Studies The Effect Of Magnetic Field On Argon Plasma Characteristics

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Abstract: In this paper, we represent a study of some physical characteristics of argon plasma, product by Hollow Cathode Discharge with and without magnetic field achieved in the negative glow region of hollow cathode discharge. The electron temperature and ion density calculated from *I-V* curves of double probe at gas pressure range of 0.4-1.0 *mbar*, discharge current constant at 15 *mA* and the magnetic field changed from 7 to 47 *mTesla*. Results of electron temperature and ion density indicate that, the behavior of electron temperature and ion density are the same, decreases with increases the gas pressure with and without magnetic field, but values of electron temperature are smaller in case of applied magnetic field than without magnetic field. Also, values of ion density without applied magnetic field are higher than the ion density with magnetic field.

Key words: Hollow Cathode Discharge (HCD), *I-V* characteristics, Breakdown Voltage Langmuir Probes, Electron Temperature, Ion Density and Magnetic Field.

INTRODUCTION

Hollow cathode discharges (HCD) are split in two big groups; conventional hollow cathode (CHC) and modified hollow cathode (MHC). Paschen developed the conventional hollow cathode discharge device in 1916. The HCD characterized, in their conventional form, by cathode surfaces (planar, cylindrical, spherical or other geometry) which contain the negative glow while the anode placed outside the discharge cavity. The modified hollow cathode discharge (MHCD) has the anode inside the cavity of cathode. The theory of hollow cathode discharge stays on the primary stage as far (Petere *et al*. 2004). Due to the high current density and non-Maxwellian energy distribution of electrons, hollow cathode discharge (HCD) has made for a wide variety of applications (Gorin. 2008 and Becker *et al*. 2006). It can operate at low or high pressure up to atmospheric pressure, the latter called micro hollow cathode discharge, which has attracted much interest in recent years. In a conventional HCD, the discharge develops in different modes depending on the discharge current, each with a distinct voltage-current (*V−I*) characteristic (Shang *et al*. 2010). Hollow cathode discharges, HCD, are capable of generating dense plasmas, high-density plasmas typical of HCD based on efficient avalanche multiplication of electrons known as a hollow cathode effect, HCE. It is effect of the strong ionization produced by fast electrons in the cathode region of a glow discharge. These fast electrons have been accelerate in the cathode sheaths, and then electro-statically were confining to oscillate between cathode surfaces. This is the so-called pendulum effect responsible for the HCE. Due to a HCE, a large increases in current density with reduced separation of the two cathodes. In direct current, this effect connected with oscillations of electrons between equivalent repelling potentials of sheaths at opposite inner walls in the cathode and consequent effects. At the same power, HCD exhibits plasma density one to two orders of magnitude higher than that of conventional planar electrodes and the ionization of gas, ion bombardment of inner walls with the secondary emission and thermo emission of electrons (Zhechev *et al*. 2003). Hollow cathode discharges have two important processes, i.e. sputtering and excitation/ionization of the sputtered atoms. The HCD plasma properties enhanced by various geometrics, magnetic field and discharge-operating mode modifications. It knows that by controlling the magnetic field geometry close to the discharge, the electrical characteristics (discharge current versus discharge voltage) modified, for more efficient processing. This feature is particularly useful to increase the discharge current at low running pressures and hence increase the sputter and deposition rates. A study of the HCD plasma system was important for known of its applicability for material processing, thin films fabricate. Where many techniques, such as sputtering, chemical vapor deposition, laser chemical vapor deposition and pulsed laser ablation, used to fabricate thin films on various substrates. In most methods, the deposition temperatures are quite high. High temperature deposition has the disadvantage of degradation of the substrate and thin film during deposition due to thermal damages. However, the hollow cathode is a much simpler, cheaper system, and may have some advantages for the generation of a high-density plasma and efficient cathode sputtering. Hence, deposition of thin films at low temperatures has become increasingly important and valuable (Chenga *et al*. 2003). Hollow cathode discharges (HCD) studied extensively for many years due to their wide range of applicability in different fields: atomic spectrometry, vacuum microelectronics, UV generators, plasma processing as etching, thin film deposition, surface treatments, etc. To understand better the effect of the various physical processes occurring in the hollow cathode plasma, knowledge of plasma characteristics and their

