Electric Characteristics Of Barrier Electric Discharge

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Abstract – **The external or static volt-ampere characteristic describes the behavior of the barrier discharge at the various stages of development and regimes of application. The technological regime of plasma-chemically active oxygen-containing plasma is examined. The effects of the non-uniformity of the electrical field of discharge, of the barrier gauge and of air gap size on the no-load regime of the discharge are shown.**

Keywords – **plasma treatment, cold plasma, oxygen-containing plasma, barrier discharge, external characteristic.**

I. Introduction

The barrier discharge has many technological advantages that impose its application to the technology of textile and textile fibers, the electronics and microelectronics, the printing industry [1].

The barrier technological discharge burns in air or in various gases and vapors at atmospheric pressure. The absence of a vacuum technological system is one of the great advantages of the barrier discharge in comparison to vacuum discharges used as sources of cold technological plasma, namely the *RF*- and glow discharges.

The great number of ionization and chemical processes going on simultaneously during burning of barrier discharge create certain difficulties not only for the description of this discharge, but also with respect to its control.

The experimental investigations [2] conducted for a continuous time period allow searching for a new integral description and control of the barrier discharge through its external characteristic expressing the relationship between the average value of the electrical current passing through the discharge and the effective value of applied voltage, Fig. 1.

Moreover, it has turned out that this characteristic can be presented by a broken polygon of three linear sectors corresponding to:

- ◇ the stage before discharge ignition or the so-called non-operating regime;
- ◇ the stage of existence of a cold ozone- and oxygen-containing plasma;
- ◇ the stage of existence of a cold plasma that contains nitrogen oxides, Fig. 1.

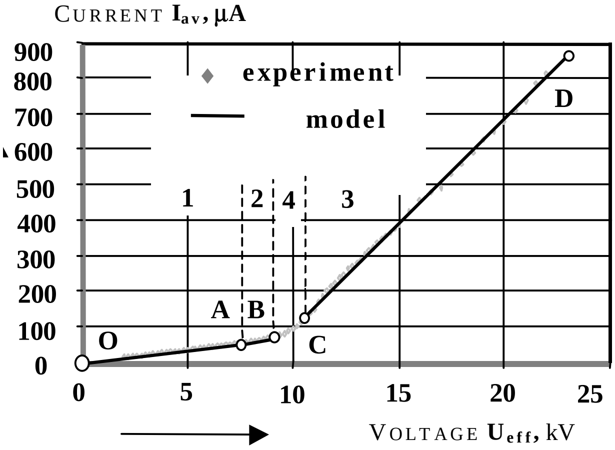

Fig. 1. Operating sectors on the external characteristic of electrical barrier discharge, namely the relationship between the average value of current I_{av} and the effective value of applied voltage U_{eff}: OA – non-operating sector; AB – first operating sector – a cold technological plasma containing ozone and products of its decomposition; CD – second operating sector – a cold technological plasma containing nitrogen oxides; BC – transient area.

THE TASK of the present work consists in examining the behavior at no load, i. e. without any material to be treated in the air gap, of low-frequency (50 Hz) barrier discharge burning in air at atmospheric pressure. The investigations are focused on the first operating part of the external characteristic of the discharge responsible for the generation of oxygen-containing technological plasma.

It is necessary to find new possibilities for increasing the effectiveness of the technological discharge, which is expressed by the high steepness of the working sector and the large intercept on the ordinate axis, Fig. 1.

The experimental investigation is carried out by varying: the non-uniformity of the electric field, the gauge of the glass barrier, and the size of the working air gap of plasma generator.

II. Experimental Investigations

The barrier is a plate with various gauge values that is made of alkaline silicate glass with dielectric permittivity ε=10, electrical volume resistivity $\rho = 10^9$ Ω.m, and $tg\delta = 25$ (at 20°C).

The change in thickness δ of the glass barrier determines the actual change in capacitance C_δ that is introduced by the barrier in the electric discharge circuit. The electric current is of capacitive character.

