

## The Electrical Characteristic of Plasma Discharge by Using Different Operating Conditions in Vanadium Sputtering System

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### Abstract

This paper report the experimental results of the effects of the inter-electrode distances and applied voltages for various operating pressure on the electrical characteristic of plasma discharge. We have studied the Current-voltage (I-V) characteristics and discharge current – gas pressure (I-P) for different inter-electrode gaps (3, 4, 5, 6, and 8) cm of the planar magnetron discharge. Also Paschen curve were measured at different spacing, The Paschen curves in Ar gas show that the breakdown voltage between two electrodes is a function of pd (The product of the pressure inside the chamber and distance between the electrodes). The results show the sensitivity of electrode separation lead to change the electrical characteristic of generating plasma; where The I-V characteristics of argon gas were deduced as a plasma system operated in abnormal glow discharge region, which is very impotent deposition sputtering. As well as the discharge current was increased for argon plasma discharge with the increasing of the working pressure lead to increase the deposition rate. Paschen curve is analyses at different working pressures and gap distances between two electrodes .the behavior between discharge current and discharge voltage for different gap distances between two electrodes was nonlinear, In addition the experimental finding validated that the suitable electrical characteristics of glow discharge current as a function to applied voltage for varying argon gas pressure at inter-electrode spacing equal to 5 cm.

[DOI: [10.22401/ANJS.22.2.06](https://doi.org/10.22401/ANJS.22.2.06)]

Keywords: Plasma, Glow discharge, Paschen law, Magnetron sputtering.

### 1- Introduction

Cold plasma technologies have found a widely field used in different applications such as, in material processing, manufacture of thin film material, medicine and industrial process [1]. Non-thermal plasmas in dc discharges are generally created in closed discharge vessels using interior electrodes. Different types of discharges and plasmas can be obtained depending on the applied voltage and the discharge current. [2]. The glow discharge is a common source of plasma that can be established through an avalanche like ionization of gas neutrals at specific conditions for gas pressure and applied voltage [3]. Gas discharges and related plasmas are used in a large number of application fields, is especially recognized as a promising tool on the road towards the search for new materials. The creation of such materials by the cold plasma technology can be carried out in two ways. The first one is the deposition of completely new materials in the form of thin

films and the second way consists in the modification of conventional materials, performed by their cold plasma treatment [4] as well as produce and treating the material as changing the chemical structure and topography of the surface of the material. In a wide range of these implementations, the glow discharge occurs between two electrodes located in the discharge oversize, incomparably to systems of inductively coupled or microwave excited. Hence, the reactor design and optimization, including the inter-electrode distance, is one of the key issues in the technical practice [5]. A glow discharge is characterized by its distinctive regions between the cathode and the anode electrodes across the tube. The physical characteristics of these regions depend on the parameters of the discharge that is, geometry of the discharge tube, pressure of the working gas, type of gas, cathode material, applied potential and the discharge current [6]. The phenomenon underling for any plasma

operation is the electrical breakdown of ambience gas. In this study the influence of the gap space between two electrodes on the break-down voltage in addition to the effect of the product of the pressure of the ambience gas and the gap space two electrodes, as well as plasma characterization estimated from the electrical discharge characteristics on the basis of homogeneous discharge model in Ar ambience for range of pressures and discharge voltage for different electrodes separations.