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dependence on different external parameters is required. The Hollow cathode discharge (HCD) can be producing by using direct current (*DC*) or Radio frequency (*RF*). The regions of HCD are different from the regions of normal glow discharge (*GD*) produced by two parallel plates. HCD has two basic regions only, positive column (*PC*) and the negative glow (*NG*) region (Nikulin. 1997). At used *DC* current to obtain hollow cathode discharge effect (HCDE) the distance between the walls of cathode electrodes must be equal to some millimeters and the pressure in the range from 0.13 to 13.3 *mbar*. The HCDE is that increase of the electron density between the walls of cathode (Bardos *et al*. 2003). The condition of HCE at used *DC* current for cylindrical cathode is that, product of pressure (*p*) and the inner diameter of cathode (*a*), (*p $_x$ a*), must be to realize the next relation (Rohrabach *et al*. 2000):

$$0.75 \; torr \, cm(0.987 \; mbar.cm). \leq p_x \, a \; \leq 37.6 \; torr \, cm \; (49.47 \; mbar.cm) \qquad (1)$$

The purpose of the present work is to investigate experimentally the main features of *DC* hollow cathode discharge in the negative region, with and without effect of magnetic field, in order to evaluate its characteristics at used argon gas discharge in a cylindrical cavity. The characteristics studies are the breakdown voltage, V_B, and the discharge current-voltage characteristics (*I−V*)**,** will be measure at different gas pressure, *p*, without magnetic field. However, the electron temperature, T_e, and ion density, N_i, calculated from *I-V* characteristics of double probes with and without magnetic field. The double probe used of measuring the electron temperature and ion density since it was the most reasonable method for measurements in a magnetic field, the measurements achieved at different values of the gas pressure, and at constant discharge current. The data obtained from electrical double probes characteristics on *dc* HCD with argon gas presented and discussed.

