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Effect of Electrodes Geometry on Self-Organization of Microdischarges in Dielectric Barrier Discharge

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Abstract – **Although self-organization of microdischarges in dielectric barrier discharges was intensively studied during the last century, the effect of electrodes geometry, or the interaction between microdischarges and their own current's magnetic field, discussed in this paper, has been revealed only recently. It is responsible for the formation of very different microdischarge patterns, volt-ampere characteristics, and critical parameters.**

Keywords – **dielectric barrier discharge, microdischarges, volt-ampere characteristic, critical parameters, burning voltage.**

I. Introduction

There has been considerable interest in non-thermal atmospheric pressure discharges plasma over the past decade due to the increased number of its industrial applications. Diverse applications demand a solid physical and chemical understanding of the operational principals of such discharges, [1].

In contrast to a glow-discharge, the dielectric barrier discharges (*DBDs*), at low frequency and atmospheric pressure, consist of a large number of bright filaments distributed in the discharge gap, so called "families" of microdischarges. These filaments are actually microdischarges that repeatedly strike at the same place as the polarity of the applied voltage changes, thus appearing as bright filaments to the observer's eye.

It is implied by microdischarge patterns observed that the microdischarge interaction should have two main features:

- repetition of microdischarges at the same place during each voltage cycle due to the existence of a pre-ionized channel (and surface charge) left by the previous microdischarge - microdischarge *remnant*: the so called *memory effect*. This effect results in the formation of bright filaments.

- "repulsion" of nearby microdischarge within the same voltage cycle by the microdischarge *remnant*, because of local electric field distortion. This "repulsion" results in the self-organization of microdischarges into a regular structure.

Self-organization of microdischarges appears to be a strong effect and dominant feature of the dielectric barrier discharge. The underlying memory and repulsion effects thus create quasi-Coulomb crystal patterns in *DBDs*, [1].

The short duration of microdischarges leads to a very low overheating of the streamer channel, and the DBD plasma remains strongly non-thermal. The principal microdischarge properties for most of the frequencies depend not on the characteristics of the external circuit, but just on the gas composition, pressure, and electrode geometry and configuration.

Electrode geometry and configuration is in position to provoke various schemas of electromagnetic interaction between microdischarges into a regular structure and the magnetic field of currents through electrodes. This electrodes geometry effect (*EGE*) needs a change in microdischarges self-organization, and different "crystal" patterns in *DBDs*. It exerts strong influence on the breakdown conditions and avalanche transformation into a streamer that modify the DBD volt-ampere characteristic, burning voltage, and critical parameters of operating (oxygen and nitrogen) areas – the breakdown voltages and currents, [2].

The aim consists in identifying *EGE* or the influence of the magnetic field of currents through electrodes upon microdischarges patterns by means of the *DBDs* volt-ampere characteristic and critical parameters of operating (oxygen and nitrogen) areas.

II. Experimental Investigations

The physics of microdischarges is based on an understanding of the formation and propagation of streamers, and consequent plasma channel degradation.

Instead, the probability of appearance of a streamer at the location of the microdischarge remnant increases when the voltage is switched. After the voltage is switched, the electric field of the microdicharge remnant adds to the strength of the applied electric field, thereby increasing the local field. The increased electric field increases the likelihood for a new streamer to occur at the same place. The net result is that if the original streamer was formed just before voltage switching, there is an increased probability of streamers occurring at the same place or in its nearest vicinity.

The microdischarge interaction model, based on the assumption that avalanche to streamer transition and microdischarge formation are influenced by the microdischarge remnants interaction, allows us to perform a study of the influence of electrodes geometry, schema of power supply, and electrodes magnetic properties upon breakdown (burning) electric field $E_{b,1}$, and critical parameters – critical voltage $U_{cr,1}$ and current $I_{cr,1}$ of *DBD*, Fig. 1b.

