A Comparative Spectroscopic Study on Emission Characteristics of DC and RF Discharges Plasma using Different Gases.

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Abstract: The optical emission spectrum and the spatial distribution of optical emission lines and bands of N_2, Ar and He gases are measured for rf and dc glow discharges. A comparative investigation of the plasma characteristics between dc and rf power modes is presented using the emission lines of the different gases. Optical emission spectra from nitrogen discharges in the wavelength range from 350 to 750 nm are recorded. The second positive system of N_2(C–B) and the first negative system of N_2^+ (B–X) spectra are observed. Various emission lines of argon ions are commonly observed from the argon discharges regardless of the rf power and/or discharge current. The main emission atomic lines of He I glow discharge plasma are obtained for both discharge modes, while the ionized He II line at 468.6 nm is recorded for rf discharge and absent in dc glow discharge. The electron temperature T_e is determined from the optical emission spectra by the line-to-line method. T_e decreases with increases the gas pressure and increases with increases the rf input power.

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1- Introduction

Plasma spectroscopy relies on the excitation of plasma species and subsequent de-excitation by radiative decay. The nature and the frequency of excitation processes are therefore fundamental in the production of spectral data; plasma excitation processes determine the spectral line availability and strongly affect line intensity [1-4].

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 their reaction rates are generally dependent on the density of the charged particles and their energies [5].

Radio-frequency powered rf discharge plasma as well as the conventional dc glow discharge are employed in analytical applications. The previous studies lead to almost the same emission characteristics between the dc and the rf glow discharges, it is necessary to clarify the properties regarding the plasmas themselves so that both plasmas can be compared in more detail [6-10].

One of the most spectroscopically studied diatomic molecules is nitrogen. An extensive compilation and critical review of the observed electronic band systems of the N_2 molecule and its ions has been reported by Lofthus and Krupenie [11]. As the principal component of the Earth's atmosphere, nitrogen plays a significant role in atmospheric phenomena including auroras and airglows. In laboratory, nitrogen is often present in gas mixtures in discharges, including various laser gas media as the CO_2 laser [12].

Abdel-Fattah *et al.* [13] carried out the measurements with a rf compensated Langmuir probe and optical emission spectroscopy in capacitively coupled rf (13.56 MHz) pure nitrogen N_2 discharges at fixed rf voltage over a wide range of pressure. The emission intensities of nitrogen (0-0) band of second positive system at 337.1 nm and (0-0) band of first negative systems at 391.4 nm are used to determine the dependence of their radiative states with nitrogen pressure. It is observed that the pressure influences the radiative states differently owing to their different populating mechanisms.

Donnelly [14] reviews a spectroscopic method for extracting plasma electron temperatures and electron energy distributions: trace rare gases optical emission spectroscopy. Specifically, traces of Ne, Ar, Kr, and Xe are added to the plasma and the intensities of emissions from the Paschen 2p levels are recorded. Intensities are also computed from a model that includes direct excitation from the ground state, as well as two-step excitation through the $^3P_2$, and $^3P_0$ metastable levels.

Accurate measurement of T_e depends critically on accurate cross sections for electron impact excitation.

Gulati *et al.* [15] reported the optical and electrical characterization of sinusoidal and pulse glow discharge plasma in helium gas. Optical emission spectroscopy has been used to determine the main emission lines of the helium glow discharge plasma. It has been observed that the spectral lines of helium plasma become more intense with increase the gas pressure and rf input power.

In this paper, we investigate the intensity variations of the N_2, Ar and He emission bands and lines, which are identified to different transitions when glow discharge source is operated with either dc or rf power supplies, in order to compare each plasma conditions. Also, the electron temperature T_e in different gases and at different experimental conditions was determined using optical emission spectra by the relative intensity line to line ratio method.

2- Experimental Setup

The discharge plasma was formed in parallel plate configuration of stainless-steel 304 electrodes with a diameter of 5 cm and spacing 6 cm, housed in a cylindrical stainless-steel vacuum chamber of 25 cm in diameter and height. The side and back of the two electrodes were covered with ceramic casing to prevent additional discharge. The lower electrode was powered by rf source (13.56 MHz and 0-200 W power), type ENI model OEM-6, through a matching box, while the upper electrode as well as the stainless-steel discharge chamber were grounded. Also, the discharge chamber was operated using 2000 VDC power supply, whereas the current density was varied between 5−20 mA/m^2. The chamber was pumped down by a vacuum system to base pressure of 10^{-4} torr.

During all measurements, continues flow of a gas through the discharge chamber was maintained. High purity N_2, Ar and He gases were used as working gases and were fed to the chamber through a needle valve. The pressure of the working gas was varied between 1 − 10 torr and measured using a digital vacuum gauge (VAP 5).

The Ocean Optics Red Tide spectrometer type USP 650 was used to scan the emission spectra of the different gases. It has a wavelength range of 350–1000 nm and uses a detector with 650 active pixels Sony ILX511 linear silicon CCD array detector. The USP 650 is a microcontroller controlled spectrometer and all operating parameters are implemented through a software interface. The wavelength calibration of the spectrometer is performed by standard lamp.

The emission line intensities of different gases were determined from three or four replicates after a pre-discharge period of at least 10 min. The relative standard deviations ranged were from 1 to 15 %.

Figure 1 shows schematic drawing of the experimental set up.

