Design and Construction of Argon D.C Glow Discharge Plasma Using Al Target

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Abstract

In this work, we have successfully designed and constructed argon D.C glow discharge plasma. A planer D.C diode system consisted of two aluminum electrodes which were designed and constructed to study Paschen's curves at two different interelectrode distances (3cm and 4.5cm). The breakdown voltage (V_b) was experimentally measured as a function of the pressure product of inter-electrode distance (Pd) for argon discharges gas. The behaviour of breakdown voltages as a function of (pd) coincide with Paschen’s law at the two different interelectrode distances. The minimum breakdown voltages were $(V_b)_{\min}$ =(232, 244)volt for d=(3, 4.5)cm respectively and the minimum pressure product by the inter-electrode distance namely $pd_{\min}$=. (1.1,1.5) mbar.cm at the two above distances.

Key words: Paschen's law, Glow discharge, Breakdown voltage.

الخلاصة

في هذا البحث تم بناء وتصميم منظومة D.C لتوهج البلازما لغاز الأركون. منظومة ال D.C دايود المستوية احنوت على قطبين من الألمنيوم عندما صممت وركبت لدراسة منحنيات باشن عند مسافتين مختلفة ما بين الأقطاب مقدارها (3, 4.5)cm . فولتية الأنهيار $(V_b)_{\min}$ قيست عمليا كدالة لحاصل ضرب الضغط بالمسافة مابين الأقطاب $(pd)_{\min}$ لتوهج غاز الأركون. فولتية الأنهيار الصغرى $(V_b)_{\min}$=(232, 244)volt للمسافة (3, 4.5)cm على التوالي. القيمة الصغرى للضغط مضروب بالمسافة مابين الأقطاب كانت قيمتها على التوالي $pd_{\min}$=(1.1, 1.5)mbar.cm لتلك المسافتين.

الكلمات المفتاحية: قانون باشن، توهج البلازما، فولتية الأنهيار.

1. Introduction

DC-glow discharge plasma is widely used as a tool for thin film preparation such as sputtering [1] and plasma enhanced chemical vapor deposition (PECVD) [2]. Plots of the breakdown voltage versus *pd* are known as Paschen curves. Characteristic minimum in the function appears at some intermediate value of pd. At low pd values, the breakdown voltage is high because too few collisions (at low p, or small gaps). At high pd values, the V_b is high because of too many collisions (at high p , or large gap). Breakdown voltages for many different gases have been studied at which breakdown occur is described by Paschen's law. It has been found that the breakdown voltage depend only on the product pd for a given gas and cathode material [3]. Bogaerts *et al.* reviewed the topic of plasmas gas discharge and their applications [4]. Hassouba *et al.* studied the minimum breakdown potential for three different cathodes. They observed that the value of pd_{min} was 80 Pa cm (0.6 torr cm) for Ar discharge and 530 Pa cm (4 torr cm) for He discharge. They concluded that the minimum breakdown potential increases with the increase of the work function of the cathode materials. For Ar and He gases, it was clear that the minimum breakdown voltage of He gas is lower than that of Ar gas. They attributed this to the higher efficiency of secondary ionization processes in He discharge rather than in Ar discharge [5]. Paschen's law predicts the value of the breakdown voltage as a function of the product of the pressure and the inter-electrode distance, V_b = f (pd) for a given reactor configuration [6]. The independent influence of the inter-electrode distance on the V_b for different reactor set up, inter-gases, electrode materials, electrode sizes, inter-electrode distances has been previously observed by many workers [7, 8, 9]. Experimental and theoretical studies of breakdown at low pressure for dc discharge in argon, nitrogen, air and oxygen for different inter-electrode gaps, discharge tube radii and cathode materials. It was found that the ratio of $(E_d/p)_{\min}$ at the minimum of breakdown curves is shown to be constant for any inter-electrode gap (L) , discharge vessel radius (R) and the ion – emission rate from the cathode surface γ. A modified breakdown law for the low-pressure dc discharge V_b = f (PL, L/R) has been obtained [10]. It has been shown that Paschen law should include the inter-electrode distance as a separate parameter. Paschen curve measurements in an argon discharge for inter-electrode distances varying from 2-9cm confirm these results [11, 12].

A partial ionized plasma source of DC-glow discharge at low pressures has been constructed, characterized, and operated as home-built system. Our system is a direct current discharge formed between two metal electrodes. The inter-electrodes were varied between 4-6 cm. Using N_2 as discharging gas source. The characteristics of glow discharge (plasma) column were observed influenced with inter-electrode spacing and gas pressure.

