Three stages in development of a surface DBD in dense gases excited by a single negative high-voltage pulse

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The results of experimental and theoretical study on spatial-temporal dynamics of plasma sheet covering a dielectric barrier under development of a pulsed surface DBD are presented. To exclude the influence of the surface charge deposited by preceding pulses and to diminish the contribution of a displacement current in total discharge current we used a single pulse with a long rise time. We have revealed an existence of three stages in development of surface DBD and showed that plasma sheet expands over barrier not only at the stage of current rise but at the diminishing current stage as well. Theoretical interpretation of the results obtained is given.

A negative surface dielectric barrier discharge (NSDBD) is more convenient subject for experimental investigation because negative streamers develop more slowly compared with positive streamers. This is why we have dealed with NSDBD. The experiments were done with a pulsed NSDBD in Ar and air at pressure of 300 and 750 Torr. Barrier electrode was a grounded metallic plate of 60x60mm^2 covered with a dielectric (ceramic or glass) of 2 mm in thickness. High voltage electrode was either sharpened metallic pin of 1mm in a diameter and perpendicular to the barrier or metallic strip (7x35mm^2) of thin foil (20μm) located on the barrier. To exclude the influence of the surface charge deposited by preceding pulses and to diminish the contribution of a displacement current in total discharge current we used every time a single and long negative high-voltage pulse (about 1ms) with variable amplitude (up to 25kV) and moderate rise time (about 10kV/μs). Taken together these enable us to trace thoroughly a spatial-temporal evolution of plasma sheet formed by pulsed NSDBD and to find out a correlation of this evolution with discharge current. The current and voltage waveforms were recorded with a Tektronix digital oscilloscope DPO2024. The behavior of plasma sheet on the barrier was observed by use of a multiframe high-speed camera (LV-03).

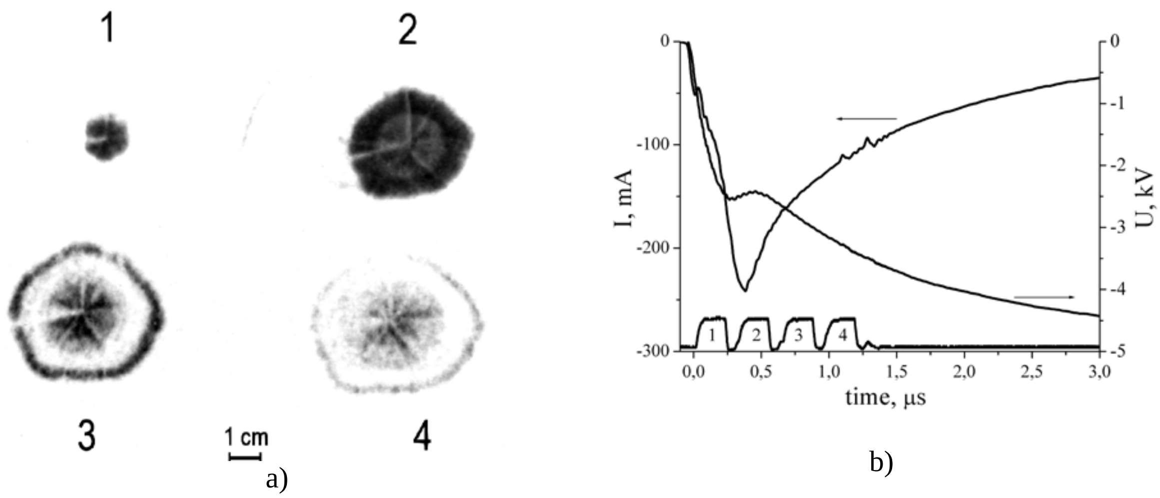
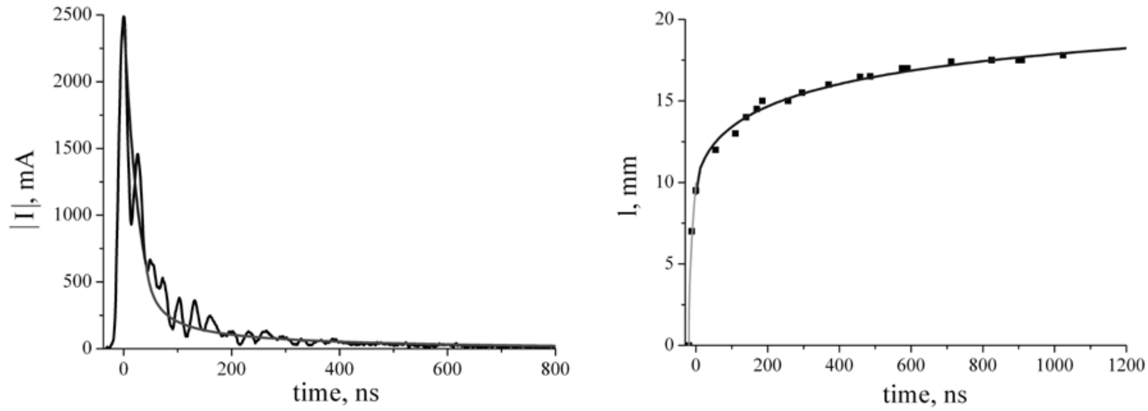


