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CONTENTS

DIELECTRIC BARRIER DISCHARGE IN TRIODE SYSTEM WITH HEXAGONAL NETWORK OF BIPOLAR ROUND ELECTRODES

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**SINVESTAV, Merida, Yucatan, Mexico

Abstract. Introducing a fine-wire metal mesh or a perforated metal sheet as a third electrode on the dielectric barrier surface galvanically supplied through additional capacitor, serially connected to the grounded electrode, finds a new technical solution in the present work. There is however one more possibility to manage the barrier discharge without external power supply of the "third electrode". There is a new electrode made of multiple bipolar round electrodes, forming a hexagonal network. The technological characteristics of a dielectric barrier discharge with bipolar hexagonal network of round copper electrodes have been studied.

Keywords: fine-wire metal mesh, perforated metal sheet (or foil), etching metal sheet or foil (printed circuit board).

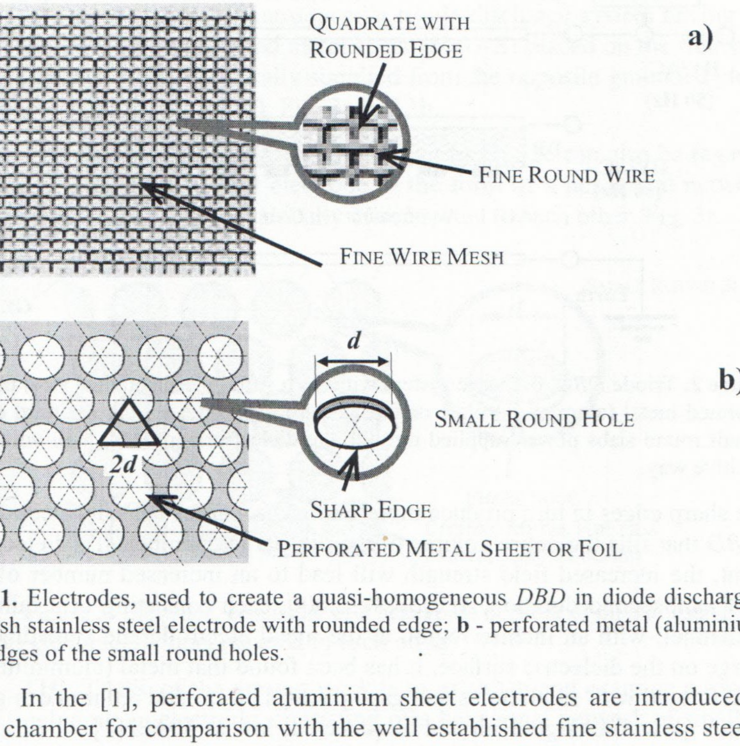
INTRODUCTION

In general it is well-known, S. Okazaki (1993) and J. Tepper (2002), that a glow discharge is stable or in thermodynamic equilibrium, only at pressure of less than a few mbars. At atmospheric pressure and ambient temperature the glow discharge becomes normally unstable and in non-equilibrium, and it tends to change to a filamentary discharge, *F. Massines* (1998), *J. Tepper* (2000), and *S. Kanazawa* (1988), depending on *the material of the dielectric barrier, the structure of the discharge electrode, the air gap spacing,* the frequency of the pulsed power supply, the feed gas, and the humidity of the gas.

S. Kanazawa (1988); *T. Yokoyama* (1990); and *J. Harry* (1999) claim however to have obtained a stable and homogeneous glow discharge at atmospheric pressure depending on three simple requirements, [1]: *i* - a source frequency above 1 kHz, *ii* - the insertion of a dielectric barrier (or barriers) between the two co-planar metal electrodes, and *iii* - the use of helium as a dilution gas.

The ability of helium to produce a stable and homogeneous dielectric barrier ·ge (*DBD*) at atmospheric pressure is related to its low breakdown stress, *Y. Ra-* 991). It is relatively easy to produce the small avalanches that are required - its ɜakdown stress is only about 300 V/mm, some ten times lower than that of air, *Y a* (1995). Despite its attractive features, it is however impractical to use helium in ergy surfaces functionalization, due to its high cost and the low efficiency of the s, [1].

