

PAPER • OPEN ACCESS

Operational characteristics of disc and spherical cathode electrodes in dc plasma discharge

To cite this article: Estbrq A Abd-Alwahed and Khalid A Yahya 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **871** 012059

View the [article online](#) for updates and enhancements.

You may also like

- [Analysis of gas discharge characteristics across micro-gap under different pressures](#)

Yansen Li, Yanzhou Sun, Yining Sun et al.

- [Breakdown voltage of zinc and magnesium vapours](#)

E Zoestbergen, C Commandeur and T Maalman

- [The breakdown characteristic of porous dielectric discharge based on percolation structure](#)

Yuheng Hu, Libo Rao, Feiyu Wu et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Operational characteristics of disc and spherical cathode electrodes in dc plasma discharge

Estbrq A Abd-Alwahed and Khalid A Yahya

^a Department of Physics, College of Science, Al-Nahrain University, Baghdad-Iraq.

*e-mail: drkayahya2005@yahoo.com

Abstract -In this work, the effective of shapes for disc and spherical cathode electrodes on the operational conditions of dc discharge has been studied. Paschen curve was studied of the two cathode shapes electrodes at the discharge voltage (0- 450 V) at 38 mm distance between the electrodes. Theoretically, the distributions of equipotential line and electric field before the minimum discharge voltage between the electrodes were estimated by using SIMION software. The study showed the effect of the geometry of the cathode electrode on the operational conditions where the discharge voltages require for the spherical shape was greater than the disc at minimum values in Paschen curve. The results showed a diagnostics of plasma using a single Langmuir probe that electron temperature and ion density for spherical cathode shape was higher than the disc by, 20% and 17.9% respectively.

1. Introduction

Gas discharge is a type of plasma. Actually, the plasma is luminous. The reason of this laminated of plasma is the result of colliding electron with atoms and excited it to generate visible light and generate photons[1].

The two most common types of electric discharge are direct continuous dc and radio frequency rf discharge. Both types have the characteristics and requirements for electrical discharge and its applications. Glow discharge can be generated by applying a potential difference between the two electrode which filled with a gas at a limited pressure inside a chamber [2,3].



There are several parameters that affect the process of gas discharge such as the shape of the electrodes, the distance between the electrodes, type of electrode material and the pressure and type of gas used[4,5]. The electrical discharge of gases has different important applications, including in the manufacture of microelectronics, surface treatment, and nano materials as well as in the manufacture of integrated circuits and coating technology. Furthermore, the emitted light from excited atoms in discharge gas is used in flat plasma display panels and fluorescence lamps and also, in medical applications such as cutting tissue and tool's sterilization [6, 7]. The effect of discharge electrodes on the discharge curve has been studied by several researchers [8,9].

In this paper, the dc discharge operation was studied experimentally for two electrodes different of cathode shape (disc and spherical) using argon gas. Furthermore, the parameter for generated plasma between the electrode was determined using single Langmuir probe. The distribution equipotential lines between the electrodes was calculated theoretically using SIMION software.

2. Experimental Setup

Figure 1 shows the parts of the plasma reactor and the electrical circuit. The discharge chamber was a cylindrical cross made of stainless steel with outer diameter 220mm, inner diameter 115mm and length 285mm. The chamber was closed by two blind flanges and two flanges with window. The vacuum inside the discharge chamber is achieved by using a rotary pump in order to reach the pressure of $\sim 10^{-3}$ mbr with a pirani gauge for measuring the pressure.

The cathode and anode electrodes are made of pure copper. The cathode in the system was used a spherical shape with a diameter 20mm and a disc in diameter 45mm. The anode electrode was used a disc shape. In this work the distance between of the electrodes was fixed at 38mm with work pressure ranged (0.5-2mbr). Plasma parameters have been studied by using cylindrical single Langmuir probe made of tungsten wire with diameter (0.25) mm and length 4mm , which was located at 14mm distance from a cathode.

