Effect of Electrodes Geometry on Technological Behavior of Dielectric Barrier Discharge

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Abstract – **Effect of electrodes geometry on technological behavior of dielectric barrier discharge, 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 operating regimes of plasma-chemical surface functionalizing.**

Keywords – **dielectric barrier discharge, microdischarges, volt-ampere characteristic, true power, critical voltage.**

I. Introduction

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 $I_{avg} = f\,(U_{rms})$, breakdown (burning) voltage U_b, and true power P and power factor (cosine of the phase difference) of oxygen and nitrogen operating areas, Fig. 1a.

The true power P is a criterion of dissociation, ionization, and chemical reaction processes in air at atmospheric pressure. It can be determined quantitatively by calculating it (for quasi-harmonically changing supply voltage) from the experimentally plotted volt-ampere characteristic of *DBDs*, Fig. 1b.

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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* true power technologic characteristic: $P = \varphi\,(U_{rms})$.

II. Experimental Investigations

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.

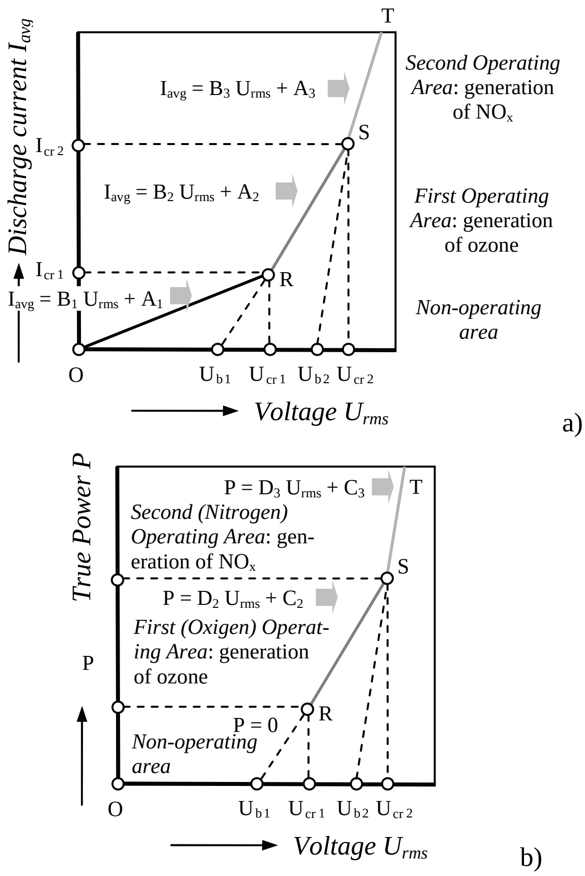

Fig. 1. Volt-ampere electrical characteristic (**a**) and technological characteristic (b) of *DBD* with first (or oxygen) operating stage *RS*; and second (or nitrogen) operating stage *ST*.

For a quasi-harmonic law of changing the supply voltage U (50 Hz) there exists the following relationship (*RS* and *ST*):

$$P = U_b \left(I_{avg} - I_{cr} \right) \tag{1}$$

$$I_{avg} = B\,U_{rms} + A \tag{2}$$

$$P = U_b \left(B\, U_{rms} + A - I_{cr}\right) \tag{3}$$

$$P = D\, U_{rms} + C; \qquad D = U_b\, B; \qquad C = A - I_{cr} \tag{4}$$

The ionization of the gas as well as all the chemical changes occurring in it and on the surface treated are conducted with electron exchange, which allows using the true power as a technologic characteristic, because the true electrical energy is proportional to the quantity of electricity carried through the discharge gap:

$$E = Pt = U_b \left(I_{avg}\, t - I_{cr}\, t\right) = U_b \left(Q - Q_{cr}\right) \tag{5}$$

where Q_{cr} is the critical quantity of electricity not causing ionization and chemical changes in the discharge gap.

The exhibition of *EGE* on the technological behavior of *DBDs* 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 (with the same area), for two different distances *d* (3 and 6 mm) and different manner of electrodes power supply, Fig. 3.

