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The influence of an external magnetic field on a "macro" hollow cathode discharge (MHCD) in argon

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The method with large "macro" hollow cathode geometry at low pressure is used to understand the discharge regime and I-V characteristics of micro hollow cathode discharges (MHCD) at high pressures. We can use this method to study the influence of an external magnetic field on a dc discharge with MHCD geometry. Thus, if a strong axial magnetic field is applied at the open end of a "macro" hollow cathode, the negative glow emission in the centre of the hole is accompanied by a secondary annular ring, probable the first standing striation of the positive column in this coaxial geometry. Also the I-V "macro" characteristics are changed at these low pressures in the presence of this magnetic field.

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1. Introduction

There is a growing interest in the development of micro-plasmas or micro-discharges for a range of applications [1]. For example, the so-called micro hollow cathode discharges (MHCD) are used as sources of vacuum ultraviolet (VUV). A common feature of micro-discharges is that they can be ignited and sustained at relatively high pressure, removing the need, in some cases, for vacuum chambers. High pressure operation is a natural consequence of the pressure-discharge gap scaling. However, a disadvantage of this operation is the highly collision environment, which precludes the diagnostics and some applications that may require high ion energy. The generation and operation of discharges at low pressures and low power density but with geometries similar to that of the micro discharges at high pressure and high power density can be very useful for understanding the physics of the micro discharges and their applications [2]-[4].

In "macro-cell" experiments firstly made by the group of L.C. Pitchford and J.P. Boef, it was the same MHCD geometry but with thicknesses of the hole diameter, electrode and dielectric of 1 cm at a pressure of few mbar [5]. As previously shown in MHCD at high pressure, the same structures of the I-V characteristics with two different sections separated by a voltage peak are obtained. Also the same end-on images of the light intensity emitted from the cathode hole section can be observed in the absence of any magnetic field.

Therefore, the purpose of our work is to investigate the influence of a strong axial magnetic field, applied end-on at the open end of the "macro" hollow cathode, in order to obtain there the same conditions like in a miniature cylindrical magnetron discharge [3].

Under these conditions also an annular positive plasma formation can be observed on the axial direction.

2. Experimental

The discharge geometry is the same as those used in contributions [5] and is sketched in Fig. 1. Here, the "macro" dimensions of the device are about 50 times larger than those of the MHCDs of Schoenbach's et al. and the operating pressures are 50 times lower. So, the hole diameter and the thicknesses of the dielectric insulator and hollow cathode are of 10 mm (instead of about 200 μm as in the "standard" MHCD at high pressure).

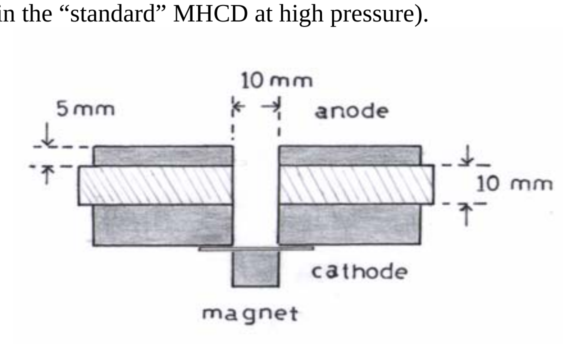


Fig.1. Schematic of the "macro" hollow cathode (not to scale for the permanent magnet).

The argon pressure is in the 1-10 mbar range, which corresponds to 50-500 mbar for a MHCD at high pressure. The hollow cathode and anode are made of aluminium and iron, respectively. The dielectric insulator is made of macor material.

A cylindrical permanent magnet can be attached at the open end of the hollow cathode. This is electrically isolated from the cathode by a thin mica foil. The radius and height of the permanent magnet with a polarization B_z of 1.31 T is 15 mm

The optical measurements are made by a CCD camera with neutral filters and the spectral analysis is performed by a miniature fibre optic spectrometer from the Ocean Optic type USB2000+2E2142.

3. Experimental results and discussion

The smallest possible distance between the front of the magnet and the cathode end of the discharge channel is given by the mica foil thickness of about 0.2 mm. Since the mica foil cover back the plane surface of the hollow cathode, it prevents the expansion of the negative glow to this surface at higher discharge currents. Therefore, in Fig. 2 it is shown that the current-voltage (I-V) characteristics are flat, in contrast to those into the open hollow cathode geometries.

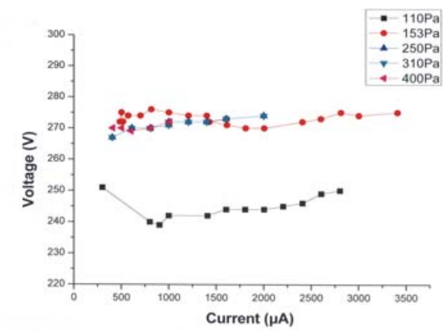


Fig. 2. Current-voltage characteristics of “macro” hollow cathode discharges for different argon pressures. The axial magnetic field strength is of about 1 T.

