

## MICRODISCHARGES IN THE CURRENT RANGE FROM MICROAMPERES TO AMPERES

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**Abstract.** The electrical and spectroscopic results of the comprehensive investigations of the microdischarges in atmospheric pressure helium, argon, nitrogen and air at gaps less than 1 mm and in a large current range from microamperes up to amperes are presented. Two oscillation discharge regimes were revealed in discharge current range comparable or less than the low current limit of normal glow discharge existence.

### 1. INTRODUCTION

Microdischarges have demonstrated the possibility of generating stable diffuse, non-thermal plasmas with characteristic dimensions in the 0.01–1 mm range; see e.g. Becker et al. (2006) and Staack et al. (2008). The main source for producing of non-thermal atmospheric pressure microplasmas is the cathode region. At that, the considerable part of cathode region consists of cathode fall which is characterized by high volumetric power densities in range of tens to hundreds of  $\text{kWcm}^{-3}$ , while maintaining comparatively cool background gas temperatures. The energy losses to the surface surrounding the plasma contribute to enhanced plasma stability. Among the most attractive features of microplasmas are such applications as plasma cathodes, which can support larger volume DC atmospheric pressure glow discharges (APGD) in various gases (see Kunhardt 2000 and Arkhipenko et al. 2009), and volume plasma chemistry (see Qui et al. 2009).

Arkhipenko et al. (2002, 2009) have presented the results of DC self-sustained APGD investigations in helium, argon and nitrogen in the wide current range for interelectrode gaps of 1 and 10 mm, when the APGD was in normal glow discharge mode. In this paper, we focus our attention mostly on the APGD at small interelectrode gaps, comparable with dimensions of near cathode layers when there is an influence of electrodes on discharge structure and its electrical and optical parameters.

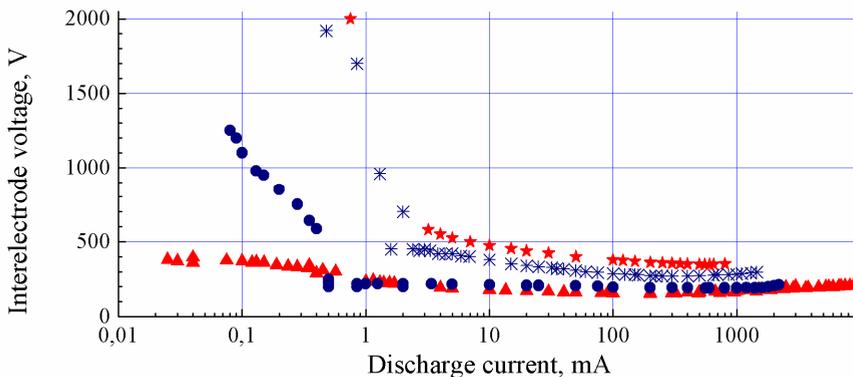
## 2. RESULTS

Glow discharge is ignited between two electrodes in air-locked chamber (see Arkhipenko *et al.* 2009). Weakly rounded tungsten anode is 6 mm in diameter and flat copper cathode is 36 mm in diameter. A weak flow of helium, argon, nitrogen or air through the discharge chamber (from 5 to 100 cm<sup>3</sup>/s) was provided. The impurity concentrations in the gas flows did not exceed 0.02%.

The V-I characteristics of the discharges at the gap of 1 mm are relatively “flat” in stable normal glow discharge mode at currents larger 1 mA (Fig. 1). At low currents (less than 1 mA), the discharges transfer into an oscillating regimes and corresponding parts of V-I characteristics become sharply falling at current increase. Current value, when this transition occurs, defines a low current limit of the normal glow discharge mode  $I_{n-sn}$ :

$$I_{n-sn} = j_c \pi d_c^2, \quad (1)$$

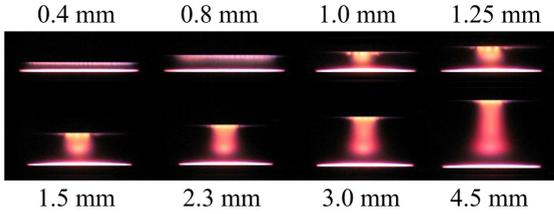
where  $j_c$  – normal current density and  $d_c$  – cathode fall thickness.



**Figure 1:** The V-I characteristics of the APGDs in helium(triangles), argon (circles), nitrogen (snowflakes) and air (stars) at interelectrode gap of 1 mm and gas flows of 40 cm<sup>3</sup>/s.

