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CONTENTS

SECTION 1: Higher Engineering Education

SECTION 2: Information Technologies in Education

SECTION 3: Design

CONTENTS

CONTENTS

SECTION 6: Measurement and Control !!!novo

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s. N. Kolev, L. Dimitrov, Heron Press, Sofia, 2007

CHARACTERISTICS AND BEHAVIORS OF DIELECTRIC BARRIER DISCHARGE AT CHANGING AIR PRESSURE

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Abstract: In the present work, the behavior and parameters of a 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 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 - as well as the electric parameters, characterizing those areas, are determined.

Keywords: cold discharge plasma, dielectric barrier discharge, plasma surface activation and modification, vacuum and atmospheric discharges, volt-ampere characteristic method, voltage of burning

. Introduction

he *dielectric barrier discharge* (DBD) is an important type f alternating current (AC) glow discharge (or silent disharge), operating at atmospheric pressure and in a lower requency range (50 ÷ 60 Hz), where the two or at least one f the two electrodes are typically covered by a dielectric arrier.

As a result of applying an AC voltage to an electrode ystem with one or both electrodes covered by a dielectric ayer, a DBD appears in the gas gap. Such non-thermal cold) discharges are suitable for a wide range of applicaions, e. g. ozone generation, surface treatment and modification of plastic foils, textiles and even metals, polluion control, sterilisation, ultraviolet and vacuum ultraviolet light sources for pumping of laser, AC plasma displays and others, [1].

THE TASK of the present work consists in studying and comparing the behavior and characteristics of DBD at atmospheric pressure and also at diminished pressure (vacuum) by using the method of the external or static volt-ampere characteristic in accordance with [2].

2. Experimental Investigation

The electrical behavior of a DBD volume plasma generator with two co-planar plate electrodes is studied. The size of the discharge gap is 6 mm. One of both electrodes is covered by a dielectric glass layer with thickness 3 mm.

Volt-ampere characteristics of *DBD* at various pressures are plotted with the help of the electric circuit shown in Figure 1.

The critical parameters are calculated after linearization of the characteristic, whereupon the two characteristic regimes of *DBD* – *RS* and *ST* – are differentiated, Figure 1.

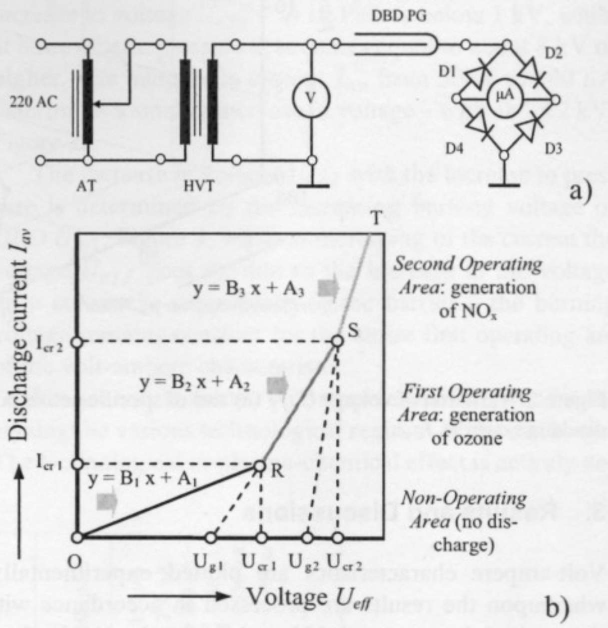

Figure 1. Electric circuit of a DBD plasma generator (**a**) and polygonal linear model of a volt-ampere characteristic with two operating plasma areas - *RS*: ozone and oxygen plasma; *ST* - NO_x plasma (**b**).
AT - transformer for voltage regulation; *HVT* - step-up transformer; *D1, D2, D3,* and *D4* – diodes enabling direct measurement of the average value of discharge current I_{av}.

The critical parameters characterize the *DBD* ignition for each of the two operating plasma areas - for RS: burning voltage $U_{g,1}$; critical voltage and critical current $U_{cr,1}$, $I_{cr,1}$; for ST: burning voltage $U_{g,2}$; critical voltage and critical current $U_{cr,2}$, $I_{cr,2}$. In addition to these, the parameters characterizing the discharge burning are calculated, too, - for RS: the rate of current increase (or slope) B_2 and intercept A_2; for ST: the rate of current increase (or slope) B_3 and intercept A_3, Figure 1, [2].