Under the conditions of relatively low argon pressures this behaviour may by related to something like a cylindrical magnetron effect. On the contrary, at a higher pressure of about 1000 Pa, the I-V characteristic has the shape shown in the top of Fig. 3.

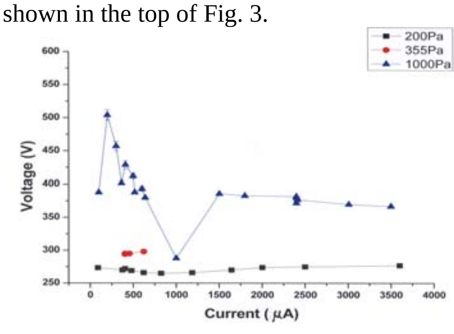
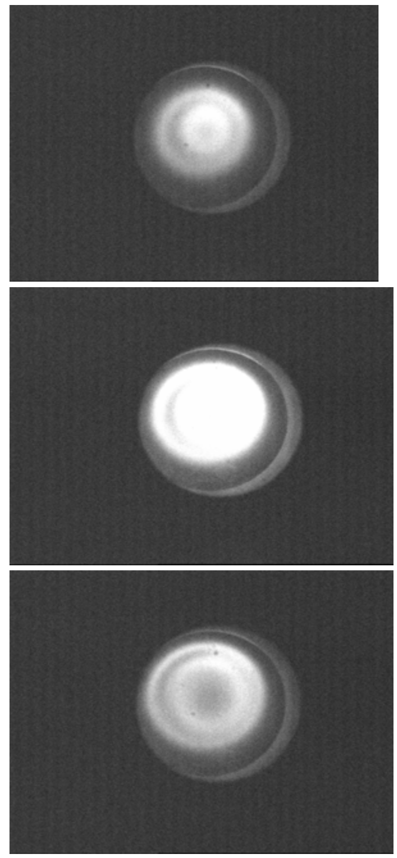


Fig. 3. The current-voltage characteristic with an S-type negative differential resistivity for a high argon pressure of 1000 Pa. The magneticfield strength is the same as in Fig. 2.

This exhibits an S-type negative differential resistively between a threshold voltage of 500 V and nearly the “normal” voltage of 300 V. A similar behaviour was observed for a double injection diode under the influence of a surface magnetic field [6].

The radial distribution of light intensity in the visible range from the hollow cathode in the presence of the axial magnetic field is shown in Fig. 4. These are recorded with the CCD camera through neutral filters from the hollow anode side at a pressure of 200 Pa and three increasing discharge currents.



I =224 µA

I = 475 µA

I = 828 µA

Fig. 4. Radial distribution of the light intensity recorded through the hollow anode. The pressure is 200 Pa and the increasing discharge currents are of 224, 475 and 828 µA, respectively. An axial magnetic field of approximately 1 T is applied at the open end of the “macro” hollow cathode. In the last image a strong neutral filter is used to see the same double structure as in the first two images (the second image is obtained without any filter).

The distribution of light emission inside the hole exhibits a double structure with two rings. The first one, nearer to the cathode, is associated with the usual negative glow in the hollow cathode. The relative intensity of these two rings increases while the thickness of the hollow cathode fall decreases with increasing discharge current.

The second smaller ring can to be related to the first standing striation of the positive column into this coaxial geometry, restricted to lower pressures and currents. Like in cylindrical positive columns, also this “precursor” becomes more striated under the influence of a magnetic field if this remains perpendicular to the electric field.

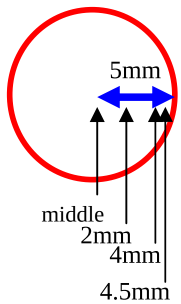


Fig. 5. Spatial resolution of optical measurements

To obtain new data about this positive plasma in comparison to the negative glow we proceed to some spectral measurements. Thus, as sketched in Fig. 5 a miniature fibre optic ended with a pinhole can be moved radial over the open cross section. Unfortunately, due to the low spatial and spectral resolution, we are restricting ourselves to the light intensity spectra shown in Fig. 6 and 8, which corresponds to the conditions for the last images from Fig. 4 and 7, respectively.

