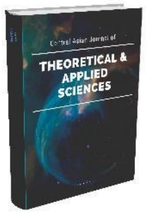

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The Effect of Magnetic Field Strength in DC Magnetron

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Abstract: *Plasma parameters (electronic temperature (T_e), electronic density (n_e), electronic cyclotron frequency, ionic cyclotron frequency, electronic gyro radius, ionic gyro radius, drift velocity (V_d), plasma potential (V_p), were determined under the effect of magnetic field strengths ((0.021-0.062) Tesla) in homemade (DC) magnetron sputtering system and discussed to improve the operation of it. Argon gas pressures is (0.5 mbar), a single langmuir probe was used as diagnostic tool. Generally it's found that the behaviors of the electronic temperature, the electronic and ionic gyro radius and the plasma potential decrease with increasing the magnetic field strengths, but the electronic density, electronic and ionic cyclotron frequencies and the floating potential increase with increasing the magnetic field strengths.*

Keywords: *Magnetron; Plasma Discharge; Single Langmuir Probe; Plasma Parameters.*

1. Introduction

Magnetron sputtering systems are broadly applied in industrial processes and in advanced material developments or treatment. The energetic electrons are trapped by the externally applied magnetic field which increases their ionization efficiency, that lead to an efficient deposition rate at a relatively low pressure. Basically, it uses magnetic field transverse to the electric field at sputtering target surface and this affects ionization probability and therefore the deposition rate as well as onto the growing film [1,2]. Knowledge of behaviors for the plasma parameters can be performed through the various modes in magnetron sputtering technology including (DC) (direct current), (MW) (microwave frequency), (RF) (radio frequency), and their combinations. Recently, the effect of magnetic field strength on plasma parameters has been assessed and became important to improve the characteristics of thin films. The benefits of magnetic field removed limitations (low ionization, low deposition, unstable plasma etc.) [3,4]. In [5] designed a very flexible computerized package with an excellent results ,which describe the magnetic field in front of a planar magnetron system. In [6] studied how the plasma was perfectly confined by a magnetic field applied perpendicular to both of the target planes through a design an auxiliary magnet for each target and placed at a distance from the main magnet, which was located behind the target.. In [7] concluded that the density and confinement of discharged plasma are function of the arrangement of a permanent magnet in the cathode during the film sputtering process. Also, the magnetic field will increase the path length of the electrons before the anode collects them, and keeping electrons away from the vacuum chamber, and ensures a sufficiently high ionization rate [8,9]. This bombardment of ions not only sputters out target material, but also produces secondary electrons that maintain discharge. We still need good deposited thin films through a variation of magnetron configuration , which can be used for highly density of magnetic field strengths and other applications[10,11].

2. Experimental work

A homemade(DC) magnetron sputtering system consist mainly of vacuum stainless - steel cylinder chamber with two open ends, which covered by two stainless steel flange. The diameter and length of the cylinder are (31 cm) , (35 cm), respectively and (4 cm) thickness, with the four side glasses windows. In this chamber a two parallel stainless steel planer electrodes used as anode and cathode each of diameter is (14.5 cm), which was pumped by rotary pump followed by oil diffusion pump. A variable high voltage dc-power supply delivering (6 kV). Working pressure (0.5 mbar) and the flow rate of working gases was limited (9 ml/min). Here a single Langmuir probe (its material tungsten) located at (2 cm) from cathode ,which is the max. of magnetic field point, with tip's dimension (0.2*3 mm)was used to investigate the plasma parameters of glow discharge in Ar gas (99.998% purity). The Langmuir characteristics are obtained by sweeping the probe voltage slowly between (-100 to 100V) (stabilized DC power supply) to include all the important regions of the curve. The permanent magnets (200-600 Gauss) positions are placed up the cathode to ensure that the magnetic field lines encompass the target area. This feature helps ensure an efficient electron trap. The schematic diagram of setup shown in **Fig.** (1) (a and b).

