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Basic investigation of plasma glow discharge phenomena with modifiedbreakdown condition using aluminum and graphite disc electrodes

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Abstract

Experimentally, we study the effect of work function anode - cathode materials and their surface area on direct current glow discharge.Also, this effecthas been investigated using SRIM code. The different diameters for parallel discs anode - cathode and their materials at different atmospheric pressures were determined. Here, the six gas discharge cases of 7.5cm and 9.5cm anode - cathode electrodes diameters from aluminum and graphite have been investigated. Then, Paschen curve and the voltage - current characteristics were determined.

Keywords:Glow Discharge - Breakdown Voltage - Paschen Law- SRIM - Backscattered Ions.

1. Introduction

One of the best studied types of glow discharges is the glow direct current discharges in tubes [1,2].The glow discharge source is used in the microelectronics industry for plasma etching [3], surface treatment [4], gas lasers [5], light source [6], also in analytical chemistry [7], biomedical science [8] and the pollution control [9].A glow discharge is characterized by its distinctive regions between the anode and cathode electrodes across the tube. The physical characteristics of these regions are depending on the parameters such as the discharge tube geometry, working gas pressure, gas type, cathode material, applied potential and discharge current [10]. The plasma discharges formed in atmospheric pressure with spatially uniform are desirable due to their potential industrial applications [11].

The plasma of low pressure glow discharge is created by applying a potential difference between two plate electrodes placed at certain distance. The discharge is maintained stable because of the equal degree of simultaneous ionization according to the continuous loss of electrons. Also, an additional electrons are produced due to the secondary emission from the cathode surface [12].Then, many ionization processes take place to produce a large number of charge carriers in the gas.

Large amount of work carrying on the electric breakdown process because of its application in the accelerators, ion sources and plasma physics [13]. The electrical breakdown of a gas is possible only when a highly conductive channel is formed between the two electrodes translating from an insulator to a conductingstate. This transition occurs at minimum voltage which is called the breakdown voltage(V_b). In Paschen's Law,the breakdown voltage between two electrodes is a function of pressure inside the chamber and the electrodes gap distance multiplied (Pd)according to the following relation[14]:

$$V_b = \frac{Bpd}{\ln\frac{(Apd)}{\ln(\frac{1}{\gamma})}} \quad (1)$$

Where A, B are constantsof a particular gas and γ is the secondary electron emission coefficient of the cathode. From equation (1), it is clear thatV_b of a gas depends only on Pd and cathode material [15]. Also, it depends on the charged and noncharged particles in the gas, the electrode configuration, the surface properties of the electrodes and the inner radius of discharge tubes. These factors are not considered in the Paschen's Law and might therefore responsible for the deviation between experimental and theoretical results [16].

In vacuum chamber, there are several free electrons due to cosmic rays. If a voltage is applied between the two electrodes, a free electron will begin to accelerate towards the anode. If the gas is sufficiently dense, the electron may collide with a neutral atom, causing ionization. When the resulting positive ion collides with the electrode and accelerates towards the cathode. Then, there is a finite probability (γ) that a secondary electron will be emitted. This secondary electron may ionize more neutrals; the positive ions that result will stream towards the cathode. If an electron creates enough ions to release at least one additional secondary electron from the cathode, the process becomes self-sustaining and then the breakdown occurs.

The open source**SRIM**,**S**topping and **R**ange of **I**ons in **M**atter, which is a convenient tool to estimate the range of low energy particles in matter and based on the concept of nuclear and electronic stopping [17,18].It is used to simulate the backscattered ions for the different gas discharge cases.

The aim of this experiment is to investigate experimentally the effect of two parameterson both Paschen's curve and the voltage - current characteristics which are the diameter and materialof the anode and the cathode electrodes. In which, we study the effect of 7.5cm and 9.5cm diameters of parallel discs for anode - cathode from aluminum and graphite materials.Furthermore, we can compare the backscattered ions between some cases of these gas dischargesusing SRIM.

