Spectroscopic study for plasma parameters in co-sputtering system

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Abstract

In this work the parameters of plasma (electron temperature Te, electron density ne, electron velocity and ion velocity) have been studied by using the spectrometer that collect the spectrum of plasma. Two cathodes were used (Si:Si) P-type and deposited on glass. In this research argon gas has been used at various values of pressures (0.5, 0.4, 0.3, and 0.2 torr) with constant deposition time 4 hrs. The results of electron temperature were (31596.19, 31099.77, 26020.14 and 25372.64) kelvin, and electron density ($7.60*10^{16}$, $8.16*10^{16}$, $6.82*10^{16}$ and $7.11*10^{16}$) m^{-3}. Optical properties of Si were determined through the optical transmission method using ultraviolet visible spectrophotometer with in the range (300 – 1100) nm.

Key words
Co-sputtering, OES, Spectroscopy diagnostic.

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دراسة طيفية لمعلمات البلازما في منظومة الترذيذ المزدوج

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الخلاصة

تم دراسة معلمات البلازما (درجة حرارة الالكترون، الكثافة العددية للالكترونات، سرعة الالكترونات، سرعة الايونات) بإستخدام جهاز الطيف الذي يجمع طيف البلازما. حيث استخدم الكاثود المزدوج (سيليكون – سيليكون) من نوع P-Type وتم ترسيبه على زجاجة. تم استخدام غاز الاركون في ضغوط مختلفة (0.5, 0.4, 0.3 و 0.2) تور، بثبوت زمن الترسيب لمدة 4 ساعات. حيث اظهرت نتائج درجة حرارة الالكترون (31596.19, 31099.77, 26020.14 و 25372.64) كلفن، ونتائج الكثافة العددية للالكترونات و ($7.60*10^{16}$, $8.16*10^{16}$, $6.82*10^{16}$ و $7.11*10^{16}$) m^{-3} كذلك تم ايجاد الخصائص البصرية للسيليكون بطريقة طيف النفوذية البصرية وذلك بإستخدام جهاز الطيف البصري (فوق البنفسجي / المرئي) للاطوال الموجية (300-1100) نانو متر.

Introduction

Co-sputtering is widely used technique for the metal oxide and metal nitride surface coatings. Plasma species in the discharge are governed by the reaction of gases and metals in particular ratio due to the electrical fields, cathode (material used for sputtering), pressure, discharge power density and sputter gas used [1]. When co-sputtering is performed in the presence of a reactive gas, it is called reactive co- sputtering. Co-sputtering of two different materials has typically been accomplished with ion beam sputtering or the use of RF or DC supplies to deliver power to sputtering targets and preparing thin films and it is a superior in terms of composition reproducibility and thinness on a large-area substrate [2-4]. Sputter deposition is one of the most important preparation methods because the composition of alloy films can be controlled and the adhesion of film to substrate can be increased [5].

The optical emission spectroscopy (OES) technique is non-invasive, easy to implement and measurements are fast. The OES is passive and based on recording light emitted from the plasma. Through collisions of plasma particles with electrons, plasma particles are excited to higher electronic states. Relaxation, of excited particles which are present in the chamber, that the lower energy's levels is the origin of emitted photons of light. Energy of released photon is equal to the difference between excited and lower energy state and corresponding with wavelength of spectral line described by relation [6]:

$$\lambda = \frac{hc}{E_j - E_i} \qquad (1)$$

where h is Planck's constant, c is the speed of light, Ej and Ei is upper and lower energy state, respectively. Since the energy of a transition is a characteristic of the particle species, the analysis of the photon energy can reveal the composition of the plasma.

