------ Raf. Jour. Sci., Vol. 18, No.2, pp.91-97, 2007 ------

The Effect of Transverse Magnetic Fields on Plasma Parameters in Rectangular Discharge Tube

Qais T. Algwari
Department of Electronics
College of Electronics Engineering
Mosul University

ABSTRACT

The effect of transverse magnetic field on the sparking potential, I-V characteristics and electric field in rectangular discharge tube was measured. The experiments were conducted for the N_2 gas pressure from (0.75 to 7.5 torr) and the applied transverse magnetic field up to (150 Gauss). The results show that the magnetic field effect on sparking potential and I-V characteristics as increasing the equivalent pressure. Also it is found that axial electric field increase as the applied magnetic field increase.

تاثير المجالات المغناطيسية المستعرضة على متغيرات البلازما في أنبوب التفريغ المستطيل

الملخص

تم قياس تاثير المجال المغناطيسي المستعرض على جهد الانهيار وخـواص الفولتيـة – التيـار والمجال الكهربـائـي فـي أنبـوب الـتفريغ المستطيل. أجـريـت التجـارب فـي مـدى الضغـوط لغـاز N_2 مـن (0.75 الى 7.5 torr) ولقيم المجال المغناطيسي المسلط الى حد (Gauss 150). أظهرت النتائج ان تاثير المجال المغناطيسي على جهد الانهيار و خواص الفولتية – التيـار كـان كزيادة في الضغط المكافئ. كذلك وجد ان المجال الكهربائي المحوري يزداد مع زيادة المجال المغناطيسي المسلط.

INTRODUCTION

The production of plasma in rectangular tubes has been carried out and reported by various authors (Chang et al., 1979; Kaneda et al., 1984; Kaneda, 1990; Saffaa Aldeen, 2005). They were concerned mainly with the study of the characteristics of the positive column. The researches in rectangular discharge tubes have acquired a great importance as a result of developments in gaseous lasers (Abrams 1974).

When a magnetic field act upon a glow discharge, various changes such as increase of equivalent pressure take place. If a D.C. transverse magnetic field is applied to the positive column, the electron density distribution is deflected to the wall by the influence of the magnetic field (Kaneda, 1978). The aim of the present work is to study the effect of a D.C. transverse magnetic field on the sparking potential, I-V characteristic curve and electric field gradient in rectangular discharge tube.

Theoretical Analysis

When a steady uniform positive column is acted upon by transverse magnetic field, the charged particles drift a cross the magnetic lines of force in cycloidal motion between collisions. This will increase the flow of electrons to the wall. Thus in a positive column with a transverse magnetic field, the energy gain of electrons from the axial electric field must balance with the wall loss in addition to the collision loss with neutral gas atoms. The wall loss per unit length of a positive column per second can be expressed as the product of the mean electron energy attaining to the wall and the number of electrons to the unit length of the wall per second. As a result the energy balance equation is modified by take into account the wall loss as follows (Kaneda, 1978):

$$N v_d e E_z = N \overline{f_e}\left(3kT_e/2 - 3kT_g/2\right)C_e/\lambda_e + \phi\bar{\varepsilon} \qquad \ldots(1)$$

where N is the number of electron in a unit length of positive column, ϕ is the number of electrons flowing to the unit length of the wall per second, E_z is the axial electrical field, T_e is the electron temperature, T_g is the gas temperature, $\overline{f_e}$ is the collision loss factor, $\bar{\varepsilon}$ is the mean energy of electrons flowing to the wall, v_d is the axial drift velocity of electron, C_e is the thermal velocity of electron, given by: $C_e=(8kT_e/m_e\pi)^{1/2}$, where m_e is the mass of electron, λ_e is the mean free path of electron at gas pressure p, given by $\lambda_e=l_e/p$ in terms of the mean free path l_e in a unit gas pressure, e charge of electron and k is Boltzmann's constant.

