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Effect of Argon and oxygen pressure on Zn magnetron plasma produced by RF power supply

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Abstract

In this work, the plasma parameters (electron temperature and electron density) were determined by optical emission spectroscopy (OES) produced by the RF magnetron Zn plasma produced by oxygen and argon at different working pressure. The spectrum was recorded by spectrometer supplied with CCD camera, computer and NIST standard of neutral and ionic lines of Zn, argon and oxygen. The effects of pressure on plasma parameters were studied and a comparison between the two gasses was made.

Key words
RF magnetron, spectroscopy, ratio method, plasma characteristics.

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تاثير ضغط الاركون والاوكسجين على بلازما الخارصين الممغنطة والمتولدة بواسطة مجهزقدرة ذوالترددات الراديوية

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الخلاصة

في هذا العمل، تم تحديد معلمات البلازما (درجة حرارة الإلكترون وكثافة الإلكترونات) من خلال تحليل طيف الانبعاث الضوئي (OES) التي تنتجها بلازما الترددات الراديوية الممغنطة للخارصين RF المتولد بوجود الأوكسجين والأركون و بالضغوط المختلفة. تم تسجيل الطيف بواسطة المطياف اوالمجهزبكاميرا نوع CCD، الكمبيوتر، NIST لخطوط الطيف الذرية والأيونية للزنك، والأركون والأوكسجين. وقد تم دراسة تأثير الضغط على معلمات البلازما وتم المقارنة بين الغازين.

Introduction

Thin films, which used in many applications, have been prepared by different techniques such as continuous direct current (DC), pulsed mid-frequency (MF) and radio-frequency (RF) sputtering from either metallic, alloyed or ceramic targets. Among these techniques, RF sputtering has gained special attention owing to a good product quality and high yield[1]. Also RF plasma used to produce nanoparticles for enhancing photovoltaic devises [2] and etching process [3].

OES is one of the fundamental plasma diagnostic methods. It is used elemental content investigation [4]. Also it is a common tool used in various plasma kinds to obtain information about the nature of plasma, such as plasma density, electron temperature, chemical compositions and species within plasma [5]. Optical emission study was help to obtained high quality thin films.

For the case of local thermodynamic equilibrium (LTE), the spectral line intensity can also be described as [5]:

$$I_{ji} = \frac{N}{U(T)} g_2 A_{ji} h\upsilon_{ji} e^{-E_j/kT} \qquad (1)$$

where g_j is the density of states, E_j is the upper level energy and T is the excitation temperature. So, the electron temperature of plasma can calculated using ratio method between atomic and ionic lines for same species depending on the equation [5].

$$\frac{I_1}{I_2} = \frac{g_2}{g_2}\frac{A_1}{A_2}\frac{\lambda_2}{\lambda_1} e^{[-(\frac{E_1-E_2}{kT})} \qquad (2)$$

The electron number density in the plasma can be measured through different methods such as; measurement of the optical refractivity of the plasma [6], the measurement of the absolute emission coefficient of spectral line and measurement from Stark profile of certain optically thin emission spectral lines [7].

The electron density can be calculated, utilizing stark broadening relation using the relation

$$n_e(cm^{-3}) = \left[\frac{\Delta\lambda}{2\omega_s(\lambda,T_e)}\right] N_r \qquad (3)$$

where, Δλ is the FWHM of the line, and ω_s is the Stark broadening parameter, that can be found in the standard tables N_r is the reference electron density which equal to 10^{16} (cm^{-3}) for neural atoms and 10^{17} (cm^{-3}) for singly charged ions

Experimental work

Fig. 1 shows the schematics diagram of plasma magnetron sputtering system which consisting of a cylindrical glass chamber with a base and cover made from aluminum. The chamber is evacuated by double stage rotary pump and the pressure was noticed by pressure gauge (perani type Edward). The gas flow was controlled by needle valve and flow-meter. Stainless steel anode of 4 cm diameter and zinc cathode of 3.75 cm diameter, separated with 4 cm. Cathode equipped with two circular concentric permanent magnets for confining plasma on the cathode to enhance the sputtering. RF power supply of 4 MHz frequency were used in the experiment. Optical fiber transfer the emission light to photo spectrometer device, connected with a computer, to record the plasma emission spectra which emitted from the plasma species as argon and oxygen gas, at different pressures (0.05 to 0.4) mbar.

