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Correlation of Paschen parameters in magnetized argon plasma

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Abstract

A number of glow discharge experiments has been carried out in a relatively large-volume metallic vacuum chamber containing argon at low pressure and immersed in an inhomogeneous magnetic field generated by a solenoidal coil capable of delivering 2100G. Two Paschen curves demonstrating the dependence of the discharge voltage on sparking parameter Pd and magnetic field strength B were deduced. A graphical correlation showing the behaviour of the voltage difference from the two curves on the ratio B/Pd was constructed. Investigations showed a reduction in the nominal impedance of the discharge device of nearly 20% when B reaches a value of 525G. Plasma confinement regions were found around the internal surface of the chamber at the entrance of the electrodes which may be attributed to pressure gradient by **J**x**B** effects as well as **E**x**B** drifts.

Keywords

Paschen curve
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ترابط أعلومات باشن في بلازما أركون ممغنطة

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الخلاصة

أجريت تجارب متعددة في بلازما أركون ممغنطة منتجة بالتوهج الكهربائي في حجرة فراغ معدنية ذات حجم كبير نسبياً وتحت ضغط واطىء . كانت الحجرة مغمورة في مجال مغناطيسي غير متجانس يولده ملف له القابلية على الوصول الى شدة مقدارها 2100 جاوس .بعد الحصول على منحنيين لفولتية التوهج وأعتمادها على المعامل (Pd) وشدة المجال المغناطيسي (B) , بنيه منحني أخر لتوضيح الترابط البياني بين معاملات باشن وهي الفرق بين قيم الفولتية في المنحنيين والنسبة (B/Pd) .

أوجدة التجارب كذلك نقصان قيم ممانعة التفريغ الكهربائي بمقدار 20% تقريباً بوصول قيمة B ألى 525 جاوس بالأضافة ألى أنحصار البلازما في مناطق دخول الأقطاب ألى الحجرة بسبب تأثير العامل **J x B** وقوى الأنجراف **E x B**

Introduction

When a potential difference is sufficiently applied across two electrodes in a chamber containing a gas at low pressure, a glow discharge is initiated and can be maintained under properly required conditions. It is, therefore, a stage characterized after a gas experiences an electrical breakdown when its atoms are ionized leading to the formation of glow discharge plasma [1-3].

Over a number of decades, glow discharges have been the subject of considerable researches and a wide area of applications in science, technology, and industry [4,5]. Experiments with complex(dusty) plasma devices carried out with glow discharge modes have also been of great interest since they establish a cornerstone for understanding the formation of strongly-coupled systems and dust-driven nonlinear phenomena[6-8]. Typical studies [9,10] under certain gas pressure and discharge-generating source showed that the current-voltage curves and other spectroscopic measurements may illustrate the main characteristics of the glow discharge plasma. Other experiments [11,12] involving the effects of the cathode parameters and geometry of the plasma containing vessel on electron temperature were carried out when the plasma forming gas was argon and spectroscopic measurements were used for plasma diagnostics. The sparking parameter, electron energy, and ionization processes were included in other experimental and theoretical analysis for certain applications. These studies emphasize on specific engineering applications including high current switches for pulse power technology[14], shock wave propagation in diffuse plasma[15], radiation emission sources and discharge lamps[16-18], modeling and glow discharge processing in magnetron discharge for semiconductor deposition and surface modification[19], pseudo discharges and nitrogen plasma parameters [20], construction of high efficiency ion source[21], and chaotic current oscillations for studying active media of gas lasers[22].

The effect of an externally-applied magnetic field on the breakdown conditions and glow plasma parameters in various gases has also been studied. The effect of magnetic field strength on both electron density and temperature was studied in air, hydrogen, and argon in a small discharge tube [23]. Results showed that the electron temperature decreases and the radial electron density increases for longitudinal magnetic field exceeding 1000G in argon while this density diminished and the electron temperature increased with transverse magnetic field of strength reaching 150G in air and less in hydrogen and argon. In another study [24], the Paschen minimum voltage was found to be reduced from 315V to about 310V in argon glow discharge as an applied longitudinal magnetic field strength was changed from zero to 350G over a pressure range (0.08-0.04) torr when the electrode spacing was taken from 4cm to 8cm in a glass tube of 30cm in length and 13cm in diameter.. The effect of the magnetic field was also investigated in a “macro” hollow cathode discharge in argon [25]. Current-voltage curves were deduced at pressure of (1-10)mb under a magnetic field strength of 1T. Although the discharge current was relatively low (few milliamperes), the hollow cathode fall was found to decrease with increasing this current.