## 2-Theoretical Background

Investigation of the break-down mechanism of the glow discharge is of first interest. In 1889, Friedrich Paschen performed experiments studying derivate a formulation which set the break-down voltage  $V_{br}$  as a function of the productive of the value of working pressure  $p$  of gas with the gap space  $d$  of two electrodes [7]. The main operation in the gas system which causes creating to electrical breakdown is ionization and secondary electron generation. In the first operation of ionization process where the energy of arrivals electron is exceeded the energy of ionization of an electron in a molecule of gas, that electron will be separated oneself from the molecule, to forming a positive molecular ion. On another hand the second operation accrues when the energy radiating from the recomposing of a positive ion and a on the negative electron from the cathode larger than work function of an electron in the conduction band of the cathode, which represents the energy allowance among the vacuum and the electron band. Already this electron then will be ionized outside of the cathode (Auger effect). according to this condition Thus electrical breakdown occurs as well as charge carriers are generated [8]. Spark breakdown is the transition of a non-sustaining discharge into a self-sustaining discharge is a complex process which generally converts from an insulator to a conducting state [9] The minimum potential difference that leads to this change (i.e. create a spark between two electrodes) is called the break - down voltage ( $V_{Br}$ ) in a chamber of discharge. The electrical voltage should have high value enough in order to ignite the breakdown of the gas[10]. The Paschen law  $V = f(pd)$  basically adjectives

the breakdown voltage characteristic of a gas in a gap spacing is a nonlinear relation of the product of the working pressure and the gap spacing and which usually written as [11]

$$V_{Br} = \frac{BPd}{Ln(APd) - Ln[Ln(1 + \gamma^{-1})]} = f(pd). \dots\dots (1)$$

Where A and B deepened on specific gas, and  $\gamma$  (secondary electron coefficient) is constant depends on the electrode material. In equation (1) independent that the breakdown voltage of a gas gap does not rely individually on the pressure of the gas and the gap distance, but depends on their product the pressure of a gas and the gap distance. The breakdown voltage also affects by many factors such as charged and non-charged particles in the gas, locations of the inter-electrode space charges, surface properties (natural and area) of the electrodes and inner radius of plasma discharge chamber [12], In addition the breakdown voltage decreases with increasing pressure in constant mode of current, and at a imitate pressure it reaches a minimum value and then increases. A breakdown is usually represented by a Paschen curve of the glow discharge which described by Paschen law is analyses at variant pressures and gap distances between electrodes.

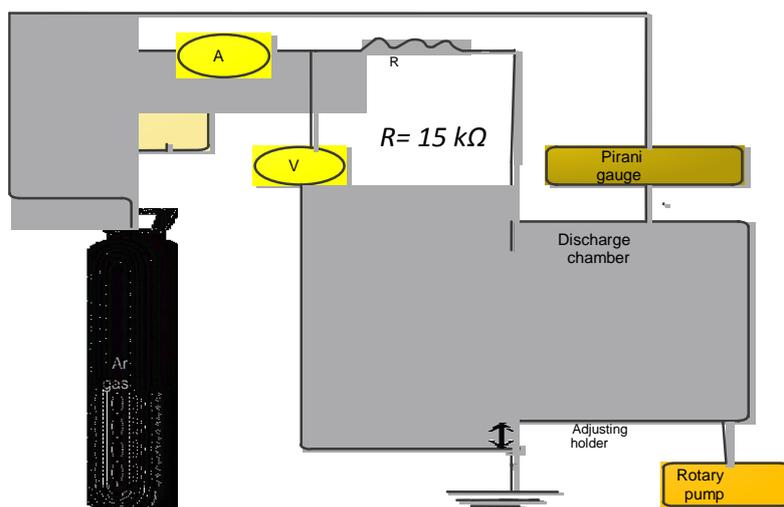
## 3-Experimental Setup

A Photographic of the plasma reactor system utilized for the low-pressure dc glow discharge in air ambience is displayed in Fig.(1). On the right-hand side the plasma chamber: a stainless steel cylindrical vacuum cell with length 40 cm and diameter 30 cm. Basically, the chamber consists of two electrodes between which the glow- discharge is formed; one of them movable electrode (denoted anode Fig.(1b)), and the fixed electrode (denoted cathode Fig.(1c)) (magnetron). The cathode and anode is machined from a stainless steel 316L. The magnetron was cooled by water circulation to avoid power dissipation. In other hand, the chamber cell had a window fixed in side, and four inlets for vacuum, high voltage inlet, electrical inlet, cathode cooling inlet, and gas supply inlet were edit into the cell chamber.