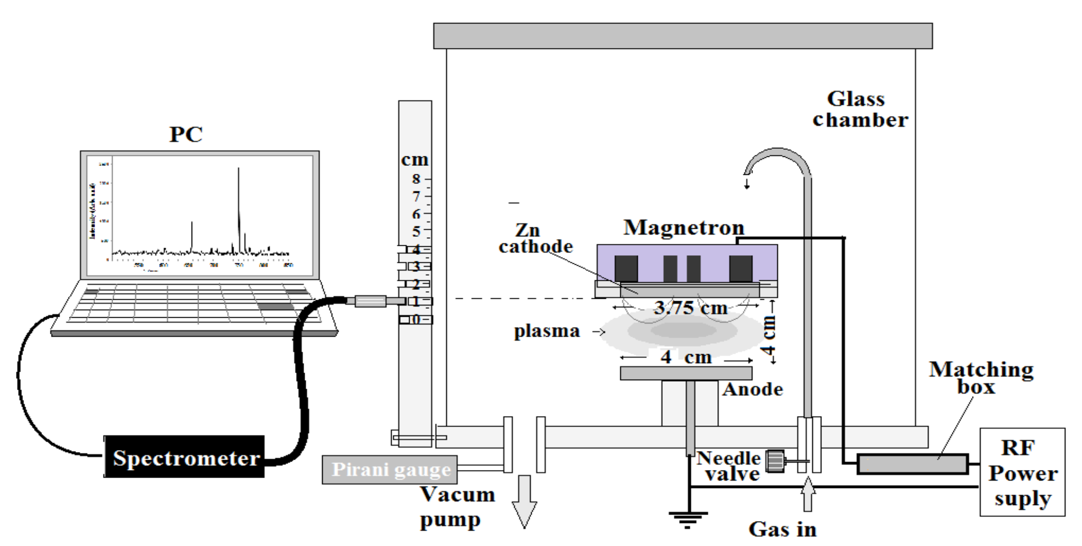

Fig. 1: Schematic diagram of plasma magnetron sputtering system.

Results and discussion

The optical emission spectra of RF Zn plasma in Ar and O_2 gases using Zn target were recorded by optical emission spectrometer at different working pressure. Fig. 2 shows the spectroscopic patterns for emission spectra from RF plasma in argon at different working pressure (0.05, 0.06, 0.08, 0.1, 0.2 and 0.4) mbar. this spectra contained strong standard lines belong to (Ar I, Ar II and Zn I, Zn II) [8]. There are many atomic and ionic argon and zinc spectra lines. It can be noticed that the intensity corresponding to atomic lines increase, while the intensity for ionic lines decrease with increasing pressure, as a result of decreasing plasma temperature which leads to decrease the number of ionized atoms comparing with neutral atoms. The peak at 656.3 nm for Hα emission appears in all spectrum as a result of the presence of water vapor desorbed from discharge chamber walls.