T. Yokoyama (1990) and *S. Okazaki* (1993) report another important result re- to the stabilization of an atmospheric pressure *DBD* - its appearance in air, argon ygen when using a 50 Hz power supply source and a fine wire mesh as the dis- electrodes. These initial experiments have been confirmed by *J. Tepper*, (2000), has also been established that fine mesh electrodes produce a more stable homo- ıs *DBD* (glow) than do coarse mesh electrodes (2002). Since ozone is commonly ted in air (or in oxygen), the production of a homogeneous *DBD* in air is poten- nportant, and forms therefore the focus of some investigation, [1].



1. Electrodes, used to create a quasi-homogeneous *DBD* in diode discharge system: **a** - sh stainless steel electrode with rounded edge; **b** - perforated metal (aluminium) plate with dges of the small round holes.

In the [1], perforated aluminium sheet electrodes are introduced into a dis- chamber for comparison with the well established fine stainless steel wire mesh. forated sheet consisting of a series-parallel arrangement of small sharp-edged holes, Fig 1b, is expected to produce a higher local electric field strength than a fine wire mesh, Figs. 1a, which may be sufficient to cause ionization of the gas in the vicinity of the sharp edges.

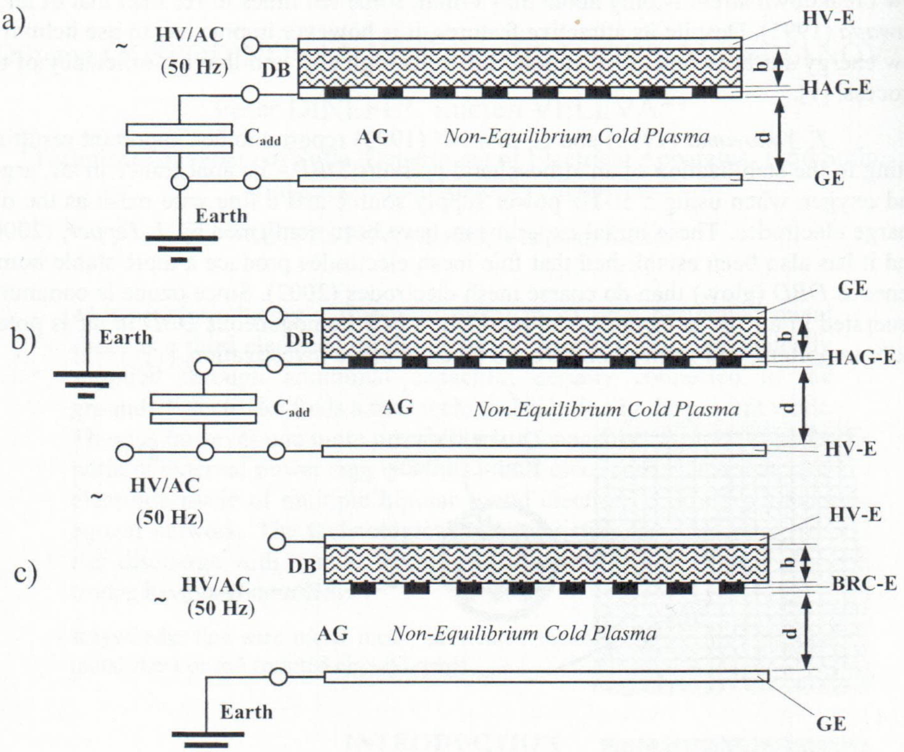


Figure 2. Triode *DBD* discharge system with: **a, b** - fine-mesh stainless steel third electrode or perforated metal (aluminium) plate or foil as third electrode; **c** - bipolar third electrode containing small round slabs power supplied through the dielectric barrier by high voltage electrode in capacitive way.