Plasma diagnostics are the techniques used to obtain information about the nature (properties) of plasma, such as the chemical compositions and species of the plasma, density of the plasma, plasma potential, electron temperature, ion/electron energy distributions, ion mass distributions and neutral species. Spectroscopic methods for plasma diagnostics are the least perturbative, and for the evolution of the plasma parameters, they study the emitted, absorbed or dispersed radiation [7]. The simplest approach in determining temperature is done by taking the intensity ratio of two spectral lines, provided that the population densities of the lines in upper level are in local thermal equilibrium (LTE). Take note that the temperature determined from this method refers to excitation temperature hence if (LTE) condition holds, the temperature is then known as electron temperature. The intensity of the spectral line which is assumed to be optically thin is given by [7]:

$$I_{ij} = \frac{hcA_{ij}g_j\,n}{\lambda_{ij}U(T)}\, e^{(\frac{Ej}{kT})} \qquad (2)$$

where Ii, j and λ_{ij} is the intensity and wavelength corresponds to transition from i to j respectively, h is the Planck's constant, c is the speed of light, number density of emitting species n, partition function U(T), A_{ij} is the transition probability between level i and j, Boltzmann's constant k, excitation temperature T, g_j is the statistical weight of upper energy level and Ej upper energy level in eV unit.

The electron temperature and density can be calculated in low pressure plasma spectroscopically. Also, electron temperature can be measured by using line intensity ratio method by considering the integrated intensity ratio of two spectral lines belonging to the same atomic species, the formula is given by [8];

$$T_e = \frac{E_2 - E_1}{k}\left[\ln\left(\frac{A_2 g_2 I_1 \lambda_1}{A_1 g_1 I_2 \lambda_2}\right)\right]^{-1} \qquad (3)$$

where (E_1-E_2) is the energy difference of two spectral lines.

Wavelength nm	g	A	E(ev)
SiI 698.85	5	1.60E+07	7.730406
SiII 772.1	4	7.56E+05	14.131312

The electron collisions is the condition that the atomic levels should be populated and depopulated predominantly, rather than by radiation, which is requires an electron density which is sufficient to ensure the high collision rate. According to the LTE, the formula was used to determine the electron density is [9, 10];

$$n_e \geq 1.6 \times 10^{12} T^{1/2} (\Delta E)^3 \qquad (4)$$

where T (K) is the plasma temperature and ΔE (eV) is the energy difference between the states.

Finally, the electrons and ions velocity in plasma was measured and have been illustrate the behavior with the changing of pressure, using the following equation [9];

$$v_{e,i} = \left(\frac{8kT_e}{\pi m_{e,i}}\right)^{1/2} \quad (5)$$

where $\boldsymbol{v_{e,i}}$ is the electrons and ions velocity.

Experimental procedure

In the plasma laboratory at university of Baghdad, college of science, dept. of physics, DC co-sputtering deposition system was used for the study of (Si:Si) plasma. It consists of dual in which pure (99.99%) Si targets are connected to DC power supply as shown in Fig. 1. The distance between the targets and the substrate is about 40mm. (Si:Si) films with is a thickness of about 56 nm were deposited on class substrates at room temperature by DC co-sputtering at an Ar gas (99.9995% in purity) pressure of (0.2 - 0.5) torr. The sputtering power applied to the targets was fixed at 50W. The substrate holder was rotated using a stepping motor during deposition in order to obtain a uniformly thick film.