3- Results and Discussion

3-1. The spectra of N_2

The emission spectrum of nitrogen discharge has a continuum on which the emission lines are superimposed. It is due to the interactions between free electrons (bremsstrahlung) and to the interaction of free and bound electrons (recombination continuum). The former one is particularly important in the UV spectral region, whereas the latter one is important at longer wavelengths [12].

Figure 2 shows typical emission spectra in N_2 plasma for rf and dc discharge, respectively. The discharge current was kept at 20 mA for dc discharge and at 150 W for rf discharge while the gas pressure was kept at 2 torr for both discharges. The most pronounced bands in Fig. 2 are the nitrogen second positive system (N_2 2P system) bands (300–450 nm), and the nitrogen first positive (N_2 1P system) bands (625–750 nm), also the nitrogen first negative system (N_2 1N system) has been observed. In addition to excited oxygen and nitrogen species, weak emission bands from NO_2 were found from 430 to 480 nm.

Regards of the discharge power modes both spectra have some differences and not identical. In rf discharge spectrum few bands and lines are recorded whereas they are absent in dc discharge spectrum. Also, the emission band heads of the rf glow discharge spectrum are more intense than that in dc spectrum, this may due to the energetic ions in the rf discharge which play an important role in generating the energetic electrons and neutral molecules than that in dc discharge. Also, the energy of the bulk electrons increases due to the Ohmic heating, which is the dominant heating process in our experimental conditions [16]. So, many channels of vibrational/rotational excitations will occur.

It's clear from Fig. 2 that, the spectrum of the generated plasma is dominated by the emission of strong N^+ and N and very weak N_2^+ atomic lines and molecular features of $N_2^+(B^2\Sigma_u^+ - X^2\Sigma_g^+)$, $N_2^+(D^2\Pi_g - A^2\Pi_u)$, $N_2(C^3\Pi_g - B^3\Pi_u)$, and very weak $N_2(B^3\Pi_g - A^3\Sigma_u^+)$. The relative intensities of the 0–0 band heads in the N_2(C–B) and N_2^+ (B–X) systems are very weak for dc discharge as compared with the spectrum of nitrogen formed in rf glow discharge, this is because the rf discharge has more energetic gas-phase processes.

Lianzhu *et al.* [17] show that, the cathode glow in N_2 discharge is found to be mainly caused by N^+ impact excitation and the intensity of cathode glow decreases with the discharge voltage.

Two main collision mechanisms for the excitation and ionization processes of the nitrogen molecules are suggested: the electron collision process: in this process electrons collide with the nitrogen molecules in the ground state $N_2(X^1\Sigma_g^+)$, or with the nitrogen metastable state $N_2(A^3\Sigma_u^+)$ and cause the excitation of nitrogen molecules to $N_2(C^3\Pi_u)$. The second process is the Penning excitation process which is responsible for the enhancement of population of $N_2(C3\Pi u, v')$ and its vibrational temperature [11].

Figure 3 (a) shows the dependence of some emission bands intensity (380.5, 425.3, 481.5 and 502.9 nm) as a function of rf power and at gas pressure p = 2 torr. This figure depicts an increase in the emission intensity of these radiative states with input rf power suggesting an increase in the population density of these states. This fact is explained by the expansion of the electron energy distribution function (EEDF) towards higher energies causing an increase in the dissociation of N_2 molecules with increasing input rf power [3]. Also, Fig. 3 (b) shows the dependence of the same emission bands intensity as a function of the discharge current of the dc glow discharge and at gas pressure p = 2 torr. When the discharge current increases, the intensity of the selected bands increases. This is due to the increases in the electrons density which is directly proportional to the discharge current.

On the other hand, Fig. 4 (a) shows the intensity ratio (399.8/425.3 and 461.4/425.3) of N_2 bands measured at different rf power and at gas pressure equal to 2 torr. While, Fig. 4 (b) shows the same intensity ratios of the dc discharge but as a function of gas pressure and at constant discharge current (I = 20 mA). The pressure-dependence of intensity ratios of examined transitions is due to the differences in collisional deactivation rate constants of different states. Therefore, the radiation intensities of the bands change differently with the gas pressure and consequently, the intensity ratio of the given bands is pressure dependent.

Paris *et al.* [18] measured the ratio of intensities of some bands of N_2 as a function of electric field strength in dc glow discharge and deduced empirical formula for this function. They found that, reduction of intensity ratios to standard conditions is possible if the deactivation rate constants are known and also, if the excitation of molecules from the ground state by electron impact is the dominant process.

3-2. The spectra of Ar

Figure 5 shows a comparison between two spectra, one obtained for the dc glow discharge at discharge current equal to 20 mA, and the other recorded for the rf discharge at input power equal to 150 W, and both spectra are at gas pressure equal to 2 torr.

The characteristic blue light of the glow discharge of the argon is caused by the lines corresponding to 5p→4s transitions (lying in the blue–violet part of the spectrum). It can indeed be seen that there are quite a lot of lines lying close to each other in the blue and violet part of the spectrum, with still reasonably high intensities.

A large number of singly-ionized argon lines (Ar II) are emitted by the argon spectra for both discharge modes. The intensities of the Ar II lines reflect the relative population among various energy levels of argon ion, and consequently depend on the discharge conditions: gas pressure, the discharge current and/or input rf power.

The two spectra are still not identical completely, some exceptions are found. The line 475.5 nm in dc discharge which corresponding to a 6p → 5s transition (one of the 'blue' lines) is weak than that in rf discharge, which attributed to the higher electrons energies found in rf discharge. The emission intensities of the lines of the Ar II, 443.9, 456.4, 468.2 and 488.8 nm slowly increase with electric power supplied to the discharge device; these variations are not identical for both discharge modes. It has been indicated that the emission intensities of various Ar II lines can be employed as an indicator to estimate the plasma conditions [19].