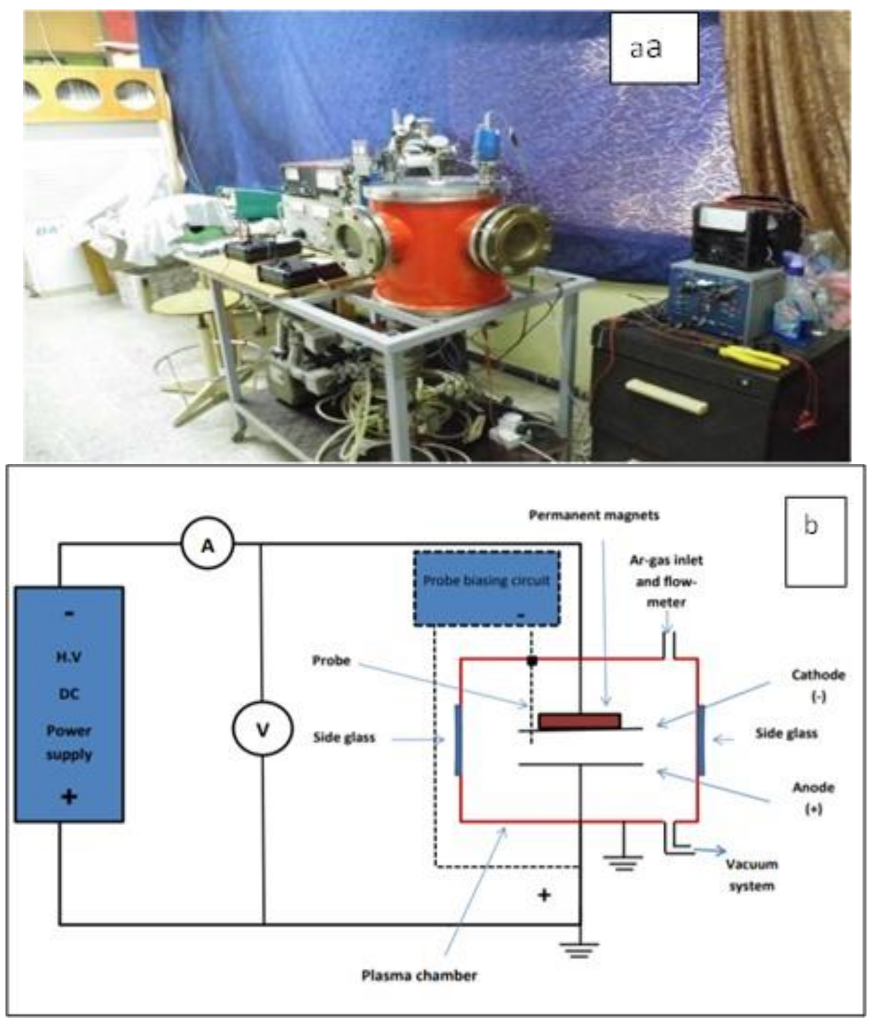

Fig. (1): (a and b) Experimental setup.

3. Theoretical consideration

The determination of all parameters and therefore its effect on the operational controlling conditions is another part of our work.. In the consideration of probes in a magnetic field, the field is usually classified into three cases. First, weak field; when (r_p/ r_{Le} <<1) and (r_p/ r_{Li} <<1), here the larmor radius of electrons and ions are both larger than the probe radius. The I-V characteristics of the probe are similar to collision less theory or collision zero-magnetic field theory. Second, strong field; when (r_p/ r_{Le} >>1) and(r_p/ r_{Li} <<1), the anisotropies appear in electron transport coefficients and collision-like behavior becomes evident. Third, very strong field, when (r_p/ r_{Le} >>1) and (r_p / r_{Li} >>1), here there will be no true collision less case, and unlike electron current collection, diffusion to the probe surface determined by the magnetic lines of force may become important during ion collection. On the other hand, when the electric and magnetic fields are present simultaneously in a magnetron trap, the electrons are brought close to the cathode's surface. (in the region of strong electric field). Electrons follow helical paths around the magnetic field lines and so undergoing more ionizing collisions with gaseous atomic neutral near the target surface. The ions created by these collisions leads to a higher deposition rate. It also indicates that the plasma can sustained at a lower pressure. The single Langmuir electrostatic probe has long been used as a basic tool for measuring the local properties of the plasma. The (I-V) characteristics are measured currents according to the applied probe voltages and the main plasma parameters which can be identified in this mode are [12,13]:

3.1. Electronic temperature (T_e)

The electronic temperature can be determined directly from the slope of (I-V) curve in the transition region of it and according to the following equation [11-13] .

$$\text{slope} = \frac{1}{T_e} \qquad (1)$$

where (T_e) in (eV).

3.2. Electronic density (n_e)

The electron density can be calculated as a function of electron-saturation current (I_{sat}), according to the following relation [12-14]:

$$I_{sat} = \frac{n_e e A_p}{4}\left(\frac{2\,k\,T_e}{m_e}\right)^{1/2} \qquad (2)$$

To:

$$n_e = 3.73 \times 10^{13}\,\frac{I_{sat}}{A_p T_e^{1/2}} \qquad (3)$$

(A_p): is the surface area of the probe; (m_e) is the electronic mass(($9.1\text{x}10^{-31}$) kgm; (atomic mass unite, 1amu= 1.67×10^{-27} kg) for proton; (n_e) is the electronic density (m^{-3}).

