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CHARACTERISTICS AND BEHAVIORS OF MAGNETRON DIELECTRIC BARRIER DISCHARGE

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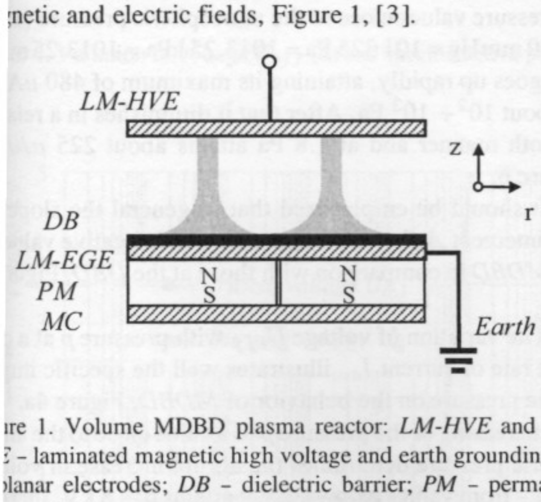
Abstract: In the present work, the behavior and parameters of a magnetron dielectric barrier air discharge are considered for industrial frequency and a pressure variation, which includes the entire working range of pressures for the existence of the discharge at room temperature - from the atmospheric pressure to the medium vacuum region. The magnetron dielectric barrier discharge is examined by means of the external static characteristic representing the average value of the current vs. the effective value of the voltage applied to the electrode system. The two characteristic areas of using the discharge – the area of ozone-and-oxygen-containing cold plasma and the area of plasma which contains nitrogen oxides NO_x - are determined. The electrical characteristics and parameters, characterizing the area of ozone-and-oxygen-containing cold plasma, are analyzed.

Keywords: cold discharge plasma, magnetron effect, magnetron dielectric barrier discharge, permanent magnet, vacuum and atmospheric discharges, volt-ampere characteristic method, voltage of burning

Introduction

most well-known discharge type with crossed mag- : and electric fields is the *magnetron discharge* at pressure (vacuum). The electrons circulate in helices ınd the magnetic field lines and give rise to more ioni- ɔn. The magnetron discharge is considered a variety of DC normal or abnormal glow discharges.

The magnetron effect is applied *to a dielectric barrier harge* (DBD) by building a plasma generator with per- ent strontium magnets and ferromagnetic electrodes ning an open magnetic system, which ensures the burn- of the magnetron dielectric barrier discharge at crossed ;netic and electric fields, Figure 1, [3].



ıre 1. Volume MDBD plasma reactor: *LM-HVE* and *LM-* *:* - laminated magnetic high voltage and earth grounding flat ɔlanar electrodes; *DB* – dielectric barrier; *PM* – permanent ;nets; *MC* – magnetic core.

Upon applying *AC* voltage to the electrode system with electrode covered by a dielectric glass barrier, a *MDBD* ears in the air gap.

Such non-thermal (cold) discharges are suitable for a le range of applications, e. g. ozone generation, sur- e treatment and modification of plastic foils, textiles and even metals, pollution control, sterilisation, ultraviolet and vacuum ultraviolet light sources for pumping of laser, *AC* plasma displays, etc., [1].

The task of the present work consists in studying and comparing the behavior and characteristics of *MDBD* at atmospheric pressure and at decreased pressure (vacuum) by using the method of external or static volt-ampere characteristic according to [2,3].

2. Experimental Investigation

The electrical behavior of an *MDBD* volume plasma generator with two co-planar plate electrodes is investigated. The size of the discharge gap is 6 mm. One of the two electrodes is covered by a dielectric glass barrier with thickness of 3 mm, Figure 1.

Volt-ampere characteristics of *MDBD* at various pressures are plotted with the help of the electrical circuit shown in Figure 2.

The critical parameters are calculated after linearization of the characteristic, whereupon the two characteristic regimes of *MDBD* – *RS* and *ST* – are differentiated, Figure 2.