Experimental setup:
   A schematic of the HCD device used in this investigation shows in Fig (1). High purity Argon gas used in discharges. The discharge was operated in *DC* mode, and digital multi-meters was used for measured the discharge current and the voltage. The discharge resembles a glow discharge regime extending from the hollow cathode up to the flat anode. The hollow cathode and anode is made of Brass, the distance between them changed, 2.0, 3.0 and 5 *cm*. The internal diameter of the cathode was 2.5 *cm*. and outer diameter was 4.2 *cm*, the anode was a disk plate with diameter 4.2 *cm* and 1.0 *cm* thickness. The dimensions of vacuum glass chamber were 4.2 *cm* inner diameter 5.0 *cm* outer diameter and 20.0 *cm* length. The measurement of plasma properties performed by used the configuration of cylindrical double probe. Since the application of a single probe for measurements in a magnetic field causes serious complications during interpretation of the results obtained and the double probes can be used in rather strong magnetic fields, which is due to the fact that ion saturation current plays a decisive role for such a probe. The probes inserted to the discharge tube at an angle such that the probe tip is perpendicular to discharge axis, at a distance of 0.2 *cm* from the cathode aperture. The diameter and the length of the probes chosen such that it draws a measurable current from the plasma causing a minimal perturbation to the surrounding plasma, the probes length determined by the condition that cylindrical probe theories were applicable while calculating the electron temperature and ion density from the probe *I-V* curve data. Probes essentially consist of two-tungsten wire of 0.3 *cm* in length and 0.04 *cm* in diameter, the distance between them was 0.3 *cm*, which satisfies a scale length larger than the Debye length and smaller than the plasma diameter. The glass chamber was preliminary evacuated using a combination of rotary pump (Edward-E2M2) and diffusion pump (Edward-Diffstak-M-65) to achieve a residual pressure of 10^{-6} *mbar*. The gas flows controlled with flow meter as a gas flow rate was constant and the gas pressure was monitored by two gauge (Edward, models Pirany-M501and Penning PRE-10K) with control unit. The pressure in the glass tube changed from 0.4 to 1.0 *mbar*. Electro magnet (model 8598/8) consists of two coils from cupper, number of turns are 820 turn, the inner diameter is 5 *cm* and 12 *cm* is outer diameter, the distance between the poles of the magnet can be are changed, but in this work fixed at 5 *cm* equal to the outer diameter of glass discharge tube. The magnetic flux density at center of magnet poles was measured, used of a Tesla-meter (Laybold.-Model VDE 0789T100) and Hall probe (Laybold-Model-516-60), as a function of the total current in two coils changed up to 1.5 *A*.
   The electro-magnet used to produce a low intensity and uniform magnetic field along the axis of the discharge, with strength within the range of $(7-47)10^{-3}$ *T*. The confining magnetic field perpendicular to regions of plasma discharges enhances the pendulum motion of hot electrons between the cathodes wall thus facilitating the hollow cathode effect (HCE).
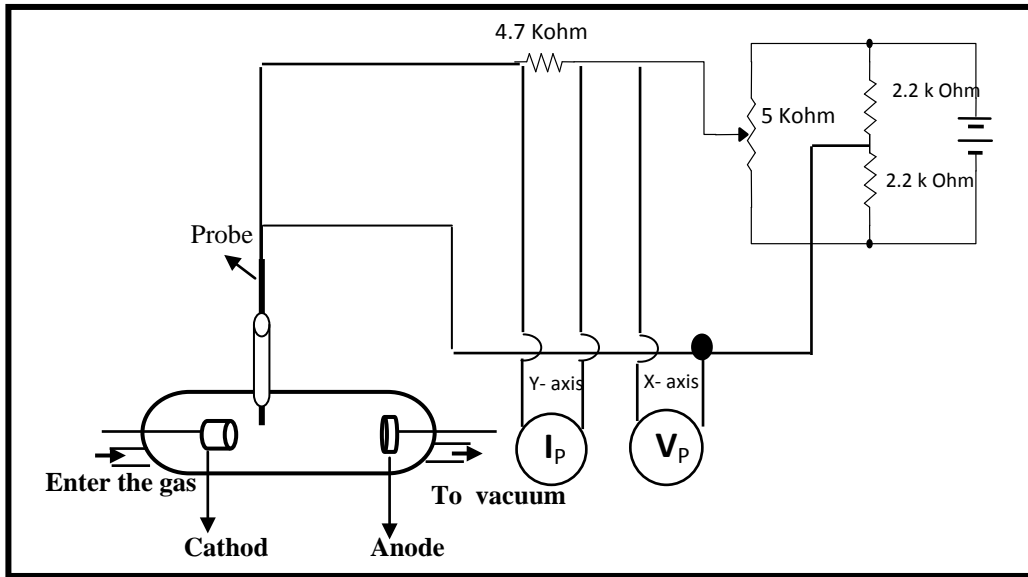
Fig. 1: The double probe electrical circuit

RESULTS AND DISCUSSION

Breakdown Voltage:

The breakdown voltage of Ar gas measured using the electric circuit as shown in Fig (2) without probes and it electrical circuit. The measurements have carried out in pressure range 0.1 to 1.5 *mbar*, and the distance between two electrodes changed 2, 3, 4 and 5 *cm*. The breakdown voltage is related to the electrode spacing parameter *pd*, where *p* is the gas pressure and *d* is the inter-electrode gap spacing. The values of the breakdown voltage for argon gas, as a function of (*pd*) are shown in Fig (2). The results show that the behavior of breakdown voltage curves similar to Paschen's curves.
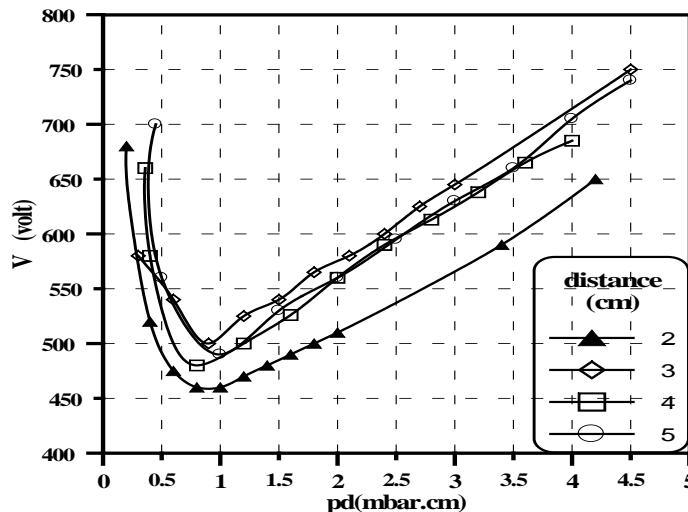

Fig. 2: The breakdown voltage for argon gas V_B as a function of *pd*

Breakdown potential voltage below V_{min} value can be decreased by increasing parameter pd. For large values of *pd* > 1.0 *mbar.cm*, breakdown voltage increases essentially linearly with pd. For small *pd* there is a limiting value of $pd = A^{-1} ln (1+1/\delta_{sec})$ below which breakdown cannot occur, where *A* is constant and δ_{sec} is the secondary electron emission coefficient. The values of V_{min} and (pd_{min}) play an important role in the more complicated problem of the cathode sheath (Lisovskiy *et al*. 2011and Chiad *et al*. 2009). At low pressure of gas the collision frequency is so low, that sufficient ionization is only maintained by increasing the probability of ionization at each collision, thus electron velocity, and electric field, must be high enough, consequently the breakdown voltage (V_B) must be increased as gas pressure diminish. At high gas pressure, the collision frequency is high enough so that the rate of the corresponding energy loss is high also. The energy gained per

free path is low unless the applied electric field is high. Thus, V_B must be increases when p is increased, and the curve must have a minimum value. But at minimum breakdown voltage occurs at $pd < 1.0$ *mbar.cm*, the average potential difference between electronic collision may be about equal to the ionization potential, or less than it, according to the nature of the gas. Fig (2) Shows the minimum breakdown voltage (V_{min}) at different distance for argon gas at values of (pd_{min}) smaller than 1.0 *mbar.cm*. The results of these measurements are agreement with many researchers where they wrote that the values of (pd_{min}) must be in the range of 1.0 torr.cm (~1.3 *mbar.cm*) for argon.

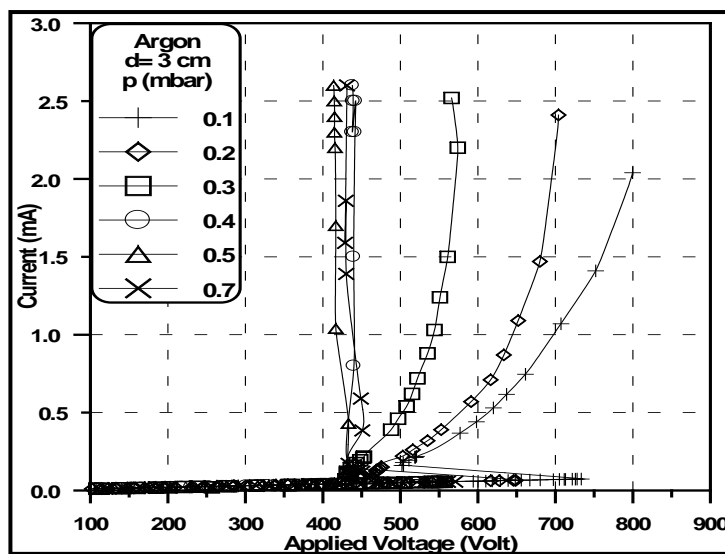### 3.2 I-V Characteristics:

I-V curves of HCD measured for Ar gas at different gas pressures range 0.1-1 *mbar* and different distance between two electrodes of discharge 2, 3, 5 *cm*, Measurement of *I-V* curves achieved by used the circuit shown in Fig (1). Fig (3) shows the results of measurements at different gas pressure in the range 0.1–0.7 mbar and constant distance between electrodes at 3 cm. For each pressure, approximately 40 points measured at pressure range from 0.1 to 0.7 mbar only, where the curves at pressure 0.8 to 1.0 are approximately in the same region of pressure 0.4 to 0.7 *mbar*.
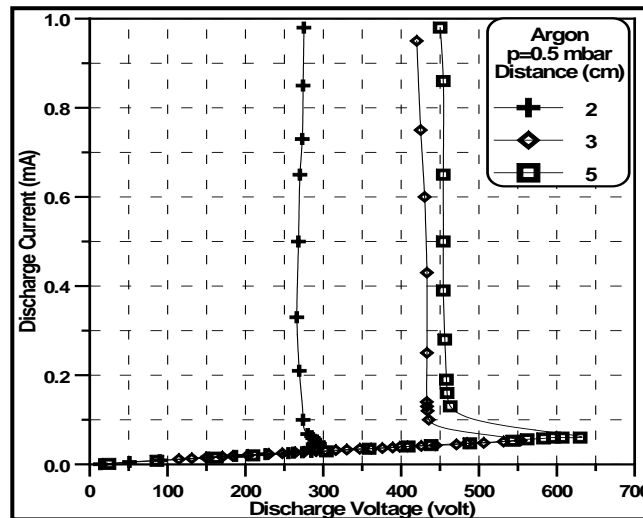
Fig. 3: *I-V* curves of Argon gas for HCD

Fig (4) shows a sample of *I-V* characteristic results curves of argon discharge at different electrodes distance 2, 3, 5 *cm* and gas pressure constant 0.5 *mbar* while Fig (5) shows one curve of *I-V* characteristic when electrode distance constant at 3 *cm* and pressure 0.5 *mbar*.

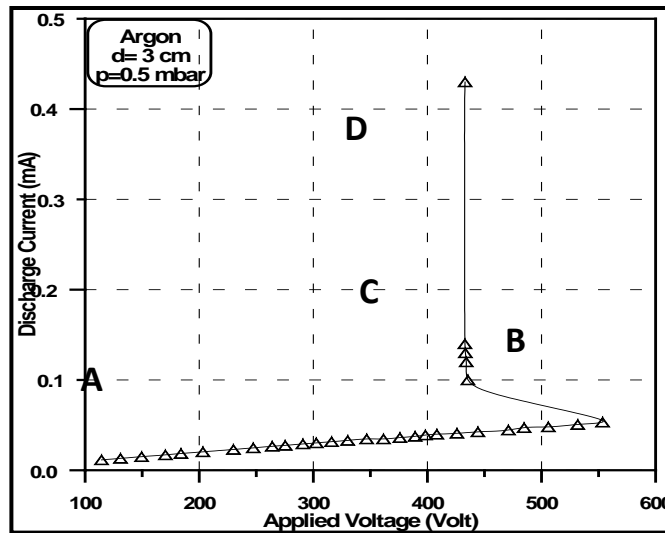**Fig. 4:** *I-V* characteristics of HCD at constant gas pressure and different distance

Fig. 5: *I-V* characteristic when electrode distance constant at 3 *cm* and pressure 0.5 *mbar*.

Generally, all figures show that *I-V* characteristics curves of HCD identical to *I-V* curves of normal glow discharge. The figures show that HCD have three different discharge regions, Townsend (or pre-breakdown) discharge region, AB, with low current and slope a positive value, followed by the hollow cathode discharge (breakdown) region, BC, with a slope negative value these transferred is suggested to be results a signature of the HCE, and transferred to normal glow discharge region, CD, third region (Shang *et al.* 2010). The hollow cathode effect started at point B and manifests itself in considerable increase in the discharge current and some decrease in the discharge voltage, arises at a specific proportion of the discharge voltage to the distance between the hollow cathode and anode in glow discharge (Steflekova et al. 2010).

