

Some new properties of the micro hollow cathode discharges (MHCD) in xenon

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Some properties of the micro hollow cathode discharges (MHCD) in xenon are related to their actual geometry. It is shown that for the "standard" geometry, the VUV intensity strongly depends on the electrode side from which this emission is measured. The VUV intensity from the cathode side is by order of magnitudes larger than from the anode side, keeping the other discharge parameters constant. Also from the cathode side an afterglow phenomenon of the VUV emission can be measured by superposing a high voltage pulse. All these phenomena could be correlated with the negative glow which spreads out on the external cathode surface. Finally, at small dc currents, some regular structures of cathode spots into the cathode hole can be observed.

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1. Introduction

Several topical reviews have been appeared in the last time emphasizing the scientific interest and important applications of the micro hollow cathode discharges (MHCD's) [1]. More exactly, this term is applicable only to dc or pulsed driven devices operating under micro hollow cathode discharge conditions. They were investigated initially by the groups of Schoenbach and Eden. In the last time these have been explored to describe a variety of micro plasma devices operating under a wide range of parameters. This geometry also included some capillary tubes as an elongated micro hollow cathode [2].

In a previous contribution [3], we have shown that at lower pressures, the VUV intensity measured from the anode side was by two orders of magnitude smaller than those from the cathode, all the other discharge parameters being kept constant. Also the shapes of the VUV spectra were different from the two electrode sides. But, at a constant discharge current, the VUV intensity from the anode exponentially increased with the xenon pressure, nearly independent of the cathode geometry. This could be explained by the higher temperature of the neutral gas and thus their lower density into the hole when the gas pressure is increasing.

Then, for the pulsed operation we have observed that if the pulse length is enough short, something like a VUV afterglow phenomenon could be measured for the excimer radiation in xenon [4].

In conclusion, all these phenomena could be related to the occurrence of a second negative glow connected to the outer surface of the micro cathode. This negative glow might have different properties than those into the hole.

2. Experimental

The MHCD devices were manufactured from polished molybdenum foils of 250 μm in thickness, separated by a 250 μm thick alumina or mica sheet as an insulator. A hole with a diameter between 200 μm and 600 μm was drilled through this sandwich structure. In order to measure the VUV intensity on both electrode sides, the polarity of voltage could be changed. In Fig. 1 is shown a sketch of the 50 Ω self-matched transmission line pulse generator using a PFN line type. The pulse duration depends on the 50 Ω cable length (with 5 ns/m) and the rise time depend on the switch S. Pulse reflection is minimized by the matching resistor of $Z_0 = 50 \Omega$. Thus, pulse durations below 20 ns and rise times as low as 3 ns can be obtained with this system.

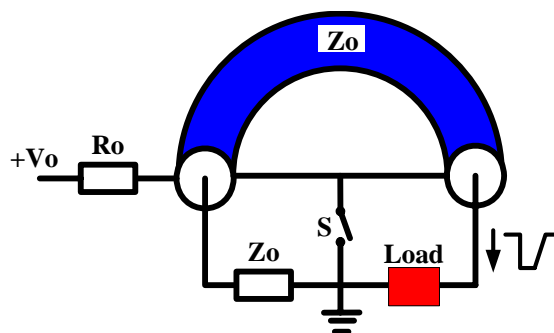


Fig. 1. Sketch of the voltage pulse generator

The set-up arrangement for recording the VUV emission is the same as used previous in papers [3] and [4].

Especially, using a magnesium fluoride (MgF_2) lens, the VUV emission is collected either from the anode or cathode side and is focused on the entrance slit of the VUV monochromator (Acton Research VM 505, 1200 G/mm grating, blazed at 190 nm). The VUV detector is a CCD camera or a fast photo multiplier.

3. Results and discussion

3.1 DC mode

Fig. 2 shows the VUV excimer intensities measured from the anode and cathode sides, respectively, as functions of the discharge current and with the pressure of 800 mbar and the hole diameter of 200 μm as parameters. It is shown that the VUV intensity from the cathode side exponentially increase with the discharge current, whereas that from the anode side slowly decreases.