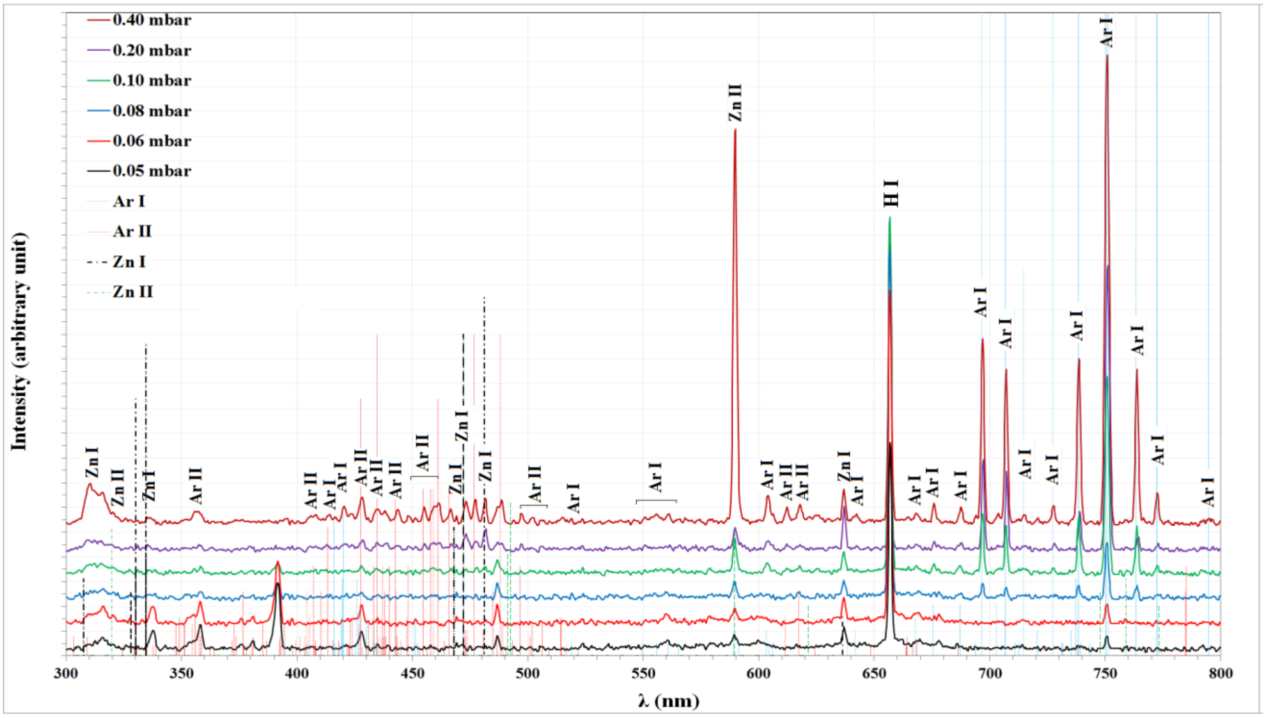

Fig. 2: Emission spectra for RF plasma in Ar with different working pressure using Zn target.

The electron temperature is calculated by the ratio method using two lines Ar I at 750.38 nm and Ar II at 357.66 nm for different working pressure. these two lines selected because they are isolated and presence in all spectrum, also because of the high difference of their upper energy levels seeking more measurements accuracy [9].

Fig. 3 shows the 427.75 nm Ar I peak profile where full width at half maximum found by Gaussian fitting. The electron density determined from the fitting peaks at different pressures using Stark effect depending on the standard values of broadening for this line [10]. It can be seen that the full width increase with increasing pressure.