The sharp edges in turn produce more micro-discharges near the electrodes and provide a *DBD* that fills the entire volume of the discharge chamber. If a dielectric barrier is present, the increased field strength will lead to an increased number of micro-discharges of nanosecond duration, *M Haacke*, 2000, each consisting of a thin almost cylindrical channel, with an intense region at the metal electrode and spreading into a microdischarge on the dielectric surface. It has been found that metal (aluminium) sheet electrodes perforated with small holes and gap spacings of 1,5 and 3,0 mm can generate a homogeneous glow discharge in air at a frequency as low as 50 Hz [1].

P. Dineff (2004) experimentally has demonstrated the strong influence of the *edge effect* on the *DBD's* energy characteristics in diode discharge system in air at atmospheric pressure. The electrode consists of multiple round electrodes, which are at a reasonable distance from each other, so that the edge effect manifestation along the perimeter of each of them is independent of its neighbours. This approach remains quite attractive but there is one major drawback - with the reduction of the round electrodes' diameter and the increase of their number it becomes technically impossible to ensure their electrical power supply in galvanic way, [2, 3].

The only way to electrically supply so many and so small electrodes without galvanic contact between them is their simultaneous power supply by the high-voltage electrode (*HV-E*) via dielectric barrier (DB) in capacitive way. A new type of sandwich-shaped electrode is thus created (*HV-E/DB/BRC-E*) - with a dielectric board (*DB*) in the middle, carrying on one side the power supply high-voltage electrode (*HV-E*), and on the other - the bipolar round electrodes network (*BRC-E*) supplied by it via dielectric barrier. This is an asymmetric diode discharge system, containing the described new type of electrode, Fig. 2c.

P. Dineff (2005) has introduced a triode discharge system having a third electrode in the form of a perforated metal sheet (*HAG-E*) placed on the free surface of the dielectric barrier (*DB*), electrically supplied from the opposite grounded electrode (*GE*) via reactive element (capacitor), Fig. 2a and 2b.

The electrode discharge system shown in Fig. 2c can also be regarded as a triode system, containing a third electrode in the form of a hexagonal network of round metal (copper) electrodes, galvanically unconnected to each other, Fig. 3a.

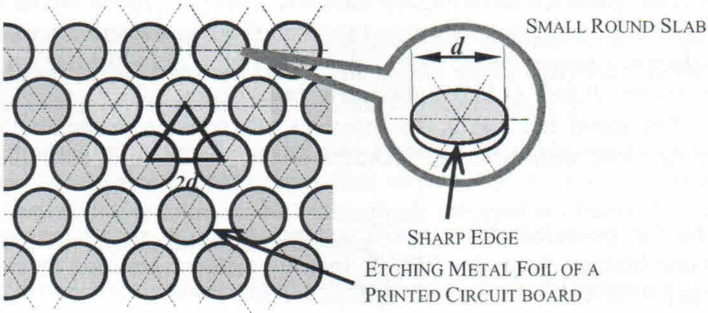


Figure 3. Electrode, consisting of a hexagonal network of bipolar round metal (copper) electrodes galvanically unconnected to each other.

THE TASK of the present work is to establish and examine a triode discharge system, including an electrode, consisting of a hexagonal network of small round bipolar electrodes. Each of these electrodes is electrically supplied by means of capacitive high-voltage electrode through the dielectric barrier.

The *dielectric barrier discharge* (*DBD*) behaviour in the described triode discharge system in air at atmospheric pressure was studied by the method of the external static characteristic (*Peter Dineff, Dilyana Gospodinova*, 2001). The discharge real power (P_R), and the more frequently used real power surface density ($p_R = P_R/S$, where S is the electrodes' active area), is perceived as *DBDs* major characteristic. This determines the overall approach for defining the *DBD* operational modes, based on the discharge's technological characteristic „*surface density of real power* (p_R) – *effective voltage value* (U_{RMS})", [1].

Something else, the use of technological characteristics when changing the coordinates, or dependencies of the type " *real power surface density* p_R - *air or working gap size* d", at constant value of the applied voltage on the electrodes (U_{RMS}= *const*), makes the different technological (operation) modes manifested in the form of a spectrum of characteristic peaks. These peaks correspond to different stages of *DBD* operation modes - avalanche operation mode; cathode and anode targeted streamers operation modes [2, 3].