Also, the intensity of the line Ar I 420.08 nm which corresponding to the transition 5p → 4s is dominant and strong line in dc discharge than that of rf discharge. This is due to; this line is emitted when electron transfer occurs between levels $4s_{1/2}$ and $5p_{5/2}$. Electron excitation of the $5p_{5/2}$ levels is necessary for the production of this particular emission line. The electron transfer process is dominant process in the dc discharge as the cathode of the dc glow discharge is bombarded with Ar ions accelerated in the cathode fall region and with fast neutrals creating secondary excited electrons.

Figure 6 (a) shows the variations in the emission intensities of some Ar emission lines (404.4, 420.08, 470.3, 480.6 and 549.5 nm) as a function of the rf power at gas pressure 2 torr. This figure depicts a significant increase in the emission intensity of Ar lines with input power suggesting an increase in the excitation efficiency of the discharge. These results also make clear that the emission intensity of the spectral lines cannot be used as a true monitor of the density of the emitting species unless excitation efficiency of the discharge is normalized [3]. Also, Fig. 6 (b) shows the variations in the same emission intensities of some Ar emission lines as a function of the discharge current of the dc glow discharge at gas pressure equal to 2 torr. The emission line intensities increase when the discharge current of the dc discharge increase. As the discharge current increases the electron density and the density of Ar atoms or the density of Ar ions increases, and hence the lines intensity increases.

Furthermore, the intensity ratios between some Ar lines (Ar II 426.6 to Ar I 404.4 and Ar II 480.6 to Ar I 404.4) as a function of rf power at gas pressure equal to 2 torr is plotted in Fig. 7 (a). While Fig. 7 (b) shows the same lines intensity ratios as a function of gas pressure and at discharge current equal to 20 mA. The results presented in these figures indicate that the input power and the gas pressure affect the intensity of the emitted lines of Ar discharge. Slight increase in the intensity ratio $I_2(426.6)/I_1(404.4)$ and $I_2(480.6)/I_1(404.4)$ with gas pressure and rf power indicates that the intensity of the line (5p[3/2] to 4s $[3/2]^0$ at 404.4 nm) decreases more rapidly with increasing gas pressure and/or rf power than do the lines (5p [3/2] to 4s $[3/2]^0$ at 426.6 nm) and ($4p^4P_{5/2}$ to $4s^4p_{5/2}$ at 480.6 nm). This means that the high energy tail of the electron energy distribution function contracts to lower energies as the gas pressure is increased suggesting that the number of electrons present at lower pressure is reduced. This implies that the plasma conditions are also comparable in both discharge power modes.

Moreover, the intensity variation of the ionic lines is greater compared to that of the atomic line, which results in an increase in the intensity ratio of the ionic line to the atomic line, as illustrated in Fig. 7. Its notice that, the variation in the ionic-to-atomic line intensity ratio is due to more active ionization in the plasma as the Ar gas pressure became higher.

3-3. The Spectra of He

Figure 8 shows a comparison between two spectra, one obtained for the dc glow discharge at discharge current equal to 20 mA, and the other recorded for rf discharge at input power equal to 150 W, both discharges at gas pressure equal to 2 torr. For instant, the both spectra are drastically similar. The most intense emission lines are from the transitions (3p→4d) in the range of 400-500 nm. Both spectra are strongly depended on the input power and on the gas pressure. The spectrum for the singlet line of He I becomes strong when the gas pressure is high enough. Also, the ionized He II line at 468.6 nm appears in a weak intensity in rf discharge and strongly depends on rf input power, while its absent in the dc discharge.

Emissions from atomic lines have a similar two step excitation possibility by means of excitation from metastable levels (2^1S and 2^3S) present in the plasma. Excitation of metastable states would lead to increased emissions over those predicted from electron impact excitation of the ground state. It's known that, helium has the highest metastable energies among the other inert gases, making it a powerful Penning reagent for exciting plasma species through inelastic collisions. This explains why the atomic lines of He discharge are stronger than ionic lines.

Figure 9 shows the variations in the emission intensities of some He emission lines (447.1, 471.3, 492.1, 501.6 and 587.6) as a function of the rf power and discharge current at kept gas pressure equal to 2 torr, respectively. The line intensities of these lines are increased by increasing the input rf power implying that the number of energetic electrons is dominantly increased as an increase in the supplied input power. Also, the intensity of all lines increases with increasing the discharge current which is in accordance with increasing electron density and/or electron temperature.

Furthermore, the intensity ratios between some He I lines (singlet line at 501.6 to triplet line at 471.3 nm and singlet line at 504.8 to triplet line at 471.3 nm) as a function of rf power and at gas pressure equal to 2 torr is plotted in Fig. 10 (a). While Fig. 10 (b) shows the same intensity ratios for the dc discharge as a function of gas pressure and at constant discharge current equal to 20 mA.

Generally, it's noted from the emission spectra of the three gases that, the emission spectrum of rf discharge having higher intensities than that of dc discharge. Also, it's found that, the dominant atomic line intensities for the dc discharge is lower than those for the rf discharge by 30 %, whereas in the case of ionic lines they are lower by 20%. This is due to the following reasons: 1- The electron and ion densities tend to be higher for the rf discharge than for the dc discharge, 2- The heating of electrons in the rf plasma showed greater diffusion away from the cathode region in the rf plasmas as compared with the dc mode. This means that the negative glow is larger for the rf plasma [20]. 3- The rf discharges have lower sputtering rates but have higher excitation efficiencies than dc discharges. 4- It is can easily be seen that the electron impact ionization is much more prominent process in the rf plasma and is a function of the position in the rf cycle. 5- The oscillating nature of the discharge potentials and their effect on the charged particles motion in the rf discharge [21].

