EXCIMER EMISSION OF OPEN AND CLOSED MICROHOLLOW CATHODE DISCHARGES IN XENON*

L.-D. BIBOROSCH[1], I. PETZENHAUSER[2], BYUNG-JOON LEE[2], K. FRANK[2], K. H. SCHOENBACH[3]

[1] Al. I. Cuza-University, Dept. of Plasma Physics, R-700506 Iasi, Romania
(e-mail: biboros@uaic.ro)
[2] F.A.-University of Erlangen-Nuremberg, Physics Dept. I, D-91058 Erlangen, Germany
[3] Old Dominion University, Phys. Electron. Res. Inst., Norfolk, VA 23529, USA

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In the open and closed geometry of microhollow cathode discharges the excimer emission recorded end-on from the anode side is at least by two order of magnitudes lower than from the cathode side and also the shapes of the excimer spectra are different. But, for a constant dc current, the excimer emission from the anode side strongly increases with the xenon pressure, independent on the micro cathode geometry. The phenomena are explained by density changes due to the different gas heating inside and outside the micro cathode hole.

Key words: Low temperature plasma excimer radiation, plane and microhollow cathode discharges.

1. INTRODUCTION

The excimer emission from high-pressure discharges in rare gases and rare gas halides, as for example, the dielectric barrier discharges (DBD) are widely used as efficient non-coherent radiation sources in the vacuum ultraviolet (VUV) range [1]. The so-called microhollow cathode discharges (MHCD), first investigated by White [2] and rediscovered later by Schoenbach [3], have been received a special attention as a promising new excimer radiation source [4–9]. The main advantage in comparison with the DBD is the low operation voltage, *i.e.* the cathode fall potential, and the simple device geometry. This allows the fabrication of arrays [10–15] or serial multistage devices [16, 17].

Unfortunately, in the simplified open microhollow geometry proposed by Schoenbach, the negative glows of the MHCD can expand outside the cathode hole and connect to the plane surface of the same microhollow cathode. Under these conditions, the inner surface hole and the external plane areas act as two parallel-connected microcathodes [11]. It was experimentally proved that this

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plane part of the microhollow cathode essentially contributes to the excimer emission [18]. Several applications of MHCD like VUV sources for plasma diagnostics [7] or the back lighting of flat panel LCDs need intense and confined radiation from closed MHCD, even with plane micro cathodes [10]. For example, the MHCD devices firstly manufactured by Eden [6, 10, 12–14, 17, 19] with technologies from the microelectronics have all closed geometry, so that the VUV radiation can be used only through a hollow anode. These devices works well stable, their current-voltage (I–V) characteristics having a consistent positive slope so that parallel or series operation of several MHCD without or with a single ballast resistor becomes possible [11, 20, 21].

Up to now, only little data are available for the excimer emission from the anode side of the closed or open MHCD [16]. Therefore, the purpose of this paper was to investigate the excimer emission radiated end-on from the anode side comparatively with those from the cathode side of MHCD, as functions of the discharge current, xenon pressure and the micro cathode geometry.

2. EXPERIMENTAL DETAILS

The MHCD devices consist of polished 0.2 mm thick molybdenum electrodes, which are separated by a 0.25 mm thick alumina or mica as insulator. The cylindrical discharge channel with a diameter of 0.1 or 0.2 mm, acting as the discharge gap, was drilled by laser ablation through the electrodes and insulator sheets. The different open and closed micro cathode geometry are sketched in Fig. 1; the arrows denominated "anode side" indicate the end-on measurements for the different micro cathode geometry.

To obtain the data denominated as "cathode side", we simply invert the electrode biasing so that the microhollow electrodes from the top of Fig. 1 acts now as open microhollow cathodes with different anode geometry. Because the anode geometry is of minor importance for the plasma physics of the MHCD, the data obtained from the cathode side of these microhollow cathodes were used for comparison with those registered through the anode side of the MHCD devices.

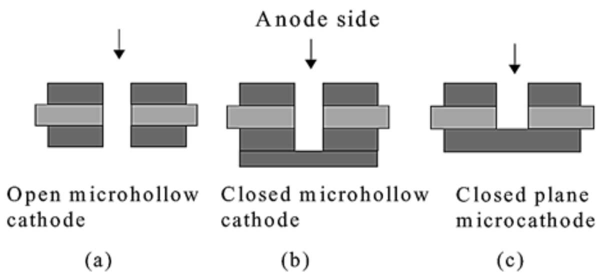

Fig. 1. – Geometry of (a) open, (b) closed microhollow cathode and (c) of the plane micro cathode. The arrows indicate the anode side.