3.3. Electronic and Ionic Cyclotron frequency (Hz)

Theoretically, the behavior of electronic cyclotron frequency is similar to the ionic cyclotron frequency, but because the ion is more heavy than the electron, the electronic cyclotron frequency has values higher than the ionic cyclotron frequency., this done according to the following relations [12].

$$w_{cycl.e} = \frac{e\,B}{m_e} \qquad (4)$$

$$w_{cycl.i} = \frac{Ze\,B}{M_i} \qquad (5)$$

(M_i is the argon mass ($6.62\text{x}10^{-26}$) kgm)

3.4. Electronic and ionic gyro radius (m)

For magnetized plasma, the gyro cyclotron radius and cyclotron frequency are important parameters. The gyro cyclotron radius (larmor radius) is defined mathematically for electrons and ions as [12]:

$$r_{L_e} = \frac{m_e v_e}{eB} \quad (6) \text{ for electrons}$$

$$r_{L_i} = \frac{M v_i}{ZeB} \quad (7) \text{ for ions}$$

3.5. Drift Velocity (V_d)

Due to the fact that the magnetron drift velocity depends on both the electric and magnetic fields, the plasma itself and its effects on a workpiece are more uniform in the direction of the drift, ($\frac{E\times B}{B^2}$). The drift velocity during the mutually perpendicular E and B fields is written as[15,16] :

$$V_{E\times B} = \frac{E\times B}{B^2} \quad (8)$$

$$V_{(E\times B)_\theta} = \frac{E_z}{B_r} \quad (9)$$

3.6. Plasma potential (V_p)

One of the crucial plasma characteristics that shows the ion's incident energy upon the substrate. To obtain the plasma potential (sometimes called space potential) as a point located at the intersection between the extrapolations of the transition region with the electron saturation region [14,17].

4. Result and Discussion

The plasma properties are measured by using Langmuir probe under (0.5) mbar pressure and therefore discussing the influence of magnetic felid strengths on the behaviors of the plasma parameters. It was found a similarity between the behaviors of our results and which obtained by the researchers in [18,19]. In Figure (2), the (I-V) characteristic curves shows the non-linear variation of ($\ln I_e$) as a function of probe voltage (V_{Probe}) at different magnetic field strengths (B) In general, it can be observed that its shifted to the less negativity, as well as increasing in electron saturation current with increasing magnetic field strengths because of accumulation of high energy electrons near the cathode due to ionizing collisions which lead to increasing the electron saturation current. It's also found that the increasing in magnetic field strengths have no effect on ion saturation current. It is also noted, that the magnetic fields does not change the energy distribution because of Lorentz force is normal to the velocity and therefore cannot impart energy to any electron. In Figure (3), Illustrate the inverse proportionality between electron temperature (T_e) and (B) in a nonlinear manner with magnetic field. The following statements illustrate this behavior: when electrons move from the strong magnetic field region towards the cathode end (weak magnetic field region), the electrons have sufficient energy to make collisions with the neutral atoms and reducing the energy of electrons and thus decreasing(T_e). Increasing the charged particle densities are due to effect of magnetic field strength, which causes the electrons' trajectories to change to helical ones, increasing the likelihood of collisions, extending the time the electrons spend inside the plasma reactor, and also confining them before they are either collected at the electrodes or undergo recombination, which raises the ionization rate, therefore the resultant effect is that the plasma density become very high in the vicinity of the cathode as shown in Figure (4). In Figure (5) (a and b), because of presence of $(E \times B)$ in plasma will generated Lorentz force and this force causes a circular motion of the electrons and ions with cyclotron frequencies, which is independent of velocity and depends only on the charge-to mass ratio, the behaviors of electron cyclotron frequency is similar to ion cyclotron frequency, but the first one have values greater than other because of the disparity in masses, electron mass is less than ion mass and it's found a linear relations with (B) that the increasing in magnetic field strength leads to increasing electron and ion cyclotron frequencies and which was proved by mathematical expression (equations (5,6)). Also the disparity of reacted masses causes the values of ion gyro radius is greater than the electron gyro radius (the square root of the mass ratio), which reflect a real that magnetic field strengths have a small effect on the ions motion which have the same behaviors and display in Figure (6) (a and b). The nonlinear decreasing in the electron and ion gyro cyclotron radius with increasing magnetic field strengths can be understood as: the collisions in the weakening E-field beyond the sheath and plasma oscillations cause the electrons migrate to the anode, and decreasing azimuthal direction which causes the reducing in gyro cyclotron radius. In Figure (7), the magnetic field and its gradient are parallel to the electric field (in the z-direction) in the magnetron configuration, and the (EB) drift velocity is produced (in the azimuthal direction)., v_d equal to $v_{(EXB)\theta}$). Its value described by equation (9), and is independent of (q, m_s) ,so the whole plasma drifts across the electric and magnetic fields with the same velocity. This drift velocity has a minimum values in the strong field region and increase with the decreasing (B), as well as the plasma oscillation lead to losses energy causing decreasing in (r_L) Plasma potential (V_p) is one of the most important plasma parameters because it's a function of the incident energy of ions. In Figure (8) demonstrates the experimental data of plasma potential as a function of magnetic field strengths. The increasing of magnetic field strength is attributed to the fact that electrons are confined effectively, the accumulation number of electrons on the surface increases and this will lead to the decrease of plasma potential, so (V_p) will decrease.