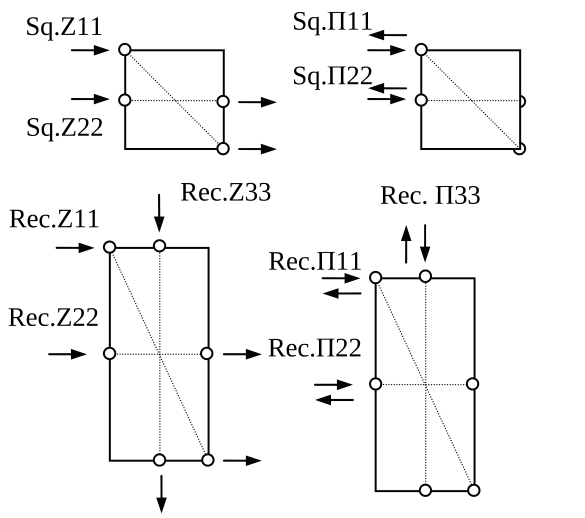

Fig. 2. Various schemes of electrodes power supply to the flat-parallel electrodes having a square or rectangular shape. One of the taps shown is connected to the lower electrode, and the other to the upper one.

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 technological characteristics of *DBDs*. The dielectric barrier is made of alkaline glass of thickness *b* = 3 mm.

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 burning regimes of *DBDs*, but also all the influences on elementary processes in the discharge gap, Fig.1, [2].

III. Results and Discussions

The volt-ampere 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 parameters of the non-operating area, first and second *DBD* operating areas have been calculated.

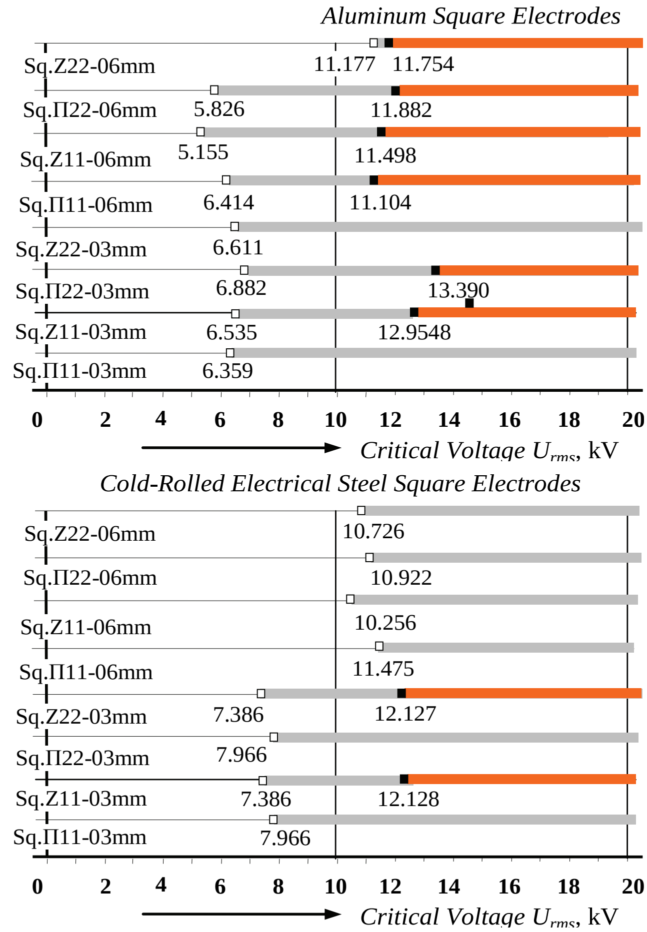

Fig. 3. Operating burning regimes of *DBDs* with square aluminum, and cold-rolled electrical steel electrodes, different discharge gaps and electrodes power supply schemes (Z--, or Π--), according to Fig. 2 – critical voltages $U_{cr,1}$ and $U_{cr,2}$ (RMS).

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 critical parameters of ignition and burning of *DBDs*, including critical voltages $U_{cr,1}$ and $U_{cr,2}$, Figs. 3 and 4.

For square electrodes, irrespective of the size of discharge gap *d*, using of iron electrodes leads to an increase in the critical voltage $U_{cr,1}$, Fig. 3, whereas for rectangular electrodes the exactly opposite phenomenon is observed – a decrease in the critical voltage $U_{cr,1}$ (to the exclusion of scheme Rec.Π33-0.6 mm), Fig. 4.

