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ELECTRICAL PROPERTIES AND SPATIOTEMPORAL PROFILES OF THE LOW PRESSURE HOLLOW CATHODE DISCHARGE

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Abstract. We report measurements of electrical properties and spatial emission profiles of hollow cathode discharge, both for steady state and transient phases during formation of the discharge. A commercial hollow cathode tube normally applied as a spectral source has been studied. Our aim was to relate discharge anatomy to the voltage-current characteristics in a wide range of the discharge currents. It was particularly interesting to track down in time formation of the discharge structure, which is typical for hollow cathode effect.

1. INTRODUCTION

Ever increasing number of hollow cathode applications invokes continuous research of these discharges with complex geometry discharge. Apart from long-standing spectroscopic applications (e.g. Caroli 1983), many more have been introduced recently including newly developed micro size devices (Becker et al. 2006, Djulgerova et al. 2004).

The most important feature of these devices is the hollow cathode effect, manifesting itself trough a large increase in the current density and discharge light intensity accompanied by a drop of the sustaining voltage (e.g Pillow 1981). It can occur for certain discharge conditions in a given discharge geometry. During appearance of the effect, negative glow regions facing opposed cathode surfaces overlap. If one compares hollow cathode and parallel plate glow discharges, lower operating voltages for the same current density can be detected (Baguer et al. 2002, Eichhorn et al. 1993). Discharge is running more efficiently due to the fast electrons and ions, confined inside the cathode hole (Arslanbekov et al. 1998).

2. EXPERIMENTAL SETUP

We used a commercial hollow cathode Hilger and Watts lamp connected to the power circuitry and detection system. Lamp is a glass tube filled by Ne ($p = 3.5$ Torr) and sealed. The lamp has connections for cylindrical Mn hollow cathode with bottom and a ring shaped anode. Cathode hole is 3 mm in diameter and 15 mm long. Our power circuitry is able to impose a current pulse of desired length while running a low current DC discharge. This technique allows us to avoid long breakdown delay times and it enables us to follow formation of the discharge (e.g. Marić et al. 2002). Spatial profiles are recorded in the visible range of spectra using an ICCD camera (Andor, iStar DH720-18U-03). Recording of voltage and current signals as well as camera gating are synchronized with the current pulse

3. RESULTS AND DISCUSSION

3. 1. STEADY-STATE MEASUREMENTS

In Fig. 1, VI characteristic and current dependence of the peak emission intensity inside the cathode cavity are shown. The discharge voltage is presented as the difference between the operating (V) and the breakdown (V_b) voltage. Fig. 2 shows 2D images of selected radial emission profiles (labels (a)–(f) correspond to those in Fig. 1). In the range of low currents, the discharge dominantly operates outside the cathode cavity (Figs. 2(a) and (b)) and it resembles discharge in parallel-plane geometry (Marić et al. 2002). The gap in descending part of VI characteristic corresponds to region of free-running oscillations. Further increase in current leads to the changes of the discharge regime. Now it operates mainly intra-cavity becoming more constricted and intense in the center (Fig. 2(c), (d), (e)). With a large increase in current density followed by voltage decrease, discharge switches to a more efficient regime typical for hollow cathode effect. Further rise in current is accompanied by the discharge expansion within the cavity and emission increment. This kind of behavior is typical for normal glow in parallel plate geometry. At even higher currents, the voltage current slope becomes positive, as in an abnormal glow mode. Almost entire cathode cavity is covered by the discharge (Fig. 2(f)).

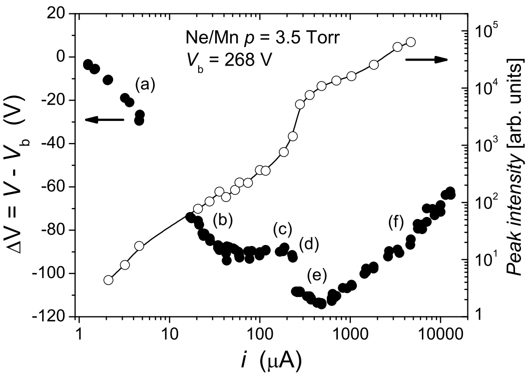

Figure 1: Discharge voltage (solid symbols) and peak emission intensity (open symbols) plotted against discharge current. Labels (a)-(f) correspond to spatial profiles in Fig. 2.

