Arab J. Nucl. Sci. Appl, Vol 51, 2, 82 -88 (2018)

Arab Journal of Nuclear Sciences and Applications

ISSN 1110-0451 *Web site: ajnsa.journals.ekb.eg* (ESNSA)

Performance of the Secondary Townsend Emission through the Electric Discharge Characteristics in Coaxial Vircator

A.M. Shagar, S.T. Abd El-Latif *and F. A. Ebrahim

Plasma Physics Department, Materials and Nuclear Industrialization Division, Nuclear Researsh Center, Atomic Energy Authority, Cairo, Egypt

Received 28th May 2017
Accepted 9th Jul 2017

The influence of secondary electron emission on self-sustaining and maintaining discharge current is studied using a new type of DC glow discharge operated on virtual cathode theory through argon gas. The radial electron beam is generated outside the diode in coaxial Vircator. The transported electric discharge, from non-self-sustaining to self-sustaining discharge, occurs in the Townsend region and strongly depends on the secondary electron emission. The first ionization acts as a breakdown starter, then the second emission completes the electric discharge without consumed energy. The present work aims to study the effect of some physical parameters on the secondary electron emission to reduce the applied breakdown voltage and improve the ionization process, as well as to reduce the consumed electric energy. During the study, it was found that the self-discharge started due to the second electron emission (γ) from the cathode which increased by increasing the ionization potential and decreasing the electric field. There was a balance between the first ionization coefficient and the electron attachment which confirms that the (γ) is the main element in the glow discharge. The minimum breakdown voltage for argon gas is 219 volts at Pd= 8 x 10^{-2} Torr.cm.

Keywords: Glow Discharge / Coaxial Vircator / Ionization potential / Electron emission - Breakdown voltage / Electron attachment

Introduction

Direct Current electric discharge has a wide range of technical applications. These applications range from classical lamps reaching to advanced technology such as plasma display panel and nanostructure materials [1-6]. The present work is concerned with decreasing the applied voltage and increasing the total current, as well as to reducing the consumed energy through argon discharge in cylindrical coaxial Vircator. In normal GD, the breakdown takes place between the cathode and anode due to the excitation and ionization processes where the current density has constant value. As a result, the normal glow discharge experiment is modulated according to the virtual cathode theory to increase the current density and improve the energetic electrons [7-9]. In the modulated system, the diode is constructed from cathode and semi-transparent anode. The distance between the two electrodes must be smaller or at least equal to the collision mean free path. When an electric field is applied between the coaxial cylindrical diode, free electrons are accelerated to excite and ionize the atoms and molecules of the gas outside the diode. The electric discharge occurs in two stages, the first forms virtual cathode (VC) or virtual anode (VA) (based on the electrodes polarity). The second is the breakdown process and starting the glow discharge (GD) [7, 10, and 11].

Corresponding Author: Samar_tawfik2004@yahoo.com
DOI: 10.21608/ajnsa.2018.6513

In 1889, Paschen presented a law stating that the sparking voltage is dependent on the product of the gas pressure and the space between the two electrodes.

In 1915, Townsend introduced two quantities to explain the current growth through the electric discharge known as the first Townsend ionization coefficient (α), and second Townsend ionization coefficient (γ), both of them are a function of (E/P).

$$\frac{\alpha}{P} = F_1\left(\frac{E}{P}\right) \quad (1)$$

$$\gamma = F_2\left(\frac{E}{P}\right) \quad (2)$$

$$E = \frac{V}{d \ln(\frac{b}{a})} \quad (3)$$

Where: (*E/P*) represents the electron energy gain between collisions (reduced electric field), and E is the electric field strength, *P* is the gas pressure, *a* and *b* are the inner and outer radii in the coaxial cylindrical diode, V is the applied voltage and d is the inter-distance between two electrodes.