AT – transformer for voltage regulation; HVT - step-up transformer; D1, D2, D3, and D4 – diodes allowing direct measuring of the average value of discharge current I_{avg}.

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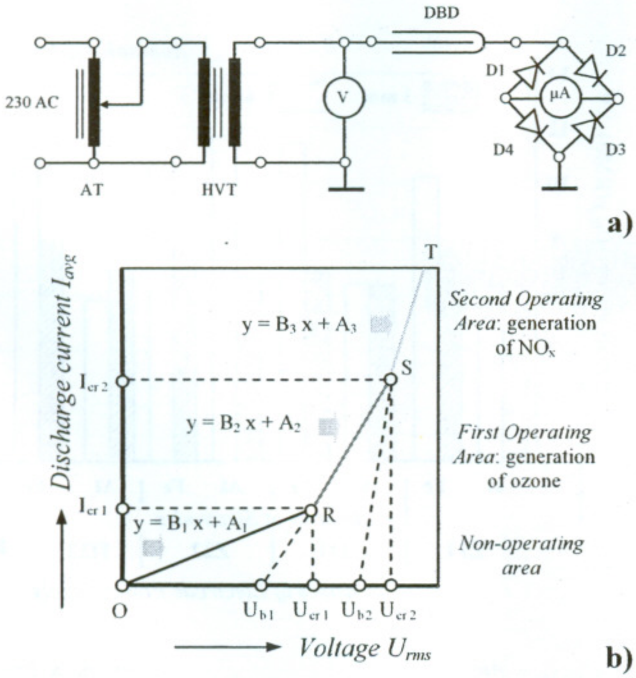

Fig. 1. Electric circuit of the experimental *DBDs* (**a**) and volt-ampere characteristic (**b**).

The electrode geometry and configuration, combined with the way of power supply to the electrodes, and the magnetic properties of electrodes define the strong interaction between microdischarge and electric currents passing through the electrodes themselves. The location of the electric power supply may be selected in a manner determining the realization of one of the two schemes of strong electromagnetic interaction, Fig. 2.

In such a way, the electrodes geometry effect (*EGE*) will be expressed in the impact of the electromagnetic interaction on elementary processes in the discharge gap for diverse shapes (having the same active area), various manners of power supply, and diverse materials (magnetic, non-magnetic) of the electrodes.

The exhibition of *EGE* is investigated experimentally on two flat-parallel electrode systems – *the first one*, with square electrodes: 150×150 mm, $S = 225$ cm^2, *the second one* – with rectangular electrodes: 75×300 mm, $S = 225$ cm^2, for two different distances d (3 and 6 mm) and different manner of power supply, Fig. 3.

Investigations are performed with two types of electrodes, namely by using non-magnetic (made of aluminum) or magnetic (made of cold-rolled electrical steel) electrodes. The magnetic electrodes should also change the discharges pattern and characteristics of *DBDs*. The dielectric barrier is made of alkali glass of thickness $b = 3$ mm.

The elementary processes (impact dissociation and impact ionization, electron avalanches, transition from avalanche to streamer; formation of discharges pattern and filaments, chemical reactions), which are conducted in the discharge gap, play different roles as regards not only the generation of ozone and products of its decay, but also the generation of nitrogen oxides. Generally, conditions for influencing the two burning regimes of *DBDs* are created.

