A Study of Plasma parameters in gold sputtering System by Means of Optical Emission Spectroscopy

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Abstract: This paper aims at shedding light on investigating the effect of varying plasma parameters of the magnetron sputtering system, the optical emission spectroscopy was used to reach the aim of the paper; i.e. intensity of spectral Ar-I and Ar-II lines, electron temperature (Tₑ), electron density (nₑ) with applied (300-700) V, and working pressure (0.5 – 3.5) mbar. The glow discharge plasma was produced by using Ar gas and gold as a sputtering target. The obtained results showed that the relationship between the spectral lines intensity and electron temperature is positive: the increase of them lead to an increase in the applied voltage while density of electron decreases as the applied voltage is increase in the range (350 – 550) V. Moreover, the Ar-I and Ar-II spectral lines and electron density increased while its electron temperature decreased following the rise of the gas pressure. The increment in emission intensity and electron density started to enhance or reduce from low pressure to medium and then increased nearly exponentially, while for high pressure no significance change was observed.

Keywords: Glow discharge, OES, Plasma diagnostic.

1. Introduction

The plasma production is considered an important topic, because it is a very effective method for the fabrication and post treatments of materials. Glow discharge plasma can be defined as a partially ionized gas forming from electron and positive ions and negative electron, and a big amount of neutral species. It is considered as one approach of plasma production under low pressure. Glow-discharge plasma can be easily generated by striking a high voltage electrical discharge through a low pressure gas system [1,2]. This can be done using DC, AC or more usually high frequency AC. The glow discharge of DC is achieved by applying an electric potential between two electrodes at moderate low pressures (10 – 100 Pa). The high electrical potential (0.1 – 10Kv) is sufficient to generate a plasma through breakdown. This also causes high emission due to the between excited atoms [3,4,5]. Compared to conventional methods, the sputter deposition presents an important advantage. For example, refractory material can be easily prepared by sputtering; better film adhesibilty from be accomplished, and this technique can preserve the stoichiometry of the complex chemical compound [6].

It the literature, it has been reported that the properties of physical thin films are found to be strongly dependent on the deposition technique and growth parameters as well as the film thickness [7,8] and nature of substrate. Current research on plasma focuses on plasma diagnostics. Important plasma parameters, such as chemical composition, plasma species, plasma density, potential of plasma, temperature of plasma, electron and ion energy distribution [9,10]. Can be determined through using various plasma diagnostic techniques, such as Langmuir probe, OES, mass spectroscopy, microwave interference [11,12,13].

OES is a practical technique to investigate glow discharge, because its simplicity and it has no perturbation in the plasma. The parameters of plasma and composition of gas are two essential factors in emitting the radiation of plasma. The aim of optical emission spectroscopy (OES) consists on measuring and analysing this radiation in order to obtain an insight into the plasma. By just measuring the radiation from the plasma there is no need to bring a probe system in contact with the plasma (like Langmuir-Probe or Multipol Resonance Probe), which might influence the plasma itself. Furthermore, OES enables to investigate very small plasmas. Therefore, it is often the only usable measurement...
technique in addition to laser absorption spectroscopy. One common remote diagnostic is OES, which is the optical part of the more general treatment of radiation. In OES, visible light is usually collected by a lens and focused onto the slit of a spectrometer [14,15]. From the information taken from OES, the temperature of electron and density of electron can be measured. The equations used to obtain electron density and electron temperatures are:

\[
\frac{l_1}{l_2} = \left( \frac{\lambda_{n,m,z}}{\lambda_{k,l,z}} \right) \left( \frac{g_{k,z}}{g_{n,z}} \right) e^{\left( \frac{-E_{k,z} - E_{n,z}}{kT_e} \right)} \\
ne = \left( \frac{2\pi m e}{\hbar^3} \right)^{3/2} \times \left( \frac{2A_{k,l,z} g_{k,z} A_{N,M,Z} l_z}{A_{n,m,z} g_{n,m,z} \lambda_{k,l,z} l_k} \right) e^{\left( \frac{-E_{k,z} - E_{n,m}}{kT_{ex}} \right)} \times T_e^{3/2}
\]

F.J. Vazquez et al. [16] reported an increase in the electron density and decrease in the electron temperature with increasing gas pressure, while electron temperature increases with increasing the power.

The aim of the this study is to study the evolution of the spectral lines intensity, temperature of electron and density of electron as a function of applied voltage and working pressure in Ar plasma discharge. Herein, up to the knowledge of the authors, it is important to highlight that several previous studies in the literature reported on the plasma electrical characteristics; however, few studies or even not have focused on plasma spectrum characteristics.

