Study of DC Breakdown Voltage in Low Pressure Argon and Nitrogen Gases for Several Electrode Gap

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Abstract

In this paper the breakdown of Argon and Nitrogen in DC electric field are studying at different electrode gaps d. The discharge system consists of two electrodes; Cathode electrode is made from Aluminum with 7cm diameter, whereas Anode electrode made from molybdenum metal with 7 cm diameter. Electrode gap ranges between 2-5 cm. Pressure vacuum varies from 0.08 mbar to 0.2 mbar and DC power 750 W. The breakdown voltage V_b is shown to depend on the product (p.d), for lower values of pressure, p or gap, d. This work represents the investigation of the dependence of the breakdown voltage on the gas pressure and on the distance between electrodes and the type of gas. The minimum value of breakdown voltage increases with increases gap d and this value for Argon gas is lower than Nitrogen gas and from this value can determine pressure and current sputtering, while the discharge current increases with pressure. [DOI: 10.22401/JNUS.20.1.12]

Keywords: Paschen curve**,** DC power supply, Argon and Nitrogen discharge.

Introduction

The electric breakdown of a gas is the result of self sustained collapse processes which depend on the relative activity of electron generation and loss mechanisms. Static (DC) breakdown occurs when the rate of change of the applied voltage is much less than the rate of elementary processes related to electrical breakdown [1]. The avalanche and the streamer mechanisms are used in the electrical breakdown in the gases. The spatial growth to breakdown of small ionization currents or of the temporal growth of a pre-breakdown discharge is studied in most of the papers on this topic. For the breakdown to occur, two criteria, must be determined: there must be suitably placed initiatory electrons and a mechanism of ionization must occur to produce amplification of the ions or electrons which compensate the loss by diffusion. The Townsend mechanism by which successive ionizations of gas molecules induce the gas breakdown, explains the process satisfactorily at large separations. However, avalanches can not be built up in the same way at micrometer separations so the gas breakdown is initiated by the secondary emission process rather than processes in the gas [2]. DC glow discharge are applied in several fields depositing a thin polymer, oxide films, cleaning the surface of materials, pumping gas discharge lasers, plasma display panels, voltage stabilizers, and etc. Therefore the research into the conditions of the glow discharge breakdown is of considerable interest [3, 4].

Electrical breakdown of gases can be defined as the transition from an insulator to a conducting state and the minimum voltage at which this transition occurs is called the breakdown voltage V_p. The Paschen's law is considered the breakdown curves of the glow discharge and is described by $V_p = f$ (P.d), i.e. the breakdown voltage depends on the electrode gap (d) and the gas pressure (P) [5,6]. The Paschen curve can be obtained by computing the voltage required for the process of electron emission and multiplication to become self-sustaining [7]. One obtains:

$$V_p = \frac{Bpd}{\ln(Apd) - \ln(\ln(1+\gamma^{-1}))} \quad \text{.........................} (1)$$

where, A and B are constants for a particular gas and γ is the secondary electron emission coefficient of the cathode. From Eq. (1) V_p of a gas depends only on the pressure and gap distance product (Pd) and cathode material. The breakdown voltage also depends on several parameters such as charged and non-charged particles in the gas, electrode configuration, the surface properties (state and area) of the electrodes and inner radius of discharge tubes.

However, these parameters are not considered in the Paschen's law and might therefore responsible for the deviation between experimental and theoretical results [5]. The minimum DC breakdown voltage between plane parallel electrodes is typically in the domain of a few hundred Volts [8]. This paper reports the results of experimental study of the effects of gas pressure, gas type and electrode gap on the breakdown voltage of argon and Nitrogen gases with DC electric field in cylindrical discharge vessel as shown in Fig.(1). From this study one can determine minimum breakdown voltage also pressure and electrode gap at this point, which is considered very important in the deposition processes.