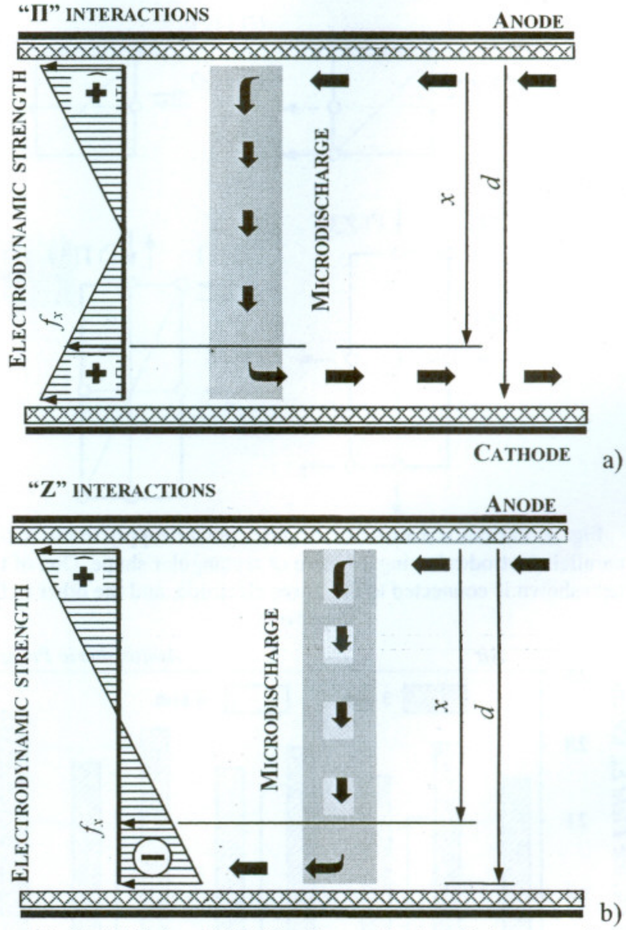

Fig. 2. "Π" (a) and "Z" (b) schema of microdischarges – electrodes currents strength interactions.

The external (volt-ampere) characteristic of *DBDs*, representing the relationship between the average value of discharge current I_{avg} and the root mean square value of the voltage applied across the discharge gap U_{rms}, reflects not only the existence of those two characteristic regimes of burning of *DBDs*, but also all the influences on elementary processes in the discharge gap, [2].

III. Results and Discussions

The external characteristics of *DBDs* have been plotted experimentally, discharge models have been worked out in accordance with [2], and according to Fig. 1b, for a minimal coefficient of linear correlation, not lesser than 0.9850, and then all the electrical parameters of the non-operating area, first and second *DBD* operating areas have been calculated: i) the stage processing the ignition of *DBDs*, or so called free or non-operating regime: intercept A_1, μA; and slope B_1, μA/kV; ii) the first stage of burning, or the first operating area: intercept A_2, μA; and slope B_2, μA/kV; burning voltage $U_{b,1}$, kV; critical voltage $U_{cr,1}$, kV, and critical current $I_{cr,1}$, μA; iii) - the second stage of burning, or the second operating area: intercept A_3, μA; and slope B_3, μA/kV; burning voltage $U_{b,2}$, kV; critical voltage $U_{cr,2}$, kV, and critical current $I_{cr,2}$, μA.

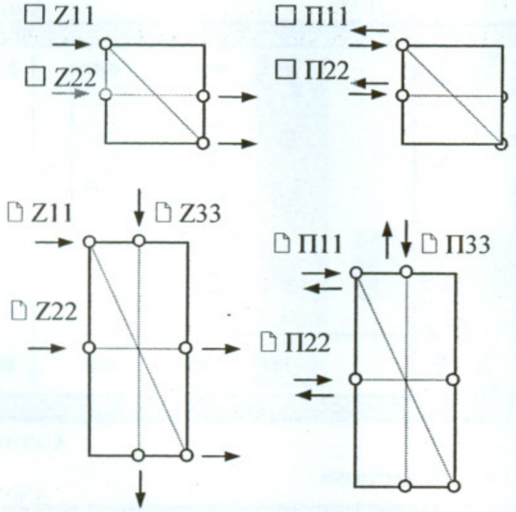

Fig. 3. Various schemes of electrodes power supply to the flat-parallel electrodes having a square or rectangular shape. One of the taps shown is connected to the lower electrode, and the other to the upper one.