The values of capacitance C_δ of used glass barriers with various values of thickness δ, which have been calculated

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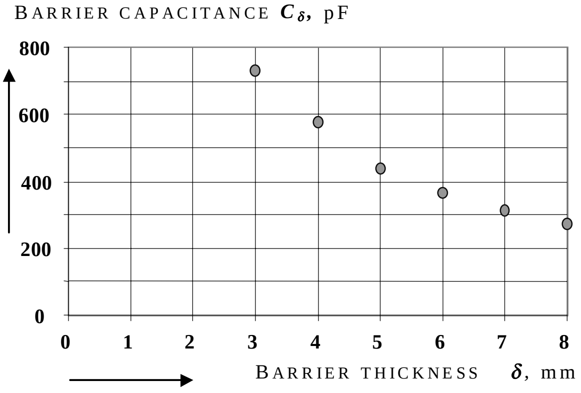

Fig. 2. Change in the electric capacitance C_δ of dielectric barrier - alkaline silicate glass, as a function of the change in its thickness δ.

through the experimentally plotted external characteristics for virtually uniform electrical field of discharge, are shown in Fig. 2.

The virtually uniform electrical field of discharge is realized by using two flat rectangular electrodes placed in parallel to each other at a distance b, forming the working gap in between. The ends of the two electrodes are rounded with a radius of 5 mm in order to diminish the non-uniformity of the field caused by the so-called edge effect.

The non-uniform electrical field is realized by using one of the two large electrodes with active area S_{E1}=651cm^2 and eight flat round electrodes with ∅50 mm and total area S_{E2} = 8× 19.6=156.7 cm^2. The coefficient of non-uniformity is $\beta = S_{E1}/S_{E2}$=4.15.

These eight electrodes may be situated in a large number of ways with respect to the large rectangular electrode. Two such approaches have been selected and they differ essentially from each other. According to the first one the eight electrodes are placed at distances not permitting their electrical interaction; the second approach requiring that the electrodes are placed in a group forming a maximally dense (hexagonal) package in the plane.

These configurations correspond to two different degrees of non-uniformity of the electrical field despite the same coefficient of non-uniformity β=4.15.

III. Results and Discussion

Based on the experimentally plotted external characteristic, the intensive characteristic of barrier discharge, namely the average value of current density J_{av}, is determined numerically as a function of the effective value of applied voltage U_{eff},Figs. 3÷ 5. It expresses the specific quantity of electricity transferred through the discharge gap in unit time.

The investigation performed shows that the introduction of an increasing degree of non-uniformity of the electrical field leads to a decrease in the intensity of ionization and chemical interactions going on in all sectors of the external characteristic: the inclination of straight sectors diminishes, and the value of intercept or free term goes up.

The cases investigated experimentally may be classified in the order of decreasing intensity of the barrier electrical discharge as follows:

- virtually uniform electrical field;
- eight electrodes placed at considerable distances from one another;
- eight electrodes placed as a group of maximum density.

The technological characteristic of the barrier discharge, however, demonstrates something else: the surface density of the active power of discharge p_a increases with the growing

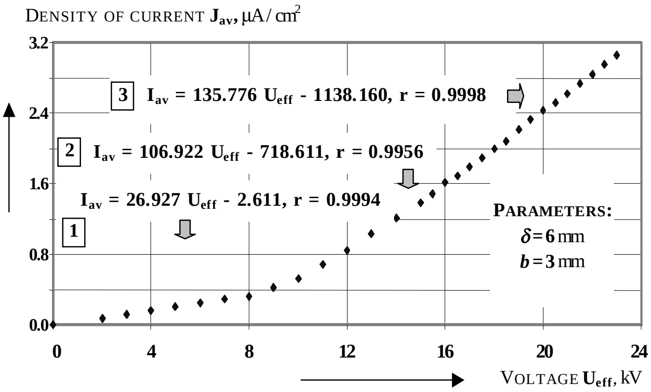

Fig. 3. Characteristic of the intensity of barrier discharge for a homogeneous electrical field. The regression equations of currents describing characteristic parts of the characteristic are presented.