Fig. 1: **a**) The set of four successive instant images of plasma sheet in a pulsed pin-to-plane NSDBD in Ar at atmospheric pressure. Exposure time of each frame is 200 ns; time interval between neigbour frames is 100 ns; figures 1-4 numbering the frames in Fig.1a) correspond to those in Fig.1b; **b**) The current I and voltage U waveforms of the pulsed NSDBD; rectangular pulses (1-4) at the bottom of Fig.1b show a time position of the frames presented in Fig.1a.

The results presented in Fig.1 show clearly that plasma sheet in the pulsed NSDBD expands over barrier not only at the stage of current rise but during the stage with diminishing current as well. The similar behavior exhibits also the pulsed NSDBD in air at 300 and 750 Torr.



a) b)

Fig. 2: a) the experimental (uneven curve) and calculated (even curve) waveform of current for pulsed NSDBD in air at pressure of 300 Torr; b) the dependence of of plasma sheet length *l* vs time (squares – experiment, smooth curve – theory).

Figure 2 presents results for NSDBD in air at pressure of 300 Torr on dynamics of both the discharge current (a) and the length of plasma sheet vs time. In this case high voltage electrode is the strip and amplitude of the applied pulse is -13 kV. One can see in Fig.2b that plasma sheet quickly spreads out to ≅9mm during short current rising stage and slowly spreads out from 9 to 18mm in the course of the stage with diminishing current.

One can show that one-dimensional distribution of an electric potential *U(x,t)* over barrier surface is ruled by the equation similar to the diffusion equation:

$$\frac{\partial U}{\partial t} = \frac{\Delta \cdot 1m}{C} \frac{\partial}{\partial x}\left[\frac{1}{R}\frac{\partial U}{\partial x}\right] \qquad (1)$$

Here Δ is the thickness of plasma sheet; R and C are the reduced resistivity of a plasma sheet and capacity of a barrier respectively; dimensions of R an C are $[R] = Ohm \cdot m$ and $[C] = F/m$.

Based on physical resonings, the development of a pulsed NSDBD can be split into three stages. First stage corresponds to quick growing the discharge current accompanied with fast spreading the plasma sheet. The solution of the equation (1) for this stage gives the dependence for the discharge current I_1 and plasma sheet length l_1 vs time as follows:

$$I_1 \sim \sqrt{t} \text{ and } l_1 \sim \sqrt{t}\,. \qquad (2)$$

First stage is finished when electric potential on the barrier near the high voltage electrode arrives to the amplitude of the applied voltage. It means that distribution of electric potential *U(x)* formed to the end of the first stage is unhomogeneous along the barrier. So the second stage is associated with a quick levelling of the potential along the whole length of plasma sheet formed. Roughly, the length of plasma sheet practically does not change at this stage but the current exponentially diminishes:

$$I_2 \sim \exp(-\alpha t). \qquad (3)$$

The third stage starts approximatelly at the moment when the applied potential approaches to the edge of plasma sheet formed at the first stage. The solution of the equation (1) for the third stage gives the dependence for the discharge current I_3 and the length of plasma sheet l_3 vs time as follows (these formulae take into account the recombination of plasma in a plasma sheet):

$$I_3 \sim \frac{1}{\sqrt{\frac{1}{\beta}\cdot \ln(1+\beta t)}} \qquad l_3 \sim \sqrt{\frac{1}{\beta}\cdot \ln(1+\beta t)} \qquad (4)$$

Mathematical checking of the dependences (2)-(4) on existence of an accordance with experimental data showed a good agreement between experiment and theory (see Fig.2).

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