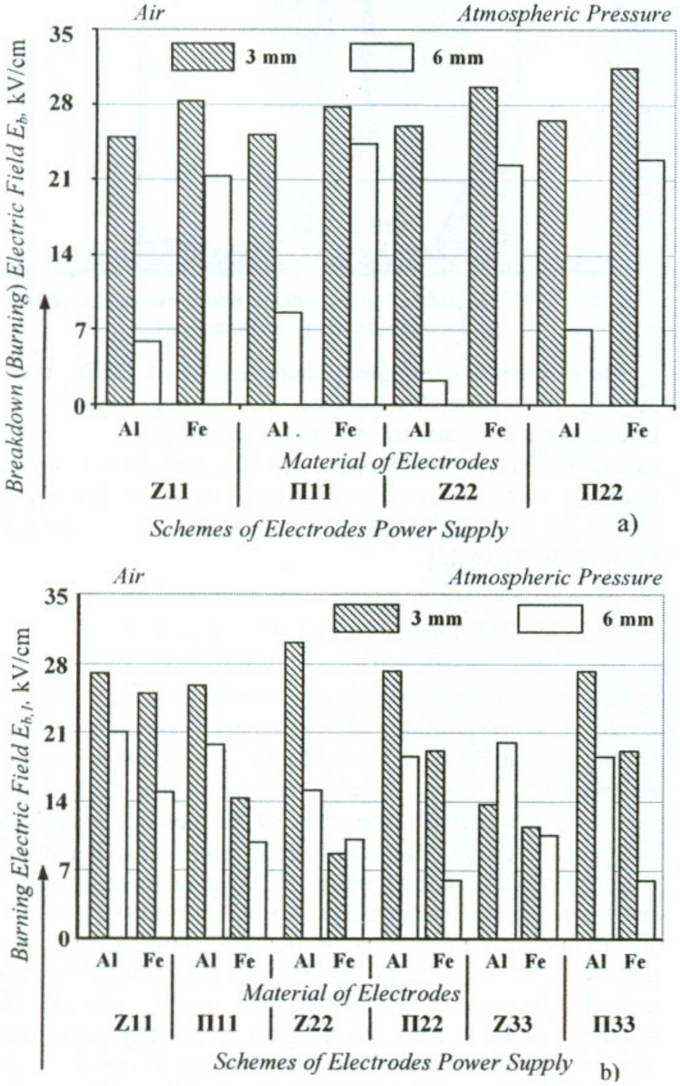

Fig. 4. Burning (breakdown) electric field $E_{b,1}$ of *DBDs* with square (a), and rectangular (b), aluminum (Al) and steel (Fe) electrodes, and different power supply schema (Z--, or Π--), according to Fig. 2.