The total current before the breakdown potential is given by the relation:

$$I = I_0 \frac{e^{\alpha d}}{1 - \gamma(e^{\alpha d} - 1)} \quad (4)$$

Where I_0 is the initial current at the cathode, $e^{\alpha d}$ representing the amplification of electrons. The discharge current tends to infinity in the above equation, if the denominator approaches to zero

$$1 - \gamma\left(e^{\alpha d} - 1\right) = 0 \quad (5)$$

By substituting equations (1) and (2) in equation (5) gives:

$$F_2\left(\frac{V_b}{Pd \ln(b/a)}\right)\left[e^{pd F_1(\frac{V_b}{Pd \ln\frac{b}{a}}) - 1}\right] = 1 \quad (6)$$

It is clear that the breakdown voltage depends on the pressure and the dimensions of the discharge system

$$V_b = F(Pd \ln(\frac{b}{a})) \quad (7)$$

This equation is known as Paschen's law. The average number of the ionization collisions made by electrons in the field direction per unit length is called the first Townsend ionization coefficient [5]. The first Townsend equation has the form:

$$\frac{\alpha}{P} = A \exp\left[\frac{-BP}{[V_b / d \ln(b/a)]}\right] \quad (8)$$

Where *A* and *B* are constants and determined experimentally for each gas.

The positive ions accelerate towards the cathode to extract secondary electrons. This process is called secondary Townsend emission coefficient (γ) [13, 14] which is the average number of the secondary electrons produced by the impact of positive ions. The secondary Townsend's coefficient equation is written as:

$$\alpha d = \ln(1 + \frac{1}{\gamma}) \quad (9)$$

Where the Secondary Townsend emission is responsible for gas transition from non-self-sustaining discharge into self-sustaining discharge [15, 16, 17]. It strongly depends on the reduced electric field intensity E/P, the collision mean free path and the work function of the cathode material [18].

Experimental Setup

The coaxial Vircator is used in this work to produce radial electron beam through a cylindrical coaxial diode inside a discharge vessel made of Pyrex glass. The diode is composed of two cylindrical electrodes. The outer electrode is a cylindrical stainless steel mesh cathode of 13 cm length and is connected to negative potential, while the inner electrode is 12 cm stainless steel rods acting as anode and has a neutral potential. The distance between the two electrodes is fixed at 4 mm where the mean free path for electron collision is comparable or larger than the electrodes gap. The diode is immersed inside the vacuum glass tube which can be evacuated up to 10^{-2} Torr. The discharge vessel is fixed with two flanges. One has a hole to introduce the argon gas and the other is connected to the vacuum pump as shown in Fig. (1a) and Fig. (1b). Argon gas is leaked through a needle valve to a constant working gas pressure

Experimental Results

When a DC voltage is applied between two electrodes, free electrons eject from cathode and accelerate towards the anode. If the electrons have sufficient energy, they will cross the anode to form a virtual cathode outside the diode where the collision mean free path is greater than the gap between the two electrodes. For this reason, many collisions will occur between the virtual cathode and the anode resulting in the ionization process to generate pairs of free electrons and ions.

The number of ionizations as a function of the reduced electric field is shown in Fig. (2). It is clear from Fig. (2) that the number of ion pairs decreases with the reduction of the electric field intensity. At a certain value of reduced energy, the number of ionization is nearly constant; so the external voltage is the essential source for the first ionization process. An opposite process is shown in Fig. (3) which shows the effect of reduced energy on the electron attachment (η). Electron attachment takes place when neutral atoms attract free electrons to form negative ions (electronegative atoms). When the ionization process is followed by electron attachment, it is expected that (η) has a similar behavior to (α) as shown in the Fig. (3).

For continuity of the electric discharge, another electron source must be used. This source is the induced secondary electron emission (γ) through accelerated ions impacting the cathode. The secondary electron emission depends on the ionization potential as well as the applied voltage and gas pressure.

Fig. (4) shows the relation between (γ) and the applied voltage. It is clear that the energy of the voltage is consumed in the ionization process; then the ions accelerate towards the cathode to extract secondary electrons which increase to reach a steady state emission. This process helps in the self-sustain and continuity of the discharge.

The effect of gas pressure on (γ) is shown in Fig. (5). The secondary emission tends to decrease with the increase of gas pressure due to the increase of gas density which needs more applied voltage. This leads to the decrease of the ionization potential causing the decrease of the ions energy and finally, very low secondary emission from the cathode.