The axial drift velocity of electrons is reduced by the influence of the cycloidal motion of electron in a transverse magnetic field. This has been analyzed by Beckman (1948) (Kaneda 1978) as follows:

$$v_d = \mu_e\left(\alpha + \beta^2/\alpha\right)E_z \qquad \cdots(2)$$

where μ_e is mobility of electron in zero magnetic field and is given by $\mu_e=3e\lambda_e/4m_eC_e$, α and β dimension less quantities, as follows (Sen and Gupta, 1971):

$$\alpha = 1 - h^2 + h^4 \exp\left(h^2\right)\int_h^\infty \exp(-h)\,dh \qquad \cdots(3)$$

$$\beta = \frac{1}{2}\left[1 - 2h^2 + 4h^3 \exp\left(h^2\right)\int_h^\infty \exp\left(-h^2\right)dh\right] \qquad \cdots(4)$$

$$h = e\lambda_e\left[B/m_e\right]\left(2kT_e/m_e\right)^{1/2} \qquad \cdots(5)$$

Where (B) is the magnetic field. The flow of electrons, to the wall, per unit length per second must balance with the production of electron per second in the unit length of the positive column.

Experimental Procedure

The rectangular discharge tube used for the measurement was schematically in Fig (1).

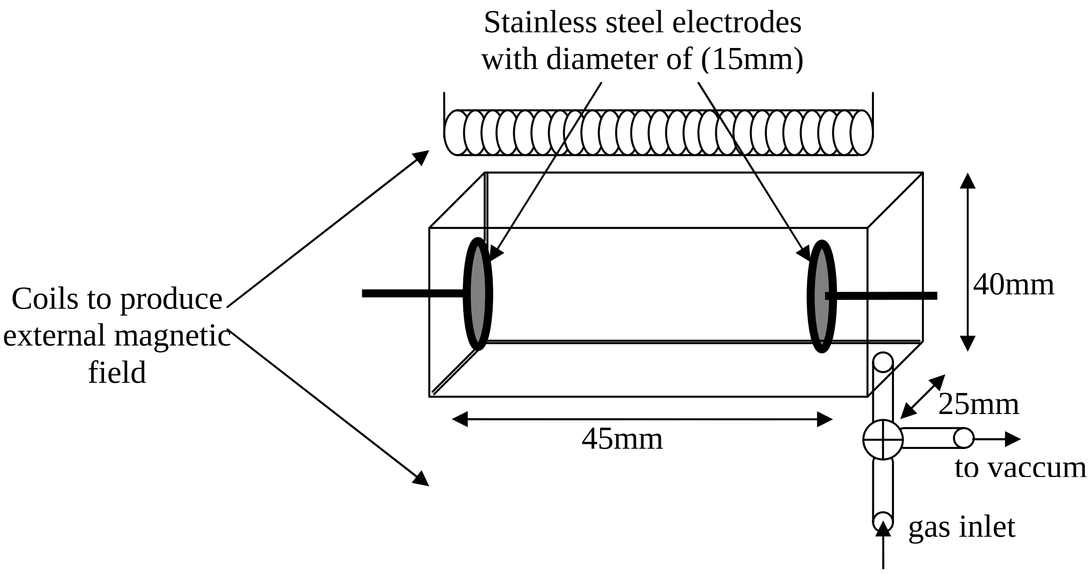

Fig. 1: The schematic diagram of the discharge tube.

The tube is made of Pyrex glass. The tube has two circular stainless steel electrodes of diameter (15 mm) and rectangular plasma length of (45 mm). The rectangular profile of the positive column is (40×25 mm). The magnetic field was provided by a coil of copper with (200 turns) and extreme care was taken to ensure that the lines of the force were perpendicular to the axis of the discharge tube. The magnetic field, various from (0 to 150) Gauss, controlled by the amount of current pass through the coil. The magnetic field was applied to the positive column perpendicularly to the tube axis in length of (40 mm). The discharge tube was evacuated to (1 mtorr) by rotary pump. The gases in the wall and electrodes were removed usual baking processes. The using gas in measurements is N_2 with 99.95% purity.

Experimental Results

As the electric field between two electrodes increases, the current increase and at some point there is a sudden transition from Tounsend, or 'dark', discharge to one of the several forms of self-sustaining discharge. This transition, or spark, implies of sudden change in the applied voltage of the gap. In this work, the sparking potential was measured as the maximum critical voltage can be applied to the gap before the sudden increase in the current of the gap. Fig (2) shows the sparking potential of N_2 as a function of (*pd*), where (*p*) is the pressure and (*d*) is the distance between the electrodes, for various values of magnetic field (*B*).