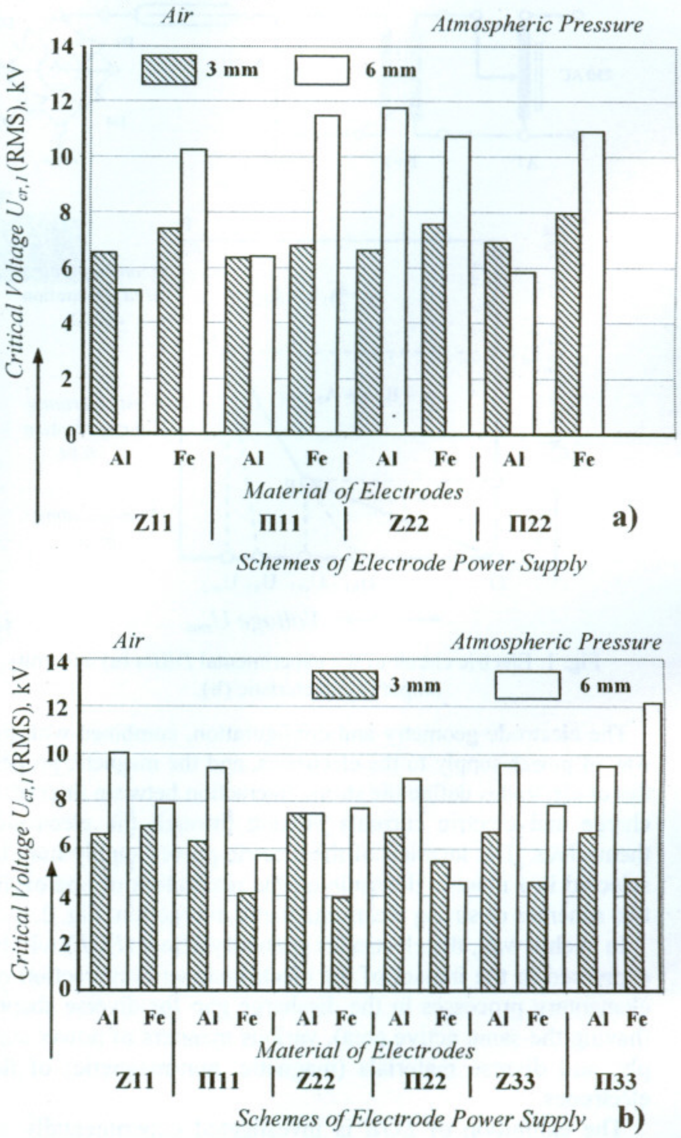

Fig. 5. Critical voltage $U_{cr,1}$ (RMS) of *DBDs* with square (a), and rectangular (b), aluminum (Al) and steel (Fe) electrodes, and different power supply schema (Z--, or Π--), according to Fig. 2.

The electrode shape (square or rectangular), way of "discharge-current" interaction ("Z" or "Π"), and characteristic manner of power supply (11, 22, or 33) exert substantial impact on the change in the main parameters of ignition and burning of *DBD,* Fig. 4, 5, and 6.

For square electrodes (Z11, Z22, Π11, and Π22), irrespective of the size of working gap *d*, using of iron electrodes leads to an increase in the breakdown electric field $E_{b,1}$, Fig. 4a, whereas for rectangular electrodes the exactly opposite phenomenon is observed – a decrease in the breakdown electric field $E_{b,1}$, Fig. 4b.

The electric field of burning $E_{b,1}$, which remains constant in the first operating *DBD* area, changes within a very large range – from 2.34 to 31.56 kV/cm, that indicates considerable influence of the factors investigated, determining the *EGE*, and indirectly of its own magnetic field upon the elementary processes being conducted in the discharge gap.

The critical ignition parameters of *DBDs*, critical voltage $U_{cr,1}$, and critical current $I_{cr,}1$, shown in Figs. 5 and 6, also confirm the existence of substantial differences in the elementary processes, being conducted, under changes in the factors investigated, which is reflected by the magnitude of critical current $I_{cr,1}$, and respectively by the magnitude of critical voltage $U_{cr,1}$.