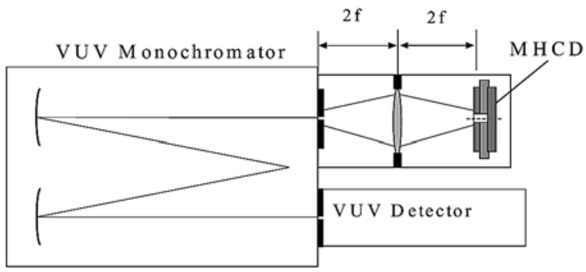

Fig. 2. – Scheme of the spectroscopic system for the VUV measurements of the excimer emission of MHCD with open and closed microhollow geometry.

The experimental arrangement for recording the excimer emission of xenon is schematically shown in Fig. 2.

The MgF_2 convex lens with a diameter of 34 mm and focal length of 114.3 mm at 193 nm, separate the high-pressure MHCD chamber from the VUV monochromator with a focal length of 0.5 m. The same lens also images the whole micro discharge on the entrance slit of the VUV monochromator. Thus, the broadband VUV spectra of the excimer emission of xenon can be monitored in the spectral range from 150 to 190 nm with an optical grating of 1200 lines/mm blazed at 150 nm. The spectra are calibrated with an accuracy of 0.5 nm using the O I resonance lines around 130.5 nm, obtained from a MHCD in argon with small traces (< 1%) of oxygen [22]. Both the MHCD and lens chambers are mounted separately on movable stages in order to focus the micro discharge image at the entrance slit of the VUV monochromator. Both the chambers between the lens and the entrance slit of the monochromator and the VUV monochromator are evacuated separately at a pressure below 10^{-5} mbar. Xenon gas of 4.0 purity was used into the MHCD chamber without a gas flux at high-pressure, monitored by a capacitance manometer. A VUV sensitive CCD detected the diffracted light from the monochromator, allowing the investigation of the entire VUV spectrum between the specified wavelengths. The reabsorption of the excimer radiation into the xenon gas on the distance between MHCD and the MgF_2 lens can be neglected. Personal computers operate the VUV monochromator and the CCD camera.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. OPEN MICROHOLLOW CATHODE

Some typical excimer spectra of the xenon gas measured from both the anode and cathode sides of the open microhollow cathode geometry sketched in Fig. 1(a), are shown in Fig. 3.

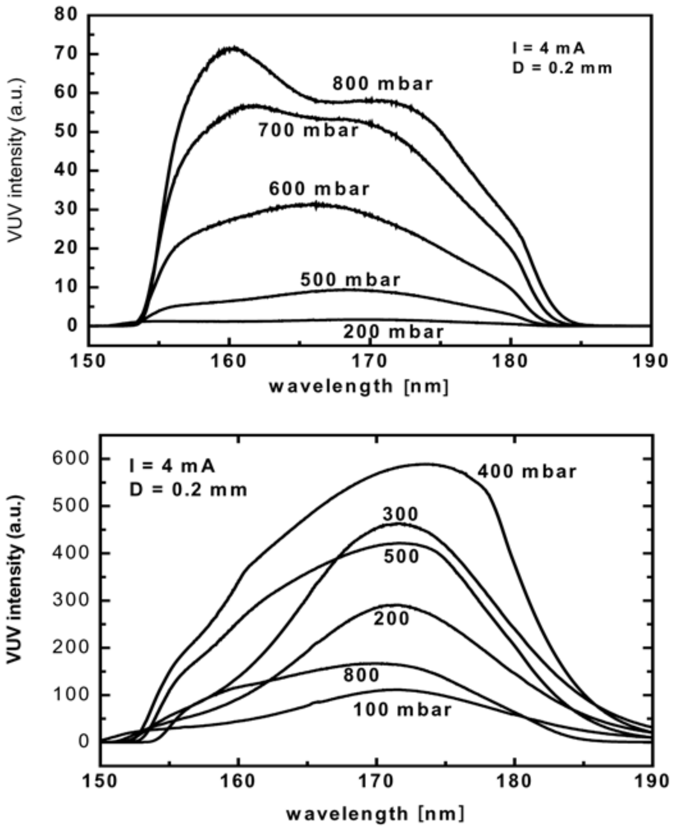

Fig. 3. – Spectral diagrams in the whole spectral range (λ = = 150–190 nm) registered from the anode side (top) and cathode side (bottom) for the open microhollow cathode seen in Fig. 1(a). The xenon pressure is the parameter. The discharge current was 4 mA and the hole diameter of 0.2 mm.