By substituting in (1) the corresponding values of  $j_c$  and  $d_c$  for helium APGD which are 2.3 A/cm<sup>2</sup> and 0.06 mm (see Arkhipenko *et al.* 2002), we will obtain low current limit equal to about 0.25 mA. If we suppose that the cathode fall thicknesses for argon, nitrogen and air APGDs are the same as in a case of helium discharge we obtain the following current limits: 0.6, 1 and 1.2 mA correspondingly. In Fig. 1, the current values corresponding to sharp rises of interelectrode voltage at the current decrease occur at discharge currents about 0.3, 0.6, 1.5 and 2 mA. It is a good agreement of calculated and experimental data. Upper limit of the normal APGD is defined by glow-to-arc transition and takes place at different currents in dependence on experimental conditions and experience of experimen-

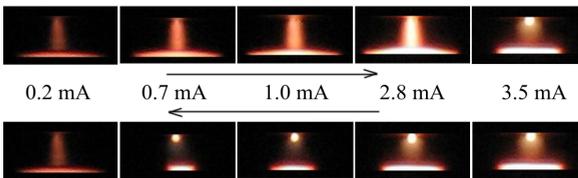
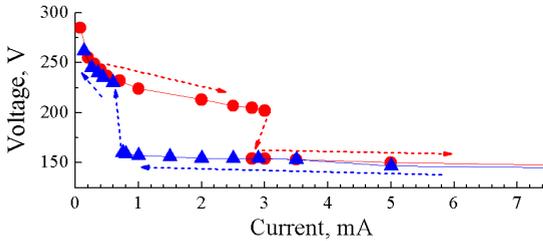
talists and these upper current limits are a few of amperes for argon, nitrogen and air and about 10 A for helium APGDs.



**Figure 2:** Images of helium discharge for flat copper electrodes at different gaps at 0.5 A.

glow are defined as thin planar layers close to the electrode surfaces. Negative glow increases a little in diameter and is homogeneous. Anode glow is inhomogeneous and consists of large number of small fuzzy spots. Thus, at discharge gaps less than 1 mm, which are typical for an operation of atmospheric pressure micro discharges, electrodes strongly influence the normal glow discharge structure.

In addition, at low currents, discharge can be unstable. For these experiments, we used discharge with gap of about 0.55 mm. Ballast resistor was 650 kΩ. Corresponding V-I characteristic is shown in Fig. 3. We emphasize ones more that in



**Figure 3:** V-I characteristic and discharge images. Arrows indicate the directions of current changes.

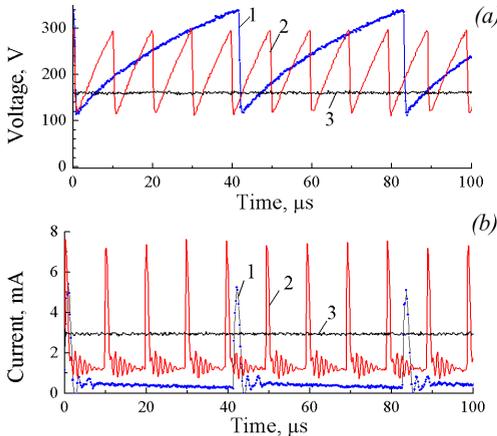
these characteristics the values of both the voltage and current are average on time. Depending on a direction of current variation we obtain two curves. Thus, we observe a hysteresis of voltage in the current range of 0.6–3 mA. The bottom row of images illustrates how discharge structure changes at current decrease. As it can be seen, the structure corresponding to higher currents is saved up to current of about 0.5 mA while current decreases. In this point, the spasmodic changes in discharge structure occur. These changes take place in all discharge regions. Especially it concerns the changes in the negative glow. Its area increases by about 5 times. At first glance it seems that we have discharges at low currents with current density on the cathode much lower than normal one. However, it is not true. These discharges have normal current density on the cathode. This fact is confirmed by the registration of the discharge parameter dynamics.

It is interesting to trace an influence of closely spaced electrodes at gaps less than 1 mm on APGDs. It turns out that the significant changes in discharge structure are observed. For example, the helium discharge becomes diffuse and discharge color changes (Fig. 2). Negative and anode

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Thus, we observe a hysteresis of voltage in the current range of 0.6–3 mA.

In Fig. 4, the waveforms of voltage and current are shown for three current values of 0.2, 1 (oscillating) and 3 mA (normal regime). The reason for the oscillations is probably connected with ionization instability. Oscillation frequency depends on a capacitance of the power supply leads, interelectrode gap, discharge current, ballast resistor and etc. Using surge current value and transverse dimension of negative glow in corresponding images in Fig. 3 we obtained the current density values on the cathode which are close to normal current density for pair of helium-copper (about  $2.3 \text{ A/cm}^2$ ). It means that helium discharge at small currents in fluctuating regime has normal current density on cathode.



**Figure 4:** Waveforms of voltage (a) and current (b) at discharge currents: 1 – 0.2 mA, 2 – 1 mA and 3 – 3 mA.

voltage increases higher than the breakdown one for actual interelectrode gap. Due to large resistance the power supply can not provide a current higher than lower current limit for normal APGD existence. The voltage decreases up to zero. The breakdown has a spark character, because the spark hissing is heard. Between two breakdowns, no discharge current and glow is observed.

### Acknowledgements

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