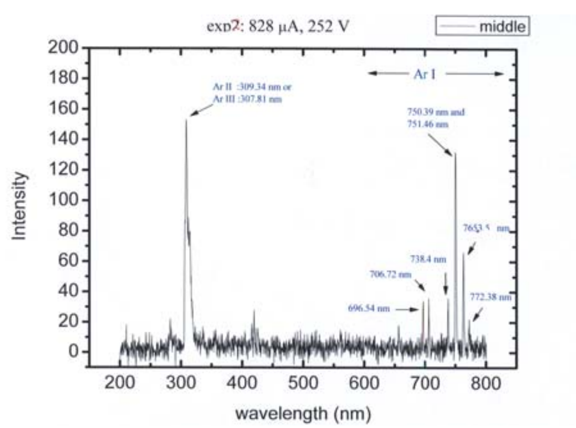
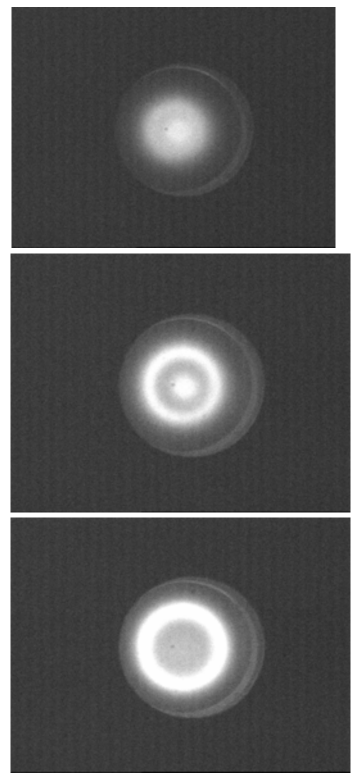


Fig. 6. Spectrum of the light intensity measured end-on for the conditions corresponding to the last image from Fig. 4.

As indicated in the spectrum of Fig. 6, the first double spectral line at 300 nm only hardly can be attributed to Ar II and Ar III. On the contrary, the second group of spectral lines with wave lengths between 700 and 770 nm definitely belong to Ar I.

Fig. 7 shows the radial intensity distributions inside the hole for exactly the same discharge currents and pressure as in Fig. 4 without any axial magnetic field. In principle, these are the same as previously reported in papers [5]. But, due to the closed cathode cross section with the thin mica sheet, in the absence of any external expansion of the negative glow over this cathode surface.

Therefore, into the first two images we observe the maximum of light emission within the "middle" of the cathode hole. As already shown in [5] these are nothing else as a certain "precursor" of a small positive column. As shown in Figs 4 and 7, the light intensities of these axial plasmas are increasing with the discharge current.



I = 223 µA

I = 475 µA

I = 829 µA

Fig. 7. The same light distribution as in Fig. 4 but in the absence of the axial magnetic field. The argon pressure and discharge currents are the same as in Fig. 4.

If we now consider the light intensity spectrum of argon, which now corresponds to the last image from Fig. 7, we see a small inversion of the relative intensities between the two groups of spectral lines. This is shown in Fig. 8, if we compare with the spectrum of Fig. 6. Now, we can see a certain colour difference between the light emission of the negative glow and that of the positive column "precursor", even with the naked eye.

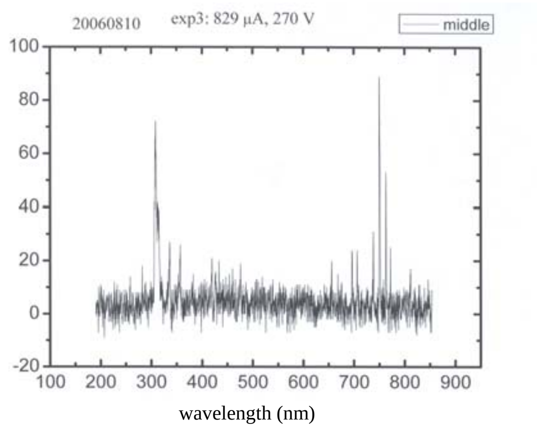


Fig. 8. Spectrum of the light intensity measured end-on for the conditions corresponding to the last image from Fig. 7.

4. Conclusions

The present contribution is a first attempt to clarify the changes of the discharge regimes and I-V characteristics for “macro” hollow cathode geometries, similar to those used by Schoenbach’s group, when an axial magnetic field is applied at the open end of the hollow cathode.

The obtained results show that in argon a certain “precursor” of the positive column becomes a coaxial standing striation in the presence of this magnetic field. Obviously, more systematic measurements are needed to prove that this positive plasma indeed is the first standing striation of the positive column in this coaxial geometry.

This behaviour is very similar with the standing stratification of a usual cylindrical positive column under the influence of a static transversal magnetic field. Thus, *“a transverse magnetic field has the tendency to cause striations to form, or to increase the number present in an already striated column”* [7].

A strong negative differential resistivity also proves the influence of this magnetic field on the I-V characteristic but only at the higher argon pressures. This may be related to a miniaturized cylindrical magnetron effect.

Acknowledgement

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