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Research Article

Calculation of Plasma Parameters in Co-Sputtering (Zn:Cu) System using Optical Emission Spectroscopic Technique

Kadhim A. Aadim and Rabah A. H. Edan*

University of Baghdad, College of Science, Department of Physics, Iraq

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Abstract

In the present work, we are calculated the parameters of plasma (electron temperature T_e, electron density n_e, electron velocity v_e and ion velocity v_i) using the optical emission spectroscopic (OES) technique by the spectrometer with wavelength (200 – 1100) nm, that collect the spectrum of plasma. Two cathodes were used (Zn:Cu) metals. In this research argon gas has been used at various values of pressures (0.6, 0.5, 0.4, 0.3, and 0.2 torr).

Keyword: *Co-sputtering, OES, Spectroscopy diagnostic*

Introduction

There is a growing interesting in the study of AC and DC discharges for their potential application in diverse industrial disciplines for surface modification, etching, Plasma assisted and plasma enhanced chemical vapor deposition. However, to be able to use the discharges in different applications, it is essential to have detailed information about plasma electron density and temperature and to have control on these parameters. The efficiency of the processes occurring in the plasma and there reaction rates are generally dependent on the density of the charged particles and their energies (A. Qayyum *et al*, 2003). 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 in diode or magnetron configuration. It is possible to configure a sputtering system such that two different target alternative materials are sputtered, with the power to each of the targets controlled independently. For alloys a sputtering system with two angled targets facing the same substrate may be used. If the two targets are simultaneously used during a single sputtering process, alloy films can be prepared using co-sputtering and the composition of alloy films can be simply controlled by adjusting the ratio of the powers applied to the two targets (M. Suhail *et al*, 2015; D. J. Christie *et al,* 2003) .Co-sputtering is one of the most important 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 (A. K. Singh *et al,* 2013; B.-Y. Oh *et al*, 2005).

The optical emission spectroscopy (OES) technique is one of the simplest and easy to implement and measurements are fast. The OES is passive and based on recording light emitted from the plasma. The most commonly used techniques for plasma diagnostics are mass spectrometry, optical methods and electric probes. Optical diagnostic techniques use photons to transmit information from the plasma to the detection tool and are the least intrusive in-situ plasma diagnostic methods. 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 (A. Kolpaková *et al,* 2011; N. V Joshy 2008).

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. The objective of plasma diagnostics is to obtain the information about the state of plasma by means of experimental analysis of the physical processes occurring in it. 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 (N. V Joshy, 2008; D. M. Devia *et al*, 2015).

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

*Corresponding author: **Rabah A. H. Edan**

(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 (D. M. Devia *et al*, 2015):

$$I_{ij} = \frac{hcA_{ij}g_j\, n}{\lambda_{ij}U(T)}\, e^{\left(\frac{Ej}{kT}\right)} \qquad (1)$$

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 (S. SHAH *et al*, 2014);

$$T_e = \frac{E_2 - E_1}{k}\left[\ln\left(\frac{A_2 g_2 I_1 \lambda_1}{A_1 g_1 I_2 \lambda_2}\right)\right]^{-1} \qquad (2)$$

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

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 (H. Shakeel *et al*, 2014 ; J. Cowpe, 2008);

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

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 (D. M. Devia *et al*, 2015);

$$v_{e,i} = \left(\frac{8kT_e}{\pi m_{e,i}}\right)^{1/2} \qquad (4)$$

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, D.C. co-sputtering deposition system was used for the study of (Zn:Cu) plasma. It consists of dual in which pure targets are connected to DC power supply as shown in Figure 1. The two cathodes were made of Zinc and Copper metal of 5.5 cm length and with a thickness of 1cm at its emitting edge. The anode, made of an aluminum disk of 15 cm in diameter, was located at a distance of 4 cm from the cathodes. Ar gas (99.9995% in purity) has been used at various values of pressures (0.6, 0.5, 0.4, 0.3, and 0.2 Torr). The sputtering power applied to the targets was fixed at 50W.

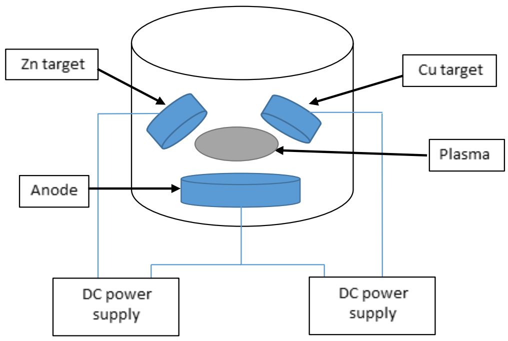

Figure 1: Schematic diagram of DC co-sputtering system

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 T_e 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.

Results and Discussion

Characteristic (OES) spectra of plasma taken in the wavelength regions of 640 – 840 nm are displayed on Figure (2).

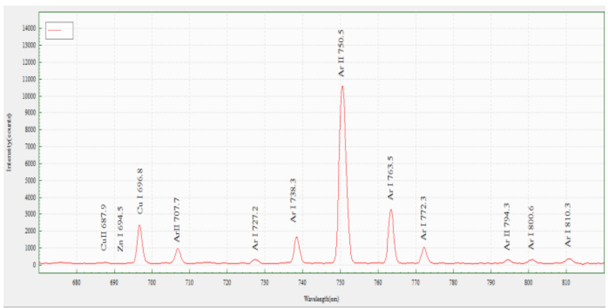

Figure 2: The intensity of spectral line in (Zn:Cu) plasma as a function of wavelength.

