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Measurement of Electron Temperature (T_e) and Electron Density (n_e) of ZnO RF Plasma

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ABSTRACT

In this study, the ratio method between the two spectral lines was used to calculate the electron temperature (T_e) and the density (n_e) of argon gas for a zinc oxide (ZnO) cathode using the spectroscopic method. These parameters were calculated at various pressure and powers parameters (0.03,0.04,0.05,and 0.06 torr) and (50,60,70 and 80 W). The results revealed that while the temperature (T_e) increase of the electron with increased power and falls with increasing pressures, the density (n_e) of the electrons increases with both power and pressure increases. The measured temperature of the electrons (T_e) was within the range of (0.372-0.422 eV).Regarding the electron density (n_e), it was in the range of (1.6×10^{17}-7.8×10^{17} cm^{-3}).

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قياس درجة حرارة الإلكترون (T_e) وكثافة الإلكترون (n_e) لبلازما الترددات الراديوية لاوكسيد الزنك

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الكلمات المفتاحية:

مقياس طيف الانبعاث الضوئي
درجة حرارة الإلكترون (Te)
بلازما الترددات الراديوية

الـــخُـــلاصـــة

في هذه الدراسة ، تم استخدام طريقة النسبة بين الخطين الطيفيين لحساب درجة حرارة الإلكترون (T_e) وكثافة (n_e) لغاز الأركون لكاثود أكسيد الزنك (ZnO) باستخدام الطريقة الطيفية.و تم حساب هذه المعلمات في مختلف معاملات الضغط والقدرة (0.03,0.04,0.05, 0.06 torr) و (50,60,70 , 80 W). حيث أظهرت النتائج أن عندما تزداد درجة حرارة الإلكترون مع زيادة القدرة وتنخفض مع زيادة الضغط . وتزداد كثافة الإلكترونات (n_e) مع زيادة كل من القدرة والضغط. وكانت درجة الحرارة المقاسة للإلكترونات (T_e) في مدى (0.372-0.422 eV) وان كثافة الإلكترونات (n_e) كانت في مدى (1.6×10^{17} – 7.8×10^{17} cm^{-3}).

1. INTRODUCTION

For diagnosing plasma in a lab or in space, there are several spectrum techniques. In a laboratory, low-density plasma emits electromagnetic radiation relative to the plasma space due to its low temperature. Plasma characteristics, such as density and temperature, are ascertained by analyzing the radiation's spectrum[١].And In many scientific institutions, sedimentation processes are also seen[٢]. When a certain amount of energy is obtained, the electrons get irritated, which causes the plasma emission spectrum and energy emission from a photon equal to the energy difference between the two levels, electrons move to a lower energy level[٣]. The plasma spectrum is often split into two parts: the absorption spectrum and the emission spectrum. Either of these two spectrums, or just one of them, can be used to diagnose plasma, although the absorption spectrum is more useful for this purpose[٤]. The density of electrons(n_e) is among more important characteristics in gas discharges, and plasma diagnosis is essential to understanding discharge physics and optimization. The Langmuir probe, Laser heterodyne interferometry, Laser Thomson scattering, and optical emission spectroscopy are common techniques for determining the electron density (OES). Due to the small discharge size and robust collision processes, the probe approach is not appropriate for measuring the electron density of non-thermal air pressure plasmas. The use of laser diagnosis in practical applications is further constrained by the complex and pricey laser setup. OES is simple, practical, affordable, and widely employed in academic and industrial research[٥]. According to the range of available energy levels, various kinds of atoms, ions, and molecules are dispersed. Based on this, ased on this, the electron temperature (T_e) and electron density (n_e) of the plasma are determined.There are several methods for measuring the temperature of an electron; some depend on the density of two spectral lines, while others depend on just one. As a result, the Te electron temperaturecan be calculated using equation[٦].

$$T_e = -\frac{E_k - E_i}{K}\left[ln\left(\frac{A_k g_k I_i \lambda_i}{A_i g_i I_K \lambda_K}\right)\right]^{-1} \quad \ldots\ldots\ldots(1)$$

where **E:** is the corresponding level's energy, **K** :Boltzmann constant, **A:** is the probability of transition, λ: is the wave length, and $\mathbf{g_i}$ is the upper level's statistical weight,$\mathbf{g_k}$ the statistical weight of the lower level, $\mathbf{E_i}$:The energy of the higher level. **i** and **k** represent for the transition's upper and lower energy levels, respectively. This formula is properly known as the electronic excitation temperature or excitation temperature (**In 1986, Guo & Zhao**)[٧]. E : energy level , Ag : Transition probability data obtained from NIST(stands for the National Institute of Standards and Technology), also The values of $(E_k, E_i, A_k g_k, A_i g_i)$, and are obtained from the (NIST) atomic spectral database. The formula may be used to obtain the electron density[٩،٨].