The critical parameters characterize the ignition of *MDBD* for each of the two operating plasma areas - for <u>*RS*</u>: burning voltage $U_{g,1}$; critical voltage and critical current $U_{cr,1}$, $I_{cr,1}$; for <u>*ST*</u>: burning voltage $U_{g,2}$; critical voltage and critical current $U_{cr,2}$, $I_{cr,2}$, Fig. 2.

In addition to these, the parameters characterizing the discharge burning are calculated, too – for <u>*RS*</u>: the current increase rate (or slope) B_2 and intercept A_2; for <u>*ST*</u>: the current increase rate (or slope) B_3 and intercept A_3, Figure 2, [2].

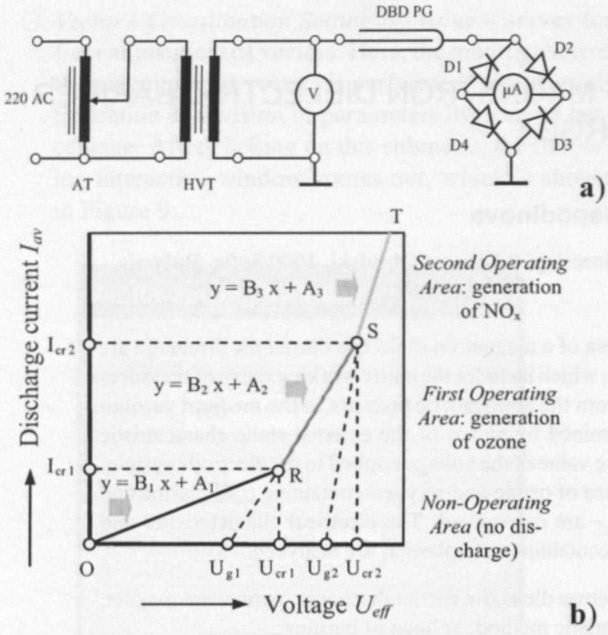


Figure 2. Electric circuit of an *MDBD* plasma generator (a) and polygonal linear model of a volt-ampere characteristic with two operating plasma areas - *RS*: ozone and oxygen plasma; *ST* - NO_x plasma (b).
AT - transformer for voltage regulation; *HVT* - step-up transformer; *D1, D2, D3,* and *D4* - diodes allowing direct measurement of the average value of discharge current I_{av}.

3. Results and Discussions

Volt-ampere characteristics are plotted experimentally, after which the results are processed in accordance with the calculation methodology created, [2], and the results obtained are shown further below for the first operating area of an *MDBD* plasma generator.

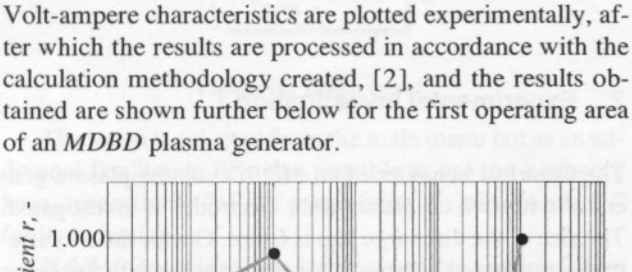


Figure 3. Variation of the coefficient of linear correlation r with pressure p for the operating plasma area *RS*.

The coefficient of linear correlation r assumes considerably higher values in the case of *MDBD* and has a specific trajectory of variation if compared to an analogous *DBD* discharge in a plasma reactor without magnetic field, [4].

The coefficient r assumes its lowest value in the area of unstable burning – at the lowest burning pressure of 1.8 Pa, Figure 3.

The region of $10 \div 100$ Pa as well as the region of the atmospheric pressure can be considered regions of stable burning ($r > 0.995$) with a strongly expressed character of *DBD*, determined by the constancy of the burning voltage.

