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MICRO DISCHARGES: BREAKDOWN, VOLT-AMPERE CHARACTERISTICS AND EMISSION PROFILES

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Abstract. We give preliminary results on breakdown and low current limit of volt ampere characteristics of simple parallel plate discharges at standard and micro discharge conditions. Experiments with micro discharges are reported attempting to establish maintenance of E/N, pd and j/p^2 scalings at small dimensions. Paschen curves and Volt-Ampere characteristics are presented and compared to those of the standard size discharges.

1. INTRODUCTION

Scope of non-equilibrium plasmas was extended recently to include micro discharges - discharges with characteristic dimensions from a few micrometers to several mm. Applications such as UV and visible light sources, sources for thin film treatment, etching, and deposition (Eden and Park 2005, Mohan Sankaran and Giapis 2003) are connected to applications in biological and environmental areas (Becker et al. 2005, Becker et al. 2006). Attractiveness of micro discharges is due to a possibility to realize non-equilibrium conditions and minimum breakdown voltages at atmospheric pressure.

The breakdown of pd scaling is essential in deciding whether one may proceed by extrapolating discharges with standard properties (centimeters and Torrs) to micro discharges, atmospheric pressure discharges and high frequency discharges. Recently we have analyzed the E/N, pd and j/p^2 scaling of low pressure discharges close to the minimum and to the left of the minimum of the Paschen curve (Marić et al. 2003). Our aim here is to extrapolate those studies to sub-millimeter discharges at high pressures. While most micro discharges are realized in complex geometries similar to hollow cathode geometries where inhomogeneous field localizes production of charges and thereby stabilized the discharge, we pursue parallel plate geometry which is more prone to oscillations and instabilities but the results are easier to interpret.

2. EXPERIMENTAL PROCEDURE

The discharge is realized in a simple, parallel plate geometry, with distance between electrodes $d = 0.5$ mm and electrode diameter $D = 2$ mm. Discharge chamber has a stainless steel cathode and transparent anode with conductive ITO (Indium tin oxide) film so radial profiles can be recorded. Before measurement, device was pumped down to low pressure (10^{-6} Torr) but no further electrode preparation was done. Electrical circuit and detection system are the same as in our cm size experiment (e.g. Marić et al. 2003). Measurements were performed in pure Ar.

3. RESULTS AND DISCUSSION

In Fig. 1 we show Paschen curves (breakdown voltage (V_b) vs. pressure x electrode distance (pd)) for micro and cm size discharges. We have shown that the standard shape of the Paschen curve is maintained at $d = 500\mu$m. It is important to emphasize that measurements in the left branch of the Paschen curve are particulary sensitive under these conditions. Mean free path of the electrons is of the μm scale and special care has to be taken to avoid long path breakdown.

Fig. 1 shows that breakdown voltages are somewhat lower in the case of micro discharges. The discrepancy is more pronounced in the left branch of Paschen curve – lower pd i.e. higher E/N. For these conditions, processes at the cathode surface are dominant in secondary electron production (Phelps and Petrović 1999). Different conditions at the cathode surface could lead to discrepancy between the two sets of results. Another issue that could be important here is that electrode gap/electrode diameter (d/D) ratio is smaller than that of the standard size discharge. Thus, loss of charged particles due to diffusion is more pronounced and can lead to an increase of the breakdown voltage (Lisovskiy et al. 2000). Both effects are more pronounced at correspondingly lower pressures.

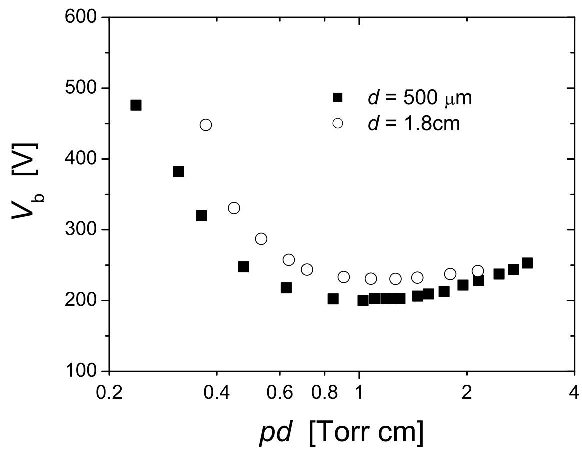

Figure 1: Comparison between Paschen curve for micro discharge (solid symbols) and standard size discharge (open symbols) in argon. In both cases, cathode is made of stainless steel.

