Axial light emission profile of a parallel plate dc micro discharge in steady state and during oscillations

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Abstract: The self-pulsing regime (current-voltage oscillations) in a parallel plate dc micro discharge (feedgas: argon; discharge gap \(d = 1\) mm; pressure \(p = 10\) Torr) was studied by means of time resolved imaging with a fast ICCD camera and by measuring Volt-Ampere (\(V-A\)) characteristics. Throughout the voltage and current oscillations, ionized gas oscillates from low current Townsend regime to high current normal glow. Axial emission profiles are similar to corresponding profiles in standard size discharges (\(d \approx 1\) cm, \(p \approx 1\) Torr).

1 Introduction

Microplasmas have recently become in the focus of research due to the wide range of their possible applications \cite{1, 2}. Reproducible and stable discharge conditions are of high importance to realize reliable applications. However, these conditions are usually not achievable over the full operation range. Observations of self-pulsing regimes were amongst others reported in micro hollow cathode discharges \cite{3}, micro plasma jets \cite{4} and recently in parallel plate micro discharges \cite{5}. Numerous experiments in standard size (\(d \approx 1\) cm, \(p \approx 1\) Torr) parallel plate dc discharges have shown that different instabilities can occur \cite{6, 7, 8, 9} and the discharge cannot run stable but runs through the transient regime, switching repetitively from low to high current mode. With the development of ICCD cameras time resolved measurements of discharge transients became possible \cite{10, 11}. Very few studies of parallel plate micro discharges exist at all \cite{12, 13, 14}. In a previous work we have shown first 2D time integrated recordings of the axial light emission in parallel plate micro discharge \cite{15}.

In this contribution we continue our studies and show time resolved 2D recordings of parallel plate dc micro discharge (\(d = 1\) mm, \(p = 10\) Torr) during relaxation oscillations. ICCD camera images are correlated with current and voltage measurements to gain a better understanding of the formation of space charge effects and the cathode fall formation. Axial light distribution under steady state conditions (static \(V-A\) characteristics) have been measured and used to compare with discharge transients.

2 Experimental setup

A schematic of the dc micro discharge chamber is shown in figure 1a. The plane parallel stainless steel electrodes are mounted within a tight fitting Plexiglas tube to avoid long-path breakdown \cite{12}. The gas inlet and outlet are mounted on opposite sides of the discharge tube and controlled by two high precision leak valves. A small flux of Argon is used as feed gas to minimize the influence of impurities. The outer and inner walls of the Plexiglas tube are polished to gain optical access to the plasma volume. The area between each electrode end and the Plexiglas tube is shrouded by a Teflon insulator as indicated in figure 1b. The discharge gap can be changed by a micro positioning linear stage, but was fixed at \(d = 1\) mm during the experiments. Electrodes with a diameter of 8 mm were used. The experiments were performed at the point close to the Paschen minimum \(pd = 1\) Torr cm.

The electrical circuit is similar to the one presented in \cite{16}. The voltage is monitored with a high voltage probe. The current is determined from the voltage drop over a monitoring resistor and corrected for the displacement current.

Prior to each experiment the discharge is sustained at low current (roughly 10 \(\mu\)A) mode for
around 15 minutes until stable discharge conditions are achieved. During the experiments the discharge is first ignited in low current (a few μAs) Townsend-like mode. Additionally, short voltage pulses (usually < 3 ms) are applied to change the discharge working point (intersection between a loading curve and micro discharge $V$-$A$ characteristics) to the higher currents, as described in [7]. Due to the short pulse length the discharge is running only for a short time in high current mode, therefore significant gas heating and conditioning of the electrodes is avoided.

3 Results and discussion

3.1 Steady state Volt-Ampere characteristics and axial light emission

Figure 2 shows a $V$-$A$ characteristics recorded under steady state discharge conditions. The $V$-$A$ characteristic shows a negative differential resistance as reported for standard size discharges [7, 9]. Due to the negative differential resistance different instabilities can form, such as current oscillations [17]. The region of current oscillations is indicated in figure 2. In this region no steady state can be reached for given discharge conditions. The analysis of the axial emission and $V$-$A$ characteristic during the oscillations will be given in the next chapter.