The existence of a linear correlation between the average value of the current and the effective value of the voltage is an evidence for the constancy of the discharge burning voltage, [1]. Based on the experimental results obtained, it can be assumed that the magnetron effect stabilizes *DBD* and emphasizes its main characteristic.

Discharge burning voltage $U_{g,1}$ demonstrates a variation, specific for *MDBD*, with pressure p: almost immediately after entering the area of vacuum the voltage diminishes abruptly to about 0.6 kV – a value that remains constant within the pressure range of $4.10^4 \div 10$ Pa, after which it starts decreasing and attains the lowest value of 0.25 kV. This relationship demonstrates that there exists a certain minimum average length of the free run of the electron (pressure), below which the burning of the discharge becomes difficult, and $U_{g,1}$ increases abruptly, Figure 5.

This variation of the burning voltage $U_{g,1}$ of *MDBD* differs significantly from a similar relationship for DBD, which in its variation character is similar to the form of the law of *Paschen* – with decreasing of the pressure value below the atmospheric pressure, the burning voltage $U_{g,1}$ diminishes until reaching its minimum at 10 Pa – the lowest burning voltage of *DBD*, [4].

The critical ignition voltage $U_{cr,1}$ of *MDBD* follows the variation of the discharge burning voltage U_g, Figure 5.

The electrical parameters of the first operating area – the rate of discharge current increase (slope) B_2 and intercept A_2 – are also changed with the air pressure p. The current increase rate B_2 remains relatively low ($150 \div 200$ μA/kV) at pressure values close to the atmospheric pressure (1 atm = 760 mmHg = 101 325 Pa = 1013.25 hPa = 1013.25 mbar) and goes up rapidly, attaining its maximum of 480 μA/kV at about $10^2 \div 10^3$ Pa. After that it diminishes in a relative smooth manner and at 1.8 Pa attains about 225 μA/kV, Figure 6.

It should be emphasized that in general the slope B_2 and intercept A_2 have lower positive and negative values at the *MDBD* in comparison with those at the *DBD*, Figure 6, [4].

The variation of voltage U_{eff} with pressure p at a constant rate of current I_{av} illustrates well the specific impact of the pressure on the behavior of *MDBD*, Figure 4a.

Increasing of the pressure p to a value close to the atmospheric pressure determines the abrupt increase in voltage U_{eff} – from values below 1 kV it attains $6 \div 8$ kV. Increasing of the current I_{av} from 50 μA up to 450 μA determines a lesser increase in voltage – from 4 up to 9 kV, Figure 4a.

The abrupt increase in voltage U_{eff} is determined by the abruptly increasing burning voltage $U_{g,1}$of *MDBD* at attaining the atmospheric pressure, Figure 5, while at corresponding increase in the current the voltage U_{eff}increases as a result of the increasing voltage drop across the ca-