In the same figure are shown the I-V characteristic (for the same MHCD conditions) with the two branches corresponding to the “abnormal” and “normal” behavior of the whole MHCD device. The arrow at the voltage maximum, which separates these two branches, indicates the onset of the negative glow onto the external cathode surface.

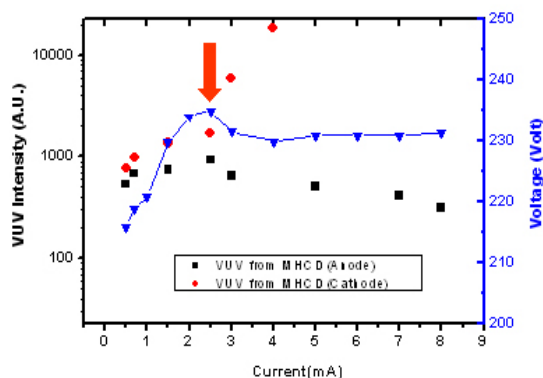


Fig. 2. The VUV intensities measured from the anode and cathode sides, both as functions of dc current values. The I-V characteristic at the same xenon pressure of 800 mbar and 200 μm hole diameter is shown by the solid curve.

Fig. 3 shows that for the current of 3 mA, the “normal” operating voltages are shifted by about 100 V to lower values if the reduced pressures pD are increasing above a value between 10-12 mbar $\cdot\text{cm}$. Actually, the whole I-V curve is shifted by 100 V at this higher pressure, almost independent of the hole diameter. This can be explained by the constriction of the micro hollow cathode sheath and their corresponding negative glow at the higher pressure.

Fig. 4 shows in the visible range the end-on images of some regular structures of cathode spots which appear at discharge currents below 0.3 mA (see also Fig. 5). These

are similar to the cathode spots reported by Schoenbach [5] at low currents self-organized in the cathode layers of plane micro cathodes. It can be seen in the same Fig 4, the transition towards usual hollow cathode structures (in the middle) and the onset of the negative glow on the plane external surface (bottom).

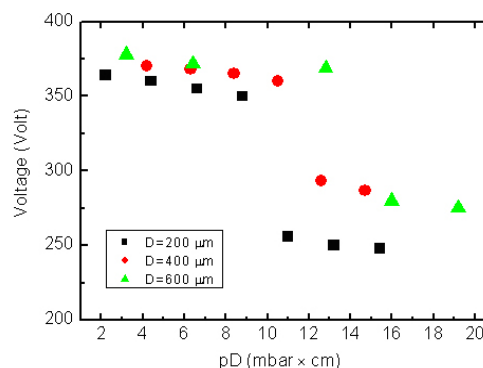


Fig. 3. Abrupt decrease of the “normal” voltage and of the whole I-V characteristics to a lower voltages with about 100 V at a reduced pressure above 10 to 12 mbar $\cdot\text{cm}$. The discharge current was 3 mA..

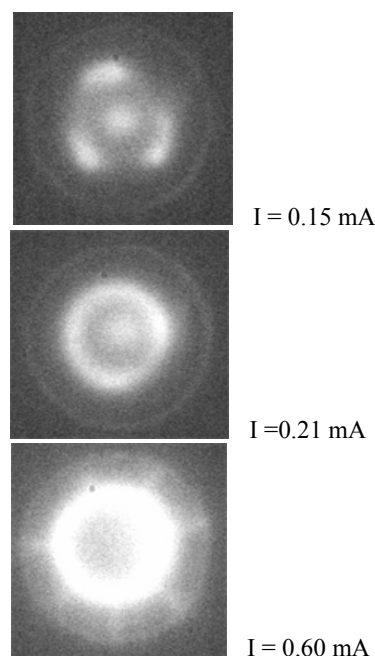


Fig. 4. End-on images of regular structures in hollow cathode boundary layers at a discharge current of 0.15 mA (in the top), an usual hollow cathode boundary layer at 0.21 mA (middle) and the onset of the negative glow at the outside of the cathode surface for 0.60 mA (bottom). The central spot in the first two images can be an anode spot or a micro positive column head. The xenon pressure is 300 mbar and the hole diameter was 200 μm .

