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On the Cathode Sheath in Microhollow Cathode Discharges

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Abstract

An experimental study has been made on the potential fall of cathode sheaths in microhollow cathode discharges (MHCD) with open planar geometries and closed cathode cavities. The corresponding hole diameters D and electrode gaps D_{AC} were between 0.1 and 0.8 mm. Therefore, we have investigated the static current-voltage (I-V) characteristics of the MHCD for discharge currents up to 15 mA and argon pressures up to 900 mbar. For the planar geometry, a scaling law of the microhollow cathode effect was found as function of the reduced pressure pD. On the contrary, for the closed cathode geometry a solely positive slope over the entire I-V characteristics is obtained. This result can be very important for the parallel operation of identical MHCD without ballast resistors.

We have also shown that in the whole existence domain of the self-sustained MHCD, a strong low-frequency instability occurs for both the microhollow cathode geometries. This can be explained by a non-stationary extending of the negative regions of the MHCD from the inside of the cathode hole to the larger plane area on the outside of the same microhollow cathode.

Keywords:

microhollow cathode discharge, static I-V characteristic, scaling law, cathode geometry, low-frequency instability

1. Introduction

Among the new systems for plasma production the microhollow cathode discharges (MHCD) present particular interest as efficient source of UV and excimer radiation and as source of charged particles or as reactive plasmas [1-6]. Since the cathode diameters D and electrode gaps D_{AC} of the MHCD devices are of a few 0.1 mm, the discharges can be operate at much higher gas pressures. Due to its easy manufacture a planar geometry is chosen for the MHCD. So, the variable parameters are hole diameter D and electrode gap D_{AC}. Ranging from 0.1 mm to 0.8 mm. Unfortunately, there is the microhollow cathode surface, which also includes the plane area on the cathode plate adjacent to it. Thus, the conditions under which the reduced pressure pD can be used, as a similarity parameter for the cathode sheath is not very clear. Since the discharge voltage is close related to the cathode fall [7,8], we investigate the I-V characteristics of the self-sustained MHCD with different cathode geometries [9,10].

In this contribution we prove that hollow cathode effect, indicated by a maximum on I-V characteristics at lower discharge currents obeys certain scaling law. Then, it was shown that for a microhollow cathode cavity with a twice-larger diameter D* than of the constricted entrance aperture, a large positive slope over their entire I-V characteristic appears at the lower pressures [10]. However, a generally occurring low-frequency instability can be observed in both these MHCD [11]. These self-oscillations can be explained by

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the non-stationary expanding of the negative parts of the MHCD from the inside of the cathode hole to a broad outside area on the same open microhollow cathode [12] or closed cathode cavity.

2. Experimental Set-up

The measurements were made with the experimental set-up and the planar cathode geometry used by Schoenbach [2]. A different microhollow cathode cavity, firstly proposed in the abstract [10], is sketched in Fig. 1. Since the anode geometry is of minor importance for the discharge physics of the MHCD [2] we have also used plane anodes. The macroscopic I-V characteristics of the MHCD with both the cathode geometries were measured digitally in order to averaging the low-frequency instabilities [11]. Optically, the MHCD were investigated end-on by a sensitive photo multiplier placed at the outside of a large window of the MHCD device or alternatively, through a microscope followed by an ICCD camera. The temporal development of the electrical and optical properties of the MHCD were monitored on a digital storage Tek-scope.

3. Experimental Results and Discussions

Some typical static current-voltage (I-V) characteristics of the MHCD with planar geometry are shown in Fig. 2 as function of the reduced discharge current I/D with the reduced pressure pD as parameter. The I-V characteristics are obtained for three different hole diameters D but the same reduced argon pressures pD as known, this reduced discharge current act a similarity parameter only in the so-called Allis-White similarity law [7,8]. But, the static I-V characteristics show a similar behaviour only near a certain value of the reduced currents. Hollow cathode effect appears at critical value of reduced current which was labeled as $(I/D)_c$. The $(I/D)_c$ can be scaled against reduced pressure like $(I/D)_c \sim F(pD)$.

As shown in Fig. 3 for two different anode-cathode gaps D_{AC}, the parameter Ip cannot be the second similarity parameter for the discharge current as knows from the Allis-White law. However, if the current density is "normalized" with respect to the gas pressure as j/p^2 and we can write $j \sim I/D^2$, then the critical values $(I/p^2)_c$ can be an other scaling parameter for the microhollow cathode effect but for different gas pressures. Otherwise, these I/p^2 values are difficult to estimate because the active area of the microhollow cathodes changes with the discharge current, i.e. the negative parts of MHCD do not cover only the inside area of the cathode hole.