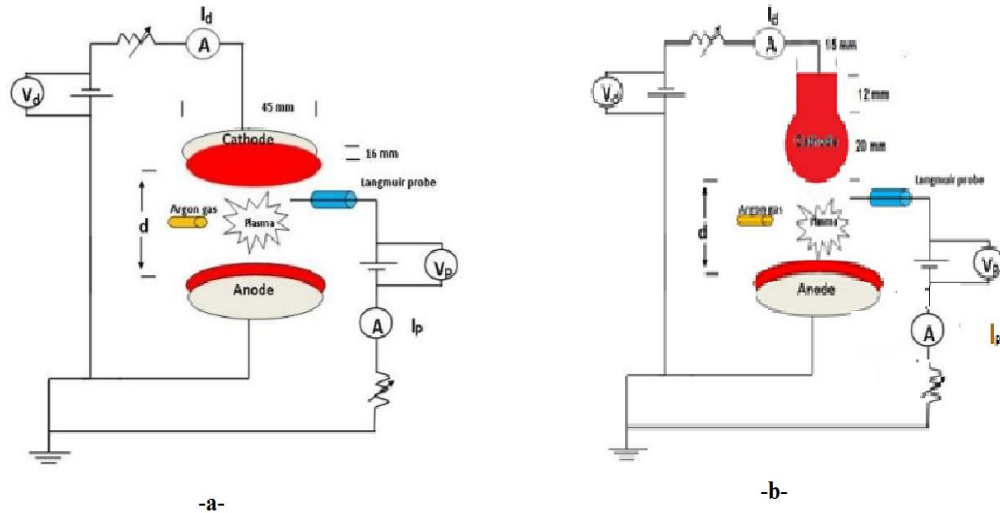


Fig1. Schematic diagram for plasma reactor and electrical circuit using (a) disc cathode shape, (b) Spherical cathode shape.

3. Results and Discussion

3.1. Electrical Characteristics (I_d - V_d) Discharge

The effects of the cathode shape on the dc electrical discharge (I_d - V_d) for a spherical, and a disc cathode shape were studied with argon gas discharge as shown in Fig.2.

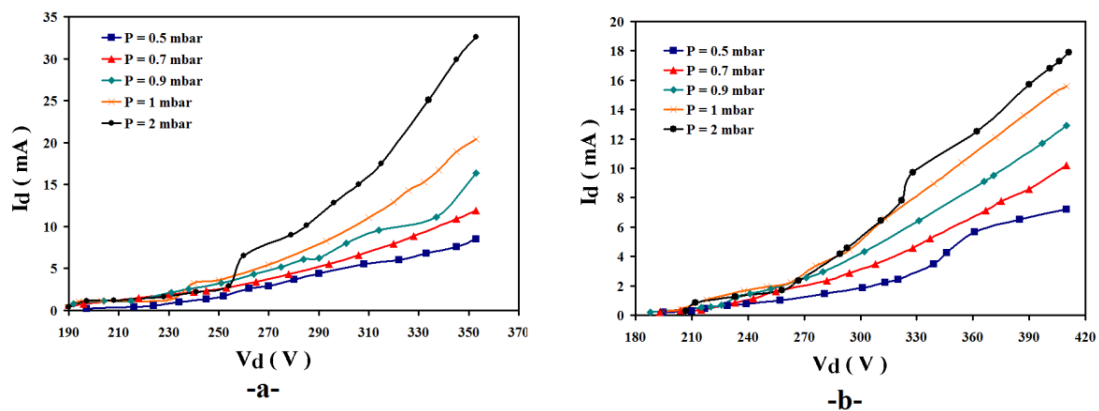


Fig. 2 Current - voltage dc discharge characteristics for different gas pressure at $d = 38$ mm for (a) disc cathode shape (b) spherical cathode shape.

It is noticed from the figure that as the discharge voltage increases, the current is increasing where higher currents were obtained in the case of disc cathode shape. Furthermore, the results from the properties' curve showed that the discharge is within normal discharge area, according to the values of discharge current.

3.2 Paschen Curve

The Paschen curve represents the relationship between the breakdown voltage V_B and the product of multiplying the pressure values P and the distance d between the electrodes.

Figure 3 shows the relationship between the value breakdown voltage V_B and pd for different value of argon gas for two shapes of the cathode (disc and spherical) electrodes.