Experimental Setup

A cylindrical plasma chamber was made from glass. Two open ends of plasma chamber were terminated by two stainless steel flange. Length, thickness, and diameter of the cylinder are 40cm, 5mm, and 30cm respectively. Anode electrode is made from Aluminum with 7cm diameter, whereas cathode electrode made from molybdenum metal with 7cm diameter. Electrode gap ranges between (2–5) cm. Pressure vacuum varies from 0.08 mbar to 0.2 mbar and DC power supply 4kV 750 W. The discharge was fed with Argon and Nitrogen at variable flow rates (100-600) sccm, and one can control the flow of gas by using a flow meter as shown in Fig.(1).

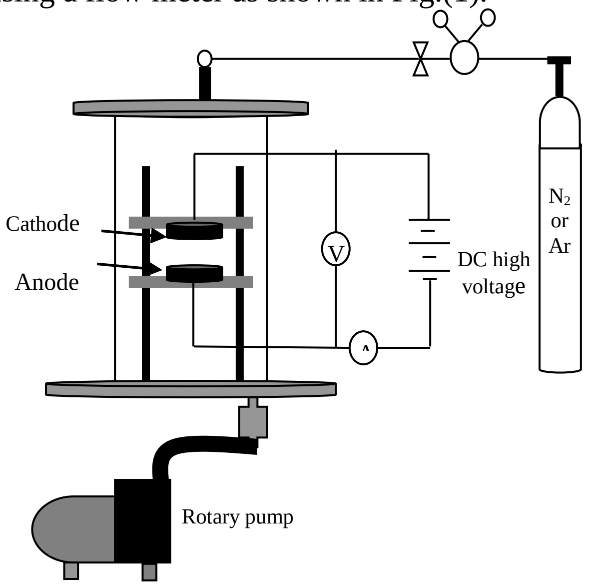

Fig. (1): Setup experiment.

Results and Discussions

Current-Voltage Characteristics

Figs.(2 and 3) represent a DC plasma glow discharge characteristics for Argon and Nitrogen gases. The variation of discharge current with the discharge voltage for electrode gap (d) 3 cm, 4 cm and 5 cm with five working pressures (0.08, 0.09, 0.1, 0.15 and 0.2 mbar) were examined.

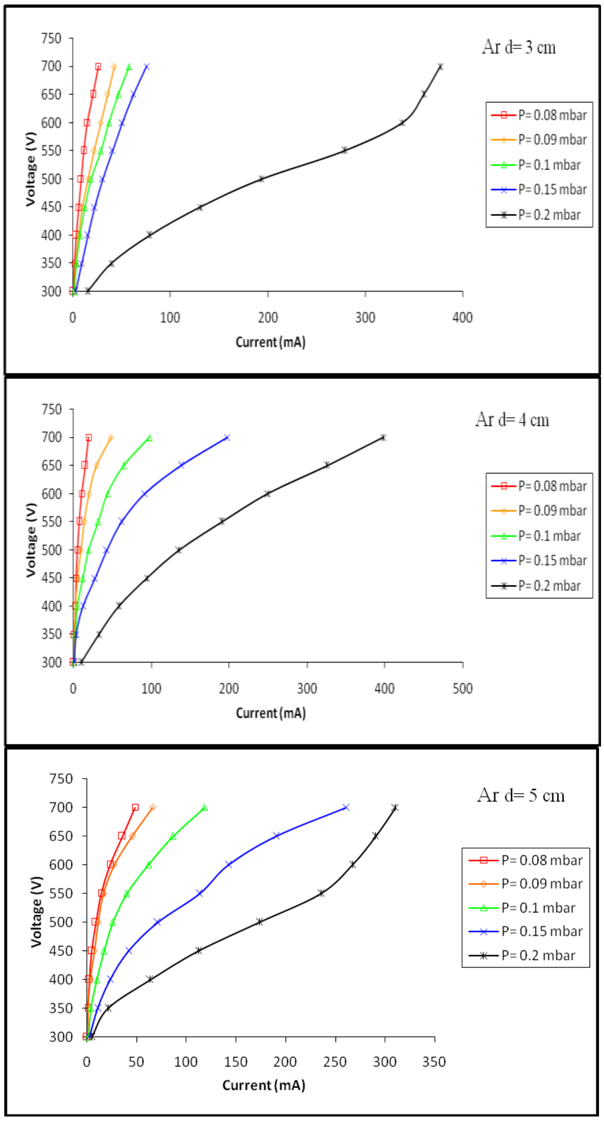

Fig. (2): The variation of discharge current with discharge voltage at different working pressures (chamber pressure) of Argon gas for different distance gaps.