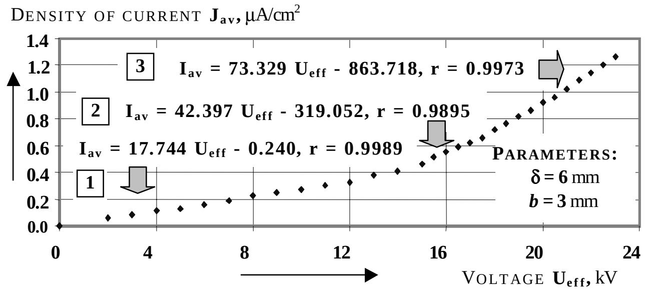

Fig. 4. Characteristic of the intensity of barrier discharge for a nonhomogeneous electrical field with eight autonomous electrodes of ∅50 mm. The regression equations of currents describing characteristic parts of the characteristic are presented.

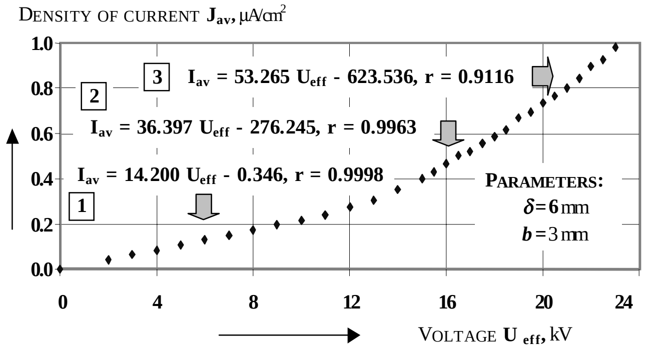

Fig. 5. Characteristic of the intensity of barrier discharge for a nonhomogeneous electrical field with eight grouped electrodes of ∅50 mm. The regression equations of currents describing characteristic parts of the characteristic are presented. These parts correspond to the graphically presented characteristics of the barrier discharge intensity.

non-uniformity of electrical field in the two operating sectors of the characteristic, i.e. in *sector* 1 characterized by the obtaining of oxygen-containing cold plasma, and in *sector* 2 characterized by the obtaining of cold plasma that contains nitrogen oxides, Figs. 6, 7, and 8.

The active power p_a is perceived as a measure for the ionization and plasma-chemical processes going on in the discharge.

The difference observed may be explained by the fact that the surface density of active power p_a accounts not only for the influence of density J_{av} but also for the influence of the crucial parameter of the regime of burning, namely the critical density of current J_{cr}, as well as of the value of the voltage applied to discharge U_S:

$$p_a = (J_{av} - J_{cr})\,U_S = J_p U_S\ .$$

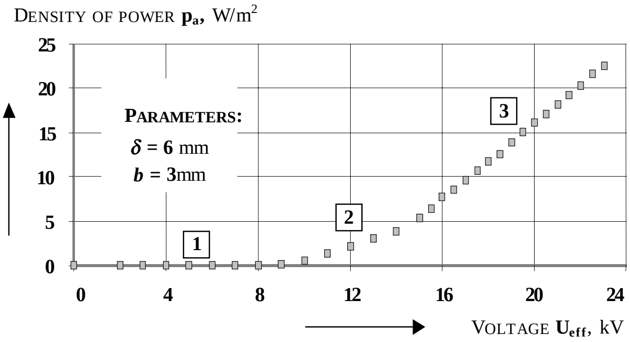

Fig. 6. Technological characteristic of the barrier discharge for a homogeneous electrical field.

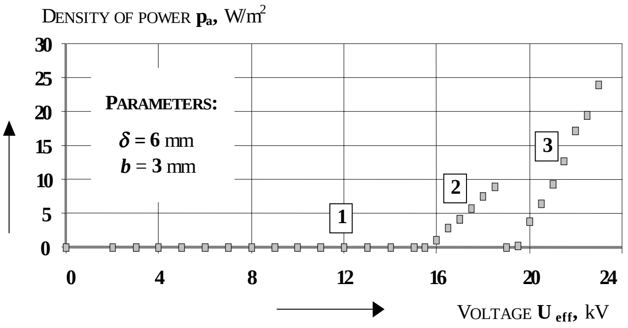

Fig. 7. Technological characteristic of the barrier discharge for a non-homogeneous electrical field with eight electrodes placed at considerable distances from one another.