2. Experimental part

As shown in Fig. 1. The glow discharge plasma has been manufactured in homemade magnetron sputtering system; it consists of an evacuated chamber that includes cathode (a gold target) and anode (disk of stainless steel). The cathode facing the anode provides an electric field for the gas discharge. Gold (Au) has been used as a target; regarding the deamination, (4 cm) is the space between the two electrodes, and the target diameter is 2 cm. This discharge occurs by using argon gas (Ar) with a flow rate (40 sccm). Both the working pressure and applied voltage the have been varied in the range 0.5-3.5 mbar and 340-700 V.

The emission spectroscopy is a technique used for optical diagnostics of magnetron sputtering plasma. Radiation emitted from the plasma are collected by (Surwit technology V2100 - UV- NIR) spectrometer with spectral resolution (FWHM) of (>2.5 nm). including optical fiber and spectrophotometer are components of Optical system which is linked with collecting lenses.

![Figure 1. Optical emission spectroscopy experimental setup.](image)

3. Results and Discussion

The result of spectrum characteristic of discharge plasma (SCDP) paved the way on shedding the light on the homogeneity of the generated plasma. SCDP includes intensities, gas working pressure inside the vacuum chamber, are of importance to introduce, and electron temperature of electron and density of electron on the applied voltage. Wavelength observed spectral lines along with their relevant
spectroscopic data are displayed in Table. 1. Depending on the (National Institute of Standards and Technology Atomic Spectra Database) (NIST) 
Typical argon discharge plasma spectrum obtained under previous operational conditions is shown in Figs. (2-5). In fig.2 it is apparent that the intensity of Ar I and Ar II growth with increasing applied voltage. This fact can be explained as follows, by increasing the power, the degree of ionization, as well the electron energy increases, so the electron-neutral influence excitation ratio will growth. The electron transfers their energy by influence with other particles and excites them. In fig.3 the variant of spectral lines intensities for Ar I and Ar II at different working pressures. At lower working pressures, the spectral lines intensities are increasing with increasing pressure, but with rising in working pressure the intensity of spectral lines suffer saturation. These results can be attributed as;at lower pressures not all the electrons that have adequate energy for excitations suffer collisions with the other particles. With increasing working pressures, the plasma density increases and the frequency of collisions became higher. In this situation, almost all electrons can transfer their energy by influencing on other particles and can excite them de-excitation, the atoms and ions release spectral line. 
We can say the relation between optical emission intensities with pressure when the power at constant value is exponential
The results indicate that Ar I and Ar II intensity rise when the supplied voltage rises, since enhancing the electric field accelerates ions and electrons as consequence collide with atoms of the working gas and this leads to generate new free electrons and positive ions. Similarly, Ar I and Ar II intensity rise when the working pressure rises as well. The collisions between the gas atoms and the electrons are higher when the chamber pressure increases, [17]. As shown in Figs. (6-7) displaying curves of the electron temperature and electron density versus applied voltage, the temperature of electron rise while the density of electron decrease with the rise in the applied voltage when the pressure is constant. This can be attributed to the increase of electron collisions with argon atoms resulting in a decrease of the electron energy.
Figs. (8-9) highlight the behavior of electron temperature and electron density under different working pressure of argon gas at constant applied voltage. The ionization process decrease because the chamber pressure increases this will decrease the electron energy and the mean free path. At higher pressure, the number of atoms and molecules becomes larger; thus the mean free path is reduced and the collisions rate of electrons with atoms is enhanced. During inelastic collisions, instead of gaining energy by the electrons from the electric field, more energy is transported from electrons to species of plasma. The collisions rate of electrons with atoms and chamber wall gets higher. Hence, the acquired energy of electrons decreases while the density of electron increases and the temperature of electron decrease [9, 18, 19].

| Element | λ (nm) | A (10^5) | gk | Ek (10^-3) |
|---------|--------|----------|----|------------|
| Ar I    | 573.952| 8.70E+05 | 5  | 15.312729  |
| Ar I    | 653.811| 1.1E+05  | 7  | 14.97152223|
| Ar I    | 696.025| 2.4E+05  | 5  | 14.95260461|
| Ar I    | 703.025| 2.7E+06  | 5  | 14.83881088|
| Ar I    | 731.600| 9.60E+05 | 3  | 15.02208821|
Figure 2. The plasma intensity as a function of different applied voltage.

Figure 3. The plasma intensity as a function of different working pressure.
Figure 4. The plasma intensity as a function applied voltage.

Figure 5. The plasma intensity as a function working pressure.

Figure 6. The electron temperature as a function applied voltage.
Figure 7. The electron density as a function applied voltage.

Figure 8. The electron temperature as a function working pressure.

Figure 9. The electron density as a function working pressure.
4. Conclusion

Optical emission spectroscopy has been used to obtain plasma parameters in magnetron sputtering system during sputter of gold thin films under conditions of applied voltage (300-700) and working pressure (0.5 -3.5) mbar. The plasma electron density and temperature are completely effect by spectral emission; however, applied voltage is mainly used to the rise the temperature of electron but is decreasing on electron density. The working pressure effect is restricted to increase the density of electron plasma while decreasing the plasma electron temperature of electron.

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