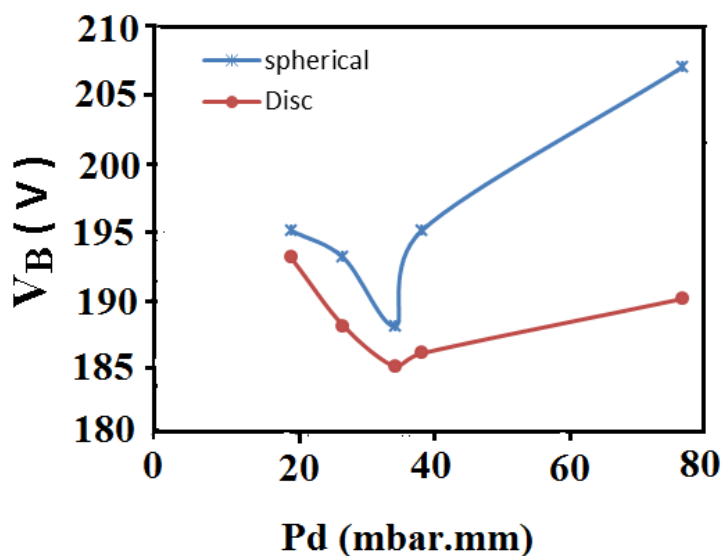


Fig.3 Breakdown voltage as a function of Pd for disc and spherical cathode shape at distance $d=38\text{mm}$.

It's obvious from the figure that as the argon pressure increases, the breakdown voltage begins to decrease until it reaching the minimum values -185V at pressure 0.9 mbr for disc cathode shape. On the other hand, the lowest value voltage for spherical cathode shape was -188V and pressure 0.9 mbr.

3.3 Computation of Equipotential Lines

Laplace equation is comprehensive and applicable where the volume charge density is zero and states that each electrode formation generates a potential field given by [10]:

$$\nabla^2 \phi = 0 \quad (1)$$

Where ϕ is the potential.

The equipotential lines have been computed by solving eq.(1) with aid of SIMION software for the two cathode electrode shapes at near minimum voltages obtained in Fig. 3 prior to the discharge at -184 V and -187 V for disc and spherical cathode shape respectively as shown in Fig.4.

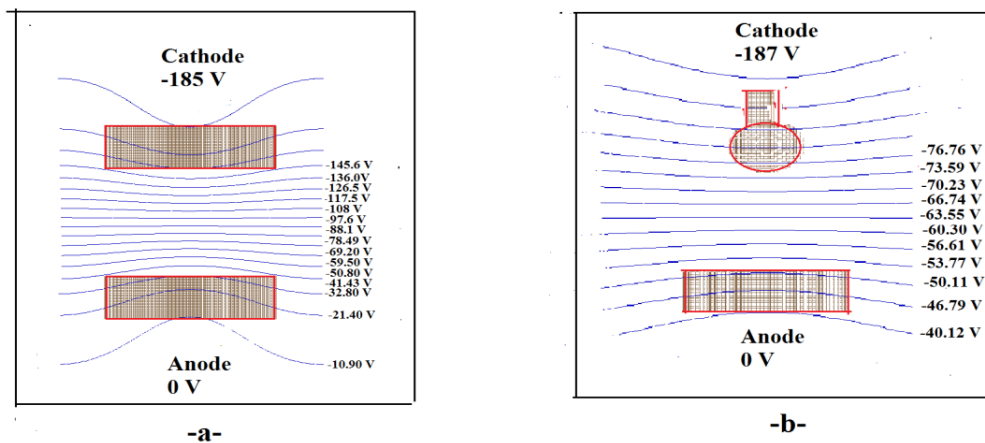


Fig.4 Distribution of equipotential lines estimated from SIMION software at $d = 38$ mm for (a) disc cathode at $V_d = -184$ V. (b) spherical cathode at $V_d = -187$ V.

Also, the electric field between electrodes was calculated at distance 38mm as shown in fig.5

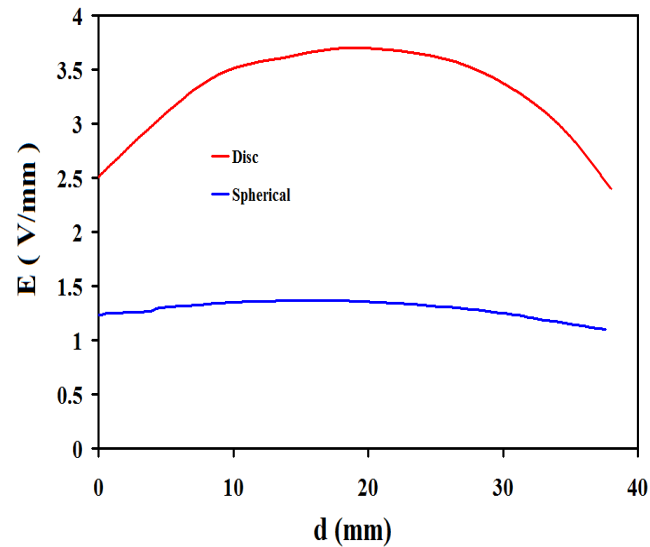


Fig .5 Electric field as a function of electrode distance for disc and spherical cathode shapes using SIMION software.

