An Investigation of the Secondary Electron Emission Coefficient of Aluminum and Graphite Disc Electrodes

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Received: 30/12/2015 Accepted: 8/3/2016

ABSTRACT

Gas discharge characteristics are seriously influenced by the secondary electron emission coefficient which was originally defined by Townsend. In this paper, six cases of gas discharge parallel disc anode - cathode of the same/different diameter using similar/not aluminum and graphite were investigated. The relations of secondary electron emission coefficient and its inverse versus the pressure-distance product for different gas discharge cases were determined. The secondary electron emission coefficient has a maximum value at the higher diameter and work function of anode disc material, lower diameter and work function of cathode disc material and its reverse polarity has a minimum value. Also, the breakdown voltage versus pressure-distance product for these cases at secondary electron emission coefficient equal to 0.1, 0.01, 0.001 and 0.0001 was determined.

Keywords: Electric Discharge, Secondary Electron Emission Coefficient, Work Function, Breakdown Voltage.

INTRODUCTION

Electric discharge is defined as the flow of electric charges through gaseous medium. It is widely used in various fields such as thin film deposition, semiconductor processing, pumping as discharge lasers, the accelerator ion sources and in plasma physics, material treatment, lamps, light sources and displays. It is also used in other applications including waste treatment and material analysis, voltage stabilizers, electromagnetic pulse generators, insulation for prevention of breakdown in high-voltage circuits and transmission lines. The primary process in the breakdown mechanism is the electron bombardment of materials leading to the emission of electrons from the materials (secondary electrons) that have a significant impact on the sheath and overall plasma behavior. In a plasma, the electrons with sufficient energy to overcome the wall sheath potential can impact the wall and produce secondary electrons. This process can be quantified by the effective secondary emission coefficient, or second Townsend coefficient (γ). This secondary electron emission depends on the discharge parameters such as the electric field, magnetic field, gas pressure, electrode materials and etc.

Theoretical studies showed that secondary electron emission coefficient plays a vital role especially in the development of particle detectors for high energy physics and astroparticle detectors for the development of scanning electron microscopy. The secondary electron emission coefficient (SEEC), γ, gives the information on the efficiency of electron emission from the cathode due to ion bombardment. Generally it is defined as the ratio of the secondary electron flux emitted from the material surface to the influx of the bombarding particles. The electron emission by ions is the only means of electron production from the cathode. The theory for this calculation, in which the emission by ions, is the major cause of electron emission and then based on γ and on the primary ionization coefficient, α, where α expresses the number of single ionizing collisions by an electron in unit distance. Then in a parallel-plane discharge, the breakdown criterion in the self-sustaining condition for a homogeneous electric field is given by:

\[ \alpha d = \ln (1 + \frac{1}{\gamma}) \]  

(1)

Where d is the inter-electrode distance and the primary ionization coefficient for a gas is given by:

\[ \alpha = A \exp \left(-\frac{Bp}{E}\right) \]  

(2)

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Where \( P \) is the gas pressure and \( A, B \) are constants of the gas used in this study is air, so \( A \) and \( B \) are equal to 14.6 and 365 respectively. 

The Secondary Electron Emission (SEE) effect is significant especially during the breakdown stage where the number of electrons is so small that the gas phase reactions can hardly sustain the discharge. Hence the breakdown voltage, which is one of the most essential parameters in discharge devices, is critically affected by the Secondary Electron Emission coefficient (SEEC). By considering that before and at breakdown, the electric field is uniform along the discharge axis and from equations (1,2) then we obtain:

\[
\gamma = \frac{1}{e^{\alpha d} - 1} = \frac{1}{\exp\left(\frac{Apd}{V}\right) - 1} \quad (3)
\]

From equation (3), we can calculate the secondary electron emission coefficient, \( \gamma \), that is defined as the number of electrons emitted from the surface for each incident ion or atom. The work function is the minimum energy required to remove an electron from a solid to point in the vacuum.

The aim of this work is to study the effect of anode - cathode discs surface area on the secondary electron emission coefficient using same/different two work function materials.

**EXPERIMENTAL SETUP**

In this experiment, the electric discharge formed between the two parallel disc electrodes at different pressures, electrodes diameter and materials using air are considered as shown in fig. (1). The anode and cathode materials are aluminum, \( \text{Al} \), and graphite, \( \text{C} \). The anode - cathode is placed in a cylindrical quartz tube of diameter 30cm at gap distance equal to 10cm and evacuated by rotary pump until \( 10^{-3} \) Torr.