2D images of the axial light emission profile at selected positions on the static $V$-$A$ characteristics (label a-d) are presented in figure 3. In the low current diffuse (Townsend-like) mode (label a) the peak of emission is located close to the anode and the discharge spreads over almost the full electrode area. Near the minimum of the $V$-$A$ characteristic the discharge is running in the normal glow (label b) and is highly constricted. The peak of emission moves closer to the cathode and the constriction to the electrode edge. As current is increasing (from b to c) the current density stays constant and the discharge is spreading radially. The discharge is still operating in the normal glow, similar to the low pressure, large scale discharges [18]. At point (c) the discharge occupies the whole electrode surface, which marks the ending point of the normal glow. With further increase of the current the discharge switches to the abnormal glow (label d) which leads to a high increase of the light intensity as well as a shift closer to the cathode. All of these observations in our micro discharge are also typical for standard size discharges [10, 18].

3.2 Time resolved development of the axial light emission during oscillations

Figure 4 shows the discharge voltage $V$ normalized to the breakdown voltage $V_b$ as well as the current as a function of time. After applying the voltage pulse, the discharge voltage increases. The discharge current starts to rapidly increase slightly before the discharge voltage reaches the maximum. With passing time space charge is building up and the circuit capacitance looses charge leading to a drop of the voltage and the increase of the current. Thus the discharge is not able to reach steady state condition, the relaxation oscillations follow and the discharge runs from low current to high current mode repetitively. The first pulse is somewhat different and follows the shape of the voltage as ex-
expected in vacuum [10]. Later, the shape of voltage and current pulses are slightly different because the discharge has switched to self sustained relaxation oscillations.

Figure 5 shows 2D images of the axial light emission recorded by the ICCD camera at different discharge voltage and current values, as indicated by the labels (a)-(d) in figure 4. During the oscillations the discharge develops from low current diffuse mode to the high current glow discharge.

In Townsend-like mode (label a) the discharge is diffuse and the peak of emission is close to the anode. The discharge occupies almost the full electrode surface. The light emission increases exponentially from the cathode to the anode, which is characteristics for the homogeneous electric field with negligible space charge effect. As space charge builds up the current rises, the light emission of the discharge increases and the peak of emission moves away from the anode (label b). The discharge is highly constricted. Comparing the current values and the emission profile with the steady state conditions (figure 3b) we conclude that the discharge is operating at the start of the normal glow. At the current maximum (label c) the light emission has reached its highest value and the peak of emission is located at around the middle of the discharge gap. The discharge is broadened in radial direction, again characteristics for the normal glow. As the current is dropping (label d) the peak of emission moves away from the center, closer to the anode while the profile becomes more Bessel-like. Afterwards, this process repeats.

4 Summary

We have shown time resolved axial light 2D images of parallel plate dc micro discharge in steady state as well as during discharge transient behavior. The static V-A characteristics is similar to the large scale, low pressure discharges, with low current diffuse mode, normal and abnormal glow. The measured axial distributions support this similarity. Between the low current mode and normal glow the region of oscillations has been found. During the relaxation oscillations the discharge develops from the low current mode (several µA) to the high current normal glow mode (≈ 600 µA) repetitively. With increasing current the discharge in-

Figure 3: 2D images of the axial light emission profile of steady state discharge. Labels (a)-(d) correspond to the conditions indicated in figure 2. Doted lines mark the central axes of the discharge chamber, while solid lines mark the position of the peak of emission. The discharge current is shown in the bottom left corner of each image. For better visualization of the axial distributions the images are un-proportionally enlarged in horizontal direction.

(a) Townsend-like discharge
(b)-(c) Normal glow discharge
(d) Abnormal glow
tensity raises and the peak of emission moves away from the anode as the cathode fall develops. The normal glow has a constant current density and shows characteristic constriction of the conducting channel, which grows in diameter as the current is increasing. Current and voltage signals, as well as the axial light emission profiles show similarities with reported results for standard size discharges.

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