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On the Self-Organization of Dielectric Barrier Discharges

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Abstract

The present paper contains experimental analysis of the spatiotemporal structure of atmospheric pressure dielectric barrier discharge (DBD) in a packet-pulse excitation mode widely used as an effective tool for plasma modification of various media. The motivation is the need to optimize the conditions for DBD plasma obtaining with a homogeneous diffuse structure. It is shown that for a discharge gap of the millimeter range (1–3 mm) in atmospheric air, under certain conditions, a number of new plasma phenomena are possible - the effects of an increase in the density (total number) of filamentary discharges over time, both unchanged and with a decrease in the area of the filaments, as well as the formation of complex space-time structures. An interpretation of this phenomenon is proposed. Homogeneous diffuse discharges are obtained in a standard electrode configuration with a single dielectric.

Keywords: Atmospheric Pressure Dielectric Barrier Discharge; Space-Time Effects of Microdischarges; Homogeneous Diffuse Discharges; Self-Organized Structures

Introduction

Non-thermal atmospheric pressure plasma generated by dielectric barrier discharge (DBD) has been intensively studied for a long time and is widely used in various industrial applications due to its high efficiency and low operating costs [1,2]. In general, DBD at atmospheric pressure appears in a thread-like form (microdischarges), which sometimes leads to uneven surface treatment and local damage to the treated surface [2]. There are also spatiotemporal features of these discharges, due to the presence of several forms of discharges - filamentary (i.e., inhomogeneous), diffuse (uniform), volumetric and surface, as well as the transition of one to another over a certain time (i.e., temporal instability), or their simultaneous excitation (mixed mode). This circumstance limits the prospects for the industrial application of microdischarges. In our case, the task was to identify new stable modes of occurrence of volumetric DBDs and the transition from the indicated mode of inhomogeneous discharges to more homogeneous, so--called diffuse discharges, as well as to a mixed mode. In this study, an attempt was made to optimize the conditions for the production and use of filamentary DBDs by varying the interelectrode distance, applied voltage, parameters of the mesh electrode and the design of the discharge cell (one or two dielectrics used), as well as the state of the surface of the massive electrode.

It is shown that varying the applied voltage for given parameters of the mesh electrode and mechanical treatment of the surface of the massive electrode makes it possible to stabilize the microdischarge pattern over time and increase its reproducibility. It has been established that by reducing the discharge gap in the simplest geometry with one dielectric in a pulse-packet mode, a complete transition to homogeneous diffuse discharges is possible. The effectiveness and purpose of a particular discharge mode is determined by its practical significance, and the question of obtaining homogeneous discharges is of an independent nature [3]. The new forms of the pattern of filamentary discharges (filaments) discovered by us in a geometry with two dielectrics are explained in the literature in the framework of the processes of self-organization of microdischarges, which allows us to better understand the physical properties of DBD plasma.

Experiment

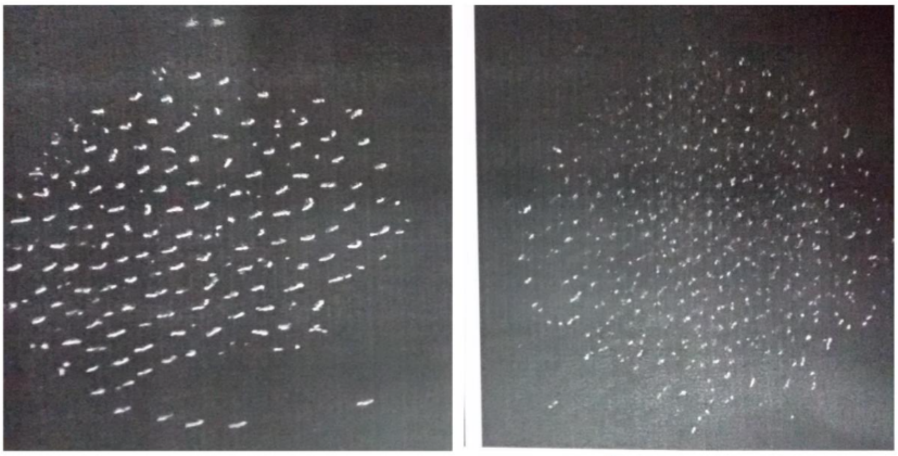
Excitation of dielectric barrier discharge was carried out in a plane-parallel electrode configuration with a diameter of 120 mm, one of which is mesh steel with a cell size ~ 1 mm, and the second is solid copper. In some cases, the surface of the copper electrode was subjected to mechanical processing (cleaning by grinding). The electrode distance varied between d = 1 3 mm. A glass plate with a thickness of ~ 1.5 mm was used as a dielectric covering the mesh electrode. There were considered variants of DBDs with a dielectric coating of only one electrode, as well as the case of a dielectric coating of both electrodes. A packet-pulse excitation mode in the form of a train of decaying alternating spikes with a repetition frequency of packets f 1 kHz at an effective pulses frequency in the packet of several tens of kilohertz was used. The applied voltage (peak-to-peak value) was up to U = 20 kV and measured using a high-voltage capacitive compensated voltage divider. The electrical characteristics of the barrier discharge were studied using a GDS-72204E digital storage oscilloscope. Pictures of the discharge were obtained using a digital camera Canon PowerShot SX50HS in the direction normally to the plane of the electrodes. The average energy of the DBD for the period of the excitatory pulse (E_{max}) was measured by Lissageu's method [3].

