Investigation of Plasma Propagation in Barrier Corona of Direct Current

Zhuravliov O. A[1]., Ivchenko A.V. [1] , Lamazhapov Kh.D.[2], Rybakov D.A.[1]

[1] *Samara State Aerospace University (SSAU), Samara, Russia*

[2] *Samara State University of Transport, Samara, Russia*

Barrier Corona of Direct Current (BCDC) [1] is implemented in the rotor-type electrode systems with the moving dielectric layer and with the corona-producing cathode and the grounded anode which are disposed near dielectric surface. In contrast to [2], key feature of this discharge consists in spatial separation of the charging and discharging processes on the dielectric barrier surface. It paves the way to new organization of electro-physical processes during the interaction of plasma structures with the charged dielectric. Remarkable physical effect observed in BCDC is associated with generation of near-wall quasi-homogeneous plasma layers in electronegative gases at sub-atmospheric and atmospheric pressure [1]. This complex electro-physical process was named by uniform surface discharge (USD) in work [3].

For USD-excitation it was used experimental setup shown in Fig.1. This installation comprises the rotor-type electrode system (1, 3, 4, 6), a system for registration of current-voltage characteristics (2, 7), a system for measuring of surface potential (5, 8, 9) and a camera (10). Blade-type (or wire-type) cathode and anode were placed above the dielectric surface at distance $h \leq 0.5$ mm according to [3]. In this case, capacitance of dielectric barrier is charged up to the cathode potential [4]. In the inter-electrode space L = 20-40 mm gas-discharge process is maintained in the air on the surface of the dielectric layer with d = 0.3-1 mm at $|U|<20$ kV and $V<20$ m/s.

The current-voltage characteristics of USD are shown on the Fig.2. Curves 1 and 2 (see Fig. 2) have inflection points (a,b) which are typical for barrier discharge [2]. These points arise due to plasma

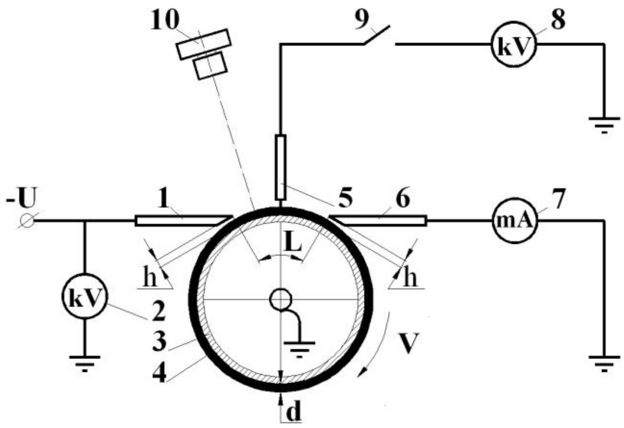

Fig.1. Scheme of experimental setup: 1-blade-type cathode; 2,8 – electrostatic voltmeters C-197; 3-rotor-electrode; 4-dyelectric layer; 5-electrostatic probe 6 - blade-type anode; 7-ampermeter; 9 - high-voltage switch; 10 camera. L-inter-electrode space; h- charge and discharge gaps; d- dielectric thickness; V- linear speed of dielectric layer

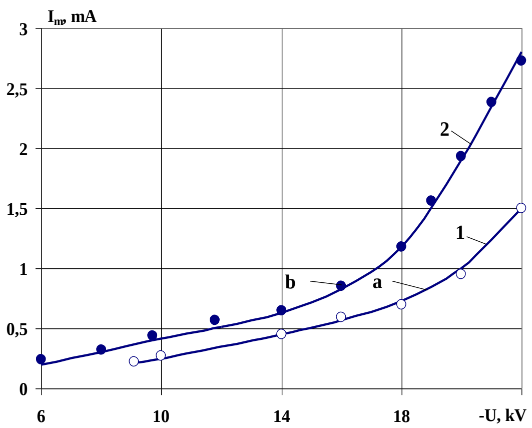

Fig.2. The current-voltage characteristics of uniform surface discharge at different dielectric thickness d (L=28 mm, h=0.5 mm, V=2.8 m/s): 1 – d=0.7 mm, 2 – d = 0.875 mm. a, b – plasma formation points in the inter-electrode space L