The second (nitrogen) operating regime occurs in only 19 of all the 40 cases investigated (i. e. in ca. 48 % of them), Figs. 3 and 4.

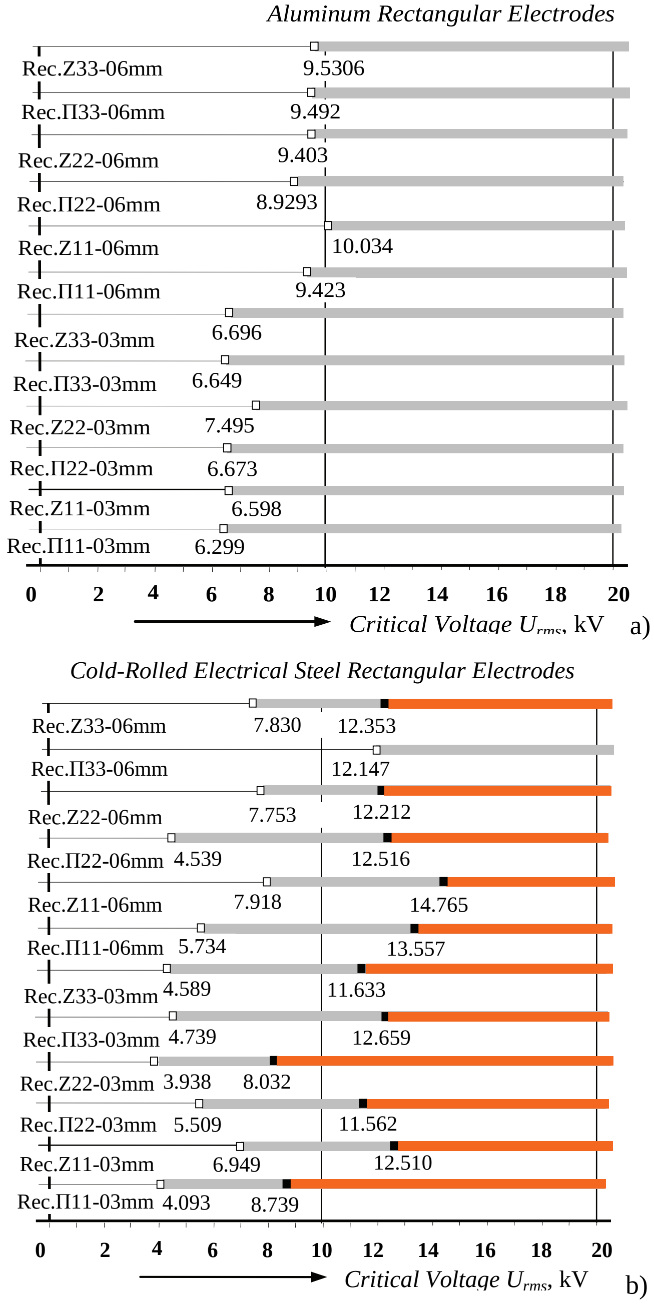

Fig. 4. Operating burning regimes of *DBDs* with square aluminum (a), and cold-rolled electrical steel electrodes (b), different discharge gaps and electrodes power supply schemes (Z--, or П--), according to Fig. 2 - critical voltages $U_{cr,1}$ and $U_{cr,2}$ (RMS).

An answer should be given to the basic question: Will the *EGE* observed be practically advantageous when priority is given to operating regimes with high specific true power, i. e. true power per a unit of area or $p_V = P/V$; $V = S.d$?

The rectangular electrodes offer better and more various applications not only for a discharge gap of 3 mm, but also for that of 6 mm: *first*, for a discharge gap of 3 mm both the aluminum and cold-rolled electrical steel electrodes provide higher specific true powers – above 200 mW/cm^3, Figs. 5 and 6; *second*, for a discharge gap of 6 mm both the aluminum and cold-rolled electrical steel electrodes provide higher specific true powers – above 150 ÷ 200 mW/cm^3.

