The development of surface charges and discharge emission in barrier discharges operated in He/N_2 gas mixtures

M. Bogaczyk, R. Tschiersch, and H.-E. Wagner

Institute of Physics, University of Greifswald, 17489 Greifswald, Germany

1. Introduction

Barrier discharges (BDs) can be operated in the filamentary or laterally diffuse discharge mode depending on the mixture of the working gas, amplitude and shape of the applied voltage, etc. [1]. The interplay between processes in the volume and on insulating surfaces controls the generation of BDs. During the discharge breakdown, surface charges are accumulated on the dielectrics, but a detailed description of surface processes in interaction with the bulk plasma is still missing. For a comprehensive understanding of the discharge mechanisms the investigations of these processes are essentially. Elementary processes in the discharge volume were investigated with the cross-correlation spectroscopy (CCS) [1]. The discharge interaction with the insulated surfaces was investigated via the electro-optic Pockels effect detecting the accumulated surface charges.

2. Experimental setup

The discharge cell configuration, in detail in [2], consists of two plane parallel dielectric electrodes. The grounded electrode is an optically polished aluminium mirror. On its top, an electro-optic BSO ($Bi_{12}SiO_{20}$) crystal is mounted enabling surface charge measurements. The driven electrode is a glass plate coated on its top side with a transparent as well as electrically conductive ITO layer. The gap distance is 1 mm. The experimental set-up is illustrated in figure 1 combining three diagnostics, namely for the electrical characterization, the measurement of the discharge emission development, and the determination of surface charges. Spectrally, spatially, and phase resolved measurements of the optical emission evolution in diffuse BDs are provided by the

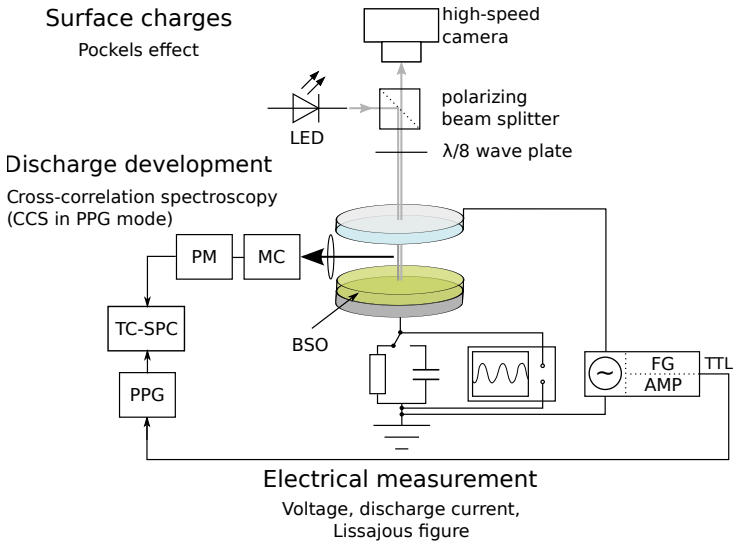


Figure 1: *Overview of the three diagnostic methods at the one discharge cell.*

highly sensitive electrically triggered cross-correlation spectroscopy (CCS). The technique is based on the counting of single photons originating from up to 10^6 discharge cycles [1]. The spectrally resolved emission is converted into an electrical signal and processed by a TC-SPC (time-correlated single photon counting) module. The result is a phase resolved intensity distribution of the discharge emission evolution. The surface charge measurement is based on the electro-optic Pockels effect [2, 3]. The BSO crystal is illuminated homogeneously by a LED ($\lambda = 634\,\mathrm{nm}$). Linearly polarized light becomes elliptically polarized by a $\lambda/8$-wave plate. The light passes the BSO crystal and the $\lambda/8$-wave plate twice due to reflection at the mirror. A phase shift depending on the value and sign of both the applied voltage as well as the deposited surface charge changes the ellipticity of the light. A high speed camera detects intensity changes of the polarized light with a temporal resolution of $10\,\mu\mathrm{s}$. The surface charge density $\sigma(x,y) \propto I(x,y)/I_r(x,y)$ depends linearly from the ratio of the intensity *with* deposited surface charges ($I(x,y)$) and the reference intensity *without* any surface charges ($I_r(x,y)$).

3. Results and discussion

Operating the BDs in $\mathrm{He}/\mathrm{N_2}$ mixtures, different discharge modes are generated depending on the applied voltage amplitude and gas mixing ratio, as can be seen in figure 2.