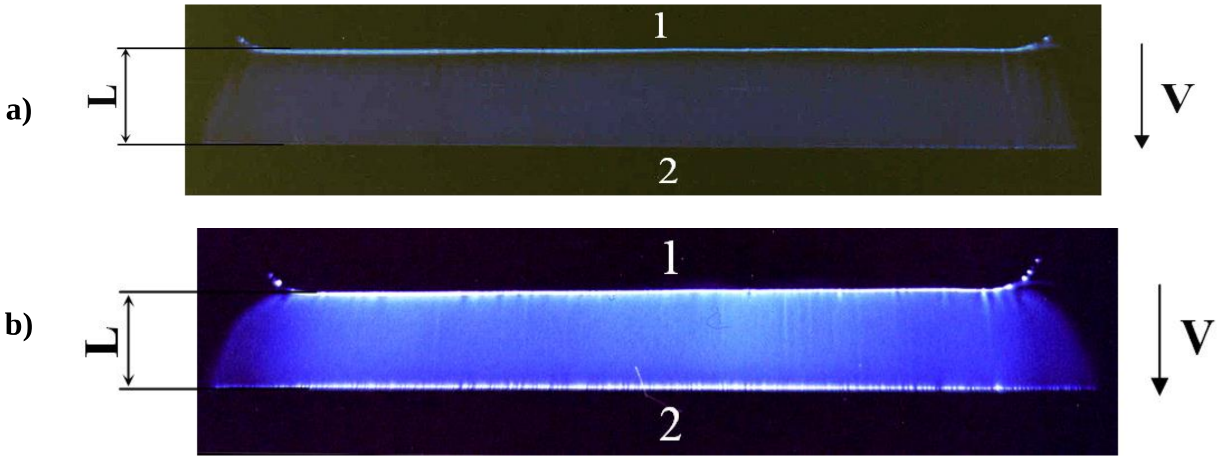

Fig.3. Light emission of uniform surface discharge on movable dielectric layer in the inter-electrode space L=28 mm (d=0.875 mm, , h=0.5 mm, V≅5 m/s): a) -the plasma layer propagation at high voltage U=-16 kV=constant; b) – full gas-discharge overlapping L at U=-19 kV=constant. 1 - Cathode. 2 – Anode.

ignition in the inter-electrode space L. Besides voltage U current-voltage characteristics can be influenced by the dielectric layer thickness d, the linear velocity V and the length of the electrode gap h. In this case, the discharge current increases proportionally with V and d as well as decreases with increasing h [1].

For low voltage U, gas-discharge process is concentrated in the gaps h while the inter-electrode space L remains dark. When the voltage U reaches the points a, b (see Figure 2) then plasma layer begins to propagate from anode to cathode. The frontier position of the plasma layer into L is determined by cathode voltage U. In this state the discharge view is shown in fig.3.a). With further increase of |U| the plasma layer overlaps the inter-electrode space L without sparking (Fig. 3 b).

It is obvious that one needs to explain high stability of the ionization processes in the discharge. In order to describe the initial stage of USD-formation we have proposed a quasi-stationary physical model which considers that charge distribution on a moving dielectric is time-invariant. In our case, it is possible when the characteristic time of the analysis does not exceed $\tau << L/V$ [1].

The model is relates to the electron output from traps by Poole-Frenkel mechanism as well as the subsequent breakdown of gas by Townsend's theory. In the simulation, it was considered that the plasma layer propagation accompanied by partial neutralization of the surface charges. According to [1], growth of |U| leads to the formation of stepped potential distribution φ(x) (see. Fig.4).