The electric discharge takes place through two processes, first ionization (starter process) and secondary emission (continuity process). Each of the two processes is a function of the reduced electric field. It is clear from Fig. (6) that, at certain point of the reduced energy at an applied voltage of 219 volt in our case, before this point, the first ionization was the main process then the secondary Townsend emission became the essential process for self-sustaining discharge.

Fig. (7) indicating the variation of (γ) with the change of (α), in which, we notice an inverse relation between the first and second Townsend processes.

The relation between the breakdown voltage Vb, and the product of gas pressure and the inter-distance between the two electrodes (Paschen curve) is shown in Fig. (8). At low pressure, the gas density is small and the collision mean free path is large; so the breakdown process needs more voltage to take place. Then, by the increase of gas pressure, the breakdown voltage decreases rapidly to reach its minimum value at 219 volts at pd of 0.08 Torr.cm. Then by further increase in the pressure, the breakdown increases slowly and completes the discharge.

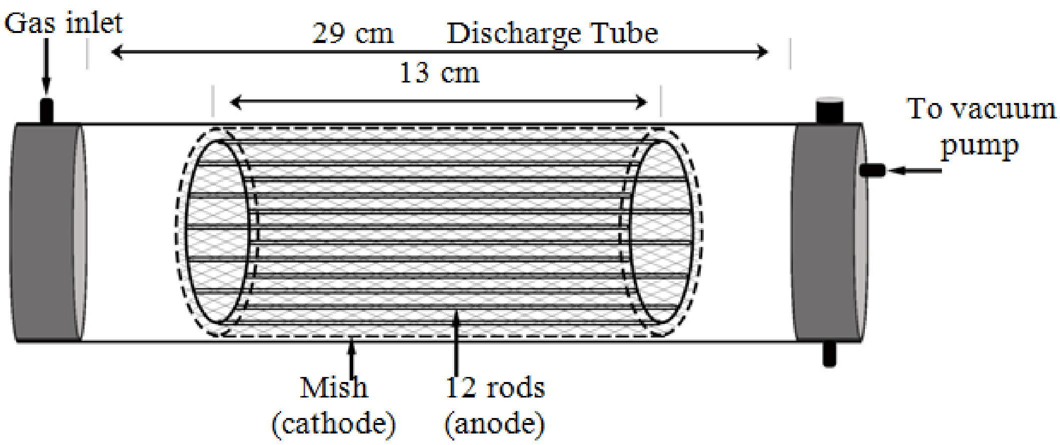

Fig. (1a): Configuration of coaxial Vircator device

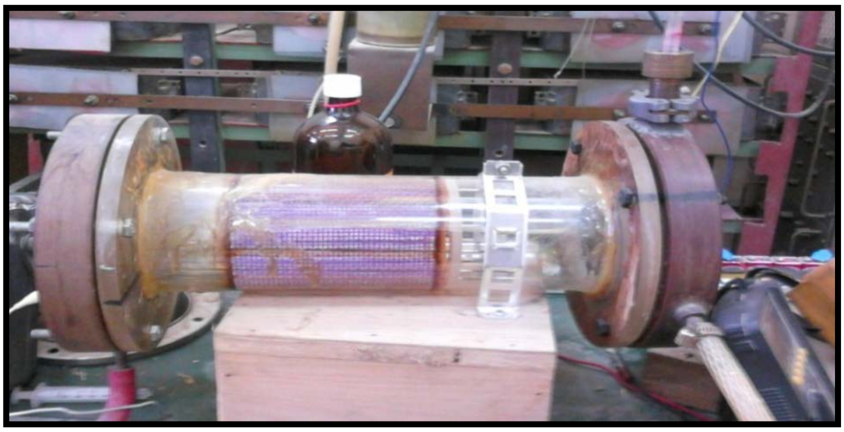

Fig. (1b): A photographic view of the discharge tube

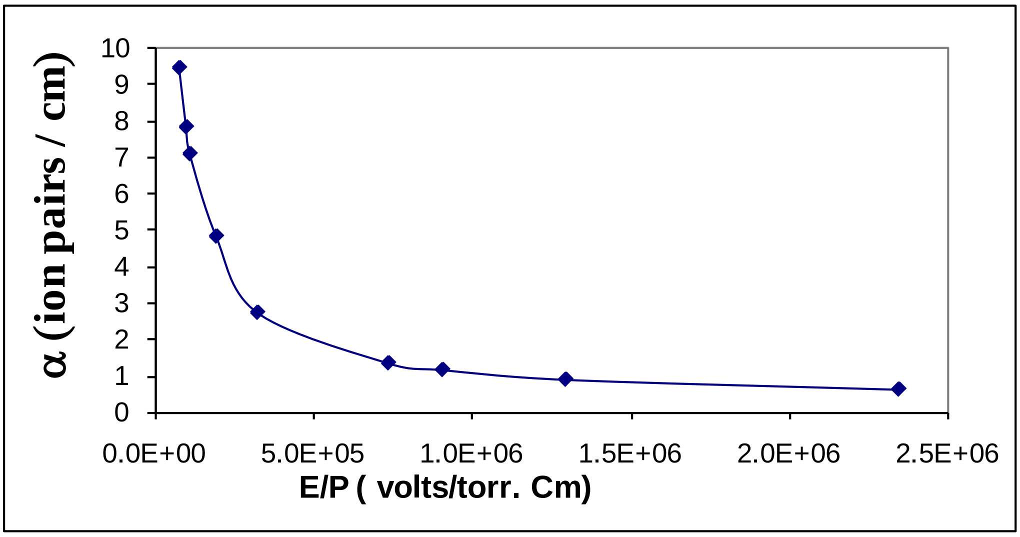

Fig. (2): The first Townsend ionization coefficient (α) with the reduced electric field strength

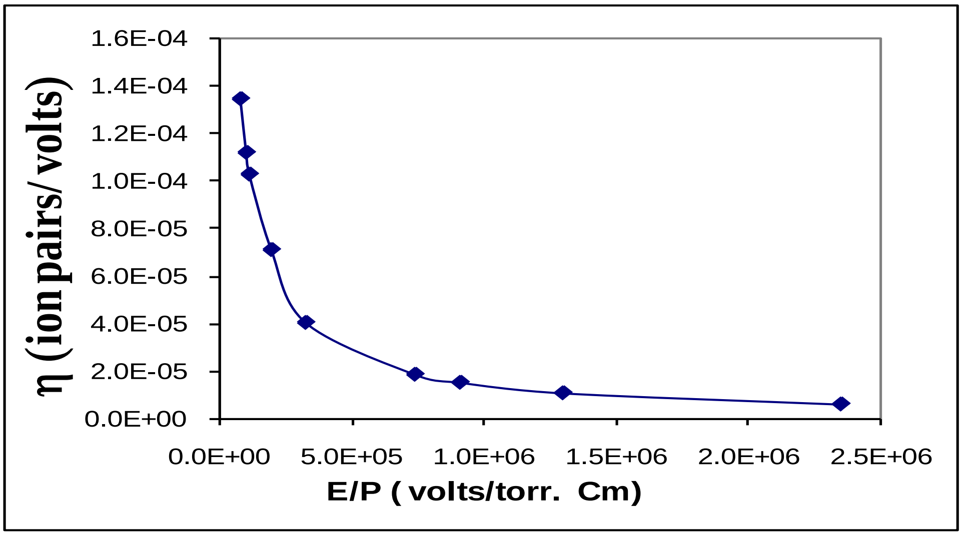

Fig. (3): The dependence of electron attachment on the reduced electric field strength