![Fig. (1): Glow discharge setup.](image1)

![Fig. (2): Electrical circuit for glow discharge.](image2)

The electrical circuit of glow discharge experiment is shown in fig. (2). This study includes the calculation of secondary electron emission coefficient for:

a- Anode and cathode of 7.5cm diameter from \( \text{Al} \).
b- Anode and cathode of 9.5cm diameter from \( \text{Al} \).
c- Anode diameter equal to 9.5cm from \( \text{Al} \) and cathode diameter equal to 9.5cm from \( \text{C} \).
2- Anode diameter equal to 9.5cm from \( \text{C} \) and cathode diameter equal to 9.5cm from \( \text{Al} \).
2- Anode diameter equal to 9.5cm from \( \text{C} \) and cathode diameter equal to 9.5cm from \( \text{Al} \).
2- Anode diameter equal to 9.5cm from \( \text{C} \) and cathode diameter equal to 7.5cm from \( \text{Al} \).

Figures (3,5,7,9,11,13) show the relation between SEEC and the pressure-distance product(Pd) for anode - cathode of diameters equal to 7.5cm from \( \text{Al} \) - 7.5cm from \( \text{Al} \), 9.5cm from \( \text{Al} \) - 9.5cm from \( \text{Al} \), 9.5cm from \( \text{Al} \) - 9.5cm from \( \text{C} \), 9.5cm from \( \text{C} \) - 9.5cm from \( \text{Al} \), 7.5cm from \( \text{Al} \) - 9.5cm from \( \text{C} \) and 9.5cm from \( \text{C} \) - 7.5cm from \( \text{Al} \) respectively. It is clear that the SEEC decreases by increasing Pd until reaching a minimum value and then increases. Figures (4,6,8,10,12,14) show the relation between the inverse of secondary electron emission coefficient versus Pd at the same diameters and materials.
It is clear that the inverse SEEC increases by increasing Pd until reaching a maximum value and then decreased.

**Fig. (3):** Secondary electron emission coefficient versus Pd for Al anode - cathode discs of 7.5cm diameter.

**Fig. (4):** Inverse of secondary emission coefficient versus Pd for Al anode - cathode discs of 7.5cm diameter.

**Fig. (5):** Secondary electron emission coefficient versus Pd for Al anode - cathode discs of 9.5cm diameter.

**Fig. (6):** Inverse of secondary emission coefficient versus Pd for Al anode - cathode discs of 9.5cm diameter.

**Fig. (7):** Secondary electron emission coefficient versus Pd for Al anode - C cathode discs of 9.5cm diameter.

**Fig. (8):** Inverse of secondary emission coefficient versus Pd for Al anode - C cathode discs of 9.5cm diameter.
Fig. (9): Secondary electron emission coefficient versus Pd for C anode - Al cathode discs of 9.5cm diameter.

Fig. (10): Inverse of secondary emission coefficient versus Pd for C anode - Al cathode discs of 9.5cm diameter.

Fig. (11): Secondary electron emission coefficient versus Pd for Al anode - C cathode discs of 7.5cm and 9.5cm diameter respectively.

Fig. (12): Inverse of secondary emission coefficient versus Pd for Al anode - C cathode discs of 7.5cm and 9.5cm diameter respectively.

Fig. (13): Secondary electron emission coefficient versus Pd for C anode - Al cathode discs of 9.5cm and 7.5cm diameter respectively.

Fig. (14): Inverse of secondary emission coefficient versus Pd for C anode - Al cathode discs of 9.5cm and 7.5cm diameter respectively.
Figures (15-20) show the relation between the breakdown voltage versus Pd for anode - cathode of diameters equal to 7.5cm from Al - 7.5cm from Al, 9.5cm from Al - 9.5cm from Al, 9.5cm from Al - 9.5cm from C, 9.5cm from C - 9.5cm from Al, 7.5cm from Al - 9.5cm from C and 9.5cm from C - 7.5cm from Al at γ equal to 0.1, 0.01, 0.001 and 0.0001 respectively. It is clear that the relation is increased linearly as the pressure increased.