The xenon pressure was the parameter at a constant discharge current of 4 mA. The statistical dispersion in the VUV intensity of the registered spectra remains below 20 %, so that the reproducibility was considered satisfactory. First, in Fig. 3 it is seen that the VUV intensity measured from the anode side is much lower than from the cathode side. Then, the two large mean peaks at the wavelength around 160 nm and 173 nm, which approximately corresponds to the first and second continuum of the excimer spectra in xenon, can be identified. Obviously, there is also a certain overlapping between the neighboring first and second continuum of the excimer spectra, which is not resolved by the VUV monochromator. For the anode side, the first continuum from Fig. 3 (top) clearly increases with the xenon pressure. This xenon pressure was obtained by remote measurements outside from the MHCD chamber. Then, for the open microhollow cathode side only the second continuum can be followed in Fig. 3 (bottom). This shows a maximum of the VUV intensity at pressures between 400–500 mbar for static gas conditions [8]. In flowing gases the same VUV intensity measured from the microhollow cathode side monotonically increases with xenon pressure.

Nevertheless, such two different excimer spectra of xenon were previously reported by several authors [4, 5] but as function of the remote gas pressure measurements into the vacuum system. It was shown, for example, that with increasing xenon pressure, the spectra shape changes from those where the first continuum are comparable or even higher than the second one (below 200 mbar), while for higher pressures (up to 700 mbar) only the second continuum can be seen in the spectra. This transition from the first to the second continuum in the excimer spectra and the overall intensity increase with the gas pressure are nearly similar with these shown in Fig. 3, but here these are for the two opposite electrode sides.

Apparently, the spectra from Fig. 3 are obtained for the same gas pressure inside and outside the micro cathode hole. Now, it must be noted that during the dc operation of MHCD, the neutral gas temperature inside the discharge hole exceeds 1500 K, whereas outside the hole the same remains almost at the room temperature [23]. Therefore, if we measure the excimer radiation emission from the anode side, this is obtained under different conditions than those from outside the microhollow cathode hole, *i.e.* at much higher gas temperatures and lower gas density. This could be the possible explanation of the changes in the integral VUV intensity and the shape of the excimer spectra of xenon measured from the anode side.

In Fig. 4 are shown the integral VUV intensities (full points) and the corresponding discharge voltages (open points) as functions of the discharge

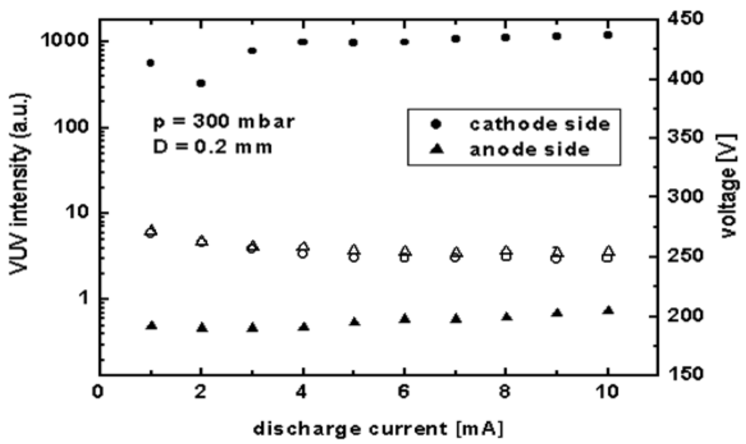

Fig. 4. – Integral VUV intensities (full points) corresponding to the spectral range between $\lambda = 150–190$ nm and discharge voltages (open points) registered from the anode side (triangles) and the hollow cathode side (circles) of the open microhollow geometry sketched in Fig. 1 (a) as functions of the discharge current. The xenon pressure was 300 mbar.

current at a xenon pressure of 300 mbar, for the two opposite electrode biasing of the open MHCD geometry sketched in Fig. 1(a). As expected, the I–V characteristics and thus the electrical power input for both the two biasing of the symmetrical hollow electrodes is the same. On the other hand, the values of the VUV intensity registered from the anode side (full triangles) are by three order of magnitudes lower than those measured from the cathode side (full circles), nearly independent on the dc current.

