore the gap voltage reaches the ignition voltage later. Despite the large influence of the laser pulse on the discharge ignition, the discharge relaxes within a few periods to the previous undisturbed situation. Hence, the laser surface interaction is only temporary without any long term effect. This allows the conclusion that the laser releases the electrons immediately in the pre-phase of the discharge, and that the heating of the surface by the laser and the resulting larger thermal desorption is of minor importance.

3.2. Dependence on laser parameter

A detailed analysis of the laser surface interaction on the discharge is performed by varying the firing time of the laser pulse, the vertical laser position and the laser pulse energy. The changes in the temporal shift of the negative discharge pulse Δt_{neg} and the less transported charge ΔQ depending of the firing time of the laser pulse t_{lsr} are plotted in figure 3. The figure illustrates that the main effect occurs when firing the laser during the pre-phase at the cathodic dielectric. To investigate this in more detail, the laser beam is vertically shifted and the strength of the effect is shown for these positions in figure 4.

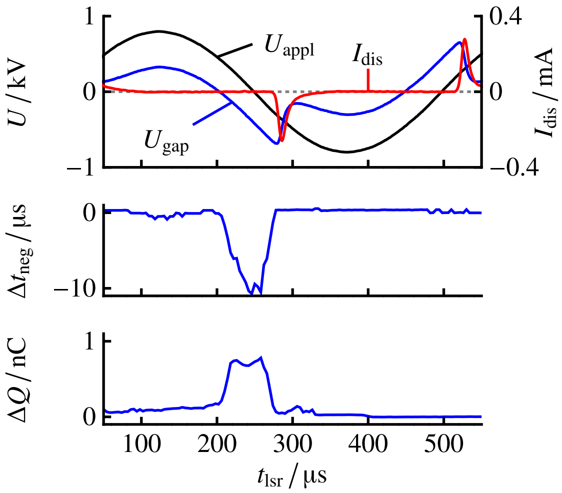

Fig. 3: Dependence of discharge pulse shift and less transported charge on the laser firing time.

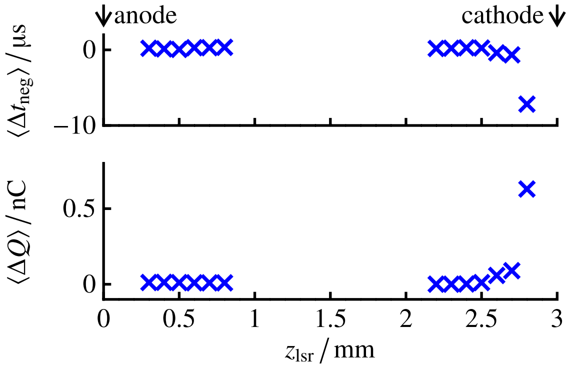

Fig. 4: Dependence of discharge pulse shift and less transported charge on the vertical laser position.

This measurement shows that the laser beam induces no effect when passing the discharge configuration in the center, but when touching the cathode the effect increases very steep. This is not the case in front of the anode, which is in agreement with the conception that only electrons released at the cathode can move through the discharge gap.

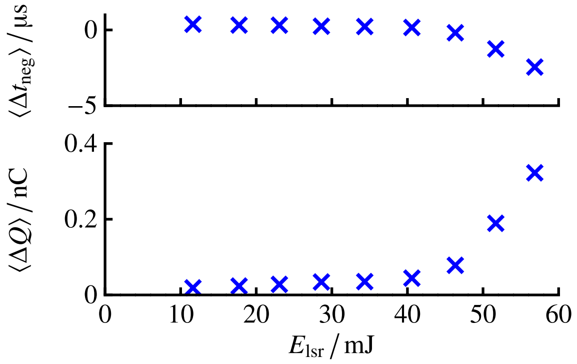

Fig. 5: Dependence of discharge pulse shift and less transported charge on the laser pulse energy.

The variation of the laser pulse energy in figure 5 shows a strong dependence as well. Up to a value of 40 mJ, the effect is very small, but above 40 mJ, it strongly increases with laser energy. This threshold behavior indicates that the number of released electrons by the laser must exceed the number of electrons released by secondary processes to have a remarkable influence on the discharge.

3.2. Comparison with modeling

Since the release of electrons by the laser induces not directly a discharge current, it is necessary to model the expected process to quantify the number of released electrons. Therefore, a fluid modeling was performed assuming a barrier discharge in helium with 100 ppm air impurity. To introduce the laser surface interaction, a release of 1 pC of electrons from the negatively charged cathodic dielectric is assumed in the modeling at the time of the laser firing. This modeling is compared with the measured spatially resolved optical emission in figure 6.