An electric field accelerates the ions and electrons which then collide with atoms of working gas giving rise to discharge current and gas temperature. The discharge in our device is operated in the abnormal regime. In this mode all cathode surface is fully covered by the discharge and an increase of the current leads to an increase of the current density on the cathode surface, therefore, to an increase of the voltage.

The plasma behaves electrically rather similar to a resistor.

The discharge current was increased for Argon and Nitrogen plasma discharge with the increasing of the gas pressure.

Paschen's Law

Figs.(4 and 5) show the variation of the breakdown voltage as a function of pd parameter (the product of the gas pressure and distance gap). To the left-hand side of the curve, the breakdown voltage (V_b) decreases with increasing gas pressure and distance gap. These results can be explained by the decrease in the collision frequency. At low gas pressure, the electron mean free path is longer and collision probability was less than that at high gas pressure, so there were few collisions.

The discharge current is proportional to $V^{3/2}/d^2$ (electrode gap(d)), and from these figures, it can note that the 5cm electrode gap has higher discharge current and 3 cm has lower discharge current. We can note the discharge current for Argon gas greater than Nitrogen gas show these Figures.

To the right-hand side, the breakdown voltage increases slowly with the increase of gas pressure, i.e. the ionization cross-section increases, with the increase of pd. Therefore, electrons need more energy to ionize the neutral atoms.

Figs.(4 and 5) shows the minimum breakdown voltage $(V_b)_{min}$ and pd_{min} at different distance between the cathode and anode for Argon and Nitrogen gases. From these Figures, the Argon gas has $(V_b)_{min}$ value less than Nitrogen gas. This result depends on the collision cross-section of gas, which related to the secondary electron coefficient and electro negativity of Nitrogen gas. Also the minimum breakdown voltage $(V_b)_{min}$ and pd_{min} increases with increase distance gap.

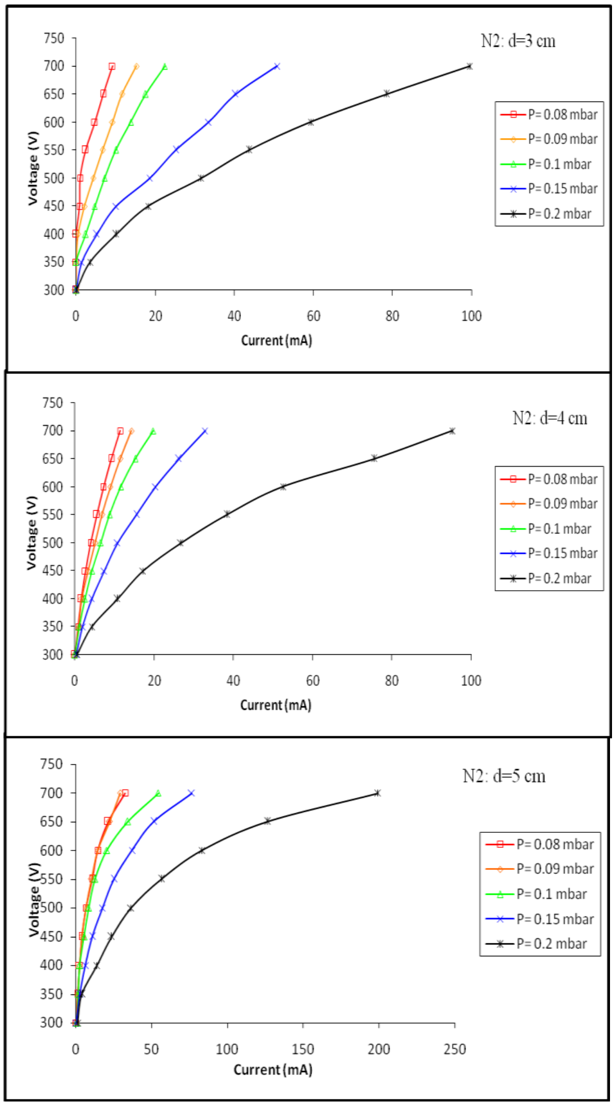

Fig. (3): The variation of discharge current with discharge voltage at different working pressures (chamber pressure) of Nitrogen gas for different distance gaps.