Figure 5 shows the effective of cathode electrode geometry on the electric field values at the center between electrodes and it are clear that the values electric field for using spherical cathode approximately constant while the behavior for disc was different.

3.4 Measurement of Plasma Parameters

The plasma parameters were measured by using a cylindrical single Langmuir probe located at 14mm distance from the two shapes of cathode electrodes .

3.4.1 (I_p - V_p) Probe Curve

The characteristics of the probe (I_p - V_p) for the two shapes of electrodes can be used to determine plasma parameters , through changing the basing voltage to probe with respect to plasma .Figure 6 shows the probe characteristics (I_p - V_p) for disc and spherical cathode shapes where IP and VP are current and voltage probe respectively at $d=38$ mm , gas pressure 0.9 and discharge voltage -300V.

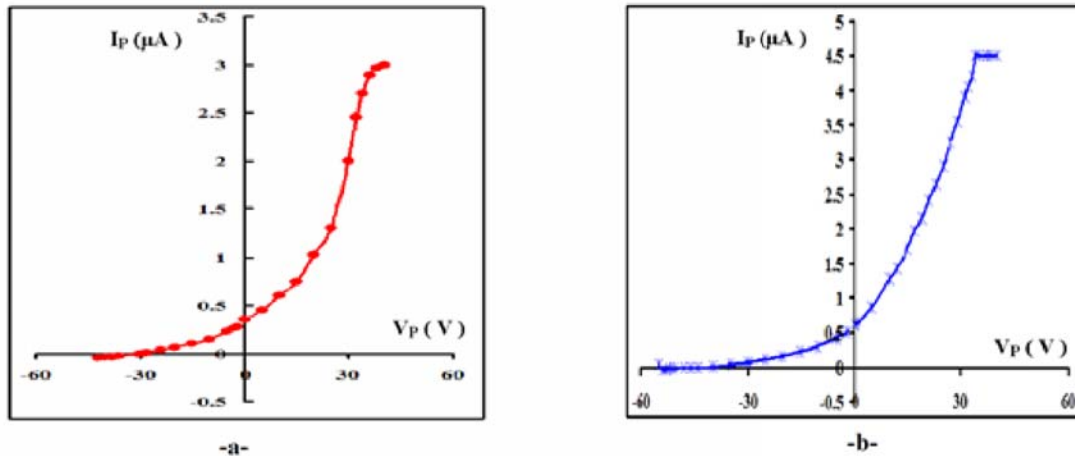


Fig. 6 Current-voltage Langmuir probe characteristics at $P=0.9$ mbar, $V_d = -300$ V and $d = 38$ mm for (a) disc cathode shape (b) spherical cathode shape.

3.4.2 Electron Temperature.

The temperature of electron can be estimated from the (I_p-V_p) probe curve in fig.6. From the slope of semi log of in a transition region of the probe curve so, it can be calculated the temperature of electron T_e for disc and spherical cathode shapes using eq.(2) [11] as shown in Fig.7

$$T_e = e/k_B \left(d \ln(I_p) / d V_p \right) \quad (2)$$

Where k_B is Boltzmann constant and e is the electron charge

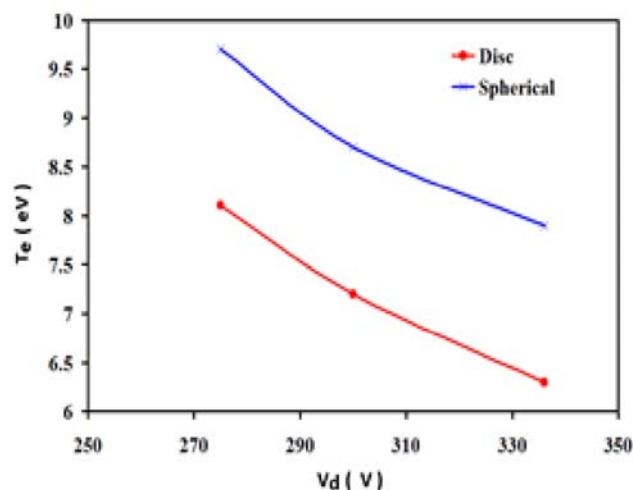


Fig. 7 .Temperature of electron verse discharge voltage for disc and spherical cathode shape at $P=0.9$ mbar.