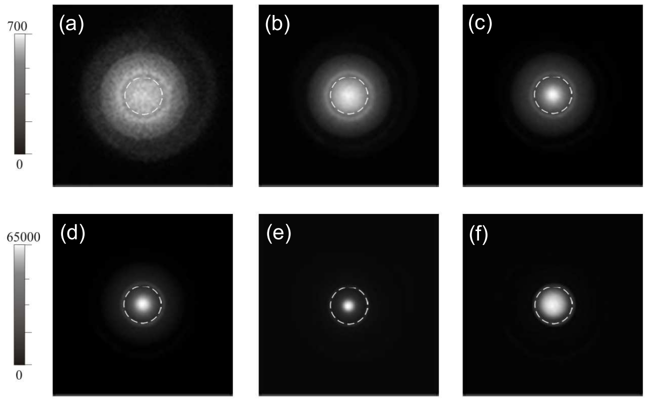

Figure 2: Radial profiles of the emission for different discharge currents: (a) $i = 3.2\ \mu$A, (b) $i = 28\ \mu$A, (c) $i = 184\ \mu$A, (d) $i = 231\ \mu$A, (e) $i = 278\mu$A, (f) $i = 4690\ \mu$A. White lines mark cathode cavity edge.

3. 2. TIME RESOLVED MEASUREMENTS

We were able to obtain temporally resolved discharge profiles by using fast ICCD camera synchronized with the power circuit. It can provide perceptible images even for short exposition and low light intensities. In that way discharge profile formation could be traced from the beginning of the current pulse, through the transient behavior and to the steady state. Measurements for several different modes of the discharge were made. Here we show formation of the hollow-cathode regime of discharge. We were able to follow transition from parallel-plate-like discharge to the regime of discharge with distinct hollow-cathode effect developed, within the single pulse. This corresponds to the gradual change of discharge regime from the point labelled by (d) to the point (e) in VI characteristic (Fig 1). Discharge voltage and current waveforms are shown in Fig 3. Transient part at the beginning of the pulse is magnified in Fig 3(a) in order to show rapid changes in waveform intensity (amplitude). Labels 1–8 in Fig 3 correspond to spatial images in Fig 4. In the beginning of the pulse, both discharge voltage and current experience steep rise. At the same time, 2D images show that discharge becomes radially inhomogeneous moving from the cathode edge into the cavity. Profile intensity increment follows current signal peeking at current maximum. Further changes in voltage and current are mirrored only through profile intensity variations while discharge stays inside the cathode. At the moment when current runs though the minimum, local maximum voltage is achieved with minor changes in the profile intensity. Discharge briefly sets at one current and then slips to another mode accompanied by a slight current increase and significant voltage decrease. Major increase in emission intensity is noticeable.

In summary, we have shown that hollow cathode discharge can be represented as a combination of discharges between parallel plates and inside the cavity. We were able to relate electrical properties to spatial structure of the discharge.

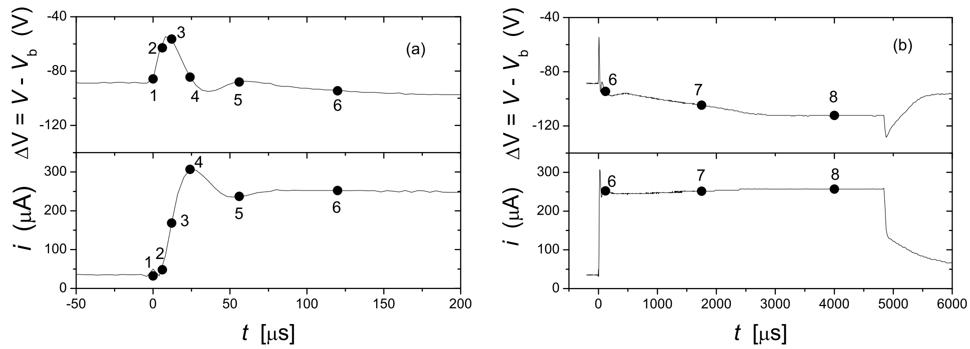

Figure 3: Voltage and current signals after the application of the voltage pulse: (a) beginning of the pulse zoomed in, (b) the whole pulse.

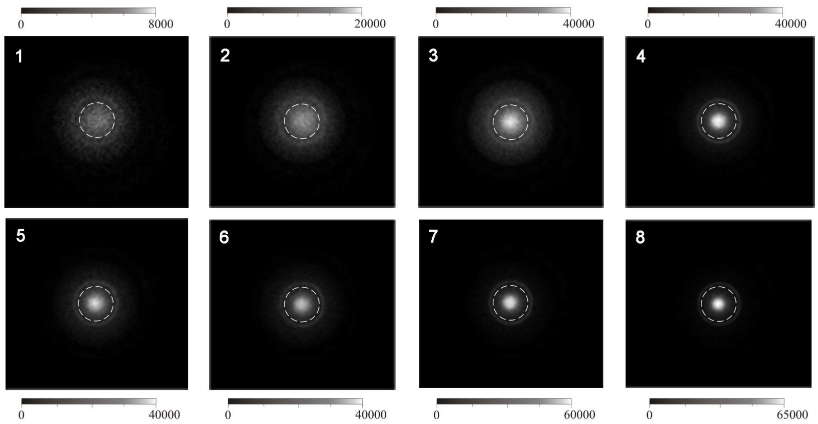

Figure 4: Axial emission profiles that correspond to labels 1-8 in Fig. 3.

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