More exactly, a small linear increase of the integral VUV intensities for both the electrode sides can be followed into a linear representation against the discharge current [4–6]. Also the two different shapes of the excimer spectra, illustrated in Fig. 3 for the two electrode biasing, are almost independent on the discharge current. Because of the different VUV intensities from the two electrode sides, the time exposure of the VUV detector at the anode side must be chosen much larger than for the cathode side. Thus, the data shown in Fig. 4 and in the followings are corrected in order to can compare directly the VUV intensities of anode and cathode sides, respectively. Also the relative VUV efficiency for both electrode biasing are nearly the same since the MHCD voltage only slightly decrease with the dc current.

In Fig. 5 are shown, for the same MHCD geometry, the dependence of the integral VUV intensity and discharge voltages on the xenon pressure at a discharge current of 4 mA. It is seen that, with increasing xenon pressure up to 800 mbar, the differences between the VUV intensities measured from the two opposite electrode sides are reduced from three to a one order of magnitude. In fact, for the VUV intensities from the cathode side a large maximum is found at about 400 mbar, whereas from the anode side the VUV intensities increase

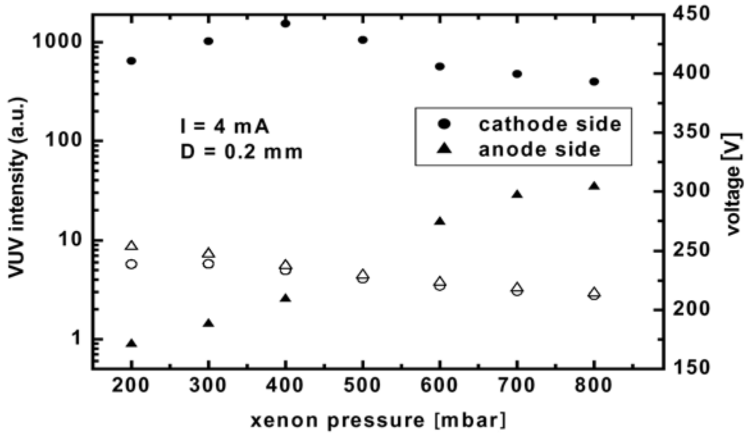

Fig. 5. – Dependencies of the integral VUV intensities (full points) and the discharge voltages (open points) for the same MHCD as in Fig. 4 (a) from the anode side (triangles) and cathode side (circles) as function of the xenon pressure. The discharge current is 4 mA.

exponentially by two order of magnitudes with the xenon pressure (the corresponding excimer spectra were already shown in Fig. 3). Because the discharge voltages for both the electrode sides only little decrease from 250 to 200 V with increasing xenon pressure, the relative VUV efficiency measured for the anode side also increases.

3.2. CLOSED MICROHOLLOW CATHODE

For comparison, in Fig. 6 are shown the same dependencies on the xenon pressure at the same discharge current of 4 mA but for the closed microhollow cathode geometry sketched in Fig. 1(b).

Thus, it can be seen that the VUV integral intensities for both the electrode biasing behave nearly similar as for the open microhollow cathode. So, for the anode side, the VUV intensities exponentially increase by one order of magnitude, whereas from the open microhollow cathode side, the same large maximum at about 500 mbar can be observed. But, owing to the electrode asymmetry of this closed MHCD, the voltages and thus the VUV efficiency for the anode side is somewhat different than for the open microhollow cathode geometry. Especially for the anode side of this MHCD, which now works with a closed microhollow cathode, the discharge voltage decreases from 400 towards 300 V. Obviously, for this closed microhollow cathode it is impossible to measure directly the VUV intensity, so that again the open microhollow electrode from the top in Fig. 1(b) was used as a reference electrode. The excimer spectra taken from the anode and cathode sides are almost the same as in Fig. 3, respectively.

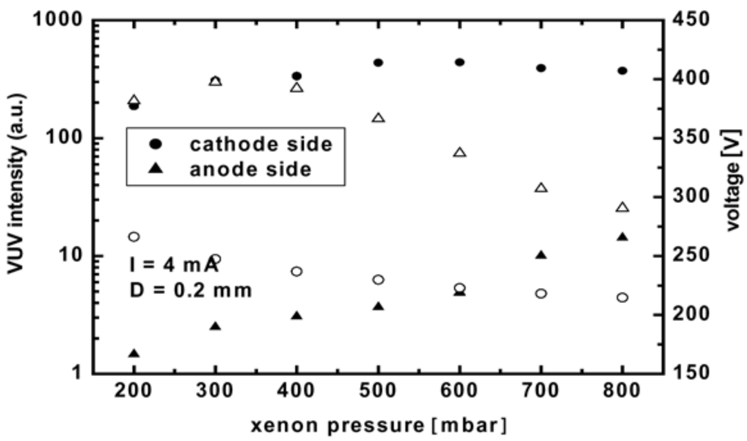

Fig. 6. – Dependence of the VUV intensity on pressure for the MHCD with closed microhollow cathode [seen in Fig. 1(b)]. The discharge current was 4 mA and the hole diameter 0.2 mm.