Limited experimental studies have been found concerning glow discharge of argon contained in a large-volume metallic vacuum chamber immersed in a magnetic field. The present study describes experiments carried out in a large volume vacuum stainless steal chamber of circular cross section similar to those used in magnetically-confined plasma experiments [26]. The glow discharge was ignited in argon at low pressure and the effect of an externally-applied magnetic field on the current-voltage characteristic curves was thoroughly investigated when the geometry of the electric field was modified and discharge currents, higher than those discussed above, were recorded corresponding to the applied discharge voltages.

Experimental set-up and technique

A slightly-tapered stainless steel vacuum chamber of a nominal volume of about 0.5m^3 was used to contain the plasma forming argon. Six openings were machined around its circumference so that two of them were fitted to the ducts of the vacuum system and the other four were closed by flanges designed to allow the electrode insertion, viewing, gas feeding, and electrical connections. Such design allowed inserting three electrodes through the centers of three flanges in such a way that the angle subtended between each two electrodes is 120^0. These electrodes, each of 1.0m in length and 2cm in diameter, were made of stainless steel and they were water-cooled to avoid any possible heating effect resulting from the discharge current. A central column which had been machined as a part of the chamber structure was taken as a reference surface to define a relevant distance between the electrodes tip and the internal surface of the chamber which was electrically at earth potential. All the three electrodes were threaded into the flanges through Teflon insulating bushings with O-ring arrangement to maintain electrical insulation and they could be moved to and away from the central column of the chamber. A sectional schematic diagram of the experimental setup including the electrode-chamber assembly is shown in Fig. (1). The vacuum system consisted of a double stage rotary pump and a turbomolecular pump to evacuate the chamber down to an ultimate pressure of about 10^{-5}mb before argon feeding.

A DC-stabilized voltage was applied the assembly supplied by a 1kV, 25A power supply so that the three electrodes were at positive potential and the chamber was at earth potential.. The experimental values of the discharge current I_d and the discharge voltage V_d were recorded by digital multimeters while a current-limiting resistance was connected in series with the power supply to avoid any short circuit current effect across the power supply. The magnetic field in which the vacuum chamber was immersed was generated by a water-cooled coil capable of delivering a field strength exceeding 0.2T set in the region of the electrode tips. The magnetic field strength B was varied by adjusting the electrical current flowing through the coil.

The experimental run starts when the chamber was evacuated down to the ultimate pressure and then feeding the argon into the chamber, allowing the pressure to reach 100mb before pumping the gas out to reach the desired operating pressure. This process of chamber flushing was repeated three times prior to each experiment to pump out the background air and to ensure that the plasma forming gas was pure argon. Once the desired pressure was reached, the applied voltage was gradually increased until the glow discharge appeared. With each discharge voltage, the corresponding current was recorded. For a certain value of B, a range of discharge voltage values and their corresponding current values were recorded.