2. Experimental setup

Figure 1 shows the schematic diagram of the diode sputtering technique with two electrodes. The distance between cathode and anode is either 3 cm, or 4.5 cm. The base pressure inside the chamber is $5\times10^{-2}\,mbar$. The DC applied voltage is 1000 volt. The real pressure with Argon inside chamber can be normalized by a correction factor which is equal to 2 in our system.

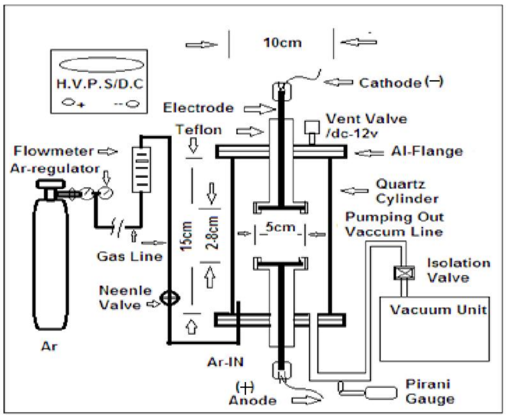

Figure (1): Schematic diagram of D.C diode-glow discharge.

Figure 2: Photograph of D.C diode-plasma set-up discharge.

2.1. Basic Design and Construction:

A schematic diagram of D.C glow discharge setup for low pressure plasma system has been already shown in Figure (2). The vacuum chamber has a cylindrical shape made of quartz with diameter and length of 10 cm and 15 cm respectively. Two pure aluminum disc each with diameters of 5 cm and thicknesses of 5 mm. The electrodes surface area was 20cm^2. These are working as cathode and anode electrodes. The plasma chamber is pumped through a small bottom port by a mechanical pump. A typical routinely achievable base pressure can be as low as $1\times10^{-2}\,mbar$. A Pirani gauge head (Edward/model PRM 10) with measuring pressure range $10^{3}-10^{-3}\,mbar$ were used to measure the base pressure. This gauge was controlled by an Edward Pirani (model 1101). The gauge was previously calibrated by Edwareds relative to the argon gas. For basic studies of the plasma source operation and characterization, pure argon (99.99/ purity) was used as a working gas. In order to control the rate of the gas and the equilibrium pressure within the plasma chamber, manual flow meter with range of 150 sccm was connected through a needle valve.

2.2. Plasma Chamber

The chamber for deposition on planer substrates was designed. It was essentially cylindrical in geometry made of quartz, 3mm thickness and covered with two aluminum discs sealed with O-rings. The overall inside dimensions of the chamber was 15 cm height and 10 cm in diameter (≈1200cm^3). A photograph of the chamber is shown in Figure (3) and the diagram of its main internal components is shown in Figure (1). High voltage D.C. power supply (WALLIS-UK) with regulated voltage range from 0-2500 volt and current up to 250 mA was used for plasma generation experiments.

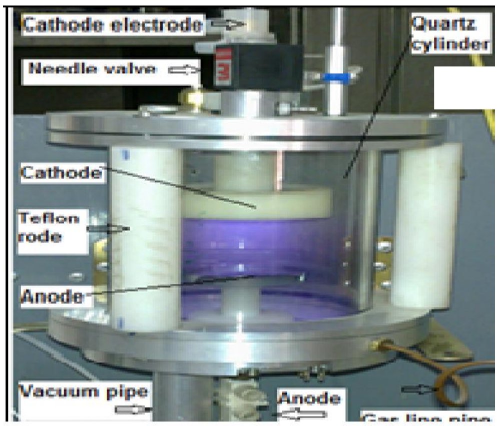

Figure 3: Glow discharge chamber.

2.3. Gas Line Feeding System

During glow discharge, argon gas was admitted to the chamber by a mass flow meter. A rate of 10-20 sccm of argon gas is admitted to maintain a suitable a pressure for glow discharge inside the chamber. The chamber was vented by a vent valve (12volt solenoid valve) to the atmosphere. The gas was supplied to the reaction chamber through small copper tubes (3mm-diameter) to the reaction chamber from a regulated 200 litter of pure argon gas bottle. The pressure gauge in the setup was calibrated for N_2 gas.

2.4. Mean Free Path Calculation:

According to the kinetic theory of gases, the particles travel in a straight line until they collide with another particle or wall. The distance a particle traveled before a collision is known as a free path. The mean free path is dependent both on the physical properties of the gas and the amount of gas [13].