3-4. Electron Temperature determination by Optical-Emission-Spectroscopy Technique.

Optical emission Spectroscopy (OES) is the most popular technique to investigate glow discharge. Since it is simple and that it produces no perturbation in the plasma. Atoms and ions of the working gas and trace impurities emit radiation when transitions of electrons occur between the various energy levels of the atomic system. The radiation is in the form of narrow spectral lines, unlike the continua of free-electron radiation such as bremsstrahlung [22]. Four plasma models were suggested by Mc-Whirter [23], which are dependent on the mechanism of electron interaction. These are the local-thermal-equilibrium (LTE) model, the steady-state Corona model, the time-dependent Corona model, and the collisional radiative (CR) model.

Corona model occurs in low density plasmas ($n_e \leq 10^{17}$ m^{-3}) where the radiative processes are much faster than the collisional processes. In that case, the excited levels are populated by direct excitation from the ground state and depopulated by spontaneous radiative decay only. Some excited levels are depopulated by radiative decay in cascade which means that some lower-lying levels are populated by radiative decay from higher-lying levels. This cascade contribution to the population of the lower-lying excited levels is however negligible compared to the contribution of collisional excitation from the ground state [22].

Because of the low charge density of the present experiment, which measured by the electric probes, excited gas particles will experience collisions at a rate that is very low compared with the de-excitation rate by radiative decay [24]. This means that local thermodynamic equilibrium (LTE) does not apply and Boltzmann distributions should not in general be assumed. It can be said that the Corona model is almost satisfied.

The methods used to measure the plasma parameters depend on the plasma model. Three methods are available for electron temperature measurement, these are [23]:

1) the ratio of two lines' intensity;
2) the ratio of a line to continuum intensity;
3) the ratio of two parts of continuum intensities.

3-4.1. Electron temperature determination using Ar lines

Determination of electron temperature T_e using optical-emission-spectroscopy technique by estimating the ratio of the intensity of two lines has been adopted here in this paper. For high accuracy, it is desirable to choose two spectral lines, whereas the ratio of the relative intensity of the two lines is a strong function of T_e. This will be the case if the difference between the transition energy levels of the two lines is large enough. The accuracy may be improved somewhat by measuring several pairs of spectral lines and averaging the resulting temperatures. However, this rather time consuming technique is only partially successful in reducing the experimental uncertainty. A larger energy difference can be obtained if one of the transitions occurs in singly ionized atom and the other occurs in a neutral atom [25].

On the other hand, the criterion of the steady state Corona model, i.e., which is:-

$\mathbf{n_e \leq 10^{17}\ m^{-3}}$

is valid in this paper. Consequently, steady-state Corona model has been assumed here to estimate T_e.

The ratio of two lines' intensity is expressed in the form [23]:

$$\frac{I'}{I} = \frac{f'g'\lambda^3}{fg\lambda'^3} \exp\left(\frac{E'_\infty \quad E' \quad E_\infty + E}{kT_e}\right)\frac{S}{\alpha} \qquad (1)$$

Where

$$\frac{S}{\alpha} = (7.87x10^{-9}) E_\infty^{'2} \left[\frac{E'_\infty}{kT_e}\right]^{3/4} \exp\left(\frac{E'_\infty}{kT_e}\right) \qquad (2)$$

Substituting from equation (2) into equation (1) one get;

$$kT_e = \left[(7.87x10^{-9}) E_\infty^{7/4} \frac{fgI'\lambda'^3}{f'g'I\lambda^3} \exp\left(\frac{E' E_\infty - E}{kT_e}\right)\right]^{4/3} \qquad (3)$$

where *I*, *λ*, *g*, and *f* are the total intensity, wavelength, statistical weight, and absorption oscillator strength, respectively, of one line and *E* is its excitation energy. The corresponding quantities for the other line are I', λ',g', f', and E'. The values of the above parameters have been taken from [25].

Equation (3) solved numerically to find the values of T_e at different lines intensity ratio and at different experimental conditions.

Therefore, the relative intensity of argon neutral lines Ar I (415.9 and 425.9 nm) and argon singly ionized lines Ar II (476.5, and 488.8 nm) have been measured at different experimental conditions (e.g. gas pressures and rf power).

Figure 11 shows the relation between the derived T_e as a function of gas pressure at discharge current equal to 20 mA for dc discharge.

The reduction of T_e with the increase in gas pressure may be explained as follows: when the gas pressure in the chamber increases, it causes an increase in the number of collisions between the electrons and the gas atoms. As a result the energy transferred from the electrons to the gas particles increases causing an increase in the gas temperature by lowering the electron temperature. Also, the mechanism of excitation and ionization of atomic and ionic species in argon plasma is supposed to occur mainly by electron impact. When the filling pressure is increased, the high-energy tail of the electron energy distribution function contracts to the lower energies. Therefore the ionization, which results from the energetic electron's impact with gas atoms, is reduced.

On the other hand, Fig. 12 shows the relation between the derived T_e as a function of rf power at gas pressure equal to 2 torr for rf discharge.