3.3. CLOSED PLANE MICRO CATHODES

Finally, very interesting results are shown in Fig. 7. Here, the dependencies on the xenon pressure of the VUV intensities and running voltages are obtained for the closed geometry with the plane micro cathode sketched in Fig. 1(c).

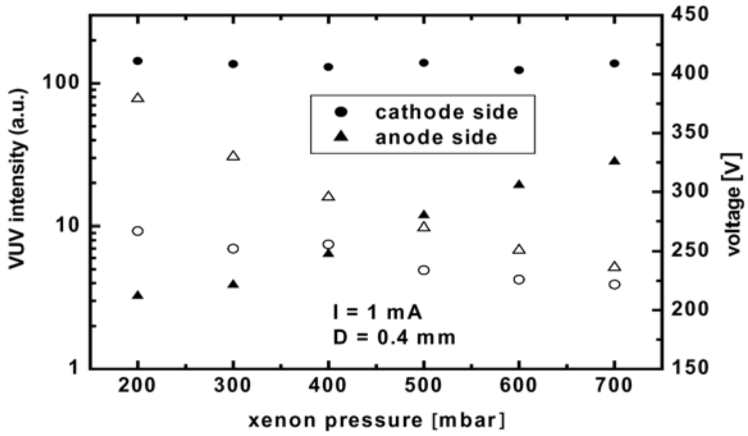

Fig. 7. – The dependence of integral VUV intensity on the xenon pressure for the closed geometry with plane micro cathode sketched in Fig. 1(c). The hole and plane micro cathode was 0.4 mm in diameter and the discharge current of 1 mA.

It is shown in Fig. 4 that the discharge current has only a minor influence on the excimer radiation, as was also theoretical proved [24]. Therefore, the discharge current was diminished to about 1 mA in order to have a stable self-sustained discharge with plane micro cathode. This cathode was chosen with a twice-larger diameter, in order to have the same active surfaces as the open and closed microhollow cathodes sketched in Fig. 1 (a) and (b). It was experimentally proved that the cathode surface plays an important role in the excimer emission [18]. Indeed, apart from the discharge current, all the other conditions being the same, the integral VUV intensities and discharge voltages measured from both electrode sides behave very similar with those shown in Figs. 5 and 6 for microhollow cathode discharges. Also the excimer spectra presented in Fig. 8 (top) and (bottom) for the conditions from Fig. 7 are similar with those from Fig. 3. For a plane micro cathode with only a half diameter, *i.e.* of about 0.2 mm, the other conditions being the same, the dependencies of the excimer spectra and of the integral VUV intensity on the xenon pressure are very similar with those shown in Figs. 7 and 8.

Only for a plane micro cathode with a hole diameter and thickness of about 0.1 mm, the pressure dependence of the integral VUV intensity and the discharge voltage shown in Fig. 9, are somewhat different [25]. Here, it is seen that the VUV intensity curves for the two electrode sides are translated over the whole pressure range, *i.e.* the VUV intensity from the anode simply follows at an approximately one order of magnitude lower those from the cathode side. On the contrary, for a twice thicker microhollow cathode of about 0.5 mm at a diameter of 0.2 mm, the differences between the integral VUV intensity and spectra shapes for the two different micro electrode sides becomes nearly the same at xenon pressures above 500 mbar [26]. For other different micro cathode geometry like metal capillaries [27] or true plane micro cathodes [28], the excimer emission of the micro discharges at high-pressures in are now under investigation.