**Fig.(1): A Photographic of the major experimental set-up utilized in this work.  
(a) Plasma Chamber cell (b) anode electrode (c) cathod electrode.**

The experiments steps carried out in a DC glow discharge plasma system as illustrated in Fig.(2).



**Fig.(2): Dc-glow discharge plasma set-up.**

Discharge occurs by using argon gas with a flow rate of 40 SCCM (Standard Cubic Centimeters). The distance between two electrodes is (3,4,5,6,8) cm for working pressure values ranging from ( $6.5 \times 10^{-1}$ ) to ( $9.4 \times 10^{-2}$ ) mbar .and voltages ranged between (300 V) and (700V). The chamber cell was vacated by using the rotary pump system (Edward of  $12 \text{ m}^3/\text{h}$ ).

The quantity of gas enters the chamber cell was specific by a flow meter and the pressure inside the chamber cavity observed by Perini gauge with Edward's controller 1105. As well the applied voltage was dominated by a DC power supply constructed for delivering 5 kv. It is consist of high voltage transformer (220 /5kV), variac (0-220Vac-10Amp) ,current limiting resistor ( $R=15 \text{ k}\Omega$ ), high voltage diodes (10kVdc ), and charging capacitor. The

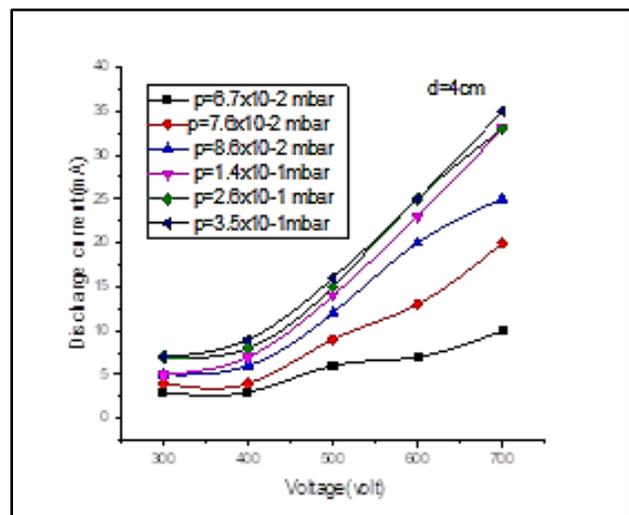
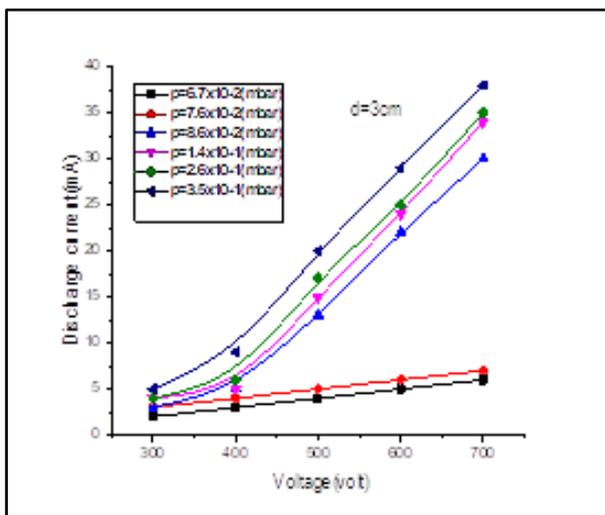
discharge current was limited by an external resistance, to conserve that the discharge would be limited to the abnormal glow discharge region. Digital *Meli-Meter* used to measure cathode potential and discharge current. The electrodes are chemically cleaned in dichloromethane and the pressure has been controlled by a throttle valve, which is mounted between the reactor system and the pumping component. The pumping unit is constructing of a rotary vane pump and a diffusion pump. The flow pressure of gas mixed delivering to plasma chamber was controlled by needle valve (0-160 SCCM) and a sputtering target of Vanadium with high purity (99.9%) is used.