The emission lines appearing in the spectra are assigned according to neutral ArI, CuI, ZnI and ion ArII, CuII emission lines dominate the OES spectra. The two lines of Ar spectra are used (Ar II = 707.7nm and ArI = 763.5nm) that applied in the ratio method to obtain the plasma parameters (Te, ne, electron velocity and ion velocity).

Figure 3 shows the spectra of the emission are recorded over a wide wavelength range (200–1100) nm. The spectra are mainly composed of (Ar, Zn, Cu) lines in the red/near-infrared spectral region (600–900) nm that belong to transitions configuration, the wavelength range was taken from (640–840) nm, that cover the whole experimental conditions explored in the study (different pressures 0.6 – 0.2 Torr). It is found that this ratio decreases with the decrease of pressure.

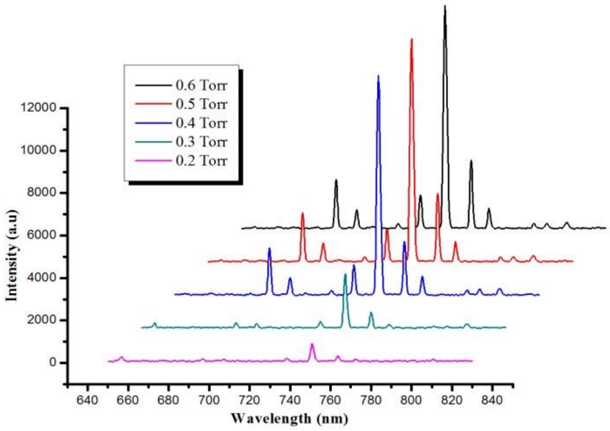

Figure 3: The emission spectrum lines as a function of pressure

Figure 4 shows that decreasing the glow of plasma with increasing of pressure, this yield to increasing the intensity of emission spectral line, because of the area of plasma has opposite behavior with pressure, as well as the mean free path of electron become large with decreasing the pressure.

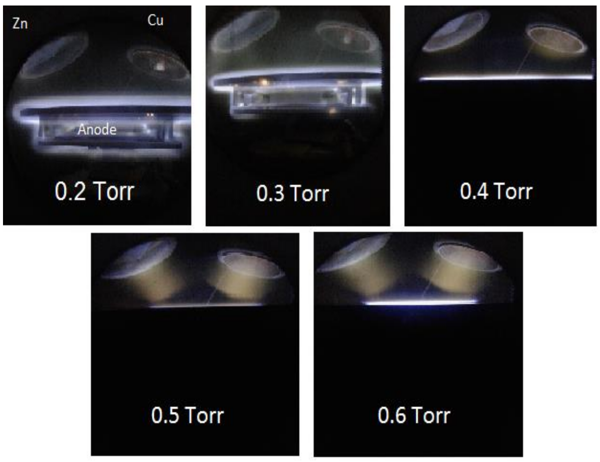

Figure 4: The changing of glow discharge plasma as a function of pressure

Most of the processes occurring in a plasma depend on the electron (or ion) density and electron temperature were illustrated in Figure 5. 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 (D. M. Devia *et al*, 2015).

Electron temperatures and electron densities as a function of gas pressure are presented in Figure 5. From the results that the electron temperatures and electron densities decrease 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 decrease due to inelastic collisions of electrons, attaining enough energy which causes the excitation and ionization of argon atoms.

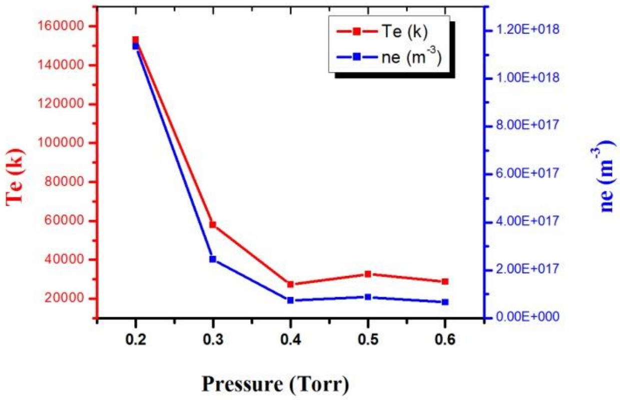

Figure 5: The electron temperature and electron densities as a function of pressure

Study of electron velocity give us description of high-energy electrons. These electrons help to ionize neutral noble gas atoms were show in Figure 6. 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 figure6. These results were compared and agreement with (D. M. Devia *et al*, 2015).

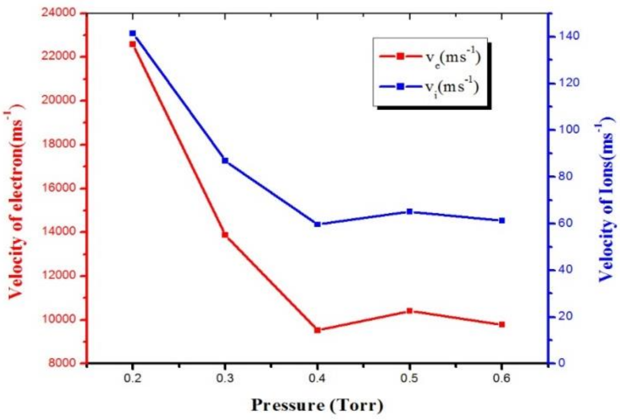

Figure 6: The electron and ion velocities as a function of pressure

Conclusion

In this work, the (OES) diagnostic was installed and tested to investigate the plasma parameters in the cylindrical co-sputtering apparatus. Using (OES) 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 decrease with the increasing of the pressure. Finally, the electron and ion densities have a decreasing with increasing the pressure, that reasons was illustrated above.

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