It is noted from Fig. 7 that the values electron temperature is decreased as increased discharge voltage. This is due to increase's collisions between the electrons and gas atoms. Furthermore, the temperature value for spherical cathode shape is higher values than disc cathode shape

3.4.3 Electrons and Ions Density.

The density of electron n_e for disc and spherical cathode electrode can be determined using (I_p-V_p) probe curve and eq. (3) [12] as shown in Fig.8.

$$n_e = \frac{4I_{se}}{eA_p} \left(\frac{m_e}{2k_B T_e} \right)^{\frac{1}{2}} \quad (3)$$

Where I_{se} is saturation of electron current, m_e mass of electron, A_p is the probe area $A_p = 2\pi r_p l$, r_p is the probe radius and l is the length of probe.

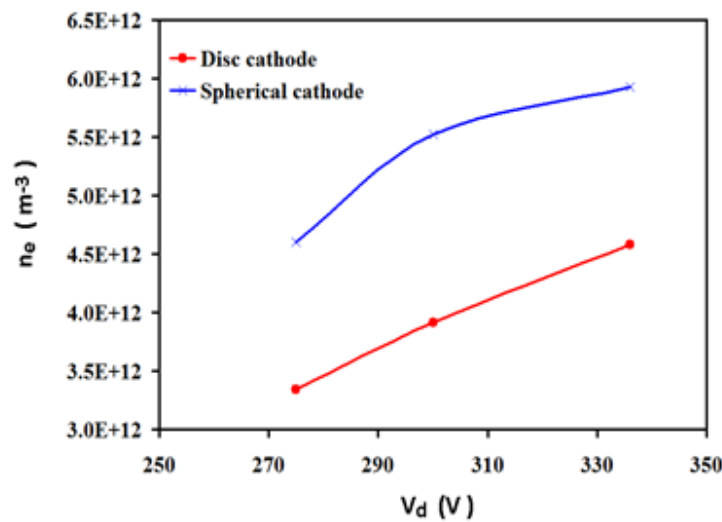


Fig. 8 Density of electron verse discharge voltage at d=38 mm and P=0.9 mbar for disc and spherical cathode shape.

It is obvious from Fig. 8 the increasing of electron density values with discharge voltage due to increases the electron emitted from a cathode surface. Also, the electron density values for spherical cathode is higher than disc shape

Also, the ions density n_i has been determined from the eq.(4)[13] and probe curve as shown in Fig. 9

$$n_i = \frac{i_{si}}{e A_p} \sqrt{\frac{m_i}{k_B T_e}} \quad (4)$$

Where m_i is the argon ion mass i_{si} is the saturation of ion current .

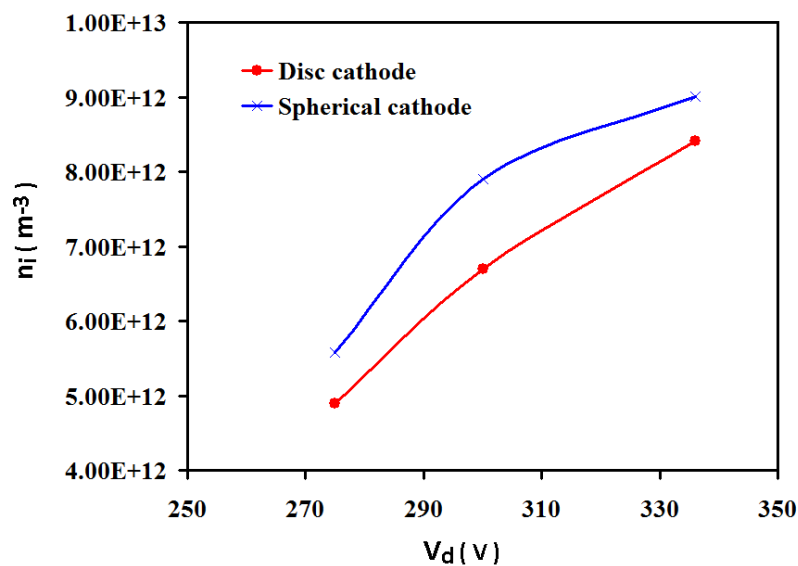


Fig.9. Ion density as a function of discharge voltage at work pressure 0.9mbr for disc and spherical cathode.