Thus, it can be shown that the appearance of such self-organized cathode spots structures is a general and reproducible phenomenon also for the micro hollow cathode geometry not only for the plane ones, as already shown in paper [5]. As shown in Fig. 5, this is also restricted to smaller discharge currents.

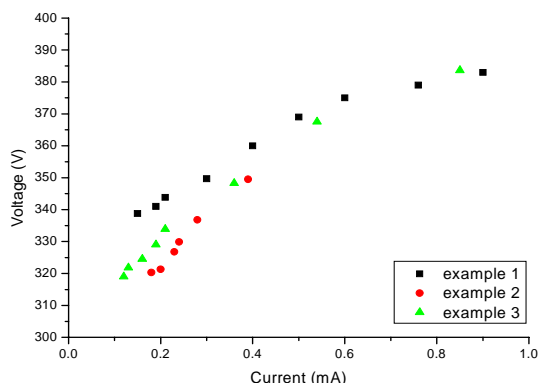


Fig. 5. The existence domain and reproducibility of current-voltage values for the appearance of cathode structures into a micro hollow cathode at discharge currents smaller than 0.3 mA. The hole diameter was 200 μm and the xenon pressure 300 mbar.

3.2. DC with pulsed mode

As shown in Fig. 6 only with both these superpose modes we could obtain an increase of the VUV intensity and radiation efficiency with increasing xenon pressure.

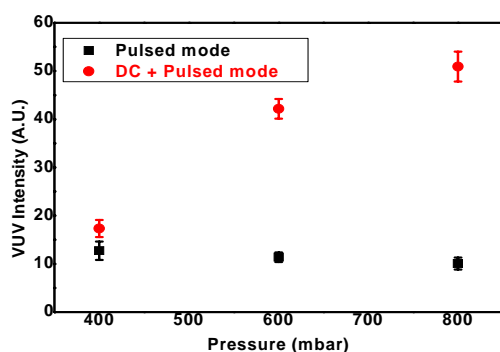


Fig. 6. VUV intensity as functions on the xenon pressure for the pulse mode (only) and for both superposed DC and pulsed modes, respectively.

For the same MHCD geometry, the temporal behaviour of the micro discharge voltage, current and of the VUV intensity is shown in Fig. 7. These are obtained by the superposing a high voltage pulse of 20 ns duration and peak value of 1.5 kV onto the continuous direct current (DC) mode (at 3 mA and 250 V). The hole diameter is 200 μm .

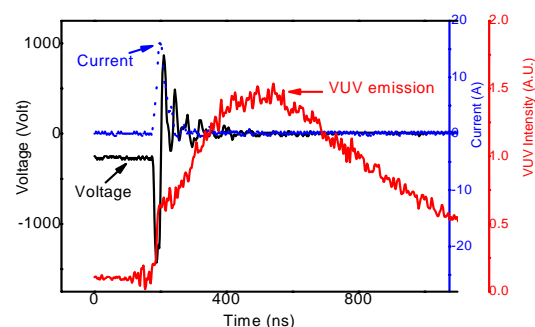


Fig. 7. Temporal development of current, voltage and VUV intensity for pulsed MHCD in xenon at a pressure of 800 mbar. The voltage peak has a value of 1.5 kV with a duration of 20 ns. The hole diameter is 200 μm .

There is an oscillating drop of the voltage after the pulse and the following recovery towards the dc sustaining voltage can not be shown in the figure. A high current peak of 15 A indicates a sudden and large increase of the electron density caused by the pulse electric field. As soon as the current pulse appears, the VUV intensity starts increasing abruptly and then it is following by the slow increase of the VUV intensity with duration of hundreds of nanoseconds.