Results and discussion

Before obtaining the required current-voltage characteristic curves for the present glow discharge device, it necessitated to plot its Paschen curve which demonstrates the dependence of the glow voltage V_g on the product of gas pressure P and the electrode spacing d, i.e., the product (pd). Such V_g-Pd curve of the device is significant to evaluate the Paschen minimum voltage, the sparking parameter, and the range of Pd-values over which the device can be operated prior to or after the Paschen minimum. A typical curve of this type is shown in Fig.(2) over a range of pressure to maintain a number of Pd-values at d = 20cm for the three electrodes. With such behaviour, the device can be operated over a broad range of sparking parameter starting from a value of Pd = 2.4mb.mm when the Paschen minimum voltage is about 320V under the effect of a eminence magnetic field of 10G. In conventional glow discharge tubes, the difference between the sparking potential and the glow maintenance potential progressively diminishes as the values of Pd falls down. Such change in the voltage difference leads to a corresponding change in the discharge current which then results in a variation in the individual glow regions between the electrodes including the plasma of the positive column. In the present electrode configuration and dimensions, the glow regions are complicated to be defined as the external magnetic field strength B increases. To investigate such effects, a plot of the glow voltage as a function of B was deduced at a typical Pd = 0.25mb.mm as illustrated in Fig (3). Over a range of B upto 525G, the value of V_g was found to decrease with increasing B until a minimum value of 330V at B =81G and then starts to increase gradually. This behaviour is a trend of Paschen curve showing the effect of B on the electron collisional ionization similar to that experienced by increasing the argon pressure P. From Figs (2) and (3), the values of the voltage corresponding to the Pd-values (denoted by V_P) and those corresponding to the B-values (denoted by V_B) were extracted. Fig(4) shows a graphical correlation between the values of the voltage difference (V_P-V_B) and their corresponding values of reduced magnetic field strength or the ratio (B/Pd). In the region of $V_P>V_B$, the voltage difference tends to decrease until a point occurring at (B/Pd) = 72 G/mb.mm where V_P is almost equal to V_B and afterwards the difference will be negative due to the higher values of V_B. This may be attributed to a possible switching of the operational mode of the glow from normal to abnormal glow prior to the fall of the ratio (B/Pd) below the above-mentioned value. Graphical correlation diagram of this type is significant to study the transport parameters of gas discharges with or without the existence of an external magnetic field [27]. Geometry effect may be considerably effective since the cathode surface in the present experiments is relatively large and cathode dark space and other regions are arranged differently [11].

The experimental device allows that the direction of B is along the chamber axis and it is perpendicular to the electric field E in a limited region within the spacing d. Over the region inside the chamber where the three electrodes were extended, E and B are both along the chamber axis. It is worth-mentioning that the cathode surface was not clean and impurities including water vapour were adsorbed onto its whole surface resulting in some observations of localized intense pencil-like beams which leads to a change in the discharge current. Within the electrode spacing, ExB difts may have different directions which might result in displacement of charged particles in these directions along with pressure gradient caused by JxB. The change in current values is an indication on the change in the discharge impedance Z (nominally the ratio of V_g and the discharge current). The value of Z was found to decrease slowly with increasing B at a sparking parameter Pd = 0.25 mb.mm as demonstrated in Fig (5). By increasing B over a range from 10G to 525G, the value of Z was found to be reduced by nearly 20%. Such observation can be explained in terms of the increase in the longitudinal component of electron velocity by the acceleration caused by the E-field. This will give rise to an increase in the discharge current despite the reduction in the electron drift velocity by E x B forces. Such behaviour of Z is different from that observed in relativistic non-neutral plasma and the existence of magnetically-confined electron beams generated by pulsed discharges [28].

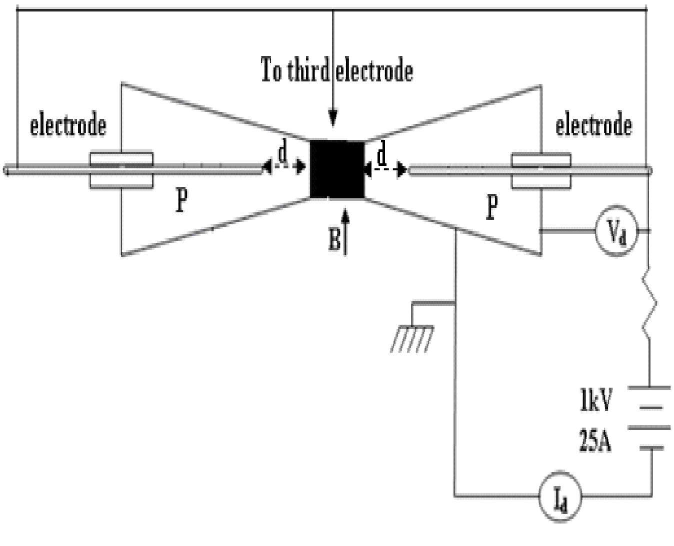

Fig (1): A cross-sectional diagram of the experimental device.

