Experimental study of transient forms of dielectric barrier discharge

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Abstract: In present article various forms of pulsed dielectric barrier discharge (DBD) has been investigated. The transition from filamentary mode to homogeneous mode of DBD has been investigated. New type of DBD, called synchronously-streamer filamentary (SSF) mode of DBD, was investigated.

Keywords: dielectric barrier discharge, non-equilibrium plasma, atmospheric pressure glow discharge, surface treatment.

1. Introduction

For many practical applications the task of finding the source of homogeneous nonequilibrium plasma at atmospheric pressure in the air is very important [1]. Homogenous DBD is a promising source of homogenous air plasma at atmospheric pressure. [2]. Homogeneous barrier discharge is known for a long time. [3]. Homogeneous barrier discharge is one of the main tasks is to investigate a criteria of transition of DBD from filamentary to homogenous form. The main criteria of existence of DBD in homogenous form is the following: duration of the front of voltage pulse is smaller than the time of development of the streamer [4]. For electrode gap ~ 1 mm time of streamer development is about 10 ns. However this case does not give the real moment of transition because it happens at much durations of the voltage pulses. Also important is to determine limits of the existence of DBD in different forms.

2. Experimental setup and methods

DBD is formed by applying high voltage pulses to electrodes separated by a layer of dielectric. Experimental setup is shown on fig.1. DBD is formed in the gap between two electrodes. Upper electrode is covered in quartz. Sample can be placed between electrodes. Discharge system is placed in hermetic chamber. If needed, the chamber can be evacuated to the pressure about 5% of atmospheric, can be filled with plasma forming gas or work in the flow of the gas. High voltage electrode is a piece of aluminum foil with a wire attached placed in the quartz breaker with flat bottom. For photographing the photosensitive film was placed in the gap between electrodes. Duration of the pulse was formed by means of the scheme on fig.2.

3. Experimental results and analysis

The change in the form of barrier discharge with decreasing of the front of the voltage duration was investigated. It was shown that decreasing the duration of the front to 1 μs one can observe a new type of barrier discharge – synchronostreamer barrier discharge. Photographic investigations of an individual pulse showed that it has filamentary space structure. No individual current peaks typical for classic DBD are
present (fig.3). Instead, one can observe fast and powerful pulse, so one can suggest that all streamers overlap the discharge gap synchronously. Moreover the current in this type of discharge flows after the discharge (plasma channels continue to exist).

It was shown that this effect is caused by a mechanism of ultraviolet synchronization of streamers. This radiation of energetic photons, which are radiated in the streamer and start photonization in adjacent areas and initiate the growth of streamers due to the electron avalanches in the whole discharge gap.

For calculation of the evolution of the electric field in the air discharge gap waveforms typical for synchronostremer and homogenous DBD were considered. Capacity of the discharge system was considered as a capacity of two planar capacitors (one filled with air, the other filled with dielectric) with capacities $C_a=9$ pF and $C_d=70$ pF connected in series and parasite capacity $C_s=30$ pF. (fig. 5). Before the discharge capacitive current is $I_c = \frac{dU}{dt}*(C_a+C_s)$, after the discharge streamers overlap the discharge gap and capacity of the system is $(C_d+C_s)$, capacitive current is $I_c = \frac{dU}{dt}*(C_d+C_s)$.

Calculated observed currents before and after the discharge are in a good agreement (fig.6). The fact that after the discharge capacitive current corresponds to the case of the discharge system that has only dielectric capacitor points to the fact that the electric field is constant after the discharge and doesn’t affect the derivative of the voltage. After streamers overlap the discharge gap (almost synchronous) plasma channels continued to exist. The electric field, needed to sustain plasma in conducting current (that flows in the process of continuous voltage rise) channels, is almost constant.
Using waveforms of current and voltage the discharge voltage was determined ($U_{\text{disch}}=8.7\, \text{kV}$) and mean electric field in the air gap is calculated ($E_a=30.8\, \text{kV/cm}$, which is close to the discharge field in air). Before the discharge the mean electric field could be found as:

$$E_{\text{mean}}=\frac{U}{d}\frac{C}{C_a}$$

(1),

where

$$C=C_a\cdot C_d/(C_a+C_d)$$

(2).

$E_{\text{mean}}$ in the moment of the discharge is:

$$E_{\text{mean}}=\frac{1}{d}\left(\frac{U}{d}+\frac{q_{\text{f}}}{}\right)$$

(3),

Flowed charge is:

$$q_{\text{f}}=\int_{t_a}^{t_b} i_d(t)\, dt$$

(4).

Thus the full picture of the development of the discharge in the discharge is obtained (fig. 7).

Fig. 7 Evolution of electric field in air discharge gap in SSF DBD.

In case of homogenous DBD the duration of the discharge is comparable with the duration of the voltage pulse. Moment of the discharge could be determined comparing measured current with the calculated capacitive current for the discharge system with the capacity of the air capacitor (as it was mentioned before before the discharge, the measured current matches capacitive (fig.8).

Fig. 8 Current waveforms and calculated displacement current

Thus in the case of SSF DBD there is no overvoltage and during the passing of a group of streamers charge appears on the surface of the dielectric that causes the shielding field, that lowers the mean field in the gap and prevents the development of the streamers in areas where streamer was formed. If the overvoltage is large, the resultant field is higher than the discharge field one has homogenous DBD (fig.10). $E_p-E_0\geq E_{br}$ can be defined as a criteria of the homogeneity of the barrier discharge.

Fig. 9 Evolution of electric field in air discharge gap in homogenous DBD

Fig. 10 Schematic illustration of criteria of homogeneity of the DBD
It was shown that increasing the discharge gap one decreases mean number of streamers on the surface of the electrode and the surface area of the gliding discharge increases and by decreasing the duration of the pulse the surface area of the gliding discharge increases but with lower rate and coefficient of surface homogeneity $K$ (ratio of treated and full area) increases until discharge doesn’t change into the homogenous form (fig. 11).

![Fig. 11 The dependence of the number of microdischarges per unit of surface and diameter of the creeping discharge area on the surface of the dielectric on $\tau$ for different values of the discharge gap](image)

To estimate the moment of transition of barrier discharge from filamentary to homogenious mode experimental dependence of coefficient of surface homogeneity was approximated by power function and intersections with $K=1$ were measured. Thus estimations of the fronts of the pulses, corresponding to the transition of the barrier discharge to homogenous form for different electrode gaps were found (fig. 12).

There are two important applications for the homogeneous DBD investigated in this paper. Both applications are extremely sensitive to the uniformity of surface treatment and filamentary DBD is unacceptable for them. The first application is the treatment of polymer gas separation membranes by plasma of DBD to increase separation efficiency up to 100 times and more.

![Fig. 12 The boundary of the existence of DBD in filamentary and homogenous modes](image)

The second application is the treatment of polymer microporous matrixes for medical applications. To increase hydrophillicity of pores surface homogenous mode of DBD have been used and hopeful results have been obtained.

4. References