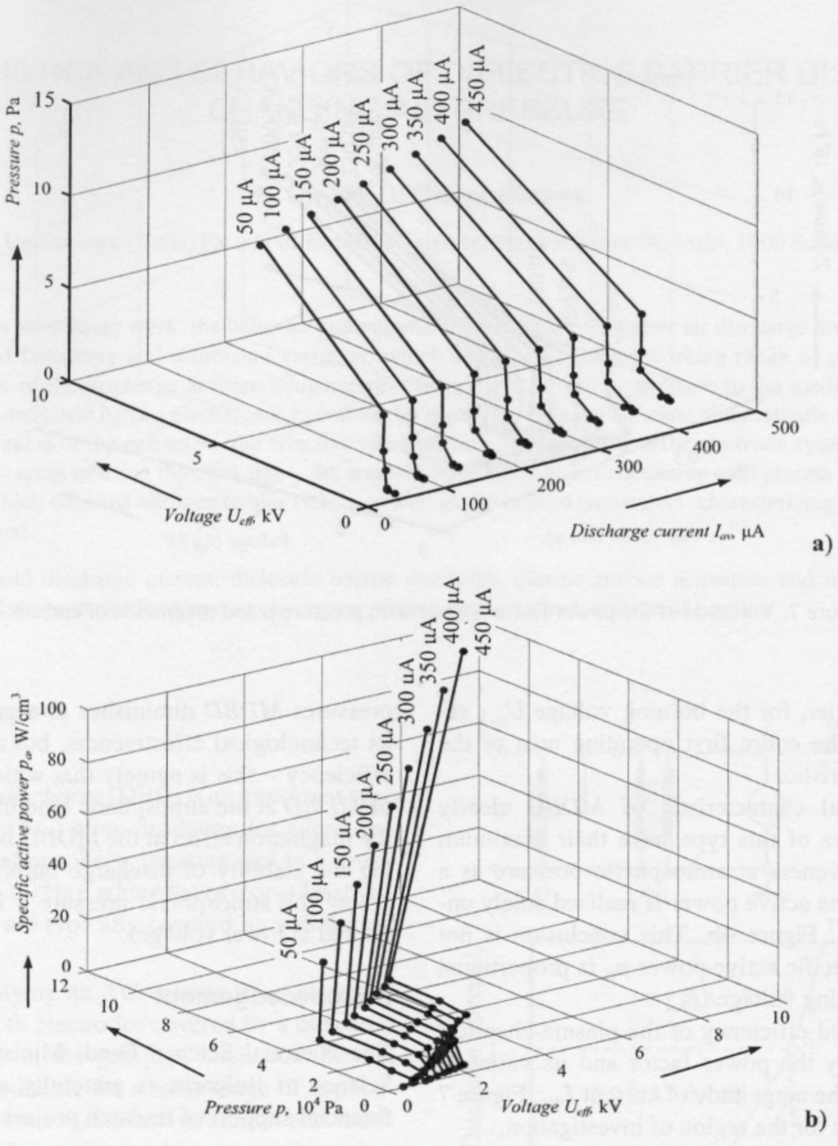


Figure 4. Variation of voltage U_{eff} (a) and specific active power p_a (b) of *MDBD* with pressure p at constant value of discharge current I_{av}.

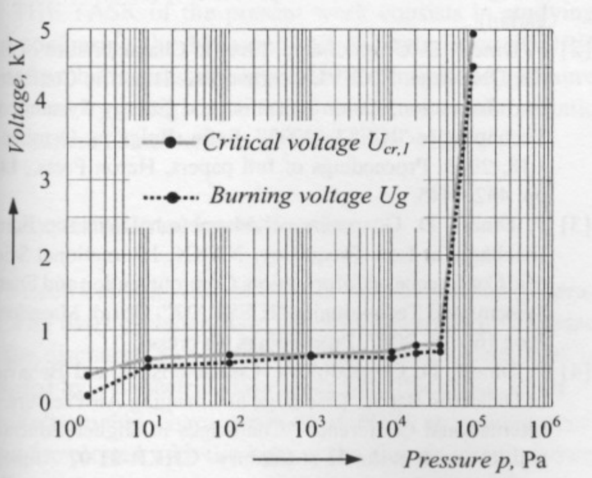


Figure 5. Variation of the burning voltage $U_{g,1}$ and the critical ignition voltage $U_{cr,1}$ of *MDBD* with pressure p.

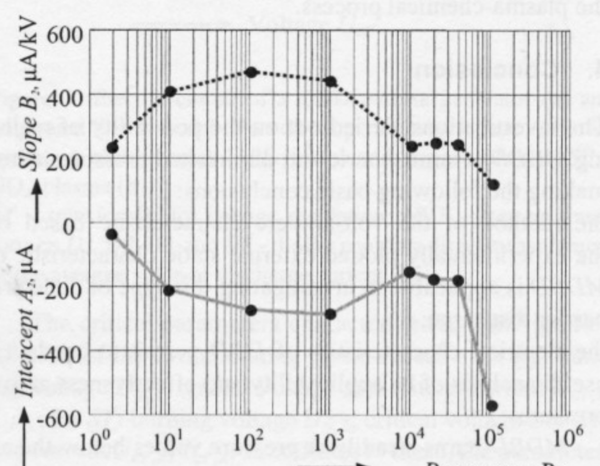


Figure 6. Variation of the current increase rate B_2 and intercept A_2, characterizing the first operating area of curve *RS*.