5. Conclusion

Application of the magnetic fields in such system increases the electron confinement which increases the rate of ionization and thus enhances the sputtering rate of the metal target due to controlling Ions and electrons trajectories in plasma. Our results indicate that the determination of the electrical properties of an argon plasma are very important as conditions for deposition of thin films by magnetron sputtering. (T_e) , (V_p), electron and ion gyro radius and drift velocity decreased with increasing magnetic field strengths, a low (V_p) will lead to low substrate temperature and weak ion bombardment damage to deposited films. n_e, electron and ion cyclotron frequencies, increases with increasing magnetic field strengths (B)The estimated drift velocity (v_d) helps to understand the electron diffusion in the magnetron sputtering device and determines the appropriate discharge conditions and plasma parameters for deposition process of thin films. Therefore, the measured plasma parameters strongly depended on magnetic field strengths(B).

Acknowledgements

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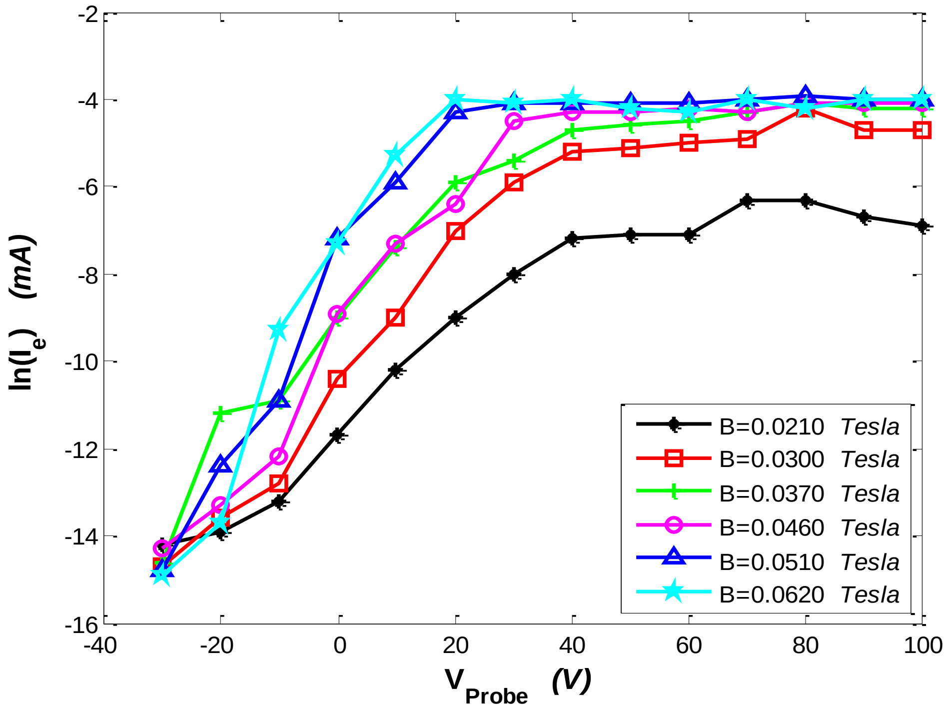