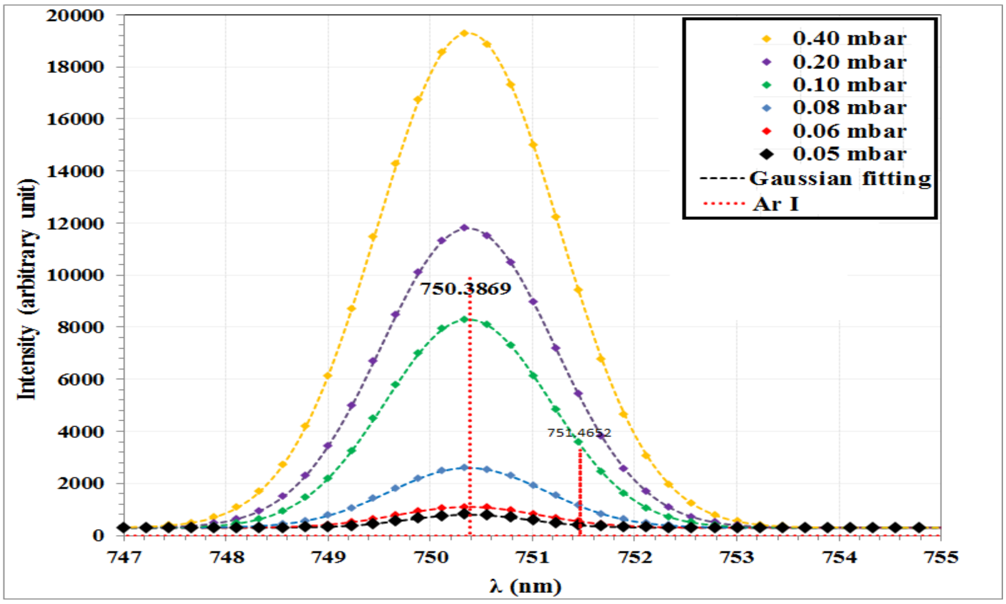

Fig. 3: Ar II 427.75 nm peaks broadening and there Gaussian fitting at different pressure.

The variation of electron temperature (T_e), calculated by the ratio method, and electron density (n_e), using Stark broadening effect with working pressure were shown in Fig.4. This figure shows that n_e increase with increasing working pressure from 0.05 to 0.4 mbar as a result of increasing electron – neutral collisions, which leads to create more electrons and ions. The increment in collision also caused reducing the mean values of electron temperature as a result of losing electron energies in many ways such as electron collisions with plasma species [11]. At high pressure n_e being near stable as a result of reducing the electron mean free path which not allowed the electrons to gain the needed energy excite or ionize more atoms. These results are agree with Hassouba (2014) [12].

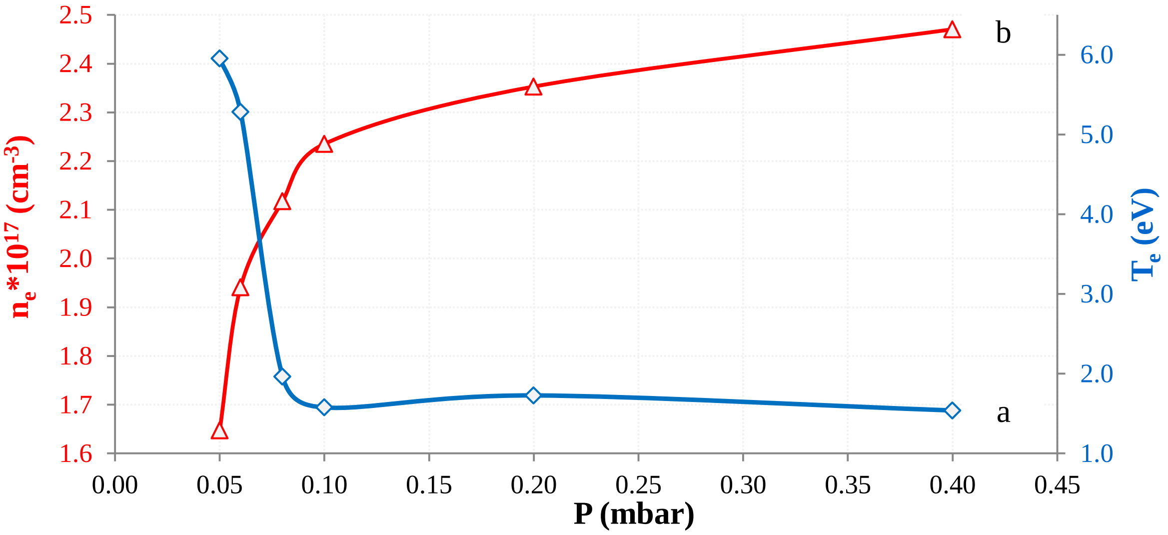

Fig. 4: The variation of (a) T_e and (b) n_e for RF plasma in Ar with different working pressure.