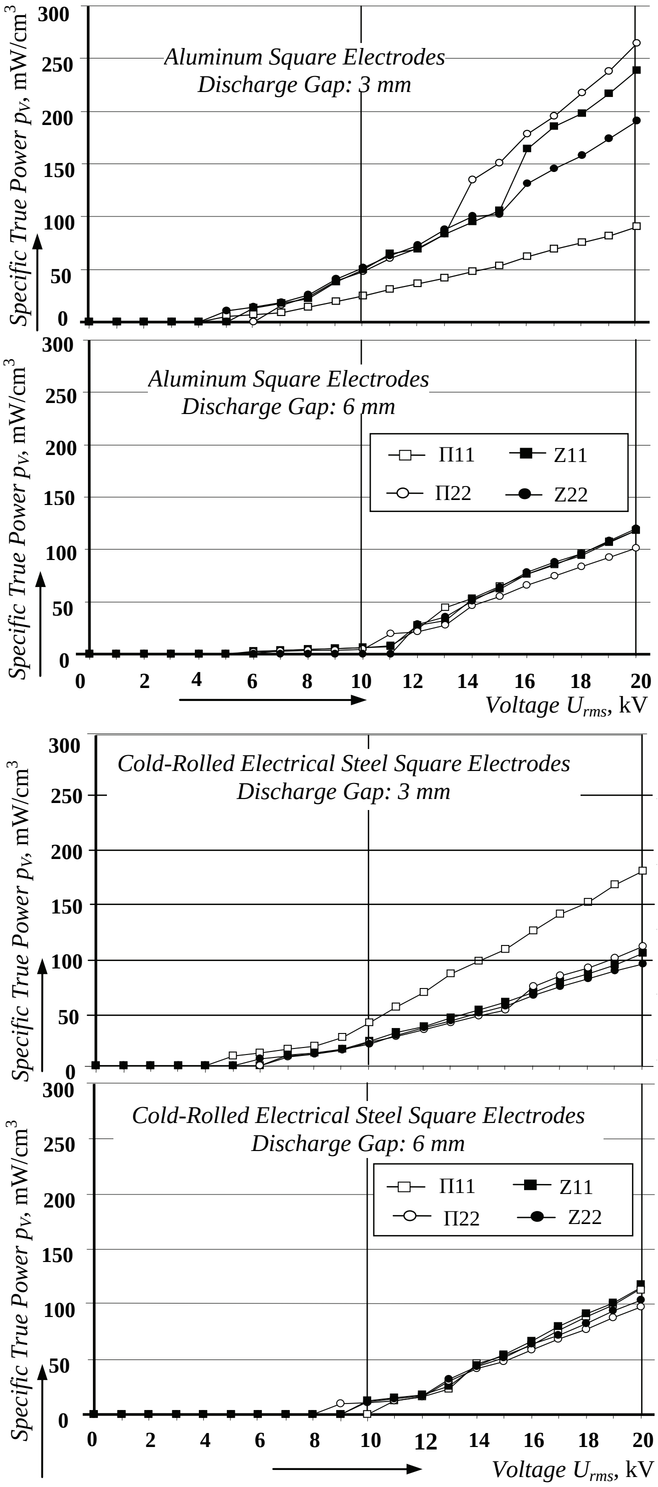

Fig. 5. Technological characteristics of operating burning regimes of *DBDs*, $p_V = \varphi\,(U_{rms})$, with square aluminum, and cold-rolled electrical steel electrodes, different discharge gaps and electrodes power supply schema (Z--, or П--), according to Fig. 2.

The magnetic electrodes allow realizing the ignition of *DBDs* at lower voltages – for square electrodes made of aluminum the minimal critical ignition voltage $U_{cr,1}$ is 5.155 kV; for square electrodes made of steel it is 7.386 kV; for rectangular electrodes made of aluminum this voltage is 6.299 kV,