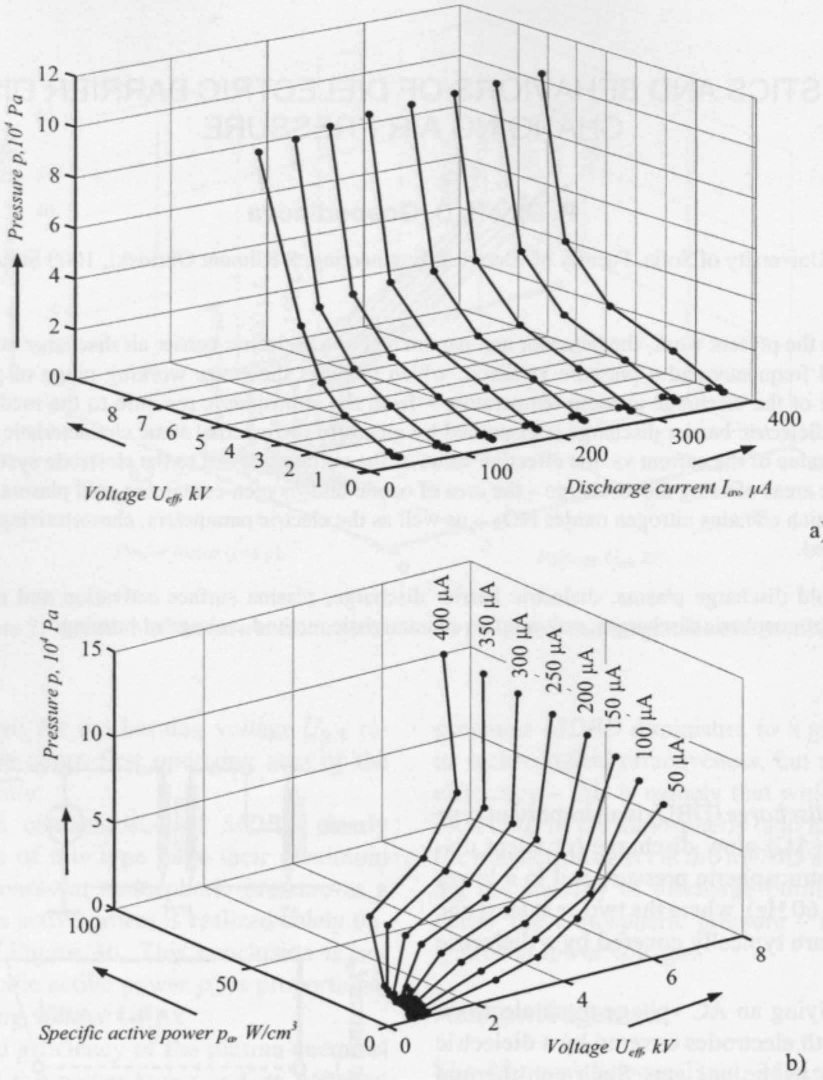

Figure 2. Variation of voltage U_{eff} (a) and of specific active power p_a of *DBD* depending on the air pressure p at constant value of the discharge current I_{av}.

3. Results and Discussions

Volt-ampere characteristics are plotted experimentally, whereupon the results are processed in accordance with the methodology created, [2], and the results obtained are presented for the first operating area of *DBD* plasma generator.

A specific change in the coefficient of linear correlation r with pressure p can be noticed, but in all cases the value of said coefficient remains sufficiently high to assume a linear correlation relationship between the average value of current I_{av} and U_{eff}, Figure 3.

Discharge burning voltage $U_{g,1}$ exhibits a variation with pressure p, which is similar to the law of *Paschen*, i. e. with the decreasing of the pressure under the atmospheric pressure the burning voltage of *DBD* diminishes as well and attains its lowest value at 10 Pa, Figure 4.

DBD is ignited at minimum critical voltage $U_{cr,1} = 0.650$ kV with corresponding minimum burning voltage $U_g = 0.500$ kV. The further diminishment of the pressure below the value indicated above ($p_0 = 10$ Pa) leads to an increase in critical ignition voltage $U_{cr,1}$ and in discharge burning voltage U_g, Figure 4.

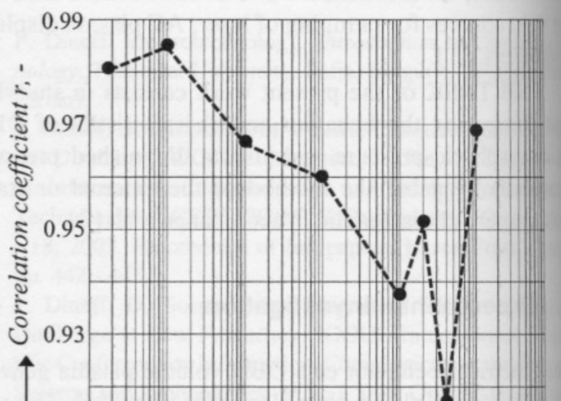

Figure 3. Variation of the coefficient of linear correlation r with pressure p for the operating area *RS*.