EXPERIMENTAL INVESTIGATION

The co-planar triode system studied here was made of materials and in a manner, shown in Fig. 2c.

The triple layer structure "*high-voltage electrode / dielectric barrier / round bipolar electrodes network*" or *HV-E/DB/BRC-E* was produced by photolithographic technology from glass-reinforced epoxy laminate (*FR4*) or printed circuit board (*PCB*) with the following parameters: density- 1850 kg/m^3; glass transition temperature- over 120 ^{0}C; dielectric constant permittivity - 4,7 (1 kHz); 4,35 (500 MHz), 4,34 (1 GHz); dissipation factor- 0,017 (1 kHz); dielectric breakdown- 50 kV; dielectric strength- 20 kV/mm. The metal foil was 35/35 μm thick. There were examined three types of triple layer structure with different thickness of the insulation board: 1,5; 2,0 and 3,0 mm.

The flat grounded electrode *GE* was positioned in such a way against a network of round bipolar electrodes *BRC-E,* that the distance between them forms an air (working) gap with size: d = 1,5; 3; 6; 9; 12; 15, and 21 mm.

The external characteristic of the dielectric barrier discharges was experimentally taken according the known method. The burning voltages and the operational modes critical parameters ware determined. Linear regression models ware created of the technological characteristics "*real power surface density* p_R - *voltage effective value* U_{RMS}" [1].

EXPERIMENTAL RESULTS AND DISCUSSION

The technological characteristics of the *DBDs* when changing the coordinates, or the dependence of the type "*real power surface density p_R - air gap size d*", at a constant value of the applied voltage on the electrodes $U_{RMS} = const$, exhibit different operation modes in the form of a spectrum of characteristic peaks, Fig. 4, 5, 6 and 7.

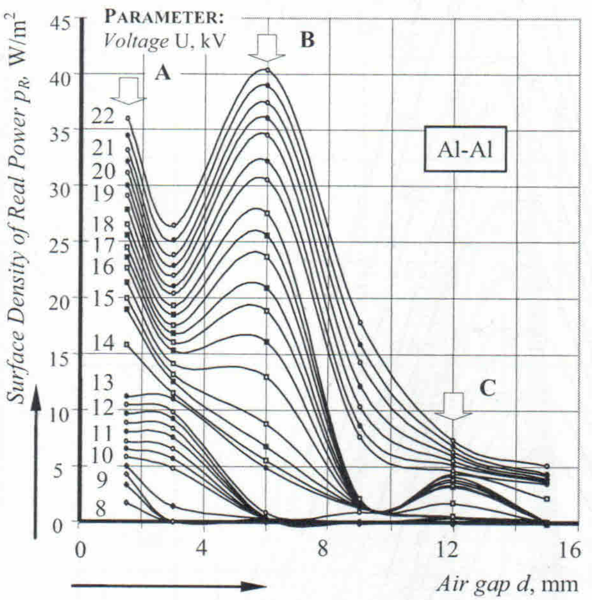


Figure 4. Family of curves representing the change of the real power surface density p_R depending on the size of the air gap d at a constant effective value of the supply voltage U (RMS) with industrial frequency (50 Hz) in co-planar triode *DBD*-system with non-magnetic (Al-Al) electrodes and glass dielectric barrier $b = 3$ mm thick.

Three characteristics peaks can be distinguished, relating to: *A* - below $d = 3$ mm, avalanche operational mode; ***B*** - about $d = 6$ mm, operational mode with cathode targeted streamers; ***C*** - about $d = 12$ mm, operational mode with anode targeted streamers.

The dielectric barrier discharge characteristics obtained in the co-planar triode discharge system studied ware compared with the dielectric barrier discharge characteristics in air at atmospheric pressure in co-planar diode system, Fig. 4.

A comparison is done between the characteristic peaks manifested during the different dielectric barrier discharge operation modes, Fig. 4: **A** - avalanche operation mode, **B** - streamer *B*-operation mode with cathode targeted streamers; **C** - streamer *C*-operation mode with anode targeted streamers.