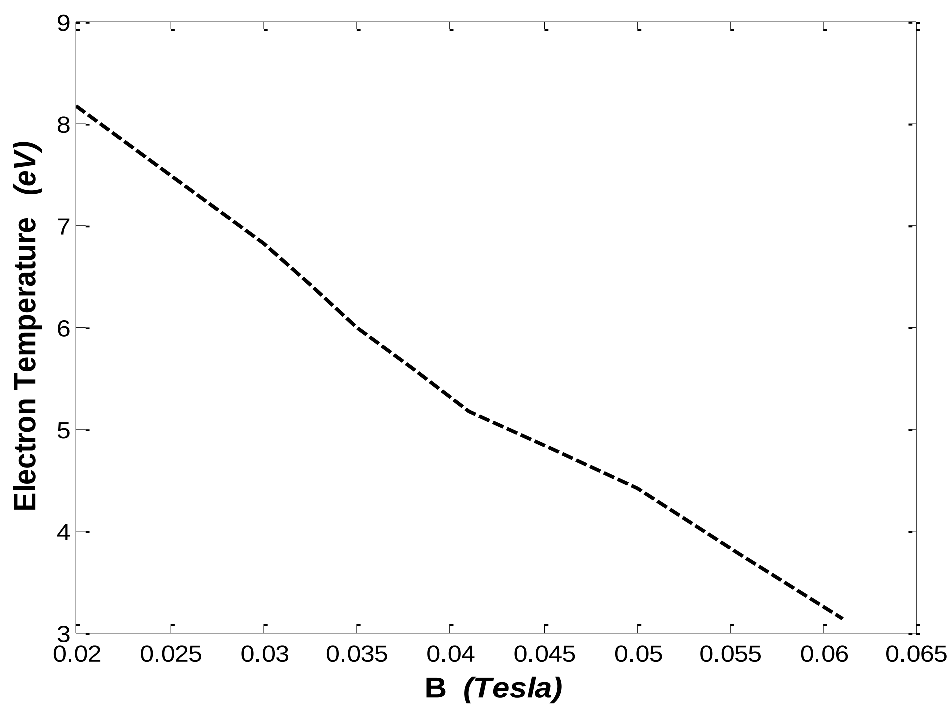


Figure (3): Electron temperature versus magnetic field strengths.

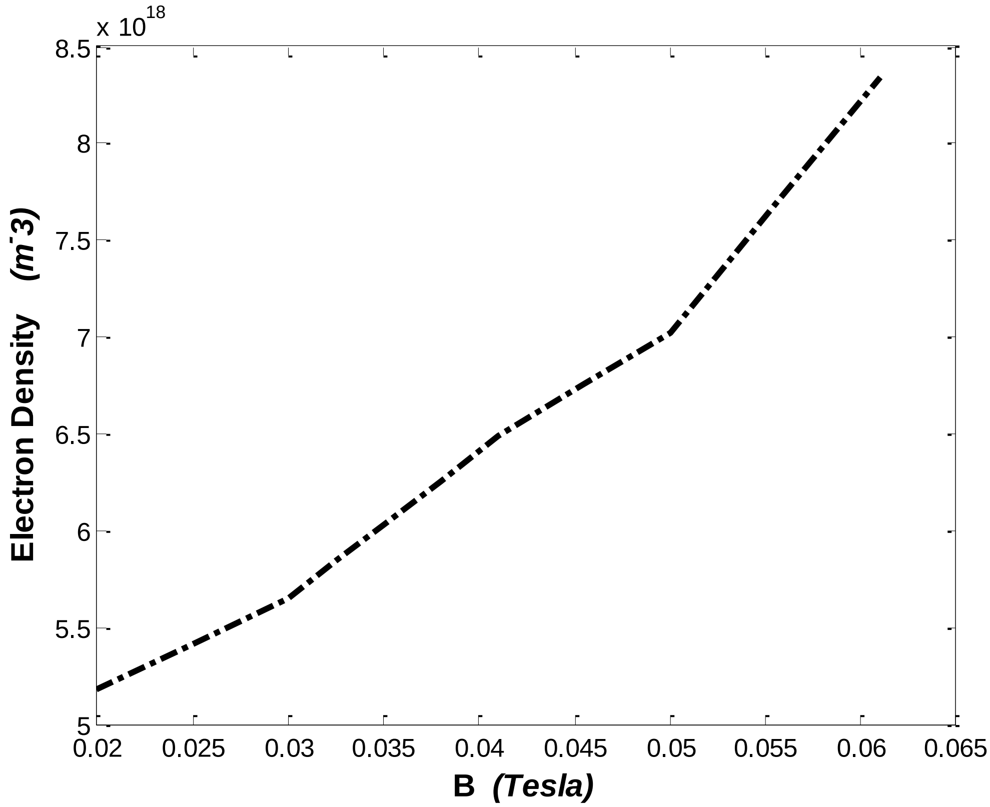
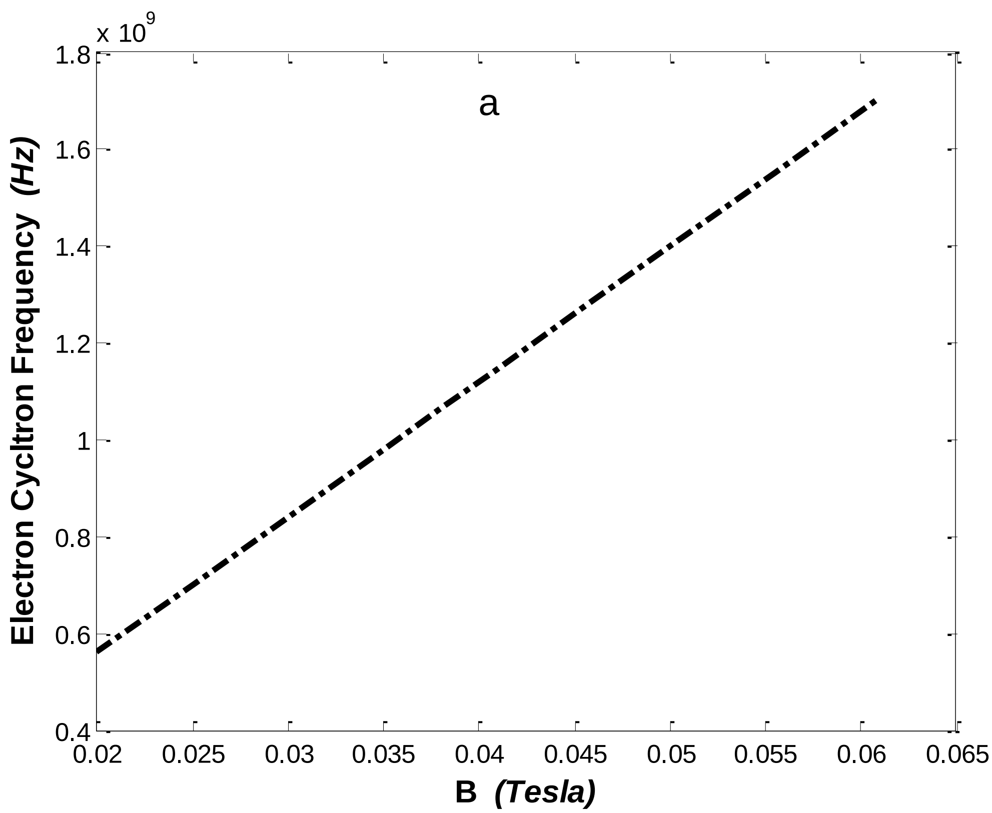