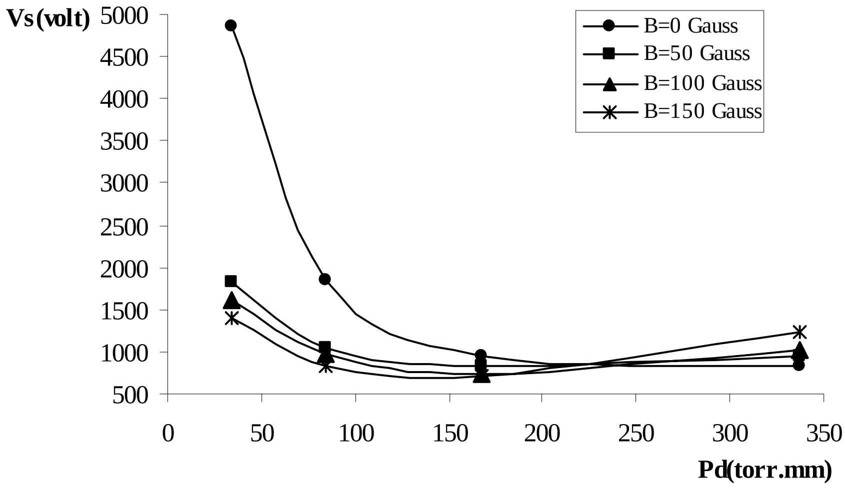

Fig. 2: Paschen curve for N2 for different values of transverse magnetic field.

Fig (2) shows that the sparking potential increase as the (*pd*) decrease at particular value of applied magnetic field. This result shows the left side of Paschen curve. Also it has been shown that as the applied magnetic field increase the sparking potential decrease at same value of (*pd*).

The behavior of electrical discharge in rectangular tube across external magnetic field was investigated by a series of (I-V) measurements. Figs (3, 4, 5 and 6) show the (I-V) characteristics curves for the gas pressures (0.75 torr, 1.875 torr, 3.75 torr and 7.5 torr) respectively for different values of applied transverse magnetic fields.

These figures show two different regions of self-sustained discharge. The left one, where the voltage decrease sharply with increasing the discharge current, which is the subnormal glow. The right region where the voltage is constant with increasing the discharge current, which is the normal glow.

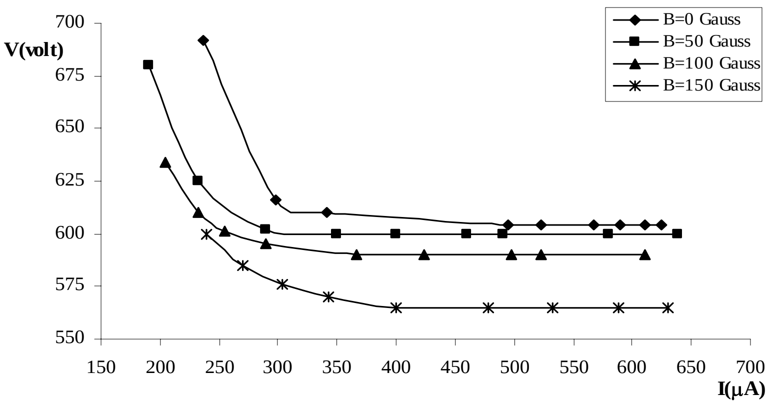

Fig 3: I-V characteristic for N_2 at ***P=0.75 torr*** for different values of transverse magnetic field

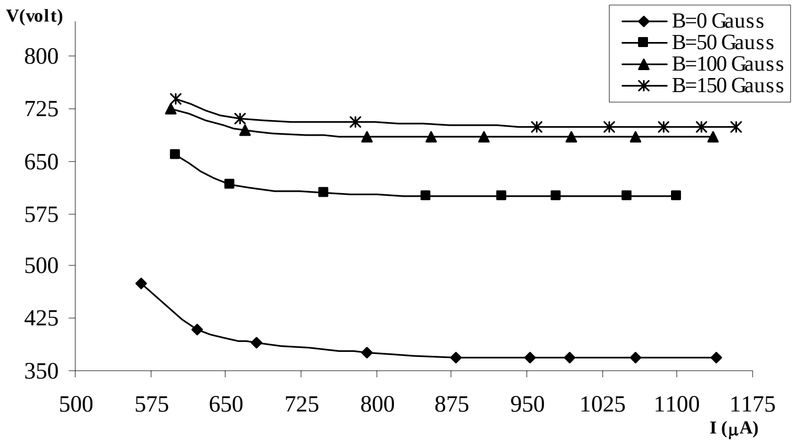

Fig 4: I-V characteristic for N_2 at ***P=1.875 torr*** for different values of transverse magnetic field.