Table 1 shows the calculated values of Debye length (λ_D), plasma frequency (f_p) and Debye number (N_d) for RF Zn plasma in argon at different working pressure.

Table 1: Plasma parameters for RF plasma in Ar with different working pressure.

P (mbar)	T_e (eV)	$n_{e*}10^{17}$ (cm^{-3})	f_p (Hz) *10^{12}	λ_D *10^{-5}(cm)	$N_{d*}10^{4}$
0.05	5.952	1.65	3.644	4.466	6.147
0.06	5.283	1.94	3.956	3.860	4.678
0.08	1.964	2.12	4.132	2.254	1.016
0.10	1.577	2.24	4.246	1.965	0.711
0.20	1.728	2.35	4.356	2.005	0.795
0.40	1.539	2.47	4.464	1.847	0.652

Fig. 5 shows the emission spectra of RF Zn plasma in oxygen gas at different working pressure. This spectra have strong lines for OI, OII, ZnI and ZnII [8]. The intensity corresponding to the atomic lines increase, while the intensity for ionic lines decrease with increasing pressure.

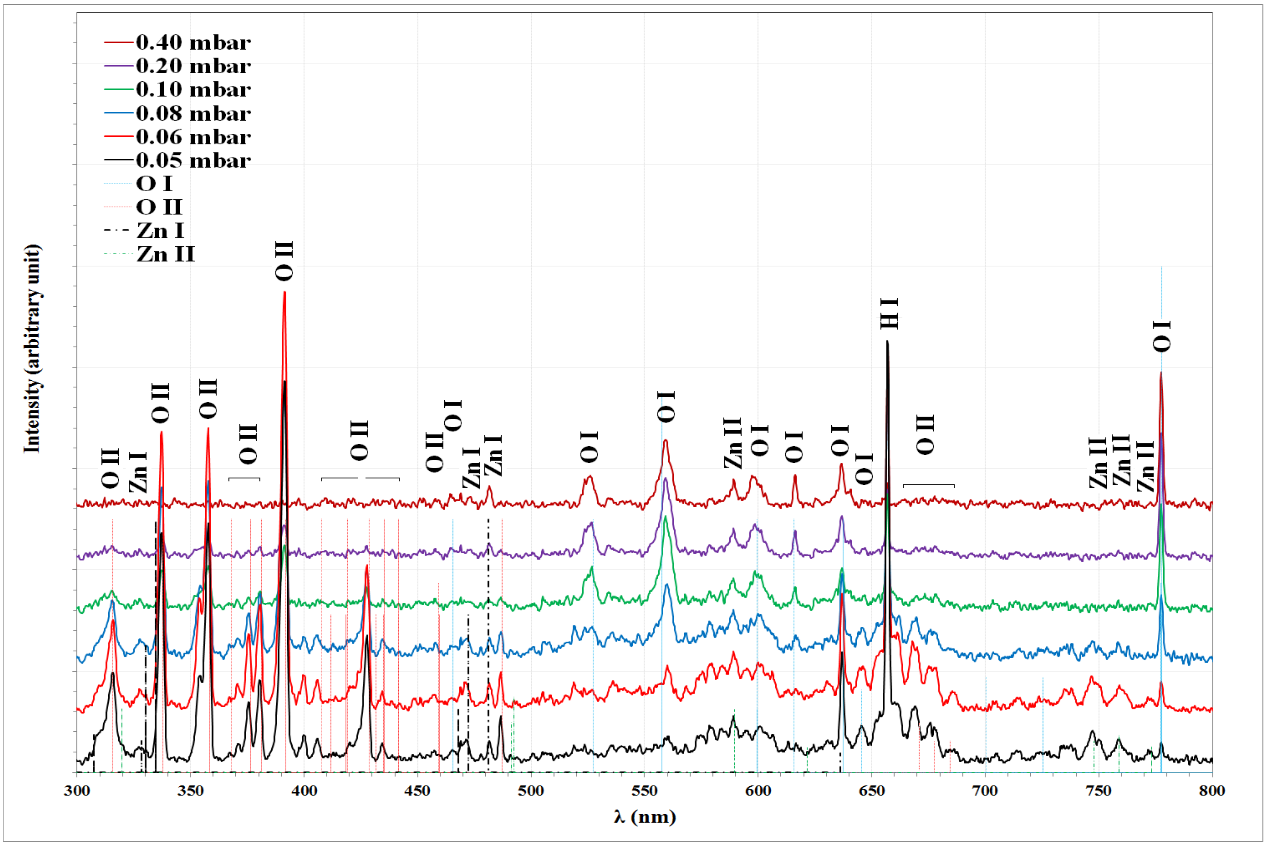

