Effect of the Geometric of (Al) Hollow Cathode on Paschen Curves in Nitrogen

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Abstract: In this paper, an experimental study of DC hollow cathode glow discharge plasma at different nitrogen pressures ranged from (0.065 to 0.75Torr) has been proposed. Investigated was carried out under the influence of the hollow cathode geometry such as diameter and depth of hollow cathode on the breakdown voltage of the nitrogen gas, the discharge system consists of two electrodes, the cathode forms various geometrical shapes and anode as a disc-shaped with diameter (8.8cm). The electrodes are enclosed in a large cylindrical glass chamber of pyrex filled with nitrogen gas. Three important physical parameters affecting the condition of the discharge are the gas pressure, constant inter-electrode distance and the cathode geometry. We used the hollow cathode with geometric shapes such as Cylindrical, conical, oppressive and variable dimensions. The cylindrical and conical shapes have inner diameters (3 & 6) cm and repressive shapes have inner diameter (1 & 2) cm. The breakdown voltage $V_b$ is shown to depend on the product (p.d), for lower values of pressure, p or gap, d. This work represents the investigation of the dependence of the breakdown voltage on the gas pressure and on the distance between electrodes and the cathode geometry. The minimum value of breakdown voltage increases with increases gap d or increase the diameter of the hollow cathode with the length of the cavity is fixed.

Keyword: Dc glow discharge, Hollow cathode, N2 gas breakdown, paschen curves, law pressure plasma.

1. Introduction

High-density plasmas typical of hollow cathodes discharges are based on efficient avalanche multiplication of electrons, large increases in current density with decrease of internal distance between electrodes. This effect is related with oscillations of electrons between equivalent repelling potentials of sheaths at opposite inner walls in the cathode and consequent effects.
Hollow cathode discharges have too an important characteristic that combines two important processes, i.e. sputtering and excitation/ionization of the sputtered atoms [1].

The properties and behavior of this discharge have been active research topics for more than 50 years, A wide range of applications can benefit from high power discharging [2].

The hollow cathode discharge was widely adopted in scientific, medical and industrial applications ,Which require active electrons or high densities of ions ,These uses include high sources of hydrogen radiation(VUV) [3,4], Treatment of environmental pollutants and destruction of biological pathogens[5], Sources of ionization in mass spectrometry[6], And chemical processes [7].

The main characteristics of plasma discharge such as voltage breakdown, I-V characteristics and discharge structure depend on the geometry of the electrodes, the container, the gas used and the pressure in the chamber and pole material and external circuit [8].

The electric breakdown of gases is the transition from the isolated state to the conductivity, and the minimum voltage in which this transformation occurs is called a voltage breakdown ($V_b$) [9].

It is also known that the collapse curves of the glowing discharge are described by the Paschen law $V_b=f(pd)$, voltage breakdown depends on the electrode spacing and gas pressure [10]

$$V_b = \frac{Bpd}{\ln(Apd) - \ln[\ln(1 - \gamma^{-1})]}$$

This equation is known as Paschen's law, where $V_b$ is the breakdown voltage, P is the pressure; d is the gap distance [11]. The constants (A), (B) for gas used and (γ) secondary electron emission coefficient of the cathode material [12]. The relationship between V and pd is not linear and has a minimum value for any gas [11].

The breakdown of the voltage also depends on several factors, such as charged particles and uncharged in gas, and the composition of the electrode and the properties of the surface (case and area) of the electrodes and the internal radius of the discharge pipes. However, these factors are not taken into account in the Paschen Law, and thus may be responsible for the deviation between empirical and theoretical results [13,14].