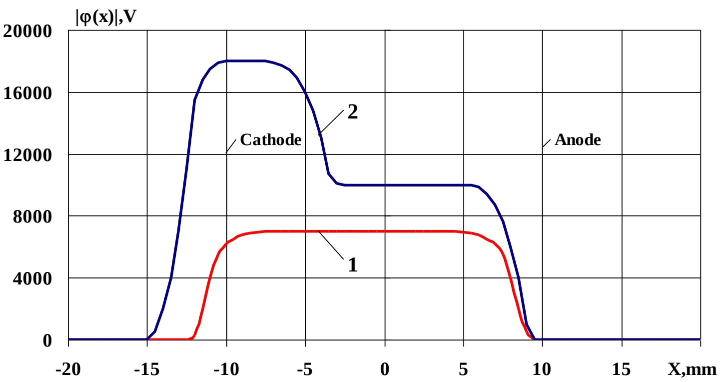

Fig.4. Simulative potential distribution on the dielectric surface at different cathodic voltages: 1-U=-7 kV; 2- U=-18 kV

a)

b)

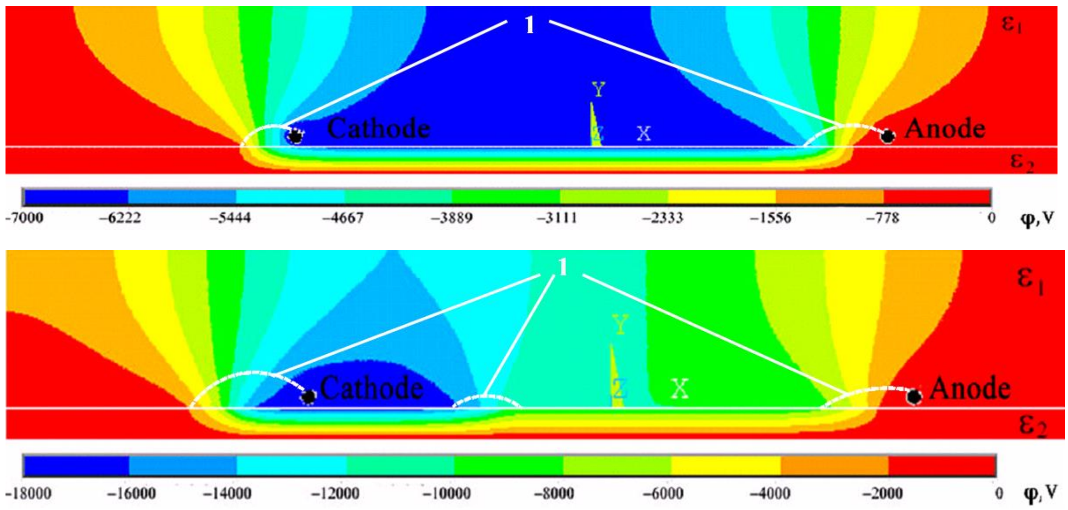

Fig.5. The calculated potential distribution in the inter-electrode space L =20 mm with the charge relief on the dielectric (see Fig.4): a) U=-7 kV; б) U=-18 kV. X,Y - coordinate system $2r_0$=0.5 mm – cathode/anode diameter; d=1 mm; ε_1=1; ε_2=3 – dielectric permeability 1-areas where electric field achieves 30 kV/cm

Believing that the volume charge density in the initial stage of USD is not great, in this work it was carried out 2D-modeling of the electric field into L using the ANSYS software. Results presented in Fig.5 are in the agreement to [7] and also they demonstrate the enhancement of the electric field at a boundary of the deposited charges structure. Enhancement occurs both in gas and in solid dielectric. Such field enhancement creates favorable conditions for the electron emission from some polymeric materials with the traps energy U_{tr} = 0.65-0.75 eV and the traps size a_{tr}<10 nm [8].

For these conditions the electron emission distribution as a function of the charges localization in the dielectric layer is shown in Fig. 6. The form-factor of curves in Fig. 6 depends on the density of the deposited charge and electric field in the dielectric. If traps are localized at a depth |Y|≅d/2=0.5 mm then distribution n_e correlates with density of the surface charge (curves 2 and 4 in Fig.6) since the field is uniformly distributed in this place. If the charge accumulation occurs in the dielectric sub-layers with |Y|<0.05 mm then emission process is shifted to the border of the charges structure (curves 1, 3) where the electric field can achieve 100 kV/cm.

Simulation of the plasma formation near the anode was executed according to an algorithm [9].