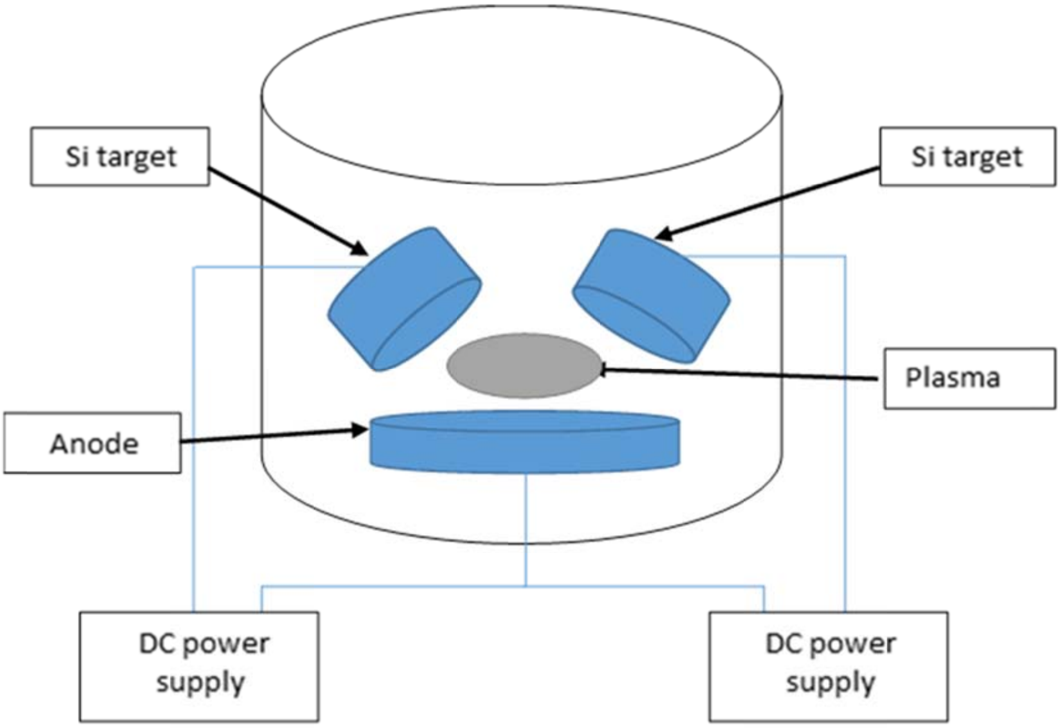

Fig. 1: Schematic diagram of DC co-sputtering system.

Another way to determine the absolute density of plasma species by OES is the calibrated light source approach. A detection system (optical fiber + spectrometer) calibrated in a special way produces the 'absolute spectra', allowing us to determine the absolute irradiance of the emission lines, thus providing direct access to the plasma parameters, such as n_e , T_e, etc. The principle of Te and ne determination by OES in cold plasmas is normally based on determination of the ratio between two prominent emission lines which are sensitive to the changes of a chosen parameter (e.g. electron temperature), often referred to as the 'line ratio method'. In the general case, this method should be adapted to each particular plasma discharge [11].

Results and discussion

Characteristic OES spectra of plasma taken in the wavelength regions of 690 – 820 nm are displayed on Figs.(2-5). The emission lines appearing in the spectra are assigned according to neutral SiI, ArI and ions SiII, ArII emission lines dominate the OES spectra. The two lines of silicon spectra are used (Si I = 697.85nm and Si II = 772.1nm) that applied in the ratio method to obtain the plasma parameters (Te, ne, electron velocity and ion velocity).