The increase of T_e with rf power may be explained by noting that there are usually two modes of operation in a capacitively coupled rf discharge; α and γ modes [26]. α mode appears at low voltage and in this mode, electrons in the bulk plasma are mainly responsible for the excitation and ionization processes in the plasma. At increased rf powers which are met in our experimental conditions, γ mode appears. In this mode electrons emitted from the electrode surface play important role for ionization and excitation processes in the plasma. Thus, with increase in power more energetic secondary electrons are emitted from the electrodes which enhance the ionizing events and as a result, increase in electron temperature may result.

3-4.2. Electron temperature determination using He lines

For helium discharge, a Corona model is employed to determine the electron temperature from the emission line intensity ratio.

According to Sovie [27] the electron temperature of helium discharge plasma using the line to line intensity ratio method is evaluated by two ratios according to Corona model. Sovie uses two pairs of helium atomic emission lines. The first one is between the intensity ratios of the singlet line transition $5^1S \rightarrow 2^1P$ at 443.7 nm to triplet line transition $5^3S \rightarrow 2^3P$ at 412.1 nm of He I. The second is the ratio between singlet line transition $4^1S \rightarrow 2^1P$ at 504.8 nm to triplet line transition $4^3S \rightarrow 2^3P$ of He I at 471.3 nm. It's safer to use lines with upper S-level since they are least affected by collisional mixing with levels of equal principal quantum number [28]. For that reason, the above lines are used for calculating T_e.

Figure 13 shows the relation between the calculated T_e as a function of gas pressure at discharge current equal to 20 mA for dc discharge. While, Fig. 14 shows the relation between the calculated T_e as a function of rf power at gas pressure equal to 2 torr for rf discharge. Again T_e increases when the gas pressure is decreased while T_e increases with rf power increases. The increase of T_e with rf power can be attributed to the increase in electron energy imparted by enhanced rf electric field at higher power.

The higher values of T_e for helium discharges than that of Ar discharges may be due to the existence of metastable 2^1S in singlet state. Also, excitation of helium atoms needs a large energy transfer from electrons, which makes electrons capable of accumulating a high energy in the external electrical field and inducing the excitation and/or ionization of helium atoms through collisions. This is the main reason for the fact that the electron temperature of helium discharge is relatively higher than that of other noble gas discharges, such as Ar [29].

Naveed *et al.* [30] reported the effect of helium percentage variation in a capacitive rf helium-nitrogen mixture plasma on various plasma parameters. Optical emission spectroscopy is used for determination of electron temperature from Boltzmann's plot of He–I lines. The results demonstrate that electron temperature, electron density and concentration of active species increase significantly with increase in helium percentage in the mixture and rf input power.

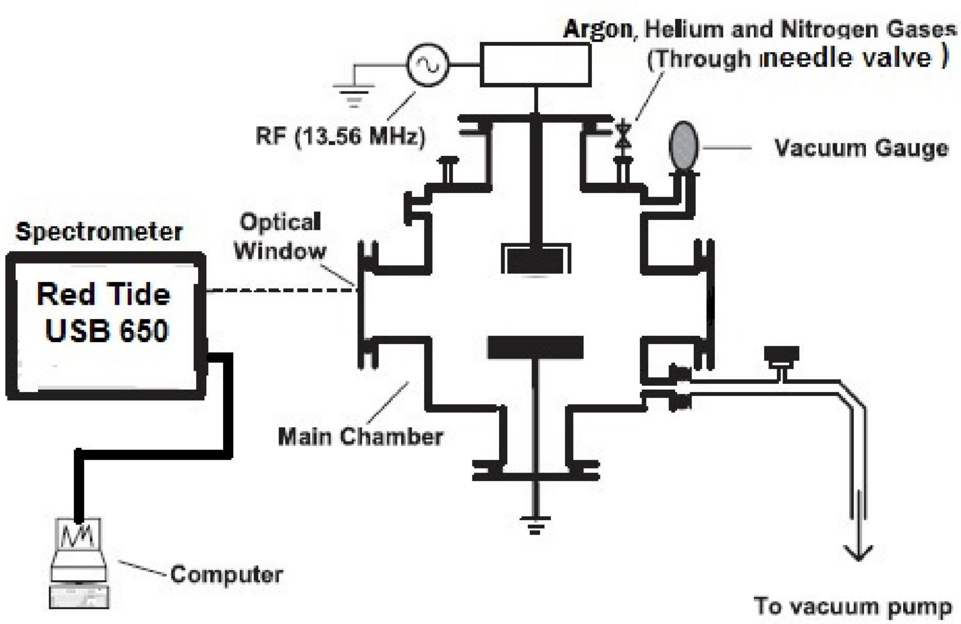

Fig. 1. schematic drawing of the experimental set up.

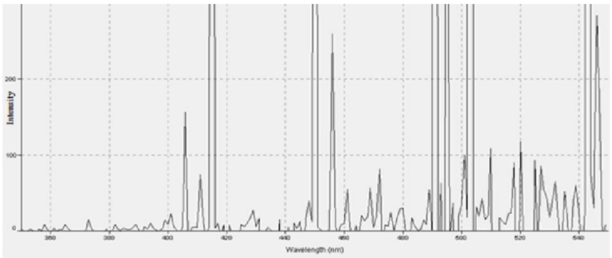

Fig. 2 (a)

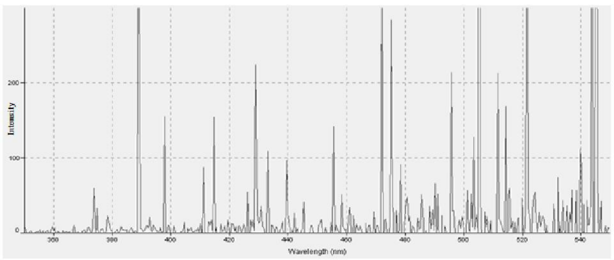

Fig. 2 (b)

Fig. 2. shows typical emission spectra in N_2 plasma,

(a) for rf discharge at 150 watt power and

(b) for dc discharge at discharge current I = 20 mA, while the gas pressure is kept at 2 torr for both discharges.