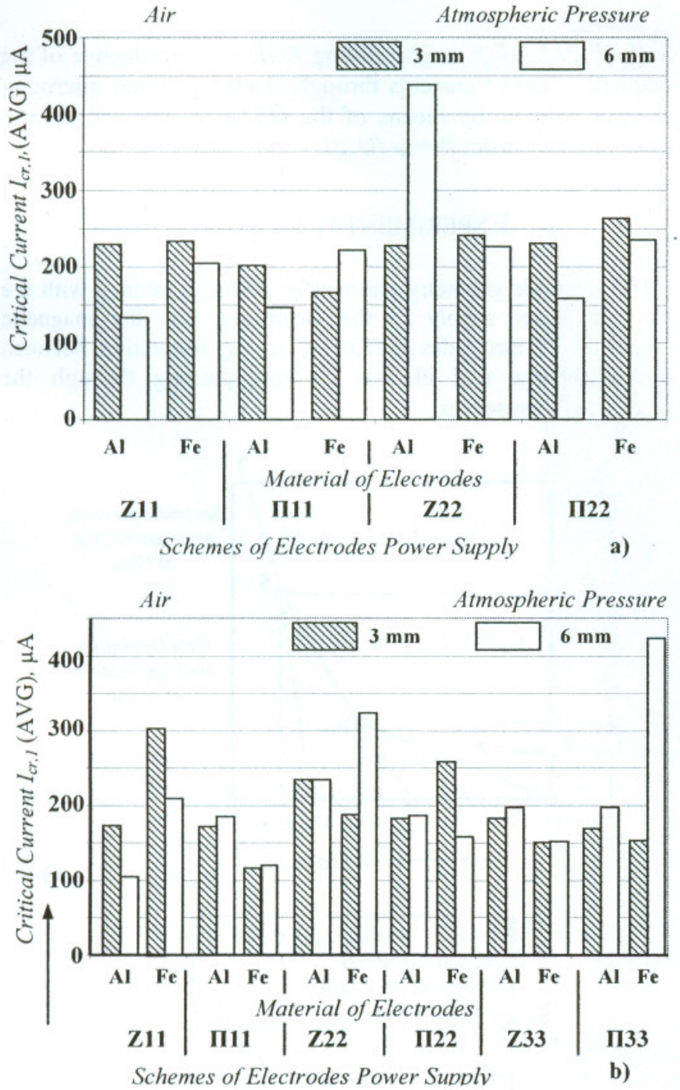

Fig. 6. Average value of critical current $I_{cr,1}$ of *DBDs* with square (a), or rectangular (b) aluminum (Al) or steel (Fe) electrodes, and different power supply schemes (Z--, or Π--), according to Fig. 2.

The observer is most impressed by the fact that in a great number of the cases studied the critical voltage $U_{cr,2}$ (RMS) exceeds 20 kV, i. e. there is no second operating DBD area in the voltage range investigated (up to 20 kV), whereas in other cases these values drop to 8.739 kV (Rec.Π11Fe-3 mm), 8.032 kV (Rec.Z22Fe-3 mm), 11.104 kV (Sq.Π11Al-6 mm), and 11.882 kV (Sq.Π22Al-6 mm). The value of critical current $I_{cr,2}$ also varies within a wide range – from 556 µA (Rec.Z22Fe-3 mm) to 1351 µA (Rec.Z11Fe-3 mm); from 297 µA (Sq.Z22Al-6 mm) to 1472 µA (Sq.Z11Al-3 mm).

In such a way, when certain conditions for the manifestation of a strong electromagnetic interaction between the microdischarges and current passing through the electrodes are created, by changing the geometry, power supply and material (magnetic or non-magnetic) of electrodes it is possible to influence to a very great extent the elementary processes in the discharge gap of *DBDs*. This fact is revealed by the volt-ampere *DBDs* characteristics and parameters of the discharge, which determine the ignition, burning, and operating areas of the existence of oxygen plasma and plasma of nitrogen oxides.

IV. Conclusion

As a result of the experimental investigations performed for two geometrical shapes (square and rectangle) of the electrodes, various schemes of power supply and materials of the electrodes - magnetic and non-magnetic, the following main conclusions can be derived:

- the electrode geometry effect, which consists in the geometry impact, manner of power supply, and magnetic or non-magnetic material of the electrodes does exist and can be successfully applied to creating *DBDs* plasma technological systems;

- the electrode geometry effect is expressed in a total change in the discharge volt-ampere characteristic, ignition and burning parameters of the discharge, and the operating areas of the ozone-and-oxygene-containing plasma and the plasma that contains nitrogen oxides;

- the two schemes selected (Z and Π) for strong magnetic interactions in the discharge volume allow revealing the impact of the magnetic interactions on the electrical behavior of *DBDs*;

- the present work formulates the problem of the impact exerted by the electrode geometry effect in the light of strong electromagnetic interactions.

Acknowledgement

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