Effect of the cathode surface temperature on the cathode fall layer parameters

L. Simonchik[(*)1], L. Pitchford[2], Y. Safronau[1]

[1] *Laboratory of Gas Discharge Physics, Stepanov Institute of Physics NAS of Belarus, pr. Nezavisimostsi 68, 220072 Minsk, Belarus*
[2] *LAPLACE, University of Toulouse and CNRS, 118 route de Narbonne, 31062 Toulouse, France*
[(*)] simon@imaph.bas-net.by

It is shown that the cathode temperature influences significantly the main parameters (electric field distribution, thickness of the cathode fall layer, current density, gas temperature) of the cathode fall of the self-sustained normal dc atmospheric pressure glow discharge in helium. The cathode heating as a result of discharge current flow leads to increase of the interelectrode voltage. With additional cathode heating by an external heat source the interelectrode voltage decreases. Radially inhomogeneous profiles of the reduced electric field on the uncooled cathode surface have been measured.

Different research results [1-4] show that the cathode temperature has a significant influence on the glow discharge parameters. Moreover, rapidly increasing heat generation at pressure increase from low to atmospheric requires experimentalists to use cooled electrodes in order to isolate phenomena associated with changes in pressure. As it is shown in [4], the cathode heating leads to the changes in the cathode fall parameters in a self-sustained normal dc atmospheric-pressure glow discharge (APGD) in helium, in particular, the interelectrode voltage, the thickness, the current density and the gas temperature in the cathode fall layer. Thus the control of the cathode temperature and maintenance it constant in a high pressure glow discharge system are very important considerations. There is no a unique answer in references to the question: why does an interelectrode voltage increase when the cathode surface temperature rises?

The experimental setup used in these investigations is the same as in [4]. Glow discharge is ignited between flat copper 36 mm cathode and an anode in air-locked chamber at 1 litre/min flow of helium. In the case of sufficient cathode cooling at current of 1 A and 10 mm gap the discharge view is shown in the inset *a* (Fig. 1). The positive column is constricted and the diameter of negative glow is 6 mm. According to [4], the electric field strength in the cathode fall is constant in radial direction and linearly drops in axial direction (Fig. 1, squares). An image of the discharge under the same conditions, but without the cathode cooling is shown in the inset *b* (Fig. 1). In this case the electric field is radially inhomogeneous and decreases at discharge periphery by a factor of 2-3. (Fig. 1, triangles and circles).

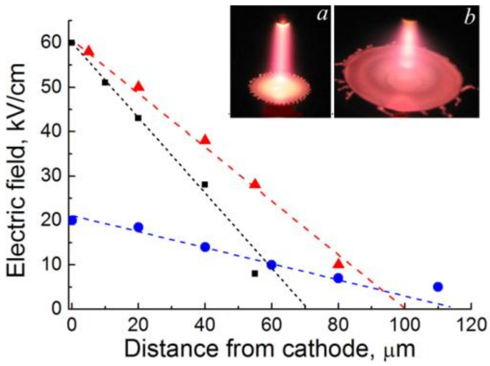

Fig. 1. Longitudinal electric field profiles for cooled (squares) and uncooled (triangles, circles) cathodes. Square and triangle symbols correspond to axial profiles, the circles – profile at a distance of 8 mm from the axis. The inset shows discharge photos with cooled *(a)* and uncooled *(b)* cathodes.

The main parameters of the APGD in helium according to [5–7] are presented in Table 1. One should note that an increase of interelectrode voltage by about 80 V in the APGD with uncooled cathode is connected in preference with the changes in the cathode fall. Reduced electric field near the cathode surface is about 700 Td on the axis and 250 Td at the periphery (8 mm from the axis). At the same time, for cooled cathode it is about 350 Td and constant.

The diffuse APGD with uncooled flat electrodes at a current 1 A can be obtained at gaps up to 5 mm. At that the reduced electric field profile close to the cathode surface is radially homogeneous. At larger gaps the discharge has constricted positive column. In this case an additional heat flux from the restricted positive column takes place and leads to radially inhomogeneous cathode heating and electric field distribution.