Results and Discussions

It was established that in the packet-pulse mode of DBD excitation at voltages U ~ 15 16 kV for the discharge gap of 3 mm there is an increase in the total number of filamentary discharges within t = 2 3 min after the onset of excitation (Figure 1, non-cleaned copper electrode surface), or "spatial compression" - narrowing of the area of occurrence of discharges (Figure 2, cleaned electrode surface). For cleaned electrode surface, a partially diffuse discharge is also observed (Figure 2b). A similar temporal effect, but manifested in the DBD area broadening accompanied by a change of modes (filamentary - diffuse and mixed discharges) was observed earlier in [2] were a sinusoidal excitatory pulse with a repetition frequency of f ~ 10 kHz was applied to the discharge with small gap distance d ~ 0.1 1.0 mm.

In our case, at such small discharge gap, no discharge compression is obtained, as it was observed at d = 3 mm, but we observed a transition over time to a homogeneous (diffuse) discharge over the entire area of the electrode (Figure 3).

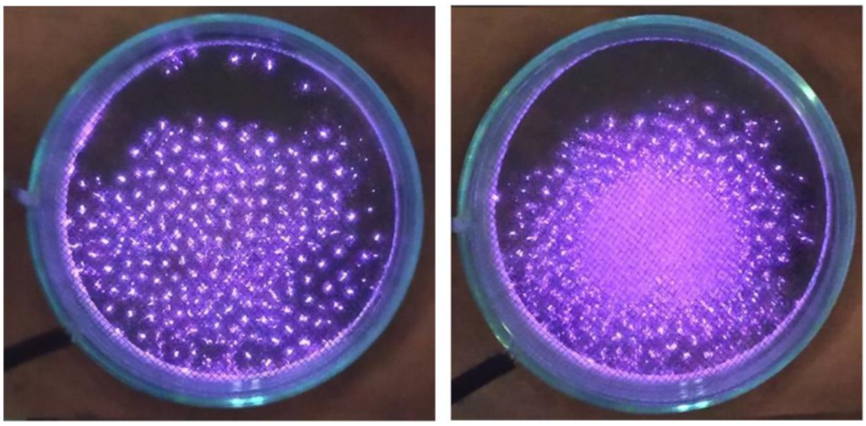
In the case of using a reactor with two dielectrics, a complex picture of filaments and diffuse discharges in the form of stationary and mobile chains of various shapes is observed (Figure 4, cleaning copper), depending on the applied voltage and the magnitude of the discharge interval. Similar space-time structures have been observed previously (for example, /4-8/), but the characteristic properties and conditions of excitation differ from those given. At the same time, for d = 2 mm, there are more pronounced structures than in the case of d = 3 mm. However, over time, after t = 2 3 min of the discharge burning, the discharges behave approximately the same as in the case of one dielectric for a gap of 3 mm, i. e. they are concentrated, and in the future the discharge pattern stabilized.



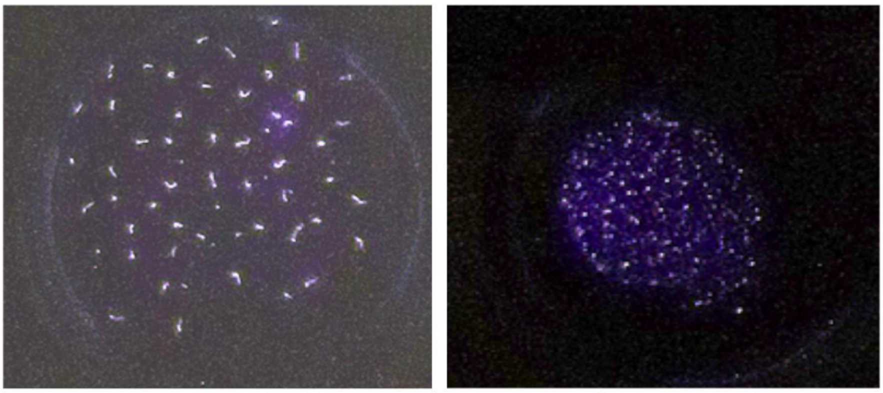
a *b*

Figure 1: The effect of increasing the density of filamentary discharges over time without changing the area of occurrence of filaments at non-cleaned copper electrode surface.