The dependencies presented in Fig. 5, 6 and 7 allow the following conclusions:

i) the co-planar triode *DBD*-discharge system studied, Fig. 5, 6 and 7, allows repeated efficiency increase of discharge real power or real power surface density at atmospheric (high) pressure and ambient temperature, as compared to the classical co-planar diode *DBD*-discharge system, Fig. 5, and what is particularly valuable - highly efficient modes at large air gaps (over 10 mm);

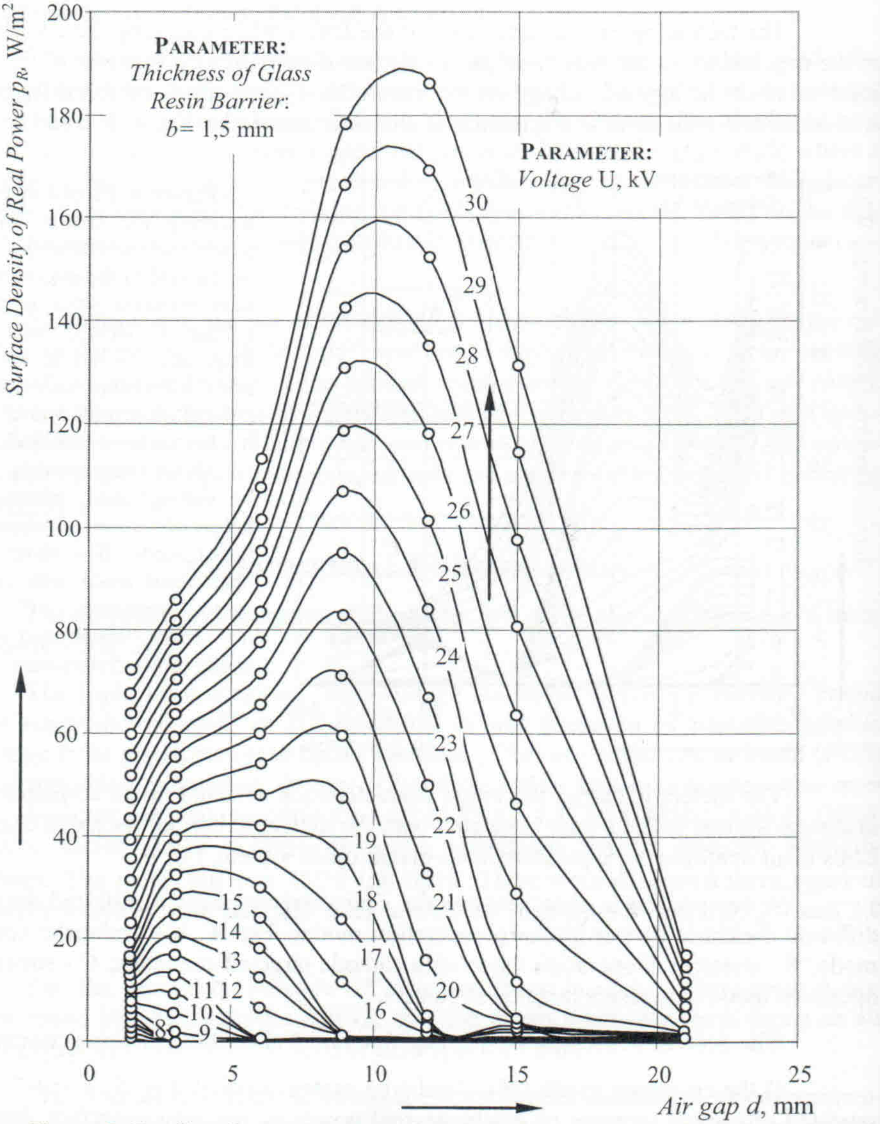


Figure 5. Family of curves, representing the influence of the air gap size d on the change of the real power surface density p_R at constant effective value of the supply voltage U (RMS) with frequency 50 Hz in co-planar triode *DBD*-system with glass-reinforced epoxy dielectric barrier b = 1,5 mm thick and hexagonal network of bipolar round electrodes with grid parameters: d = 0,6 mm; $2d$ = 1,2 mm.