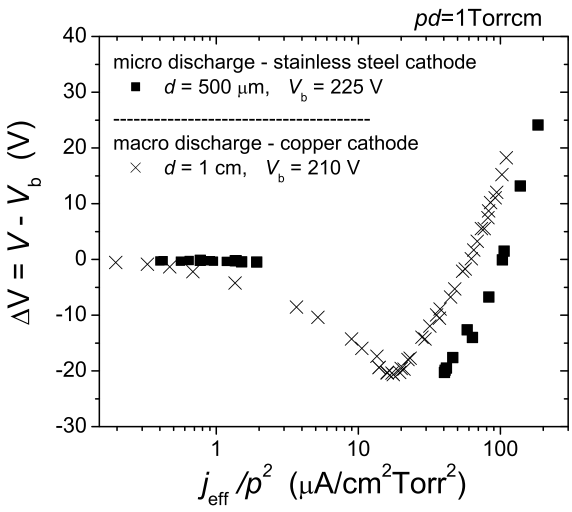

Figure 2: Discharge voltage vs. scaling parameter j_{eff}/p^2 for $d = 500\mu$m (stainless steel cahtode) and for $d = 1$ cm (copper cathode) (Marić et al. 2003). Voltage is given as a difference between discharge (V) and breakdown voltage (V_{b}).

In Fig. 2 normalized voltage-current (VI) characteristic for 1 Torrcm is shown. Measurements with micro dimensions are taken with cathode made of stainless steel. However, results for macro dimensions shown here are taken for copper cathode. Voltage is given as a function on standard scaling parameter j/p^2. Current is here normalized with "effective discharge area", not the electrode area, to produce "effective current density" (j_{eff}). Effective discharge area is estimated from emission profiles recorded by ICCD camera (Fig. 3). In our recent paper (Škoro et al. 2008), we have shown that effective discharge area is critical parameter for a proper determination of scaling parameter j/p^2.

Our measurements covered a wide range of discharge currents – from low-current (Townsend) to abnormal glow discharge. A gap that may be observed in the descending part of the VI characteristics corresponds to free oscillations interval. Comparison shows that agreement between the two sets of the results is reasonably good, considering that measurements are taken with different cathode materials and that the dimensions of those discharges differ by an order of magnitude. In the range of low currents, slope of the VI characteristics is notably smaller in micro discharge and the voltage is higher. On the other hand, in the range of the high currents, micro discharge voltage is somewhat higher than in the centimeter case. It is not clear whether those discrepancies are due to violation of scaling laws or due to different cathode materials. Further measurements in cm size discharges with stainless steel cathode will certainly clarify these results.

Selected radial emission profiles for micro-discharges are shown in Fig. 3. Emission profiles exhibit typical behavior for different regimes of nonequilibrium DC discharges. Profile of emission for the lowest current shown here is multiplied by 50 for better visibility of the graph. In this range of currents, emission profile is typical for Townsend regime of the discharge - the discharge is diffuse and the shape of the profile may be fitted by the Bessel function. Emission profile at $i = 407$ μA is significantly constricted and it gradually widens up with the increase of the discharge current, which is typical for a normal glow discharge. Finally, at the transition of the discharge to the abnormal glow mode, the discharge occupies the entire electrode diameter.

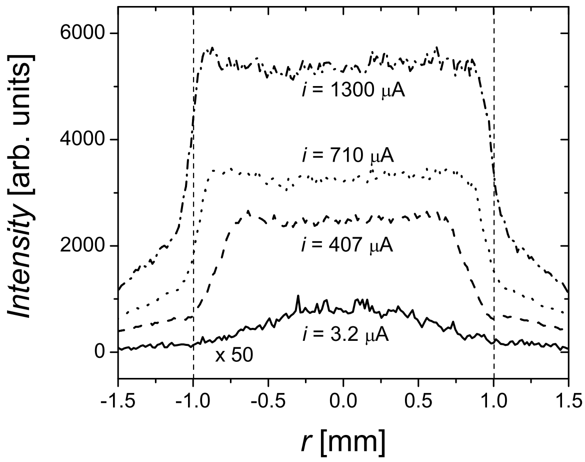

Figure 3: Radial emission profiles for micro discharge at: $i = 3.2$ μA ($j/p^2 = 0.56$ μA/cm^{2}Torr^2), $i = 407$ μA ($j/p^2 = 41.7$ μA/cm^{2}Torr^2), $i = 709$ μA ($j/p^2 = 58.3$ μA/cm^{2}Torr^2) and $i = 1300$ μA ($j/p^2 = 107$ μA/cm^{2}Torr^2).

4. SUMMARY

We have presented some of the results of measurements for sub-millimeter parallel plate DC micro discharges and compared them with the results from the cm size discharges for the same *pd*. These results are necessary for understanding of scaling laws in micro discharges. As the measurements are taken in very simple geometry and in a wide range of discharge currents, they also provide s basis for modelling.

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