Two peaks in the VUV intensity are observed. First peak is mostly related to the xenon excimer emission in the hollow cathode hole, while the second one, which represents the afterglow, is mostly contributed by excimer emission from the plasma on the cathode surface. As shown in Fig. 8 the delay of the VUV afterglow maximum (the second peak) against the voltage peak is monotonically reduced about five times with the increasing of the xenon pressure from 200 to 800 mbar. The FWHM of the VUV intensity also decrease as pressure increases.

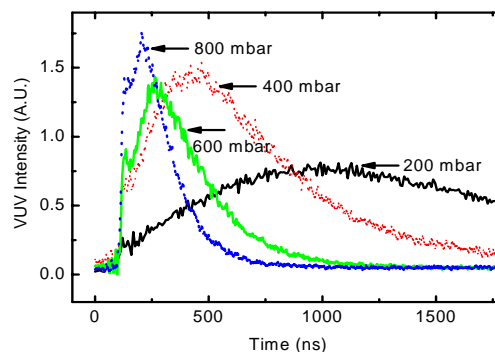


Fig. 8. Afterglow of VUV intensities from the cathode side as function on the xenon pressure for the same conditions as in Fig. 7.

It was shown that for short pulses the VUV efficiency increases with the pulse duration and xenon pressure.

On the contrary, for relatively longer pulse duration, the VUV efficiency decreases with the pulse duration as

shown in Fig. 9. This result was already reported in paper [4].

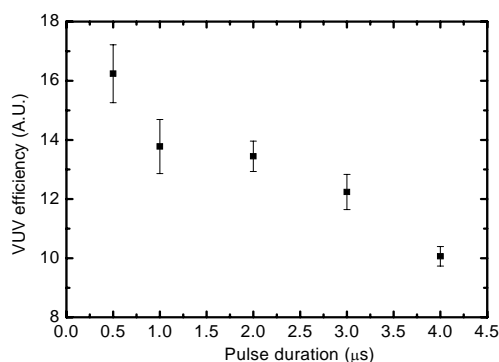


Fig. 9. Dependence of the VUV efficiency on the pulse duration for longer pulses. The gas pressure is 800 mbar and the DC energy input is the same as previous, i.e. of 250 V times 3 mA.

Taking into account the time functions of the VUV intensity for different pulse durations as shown in Fig. 10, the explanation of this behaviour can be given as follows:

1. The first short and large peak of the VUV intensity results from Xe^* produced by the electron impact excitation;

2. The second longer (of 0.7 μs) but much lower peak and the following are caused by Xe^* formed by the recombination process (step down) from Xe^+ .

Thus, the radiation powers corresponding to the two fundamental processes are quite different. The first one is almost independent on the voltage pulse duration whilst the second one, strongly depends on the voltage pulse duration.

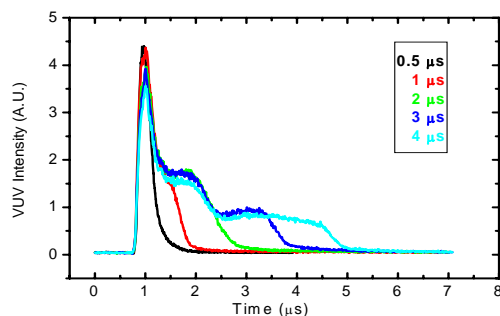


Fig. 10. Temporal development of VUV intensity for different longer pulse duration. The discharge conditions are the same as in Fig. 10.

4. Conclusions

The VUV excimer emission has been investigated in the dc and pulse micro hollow cathode discharges, operated at high-pressure xenon in the range from 200 to 800 mbar. It was found that in the dc operation the VUV emission intensity is high only when it is measured from the cathode side where it increased exponentially with the discharge current.

An abrupt translation of the whole I-V characteristic by about 100 V to lower voltages was found above a higher reduced xenon pressures, nearly independent of the D value (D being the internal hole diameter). At very small dc currents a regular structure of cathode spots could be observed into the cathode hole, very similar to that previously reported for plane cathode layers.

For the superposed mode a true afterglow phenomenon was found but again only for the VUV emission from the cathode side. This phenomenon strongly depends on the xenon pressure.

Acknowledgements

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