Figure (4): Dependence of plasma density on magnetic fields.



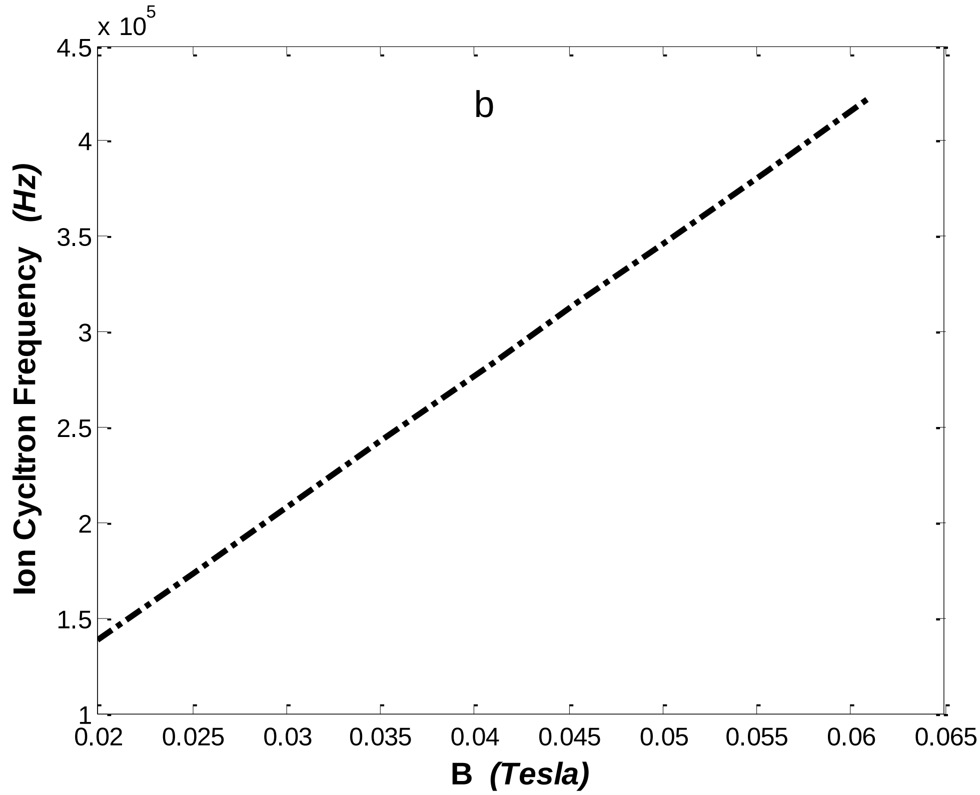
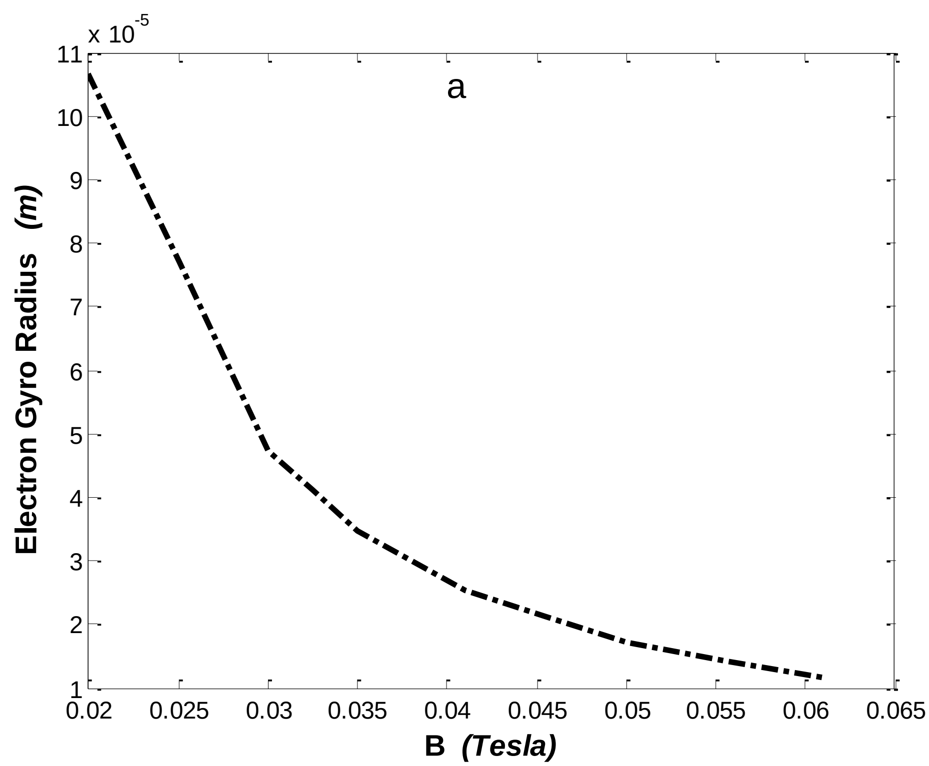