The aim of this the results of the empirical study of the effect of geometrical shape as well as the distance of the dividing gap (pd) between cathode and anode on the voltage breakdown of nitrogen gas in the electric field (dc) In the cylindrical discharge tube

2- Material and methods

In figure 1 (a, b) shows the system designed, the voltage breakdown curves in the glow discharge of nitrogen gas. At a voltage level (dc) variable from(150-900)V and compression from(0.065 -0.76 )torr, The cathode is used in three geometric forms(cylindrical, conical and repressive) with different diameter
illustrated in fig(2), enclosed in a cylinder chamber made of glass Pyrex with length 30 cm and 10cm diameter. The anode was an aluminum disc with diameter (8.8)cm and thickness(1)cm. All components of the device have been designed(Such as electrodes and insulating supports) by high precision manufacturing processes to ensure electrode parallelization and electrode surfaces, and using a gas discharge pump( Edwards Vacuum pump, model ED200) , the pressure of the gas is controlled by using a needle seal , throttle and discharge system (Pyrex tube) with flow meter, pressure is recorded in the empty chamber using the pirani gauge from a kind of (EDWARDS) So that the discharge can reach(0.05 mbar) The flow of nitrogen gas is monitored.

Figure 1.a. represents discharge unloading system b. illustrates the scheme electric circuit used to measure the voltage collapse

Figure2. Represents the shapes of hollow cathode used and its dimensions.
3- Results and discussion

Figure 3(a, b) shows the paschen curves of nitrogen gas using the cylindrical hollow cathode for different distances to the distance gap(4,8)cm.

It was observed through Baschen curves at using a hollow cylindrical cathode with an internal diameter (6) cm the breakdown voltage increases at increasing, inter- electrodes spacing. Due to the decrease of electric field. Where it is observed that the voltage breakdown is when the inter- electrodes spacing (4)cm, the Voltage breakdown is equal (252)V and (pd)min is equal (0.6)torr.cm, If the distance became between electrodes(8)cm, the Voltage breakdown is equal(281)V and (pd)min is equal (0.61)torr.cm. By increasing the inter- electrodes spacing. As well as figure(1-b) when using a hollow cylindrical cathode with an internal diameter(3)cm The breakdown voltage increases by increasing the inter- electrodes spacing, it is observed that the breakdown voltage is when the inter- electrodes spacing (4)cm, the Voltage breakdown is equal(235)V and (pd)min is equal (0.67)torr.cm, If the distance became between electrodes(8)cm, the Voltage breakdown is equal(265)V and (pd)min is equal (0.86)torr.cm.

But when compared to the two cylindrical shapes, different diameters, observed decrease voltage breakdown with the decrease of the inner diameter ,at The length of the cavity is fixed, This is due to an increase in the average free path of inflexible collisions within the hollow cathode, Where the analysis summarizes it(Kolobov and Tsendin)[15] To the exponential electron proliferation within the large sheath areas of the cathode, It is therefore responsible for the effect of the hollow cathode. While the model indicates (Arslanbekov et al) [16] To the pendulum movement (Electrostatic trapping) Striking linear electrons in the plasma leads to penetration of the very thin cathode sheath. These results are in a good agreement compared with other workers results [17].
**Figure 3.** a. Hollow cathode cylindrical with diameter (6cm)  b. hollow cathode cylindrical with diameter (3cm)

Figure 4 (a, b) shows the paschen curves of nitrogen gas using the conical hollow cathode for different distances to the distance gap (4, 8) cm

In figure (4-a) Shows Pashin's curves for nitrogen gas using the hollow cone cathode with inner diameter (6) cm, Where we get on the breakdown voltage increases by increasing the inter-electrodes spacing. Where it was found that the breakdown voltage when the gap distance (4) cm is equal (227)V and \((pd)_{\text{min}}\) is equal (0.61)torr.cm, when the gap distance (8) cm is equal (261)V and \((pd)_{\text{min}}\) is equal (0.67)torr.cm. The reason has already been mentioned.