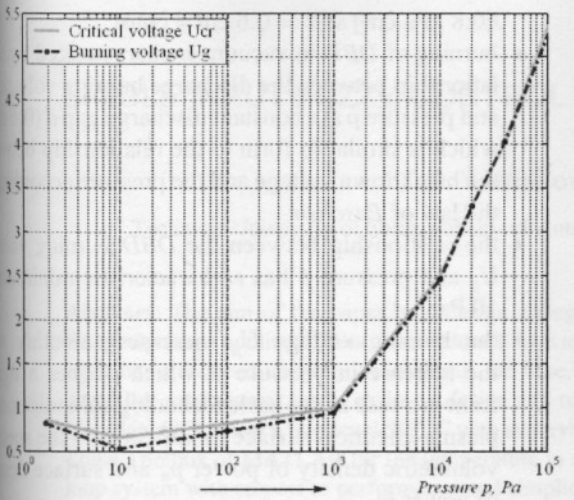

Figure 4. Variation of burning voltage $U_{g,1}$ and critical ignition voltage $U_{cr,1}$ of *DBD* with the air pressure *p*.

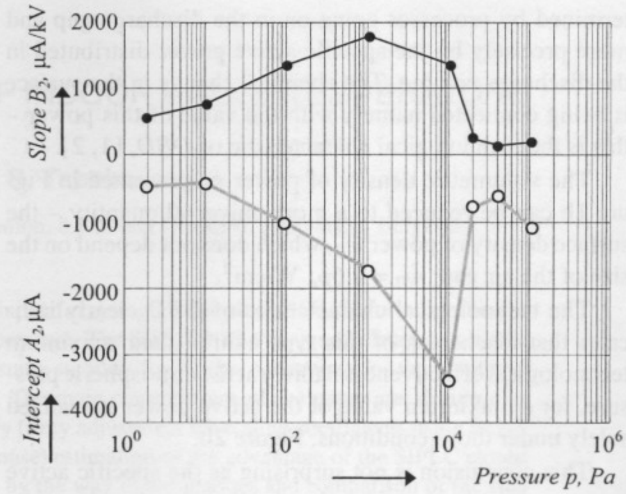

Figure 5. Variation of the rate of current increase B_2 and of intercept A_2 characterizing the first operating area of curve *RS*.

The electrical parameters of the first operating area – the rate of discharge current increase (slope) B_2 and intercept A_2 – are also varying with the air pressure *p*. The rate of current increase B_2 remains relatively low (150–200 μA/kV) at pressure values close to that of the atmospheric pressure (1 atm = 760 mmHg = 101 325 Pa = 1013.25 hPa = 1013.25 mbar) and then goes up rapidly, attaining its maximum at about 10^3 Pa. After that it decreases in a relatively smooth manner to attain about 625 μA/kV at 2 Pa, Figure 5.

The achievement of a high rate of discharge current increase B_2 is desirable, particularly for low voltages. However, the increase in the negative value of intercept A_2 indicates that the straight line is displaced towards the origin of the coordinate system, which is also confirmed by the decreasing value of discharge burning voltage U_g, Figure 4.

The variation of voltage across discharge gap U_{eff} with pressure *p* at constant value of current I_{av} illustrates in a better way the specific effect of the pressure upon the behavior of *DBD*. Increasing of pressure *p* determines a rapid increase in voltage U_{eff} – at 10 Pa it is below 1 kV, while at atmospheric pressure it becomes equal to about 8 kV or higher. The increase in current I_{av} from 50 up to 400 μA determines a smaller increase in voltage – with about 2 kV, Figure 2a.

The increase in voltage U_{eff} with the increase in pressure is determined by the increasing burning voltage of *DBD* $U_{g,1}$, Figure 4, while at increasing of the current the voltage U_{eff} goes up due to the increase in the voltage drop across the capacitance of the barrier – the burning voltage remains constant for the entire first operating are of the volt-ampere characteristic.