An influence of the cathode heating by external heat source is demonstrated in Fig. 2. We used two section discharge chamber with two independent APGD. The upper and bottom surfaces of the plate dividing discharge chamber were as cathode surfaces for these discharges. Fig. 2, *a* presents the image of discharge at 50 mA in bottom section when upper discharge does not operate. In this case the cathode heating is small and current density 2 A/cm^2 is close to the current density for cooled cathode (see table 1). When the APGD at 1 A in upper section is turned on the negative glow of bottom dischare increases, current density decreases up to 0.8 A/cm^2 and the voltage decreases by 20 V.

Table 1. The main parameters of the APGD in helium (according to [4–6])

	Cooled	uncooled
Discharge current	1 A	1 A
Interelectrode gap	10 mm	10 mm
Interelectrode voltage	**220 V**	**300 V**
Current density on cathode (average)	**2.3 A/cm^2**	**~0.4 A/cm^2**
Current density in positive column (average)	~20 A/cm^2	~20 A/cm^2
Gas temperature (negative glow)	**600 K**	**1000 K**
Gas temperature (middle of positive column)	~2300 K	~2300 K
Cathode temperature	**~400 K**	**~800 K**

Experiments were fulfilled at other discharge conditions as well. For example, the heating of nitrogen APGD cathode leads to the decrease of interelectrode voltage more than one hundred Volts.

The probable reasons for observed interelectrode voltage increase are discussed. The secondary electron emission coefficient, γ, used in models is an effective value taking into account various possible secondary emission processes including ion impact, metastable impact and photoemission. From an analysis of experimental results, Phelps and Petrovic [7] have deduced an effective γ as a function of the reduced field strength at the cathode, *E/N*. This parameterization reflects the relative importance of the different electron emission processes for different discharge conditions and also includes possible effects due to ionization near the cathode caused by heavy particles (ions or neutrals). Note that a decrease in the effective γ would lead to an increase in the operating voltage at a given current. However, on the basis of theoretical results, a decrease in the effective γ due to an increasing cathode temperature [8] or changing electric field at the surface [9] seems unlikely. Also, it should be recalled that model calculations [1, 2] using a constant γ also predict an increased operating voltage for a given current with increasing temperature.

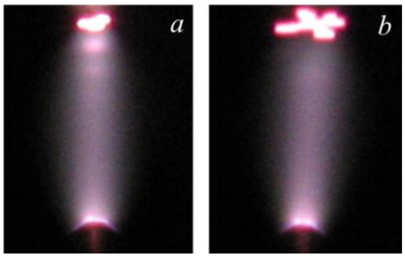

Fig. 2. Helium APGD images without *(a)* and with *(b)* additional cathode heating. Current is 0.05 A, gap is 10 mm. The cathode is on top.

The work was supported by the BRFFR-CNRS under grant F11F-002.

References

[1] A. Bogaerts, R. Gijbels and V.V. Serikov, *J. Appl. Phys.* 87 (2000) 8334–8344.
[2] I. Revel, L.C. Pitchford and J.P. Boeuf, *J. Appl. Phys.* 88 (2000) 2234–2239.
[3] M. Kasik, C. Michellon and L.C. Pitchford, *J. Anal. At. Spectrom* 17 (2002) 1398–1399.
[4] V.I. Arkhipenko, A.A. Kirillov et al, *Plasma Sources Sci. Technol.* 17 (2008) 045017.
[5] V.I. Arkhipenko, A.A. Kirillov et al, *Plasma Sources Sci. Technol.* 18 (2009) 045013.
[6] V.I. Arkhipenko et al, Spectroscopy of Plasma and Natural Objects, Minsk (2007) 10–65.
[7] A.V. Phelps and Z. Lj. Petrovic, *Plasma Sources Sci. Technol.* 8 (1999) R21–R44.
[8] H.D. Hagstrum, *Phys. Rev.* 96 (1954) 336–365.
[9] B. Eismann, PhD thesis, University Paul Sabatier, Toulouse, France, 2011.