2. ExperimentalSetup

It consists of a cylindrical Pyrex tube in which the two parallel discs anode - cathode and rotary pump are placed as shown in figure (1).This tube ispumped down to a base pressure up to the order of 10^{-3}torrusing rotary pump. This tube dimensionsare 50cm length and 36.5cm diameter. The diameters of electrodesare 7.5cm and 9.5cm with 0.7cm thickness from graphite, C, and aluminum, Al, materials. The anode - cathode gap distance was fixed at10 cm.Two cylindrical plastic rubbers were used to close both sides of the chamber to prevent the leakage of gas as well as to insert the electrodes through them. One connection from one side is mounted to the rotary pump to evacuate the chamber to ultimate pressure 7.0 X 10^{-2}Torr using thermocouple vacuum gauge. Also, one connection from the other side is the needle valve to control the air flow. The experiment was carried out under pressure ranged from 11.2×10^{-2} to 8.1×10^{-1}Torr.

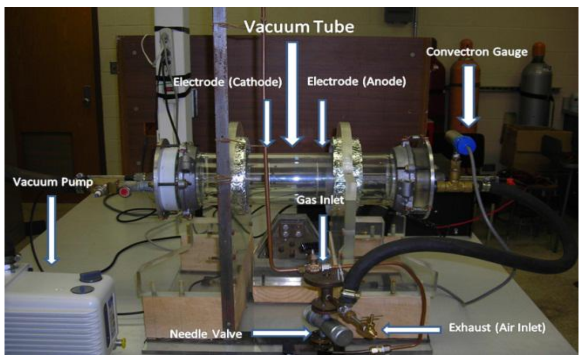
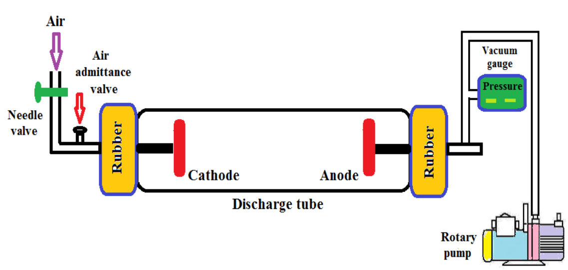


Fig. (1)Glow discharge setup.

The schematic diagram of the discharge system is shown in fig. (2). Figure (3) shows the electrical circuit in which the anode is connected to 5 kV positive power supply for initiating the discharge (glow discharge) between the anode and cathode. The cathode is connected to ground. The ammeter, A, is used to measure the discharge current between the anode and the cathode, while a voltmeter, V, is used to measure the discharge voltage between them.



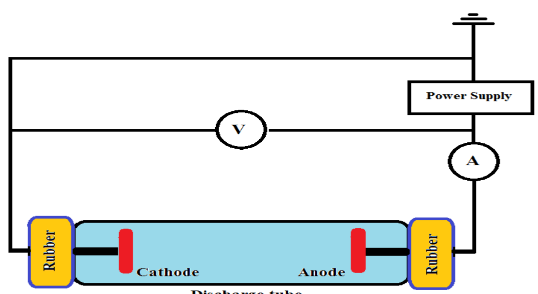


Fig.(2) Schematic drawing of the experimental setup.Fig.(3) Electrical circuit of the experiment.

In this paper, the different gas discharge cases have been studied as shown in table (1).

Gas			Its reverse polarity

discharge case	**Anode**		**Cathode**		**Anode**		**Cathode**	
1	diameter 7.5cm	Al	diameter 7.5cm	Al	-		-	
2	diameter 9.5cm	Al	diameter 9.5cm	Al	-		-	
3	diameter 9.5cm	Al	diameter 9.5cm	C	diameter 9.5cm	C	diameter 9.5cm	Al
4	diameter 7.5cm	Al	diameter 9.5cm	C	diameter 9.5cm	C	diameter 7.5cm	Al

Table (1): Gas discharge cases for the different anode and cathode diameters and their materials.