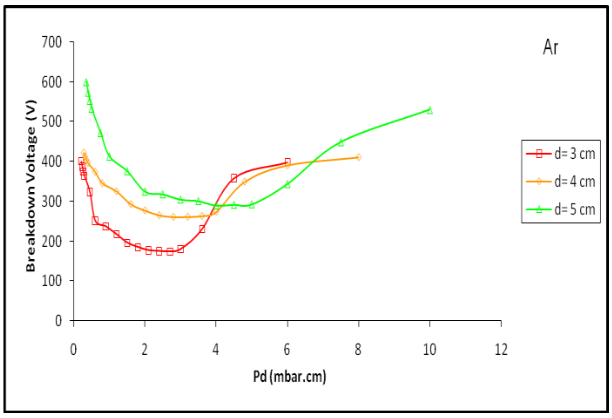

Fig. (4): Paschen's curves for DC breakdown in Argon, at gaps of: 3 cm, 4 cm, 5 cm.

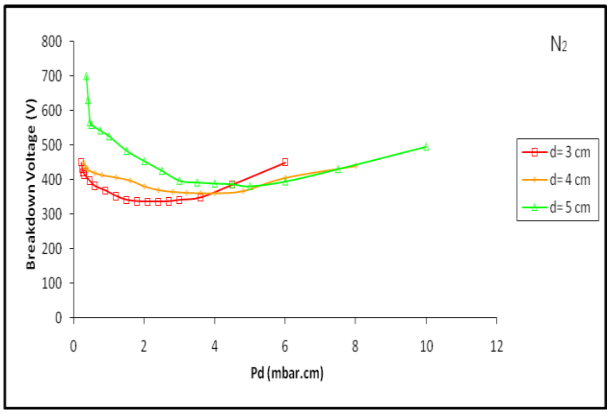

Fig. (5): Paschen's curves for DC breakdown in Nitrogen at gaps of: 3 cm, 4 cm, 5 cm.

Conclusions

The (I-V) characteristics curves of the glow discharge were studied at different gases. Also, the high discharge current occurs at minimum breakdown voltage $(V_b)_{min}$. The breakdown voltage depends on the electrode gap (d), gas pressure (P) and type of gas. Paschen's curves were determined at different electrode gap and pressures at different gases. At the same pd, the breakdown voltage $(V_b)_{min}$ was increased by increasing the electrode gap, and minimum breakdown voltage value for N_2 gas is larger than Argon gas.

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الخلاصة

في هذا البحث تم دراسة الانهيار الكهربائي لغاز الاركون وغاز النايتروجين في مجال كهربائي مستمر و لمسافات مختلفة بين الاقطاب. تتضمن منظومة التفريغ الكهربائي من قطب الكاثود والذي يصنع من مادة الالمنيوم بقطر ٧ سنتمتر وقطب الانود المصنوع من مادة المولبدنم بقطر ٧ سنتمتر. المسافة بين الاقطاب تتغير من ٢ الى ٥ سنتمتر والضغط يتغير من ٠.٠٨ الى ٠.٢ ملي بار اما مجهز القدرة المستمر المستخدم فتصل قدرته الى ٧٥٠ واط. ان جهد الانهيار يعتمد على ضغط الغاز P والمسافة بين الاقطاب d ولقيم واطئة لهما. هذا العمل يمثل بحث وتقصي على اعتمادية انهيار الجهد على ضغط الغاز والمسافة بين الاقطاب ونوع الغاز. القيمة الدنيا لجهد الانهيار تزداد مع زيادة المسافة بين الاقطاب d ولغاز الاركون تكون هذه القيمة اقل من غاز النايتروجين وتستخدم هذه القيمة في تحديد ضغط وتيار الترسيب بينما تيار التفريغ يزداد مع زيادة الضغط.