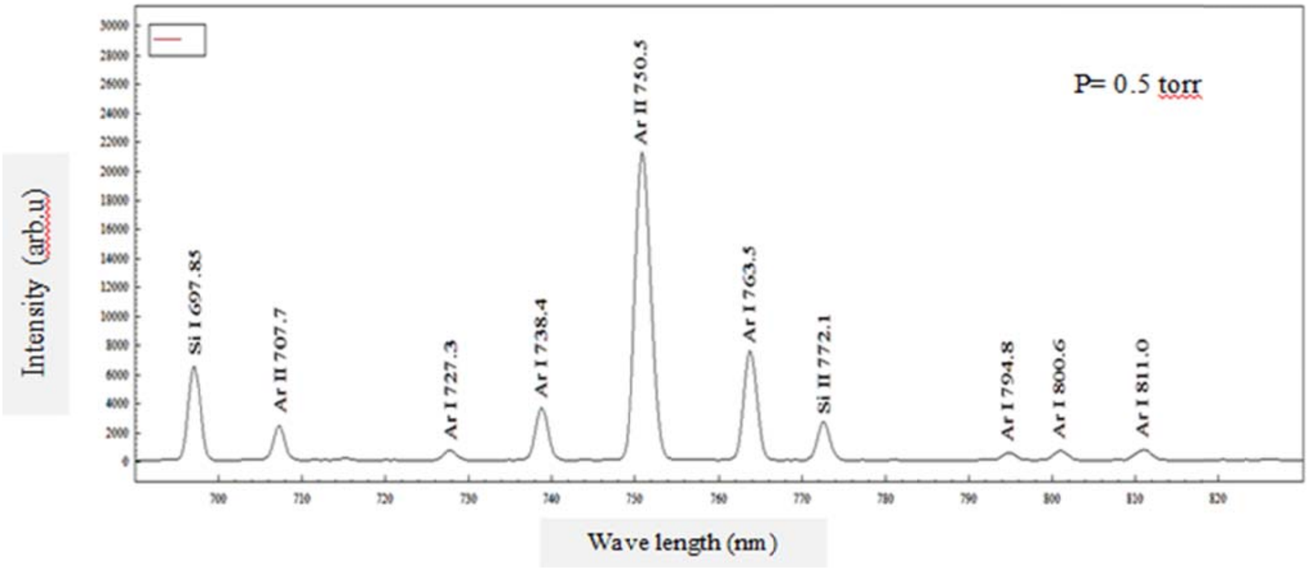

Fig. 2: The spectrum of Co-sputtering system.

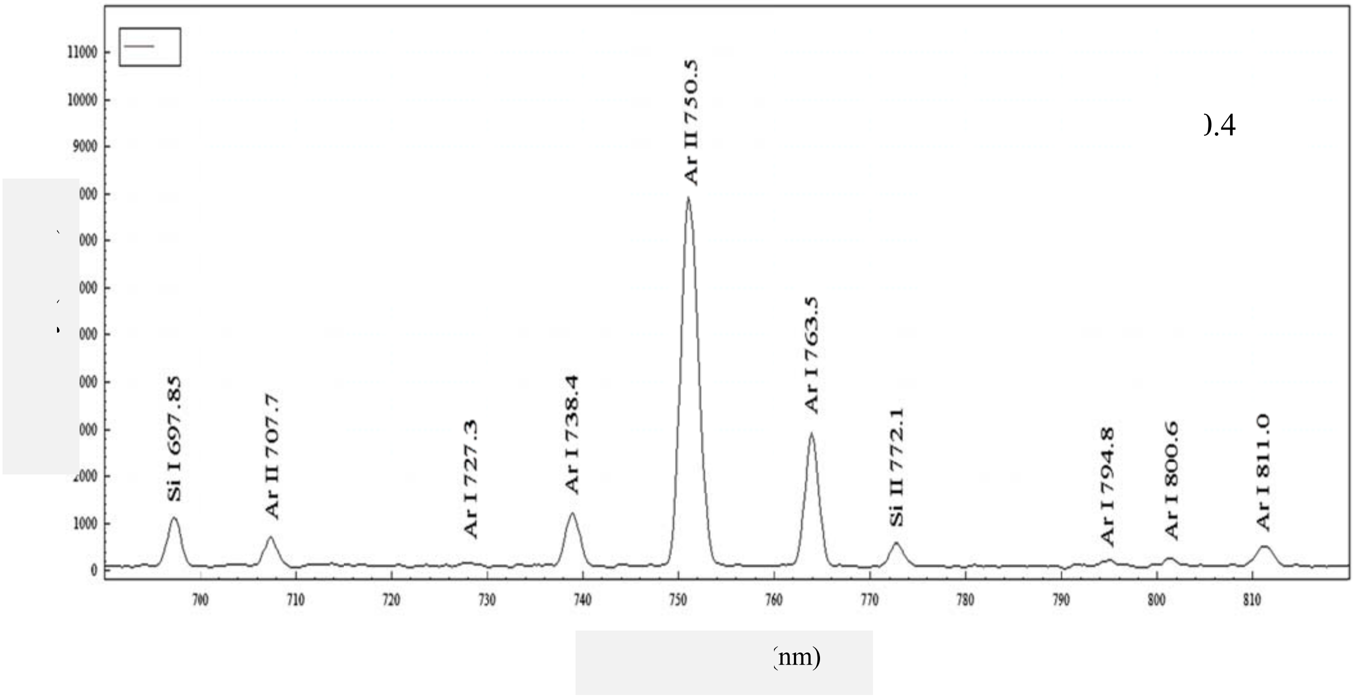

Fig. 3: The spectrum of Co-sputtering system.