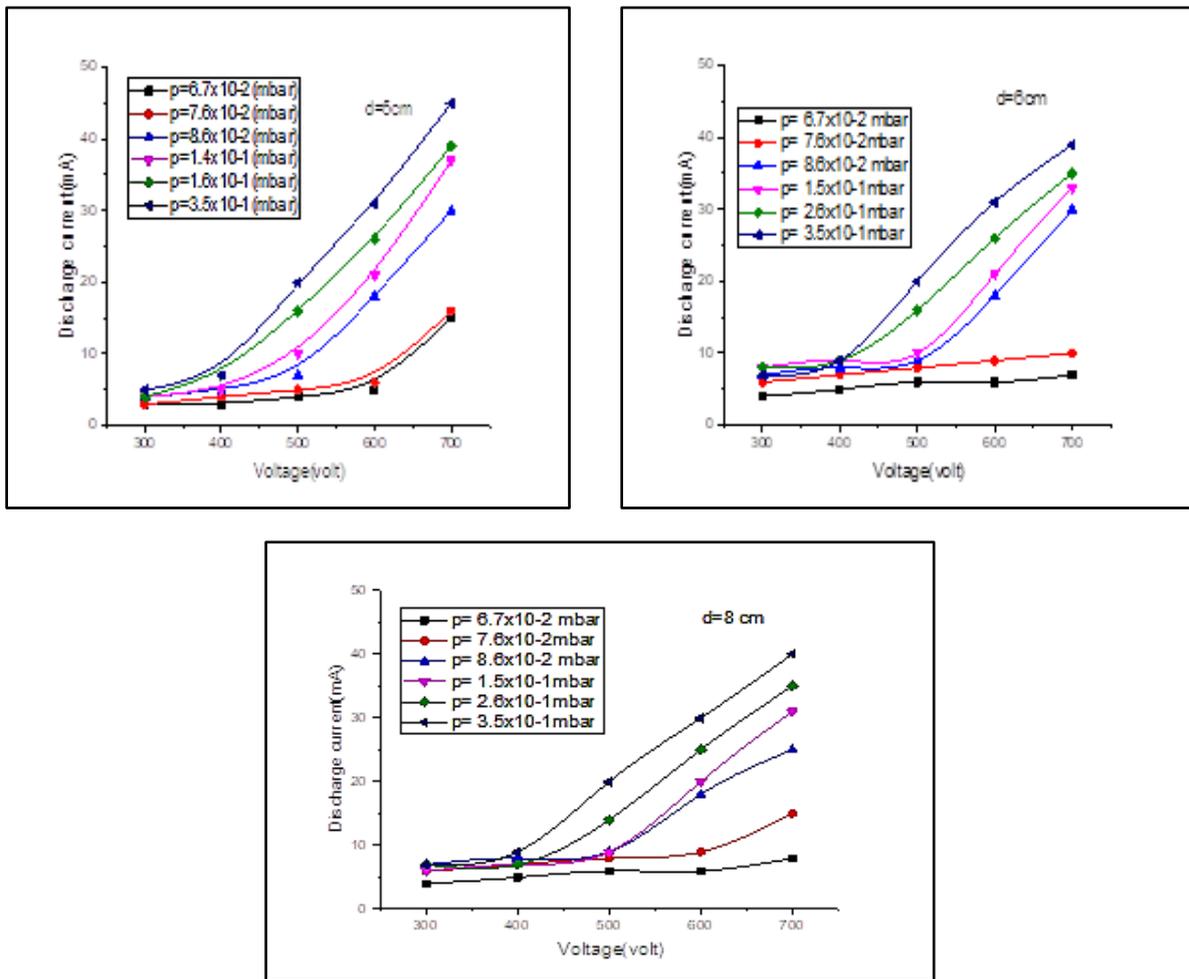
**4-Results and Discussion:**

**4-1 Current-Voltage Characteristics**

The discharge current was measured as a function of a voltage at differed working pressure for different electrodes separation (3,4,5,6,8 cm) for argon gas presented with vanadium target. In Fig.(3) it is clear in each curve the voltage applied to pass the cavity of plasma is nonlinear as a function to the current  $I_d$  (charge flow). i.e discharge voltage was supplement by an increasing of the discharge current, wherein the characteristic of such discharge is an abnormal glow. In this ordinance flatten of the cathode electrode is entirely enveloped by discharge and the rises in voltage manufactured increases in current density. The plasma obeys the rules electrically relatively alike to a resistance at small voltage. The discharge current was

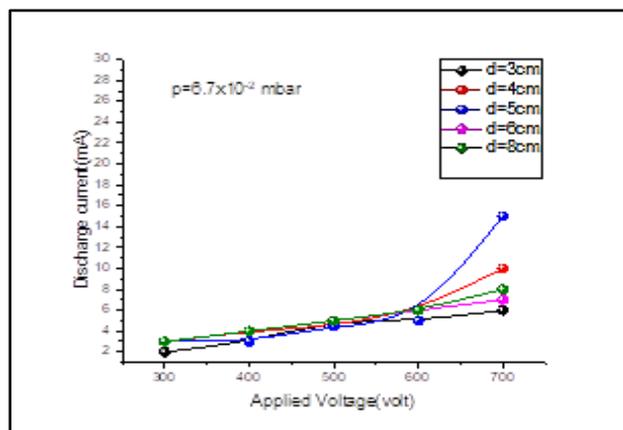
measured as a function of a voltage at differed working pressure for different electrodes separation (3,4,5,6,8 cm) for argon gas presented with vanadium target. In Fig. (3), the results demonstrate that the increase of applied