In figure (4-b) Shows Pashin's curves for nitrogen gas using the hollow cone cathode with inner diameter (3) cm, where we get on the voltage breakdown increases by increasing the inter-electrodes spacing. Where it was found that the breakdown voltage when the gap distance (4) cm is equal (226)V and \((pd)_{\text{min}}\) is equal (0.646)torr.cm, when the gap distance (8) cm is equal (255)V and \((pd)_{\text{min}}\) is equal (0.68)torr.cm, the high breakdown voltage is due to the decrease in field strength by increasing the inter-electrodes as in the relation \(E=\Delta V/d\), Where the relationship is reversed between the intensity of the electric field and the distance between the electrodes. But the difference between the inner diameter decrease and the cavity decrease can also be observed and impact on the breakdown voltage, when compared to the two conical shapes at the different diameters, observed decrease voltage breakdown with the decrease of the inner diameter, at the length of the cavity is fixed; this is due to an increase in the average free path of inflexible collisions within the hollow cathode, and therefore need to increase the electric field to compensate for the shortfall in the rate of collisions.
**Figure 4.** a. hollow cathode conical with diameter (6cm)  b. hollow cathode conical with diameter (3cm).

Figure 5 (a,b) shows the Paschen curves of nitrogen gas using the repressive hollow cathode for different distances to the distance gap (4,8) cm.

In figure (5-a) Shows Pashin's curves for nitrogen gas using the hollow cone cathode with inner diameter (2) cm, we get the breakdown voltage increases by increasing the distance between the electrodes, Where it was found that the breakdown voltage when the gap distance (4) cm is equal (225) V and \((pd)_{\text{min}}\) is equal (0.6) torr.cm, when the gap distance (8) cm is equal (246) V and \((pd)_{\text{min}}\) is equal (0.67) torr.cm, The reason has already been mentioned.

In figure (5-b) Shows Pashin's curves for nitrogen gas using the hollow cone cathode with inner diameter (1) cm, we get the voltage breakdown increases by increasing the distance between the electrodes, Where it was found that the breakdown voltage when the gap distance (4) cm is equal (212) V and \((pd)_{\text{min}}\) is equal (0.62) torr.cm, when the inter-electrodes (8) cm is equal (345) V and \((pd)_{\text{min}}\) is equal (0.71) torr.cm, The reason has already been mentioned. The breakdown voltage increasing due to a decrease in the average free path of collisions, where the current density is increased because of the cross section is decrease, when compared to the two repressive shapes at the different diameters, observed decrease voltage breakdown with the decrease of the inner diameter, at the length of the cavity is fixed; the reason has been mentioned.

![Graph](image)

**Figure 5.** a. hollow cathode repressive with diameter (2 cm)  b. hollow cathode repressive with diameter (1 cm).
Through the following shapes we noticed that all curves had almost the same general behavior as the standard Paschen curves. The breakdown voltage \( V_p \) decreases at the beginning with an increase \( (pd) \). Then it starts to increase with increasing \( (pd) \). After passing through its minimum values [14]. On the left side of the minimum of the Paschen curves \( V_b \) decrease quickly when increasing \( (pd) \). Which can be attributed to an increase in collision frequency between electrons and atoms or molecules. However, on the right side of the minimum \( V_b \) increases slowly with increasing \( (pd) \), the cross section of the variance increases. Therefore electrons need more energy to collapse the discharge gap Leading to an increase \( V_b \). This is consistent with the results [9].

4. Conclusion
In this work, we can conclude the following. First, we obtained experimentally Paschen's curves for an \( \text{N}_2 \) glow discharge and found that the breakdown voltage depended on the function between the product of the pressure and the inter- electrodes spacing, where the breakdown voltage increases by increasing the distance between the electrodes, Second, observed decrease voltage breakdown with the decrease of the inner diameter, at the length of the cavity is fixed, This is due to an increase in the average free path of inflexible collisions within the hollow cathode, this dc-glow discharge system can be used for sputtering

Acknowledgments
The authors would like to thank the University Al-Qadisiyah, Al-Diwaniyah, Iraq for its support of this work.

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