3. SRIM simulation

The SRIM code is based on a Monte Carlo simulation method where the binary collision approximation with a random selection of the impact parameter of the next colliding ion is used. SRIM and TRIM (Transport of Ions in Matter) are both useful in evaluation of material response to incident particles [19].There are a number of mechanisms operate to slow the ion, dissipate the energy if an ion is incident on a solid target material and subdivided into the nuclear and electronic energy losses [18]. Nuclear energy transfer occurs as the result of elastic collisions in whichthe energy is imparted from the incident ion to the target atom by momentum transfer. Electronic energy losses occur as the result of inelastic scattering events in which the ion electrons interact with that of the target atoms. Some ions might have a strong collision near the surface of the target and may be backscattered back out of the target surface. These ions called backscattered ions which have a trajectory that exits the target back through its surface, after one or more target collisions.

Figure (4) shows the comparison of backscattered ions versus the breakdown voltage, V_b, for 7.5cm and9.5cm diameters Al anode and cathode. It is clear that backscattered ions for 7.5cm and 9.5cm diameters are identical after $(V_b)_{min}$. They are different before $(V_b)_{min}$, depending on $(V_b)_{min}$ for 7.5cm and 9.5cm diameters anode and cathode that are 463V and 523V respectively. Backscattered ions increased by decreasing V_b until reaching $(V_b)_{min}$ and then decreased by increasing V_b.

Figure (5) shows the comparison of backscattered ions versus the breakdown voltage, V_b, for the two gas discharge cases of the same diameters (9.5cm)Al anode - Alcathode and Al anode - C cathode. It is clear that backscattered ions forAl anode - Al cathode are high than the another case. This is due to the work function of Al is lower than C. But the same behavior that backscattered ions increase by decreasing V_b until reaching $(V_b)_{min}$ and then decreased by increasing V_b. This is due to after $(V_b)_{min}$, higher gas pressure, more collisions will take place in the electron path between the electrodes. So that the electron is not always being accelerated by the electric field, always travelling back towards the cathode and decelerated forming small number of backscattered ions.

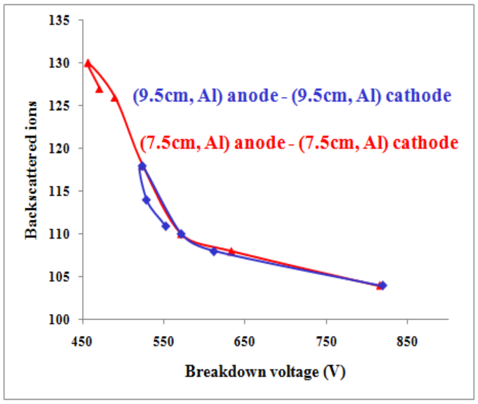


Fig.(4) Backscattered ions versus breakdown voltage (V_b) for 7.5cm, 9.5cm diameters for Al anode and cathode.

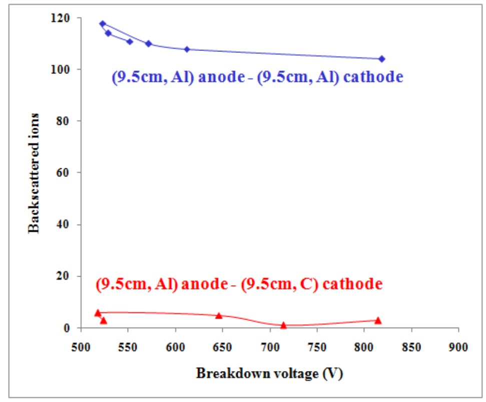


Fig.(5) Backscattered ions versus breakdown voltage (V_b) for 9.5cm diameters Al anode- C cathode and Al anode and cathode.