Figure .9 illustrated the effects of cathode shapes on the ion density values for disc and spherical shapes. The values of ion density for spherical is higher than a disc cathode.

3.4.4 Plasma Frequency and Debye Length

Plasma frequency ω_p was calculated for disc and spherical cathode shape from Eq.(5) [14] at gas pressure 0.9 mbar for different discharge voltage as shown in Fig. 9 .

$$\omega_p = \left(\frac{n_e e^2}{m_e \epsilon_0} \right)^{1/2} \quad (5)$$

Where ϵ_0 is the vacuum permittivity.

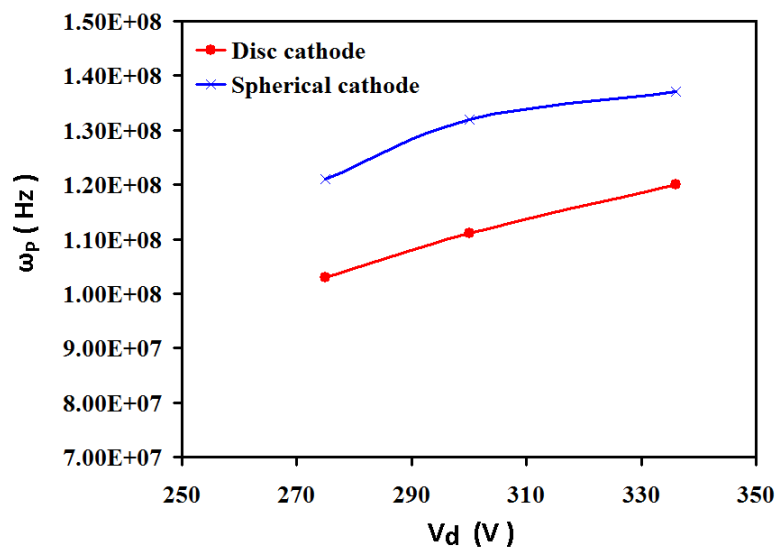


Fig. 10 Plasma frequency verse discharge voltage at P= 0.9 mbar for disc and spherical cathode shapes.

Figure 10 illustrated that the value to the plasma frequency parameters for spherical cathode electrode was higher than disc shape.

Also, the Debye Length parameter λ_D , is inversely proportional to the electron density and directly with the electron temperature which can be calculated for the two type of cathode shapes from eq. (6) [13] as shown in Fig.11

$$\lambda_D = \left(\frac{\epsilon_o k_B T_e}{n_e e^2} \right)^{1/2} \quad (6)$$

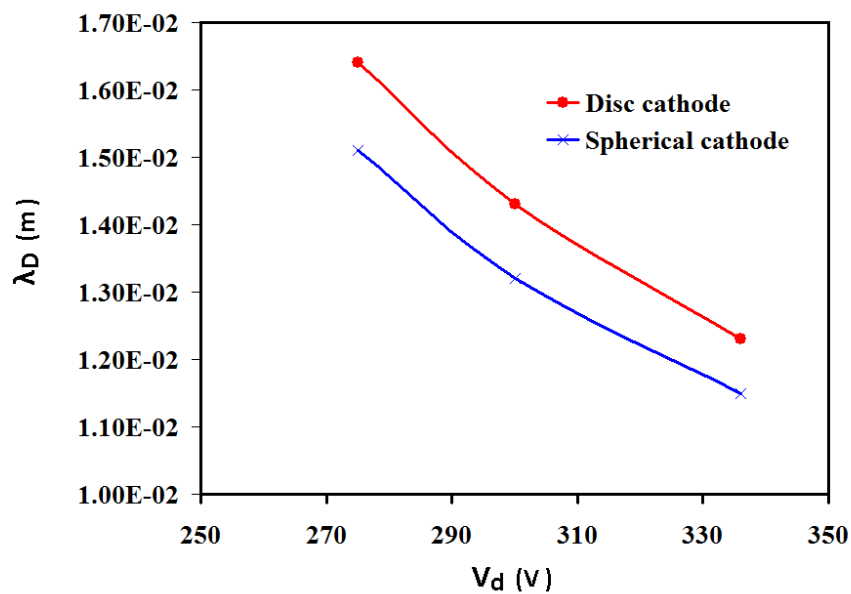


Fig.11 Debye length verse discharge voltage at $P = 0.9$ mbar for disc and spherical cathode shapes.