$$n_e = \exp(44.247 + 1.20\, ln\, \Delta\lambda_{1/2} - 0.6\, lnT_e) \quad \ldots\ldots\ldots\ldots\ldots\ldots(٢)$$

where, $\mathbf{n_e}$:represents number density of electrons in cm^{-3}, $\mathbf{T_e}$: electron temperature in K and $\lambda_{1/2}$:the width of any line at half its greatest intensity, where the electron density(n_e) proportional with $\lambda_{1/2}$. There are various techniques to measure the density of an electron, including the Doppler and Stark expansion methods(**In 2004, Brugeat., & Coitout**)[١٠] .In their study of the techniques for measuring electron temperature (T_e) and electron density (n_e) using optical emission spectroscopy to measure capacity in low-pressure nitrogen and argon discharges (OES).Cylindrical cathode (HC)was used as a source of glowing discharge plasma at low pressure.The optical description of the system was done by recording emission spectrum for wavelengths emitted from plasma in spectral range (190-1000) nm. The electron temperature was measured throughcalculating approximatelyintensity's ratio of two lines.Via the conditions that the inner cylinder diameter was R = (3,6) cm; supply voltage, (300-900)V .Also, a study of effect of gas pressure and voltage change along plasma discharging was done and the temperature of electron for plasma estimated spectrally between (0.8-1.3) eV and the density of electrons ($2.8x10^{15}$-$7x10^{17}$) cm^{-3}. (**In 2019, A. Khadayeira, A., & M.Taher, W**)*[١١]*. In this paper ,using optical emission spectroscopy of Argon Plasma for Zinc Oxide Cathode by RF power, to study different plasma calculate the electron temperature(T_e) and plasma density(n_e).

2. EXPERIMENTAL

The system consists of three main parts of the RF magnetron spraying system: the vacuum chamber, the vacuum pump and the RF power supply. (Diagram 1). The RF system is illustrated in the diagram(Figure:1) and manufactured by Zhengzhou CY Scientific Instrument Co., Ltd. In China. Pure zinc oxide cathode was used, distance between cathode and anode (8 cm), target diameters used (2 mm × 5 cm), maximum RF power (200 W) at 13.56 MHz. Pure argon gas (99.9%) was used and pumped to generate plasma in the chamber and controlled by a fluorometer. Several pressures values (0.03 to 0.06 torr) were used and the pressure inside the chamber was measured with a Pirany balance (Edwards) as well as different values for power (50,60,70,80 W) were used. By electronically monitoring the agitated species, their temperature (T_e) and density (n_e) in the argon plasma discharge, the spectra in the range of (312 - 913.5 nm) were recorded immediately after the plasma flow, and a spectrophotometer (S 3000 - UV- NIR) was used to measure the flow of plasma.

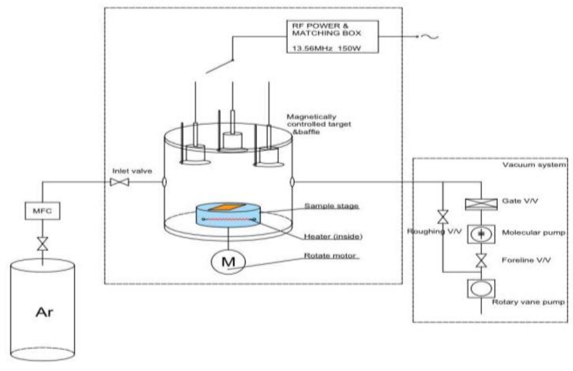
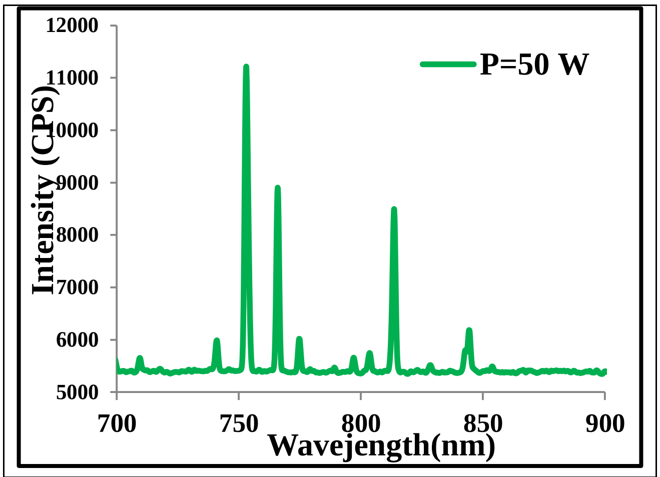


