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THE EFFECT OF THE ION-ENHANCED FIELD EMISSION ON THE WATER VAPORS IN MICROGAPS

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Abstract. In this paper, the departure of the breakdown voltage from the Pachen's law at extremely small electrode separations is theoretically studied. In the standard DC breakdown criteria the enhancement of the secondary emission coefficient has been included. The obtained expression has been applied for determination of the breakdown voltage in water vapors in microgaps. The results of this research can be applied in the construction of compact pulse power generators for bioelectric applications.

1. INTRODUCTION

Micro discharges can be regarded as a new class of plasmas that allow formation of non-equilibrium plasmas at atmospheric pressures (Korolev and Mesyats 1998, Radmilović-Radjenović and Radjenović 2007). The fact that microdischarges operate under conditions where boundary effects dominate indicates the importance of establishing scaling laws in a such small gaps.

We were motivated by the fact that the electrical breakdown in microgaps occurs at voltages far below the pure Paschen curve minimum and that the modified Paschen curve should be used instead for micron and sub-micron gaps (Torres and Dhariwal 1999). Electrons from the field emission are one of the possible reasons why the breakdown and sparks occur in a vacuum, which of course is not possible if one only considers the Townsend avalanche mechanisms for the gas phase and the surface ionization that are normally used to generate the Paschen curve (Radmilović-Radjenović et al. 2005). In this paper, we have fitted numerical solutions in order to estimate the dependence of the breakdown voltage on the gap size and on the pressure in water vapors in microgaps.

2. ION-ENHANCED FIELD EMISSION

Failures from the Paschen curve are expected when the secondary emission process is governed by the ion-enhanced field emissions rather than ion impact. The effective yield of electrons per ion defined as the ratio of the field-emission electron current density to the incoming positive-ion current density at the breakdown is given by the

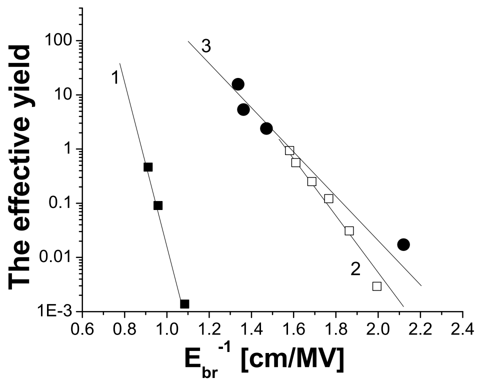

Figure 1: The effective yield versus the inverted breakdown electric field (E_{br}) for three different cathode materials: 1) stainless steel, 2) conventional steel and 3) aluminium.

expression (Boyle and Kisliuk 1955):

$$\gamma = Ke^{-D/E}. \tag{1}$$

As can be seen from Fig. 1, the equation (1) fits the experimental data (Boyle and Kisliuk 1955) well. At the same time, from the slopes of the straight lines shown in Fig. 1 the constant D was found to be equal to 26, 11 and 9.3 MV/cm for stainless steel, conventional steel and aluminium, respectively.

2. 1. SEMI-EMPIRICAL FORMULA

Putting the expression for the yield (1) and for the ionization coefficient:

$$\frac{\alpha}{p} = A\mathbf{e}^{-Bpd/V}, \tag{2}$$

in the expression for the DC breakdown criteria:

$$\gamma\Big(\mathbf{e}^{\alpha d} - 1\Big) = 1, \tag{3}$$

the transcendental equation can be obtained (Radmilović-Radjenović and Radjenović 2008):

$$K\mathbf{e}^{-Dd/V}\left(\mathbf{e}^{Apd\mathbf{e}^{-Bpd/V}} - 1\right) = 1, \tag{4}$$

Fitting numerical solutions of the equation (4), leads to the expressions for the breakdown voltage as a function of the gap size d and the pressure p, separately.

