The Electrical Breakdown Characteristics in the Presence of a Hot Filament for Ar and N₂ Gases

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Abstract: The aim of this paper is to investigate the characteristics of a DC electrical breakdown accompanied with a hot tungsten filament. Our device includes of two flat electrodes and a moveable filament which is located behind the cathode. The left-hand of the Paschen curve is obtained for different of the currents of the filament as well as various locations in the presence of argon and nitrogen gases. The ionization efficiency (η) and secondary ionization emission coefficients (γ) are evaluated in different of currents and locations of the filament. It is shown that increase of filament current causes to decrease of electrical breakdown, which is more pronounced in lower pressures. Furthermore, moving the filament far from the cathode leads to reduce of secondary ionization emission. In addition, the influence of filament current on the breakdown characteristics for two gases of argon and nitrogen are compared.

Key words: Electrical breakdown · Hot filament · Paschen curve · Ionization efficiency

INTRODUCTION

The electrical breakdown of gases has widely studied theoretically and experimentally [1, 2]. The technological applications of plasmas formed in these sources are numerous and include of thin film deposition, pumping gas discharge lasers, plasma display panels, semiconductor processing, materials treatments (modification of surface physics and surface chemistry, Sterilization), lamps, light sources and displays, voltage stabilizers and waste treatment and materials analysis [3, 4].

If an electric field is applied to flat parallel electrodes containing a gas, at sufficiently high electric field, the gas being to partially ionize and an electrical transition takes place. To optimize the electrical breakdown which has application for example in the fuse devices, there are several ways to reduce and control the breakdown voltage. The optimization of the dc electrical breakdown is one of the oldest problems in the study of low-pressure gas discharges [4].

In the current study, we are going to investigate experimentally, the influences of a hot filament located behind the cathode on the electrical breakdown characteristics. The influences of the presence of the hot filament and gas type on the breakdown voltage and ionization efficiency as well as secondary ionization coefficient.

The structure of the paper is as follow. In the section 2, the experimental setup and the governing equations are introduced. In the section 3, the results and discussion are presented and in the section 4, the summary of the results is concluded.

Experimental Setup: The dimensions of vacuum quartz glass vessel are 180 mm in internal diameter and 600 mm in length. The electrodes are made from stainless steel with 146 mm in diameter. The distance between two electrodes is 215 mm. These dimensions enable us to assume a uniform electric field throughout the electrodes. The chamber is preliminarily evacuated to a pressure below 10⁻³ Torr by a turbo molecular pump backed with a rotary pump. The range of working pressure is (0.4×10⁻²-5.5×10⁻²) Torr.

A tungsten filament is located behind the cathode and connected through a simple electrical circuit to a DC power supply ranging from 0 to 6 A. The current of the electrical breakdown is measured by the drop voltage...
across a resistor. The experiment is performed for different filament currents and repeated each run for 5 times and the average values with a relative error less than 5% are reported. To avoid the surface effects of electrodes, the edge of cathode and anode are inserted to the PTFE insulators.

The coefficient \( \alpha \), called the first Townsend’s coefficient is the most important characteristic determining the dielectric strength of a gas, where \( \alpha (\varepsilon) = 1/\lambda_{\text{ion}}(\varepsilon) \) is the inverse of “ionization” mean free path \( (\lambda_{\text{ion}}(z)) \). The first Townsend’s coefficient which depends on the gas type and reduced electric field can be expressed as [5]:

\[
\alpha_p = A \exp \left[ -\frac{BP}{E} \right]
\]  

(1)

Where \( A \) and \( B \) are constants for a particular gas and \( P \) is the pressure.

It is more convenient to use ionization coefficient \( \eta \) to investigate the breakdown phenomena (or ionization efficiency) defined as the number of ionization events caused by an electron in passing through a potential difference of one volt:

\[
\eta = \frac{\alpha}{E}
\]  

(2)

The secondary ionization coefficient can be expressed in terms of the ionization coefficient \( \eta \) [6]:

\[
\gamma = \frac{1}{e^{\eta} - 1}
\]  

(3)

Thus, \( \gamma \) depends on the cathode material and gas type, as well as on the ratio \( \varepsilon_p / P \) [5-7]. Using the above equations, we are going to obtain the ionization efficiency and secondary electron emission in the presence of a hot filament behind the cathode for argon and nitrogen gases.