Figure (5): (a)Electron cyclotron frequencies and (b)ion cyclotron frequencies as a function of magnetic field strengths.



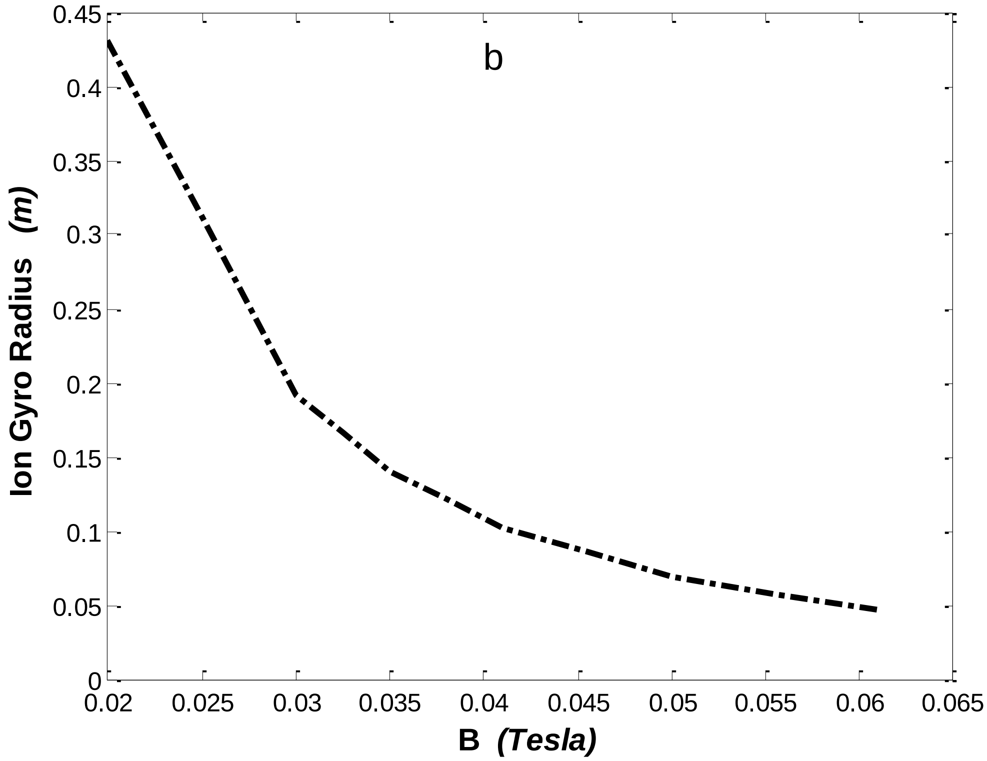


Figure (6): (a) Electron gyro-radius and (b) ion gyro-radius under the effect of magnetic field strengths.