If we complete outside the planar microhollow cathode with a closed cylindrical cavity having diameter

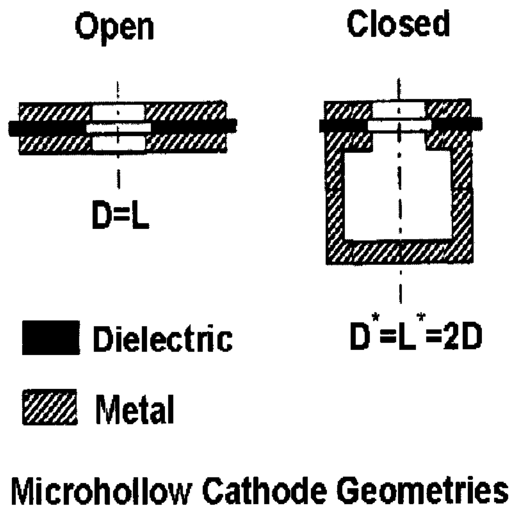

Fig. 1 The sketch of the open planar and closed larger microhollow cathode geometries. The dielectric material was mica and the electrodes were made of molybdenum and nickel.

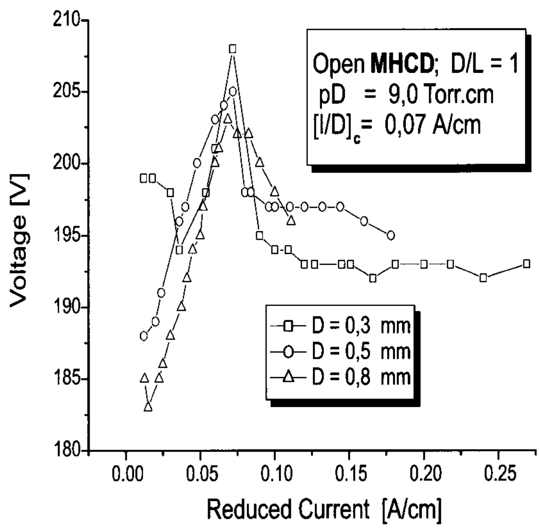

Fig. 2 Static current-voltage characteristics versus the reduced discharge current *I/D* in a planar open MHCD. The parameter is the same reduced pressure pD for three different cathode diameters of D = 0,3 mm, 0,5 mm and 0,8 mm, respectively. The weak microhollow cathode effect appears at the same value of the reduced current of about $(I/D)_c$ = 0,07 A/cm.

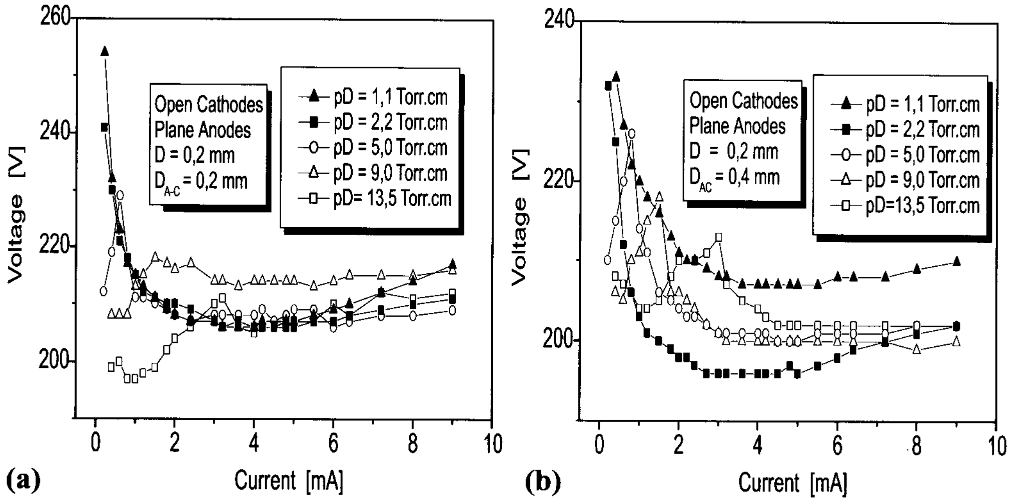

Fig. 3 The static I-V characteristics of planar MHCD for the anode-cathode distances of: a) D_{AC}=0,2 mm and b) D_{AC} = 0,4 mm. The parameters are the same reduced pressures pD.