**RESULTS AND DISCUSSION**

The Figure 1 shows the breakdown voltage as a function of \( Pd \) (left-hand of Paschen curve) for different of filament currents in the presence of argon gas. As can be seen, increase of \( Pd \) leads to the decrease of breakdown voltage which is the main feature of the left hand side of Paschen curve. By appearing of electric current in the filament, the breakdown voltage reduces and the glow discharge can be produced at a lower voltage. However, the influence of filament current on the breakdown voltage is more pronounce in higher values of \( Pd \) which is a consequence of the dependence of the collision cross section between electron-neutral backgrounds on the pressure. By rising up the pressure, the mean free path of the neutral gas atom vanishes and therefore the probability of the collision of electrons extracted from filament with the neutral atoms increases and the breakdown voltage decreases. In Figure 2, the same plot is drawn for nitrogen gas. In the case of nitrogen gas, appearing the electric current in the filament also leads to the decreasing of breakdown voltage. However, by comparison of Fig. 1 with Fig. 2, it can be concluded that the hot filament has more influence on the breakdown for argon gas respect to the nitrogen gas.

Now, we are going to study of influence of position of the filament relative to cathode on the electrical breakdown voltage. In Fig. 3, the breakdown voltage is measured as a function of \( Pd \) for different of filament positions for argon gas. Here, \( L \) denotes the distance of filament from the cathode. As can be seen, in the low pressures, the filament position has no great influence on the breakdown voltage while in the case of high pressures, by moving the filament toward the cathode, the breakdown voltage decreases. The latter one can be a consequence of the increasing the mean free path with reducing the pressure.

In the Fig. 4, the Paschen curves are shown for three values of filament distance in the presence of nitrogen gas. In high pressure regime, by increasing the filament distance from the cathode, the influence of filament diminishes, while in the low pressure, the location of the filament has no influence on the breakdown voltage.

Figure 5 shows the ionization efficiency as a function of reduced electric field for argon and nitrogen gases in various filament electric currents.

The maximum value of the ionization efficiency depends on the inverse of ionization potential of the gas and therefore, the presence of the filament does not lead to variation of ionization efficiency significantly.

In addition, it can be observed that the ionization efficiency for argon gas is higher than nitrogen gas while for high values of reduced electric field that difference disappears.

Now, we focus on the variation of secondary ionization coefficient respect with reduced electric field for three values of filament currents for argon and nitrogen gases (Fig. 6). Increase of the reduced electric field leads to the rising up the value of secondary ionization coefficient and increasing the electric current of hot filament results to the amplifying of the \( \gamma \). However, it can be concluded that the values of secondary ionization for argon gas are higher respect to the nitrogen. These results are in fully agreement with the results of Fig. 1 and Fig. 2.
Fig. 1: Breakdown voltage ($V_d$) for Argon gas as a function of $Pd$ (Paschen curves) for three values of filament current

Fig. 2: Breakdown voltage ($V_d$) for Nitrogen gas as a function of $Pd$ (Paschen curves) for three values of filament current

Fig. 3: Breakdown voltage ($V_d$) for argon gas as a function of $Pd$ (Paschen curves) for three values of filament position

Fig. 4: Breakdown voltage ($V_d$) for Nitrogen gas as a function of $Pd$ (Paschen curves) for three values of filament position

Fig. 5: Ionization efficiency ($\eta$) as a function of $E/P$, for different of filament current on Argon and Nitrogen gas
In the Fig. 7, the dependence of the secondary ionization coefficient on the filament location is presented for argon and nitrogen gases. This figure shows that by moving the filament far from the cathode, the effect of filament disappears which can be a consequence of recombination collision of electron-neutral background. However the influence of filament location is more pronounced in high pressures case.

CONCLUSION

In current study, the electrical breakdown characteristics in the presence of a hot filament are investigated experimentally for argon and nitrogen gases. Our results show that the presence of hot filament results to reducing of the breakdown voltage which has more effect on the argon gas respect to the nitrogen gas. It is also shown that the filament has no drastically influence on the ionization efficiency while has great influence on the secondary ionization coefficient. In addition, the presence of the filament is more pronounced in the case of low pressures.

REFERENCES