4. Results and discussions

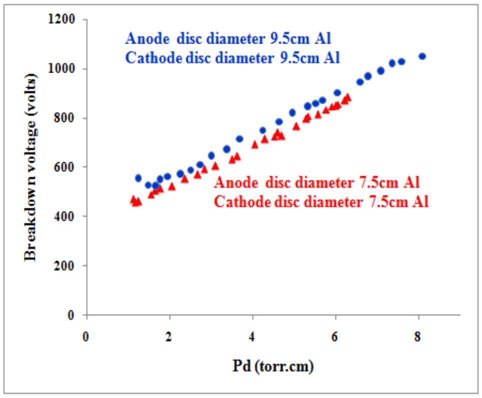
4.1. Paschen curve

The breakdown in DC discharges is usually described by the standard Townsend's theory [20]. It is represented by a Paschen curve in which the breakdown voltage, V_d, dependence on the product of gas pressure, P, and gap electrodes distance, d [21]. The parameter Pd is a scaling parameter proportional to the number of collisions over a unit distance. In this respect, a typical sharp increase of V_d at low Pd can be explained by the need to compensate for a small number of collisions. At high Pd, due to a large number of collisions, V_d is increased to enhance energy gain between collisions, so that the mean free path becomes shorter and the energy gained between two collisions becomes smaller.

Figure (6) shows the comparison of Pd (torr.cm) versus V_b (V)atthe same diameters of 7.5cm and 9.5cm for Al anode - cathode. It is seen that the minimum breakdown voltage,$(V_b)_{min}$,values are 463V and 548V at $(pd)_{min}$ of 1.25 and 1.76(torr.cm) for the discharge cases with diameter 7.5cm and 9.5cm anode - cathode respectively.

Figure (7) shows the comparison of Pd (torr.cm) versus V_b (V) at the same diameter of 9.5cm for Al anode - C cathode and C anode - Al cathode. It is seen that $(V_b)_{min}$ values are504V and 486V at $(pd)_{min}$ of 1.0 and 1.5(torr.cm) for the discharge cases Al anode - C cathode and C anode - Al cathode respectively. Also, the discharge case Al anode - C cathode has higher V_b values than another case.

Figure (8) shows the comparison of Pd (torr.cm) versus V_b (V) at 7.5cm diameter of Al anode and 9.5cm diameter of C cathode and the reverse polarity. It is seen that $(V_b)_{min}$ values are418V and 570V at $(pd)_{min}$ of 1.17 and 1.78(torr.cm) for the discharge cases 9.5cm diameter of C anode and7.5cm diameter of Al cathode and its reverse polarity respectively. Also, the discharge case of 9.5cm diameter for C anode and 7.5cm diameter for Al cathode has higher V_b values than another case.



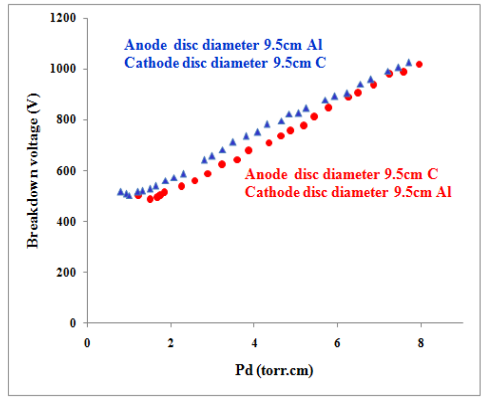


Fig. (6) Pd versus $V_b$at 7.5cm and9.5cm diametersFig. (7) Pd versus $V_b$at9.5cm diameter for Al for Alanode - cathode.anode-C cathode and the reversepolarity.

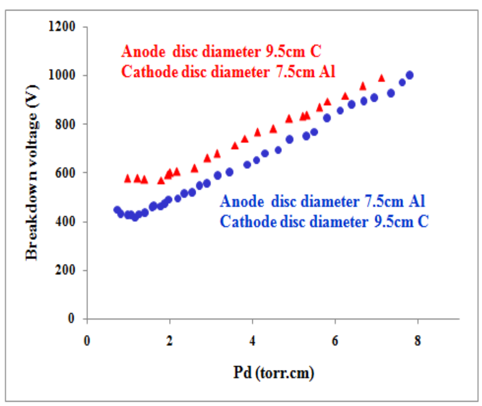


Fig. (8) Pd versus $V_b$at9.5cm diameterof Canode- 7.5cm diameterof Al cathode and the reverse polarity.