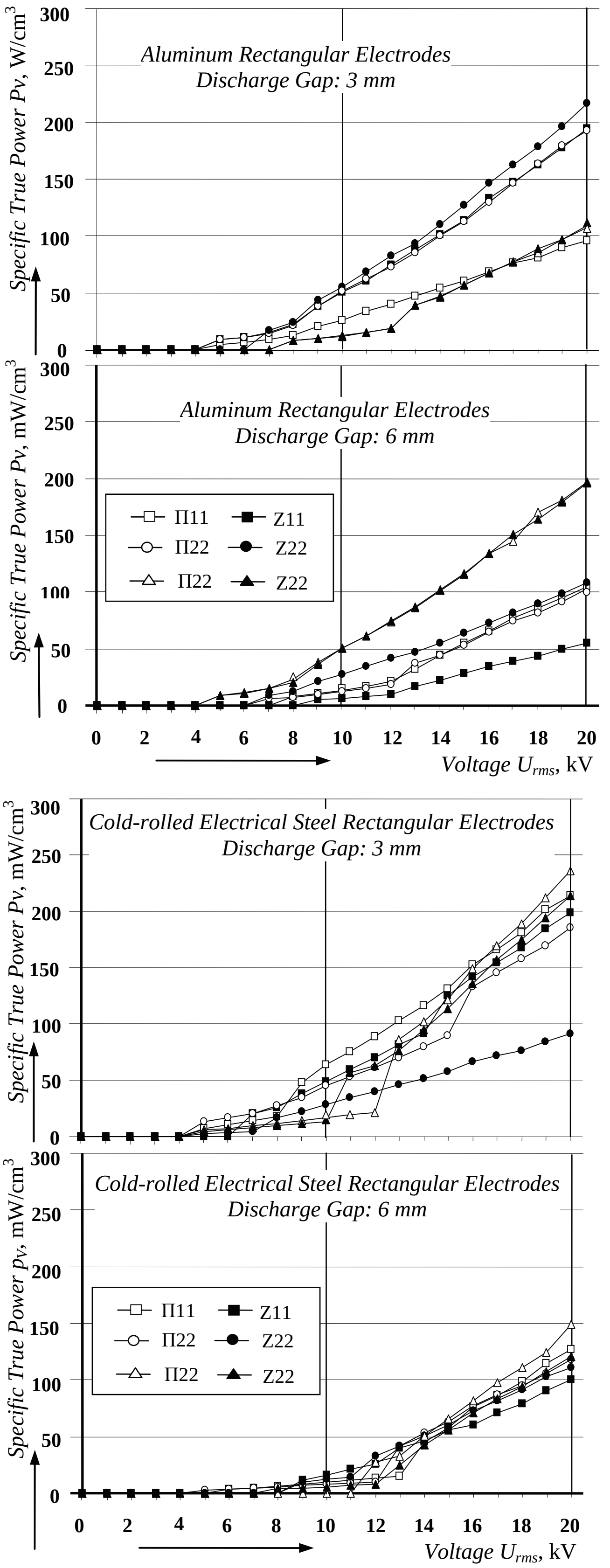

Fig. 6. Technological characteristics of operating burning regimes of *DBDs*, $p_V = \varphi\ (U_{rms})$, with rectangular aluminum and cold-rolled electrical steel electrodes, different discharge gaps and electrodes power supply schemes (Z--, or Π--), according to Fig. 2.

whereas for rectangular electrodes made of steel its values is 3.938 kV. The minimal critical ignition voltage $U_{cr,2}$ (oxygen operating regime) for square electrodes made of aluminum is 11.104 kV; for square electrodes made of steel it is 12.128 kV; for rectangular electrodes made of aluminum there is no such operating regime, whereas for rectangular electrodes made of steel the minimal critical ignition voltage is 8.032 kV, Figs. 3 and 4.

The experimental setup of the investigation performed unambiguously reveals the dependence of the elementary processes in *DBDs* from its own magnetic field. Introducing a ferromagnetic medium (electrodes) into the discharge area also influences the conducted elementary processes, their development being stimulated in some cases and suppressed in others.

IV. Conclusion

As a result of the experimental investigations performed for two geometrical shapes (square and rectangle), 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;

- a positive technologic effect should be sought not only in the direction of increasing the specific true power p_V in each of the two operating areas – oxygen and nitrogen operating regime of surface plasma treatment and functionalization, but also regarding the diminishment of respective critical ignition voltages $U_{cr,1}$ and $U_{cr,2}$.

- the electrode geometry effect is a hidden form of electromagnetic interactions and their impact upon the elementary processes in *DBDs*.

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References

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