Fig.1. Plasma RF system.

3. RESULT & DISCUSSION

The spectral lines (766, 812 nm) were chosen when the power was at and the pressure values were (0.03, 0.0.4, 0.05 and 0.06 torr) and the power was at (50, 60, 70, 80, 80 W. The pressure used was (0.03 tor), and the power used (50,70 W), these two figures serve as an example of how the power increases when pressure is confirmed and how the intensity of the spectral lines changes. As in **Fig. 2.** The emission shows the spectra in plasmas with different values of energy for a radio frequency plasma at a pressure (0.03 torr).



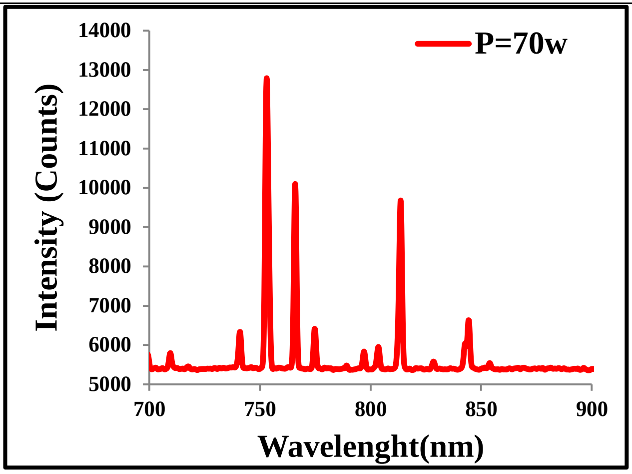


Fig.2. Emission spectra in plasma at different values of power the RF plasma at a pressure of 0.03 torr.

The electron temperature was calculated by equation (1) and **Table (1)** presents the electron temperature (**T_e**) with different values of pressures and power.

Table(1): shows the values (T_e) of the (ZnO) cathode aat various pressures and powers.

Power (w)	0.03 T	0.04 T	0.05 T	0.06 T
	T_e (eV)			
50	0.401	0.392	0.381	0.372
60	0.410	0.402	0.394	0.382
70	0.416	0.410	0.403	0.395
80	0.422	0.415	0.410	0.403

Fig.3. shows the temperature of the electron that seems to rise for each state as the power supplied at constant pressure increases. This implies that when the rate of excitation of neutral atoms and electrons grows and temperature rises, this causes an increase in energy, which results in the production of various spectral lines, increasing the energy of the electron and degree of ionization, Agree with the reference [12].

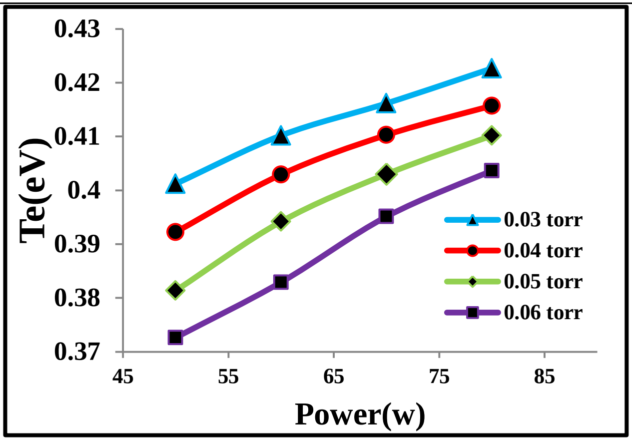


Fig.3. The change T_e with the power when pressure is constant.