Fig. 5: Emission spectra for RF plasma in oxygen with different working pressure using Zn target.

Fig. 6 shows the 777.53 nm OI peak profile where its full width at half maximum was found by using Gaussian fitting to calculate electron density at different pressures using Stark effect depending on the standard values of broadening for this line [10]. It can be seen that the full width increase with increasing pressure.

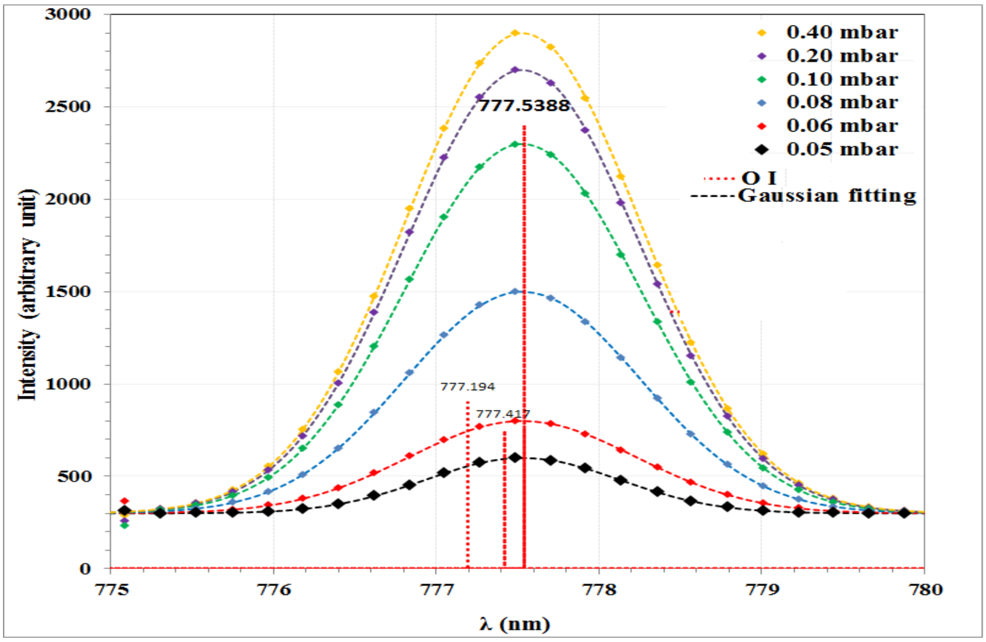

Fig. 6: Cu I 324.754 nm peaks broadening and there Gaussian fitting at different pressure.

The variation of electron temperature (T_e) and electron density (n_e), in oxygen plasma, with working pressure were shown in Fig. 7. Both n_e and T_e in oxygen plasma varied and behavior by the same manner as in argon plasma with working pressure but with higher n_e values and less T_e values.

