ABSTRACT

Generation of high frequency plasma at low pressure was studied in this paper. Breakdown voltages of a capacitively coupled radio frequency Ar, O₂, and N₂ discharge at 4 MHz were also explained, and the influence of the distance between electrodes (gap, d) on the ignition voltage in capacitively coupled. The breakdown voltage was plotted as a function of the Paschen reduced variable p·d. This work presents an investigation of the dependence of the breakdown voltage on the gas pressure, distance between electrodes and type of gas. The range of gas pressure varied from 0.07 mbar to 1 mbar and gap d=2, 3, 4 cm.

Keywords: Rf generator 4 MHz, breakdown, Ar, O₂ and N₂ discharge.

1. INTRODUCTION

The process of electrical breakdown is considered. If an electric field is applied to a plane parallel gap of width d, containing a gas, at sufficiently high fields the gas suddenly switches from being insulating dielectric to conducting gas. It is supposed that a few electrons are always around in the gap, either by the action of cosmic rays or else as a consequence of field emission from asperities on the surface, close to which electric fields are strongly enhanced. The above assumes dc conditions. RF breakdown is similar except that at a high-frequency surface processes are not so important: electrons are confined by field oscillations multiplication replenishes diffusive losses. As with dc (and low-frequency) breakdown, higher values of p.d require larger voltages to achieve breakdown and at low pd there is again a sharp rise in breakdown voltage [1]. Due to the very small electrode gap width we can describe the behavior of the charged particles in the RF field of our system with the DC Townsend breakdown theory, depending on the pressure range and gas type [2]. Typically Paschen curves are roughly “u” shaped with a minimum breakdown voltage at a specific p.d and increasing voltages at both, increasing and decreasing values of p.d. The breakdown voltage generally forms a fairly smooth curve, with the left hand branch of the curve being markedly steeper than the right hand branch. But, under certain circumstances inflection points and other changes in the slope of the breakdown curve have been measured. It was found that the left-hand branch is a multivalued function of the gas pressure i.e., a single gas pressure corresponds to several breakdown voltages. The multivaluedness of the left-hand branch is seen both at small distances between the electrodes and at a large distances, while the right-hand branch has an inflection point, but only if the distance between the electrodes is small and the minimum on the curve lies at a pressure for which the electron-neutral collision rate is much larger than the frequency of the electric field [3].

2. THE RF PLASMA SOURCE

The RF glow discharge chamber setup is shown in Figure 1. The apparatus consisted of a cross shaped vacuum vessel in which argon gas was introduced. Inside the chamber were two copper circular plates (20 cm in diameter) that served as electrodes. In the setup, the gap distance between the plates could be varied. One plate was grounded, while the other was subject to an applied RF voltage provided by an AC power supply. The driving frequency of the power supply was held constant at 4 MHz, but the input power was adjustable [4].

To generate the plasma, usually there are two types of systems: self-resonant amplifiers and linear type RF amplifiers which are based on a signal generator module followed by a couple of amplifying stages. In the self-resonant type generators, the plasma together with output coil are an integral part of the oscillator circuit, and to achieve the maximum power transfer, the output impedance must be matched to the load impedance, usually by means of capacitive elements. In this case, the ignition of the plasma is accompanied by a drop in the frequency of the generator. For this reason, the frequency of the generator must be precisely maintained in the limits of the industrial frequency domains. In case of the
generators based on crystal oscillators, the frequency is fixed and the signal is being sent through a cable to the plasma chamber assembly. [5]

In this paper the rf plasma generator operate in class E. The power amplifiers for use at 4 MHz usually employ specially designed RF power semiconductors. These devices typically use special fabrication techniques that reduce the stray capacitances down to acceptable levels to permit efficient operation at such high frequencies. The plasma unit presented in this paper was built using only general purpose components that are easily available. [6]