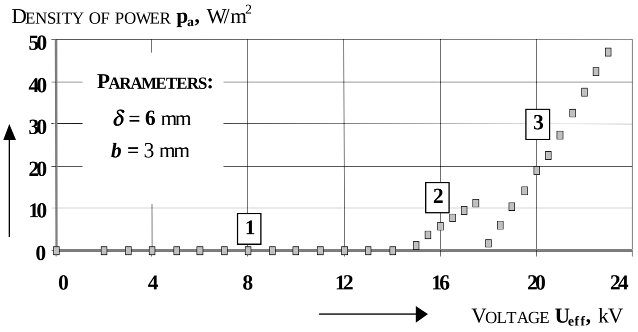

Fig. 8. Technological characteristic of the barrier discharge for a non-homogeneous electrical field with eight electrodes placed in a group.

That is why only the corrected current J_p can be a measure for the intensity of the threshold process of burning of barrier electrical discharge.

Rising the non-uniformity of electrical field decreases the critical density of current J_{cr}, and this effect is considerably larger than the decrease in the current density J_{av}, so that the difference $(J_{av}\ -\ J_{cr})$ becomes larger. The earlier ignition of the discharge and the displacement of operating sectors to the left determine the change in power density p_a.

The influence of the thickness δ of glass barrier and of the size b of discharge gap on the external characteristic of discharge or on the relationship between the average value of current I_{av} and the effective value of voltageU_{eff} applied to discharge gap is investigated experimentally for the first operating sector, i.e. for the area where the oxygen-containing cold plasma exists. Regression equations modeling the burning process of barrier discharge are obtained in accordance with a well-known methodology.

The *inclination* of the straight line or the current increase rate B, the intercept or the free term of the straight line A, and the correlation coefficient r, taking into account the degree of linear correlation between the current and applied voltage are shown in Figs. 9, 10, and 11.

The respective characteristics for a non-uniform electrical field are not presented because of the fact that the corresponding sector of their external characteristics is characterized by lower parameter values.

The maximal rate of current increase, namely within 200 to 240 μA/kV, is observed for thickness δ=4 mm of the glass barrier (the barrier capacitance being 580 pF) and size of discharge gap within 3 to 12 mm. Such rates of current increase are also observed for glass barrier thickness of 3 mm, but for a discharge gap of 1.5 mm, which is not, however, of great practical importance, Fig. 9.

The intercept B of the straight line modeling the external characteristic in the first operating sector reflects the line

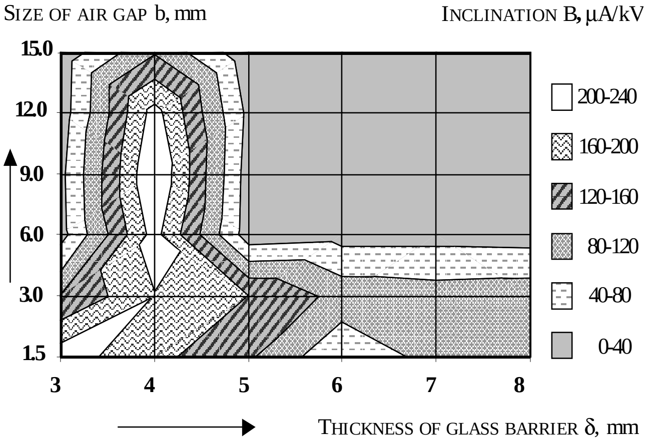

Fig. 9. Effect of thickness δ of the glass barrier and of size b of the discharge gap upon the increase rate B of the average value of current I_{av} with the increase of voltage U_{eff} applied to discharge gap for the first operating sector of the external characteristic.