voltage leads to increase discharge current, this is because the electric field accelerates the ion and the electron and as a result they collide with the atom of working gas and this leads to generate new free electron and positive ion. Since the visible glow already covers the entire work surface with increasing applied voltage (an increasing in the cathode fall), an increase in current density will now be accompanied by an increase in voltage drop through the resistance of the glow discharge. (i.e. increases discharge current with increasing in applied voltage).





**Fig.(3): Discharge current as function of voltage at different pressures of Ar gas for different electrodes separation using V target.**

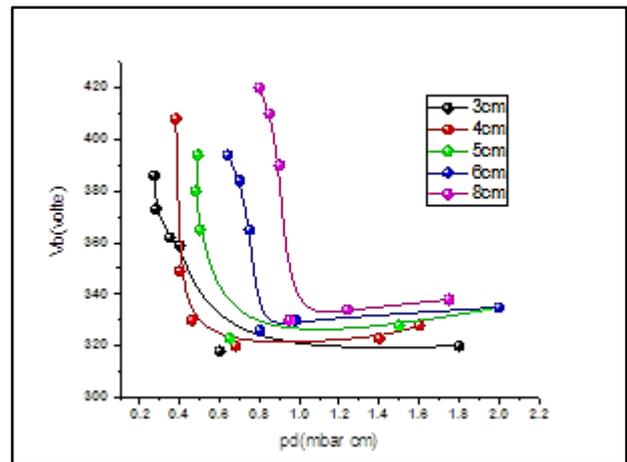
Fig.(4) show the current ( $I_d$ )-voltage (V) characteristics of the dc glow discharge at constant working pressure ( $6.7 \times 10^{-2}$  mbar) with different electrodes spacing for argon gas presented for vanadium. From this figure, it can be observed that at 5 cm electrode spacing the discharge current getting higher compared to other distances with same voltage.