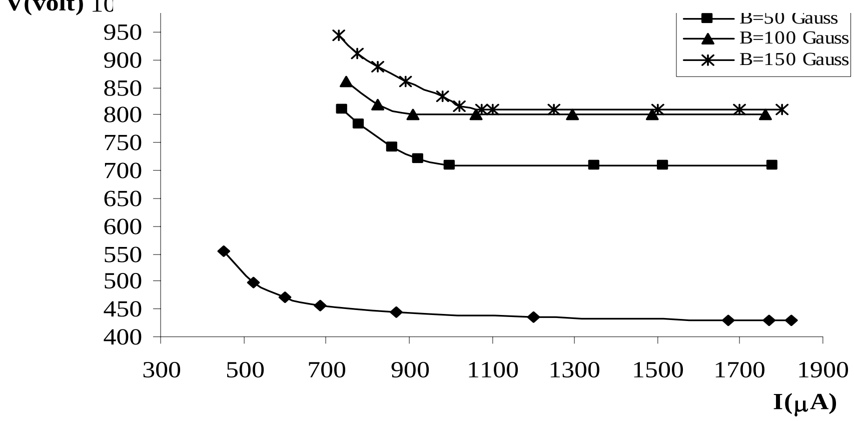

Fig 5: I-V characteristic for N_2 at ***P=3.75 torr*** for different values of transverse magnetic field.

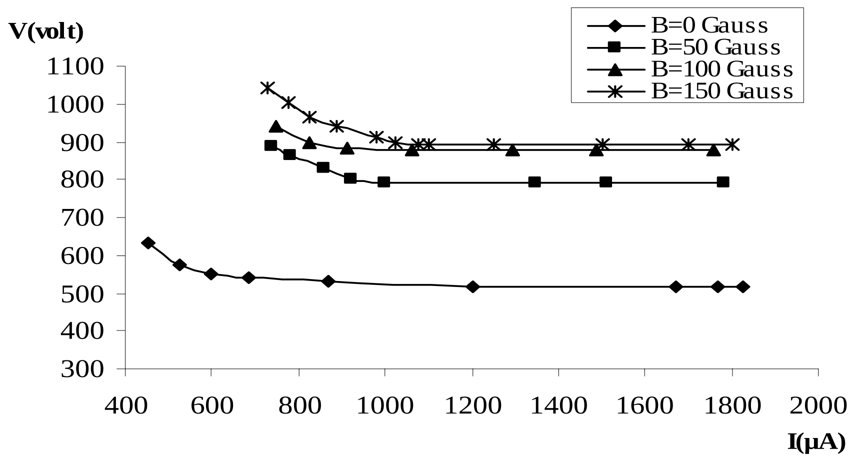

Fig 6: I-V characteristic for N_2 at ***P=7.5 torr*** for different values of transverse magnetic field.

The ratio of axial electric field (*E*) to gas pressure (*P*) at discharge current (1.2 mA) was plotted for various transverse magnetic field as a function of (*P*) as shown in Fig (7). It evident that the ratio of the axial electric field to the gas pressure is increased as the transverse magnetic field does, and that its effect is also remarked at lower gas pressure.

