

DETERMINATION OF THE TEMPERATURE AND DENSITY OF ELECTRON OF GLOW DISCHARGE IN NITROGEN BY USING OPTICAL EMISSIONS SPECTROSCOPY

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ABSTRACT: In this paper a hollow 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, then analyzing this spectrum. Finally, the electron temperature and plasma density were examined by employing a spectroscopy. The electron temperature was measured through calculating approximately intensity's ratio of two lines. Via the conditions that the inner cylinder diameter was $R = (3 \pm 6)$ cm; HCD 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 $(2.8 \times 10^{15} - 7 \times 10^{17}) \text{ cm}^{-3}$.

KEYWORD: Hollow Cathode, Glow Discharge, Spectroscopy, low-pressure, Electron temperature, Electron density

1-INTRODUCTION

Plasma diagnostics might be defined as the methods employed to know the plasma properties. These properties include the plasma types, the chemical compositions, electron temperature, the plasma density, plasma potential, electron/ion energy distributions, ion mass distributions and neutral species (Sharma, et, al, 2008), (Cal, et, al, 2001). In order to categorize the plasma, the mass spectroscopy, Langmuir probe, interferometry, the Thompson dispersion method and optical emission spectroscopy (OES) are used (De Giacomo, et, al, 2001), (Dugu, et, et, al, 2010).

One of the common tools for the plasma diagnosis is Optical Emission Spectrometry (OES). Basically, OES spectrally analyses the light coming from plasma. Beside, being the slightest worrying plasma diagnostic practice, the experimental arrangement, to a certain extent, is uncomplicated. By calculating the emitted spectral lines, the neutral particles and ions in the plasma are identified. Furthermore, the spectral fingerprint of optical plasma emission gives information in

relation to the chemical and physical processes that happen in the plasma. The spatial and temporal resolution is shown with great reliability (Grill, 1994). Nitrogen having discharges are widely used in numerous plasma processing means, like the surface modification of different materials (Cheng, et, al, 2005)

Optical emission spectroscopy (OES) is a non-intrusive and comparatively easy-to-use method that makes it extensively appropriate to distinguish this nitrogen plasma (Coitout & Cernogora 2006).

To find out electron temperature (T_e) using optical emission spectroscopy method by calculating the proportion of the intensity of two lines has been employed here in this calculation. For high precision, it is appropriate to select two spectral lines, while the ratio of the relative intensities of the two lines is a strong function of T_e . This is the state if the difference between the shift energy levels of the two lines is great (Hassouba & Dawood, 2014).

The Plasma electron temperature can be estimated based on the relative intensity of the two spectral lines of the same atom. The steady-state coronal model is applied, if there are low electron density plasmas. The line intensity ratio is evaluated relying on electron temperature in low pressure plasma (Cui, et al, 2008). Throughout the method, the electron temperature is shown to be precise even for low density plasma, which is shown in the following expression:

$$\frac{n_m}{n_n} = \frac{g_m}{g_n} \exp \left[-\frac{E(m) - E(n)}{KT_e} \right] \quad \dots (1)$$

Here n the particle density, g the statistical weight, k the Boltzmann constant and E the energy of upper level of emission spectral line. In the plasma radiation spectrum, spectral intensity is expressed as follows:

$$I_{mr} = n_m A_{mr} h \nu_{mr} \quad \dots (2)$$

Here A the transition probability, h the Planck constant, and ν electronic spontaneous transition frequency, respectively. r presents the lower transition energy level which can be as the same energy level.

To improve reducing the calculation quantity and the calculation accuracy; it is necessary to use spectrum under the same energy level. When eliminating r , the final formula will be electron temperature T_e is:

$$T_e = -\frac{E_n - E_m}{K} \left[\ln \left(\frac{A_n g_n I_m \lambda_m}{A_m g_m I_n \lambda_n} \right) \right]^{-1} \quad \dots (3)$$

The use of this formula gives the plasma electron temperature should be accurately referred to as electronic excitation temperature or excitation temperature (Guo & Zhao, 1986).

Is used the values of the parameters E (Upper energy level) and A_g (Transition probability), table (1) have been taken from NIST (The National Institute of Standards and Technology).

Temperature values were calculated for different operating pressures.

After the electron temperature has been calculated (Ancona, et al, 2008). The values of $E_m, E_n, A_m g_m, A_n g_n$, and are obtained from the NIST atomic spectral database Using equation:

$$n_e = \exp \left(44.2476 + 1.20 \ln \Delta \lambda_{\frac{1}{2}} - 0.6 \ln T_e \right) \quad \dots (4)$$

For calculate the electron density n_e . The stark broadening (full width at half-maximum, (FWHM) $\Delta \lambda_s$ of the spectral line N_2 (337.5 nm) line is measured from emission spectra and substituted in equation (4) also, the values of T_e that obtained from the previous section (T_e values are obtained from the two lines' intensity method) (Tu, et al, 2007).