3. BREAKDOWN MECHANISM

In RF discharges, electrons gain oscillatory energy from the AC field. When an electron suffers a collision, its oscillatory motion is disturbed and its momentum is randomized. In order to determine the dependence of the breakdown field strength on the gas pressure, we can consider the discharge as a diffusion-controlled one. In the steady state, diffusion loss will be balanced by ionization and described by the relation:

\[
\frac{\nu_i}{D} = \frac{1}{\lambda_D} \tag{1}
\]

Where \(\nu_i\) represents the ionization frequency, while \(D = \frac{T_e m_e}{\nu_c}\) where \(T_e\) is electron temperature, \(m_e\) electron mass and \(\lambda_D\) the diffusion coefficient. In the limit of moderately high pressures, when \((\nu_c >> \omega)\) (\(\nu_c\) is the collision frequency and \(\omega\) is the angular frequency of the RF applied field) large number of collisions take place within a wave period, so that the electrons are unable to gain their steady-state oscillation energy and thus large electric field is needed to initiate breakdown. In the low-pressure limit \((\nu_c << \omega)\), collisions are few and far between, so that many cycles of the wave period go by before a collision occurs and the field strength again rises. It follows that the breakdown field increases both in the right and low-pressure regimes. [7]

4. RESULTS

There is a range for which there is a multivalued dependence of the breakdown voltage on the gas pressure in the low-pressure region to the left-hand side of the breakdown curve’s minimum. In our calculations we were primarily concerned with the conditions to the left of the breakdown Paschen minimum where secondary emission processes dominate.

Breakdown voltage curves in argon at 4 MHz and gap sizes ranging from 2 cm to 4 cm are shown in Figure 2.

In this figure the break down voltage is drop with increase pressure and then rising. These curves have a similar behavior and have minimum value for break down voltage where the current is maximum value. When increase distance between
electrodes the curves are shifted to high voltage. Figure 3 and figure 4 are representing Paschen’s curves for RF breakdown in nitrogen and oxygen. These curves show similar behavior for that of argon, but minimum value for nitrogen and oxygen increase to 500 V and 650 V respectively. The table (1) illustrated minimum values for break down with varies distance between electrodes and pressure for argon, nitrogen and oxygen gases.

![Figure 3 Paschen curves for RF breakdown in nitrogen, at 4MHz, for gaps of: 2 cm, 3 cm, and 4 cm.](image1)

![Figure 4 Paschen curves for RF breakdown in oxygen, at 4MHz, for gaps of: 2 cm, 3 cm, and 4 cm.](image2)

<table>
<thead>
<tr>
<th>Gap d cm</th>
<th>Ar Break Down (V)</th>
<th>N₂ Break Down (V)</th>
<th>O₂ Break Down (V)</th>
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<tr>
<td></td>
<td>P (mbar)</td>
<td>P (mbar)</td>
<td>P (mbar)</td>
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The Paschen curves for the argon, nitrogen and oxygen rf plasmas are shown in Figures (5-7). These curves were obtained by varying the pressure from 0.1 to 1 mbar and using three different gap spaces, 2, 3, and 4 cm. The general shape of these curves agrees with that obtained for DC discharge. The argon plasma exhibits a minimum breakdown voltage at a Pd of about 1.2 mbar.cm. In rf discharge using an Cu electrode. The minimum breakdown voltages for nitrogen and oxygen are at 1.6 and 0.8 mbar. cm respectively.
5. CONCLUSION

Generation of high frequency 4 MHz plasma at low pressure by using argon, nitrogen, and oxygen were explained. We have investigated the physics of a breakdown voltage for capacitively coupled radio-frequency plasma source operating at pressures from 0.1 to 1 mbar. In pure argon, nitrogen, and oxygen, and gap sizes ranging from 2 – 4 cm, the breakdown voltage decreases with increase pressure. Minimum values for breakdown are calculated from curves when current has maximum value. The minimum value dependent on type of gas and gap d (distance between electrodes).

REFERENCES


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