Hole size effect on microhollow cathode discharge in air

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Abstract. In this work the values of main electrical parameters of the microhollow cathode discharge in atmospheric air (peak discharge current, discharge ignition voltage) depending on the diameter of the hole in the cathode were obtained. It was experimentally found that at currents up to 2 mA, the discharge operated in a self-pulsing mode. According to the experimental results it was concluded that the value of the discharge ignition voltage at average discharge current exceeding 2 mA didn’t depend on the hole diameter.

1. Introduction
Microhollow cathode discharges (MHCD), or discharges with a micro-hollow cathode are discharges in gas between a cathode with a micro-hole and an anode separated by a dielectric layer [1]. Devices with such a cathode attracted the attention of researchers because of their ability to operate at atmospheric and subatmospheric pressures and at low power consumption [2]. The rapid growth of applications of microplasmas [2] requires to study the discharge process in detail.

2. Experiment
In this work, we used a standard electrical scheme for MHCD operation (figure 1). The discharge cell was a sandwich-like one. Copper layers acted as a cathode and an anode. The insulating material Rogers RO4000 was used as a dielectric. The thickness of the dielectric plate was 200 μm. The high voltage source Plazon with an output power of up to 25 W was used in the experiment. The average discharge current \(I_{av}\) was limited by a ballast resistor \(R_b = 190 \, k\Omega\). The voltage from the source \(V_{sup}\) was regulated in the range from \(-600\) V to \(-1400\) V. The voltage across the discharge gap \(V_{dg}\) was measured with a Tektronix high-voltage probe. The discharge current was estimated from the voltage drop across a resistive sensor \(R_s\) connected in series with the discharge cell. The discharge current and the voltage across the discharge gap were recorded on the screen of a WaveSurfer 422 digital oscilloscope with a bandwidth of 200 MHz. Discharge cells with a different hole diameter in the cathode \(d\): from 200 μm to 500 μm were fabricated for the experiments.

3. Results
In the course of the experiment, oscillograms of the discharge current \(I_d\) and the voltage across the discharge gap \(V_{dg}\) were obtained for three discharge cells with different diameters of hole \(d\): 200, 300 and 500 μm. Typical oscillograms of the discharge gap voltage and discharge current are shown in figure 2. These waveforms correspond to the case when the value of the source voltage \(V_{sup} = -700\) V, the value of the average current \(I_{av} = 1\) mA, the hole diameter \(d = 500\) μm.
Figure 1. Scheme of experimental setup

Figure 2. Oscillograms of the discharge current $I_d$ and the voltage across the discharge gap $V_{dg}$ at a value of supply voltage $V_{sup} = -700$ V and a value of the average current $I_{av} = 1$ mA for the cell with a cathode hole diameter $d = 500$ μm.

It is seen from the figure 2 that the discharge operates in a pulse mode. The duration of the voltage pulse is about 6 μs. The oscillation frequency is 167 kHz. The voltage waveform has a negative voltage displacement $V_{dc}$ relative to zero. In this case $V_{dc} = -450$ V. This displacement is an evidence that the discharge is realized not only in the gap, but outside the discharge cell [3]. The value of the discharge ignition voltage $V_d$ is 650±25 V. As we can see from the figure 2 the peak current is an order of magnitude higher than average current. At $I_{av} = 1$ mA, the peak current equals 20±2 mA. The current pulse duration is about 1 μs.

According to the data from the waveforms there were obtained the main electrical parameters of the discharge: the peak current $I_{pk}$ and the discharge ignition voltage $V_d$ for all the cells. The dependences of the peak current $I_{pk}$ and the discharge ignition voltage $V_d$ on the average discharge current $I_{av}$ for all studied cases are presented in figures 3 (a) and (b), correspondingly.

The obtained dependences are the evidence of two operation modes of the studied MHCD in air: a classical self-pulsating mode, which can be noted by the drop in the discharge ignition voltage $V_d$ with an increase in the value of the average current $I_{av}$ and $I_{pk}$, and the other mode, when the ignition voltage is constant with current rising. The self-pulsing regime is observed for all cases at currents up to 2 mA. This mode is characterized by high efficiency in the production of ions and particles in a metastable state inside the cathode cavity [4]. The other pulse regime, which is also characterized by tending to minimize the voltage displacement is a transient to glow regime. In this regime the ignition voltage is 600±50 V despite the hole diameter.

4. Conclusions

Thus, the operation of microhollow cathode discharge in atmospheric air at low average current up to 5 mA in the discharge cells with cathodes of different holes diameters was studied. It was revealed the pulsating regime of the discharge in the whole range of studied parameters. It is worth to note that the discharge behaves like self-pulsating one at the average current value up to 2 mA, when the ignition voltage drops with the current rising. At currents more than 2 mA, but less than 5 mA the voltage at the gap and the discharge current also oscillate, but the ignition voltage does not change significantly with the current growth. It is constant and equals to 600±50 V in all cases where the average discharge current is more than 2 mA.
Figure 3. Dependences of the peak current $I_{pk}$ (a) and the discharge ignition voltage $V_d$ (b) on the average current $I_{av}$ for different MHCD cells: the diameter of hole in the cathode differs from 200 to 500 μm.

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