First of all, the cathode directed spatio-temporal emission pattern illustrates that the discharge operates in the glow-like mode. This is also reflected by the modeling, but the discharge current and the voltage drop are too large in comparison to the measured quantities. The modeling reflects also the earlier discharge ignition and the slower propagation of the ionization front towards the cathode when firing the laser in the pre-phase of the discharge. Further, the modeling allows to see the influence of the additional charge release at the laser firing time on the excitation rate in the pre-phase. The metastables excitation rate makes a jump at this time, wherefore the ionization reaches larger values at earlier times and the discharge ignites earlier. So the modeling qualitatively supports the argumentation that the few

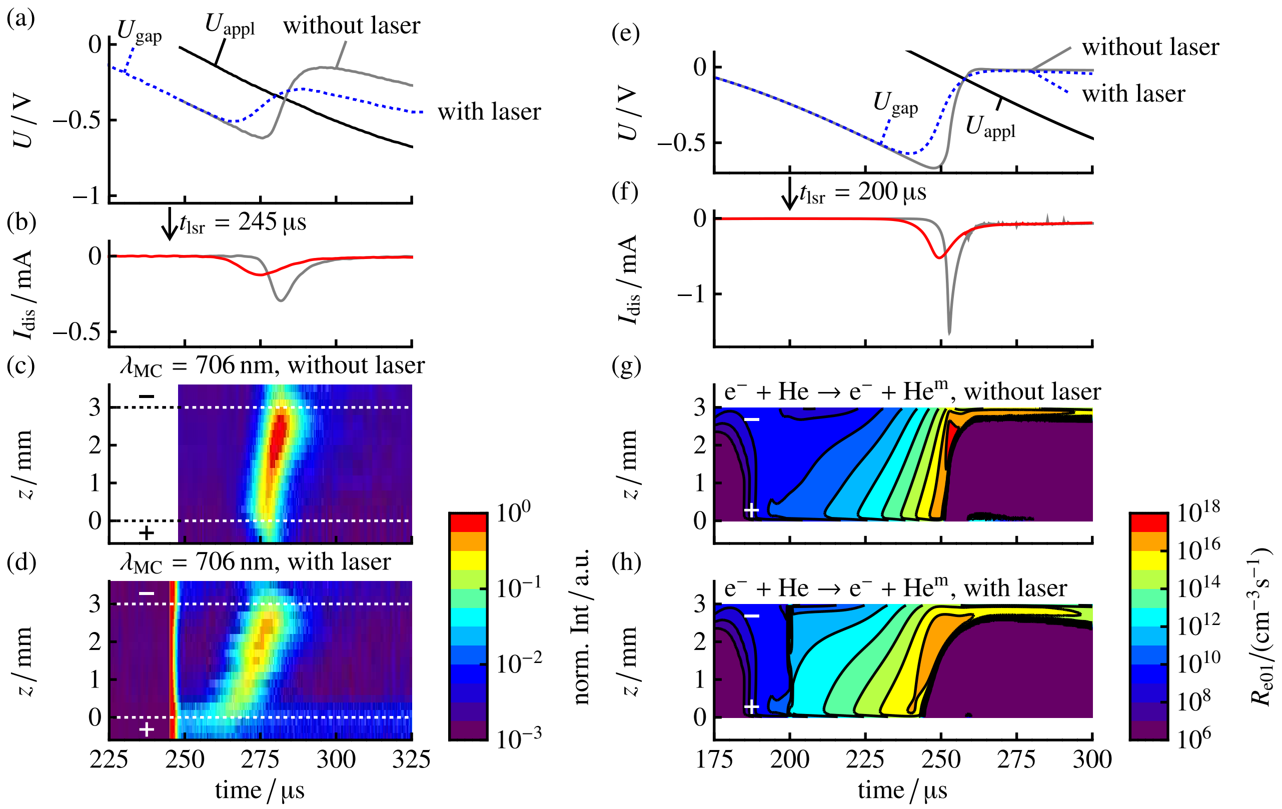

Fig. 6: (a) Applied and gap voltage, (b) discharge current and optical emission for the (c) undisturbed and (d) disturbed discharge in comparison to the modeled (e) applied and gap voltage, (f) discharge current and excitation rate for the (g) undisturbed and (h) disturbed discharge.

laser released electrons have large influence on the subsequent discharge ignition.

3. Summary and outlook

The contribution shows that the laser surface interaction at the negatively charged cathodic dielectric during the pre-phase of the discharge results in an earlier discharge ignition, a smaller amount of transported charges and a lower voltage drop during the discharge pulse. This behavior can be explained by a release of electrons from the negatively charged dielectric by the laser photons. This amount of released electrons is not large enough to measure a current, but it is large enough to enhance the excitation of metastables during the pre-phase, which is qualitatively proven by a fluid modeling.

The next step is to improve the modeling to fit better the actual discharge conditions and to quantify the number of laser-released electrons by the comparison with the experiment. The experimental investigation should be extended by using the fundamental laser wavelength of 1064 nm and other dielectric materials to learn more about the binding energy of the surface charges on the dielectric. This should be further combined with spatially resolved surface charge measurements using the opto-electric Pockels effect [2,3].

Another attempt is to check if there is a possibility to induce a mode transition by the laser surface interaction, e.g. to release enough electrons from the surface that a Townsend-like discharge develops instead of the glow-like discharge. The same effect might be used to induce a glow-like discharge at conditions usually showing the filamentary mode.

Acknowledgement

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