**Fig.(4): Variation of discharge current with a voltage at differed electrodes separation of Ar gas for V target.**

**4-2 Paschen Law Results**

The electrical characteristics of discharge plasma, such as Paschen curve to dependencies on discharge current on the applied voltage and gas pressure inside the vacuum chamber cell are of importance to introduce the homogeneity of the generated plasma. In the following Paschen curves for DC breakdown voltage in argon gas were realized by calculating the break-down voltage as a function of the parameter formed from product  $pd$  at different distances between electrodes (electrodes separation). The results within the range of DC voltage lower than 700 V and pressure  $P = 8.2 \times 10^{-2}$  to  $6.5 \times 10^{-1}$  mbar. Five different curves of breakdown voltage  $V_B$  for the five different electrodes separation (3,4,5,6, and 8) cm is shown in Fig.(5). The overall curves behaved closely in the same way and follow the general behavior of the standard Paschen curve. At low  $p.d$  values before Paschen minimum the breakdown voltage  $VB$  initially decreases with increase in  $Pd$ , and then arises to increase with  $Pd$  after going through a minimum value. However, on the right-hand side of the minimum,  $VB$  increases slowly is comparatively smooth with the increase of  $Pd$ , i.e. the ionization cross-section increases. Therefore, electrons need more energy to breakdown the discharge gap. This behavior which can be attributed to two opposite process work: although the  $pd$  value increases, for one thing, the colliding sums of electrons and atoms rise due to the growing intensity working pressure, and it is agreeable for discharge. On the other hand, dropping in the mean free path and the energy that the electrons get from the electric field as well minimize in every free path, also it is unfavourable for discharge. The ignition voltage relies on the various of these both process.



**Fig.(5): Paschen curves of the Ar gas discharge plasma at different electrodes separation.**

Table (1) reviews the lowest breakdown voltage  $(V_B)_{min}$  and  $(pd)_{min}$  at different electrodes separation. It can be shown that increasing gap spacing near and to the right of the minimum and leads to the rise of  $(V_B)$ . The change of the break-down curves to above  $(V_B)$  and  $pd$  values with the increase of the inter electrodes separation is due to the emergence of the charged particles diffusion to chamber wells. The optimize minimum breakdown voltage  $(V_B)_{min}$  and  $(pd)_{min}$  at different electrodes separation electrodes equals to 5 cm have been established with the scheme shown in Fig.(5). We draw the curve in Fig.(6) according to Table (1).

**Table (1)**  
**Minimum breakdown voltage and  $pd$  minimum for Ar gas at different distance.**

d (cm.)	3 cm.	4 cm.	5 cm.	6 cm.	8 cm.
$(V_B)_{min}$ (Volt)	318	320	323	326	330
$P.d_{min}$ (mbar.cm)	0.6	0.68	0.69	0.8	0.95

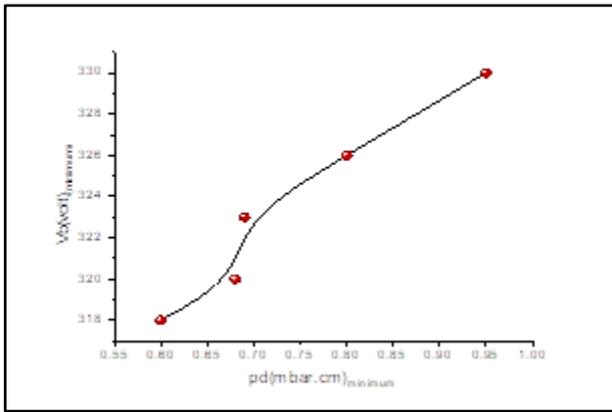


Fig.(6): Minimum values of breakdown voltage as a function of electrodes separation.

### 4-3 Current-Pressure Characteristics

The plasma sputtering device was then characterized by the relation between discharge current and gas pressure entered the chamber at different inter-electrode gaps over the vanadium target as shown in Fig.(7), where I-P dependence is monotonous growing. The decrease in electrodes distance leads to the current density from electron current emitted from the cathode is a raised because less number of electrons is able to reach the anode electrode and hence lower current flows. However, reparations are required between gas pressure and distance to work at a given discharge current beforehand converting into decreasing current as saturation is reached.