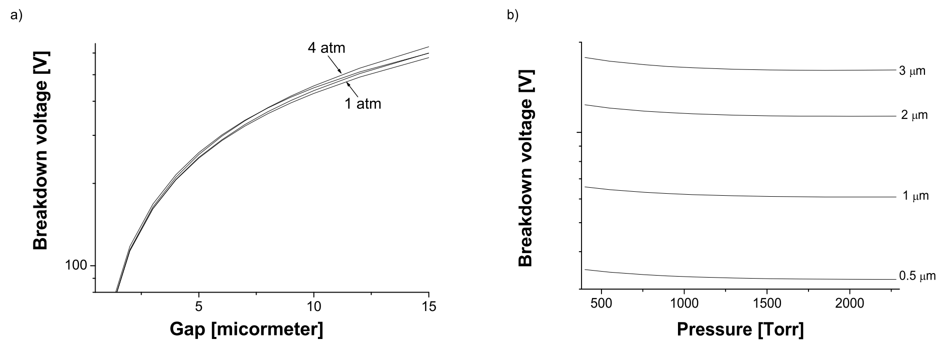

Figure 2: Dependence of the breakdown voltage in water vapors on: a) gap spacing with varying the pressure form 1 atm to 4 atm and b) pressure for gaps from 0.5 μm to 3 μm.

Table 1: Fitting coefficient for the expression (5), for the gas pressure from 1 atm to 4 atm.

Pressure [atm]	a	b	c
1	-26.122	90.012	0.719
2	-20.662	82.597	0.733
3	-14.906	76.304	0.772
4	-11.456	73.16	0.804

3. RESULTS

The obtained numerical solutions of the equation (4) for the breakdown voltage against the gap size are shown in Fig. 2a and are fitted by simple expression:

$$V = a + b * d^c, \tag{5}$$

where values of the fitting coefficients a, b and c, for the gas pressure from 1 atm to 4 atm, are given in Table 1.

The variation of the breakdown voltage with the pressure (see Fig. 2b) has been achieved by fitting based on the expression:

$$V = m * p^n, \tag{6}$$

with fitting coefficients m and n, for the gap spacing from 0.5 μm to 3 μm, listed in Table 2.

In Figure 1 we have shown results obtained by using the semi-empirical expressions (5) and (6), for the breakdown voltage. The fall of the breakdown voltage for gaps less than 5 μm is observed in Figure 1a. On the other hand, Figure 1b demonstrate weak dependence of the breakdown voltage on the pressure.

Table 2: Fitting coefficient for the expression (6), for the gap spacing from 0.5 μm to 3 μm.

Gap [μm]	m	n
0.5	45.094	-0.0442
1	85.898	-0.0456
2	166.531	-0.052
3	247.582	0.0574

4. CONCLUSIONS

The results in this paper clearly show that incorporation of the field emissions leads to deviations from the well-known Paschen curve in small gap sizes. This reduction in the breakdown voltage becomes significant for the gaps smaller than $5 \mu m$ m and may be attributed to the onset of appreciable field emissions. The fitting coefficients for semi-empirical expressions that describes the modified Paschen curve for water vapors including field emission effects in microgaps has been purposed. The results of our studies should be useful for determining minimum ignition voltages in microplasma sources as well as the maximum safe operating voltage and critical dimensions in other microdevices.

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References

Boyle, W. S., Kisliuk, P.: 1955, *Phys. Review*, **97**, 255.
Korolev, Yu. D., Mesyats, G. A.: 1998, *Physics of pulsed breakdown in gases*, URO-PRESS.
Radmilović-Radjenović, M., Lee, J. K., Iza, F., Park., G. Y.: 2005, *Journal of Physics D: Applied Physics*, **38**, 950.
Radmilović-Radjenović, M., Radjenović, B.: 2007, *Contribution to Plasma Physics*, **47**, 165.
Radmilović-Radjenović, M., Radjenović, B.: 2008, *Plasma Sources Science and Technology*, **17**, 024005.
Torres, J. M., Dhariwal, R. S.: 1999, *Nanotechnology*, **10**, 102.