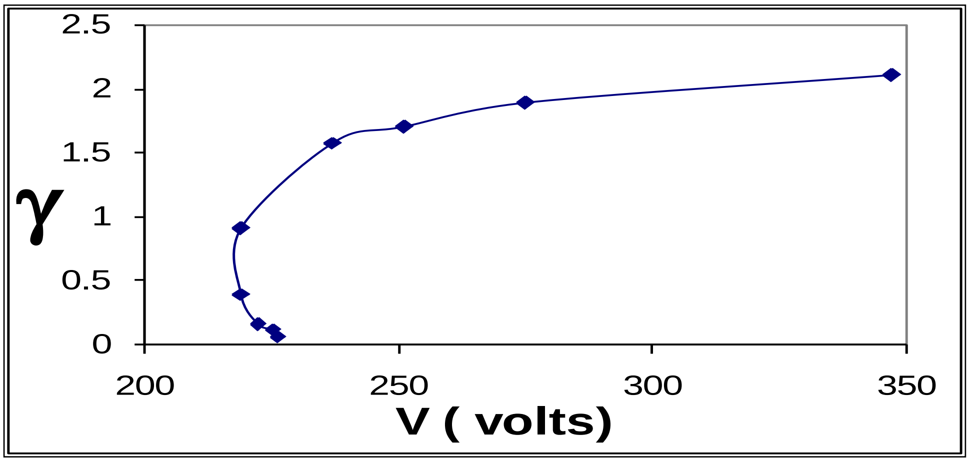

Fig. (4): The secondary electron emission as a function of applied voltage

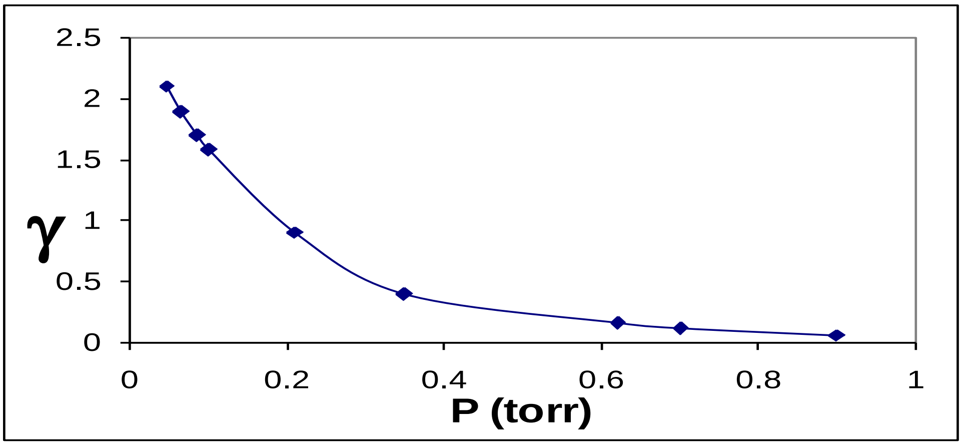

Fig. (5): The secondary electron emission as a function of the gas pressure

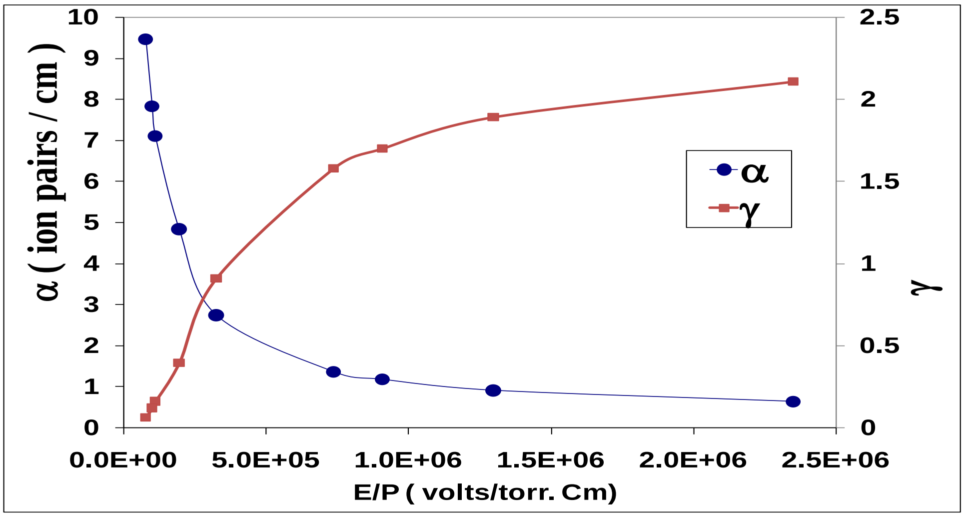

Fig. (6): The dependence of the first Townsend emission coefficient (α) and secondary Townsend emission coefficient (γ) on reduced electric field