U ~ 15 16 kV, d = 3 mm, t = 0 (a), 10 (b) min



a *b*



c *d*

Figure 2: The effect of increasing the density of filamentary discharges over time with a decrease in the area of filaments occurrence. Partial conversion to diffuse discharge at cleaned copper electrode surface (b).

U ~ 15 16 kV, d = 3 mm, t = 0 (a,c), 10 (b,d) min

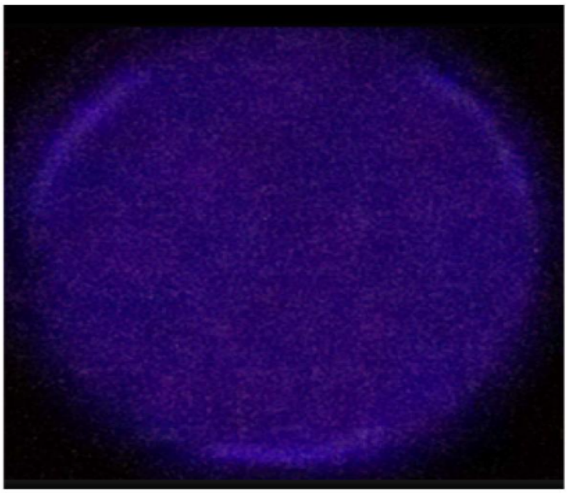


Figure 3: Excitation of homogeneous diffuse discharges.

U = 16 kV, d = 1mm, t = 10 min

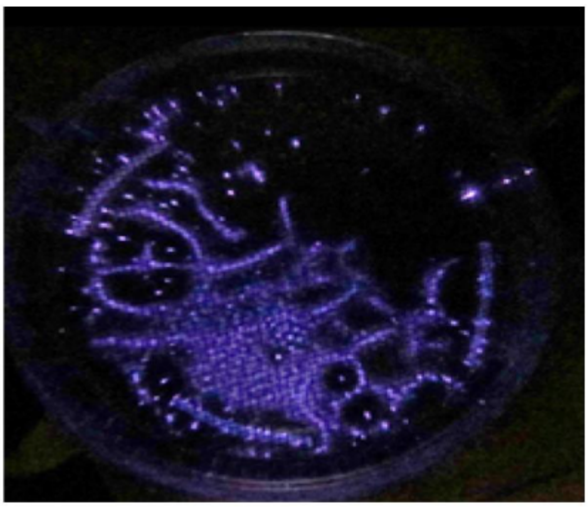


Figure 4: Formation of self-organized structures (case of using a reactor with two dielectrics).

U = 13 kV, d = 3 mm, t = 0 min

In order to optimize the conditions of excitation of DBD discharges, it was interesting to find out the dependence of the time pattern of discharges on the state of the surface of the lower electrode and the magnitude of the applied voltage. The comparison shows that with an untreated surface, unlike the case of treated and relatively low voltages U ~ 5 7 kV, filamentary discharges do not occur and surface (diffuse) ones develop. With a further increase in the applied voltage, the discharge pattern differs little for both cases. However, at U = 16 kV, the area of "compressed" discharges close to the ring is larger and more homogeneous when cleaning the copper plate. In this area, the surface density of discharges is higher than at the initial moment.

The dependence of the average energy of the DBD for the period of the excitatory pulse (E_{max}) on its amplitude, exposure time (t) and other factors was studied. At the same time, Lissageu's energy measurements give values to E_{max} = 6 10 mJ for U = 12.5 kV and ~ 25 mJ for $U \geq$ 16 kV. Reducing the applied voltage from U ~ 16 to 12.5 kV leads to a decrease in the time fluctuations of the E_{max} value. At the same time, the discharge picture does not visually undergo significant changes over a long time $t \geq$ 30 min at a pulse packet repetition frequency f ~ 1 kHz without breakdown phenomena, which indicates the stabilization and reproducibility of the operating mode. The above behavior of DBD discharges for the case of using two dielectrics in a discharge cell characterizes them as self-organized structures [9]. The study of the relevant processes is important for a better understanding of the fundamental properties of non-heated DBD plasma.

Conclusion

It is shown that in the packet-pulse mode of excitation of DBD for discharge gap of the millimeter range (~ 3 mm) in atmospheric air under certain conditions, a number of new plasma phenomena are possible - the effects of increasing the density (total number) of filamentary discharges over time both unchanged and with a decrease in the area of occurrence of filaments, as well as the formation of complex space-time structures that have not been observed before and can be explained by the processes of self-organization and should be a coupling of a discharge filaments pattern and charge pattern in a dielectric surface.. Homogeneous diffuse discharges in electrode configuration with one dielectric were obtained for a gap distance of 1.0 mm. Some optimal conditions of DBD excitation for stabilization of its energy characteristics and obtaining the discharge with a homogeneous diffuse structure are determined.

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