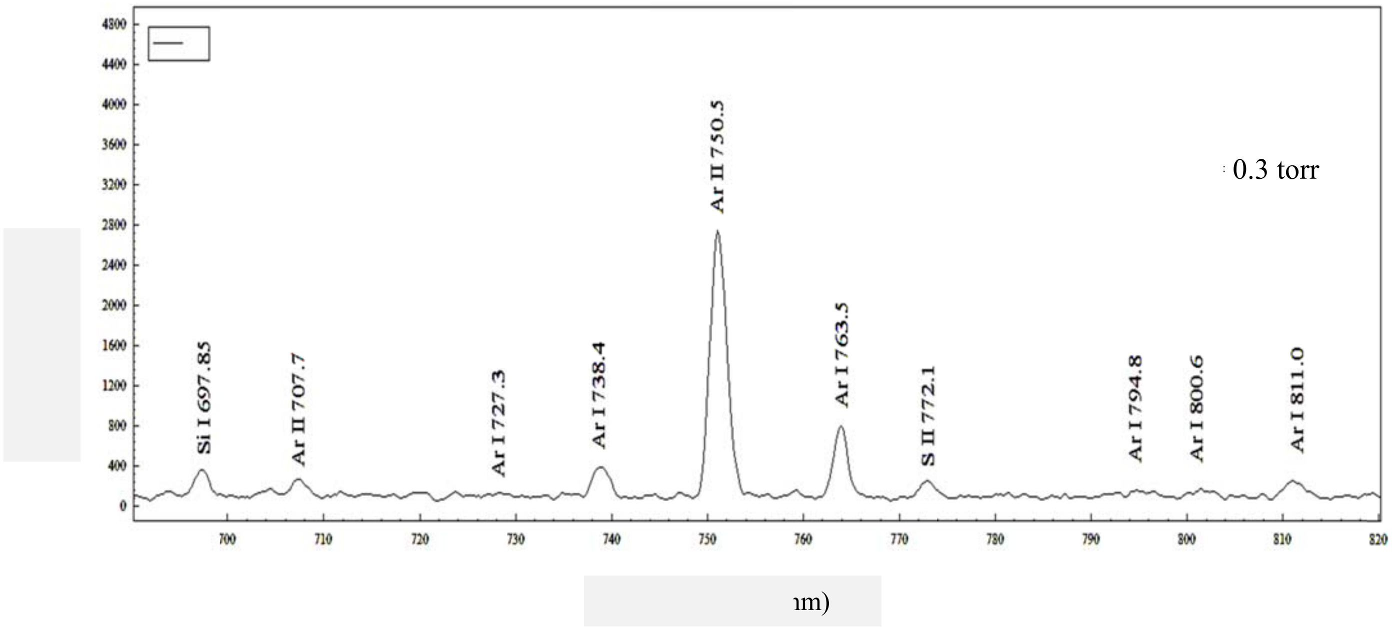

Fig. 4: The spectrum of Co-sputtering system.