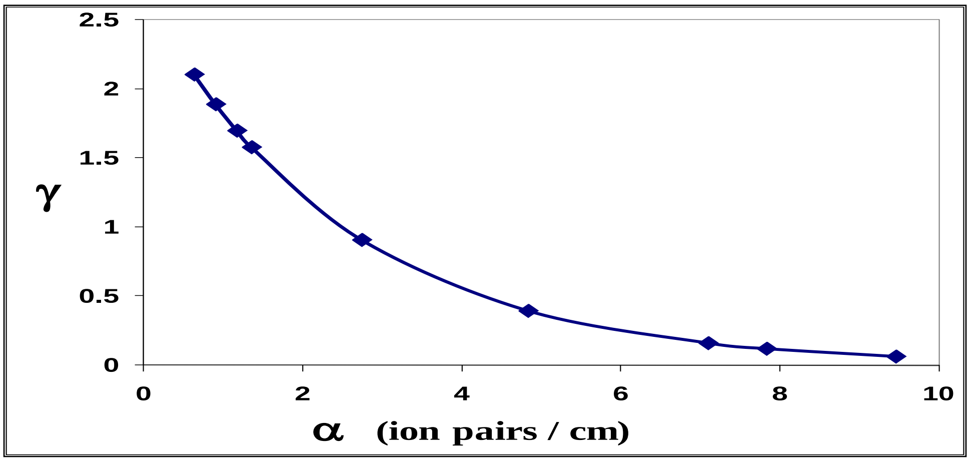

Fig. (7): Variation of the secondary electron emission with variation of the first Townsend ionization

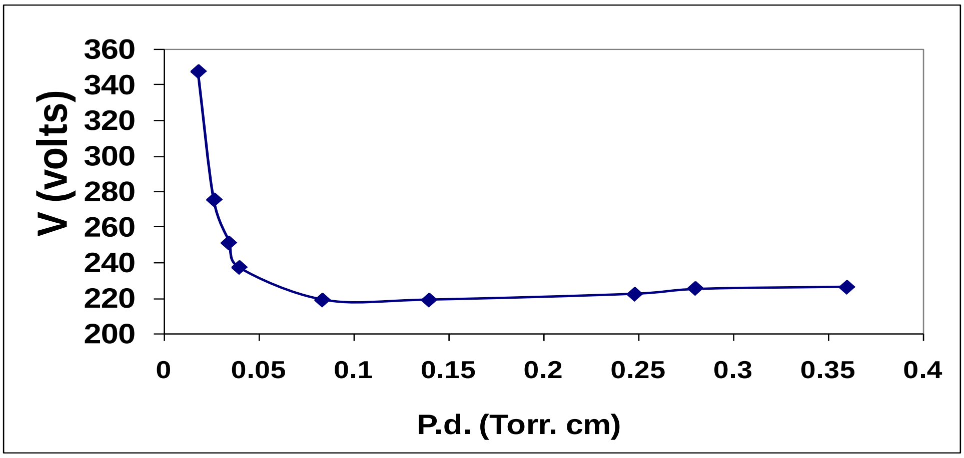

Fig. (8): variation of the breakdown voltage as a function of the pd product

Conclusion

New type of DC glow discharge (Vircator) is used to generate electrons beam outside the diode. The first ionization acts as a breakdown starter, then the secondary emission completes the electric discharge without consumed energy. The transfer of the electric discharge from non-self-discharge to self-discharge has been studied through Townsend region. From this study, it was found that the secondary electron emission is the essential factor to maintain the electric discharge without external force. This is confirmed by the balance between the first Townsend ionization coefficient and the electron attachment. At a certain value of applied voltage, the secondary electron emission reaches to a steady state value. This emission is inversely proportional to the gas density. At a critical point of reduced energy, the secondary electron emission γ becomes the essential source of discharge and increases with decreasing the first Townsend ionization. The reduced electric field leads to the increase of the kinetic energy of the ions and the extracted electrons from the cathode. From the Paschen's curve, the minimum breakdown voltage of argon gas is 219 volts at Pd= 8 x 10^{-2} Torr.cm.