Under the experimental conditions studied, the diffuse Townsend-like mode occurs in pure $\mathrm{N_2}$ as well as in pure He characterized by an electrical breakdown of several tens of microseconds and a low current density in the order of $\sim 0.1\,\mathrm{mA/cm^2}$. Typical for the Townsend-like mode, the intensity maximum of the emission is located in front of the anode as shown in figure 3a. The observed 0-0 transition of the second positive system (SPS) in $\mathrm{N_2}$ ($\lambda = 337\,\mathrm{nm}$) results from inelastic electron collisions with nitrogen in the ground state which form $\mathrm{N_2(C^3\Pi_u)}$ followed by its deexcitation. The emission profile is correlated with the discharge current and increases simultaneously which is in agreement with former results [1, 5]. A rising $\mathrm{N_2}$ admixture to He as well as an increase of the applied voltage result in the coexistence of the diffuse and filamentary mode in the positive half-period and the diffuse mode in the negative half-period due to different dielectric materials. Overvoltage leads to the filamentary mode in any $\mathrm{He}/\mathrm{N_2}$ mixture and the pure

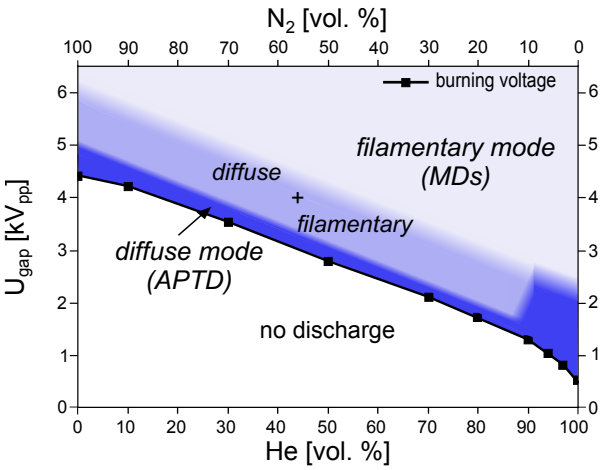
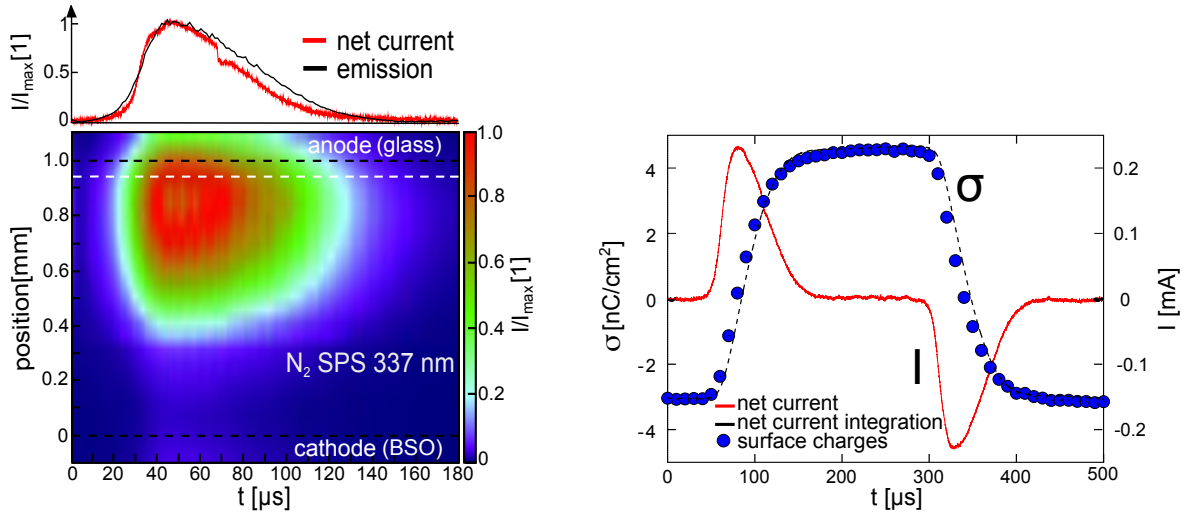


Figure 2: *Discharge modes in* $\mathrm{He}/\mathrm{N_2}$*-mixtures depends on gas mixing ratio and applied voltage [4].*