Where, T_e is the electron temperature in K and n_e is the electron number density in cm^{-3} .

In truth, different studies took advantage of various DC glow discharge strategies for the plasma method like treating gas, disposing and etching thin film, it is vital to identify the plasma limit of its temperature and density in order to understand the mechanism of the method and control those factors. In their study (Zhu, & Pu, 2008), summarize the methods of electron temperature and electron density capacity in low-pressure nitrogen and argon discharges by employing optical emission spectroscopy (OES). This paper gives description recently developed easy kinetic models for nitrogen and argon discharges and their applications in establishing the relationship between the electron parameters (temperature and density) and the OES line ratios from the discharges.

As well study (Isola1, Go' mez1 & Guerra2, 2010) new method for experimentally determining the electron density (n_e) and the electron temperature (T_e) in the negative glow of a nitrogen pulsed discharge is presented. It is based on optical emission spectroscopy (OES) and consists of a variation and refinement of relatively similar schemes previously reported for different working conditions by other authors.

In this paper, wascalculated the electron temperature and the density of the HCD plasma by employing optical emission spectroscopyvarious plasma states.

2- EXPERIMENTAL

Use two electrodes of cylindrical hollow cathode with diameter (3&6) cm and high (8cm)and thickness (2mm) to compare them.Also, the anode was disk of Aluminum with diameter (8.8) cm and thickness (1cm) enclosed in a cylinder chamber of Pyrex with length 30 cm and 10cm diameter. A schematic diagram of the device used in this investigation shown in Figure (1). The discharge was operated in DC current, the external resistance(R) was used to limit the discharge current,and digital multi-meters was used measured the discharge current and the voltage. Basically, he discharge chamber was evacuated using rotary pump (TRIVAC-D16E of 16 m³/h), and the gas pressure was monitored by perani type (Edward's) and serial number (D02173000). The applied voltage was controlled by a DC power supply which can produce potential up to 2000 volt.OES has been used to detect plasma composition by observing electronicallythe

That includes, change gas pressure, gas flow rate and finally the impact of raising the voltage applied to both the temperature and the density of electrons.

excited species and their intensities in the discharges generated by nitrogen plasma . The spectra were collected inthe range (160 – 1000 nm) directly from the plasma using advice(EOS) model (S3000-UV-NIR).

Table 1.Represents change of voltage and current for hollow cylindrical cathode of different diameter,at pressure fixed.

Cathode diameter	P(mbar)	V(Volt)	I(mA)
6(cm)	0.6	340	20.9
		353	41.5
		369	86.4
		386	153.5
		401	227.2
3(cm)	0.6	335	29.6
		353	66.9
		362	92.2
		371	129.7
		378	170.6

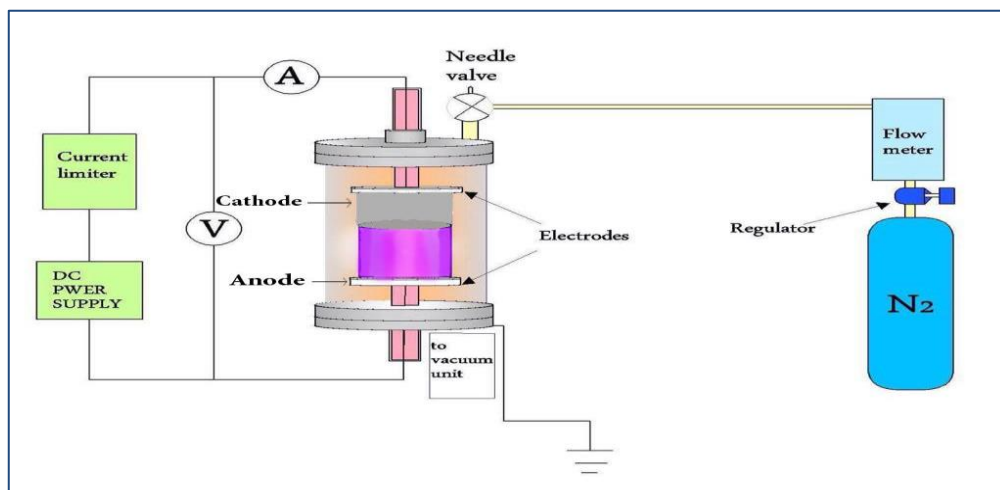


Figure2. Illustrates the scheme for electric circuit

3- RESULT AND DISCUSSION

Figure 3 (a, b) show the result of the spectroscopy forthe selected two spectrums (Wavelengths: 337.5, 376.3 nm) these