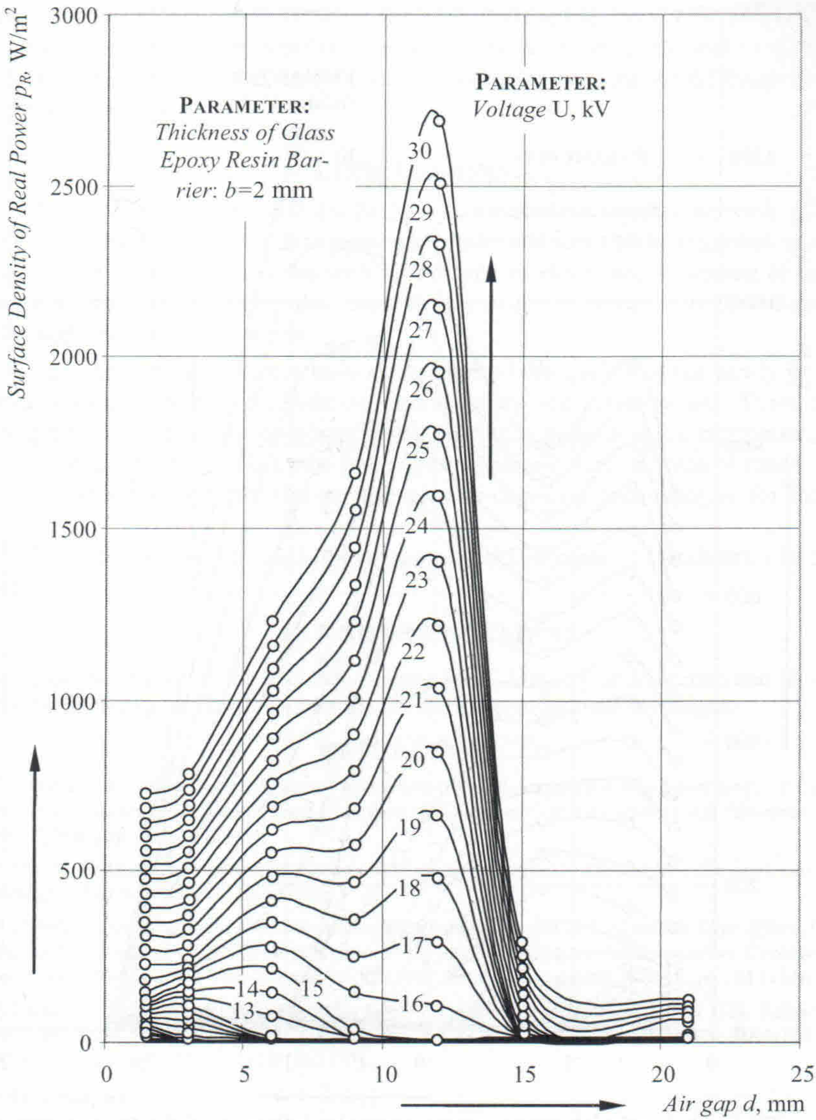


Figure 6. Family of curves, representing the influence of the air gap size d on the change of the real power surface density p_R at constant effective value of the supply voltage U (RMS) with frequency 50 Hz in co-planar triode *DBD*-system with glass-reinforced epoxy dielectric barrier b = 2,0 mm thick and hexagonal network of bipolar round electrodes with grid parameters: d = 0,6 mm; $2d$ = 1,2 mm.