The mean free path can be calculated assuming that the air consist of N_2 molecules using this formula:

$$\lambda(m) = k_B T / \sqrt{2}\,\sigma\, p \tag{1}$$

where $\lambda(m)$ is the mean free path in meter unit, σ atomic cross section p the gas pressure in Pa unit (where Pascal=10^{-2} mbar) and k_B Boltzmann constant. To calculate the mean free path as a function of nitrogen gas pressure, at room temperature (T=298K). The cross section area was σ (N_2) = 0.43 nm^2. The calculated results for both gases are shown in Table (1). It is well known that the mean free path is inversely proportional with pressure. The calculated mean free bath (λ) as a function of nitrogen gas pressure in the range of $1\times10^{-2} - 50\,mbar$ is shown in Table (1). The accepted value for the mean free path according to Table (1) is up to 6.8 cm and 8.1 cm for nitrogen gas (air). The calculation implies that the mean free bath between collisions should be smaller or comparable to the inter-electrode distance (d) used in this work (i.e.: $\lambda \geq d$), where the gas dynamics are dominated by molecular collisions with the inter-electrode walls.

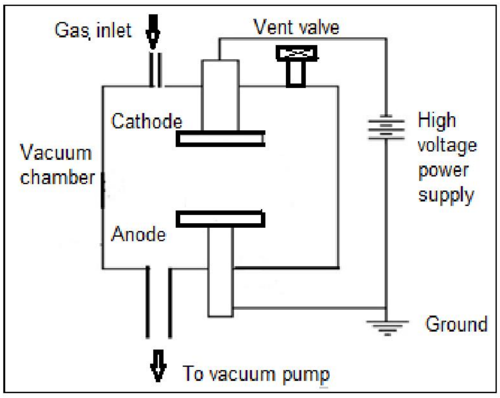

Figure 4.The schematic diagram of the DC-diode system.

Table (1): The calculated mean free path as a function of nitrogen gas pressures. The symbol (**) indicates the undesired pressure values for our vacuum chamber design with inter- electrode distances (3 cm and 4.5).

P(mbar)	*λ (cm) Nitrogen*	*d=3cm λ/d*	*d=4.5cm λ/d*
10^{-2}	6800	2267	1511
5.10^{-2}	1360	453	302
10^{-1}	680	227	151
5.10^{-1}	136	45	30
1	68	23	15
3	22.7	7.6	5
5	13.6	4.5	3
10	6.8	2	1.5
20 (**)	3.4	1.1	0.75
50(**)	1.3	0.4	0.28

3. Results and Discussion

3.1. Experimental Measurements of Applied Voltage versus Argon Pressure:

As a preliminary experiments were conducted to find out the relation between the applied voltage and the gas pressure used at different inter-electrode distances. The applied voltage. Figure (4): shows the schematic diagram of the diode sputtering technique. The distance between cathode and anode was (3, 4.5) cm was used. The base pressure inside the chamber $5 \times 10^{-2}\ mbar$. The DC applied voltage is 1000 volt. The real pressure with Argon inside chamber can be normalized by product 2 (correction factor) the read pressure that reading in PRM 10 gauge head (Edward co.) controlled 1101 Pirani .The voltage and current of the diode sputtering should be read for each value of each pressure. As shown is Table (1). The voltage is plotted against *pd*. The minimum point in the V_b is called break down voltage. Figure (5) shows Paschen curve using argon medium at different electrode distances .The left hand side of the curves the breakdown voltage rises rapidly as pressure times distance (*pd*) decreases due to the low possibility of ionizing collisions requiring a strong electric field .The right hand side of the curves the breakdown voltage rises gradually as (*pd*) increases due to the probability that an electron will produce ionization even at lower electric fields than the left hand side. The minimum of the curve is where the ionization process occurs at the minimum breakdown voltage. This minimum voltage region is characterized by specific (pd) and these two parameters [$(pd)_{min}$ and $(V_b)_{min}$] are the primarily concerns for the minimization of the ionization chamber as shown in Table (2) and the data as shown in Figure (3). This Table (2): Experimental data taken from Paschen's curves for argon gas discharge at inter-electrode distance of *d*=3cm, and 4.5

cm. figure illustrate Paschen curves for two different inter-electrode distances (3cm and 4.5cm) .We measured the minimum voltage for discharge in argon atmosphere as shown in Table 2. However, nearly at the same pd value, the breakdown voltage differs depending on the inter-electrode distances. The breakdown voltage variation becoming noticeable at the lower values of the product $(pd)_{min}$ near the minimum breakdown voltage.