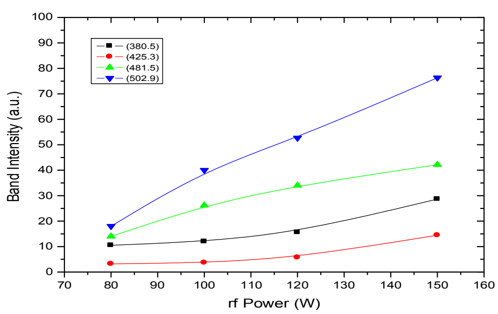

Fig. 3 (a)

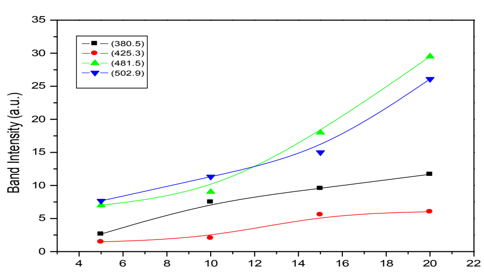

Fig. 3 (b)

Fig. 3. shows some emission bands intensity (380.5, 425.3, 481.5 and 502.9 nm),

(a) as a function of rf power and,

(b) as a function of discharge current, both at gas pressure = 2 torr.

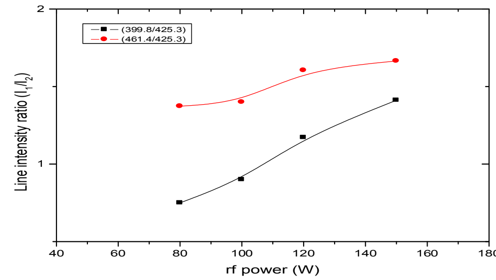

Fig. 4 (a)

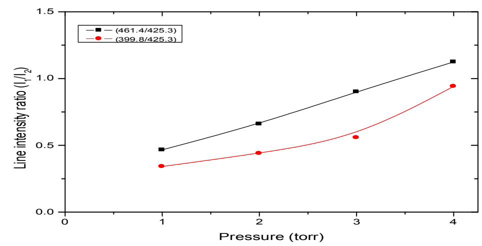

Fig. 4 (b)

Fig. 4. shows the intensity line ratios (399.8/425.3 and 461.4/425.3) of N_2 bands measured,

(a) as a function of rf power and at gas pressure equal to 2 torr.

(b) as a function of gas pressure and at discharge current equal to 20 mA.

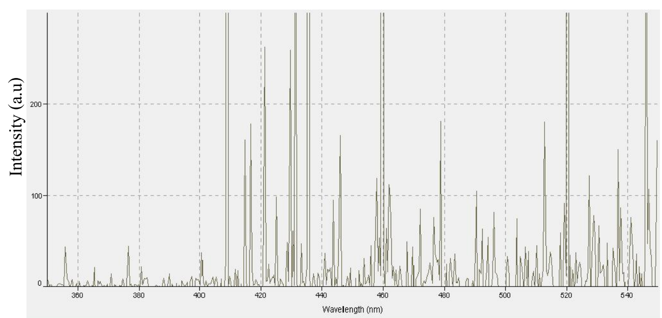

Fig. 5 (a)

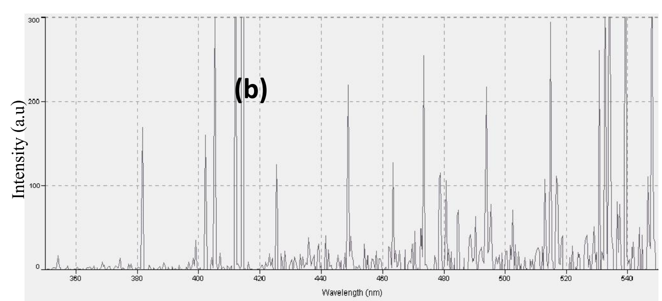

Fig. 5 (b)

Fig. 5. shows typical emission spectra in Ar plasma,

(a) for dc discharge at I = 20 mA and

(b) for rf discharge at 150 W power, while the gas pressure is kept at 2 torr for both discharges.

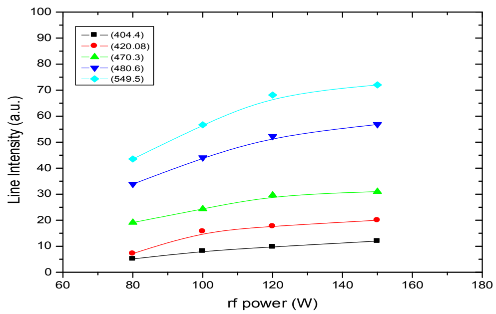

Fig. 6 (a)

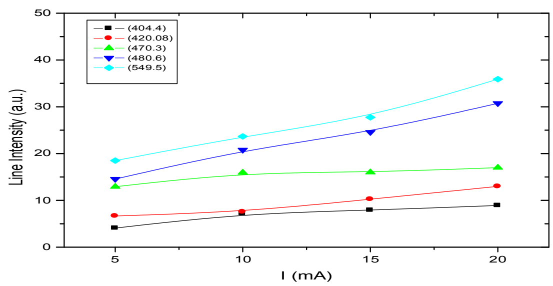

Fig. 6 (b)

Fig. 6. shows the variations in the emission intensities of some Ar emission lines (404.4, 420.08, 470.3, 480.6 and 549.5 nm),
(a) as a function of the rf power and,
(b) as a function of the discharge current, both at gas pressure =2 torr.