Initially $V_B$decreases with increase in Pd, reaching to the minimum value and then begins to increase [22].It is obvious that near $(V_b)_{min}$, the density is low and then there are relatively few collisions. In fact, an electron does not necessarily ionize a molecule during collision, even if its energy exceeds the molecule ionization energy. The electrons have a finite chance of ionizing, which depends upon its energy. If the density and hence the number of collisions is decreased, the breakdown can occur only if the chance of ionizing is increased, and this accounts for the increase in voltage to the left of the minimum. Before$(V_b)_{min}$of Paschen's curves, V_b decreases fast by increasing Pd,due to the increase in collision frequency. As a result ofthe increasing in the number of collisions between the electrons and neutral atoms or molecules. If the density is fixed, the breakdown to the left side of the minimum occurs more readily (i.e. at lower voltage) at longer distances. Butafter $(V_b)_{min}$, V_B increases slowly with the increase of Pd, means that the ionization crosssection increases. Therefore, the electrons need more energy to breakdown the discharge gap, resulting in an increase of the breakdown voltage [23].

Finally, we make the comparison of Pd (torr.cm) versus V_b (V) for all the gas discharge cases as shown in figure (9). It is clear that at 9.5cm diameter of C anode and7.5cm diameter of Al cathode has the lowest V_b values. Furthermore,the two gas discharge cases at the same diameters of9.5cm for (Al anode - Ccathode, Al anode - Al cathode) and 7.5cm diameter for Al anode - 9.5cm diameter for C cathode are nearly the highest V_b values. The two remaining gas discharge cases at 7.5cm diameters for Al anode - cathode and 9.5cm diameters for C anode - Al cathode nearly have the same V_b values in between the other cases.

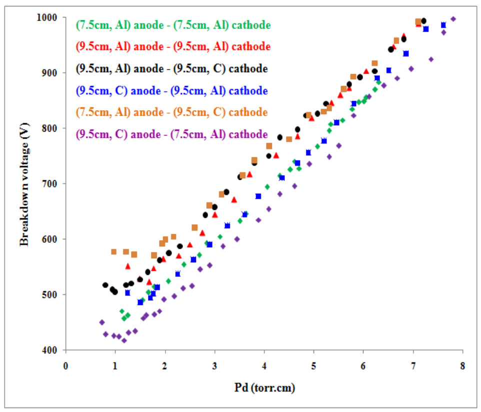
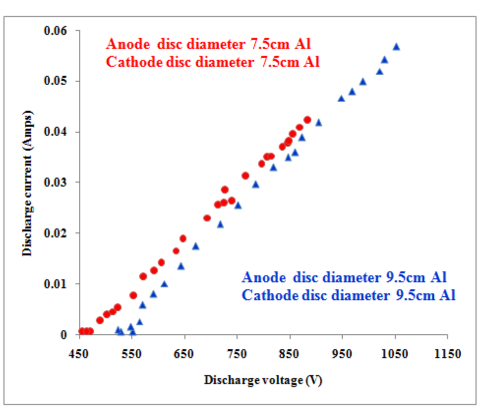


Fig. (9) Comparison of Pd versus $V_b$for all the gas discharge cases.

4.2.Voltage - current characteristics of the discharge

Figure (10)shows the breakdown voltage, V_b,versus the discharge current, I_d,atthe same diameters of 7.5cm and 9.5cm for Al anode - cathode. It is clear that the discharge current increases by decreasing the breakdown voltage until reaching $(V_b)_{min}$. After $(V_b)_{min}$, the discharge current increases by increasing the breakdown voltage(positive resistance). For 7.5cm diameter Al anode - cathode has higher discharge current values than another case.

Figure (11) shows the breakdown voltage, V_b, versus the discharge current, I_d,atthe same diameter of9.5cm Al anode - C cathode and the reverse polarity. It is clear that the discharge current increases by decreasing the breakdown voltage until reaching $(V_b)_{min}$. After $(V_b)_{min}$, the discharge current increases by increasing the breakdown voltage. For Al anode - C cathode gives higher values of discharge current than the reverse polarity.