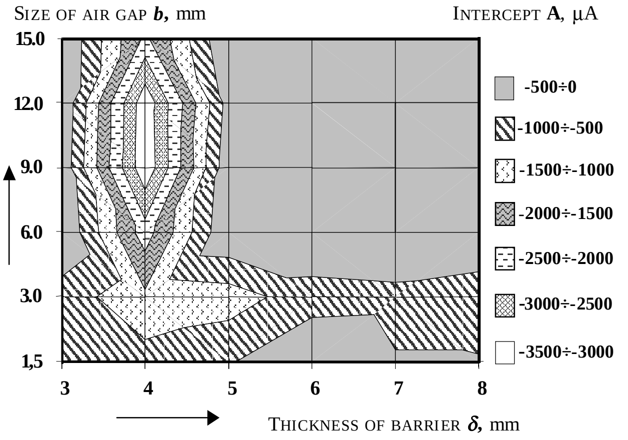

Fig. 10. Effect of thickness δ of the glass barrier and of discharge gap size b on intercept B of the straight line modeling the external characteristic in the first operating sector.

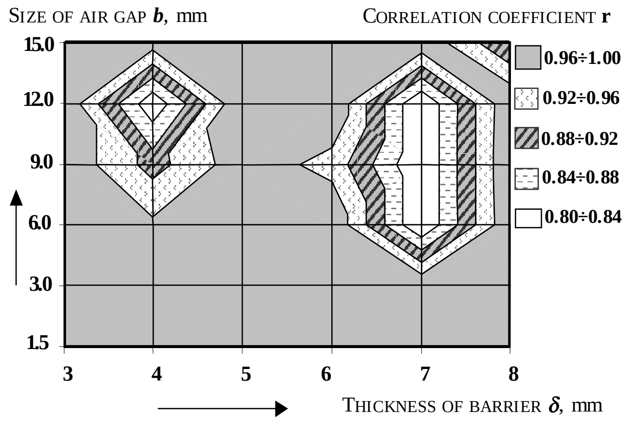

Fig. 11. Effect of the thickness of glass barrier δ and of the size of discharge gap b on the correlation coefficient r of the straight line modeling the external characteristic in the first operating sector.

location with respect to the voltage scale; a larger intercept means displacement of the line to the high values of voltage applied to the discharge gap, and vice versa. From the viewpoint of energy effectiveness it is better to operate at low voltages of discharge burning.

Unfortunately, the large values of intercept A are related to gauge δ=4 mm of the glass barrier or are found where the highest inclination is, Fig. 10.

The inclination is maximally high, but the curve is displaced strongly to the right on the voltage scale, which diminishes the advantage of the high rate of current increase. It is natural to seek an improvement of the characteristic by augmenting the non-uniformity of the electrical field of discharge for this gauge of the glass barrier.

The value of the coefficient of linear correlation r remains relatively high in the whole region of investigation, except in two small areas, Fig. 11.

For barrier thickness δ=4 mm this relates to large distances between electrodes, namely b=7$\div$15 mm. For barrier gauge δ=7 mm this concerns nearly the whole range of investigation; it includes values of the discharge gap size b=3$\div$15 mm.

The observed relatively low values of correlation coefficient r are associated with the characteristic discharge instability in these regions.

IV. Conclusion

The electrical characteristics of the barrier electric discharge with industrial frequency (50 Hz) are obtained on the basis of the external discharge characteristic plotted experimentally.

The average value of the electric current density can perform the role of an intensive parameter of the process of discharge burning, because it does not reflect the threshold character of the process of discharge ignition and the transition to each of the two working parts of the external characteristic.

The growing extent of non-uniformity of the electrical field of discharge increases the surface density of the active power and its rate of increasing with the augmentation of voltage applied to the discharge gap. In such a way the non-uniformity of the electrical field influences positively the electrical and technological characteristics of barrier electrical discharge.

The thickness of the glass barrier exerts an influence on discharge burning through the capacitance it introduces in the electrical circuit of discharge.

References

[1] P. Dineff, D. Gospodinova. Energy-effective plasma-chemical surface modification of polymers and polymeric materials at atmospheric pressure. International conference MED-POWER'02, November 04-06, 2002, Athena, Greece, Proceedings, pp. 1124-1128.

[2] P. Dineff, D. Gospodinova. The surface density of the power as a basic parameter of the plasma-chemical modification of the materials in a barrier electrical discharge, International conference ELMA' 02, September 13-14, 2002, Sofia, Bulgaria, Proceedings, pp. 304-310.