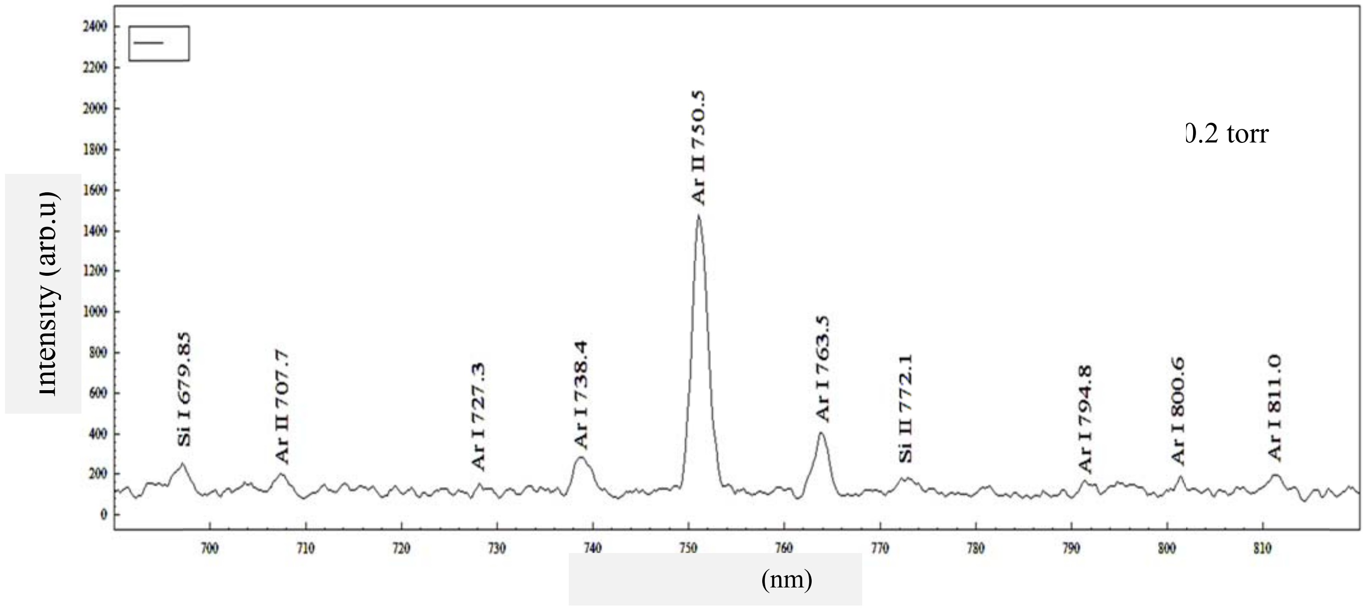

Fig. 5: The spectrum of Co-sputtering system.

Figs. (2-5) show the emission spectra recorded over a wide wavelength range (200–1100) nm. The spectra are mainly composed of silicon lines in the red/near-infrared spectral region (690–900) nm that belong to transitions configuration, the wavelength range was taken from (690–820) nm, that cover the whole experimental conditions explored in the study (different pressures 0.2 – 0.5Torr). It is found that this ratio decreases with the decrease of pressure.

Most of the processes occurring in a plasma depend on the electron (or ion) density and electron temperature were illustrated in Fig. 6. In sputtering as electrons get accelerated and gain energy from the power source, they transfer part of this energy to atoms, ions and molecules, if present in the plasma through collisions. Hence in order to have a better control on chemical or physical processes in a plasma, information about the electron energy distribution is important. The concept of electron temperature is applicable if electrons are in thermal equilibrium with each other. At low pressure, the density of species of argon is smaller and mean free path of free electrons is larger. However, by increasing pressure this path is not large enough to accelerate free electrons. Therefore, emission intensities increase and collisions among plasma species and electrons increase causing increase in species temperature by lowering electron temperature and hence high energy tail of electron energy distribution is quenched, these results are agreement with [9].

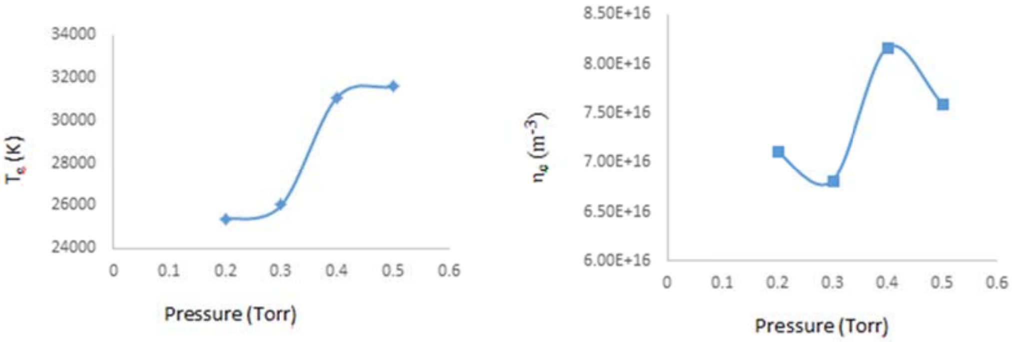

Fig.6: Electron temperature and electron densities as a function of pressure.