spectrums were clearly distinguished byusing two different cathodes in diameter.Show the variation of one of the N₂

spectral line intensity 337.5nm at different in cathode diameter. The intensities of spectral lines increase with the increasing cathode diameter at stabilize both voltage and pressure. If decrease in the volume of cavity leading to a decrease in the mean free path for the electron-neutral inside

the cavity and thus an increase in the number of collisions. Due a result, the electron can produce ionization and excitation depending its energy, that increases the radiation emitted (Awsi. 2013)

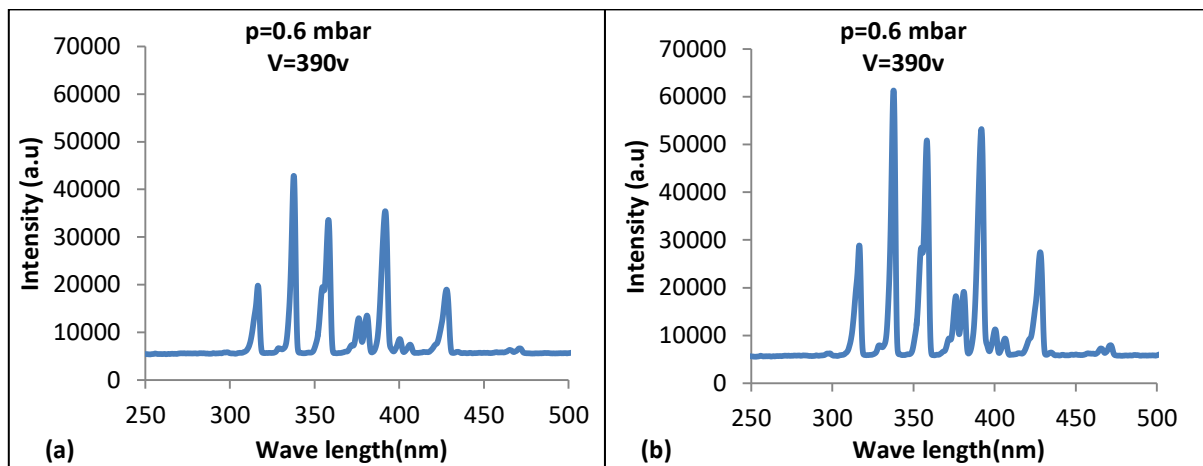


Figure 3. Emission spectra in nitrogen plasma

a. by using cylindrical hollow cathode with diameter (6 cm), b. by using cylindrical hollow cathode with diameter (3 cm).

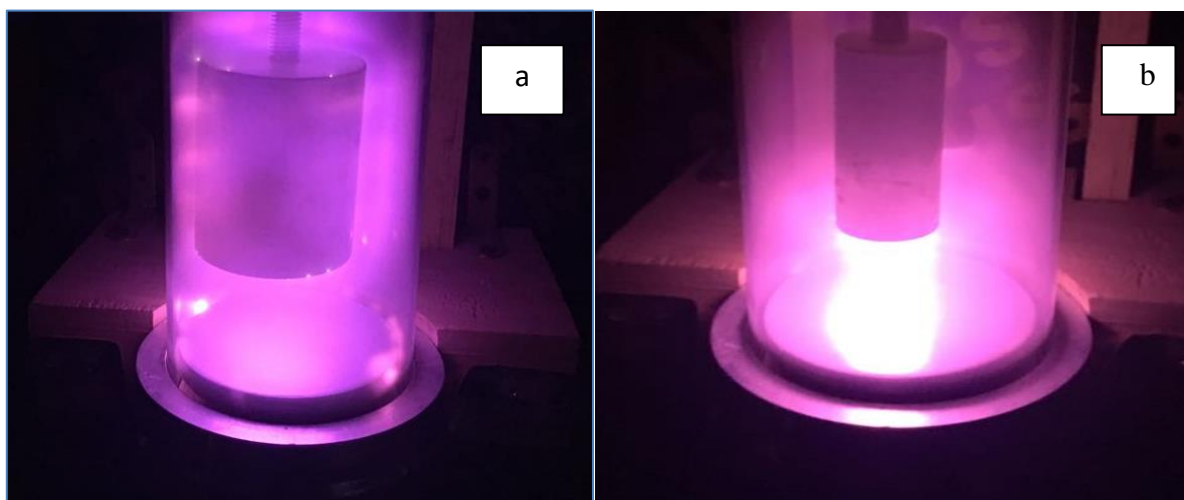


Figure 4. Glow discharge images by using cylindrical hollow cathode:

a. with diameter (6) cm b. with diameter (3) cm.