It is noted from fig.11 that the parameter of debye length values for disc cathode is higher than spherical shape.

Table 1. shows the result of different plasma parameter values for disc and spherical

Table 1. Represent the effect of cathode electrodes shapes on plasma parameters .

Plasma parameters	Disc electrode	Spherical electrode
$T_e(275)$ eV	8.1	9.7
$T_e(300)$ eV	7.2	8.7
$T_e(336)$ eV	6.3	7.9
$n_e(275) * 10^{12} \text{ m}^{-3}$	3.34	4.6
$n_e(300) * 10^{12} \text{ m}^{-3}$	3.9	5.52
$n_e(336) * 10^{12} \text{ m}^{-3}$	4.58	6.62
$n_i(275) * 10^{12} \text{ m}^{-3}$	4.9	5.58
$n_i(300) * 10^{12} \text{ m}^{-3}$	6.7	7.9
$n_i(336) * 10^{12} \text{ m}^{-3}$	8.41	9
$\lambda_D(275) * 10^{-2} \text{ m}$	1.64	1.51
$\lambda_D(300) * 10^{-2} \text{ m}$	1.43	1.32
$\lambda_D(336) * 10^{-2} \text{ m}$	1.23	1.15
$\omega_p(275) * 10^8 \text{ Hz}$	1.03	1.21
$\omega_p(300) * 10^8 \text{ Hz}$	1.11	1.32
$\omega_p(336) * 10^8 \text{ Hz}$	1.2	1.45

4. Conclusions

The effects of geometry for disc and spherical cathode electrode shapes and plasma diagnostics have been studied experimentally for dc discharge argon gas. Also, SIMION software was used for estimated the distributions of equipotential line and electric field before the minimum discharge voltage between the electrodes as follows:

- In the spherical shape of the cathode, the minimum values of the discharge voltage in Paschen curve were higher than the disc, by 1.62%.
- The theoretical results from SIMION software for electric field illustrated that as increasing the distance between the electrodes, the values of electric field for spherical cathode approximately constant get the system a good stability
- The diagnostics for generation plasma between electrodes by using Langmuir probe showed that the values of electron temperature for spherical cathode was higher than the disc, by 19% ($v_d=275$) ,20% ($v_d=300v$) and 25% ($v_d=336$) respectively. Also electron density , ion density and plasma frequency for spherical cathode electrode were higher than disc cathode by 37.7%($v_d=275$) , 17.9%($v_d=300v$) and 14.1%($v_d=336$) respectively .In another hand debye length for disc cathode was higher than the spherical cathode by 8.6% ($v_d=275$).

References

- [1] Howatson A M 1976 *An Introutction to Gas Discharges* (Frankfurt : Pergamon Press Ltd) p.3
- [2] Boyd T J M 2003 *The physics of plasmas* (Scotland: Cambridge university press) p 30
- [3] Smirnov B M 2015 *Theory of gas discharge plasma* (Canada :Springer) p54
- [4] Hontanon E , M. Palomares J, Guo X, Engeln R , Nirschl H and Kruis E F 2014 J Phys. D: Appl. Phys. 47 415201
- [5] Mathew P ,George J , Mathews S T and Kurian P J .AIP Advances **9**, 025215 .
- [6] Harry J E 2010 *Introduction to Plasma Technology: Science, Engineering and Applications* (Germany :Wiley-VCH Verlag & Co. KGaA, Boschstr.12, 69469 Weinheim) p 76
- [7] Akitsu T, Ohkawaa H , Tsujib M. , Kimurab H.and Kogoma M 2005 *Surface & Coatings Technology* 193 29
- [8] Lisovski V A, Kharchenko N D. and Yegorenkov V. D 2010 J. Phys. D: Appl. Phys. 43 425202
- [9] Radwan S I , El-Khabeary H, and Helal A G 2016 J . Phys. 94 1275
- [10] Guru B S and Hiziroglu H R 2004 *Electromagnetic field theory Fundamentals* (Cambridge university press, Sao Paulo) p 113
- [11] Godyak V A and Alexandrovich B M 2015 Appl Phys 118 233302 .
- [12] Kelly P J and Arnell R D 2000 **56** 159
- [13] Merlino R L 2007 J . Am Phys 75 1078