Fig.4. shows how the temperature of electron (Te) decreases when pressure increases but with power remains constant because as gas flow increases, more gas atoms and electrons collide, transferring more energy from the electrons to the gas molecules increases and leads to an increase in the gas temperature through a decrease in the temperature of electrons, agree with the reference [١٢].

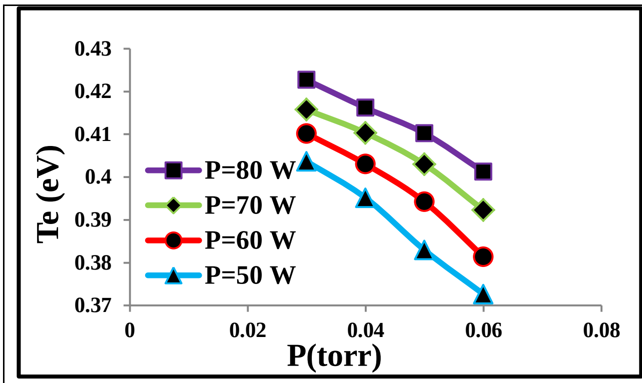


Fig.4. Shows the change in electron temperature with pressure at constant power.

Equation(2) was used to measure the density of electron (n_e),and the density (**n_e**) was calculated at various pressures (0.03, 0.04, 0.05 and 0.06 torr) when the power values (50, 60, 70, 80W). By substitute the electron temperature in equation (2) to obtain the electron density (**n_e**), electron temperature (T_e) values obtained previously from the equation (1). **Fig. 4.** Shows the change in electron density with the power applied to pressure stabilizers for each case.

Fig. 5. Shows a change between the electron density and the power at constant pressure. As the power is increased at constant pressure the electron density rises because the electrons' heat and speed increase as they collide with neutral atoms or molecules which in turn raises the electron density , this agreed with behavior of reference*[١٤]*.

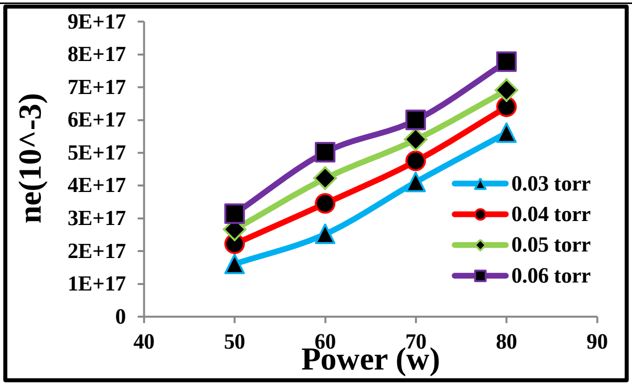


Fig.5. Shows change between electron density and power when pressure is constant.

Fig.6. Shows a change between the electron density (n_e) and pressure when power is constant **.**When the power is constant, it shows a change in the electron density as a function of pressure, as we can notice that the electron density rises as the gas pressure is increased because more atoms or gas molecules are present which causes more collisions and an increase in the rate at which the atoms become ionized increasing the electron density, Agree with the reference [15].

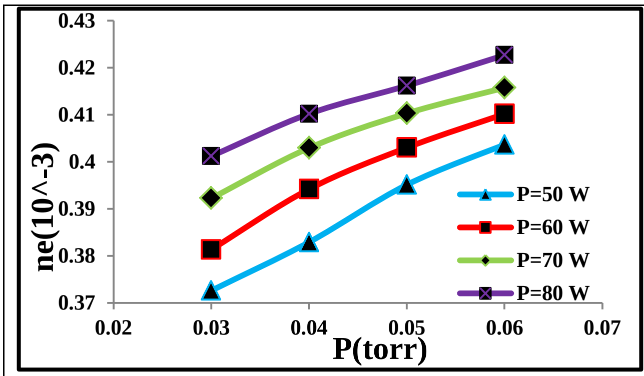


Fig.6. Shows change between electron density and pressure when power is constant.

4. CONCLUSION

Optical emission spectrometry (OES) was used to study the plasma parameters (T_e and n_e) of argon plasma. It was observed that raising the applied power increases the temperature of the electron and it was in the range of (0.37 -0.42 eV). The electron temperature (T_e) decreases with the increase of the gas flow rate, which indicates that the increase in the gas flow rate cools the plasma. The electron density (n_e) also increased with increasing applied power and gas pressure and was in the range of (1.6×10^{17} - 7.8×10^{17} cm^{-3}).

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