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BREAKDOWN PHENOMENA IN RADIO-FREQUENCY HELIUM MICRODISCHARGES

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Abstract. In this paper, the Kihara equation has been applied in order to determine the breakdown voltage in helium rf microdischarges. It was found that the Kihara equation, with modified moleculer constants, describes the breakdown process well even for gaps of the order of a few millimeters. A good agreement between numerical solutions of the Kihara equation and the available experimental data reveals that the breakdown voltages depend on the *pd* product and vary substantially with changes in rf frequencies.

1. INTRODUCTION

Capacitively coupled rf discharges are attracting an increased attention due to their wide applications in many technological processes such as plasma etching for semiconductor materials (Flamm et al. 1983, Moreu 1988), thin film deposition (Catherine and Couderc 1986, Yalamanchi and Thutupalli 1988) and plasma cleaning (Raizer et al. 1995).

The majority of plasma processing, so far, is done at low pressures. Atmospheric pressure plasmas, however, can provide a critical advantage over the widely used low pressure plasmas since the cost of the material processing could be reduced substantially (Park et al. 2001). In this paper, we have investigated the applicability of the Kihara equation (Kihara 1952) in describing rf discharges in microgaps.

2. KINETIC THEORY OF THE RF BREAKDOWN

During rf discharges, the gas breakdown mechanism in low frequency alternating electric fields is essentially the same as for dc fields, i.e. it is controlled by secondary electron emission due to ion impact (Phelps and Petrović 1999, Radmilović-Radjenović and Lee 2005). At sufficiently high frequencies, however, ions are not capable to respond to the ac field and electrons are "trapped" in an oscillatory motion within the inter-electrode gap. In that case, the electron loss is dominated by diffusion and a significant reduction of the breakdown voltage is observed as compared to the dc case (Radmilović-Radjenović and Lee 2005).

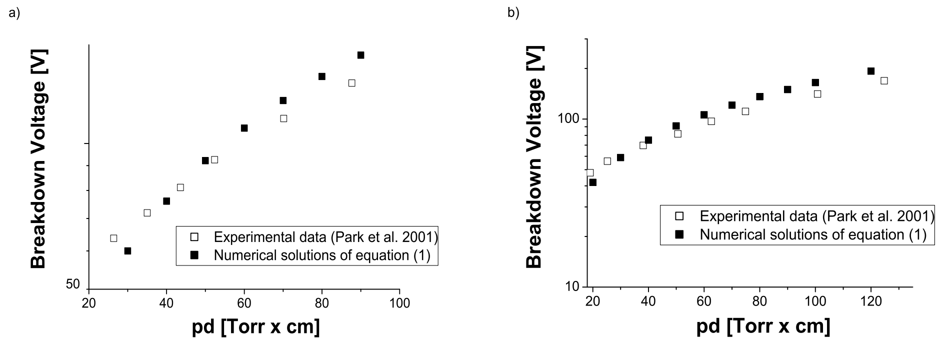

Figure 1: Breakdown voltage as a function of *pd* product in helium discharges at 13.56 MHz and gap size of: a) 0.18 cm and b) 0.25 cm.

In studying the rf breakdown it is customary to use the Kihara equation (Kihara 1952]) that describes conditions for the rf gas breakdown:

$$\mathrm{e}^{\frac{B_0 p}{2E}} = A_1 pd\Big(1 - \frac{E/B_0 p}{C_2 d/\lambda}\Big), \tag{1}$$

where $E = E_{rf}/\sqrt{2}$ is the effective rf field, p is the gas pressure, d is the electrode spacing, λ is the vacuum wave length of the rf field and finally, A_1, B_0 and C_2 are molecular constants (Kihara 1952, Lisovsky and Yegorenkov 1994).

3. RESULTS

Comparison between numerical solutions of the equation (1) (solid symbols) and measurements (open symbols) carried out by Park and his co-workers (Park et al. 2001) is shown In Fig. 1. For both gap sizes, a satisfactory agreement between theoretical and experimental results were achieved by using modified values for molecular constants $A_1 = 28$ and $B_0 = 18$.

As can be observed from Fig. 2, the breakdown voltage decreases with increasing rf frequency. For pure helium at the pressure of 600 Torr and the gap size of 0.16 cm numerical solutions of the equation (1) including modified molecular constants (solid symbols) provide a good agreement with the experimental data (Park et al. 2001) (open symbols).

4. CONCLUSIONS

This paper displays theoretical studies of the breakdown voltage in rf helium discharges. The obtained numerical solutions and their good agreement with the experimental results confirm that in the case of rf discharges at 13.56 MHz and the gap spacings of a few millimeters, breakdown voltage depends on the *pd* product and is mostly independent on the gap size. At the same time, in studying the effect of frequency variation in a high-frequency helium discharges we have also obtained satisfactory agreement between numerical results and experimental data. As expected,

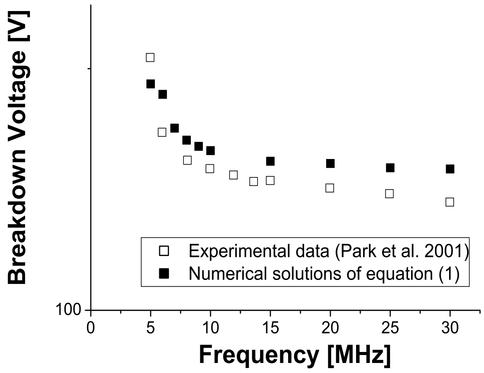

Figure 2: Breakdown voltage versus rf frequency in pure helium. Results were obtained for a gap spacing of 0.16 cm and a gas pressure of 600 Torr, varying the frequency from 5 MHz to 30 MHz.

the breakdown voltage decreases with increasing the frequency as in the case of large scale systems. The next step in our work will be investigation of the applicability of the Kihara equation for the micrometer gaps.

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