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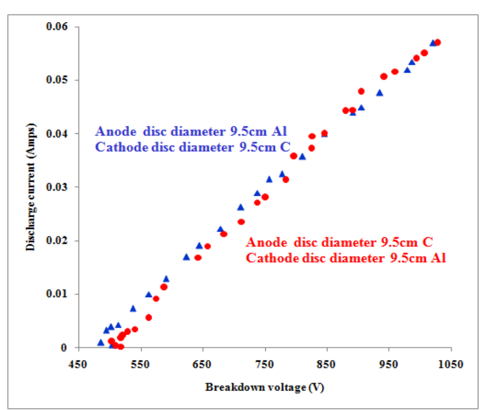

Figure shows

breakdown voltage, V_b, versus the discharge current, I_d,at9.5cm diameter for C anode - 7.5cm diameter for Al cathode and the reverse polarity. It is clear that the discharge current increases by decreasing the breakdown voltage until reaching the $(V_b)_{min}$. After $(V_b)_{min}$, the discharge current increases by increasing the breakdown voltage. For 9.5cm diameter ofC anode - 7.5cm diameter of Al cathode gives higher values of discharge current than the reverse polarity.

Fig. (10) V_b versus I_d for 7.5cm and 9.5cm diameter Fig. (11) V_b versus I_d for 9.5cm diameter Al anode Alanode - cathode.- C cathode and the reverse polarity.

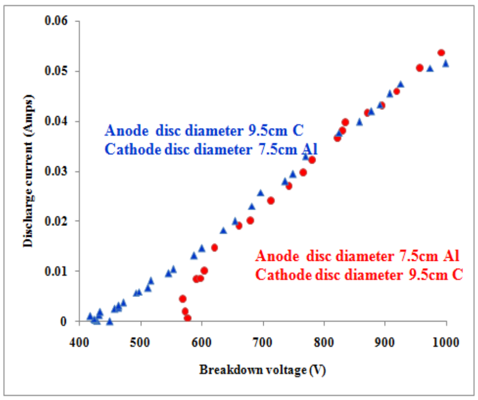

Fig. (12) V_b versus I_d for 9.5cm diameterC anode - 7.5cm diameter Al cathode and the reverse polarity.

Finally, we make the comparison of voltage - current characteristics for all the gas discharge cases.Figure (13) shows the breakdown voltage, V_b, versus the discharge current, I_d, for all the gas discharge cases. It is clear that at the same diameters of 9.5cm for Al anode - C cathode has the lowest discharge current values.Furthermore,at 9.5cm diameter for C anode - 7.5cm diameter for Al cathode,the same diameters of 9.5cm for Canode - Al cathode and the same diameters of 7.5cm for Al anode - cathode are nearly the highest discharge current values. The two remaining gas discharge cases at 7.5cm diameterfor Al anode - 9.5cm diameter for Ccathode and its reverse polaritynearly have the same discharge current values in between the other cases.

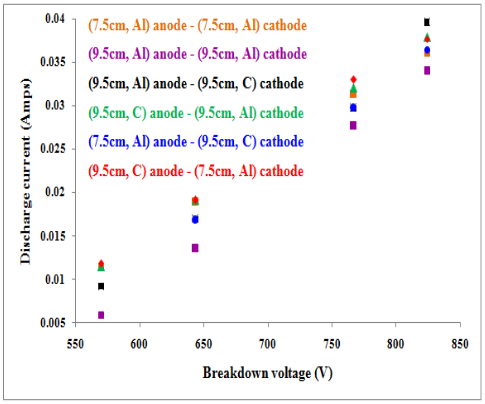

Fig. (13) Comparison of $V_b$versus I_d for all the gas discharge cases.

Due to the electrons have sufficient energy to generate visible light by the excitation collisions with the plasma carrier gas, then the luminous glow is produced. Since there is a continuous loss of electrons and ions, there must be an equal degree of ionization going on to maintain the steady state. The energy is being continuously transferred out of the discharge and hence the energy balance must be satisfied as well. The electrons absorb energy from the field by accelerating, ionize some atoms, and the process becomes continuous. Additional electrons must be produced by secondary electron emission from the cathode. These are very important to maintaining a sustainable discharge.