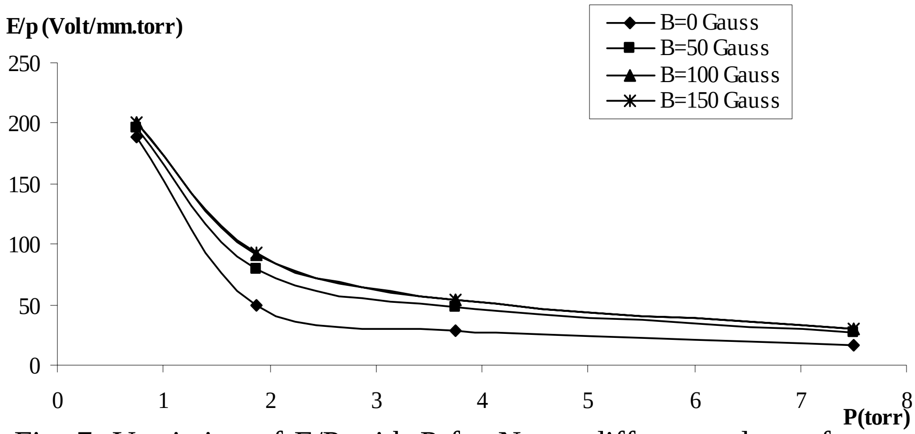

Fig. 7: V ariation of E/P with P for N_2 at different values of transverse magnetic field.

Discussion and Conclusions

As it is known that the total number of atoms in gas effect on the sparking potential, because it is limited the mean free path of electrons. Since the excitation of atoms takes place as a result of collision between electrons having higher energy than the excited level and these atoms, therefore the excitation processes will proportional to the electron density. As a result of that the gas pressure affect on the sparking potential as well as the (I-V) characteristics curve.

The Paschen curves show that at low values of (*pd*), as (*B*) is increased from zero, the sparking potential firstly decrease, reaching a minimum values. The interpretation of this effect is due to the behavior of number of electron liberate in the gas. The values of secondary ionization coefficient in crossed magnetic field decreases, at low pressure, considerably with increasing (*B*).

Having a look to (I-V) characteristics curves show the results concerning that as the pressure increases the characteristic curves will shift downward, reaching a minimum value and starts again to increase upward. This change in gas discharge characteristic can be attributed to the transition from the left side of Paschen minimum to the right. The effect of transverse magnetic on the (I-V) characteristic is same as the effect of pressure, because as the applied transverse magnetic field increase the equivalent pressure of the gas will increase.

As we have seen that the ratios of axial electric field to gas pressure increase as the transverse magnetic field increase. This is can be attribute to that the axial electric field of a positive column is derived from the power balance equation that the energy gain of electrons from the field balances with the energy losses by the diffusion of electron to the wall and by the collision of electrons with neutral gas atoms (Von Engel, 1955). The collision losses also increase with the rise of the transverse magnetic field. These increases of the wall loss, the electron temperature and the collision loss cause the axial electric field to rise in the power balance equation in the positive column. Moreover, the cycloidal motion of electrons in a magnetic field decreases the axial mobility of the electron in a positive column, see equation (2). This effect also acts as a factor to increase the axial electric field.

REFERENCES

Abrams, R. L., 1974, "Gigahertz tunable wave guide CO_2 laser", Appl. Phys. Lett., vol.25, pp.304-306.

Chang, J.S., Ichikawa, Y. and Teii, S., 1979, "The effect of discharge tube shape and flow velocity on the electron temperature of a medium pressure positive column", Jap. J. Appl. Phys., vol.18, pp.847-848.

Kaneda, T., Imamoto, N., Kubota, T. and Chang, J.S., 1984, "The electron temperature in a medium pressure rectangular tube positive column plasma", Bull. Am. Phys. Soc., vol.29, 143 p..

Kaneda, T., 1978, "The axial electric field of a positive column in a transverse magnetic field", J. Phys. D: Appl. Phys.,vol.11, pp. 279-282

Kaneda, T., 1978, "The influence of transverse magnetic field on a glow discharge tube", J. Light and Vis. Env., vol.2, pp.45-50.

Kaneda, T., 1990, "The radiation intensity distribution of rectangular positive column plasma by the AC transverse magnetic field", J. Light and Vis. Env., vol.14, pp.8-14.

Saffaa Aldeen A., 2005, "Discharge characteristics for molecular gases in rectangular tube", College of Basic Education Researchers Journal, vol.2, pp.2-10.

Sen, S. N. and Gupta, R. N.:" Variation of discharge current in a transverse magnetic field in a glow discharge", J. Phys. D: Appl. Phys., 4 (1971) pp.510-517

Von Engle, A., 1955, "Ionized gases", 1st edition, Oxford at the Clarendon press.