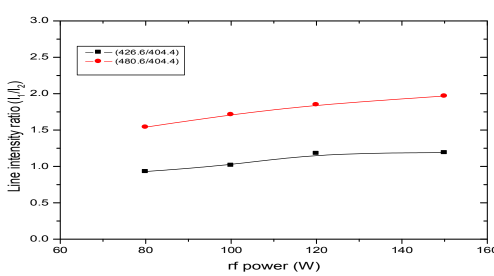

Fig. 7 (a)

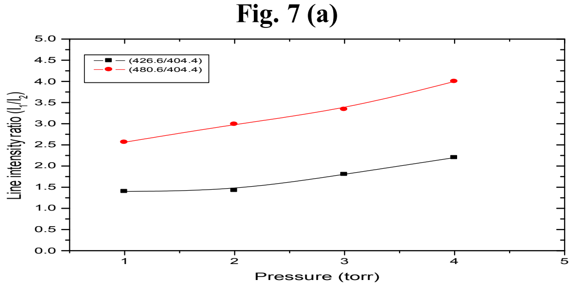

Fig. 7 (b)

Fig. 7. shows the intensity line ratios of some Ar lines (Ar II 426.6 to Ar I 404.4 and Ar II 480.6 to Ar I 404.4),
(a) as a function of rf power and at gas pressure equal to 2 torr.
(b) as a function of gas pressure and at discharge current equal to 20 mA.

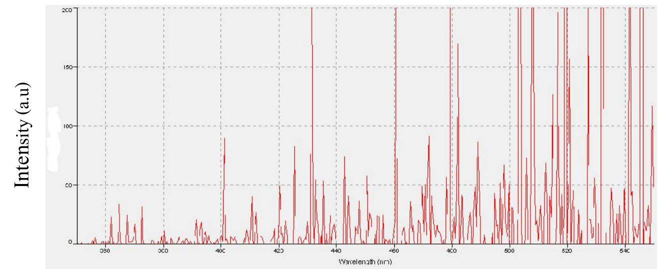

Fig. 8 (a)

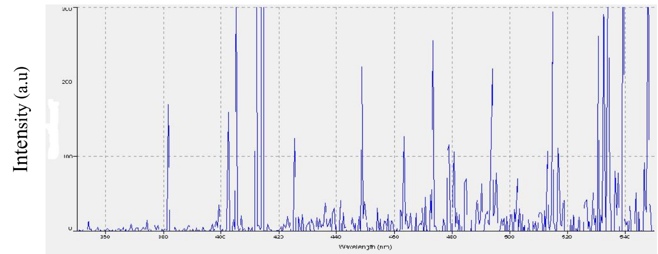

Fig. 8 (b)

Fig. 8. shows typical emission spectra in He plasma,
(a) for rf discharge at 150 W power and
(b) for dc discharge at I = 20 mA, while the gas pressure is kept at 2 torr for both discharges.

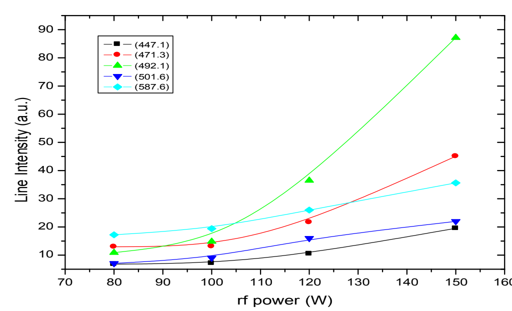

Fig. 9 (a)

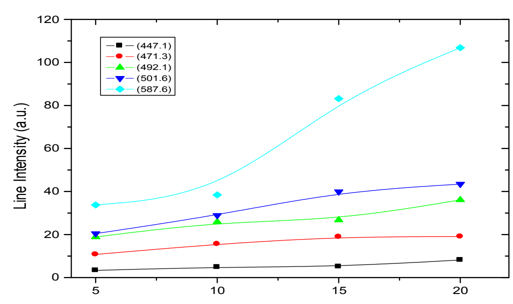

Fig. 9 (b)

Fig. 9. shows the variations in the emission intensities of some He emission lines (447.1, 471.3, 492.1, 501.6 and 587.6 nm),
(a) as a function of the rf power,
(b) as a function of discharge current, both discharges at gas pressure equal to 2 torr.