Figure (14) shows the pictures of (a- 7.5cm diameters for Al anode and cathode),(b- 7.5cm diameter for Al anode - 9.5cm diameter for C cathode)plasma expanding in the cylindrical discharge tube at pressure 3.0Torr.

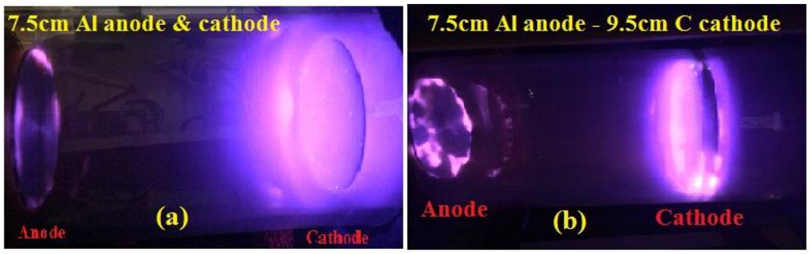

Fig. (14) Pictures of (a- 7.5cm diameters Al anode and cathode), (b- 7.5cm diameter Al anode - 9.5cm diameter C cathode) plasma expanding in the cylindrical discharge tube at pressure 3.0Torr.

It is clear that there is a high light formed due to the plasma formation.However the resulting positive ion collides with the electrode and accelerates towards the cathode, so that it gives high light surrounding the cathode. The light originates from photons emitted by radiated relaxation of the excited meta-stable atoms and from excited ions. The accelerated electronstowards the cathode’s sheath, gain enough energy to excite high energy levels of and near the cathode jaws [24].

5. Conclusions

In this work, the cathode plays an important role in the gas discharges by supplying electrons for the initiation, sustainableand completion of a discharge.

Using SRIM, the comparison of backscattered ions versus $V_b$at different diameters for low work function materials anode - cathode and large diameter low/high work function anode - high/low work function cathode. It is concluded that backscattered ions for the gas discharge cases at different diameters for low work function are identical after $(V_b)_{min}$. They are different before $(V_b)_{min}$, depending on their $(V_b)_{min}$.Also, at the same diameter for the same anode and cathode materials with low work function gives higher backscattered ions than that for low work function anode - high work function cathode materials.

From Paschen's curve, it is concluded that at large diameter for low work function materials of anode and cathode gives higher$V_b$than small diameter of the same material electrodes. In case of large diameters for low anode and high cathode work functionmaterials gives higher V_b than its reverse polarity. Also, at large diameter for high anode - small diameter for low cathode work function materials gives higher V_b than its reverse polarity. Finally, from the comparison between all the gas discharge cases. It is obvious that, at large diameter for high anode - small diameter for low cathode work function materials has the lowest V_b values. Furthermore, at large diameter for (low anode - high cathode),(low anode and cathode) and small diameter for low anode - large diameter for high cathode work function materials are nearly the highest V_b values.At small diameters for low anode and cathode work function materials and large diameters for high anode - low cathode work function materials nearly have the same V_b valuesplacing in the middle region between the other gas discharge cases.

From voltage - current characteristics, it is concluded that at large diameters for low anode - high cathode work function materials gives higher I_d values than that for high anode - low cathode. In case of large diameter for high anode - small diameter for low cathode work function materials giveshigher I_d values than small diameter for low anode - large diameter for high cathode work function materials. Also, at the same large diameters for low anode - high cathode work function materials giveshigher I_d values than that of high anode - low cathode. Finally, from the comparison between all the gas discharge cases. It is obvious that, at the same large diameters for low anode - high cathode work function materials has the lowest I_d values. Furthermore, at large diameter for high anode - small diameter for low cathode work function materials, the same large diameters for high anode - low cathode and the same small diameters for low anode and cathode work function materials are nearly the highest I_d values.

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