Townsend-like and glow-like diffuse discharge modes in barrier discharges operating in helium

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The dielectric barrier discharge (DBD) has been studied in helium by surface charge measurements, cross-correlation spectroscopy (CCS), and electrical measurements. Depending on the gap distance, the dielectrics, and the shape of feeding voltage, the DBD operates in the Townsend-like or glow-like mode. Under the studied conditions a sinusoidal voltage leads to the Townsend-like mode. Changing from the sine wave to a rectangular voltage signal results in the glow-like mode. A sawtooth voltage signal generates both discharge modes over one period. The presented results show clearly the strong correlation between transported and deposited charge and the correlation of the electrical measurements with the optical emission.

The Townsend-like mode is characterized by a weak emission intensity. Its maximum is located near the anode [1]. The applied electric field in the gap is not disturbed due to a low production of space charges. This leads to an almost constant electric field over the gap during a breakdown which can be shown by calculating the accordant gap voltage. Furthermore, the current density of the Townsend-like discharge mode is in the order of $\sim 0.1\,\mathrm{mA/cm^2}$. The duration of the discharge current is several tens of microseconds. In contrast to that, the emission intensity for glow-like mode is much higher and is located in front of the cathode. Mostly one current pulse occurs with a 10 times higher current density than for the Townsend-like mode. The duration of the current pulse is in the order of a few microseconds. Also, a strong voltage drop over the gap is characteristic for this mode in the moment of the current pulse maximum. This implies the formation of the space charge sheath near the cathode and the cathode fall region which is similar to the low pressure DC glow discharges. The length of the cathode fall is usually in the order of 1 mm. The electron density is in the glow-like mode about $10^{10} \ldots 10^{11}\,\mathrm{cm^{-3}}$, three orders of magnitude higher than in the Townsend-like mode [2].

The DBD operates in a discharge cell with two parallel dielectric electrodes. For the surface charge measurements, based on the Pockels effect [4, 5], the grounded electrode is an optoelectronic BSO ($Bi_{12}SiO_{20}$, $\varepsilon_{BSO} = 56$) crystal. The second one (driving electrode) is made of glass covered with a thin conductive transparent ITO layer. It enables the discharge investigation from the top. The gap distance between the dielectrics is 1 mm. The other operation conditions of the He barrier discharge are: frequency 2 kHz, pressure 1 bar. The applied feeding voltages have been varied between sine wave, rectangle and sawtooth. The discharge development in the volume has been investigated by the cross-correlation spectroscopy (CCS), phase-, spatially-, temporally- and spectrally-resolved [3]. All electrical measurements (voltage, current, and Lissajous figure) have been done by using a high voltage probe, an $100\,\Omega$ resistor, and an 1 nF capacitor.

For the applied sinusoidal voltage, the discharge operates in the Townsend-like mode. As expected, the maxima for the investigated spectral lines (SPS of N_2: 337 nm, FNS of N_2: 337 nm, He: 706 nm) appear near the anode at low intensities. Typical for this mode is a current pulse duration of about $30\,\mu\mathrm{s}$ which corresponds with the emission duration. The current density is in the order of $0.05\,\mathrm{mA/cm^2}$ and the voltage drop over the gap is small. In the case of a rectangle excitation voltage the DBD changes to the glow-like mode. Here, the emission intensities are much higher and appears in front of the cathode. The much higher current density of $9\,\mathrm{mA/cm^2}$ has a duration time of only $5\,\mu\mathrm{s}$. For us surprisingly, the operation of the glow-like mode was possible despite of the small gap distance. From our point of view, the reason is the steep rising voltage leading to a fast change of the electric field.

In figure 1, exemplary the situation is shown for the sawtooth voltage. Here, both modes appear in the consecutive half periods. In the smooth rising voltage part the Townsend-like mode occurs. Several small current pulses can appear together with the emission maxima near the anode (upper part figure 1, left hand side). It is followed by the glow-like mode while the steep voltage drop into the negative half period. In the (very short) glow-like mode the much higher emission intensity appears near the cathode. The corresponding measurements of the deposited surface charges shows an excellent correlation to spectroscopic and electrical measurements. The comparison of the measured surface charges and their calculation by net current integration shows an excellent agreement (figure 1, right hand side).

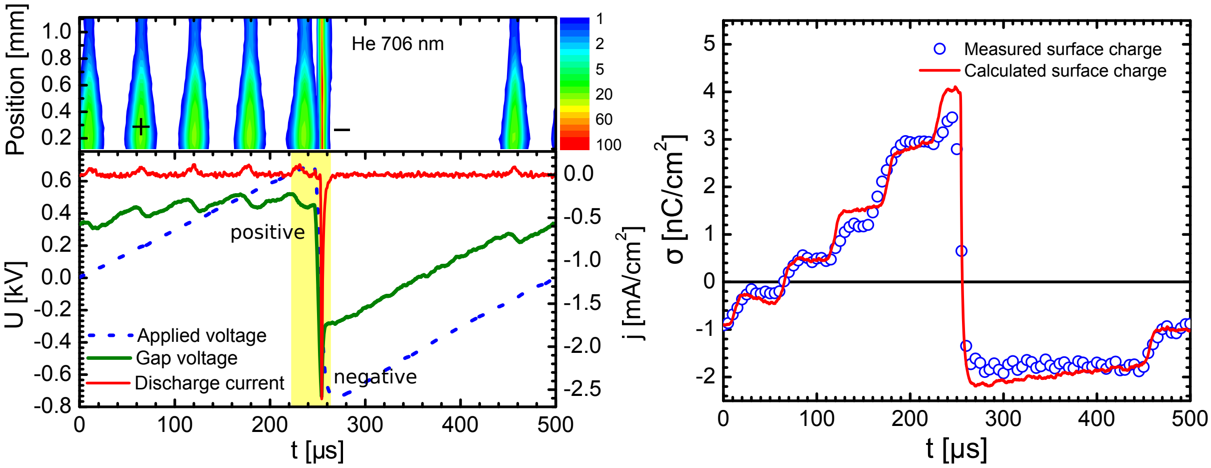

Fig. 1: Sawtooth voltage signal induces the Townsend-like mode and the glow-like mode in one period. Left: Combination of cross-correlation spectroscopy (He : 706 nm) with the electrical measurements. Right: Correlation of deposited surface charges with transferred charges.

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