Temporally resolved surface charge measurements in a laterally patterned barrier discharge

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An absolute charge density measurement of deposited surface charge is presented for a laterally patterned barrier discharge. The high temporal resolution of the technique allows the observation of charge on different timescales.

Introduction Charge deposition on confining surfaces occurs in many plasma sources such as barrier discharges or many types of surface treatment [2]. The resulting electric field commonly influences the ongoing discharge significantly. Especially during the formation of patterned discharges in the early breakdowns, surface charges have a decisive role [1].

This contribution is dedicated to the measurement of the absolute surface charge densitie and the investigation of its dynamics in laterally patterned barrier discharges. For the measurement, a BSO ($Bi_{12}SiO_{20}$) crystal is used as a dielectric. It exerts an optical birefringence that is proportional to the electrical field over the crystal. A light beam of known polarisation is passed through the crystal. The absolute charge density is deduced from the change of polarisation of the light beam. The light is emitted by a LED which is operated in a pulsed mode. Each LED pulse has a duration of 400 ns and is synchronized with the applied voltage of the barrier discharge. The temporal resolution of the charge measurement is achieved by variation of the phase positon of the LED pulse. Using a high speed camera for the observation of the light beam, the charge measurement is laterally resolved.

Timescale: 100 ns The charge measurements were performed for three significant time scales. The first time scale is given by the duration of the discharge itself (Fig. 1). In order to achieve a sufficiently high temporal resolution, the phase positions of the LED pulses are interlaced. The resulting resolution of 140 ns makes the direct observation of the charge deposition during the discharge possible for the first time. As shown in Fig. 2, the deposition of charge starts in the center of a remnant surface charge spot, where the electrical field is highest. The charge is fastly replaced by charge of opposite polarity. This causes the maximum of the electrical field to move radially outwards from the center. The result is that
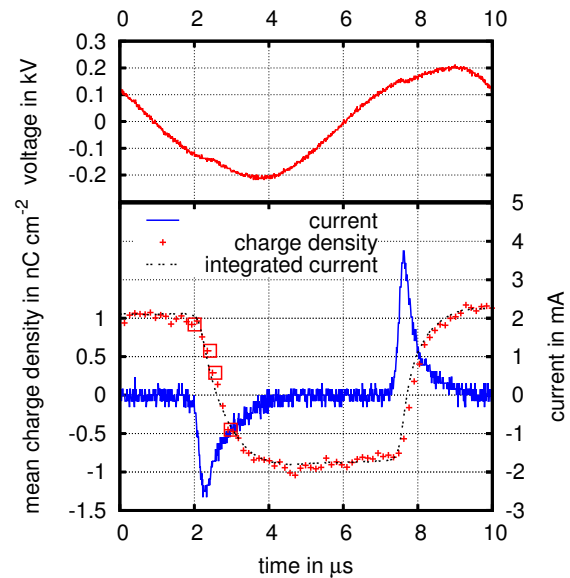

Fig. 1: Temporal behaviour of applied voltage, current and mean charge density during on cycle. Selected times of the charge distribution in Fig. 2 are marked with squares.

a surface charge spot of one polarity is replaced from the inside out by a charge spot of opposite polarity [3]. Further, the high temporal resolution of the method allows – as an alternative representation of the data – the laterally resolved visualisation of the current density. Typical maximum current densities during the breakdown have values of several mA.

Timescale: 10 μs The second timescale is given by the period of the applied voltage. On this timescale, the charge densitiy distribution after each half wave is investigated without regard to its deposition dynamics. In order to minimize errors from the applied voltage, the charge density is measured at times of the zero-crossing of the voltage. The selection of a zero-crossing after a positive or negative half wave allows to distinguish between positive and negative charge, respectively. The resulting distributions are characterized with regard
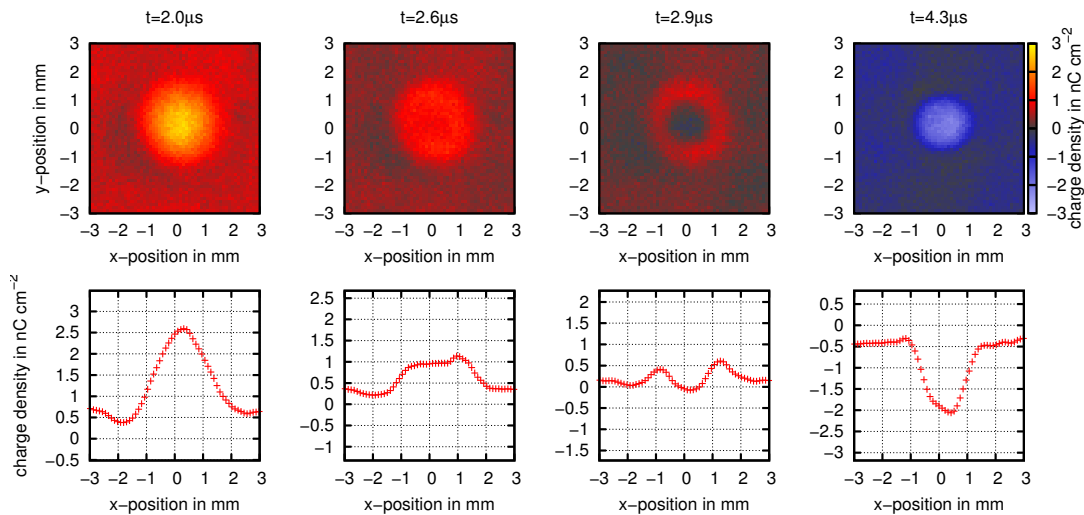
Fig. 2: Temporal evolution of a mean surface charge spot during deposition of negative charge. Upper row: charge density distribution. Lower row: cross sections of density distribution at $y = 0$ mm.

to the averagely occurring surface charge spots. They have been found to have approximately Gaussian profiles. The corresponding fitting routines allow to characterize the spots via their amplitudes, their standard deviations (which are a measure for the spot radius) and an effective offset, that corresponds to a background charge of the BSO surface. The amplitudes of the surface charge spots are in the order of several nC cm^{-2}, their standard deviations have values of about 1 mm. The dependence of these parameters on the applied voltage and gas pressure is tested, especially with regard to the polarity of the charge.

Timescale: 1 s The third timescale is given by the charge decay processes and transport on the crystal surface. The investigation of the temporal behaviour of these processes are in particular important in order to validate the stationarity of charge in smaller timescales when no discharge is occuring. Therefore, charge is deposited on the crystal in a controlled manner and the corresponding charge density is afterwards periodically measured. An initially homogeneous distribution allows the observation of charge decay on the surface. It is found that the temporal behaviour of the charge can be approximated with two superimposed exponential functions. This suggests two different decay channels. While the mechanism of the fast decay channel has yet to be investigated, the slow decay mechanism has been identified as photoconductivity of the BSO

crystal [4]. The time constants of the decay processes are in the order of seconds. The investigation of an initially inhomogeneous distribution of charge allows the observation of charge transport on the BSO surface. The charge distributions of two regions with significantly different mean charge densities are periodically measured. It turns out that the region with lower charge density firstly gains charge for several seconds before the charge decay becomes dominant. On the other hand, in the region of higher charge density the charge is removed with a higher rate than in the homogeneous case. This phenomenon is associated with charge transport on the surface. Its timescale is again in the order of seconds. Therefore, on the timescale on the applied voltage and below, the charge can be assumed to be stationary [4].

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