Electron densities and temperatures as a function of gas pressure are presented in Fig. 6. From the results that the electron temperatures and electron densities increase with the increasing of the pressure. This results illustrate evolution of electron temperature and density versus input power as well as filling pressure. Results predict that with increasing source power, electron temperature as well as electron density increase due to inelastic collisions of electrons, attaining enough energy which causes the excitation and ionization of argon atoms. The energy of secondary electrons increases excitation cross-section and decreases with electron energy.

Study of electron velocity give us description of high-energy electrons. These electrons help to ionize neutral noble gas atoms were show in Fig. 7. Created positive ions are accelerated towards the cathode with high energy and they bombard of cathode causes secondary electron emission and sputtering atoms from the cathode. Sputtered material of the cathode deposits thin films on the substrate placed near the anode was show in Fig.8. These results were compared and agreement with [9].

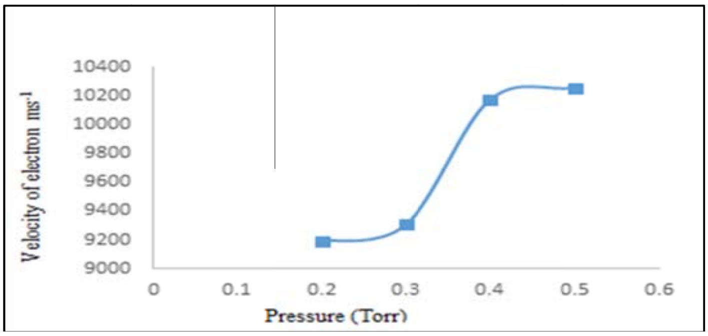

Fig.7: Electron velocity as a function of pressure.

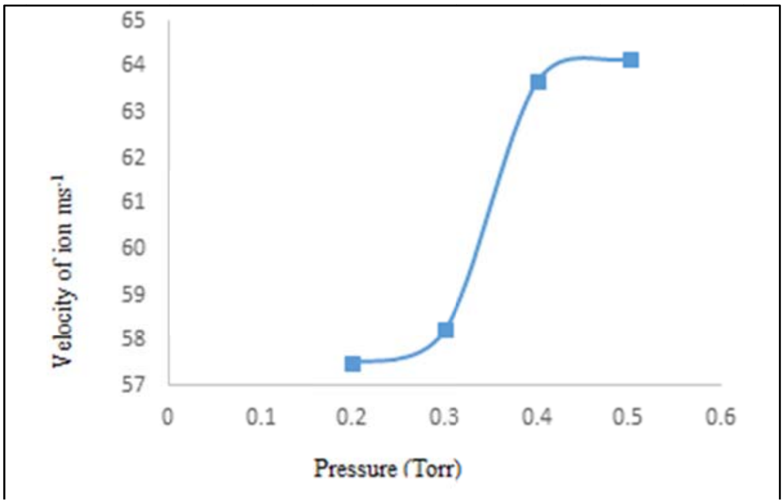

Fig.8: Ion velocity as a function of pressure.

Conclusion

In this work, the OES diagnostic was installed and tested to investigate the plasma parameters in the cylindrical D.C. co-sputtering apparatus. Using this technique at the low temperature weakly argon plasma were recorded. The increase of the intensity of spectral lines correlates with increase of the concentration of the particles emitting the light from the plasma volume and increase of the pressure. The results we get that the electron temperatures and electron densities increase with the increasing of the pressure. Finally, the electron and ion densities have an increasing with increasing the pressure, that reasons is illustrated above.

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