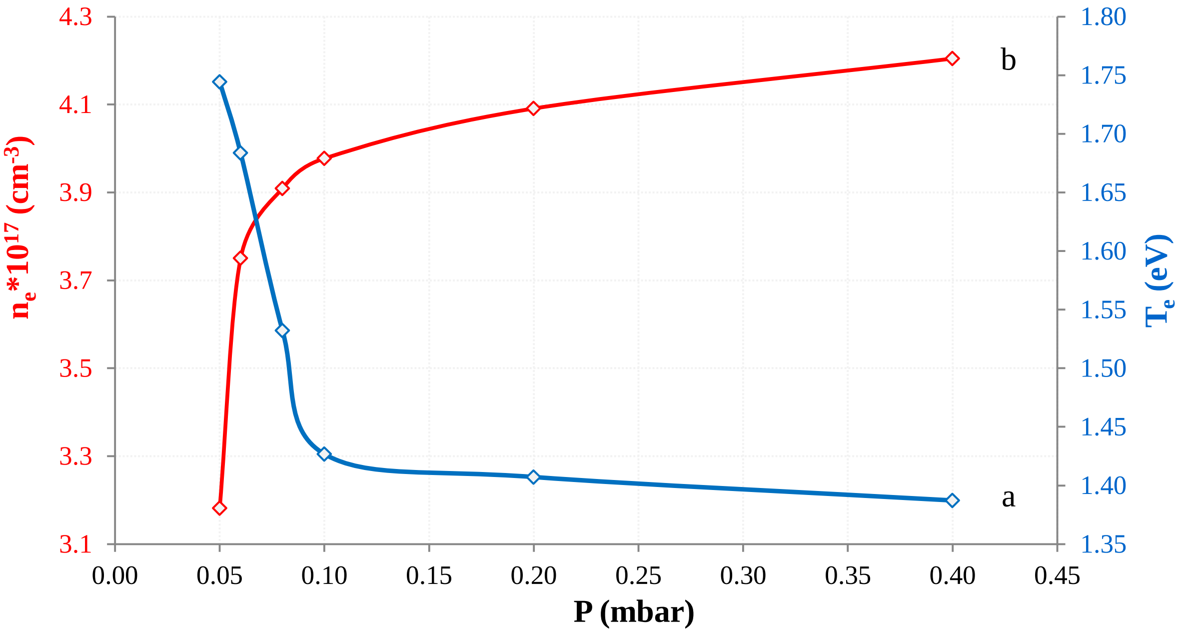

Fig. 7: The variation of (a) T_e and (b) n_e for RF plasma in O_2 with different working pressure.

Table 2 shows Debye length (λ_D), plasma frequency (f_p) and Debye number (N_d) at different laser energies. All calculated plasma parameters, Debye length, plasma frequency and plasma number, were satisfied the plasma conditions.

Table 2: Plasma parameters for RF plasma in oxygen with different working pressure.

P (mbar)	T_e (eV)	n_e*10^{17} (cm^{-3})	f_p (Hz) *10^{12}	λ_D *10^{-5}(cm)	N_d *10^4
0.05	1.744	3.18	5.065	1.740	0.702
0.06	1.684	3.75	5.499	1.568	0.606
0.08	1.532	3.91	5.615	1.465	0.515
0.10	1.427	3.98	5.663	1.402	0.459
0.20	1.407	4.09	5.744	1.372	0.443
0.40	1.387	4.20	5.823	1.344	0.428

Conclusions

Study of the effect of pressure on plasma glow spectra produced by RF Zn plasma in Argon and oxygen shows many points as follows:

- Electron density increases then being near constant values while electron temperature decreases with increasing pressure from 0.05 to 0.4 mbar.
- All plasma parameters satisfy plasma conditions.
- n_e and T_e in oxygen plasma varied as same behavior as in argon plasma with working pressure but with higher n_e values and less T_e values

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