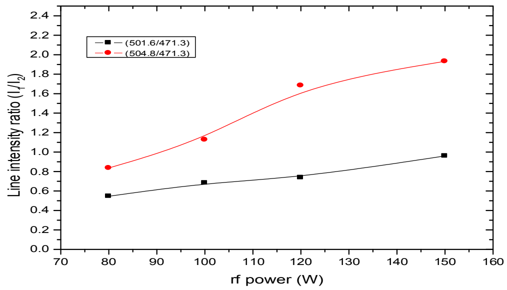

Fig. 10 (a)

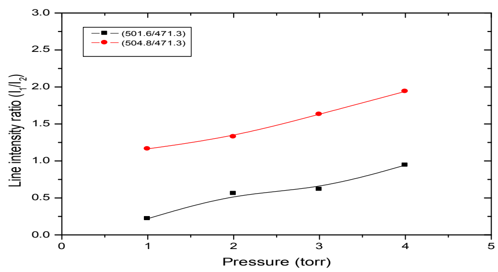

Fig. 10 (b)

Fig. 10. shows the intensity line ratios of (He I 501.6 to He I 471.3 and He I 504.8 to He I 471.3),

(a) as a function of rf power and at gas pressure = 2 torr.

(b) as a function of gas pressure and at discharge current I = 20 mA.

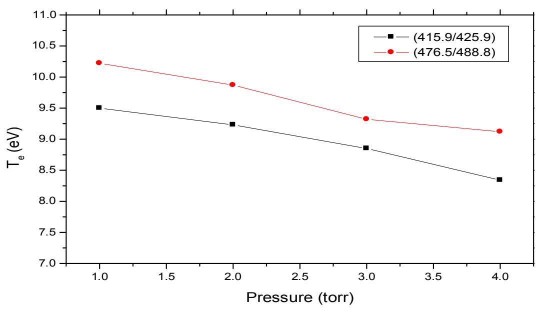

Fig. 11

Fig. 11. shows the relation between the derived T_e as a function of Ar gas pressure at constant discharge current equal to 20 mA for dc discharge.

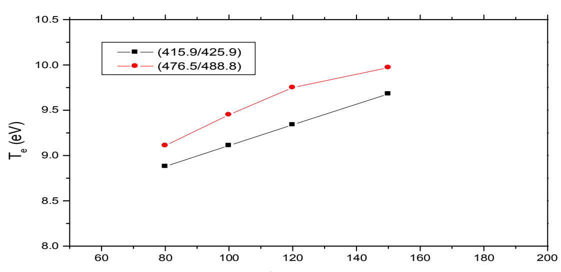

Fig. 12

Fig. 12. shows the relation between the derived T_e as a function of rf power at Ar gas pressure equal to 2 torr for rf discharge.

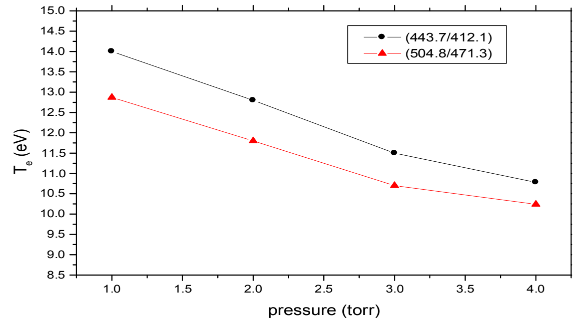

Fig. 13

Fig. 13. shows the relation between the calculated T_e as a function of He gas pressure at constant discharge current equal to 20 mA for dc discharge.

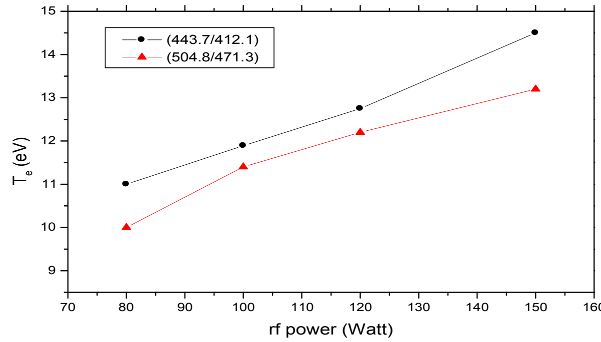

Fig. 14

Fig. 14 shows the relation between the calculated T_e as a function of rf power at He gas pressure equal to 2 torr for rf discharge.

4- Conclusion

Light emission characteristics have good explanation with fundamental modeling of plasma processes**.**

The discharge plasma was produced by either dc-current (200 mA, 2000 V) or rf source (13.65 MHz, 0-200 W), while the gas pressure was varied between 1-10 torr.

Emission spectra from N_2, Ar and He gases are measured and compared for both discharge mode power. All emission lines are dependent on discharge current, rf power and gas pressure for both discharge modes.

In the spectra of nitrogen glow discharge, we identified several bands of the second positive system of N_2(C–B), and some very weak bands of the first negative system of N_2^+. A few numbers of N^+ and N_2^+ atomic lines are also present. However, this emission spectrum exhibits a number of bands corresponding mainly to the $\Delta v' = 0$ sequence B–X band system of N_2^+.

It's concluded that, the lines corresponding to the 4p→4s and 5p→4s transitions are the most important ones in the Ar spectrum for both two power modes.

In helium discharge, the main emission atomic lines He I are present in both discharge modes, while the ionic line He II at 464.6 nm appears in a weak intensity in rf discharge and absent in dc discharge.

On the other hand, for the spectra of each gas there are some differences between the spectra of both discharge modes, in relative line intensity values and some lines appear in one mode and absent in the other. But the dominant lines of each spectrum are present in both discharge modes.

The electron temperature T_e is determined using the intensity line to line ratio method according to Corona mode. T_e increases when the gas pressure is increased while it increases with increases the rf power.

The present results are important for obtaining better insight and improving the performance of glow discharges used as light sources and as spectroscopic sources for optical emission spectrometry. Moreover, they can be extremely useful for data interpretation of optical spectra in plasma diagnostic studies.

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