Electron Temperature (T_e):
Electron temperature, T_e, and ion density, N_i, of argon gas discharge estimated by using characteristic, *I-V*, of double probe at constant discharge current, 15 *mA* and at different pressure range 0.4–1.0 *mbar*. The measurements achieved without and with magnetic field range 7–47 *mTesla*. The electric circuit used to measurement of *I-V* curves of double probes shown in Fig (1).

Electron Temperature without magnetic field:
Electron Temperature, T_e, calculated from *I-V* characteristics of the double probes at different gas pressure range from 0.4 and 1.0 *mbar*, distance between discharge electrodes was 3 *cm*, discharge current constant at 15 *mA* and don't applied magnetic field. T_e estimated by plotting the liner relation between [Ln$\square\square_{ri}$/(I_{e2}-1)] against the probe voltage (V_p)**,** where V_p is the probe voltage, I_{ri} is the ion saturation current for two probes, and I_{e2} is the electron current, T_e calculated from the slope of the line and used the relation (Abdul Qayyum Ikram *et al.* 2003).

$$T_e = \frac{e}{k} \frac{1}{(slope)} \tag{2}$$

where k is the Boltzmann's constant and e is the electron charge.
Fig (6) shows the *I-V* characteristics of the double probes at different gas pressure range from 0.4 and 1.0 *mbar*, distance between discharge electrodes was 3 *cm*, at constant discharge current, 15 *mA* and without magnetic field while Fig (7) shows the relation between probe voltage (V_p) against [Ln$\square\square_{ri}$/(I_{e2}-1)].
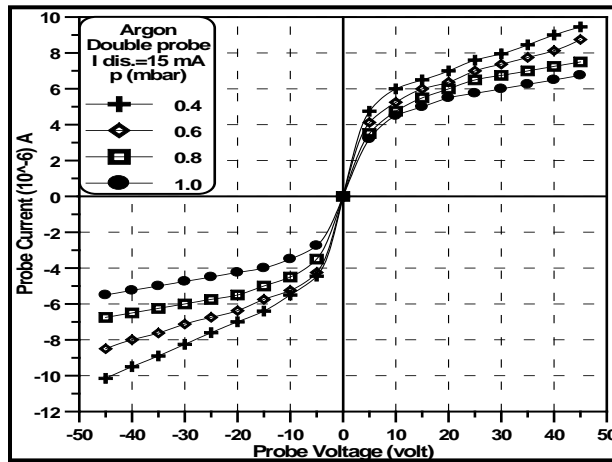
Fig. 6*: I-V* for double probes without magnetic field at different gas pressure range from 0.4 and 1.0 *mbar*.

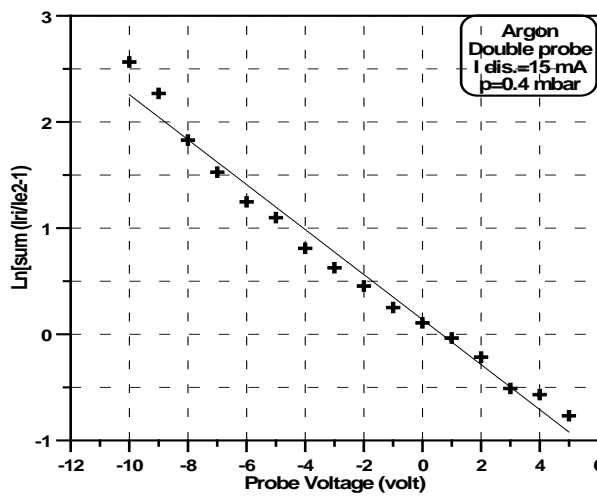**Fig. 7:** The relation between [Ln$\square_{ri}$/(I$_{e2}$-1))] against probe voltage (V_p)

Electron Temperature with Magnetic Field:

This section will explain the results concerning the effect of transversal magnetic field at the value of electron temperature for Ar gas plasma. The transversal magnetic field values change in the range of 7-47 *mTesla*, gas pressure range 0.4 to 1.0 *mbar* and discharge distance between two electrodes was 3 *cm*. Fig (8) shows sample of *I-V* characteristics of the double probes at the same condition mention before with applied magnetic field at value equal 30 *mTesla*. The electron temperature calculated by the same method explained before in pint A, without magnetic field.
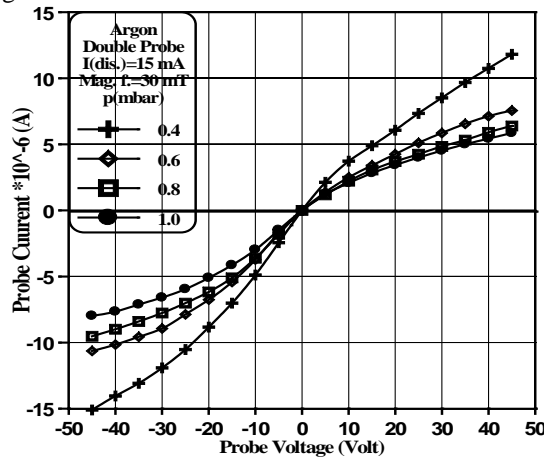

Fig. 8: *I-V* for double probes with applied magnetic field at value equal 30 *mTesla*.

The estimated values of (T_e) shown in Fig (7) with applied magnetic field and without, the figure shows that the (T_e) decreased as the pressure increases.
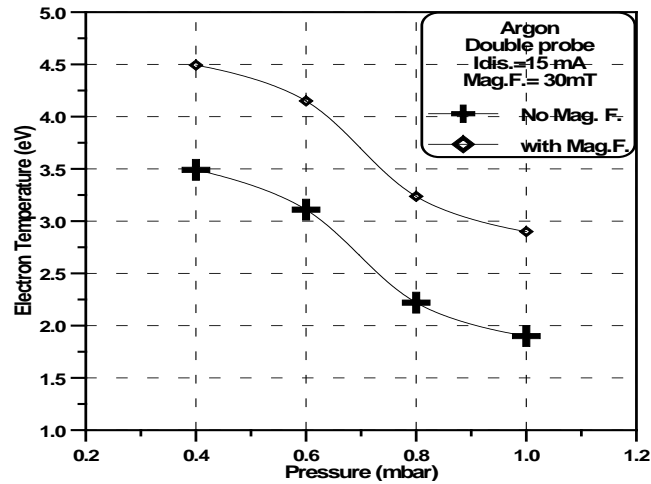

Fig. 9: shows T_e as a function of gas pressure, with and without Magnetic field

Values of T_e with magnetic field are higher than values of T_e without magnetic field, also T_e decreased when the gas pressure was increases. Without magnetic field, range of T_e was 3.5 - 1.9 *eV* and T_e was change from 4.5 to 2.9 *eV* with applied magnetic field. The reduction of temperature with the increas in filling pressure may be explained as follows. When the pressure in the chamber increases, it casuses an increase in the number of collisions netween the electrons and the gas atomes. As a result, the energy transferred from the electrons to gas particles increases causing an increase in the gas temerature by lowering the electron temperature. Also, the figure imply that the average kintic energy of electrons decreased with incresed pressure. physically, the electrons cannot acquire as much energy from the field of discharge, minimum field in ngative glow discharge, as a reslut of increased collisions with neutrals atomes and decreased mean free path. Fig (9) show that, when applied a transverse magnetic field, *B*, the electron temperature at applied magnetic fields, T_{eB}, is higher than T_e without magnentic field at the same range of pressure; and for small (*B/p*). These mean that, the values of T_{eB} with magnetic field are higher than T_e without, these is related to the relation:

$$T_{eB}=T_e \left[1+C_1(B^2/p^2)\right]^{1/2} \tag{3}$$

where $C_1=(eL/mv_r)$, *L* is the mean free path of the electrons in the gas at 1 *torr* and v_r is their random velocity, C_1 is the square of the elecreon mobilty at 1 torr. B magnetic fiels strangth and *p* is the pressure.