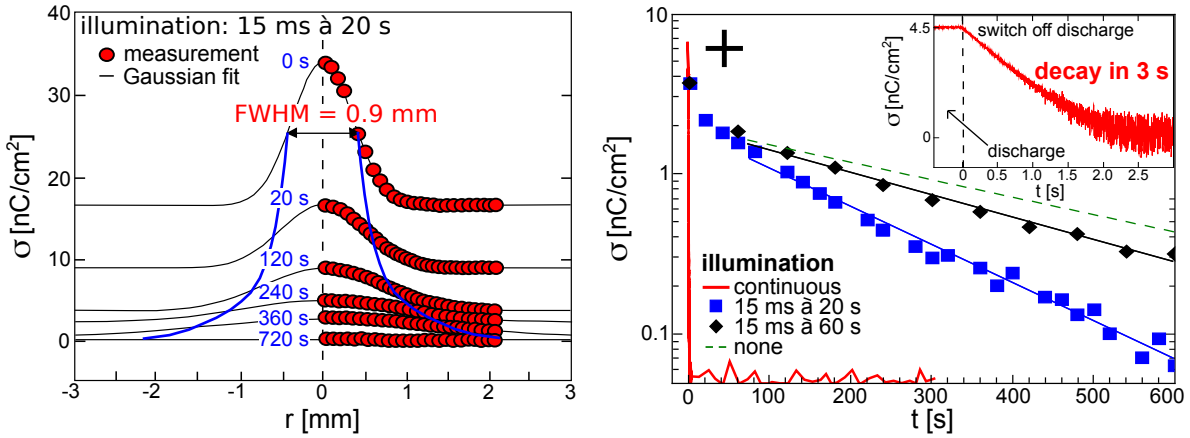


(a) *Spatio-temporally evolution of the discharge emission ($\lambda = 337\,\mathrm{nm}$, SPS) for pure N_2 operating in the Townsend-like mode.*

(b) *Phase resolved surface charge density measurement corresponding to the net current and the temporally integrated net current.*

Figure 3: *Diffuse BD operated in pure nitrogen.*

gases. In diffuse BDs the deposited charges are laterally homogeneously distributed on the dielectrics. For a BD operated in pure N_2 the phase resolved surface charge measurement is shown in figure 3b. In every half-cycle the accumulated surface charges change their polarity during the appearance of an according current pulse. In between, they remain constant on the BSO crystal. In the subsequent half-period surface charges support the re-ignition of the discharge, known as the memory effect [2]. The positive surface charge density is $\sigma_+ = 4.5\,\mathrm{nC/cm^2}$, whereas the absolute value for the negative surface charge density is lower ($|\sigma_-| = 3\,\mathrm{nC/cm^2}$) due to the asymmetry of the discharge cell, i. e. different γ coefficients of the dielectrics [2, 6]. A variation of the gas mixture from pure He to pure N_2 results in an increase of the transferred charge, i. e. the higher the N_2 admixture the higher the transferred charge due to a longer duration of the current pulse at comparable current densities. Negative surface charges are generated by electrons trapped within the dielectric. Positive ones are probably defect electrons inside the dielectric resulting from the recombination of ions from the discharge volume with electrons from the dielectric. In the filamentary mode spots of surface charges on the dielectric mark footprints of separated microdischarges [2]. The negative surface charge spots are laterally more extended than the positive ones due to differing mobilities of ions and electrons in front of the dielectric. The density profiles of both surface charge polarities are Gaussian distributed, as shown exemplarily for positive surface charges in figure 4a. After turning off the discharge operation, two time scales of the surface charge decay have been observed (see figure 4b). In the very first 0.5 s, a fast surface charge decay appears independently of the illumination. But, the reasons for this



(a) *Decay and broadening of positive surface charges after switching off the filamentary discharge.*

(b) *Decay of surface charges originating from a diffuse BD in dependency of various illumination frequencies.*

Figure 4: *Decay of surface charges in BDs operated in filamentary and diffuse discharge mode [4].*

behaviour are under discussion. Then, the surface charges of both polarities remain several seconds (continuous illumination) up to several tens of minutes (pulsed illumination) on the crystal. The reason for that behaviour is the photoconductivity of the BSO crystal induced by the LED light [7]. The decay of positive surface charges is exemplarily shown in figure 4b in dependency of various illumination frequencies. The lower the illumination frequency the longer is the residence time of the surface charges. The decay of negative surface charges shows in principle the same behaviour [4]. Figure 4b illustrates the decay of positive surface charges recorded in the filamentary mode (pure N_2). The decay constant is in the same order as for the diffuse mode. Under a continuous LED illumination, no lateral diffusion of the surface charge is observable [4]. But using a pulsed illumination, spots of surface charges show diffusion on the dielectric on the minute scale, as shown in figure 4a. However, the mechanisms of the accumulation as well as the release of surface charges are still not fully understood.

References

[1] H.-E. Wagner, K.V. Kozlov, R. Brandenburg, Low Temperature Plasmas: Fundamentals, Technologies and Techniques, WILEY-VCH Weinheim 2008, vol. 1, 385

[2] M. Bogaczyk, R. Wild, L. Stollenwerk, H.-E. Wagner, J. Phys. D Appl. Phys. **44** 465202 (2012)

[3] Yariv, A. Quantum electronics Wiley New York (1989)

[4] R. Tschiersch, M. Bogaczyk, H.-E. Wagner, J. Phys. D: Appl. Phys., accepted reference number JPhysD-101839 (2014)

[5] F. Massines, A. Rabehi, Ph. Decomps, Ben Gadri, P.Segur, Ch. Mayox, *J. Appl. Phys.* **28** (1998) 2950

[6] L. Stollenwerk, PRL **98** 255001 (2007)

[7] T. V. Panchenko, Physics of the Solid State **42** 657-63 (2000)