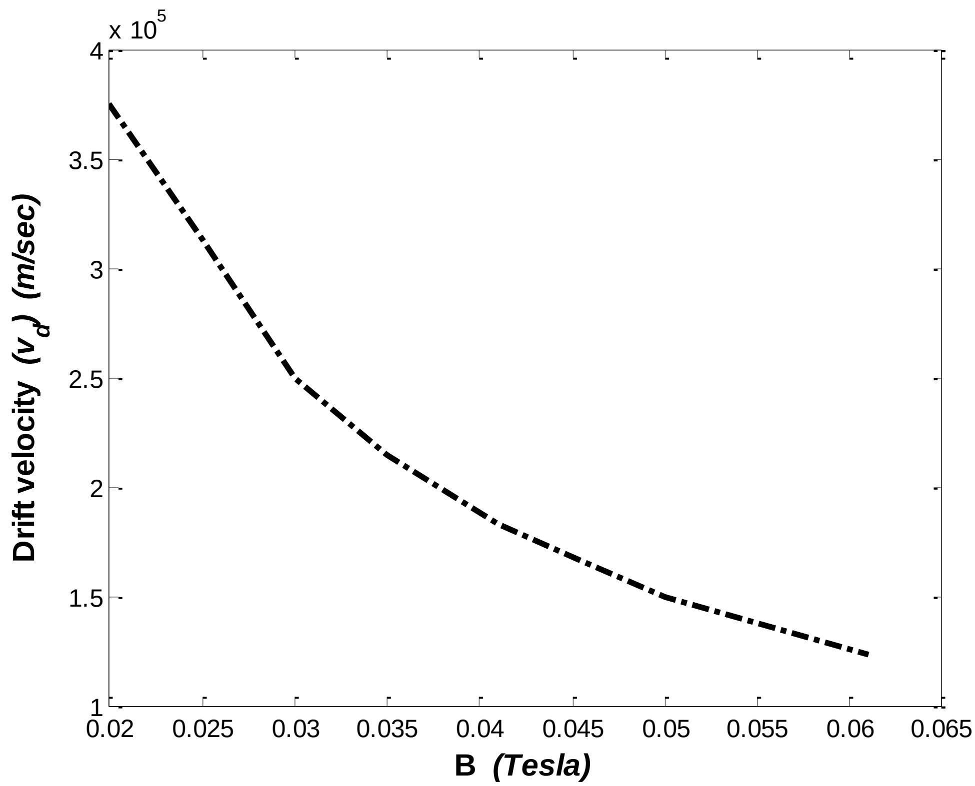
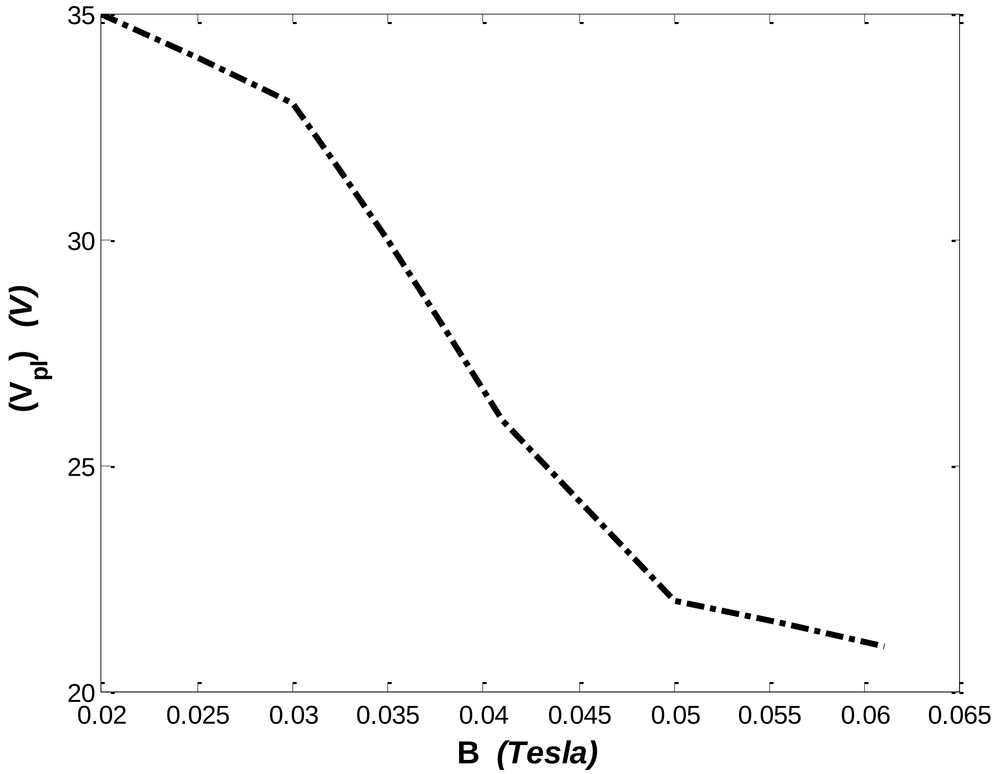


Figure (7): Electron drift velocity variation with magnetic field strengths.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