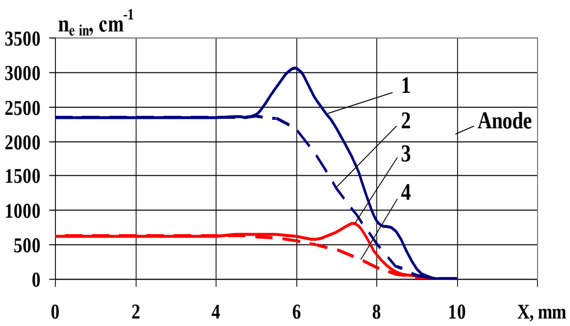

Fig.6. Distribution of the uncoupled electrons on the charged surface formed by means Poole-Frenkel's emission mechanism at different localization Y of traps in dielectric: 1-U=-18 kV, Y=-0.05 mm; 2-U=-18 kV, Y=-0.5 mm; 3-U=-7 kV, Y=-0.05 mm; 4-U=-7 kV, Y=-0.5 mm; $\tau=10^{-6}$ s.

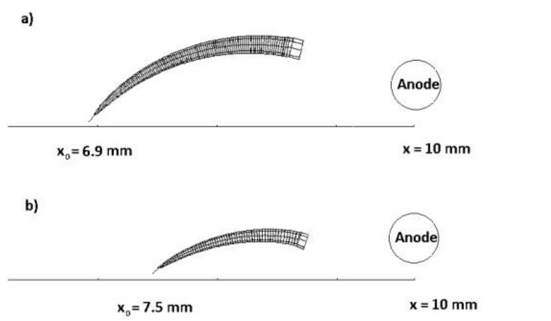

Fig.7. The modeling of electron avalanches (U=-18 kV, L=20 mm) in area near anode at different start-up position: a)-x_0=6.9 mm; b)-x_0=7.5 mm

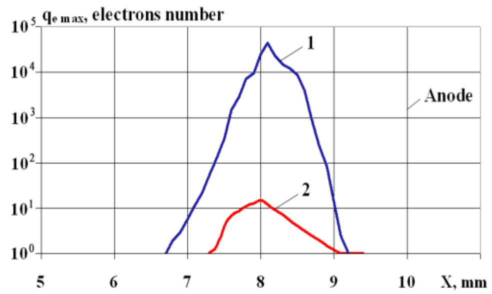

Fig.8. Effective generation zone of electrons in avalanche heads at boundary of the charges relief: 1-U=-18 kV, 2- U=-7 kV

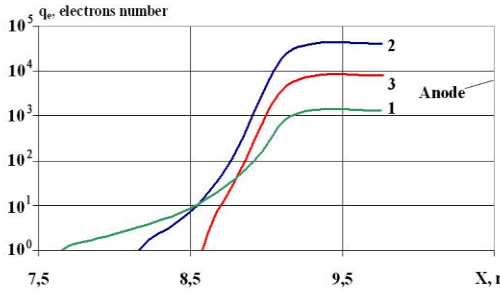

Fig.9. Dynamics of electron generation in avalanche heads depending on start position of electron emitted by dielectric substrate at U=-18 kV: 1-x_0=7.65 mm; 2-x_0=8.16 mm; 3-x_0=8.58 mm

According to Fig. 7, when electron avalanches generated by emission propagate along the electric field lines so they ere moving away to a distance 0.5-0.75 mm from dielectric. In low electric fields electrons attach to the gas molecules and only on the boundary of φ(x) there are conditions for their duplication (Fig. 8). Avalanches which arise in this area can come to the surface of the anode and increase charge of heads up to 10^5 electrons (Fig. 9). On the one hand these results demonstrate the impossibility for transformation of single electron avalanche to the streamer [6] but on the other hand the obtained data can not explain the observed increment in current-voltage characteristics (points a, b in fig.2). This leads to the necessity of analysis collective discharge processes which are associated with the propagation of the avalanches groups in the gas [10]. The merge process of electron avalanches leads to the formation a conductive cluster. In our opinion it can explain the uniform plasma formation on the charged surface of the moving dielectric.

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