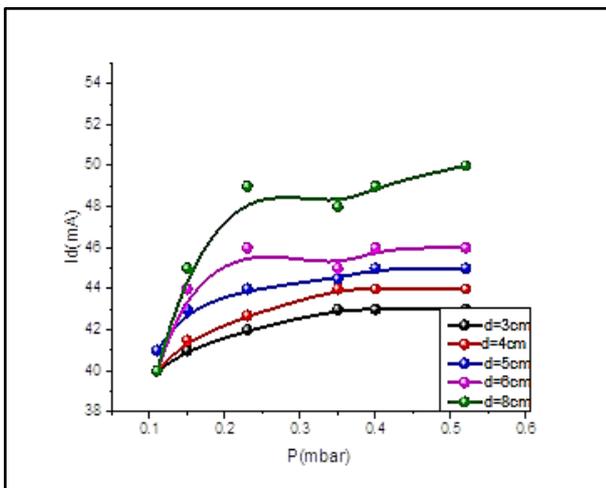


Fig.(7): Variation of discharge current with pressure at different electrodes separation.

At finite discharge voltages, the discharge current was calculated as a function of electrodes separation as shown in Fig.(8). Initially, this current somewhat increases at electrodes separation from 3 to 4 cm, flowed slightly decreases to distance of 5 cm,

reasonably increases at distance of 6cm, and decreases at electrodes separation of 7 to 8 cm. This nonlinear relation between discharge current and discharge voltage is a characteristic of the abnormal region in glow discharge; this behaviour is the similar at all electrodes separation. At high voltages (>450V), the discharge current increased with increasing the electrodes separation, while the shift in the discharge current with electrodes separation is non-apparent at lower voltages due to The electrodes are covered entirely by the discharge and any rise in discharge current founds an increase in the cathode entire. Subsequently, the potential pass the electrodes increase steeper.

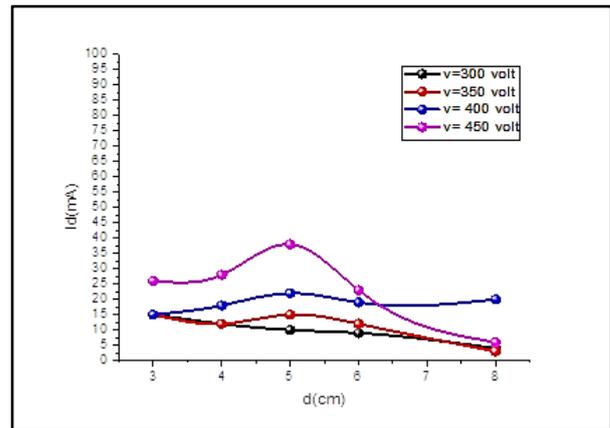


Fig.(8): Variation of discharge current with inter-electrode distance at certain discharge voltages without using a magnetron.

### 5-Conclusion

In this work we investigated Electrical characteristics of a DC glow discharge and plasma breakdown processes in low-pressure gas discharges by experimental procedures with the aim of determining the proper parameters for stable process of the plasma system. Also From these investigations we conclude that the fundamental processes involved in the breakdown phases of our discharges are the same as described by breakdown theory for parallel-plate discharges. The major consequences of this investigation can be summarized as follows:

1. An increase of the discharge voltage was accompanied by an increase of the discharge current, where the characteristics of such discharge is characterized by abnormal glow discharge.

2. The distance between two electrodes independent parameter it affects the breakdown voltage i.e. change gap electrode distance has highly affected the relation of breakdown voltage to the (pd) as the breakdown voltage was apparent changed. This is confirmed by our measurements as well as by other authors.
3. As the inter-electrode distance increased the breakdown voltage increases of range (3-8) cm.
4. shows a optimize a minimum value of breakdown voltage as a function of gap electrode distance at spacing equals to 5 cm have been established.

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