4. CONCLUSIONS

It was proved that at lower xenon pressures, nearly independent on the discharge current, the excimer radiation for xenon measured through the hollow anode for different microhollow cathode geometries of MHCD is at least by two or even three order of magnitudes lower than those measured from the microhollow cathode side of the same MHCD device. The shapes of the excimer spectra are also different when there are registered through the hollow anode. The different neutral gas density inside and outside the MHCD hole due to their different temperature can explain these phenomena. With increasing gas pressure these effects are attenuated by the increasing thermal conductivity of the xenon gas. Obviously, similar considerations are valuable for the closed MHCD, even with plane micro cathodes. Our experimental data can be also correlated with recent theoretical calculations shown in [24], which reveal that for the so-called standard MHCD, (nothing else as the open microhollow geometry used by Schoenbach):

"…The absorbed power density and the excitation and ionization rates increase as a cube of the gas pressure, the electron density as a square and the degree of ionization – linearly with the gas pressure. By comparison, the current-voltage characteristics, electron energy distribution function and the energy per electron-ion pair, only negligible changes with the gas pressure…".

Thus, in agreement with these theoretical results, the excimer radiation emission at least from the anode side and also the corresponding relative efficiency (defined by the ratio between the relative radiation output and the electrical input) non-linearly increases with the xenon pressures with the exception of the smallest micro cathode dimensions.

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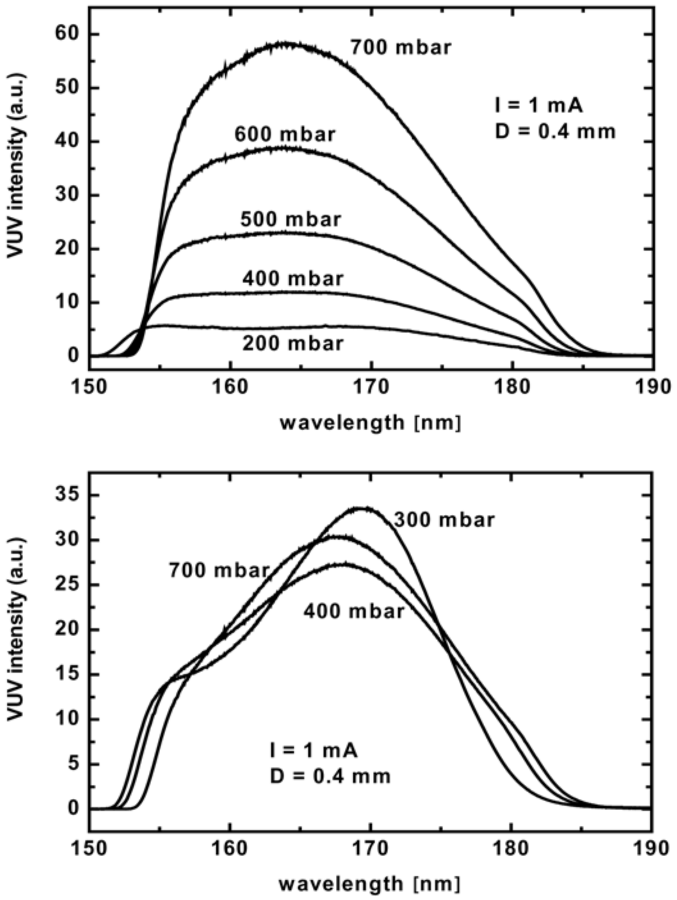

Fig. 8. – Spectral diagrams of the whole spectral range (λ = = 150–190 nm) registered from the anode side (top) and cathode side (bottom) with the xenon pressure as parameter. The plane cathode diameter and the discharge current are the same as in Fig. 7.

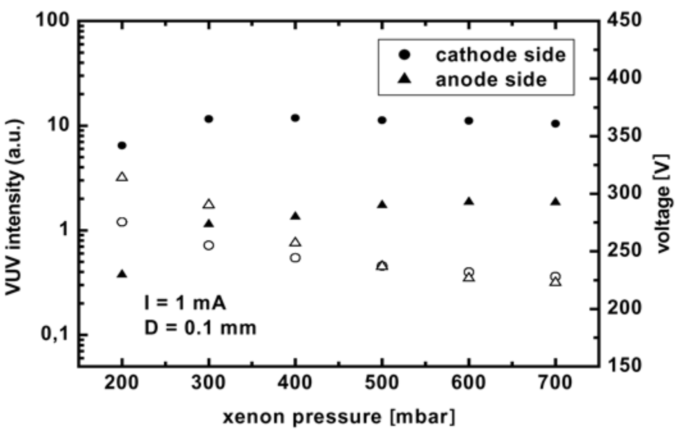

Fig. 9. – The same dependence as in Fig. 7 but for a smaller cathode and hole diameter of 0.1 mm.