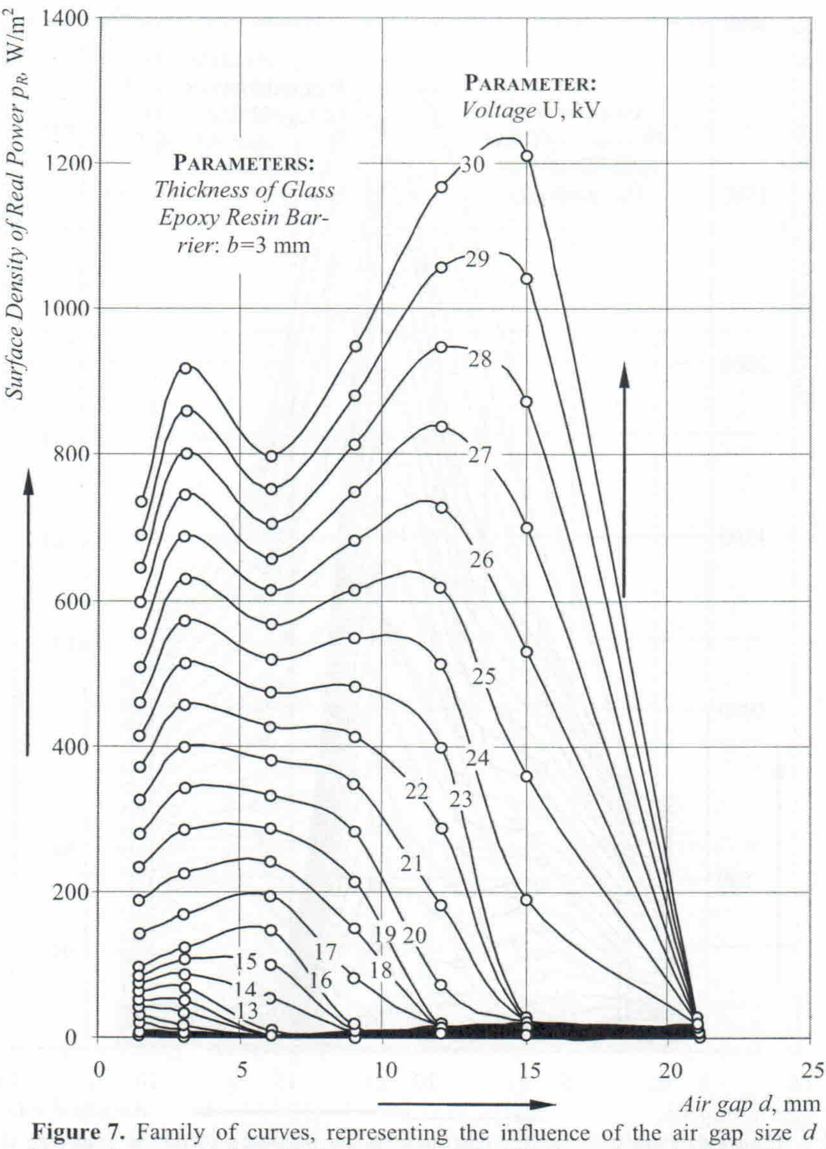


Figure 7. Family of curves, representing the influence of the air gap size d on the change of the real power surface density p_R at constant effective value of the supply voltage U (RMS) with frequency 50 Hz in co-planar triode *DBD*-system with glass-reinforced epoxy dielectric barrier b = 3,0 mm thick and hexagonal network of bipolar round electrodes with grid parameters: d = 0,6 mm; $2d$ = 1,2 mm.

ii) the change in the dielectric barrier thickness b has a significant influence on both the capacitive connection between the high-voltage electrode (*HV-E*) and the numerous round electrodes, arranged in a hexagonal network (*BRC-E*), and on the capacitive connection between them; and thence in a complex way on the different *DBD* operation modes, Fig. 5, 6 and 7.

CONCLUSIONS

A co-planar triode *DBD*-discharge system with hexagonal network of round metal (Cu) electrodes has been developed and studied. It can also be regarded as a diode *DBD* discharge asymmetric system with a new type of electrode, consisting of multiple galvanically unconnected electrodes, capacitively supplied from the high-voltage electrode through the dielectric barrier.

The experimental studies have demonstrated the quality of the newly proposed discharge system in terms of feasibility, applicability and effectiveness. There are the following new features of the co-planar triode *DBD*-discharge system, contributing to:

i - intensify the *DBDs* in the three operational application areas or modes;

ii - effectively apply the surface plasma-chemical technologies for large air gaps;

iii - effective use of quasi-homogeneous *DBD*-discharge at industrial frequency (50 Hz).

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