Ion Density (N_i):

This section show that the results of ion density, *Ni*, without and with effect of transversal magnetic field, for Ar gas plasma. The transversal magnetic field values change in the range of 7-47 *mTesla*, gas pressure range 0.4 to 1.0 mbar, discharge current constant at 15 mA and discharge distance between two electrodes was 3 cm.

N_i can be detriment by using *I-V* curves of double probes shown in Fig (6) and Fig (8) using the relation:

$$N_i = \frac{I_{ri}}{CA_p e}\left[\frac{m_i}{2kT_e}\right]^{\frac{1}{2}} \tag{4}$$

where: I_{ri}- saturation ion current for two probes, m_i ion mass, N_i- ion density, *k* - Boltzmann's constant, T_e- electron temperature, *C*- constant equal to 0.6

Ion Density without Magnetic Field:

The variation trend of N_i with changing gas pressure and without applied magnetic field shows in Fig (10) curve A, it is clear from the graph that the N_i decreases with increases in gas pressure. When the gas pressure is increased from 0.4 to 1.0 *mbar* the ion density will decreases from (7.4 to 6.4)10^9 *ion/cm³*.

Ion Density with Magnetic Field:

The results in Fig (10) curve B, show that N_i decreases with increased in gas pressure. The ion density will decreases from (7.1 to 5.6)10^9 *ion/cm^3* when the gas pressure is increased from 0.4 to 1.0 *mbar.*
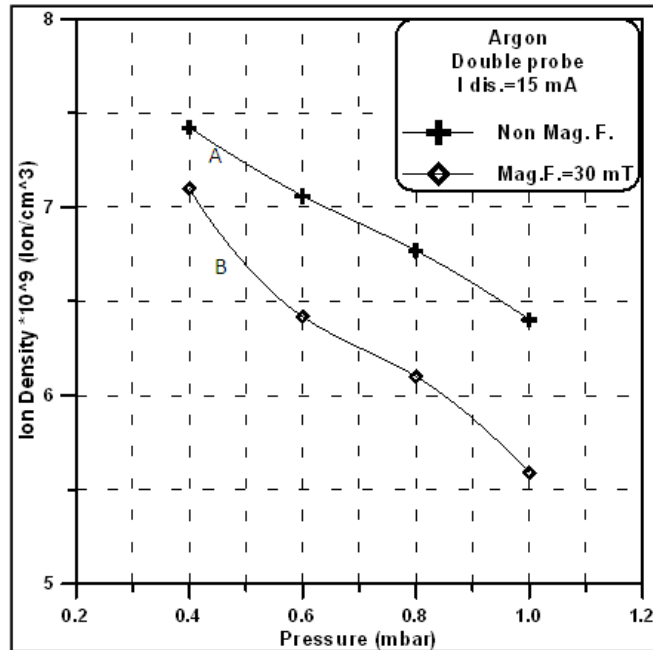
Fig. 10: N_i as a function of pressure (A without and B with Magnetic field).

The decreasing trend of N_i with filling gas pressures can be explained as follow: The rise in filling gas pressure inside the discharge plasma chamber gives a cooling effect in plasma. The cooling effect in plasma decreases the ion density *Ni.*

Conclusions:

The breakdown voltage measured for argon gas agreement with Paschen's curve. The breakdown voltage varies when gas pressure increases. *I-V* characteristic curves for HCD for argon gas confirmed that, HCD is similar to the normal glow discharge region, which is very important parameter in microelectronic industry. Also, The electron temperature, at constant discharge current, decreases with increased the gas pressure with and without magnetic field, but its values smaller with applied magnetic field.The ion density, when discharge current constant, decreases by increased of gas pressures with and without magnetic field considering the fact that ion density without applied magnetic field are higher than that with magnetic field.

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