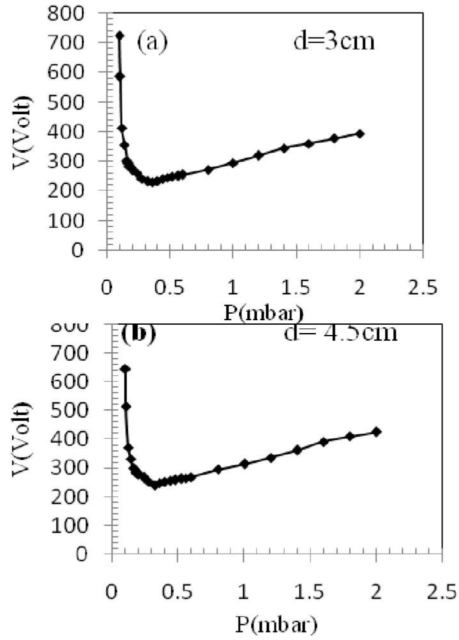

Figure 5: Breakdown Voltage and Paschen Curves for (a) *d*=3*cm* and (b) *d*=4.5*cm.*

Table (2): Experimental data taken from Paschen's curves for argon gas discharge at inter-electrode distance of *d*=3cm, and 4.5 cm.

d(cm)	*P_{min}(mbar)*	*V_b $(volt)_{min}$*	*$(Pd)_{min}$ (mbar-cm)*	*$(Pd)_{min}$ (Torr.cm)*
3	0.36	232	1.1	0.83
4.5	0.33	244	1.5	1.13

3.2. Calculated of Breakdown voltage-interelectrode distance V_b=f (d) relation:

To find the relation between the breakdown voltages and the inter-electrode distances using our experimental measurements for argon gas which they were previously measured: i.e., V_b=232volt at *d*=3cm, and V_b=244volt at *d*=4.5cm. We found an empirical formula for V_b as a function of *d* from our experimental value of V_b and d as follows:

Suppose that V_b is related to d using this

$$V_d = k d^n \qquad (2)$$

To find the values of k and n, by substituting the experimental values for both V_b and d stated above into equation 2 and solve the relations for n and k. Figure (6) show the plot of V_b against d, which explain the relation of these parameters as a power law variation:

$$V_d = 277.8\ d^{0.034} \qquad (3)$$

This result confirmed the separate dependence of V_b on the inter-electrode distances. As far as the breakdown voltage V_b is known, the breakdown curves of the glow discharge are described by V_b=f(pd), i.e., the breakdown voltage depends on the electrode spacing d and the gas pressure p according to the modified Paschen's law:

$$V_b = Bpd / \ln(Apd) - \ln[\ln(1+\gamma^{-1})] \qquad (4)$$

Where A and B are a constants for gas used and γ is the secondary electron emission coefficient of the cathode material [14].

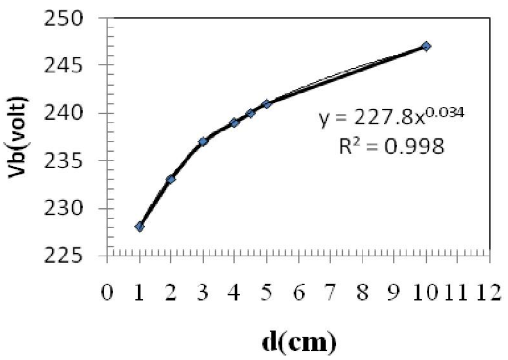

Figure (6): Relation V_b (breakdown voltage) against (inter-electrode distance).

The average values of the experimental minimum argon pressure times the inter-electrode distance (pd) for Al cathode material used in our work is equal to 1.3, 0.2 mbar-cm (1.0, 0.15 Torr-cm). These results are in a good agreement compared with other workers results [15, 16].

4. Conclusions

A minimum breakdown voltage was observed where any substantial increase of pressure below or above this point results in a higher V_b. The experimental results presented some interesting findings and confirmed some earlier theoretical data on voltage breakdowns. The pressure times distances' plots showed a trend which is in agreement with Paschen law. Our results confirmed the dependence of V_b on d by the empirical formula shown above. This system can be used in the future work to deposit metal films using argon gas sputtering technique.

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