Acknowledgement: Great Thanks to Dr. Huda El Gamal and Dr. Huda El. Tayeb for their helpful suggestions and useful adevice during this work.

References

1- Chris H. Moore et al, 1D PIC-DSMC Simulations of Breakdown in Micro Scale Gaps 28th International Symposium on Rarefied Gas Dynamics 2012, AIP Conf. Proc. 1501, 629-636 (2012); Doi: 10.1063/1.4769601
2- W. S. Boyle and P. Kisliuk, Phys. Rev. 97, 255-259 (1955)
3- P. G. Slade and E. D. Taylor, IEEE Trans. Compon., Packag. Manuf. Technol., Part A 25 3, 390-396 (2002).
4- W. Zhang, T. S. Fisher and S. V. Garimella, J. Appl. Phys. 96 11, 6066-6072 (2004).
5- M. Radmilović-Radjenović and B. Radjenović, Plasma Sources Sci. Technol. 17, 024005 (2008).
6- D. B. Go and D. A. Pohlman, J. Appl. Phys. 107, 103303 (2010).
7- M. A. Abd Al – Halim, A. Abu-Hashem and D. Moubarak , "Effect of The Mesh Transparency on the Electrical Characteristics of DC Pseudo Discharge" , Plasma Science And Technology, Vol. 17, No. 6 , 2015.
8- Shager A. M., Sroor A. T., El Tayeb H.A., etal. 2008, Z. Naturforsch, 63: 412.
9- El-Tayeb, H.A. and El- Gamal, H.A., " Negative Glow Discharge and Radial Profile in Argon" Arab Journal Of Nuclear Sciences And Applications, 35, 2, (2002).
10- Alaa Abu-Hashem, Mohamed Ali Hassouba and Mohamed Mahmoud Masoud, "Investigations of Ion Confinement by Direct Current Coaxial Glow Discharg", Journal of Modern Physics, 2012, 3, 48-56.
11- H. Shao, G. Lui, Z. Yang, C. Chen, Z. Song and W. Huang, "Characterization of Modes in Coaxial Vircator", IEEE Transactions on Plasma Science, Vol. 34, No. 1, 2006, p. 7-13.
12- L.Ledernez, F.Olcaytug ,H.Yasuda and G.Urban "A modification of Paschen Law for Argon", 29th ICPIG 12-17,2009, Cancun, Mexico.
13- H. Frederick Sanders, "The Value of The Townsend Coefficient for Ionization by Collision at Large Plate Distances and Near Atmospheric Pressure", Physical Review, Vol. 41, septemper 1, 1932.
14- V.A. Lisovskiy, R.O.Osmayev and V.D.Yegorenkov, "Gas Breakdown in Dc Electric Field in A Discharge Tube With Flat and Conical Cathodes", Problems of Atomic Science and Technology. 2014, №6. Series: Plasma Physics (20), P. 183-186.
15- (15)C. Torres, P. G. Reyes , F. Castill and H. Martinez ,"Paschen Law For Argon Glow Discharge" , 14 Th Blatin American Workshop On Plasma Physics (LAWPP 2011) Journal of Physics , Conference Series 370 (2012) 012067.
16- Danijela D. S , Ijac Ic and Ute Ebert, "Transition From Townsend to Glow Discharge", Subcritical, Mixed, or Supercritical Characteristics, PHYSICAL REVIEW, E 66, 066410 (2002).
17- Dragana Mari et al, "Gas Breakdown and Secondary Electron Yields", Eur. Phys. J. D (2014) 68: 155.
18- R. Niedrist, R. Schrittwieser And C. Ionita "Electrical Breakdown in an Argon/Titanium Hollow Cathode Gas Discharge", 40th EPS Conference on Plasma Physics, P2.406