It is not easy to use the volt-ampere characteristic for analyzing the various technological regimes of the discharge. The technological or plasma-chemical effect is entirely de-

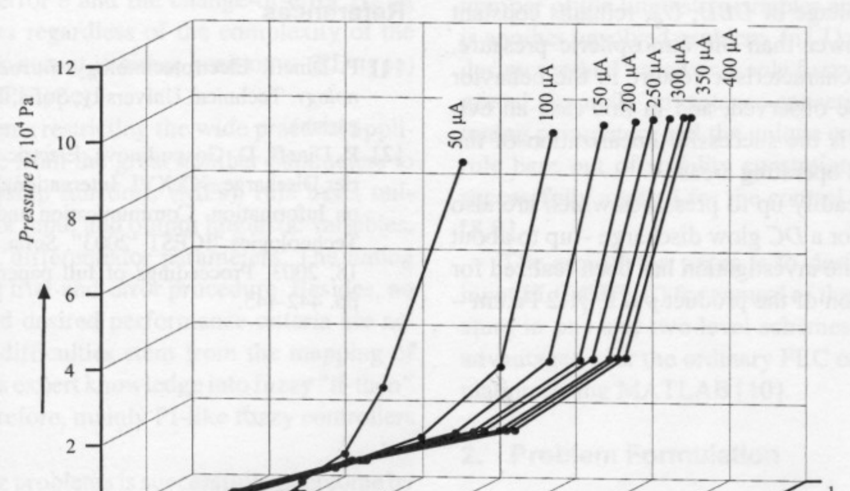

Figure 6. Variation of the power factor ($\cos\varphi$) with the air pressure *p*.

termined by processes going on in the discharge gap and more precisely by the specific active power distributed in the discharge volume. The chemical change in the surface is being connected namely with the value of this power – this is the technological characteristic of *DBD*, [1, 2].

The volumetric density of power p_a presented in Figure 1b can be reduced to a more universal quantity – the surface density of power w_0, which does not depend on the size of the air gap: $w_0 = 0.6p_a$ W/cm^2.

The technological characteristic of *DBD* clearly indicates that discharges of this type exhibit their maximum technological effectiveness namely at the atmospheric pressure, for a maximum value of the active power is realized solely under those conditions, Figure 2b.

This conclusion is not surprising as the specific active power p_a (w_0) is proportional to the discharge burning voltage U_g. At equal other conditions the low critical current $I_{cr,1}$ determines a higher specific active power.

The energy-related efficiency of the plasma-chemical process is determined by the power factor and its variation with pressure p and magnitude of current I_{av}. Figure 6 shows said efficiency for the area investigated.

Analyzing the relationship presented clearly shows that maximum values of the power factor are obtained at atmospheric pressure, and that for all examined values of the current.

4. Conclusion

Investigations conducted on the possibility of realizing a *DBD* at atmospheric and diminished pressures lead to the following major conclusions:

- the method of the volt-ampere characteristic based on the experimentally plotted external static characteristic of *DBD* – the average value of current I_{av} vs. the effective value of the voltage across the discharge gap – can be successfully applied to studying the burning of *DBD* at low pressures;
- the burning voltage of *DBD*, U_g, remains constant at pressures lower than the atmospheric pressure, i. e. the main characteristic feature in the behavior of DBD can be observed, and in this case an evidence for this is the successful linearization of the characteristic's operating areas;
- *DBD* burns steadily up to pressures which are also characteristic for a *DC* glow discharge – up to about $1 \div 2$ Pa – or the investigation has been realized for a broad variation of the product $p.d \in$ [1.2 Pa.cm – 60.8 kPa.cm] at $d = 0.6$ cm = const;
- burning of *DBD* in vacuum is characterized by a relationship between the discharge burning voltage U_g and pressure p at a constant discharge gap d (0.6 cm), which is similar in form to the relationship between the breakdown voltage and the pressure according to the law of *Paschen*;
- the relationship between the *DBD* burning voltage U_g and pressure p has a characteristic minimum at 10 Pa;
- the burning voltage U_g increases smoothly with the increase in pressure p, which defines a significant increase in the basic technological indicators of plasma-chemical surface modification – the specific volumetric density of power p_a and surface density of power w_0;
- the increase in burning voltage U_g with the increase in pressure p determines also the increase in the energy-related efficiency of the process of plasma-chemical surface activation and modification – the power factor $\cos\varphi$ goes up;
- *DBD* burns steadily at pressures below the atmospheric pressure, but with entering the area of low pressures *DBD* diminishes not only its technological effectiveness, but also its energy-related efficiency – it is namely that, which determines the use of DBD at atmospheric (and higher) pressure in the practice of plasma-chemical technologies for surface activation and modification of materials;
- the electrical characteristics of *DBD* permit to carry out a useful analysis of its applicability and effectiveness at low pressures.

Acknowledgement

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