Fig. (15): Breakdown voltage versus Pd for Al anode - cathode discs of 7.5cm diameter at different γ values.

Fig. (16): Breakdown voltage versus Pd for Al anode - cathode discs of 9.5cm diameter at different γ values.

Fig. (17): Breakdown voltage versus Pd for Al anode - C cathode discs of 9.5cm diameter at different γ values.

Fig. (18): Breakdown voltage versus Pd for C anode - Al cathode discs of 9.5cm diameter at different γ values.

Fig. (19): Breakdown voltage versus Pd for 7.5cm diameter Al anode and 9.5cm diameter C cathode discs at different γ values respectively.

Fig. (20): Breakdown voltage versus Pd for 9.5cm diameter C anode and 7.5cm diameter Al cathode discs at different γ values respectively.
Figures (21-23) show the comparison of secondary emission coefficient versus Pd for 7.5cm and 9.5cm diameters Al anode and cathode discs, 7.5cm diameter Al anode - 9.5cm diameter C cathode discs and its reverse polarity and finally 9.5cm diameters Al anode - C cathode discs and its reverse polarity respectively. It is clear from fig.(21) that the SEEC for the smallest diameter of anode and cathode is higher than the larger one. In fig.(22), the anode of higher diameter and work function material has higher SEEC. On the other hand, fig.(23) shows that the anode of high work function material has higher SEEC at the same higher diameter of cathode.

**Fig. (21):** Secondary electron emission coefficient versus Pd for 7.5cm and 9.5cm diameters discs from Al anode-cathode.

**Fig. (22):** Secondary electron emission coefficient versus Pd for 7.5cm diameter Al anode - 9.5cm diameter C cathode discs and the reverse polarity.

**Fig. (23):** Secondary electron emission coefficient versus Pd for 9.5cm diameter of Al anode - C cathode and the reverse polarity.

**Fig. (24):** Comparison of secondary electron emission coefficient versus same / different anode – cathode diameters and materials at constant Pd equal to 4.06Torr.cm.

Figure (24) shows the comparison of SEEC versus same / different anode - cathode diameters and materials at Pd equal 4.06Torr.cm. It is clear that the highest case is for 9.5cm diameter C anode - 7.5cm diameter Al cathode discs, while it’s reverse polarity has the smallest SEEC.

**CONCLUSION**

In this paper, a study was made on the effect of anode - cathode discs surface area and their work function materials on the production of secondary electron. We introduce the different anode - cathode diameters and materials as following: anode - cathode of diameters 7.5cm aluminum - 7.5cm aluminum, 9.5cm aluminum - 9.5cm aluminum, 9.5cm aluminum - 9.5cm graphite, 9.5cm graphite -
9.5cm aluminum, 7.5cm aluminum - 9.5cm graphite and 9.5cm graphite - 7.5cm aluminum respectively. From the relation between SEEC versus the pressure-distance product (Pd), it is obvious that SEEC decreases by increasing Pd until reaching a minimum value and then increased. This is because there is a minimum breakdown voltage (V)min at which there is a minimum pressure-distance product (Pd)min according to Paschen's law. From the relation between the breakdown voltage versus Pd for these cases at γ equal to 0.1, 0.01, 0.001 and 0.0001, it is clear that this relation is increased linearly as the pressure increased.

A comparison was made on γ versus Pd for different diameters of the same material, different diameters of different materials and finally the same diameters of different materials anode - cathode discs. This shows that γ for the smallest diameter of the same material is higher than the bigger one. This is due to by increasing the area of the electrodes makes it more difficult to maintain a given breakdown voltage. Thus breakdown voltage decreases slightly with the increase in surface area. In the case using different diameter of different materials, it is deduced that the anode of the higher diameter and higher work function material (C) has the highest γ value. On the other hand, the case using the same diameter of different materials showing that the anode of the higher work function material has the highest γ value.

Finally, the comparison between same / different anode - cathode diameters and materials showing that the higher SEE is for the higher surface area of higher work function material (9.5cm diameter graphite) anode, the lower surface area of lower work function material (7.5cm diameter aluminum) cathode discs. Conversely, its reverse polarity case has the smallest SEE. This means that the anode with higher diameter of the highest work function material and the cathode with lower diameter of lowest work function material produce large value of secondary emission coefficient.

REFERENCES


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