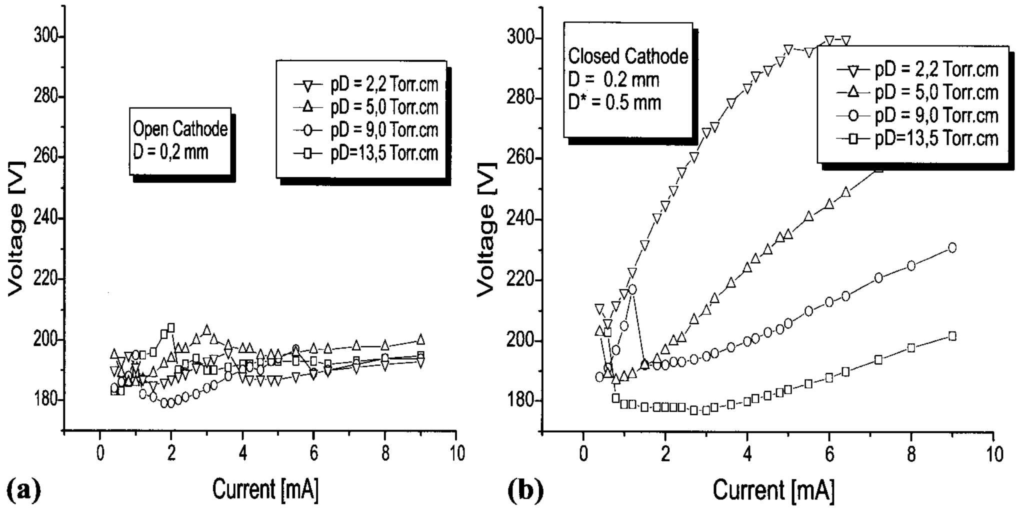

Fig. 4 The comparison between the static I-V characteristics of MHCD with: a) planar open cathode and b) closed larger cathode cavity. The parameter is the reduced pressure pD.

D^* and depth L^* about twice of an entrance aperture (see also Fig. 1), we can obtain a closed cathode cavity somewhat similar with the elliptical hollow cathodes used by White [1]. Now, if the comparison is made between the I-V characteristics of MHCD with closed cathodes and the open ones, we obtain the data shown in Fig. 4. A large positive conductance of up to 10 V/mA is obtained for static I-V characteristics of the MHCD with closed cathodes.

Recently [11], we have shown that strong non-linear self-oscillations of the discharge voltage and current (and of the end-on emitted light intensity) of the MHCD occurs, practically into the whole parameter range available for their dc self-sustaining. The ac voltage and currents (and of the integral light intensities) are of about 3 % and 10 % from their dc values. But, for a hole diameter of D = 90μm and small discharge current of $I_{DC} \approx 1.5$ mA, this ac modulation might increase up to 20 % and 100 % and discharge current appears as current spikes. Thus, in Fig. 5 we indicate by error bars on the corresponding static I-V characteristics, the usually measured ac currents and estimated ac voltage. Here, the parameters were the argon pressure and the microhollow cathode geometry, respectively. It is seen that, in spite of the large positive conductance of the static I-V characteristics for the MHCD with closed

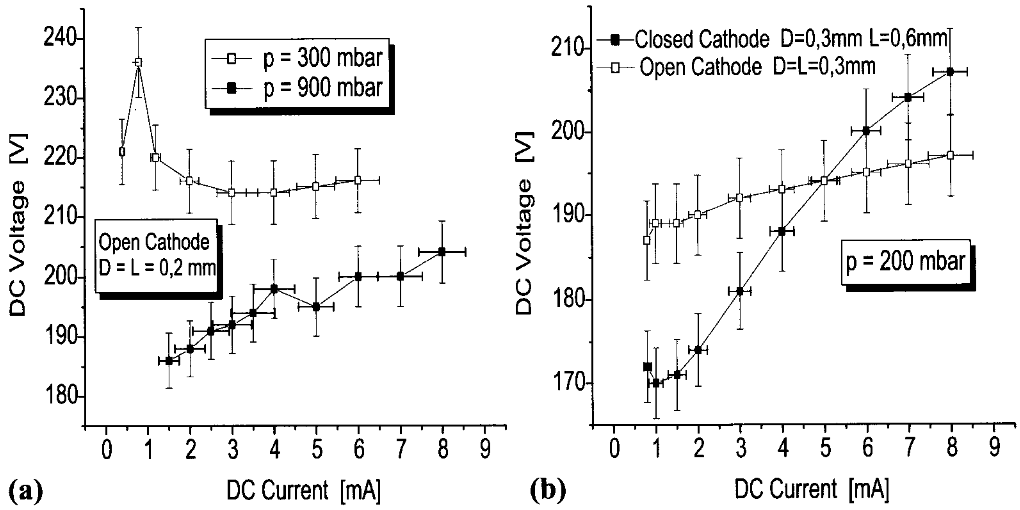

Fig. 5 The values of ac currents (measured) and voltages (estimated) for the self-oscillatory regime of MHCD, indicated as error bars on the corresponding static I-V characteristics (solid curves). Parameters are the: a) argon pressure and b) cathode geometry.

cathodes, the ac currents and voltages remain almost the same as those measured for the open geometry.

It was proved experimentally that this oscillation phenomena can be explained, at least for the open geometry, by the non-stationary expanding of all the negative regions of the micro discharge in a planar MHCD from the inside of the cathode hole to a broad outside area on the same cathode [12]. Obviously, the same explanation must be applicable for the MHCD with closed cathode.

4. Conclusions

A weak microhollow cathode effect in the planar microhollow cathode is the alone discharge phenomenon which has proved that indeed a certain scaling law apply to the planar MHCD.

If the planar open geometry are "closed" outside by larger micro cathode cavities, then the flat "normal" I-V characteristics of open MHCD changes into "abnormal" ones at the lower pressures.

The strong non-linear self-oscillations, which occur practically into the whole existance domain of the self-sustained MHCD, must be also considered in any further investigations.

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