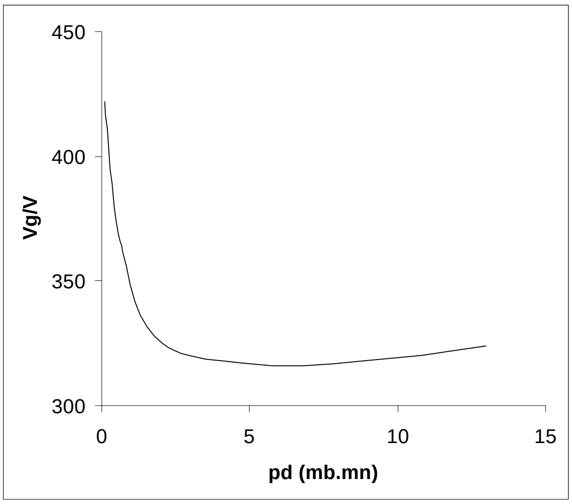

Fig (2): A typical Paschen curve of the experimental set-up at a reminance magnetic field strength of 10G.

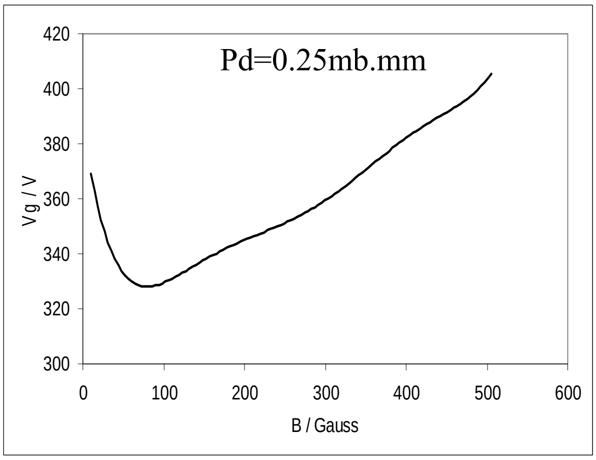

Fig (3): The bahaviour of the discharge voltage with magnetic field Strength at a typical of Pd = 0.25mb.mm.

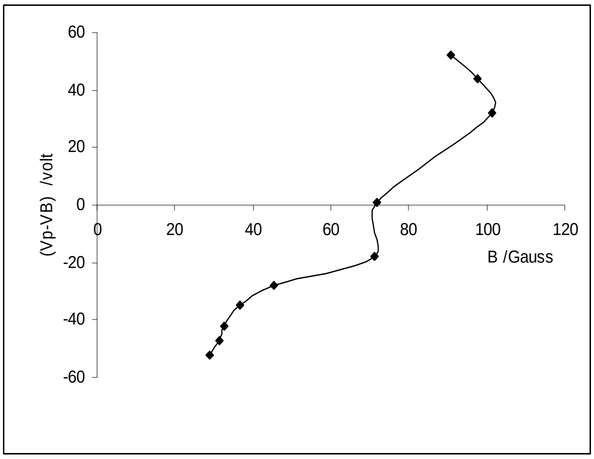

Fig (4): A graphical relationship of the glow ignition voltage difference and the reduced magnetic field strength.

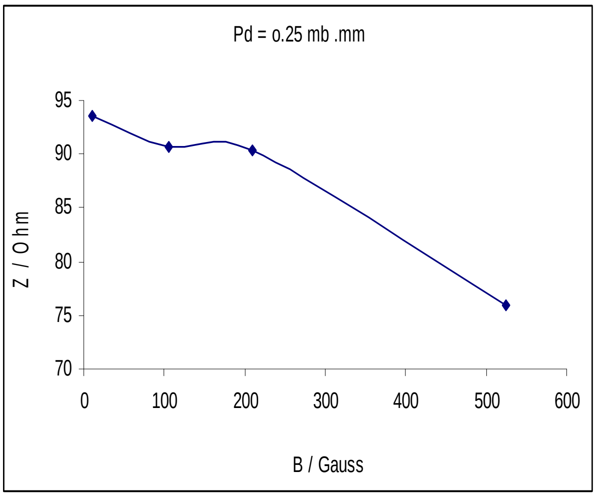

Fig (5): Impedance dependence on the externally applied magnetic field strength at a typical sparking parameter of 0.25mb.mm.

Conclusion

Two Paschen curves of a large-volume magnetized glow discharge plasma of argon have been experimentally deduced to consuct a graphical correlation of the discharge voltage and (the magnetic field strength/sparking parameter) ratio. Results involving these parameter sand the impedance of this magnetized plasma device have been found sensitive to the dimension and geometry of the plasma-containing device over a range of an inhomogeneous magnetic field of upto 525G. The discharge impedance was found to decrease as the magnetic field was increased in this range.

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