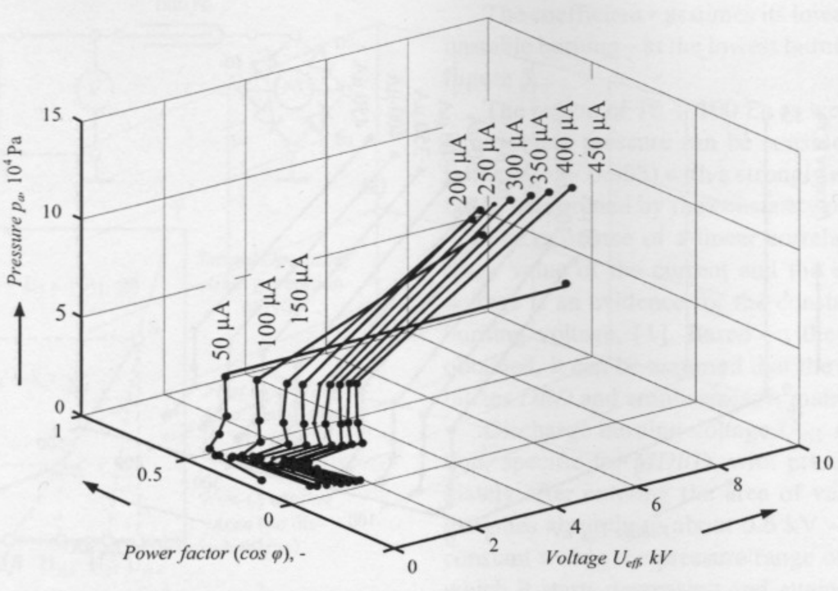


Figure 7. Variation of the power factor ($\cos\varphi$) with pressure p and magnitude of current I_{av}.

pacitance of the barrier, for the burning voltage $U_{g,1}$ remains constant for the entire first operating area of the volt-ampere characteristic.

The technological characteristic of *MDBD* clearly shows that discharges of this type have their maximum technological effectiveness at atmospheric pressure as a maximum value of the active power is realized solely under those conditions, Figure 4b. This conclusion is not surprising for the specific active power p_a is proportional to the discharge burning voltage $U_{g,1}$.

The energy-related efficiency of the plasma-chemical process is defined by the power factor and its variation with pressure p and the magnitude of current I_{av}. Figure 7 shows said efficiency for the region of investigation.

The power factor decreases considerably with the increase in the current, which should be related to the increasing voltage drop across the capacitance of the barrier. This power is transformed into heat and practically lost for the plasma-chemical process.

4. Conclusion

The investigations carried out on the possibility of realizing *MDBD* at atmospheric and diminished pressures allow making the following basic conclusions:

the method of the volt-ampere characteristic based on the experimentally plotted external static characteristic of *MDBD* is applicable to investigating this type of dielectric barrier discharge;

the electrical characteristics of *DBD* permit to conduct a useful analysis of its applicability and effectiveness at low pressures;

MDBD burns steadily at pressure values below the atmospheric pressure, but with entering the region of low pressures *MDBD* diminishes to a greater extent not only its technological effectiveness, but also its energy-related efficiency – this is namely that which determines the use of *MDBD* at the atmospheric (and higher) pressure;

the magnetron effect at the MDBD is expressed in improving the stability of discharge burning at pressure values below the atmospheric pressure – it burns and becomes ignited at lower voltages.

Acknowledgement

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