Figure 4 (a,b) show glow discharge images by using cylindrical hollow cathode with diameter (6&3) cm

To calculate electron temperature T_e using equation (1) and substitute the values of the parameters E and A_g , table (5) have been taken from NIST (atomic spectra database).

Table 5. Values of transition probability, upper energy level and statistical weight that used to calculate T_e (Lieberman, & Lichtenberg, 1994).

Wavelength (nm)	Transition probability $A_{k \rightarrow g_k}$, (s^{-1})	Upper energy level E , (eV)
N (337.5)	3.25×10^8	39.3
N (376.3)	1.70×10^7	41.6

Equation (2) was used to calculate the electron density n_e . The Stark broadening (full width at half-maximum, FWHM) $\Delta\lambda_s$ of the spectral line N (337.5 nm) line is measured from emission spectra and substituted in equation (1) also, the values of T_e that obtained from the previous section (T_e values are obtained from the two lines' intensity method).

Figure 6(a, b) shows an increasing in electron temperature T_e when applied voltage is increasing at the same pressure.

Experimental results show that the electron temperature was increases when the applied voltage increasing at the same pressure.

Through the comparison between the two above methods and according to the results that we had obtained, it's found that the ratio of two lines' intensity method is the most convenient in such measurements. With the increasing applied voltage, the neutral density increases, the mean free path for the electron-neutral impacts excitations decreases, that means the electron gained energy from the excitation field decreases due to the increase in collisions rate.

T_e can be increases with voltage that is electrons can get more energy from the increased electric field and transfer it to neutral particles through electron-neutral momentum transfer collision process. So, T_e increases accordingly with the increasing voltage, this result is similar to that obtained by (Roy & Talukder, 2016).

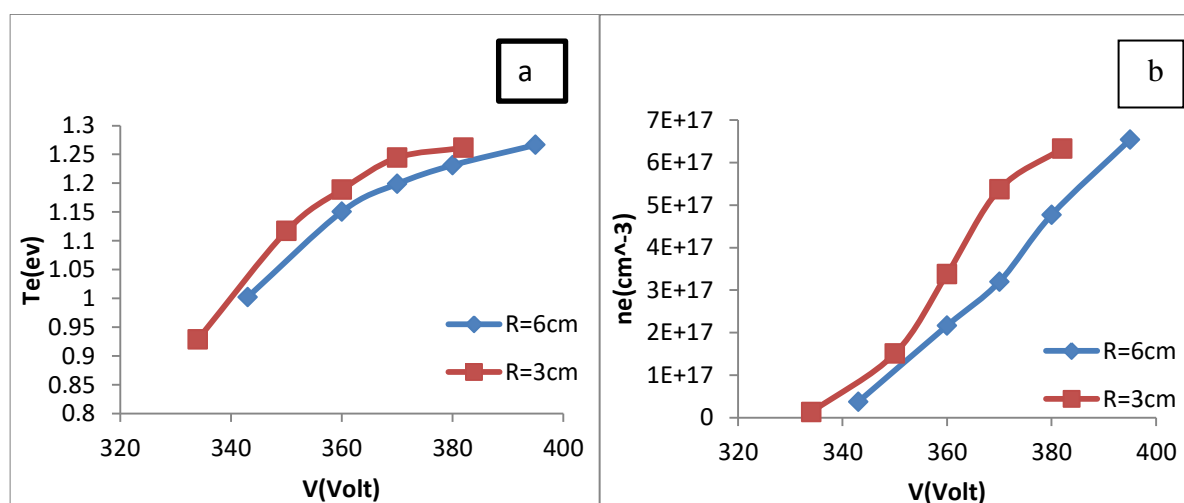


Figure 6. the effect of changing cathode diameter on both temperature and density of electrons as a function of applied voltage (V)

a. T_e (eV) as a function of applied voltage (V), b. n_e (cm^{-3}) as a function of applied voltage

While Figure 7(a,b) shows, electron density n_e and electron temperature T_e as a function with different pressures, at the same applied voltage by using hollow cathode with diameter (6&3)cm.

Figure 7a and b shows, the decreasing 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 nitrogen 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; the phenomena are similar to the results reported in (Van de Sanden, et al, 1994), (Yong, et al, 2017).

When the full pressure background increases, the radius of the plasma beam becomes small (Kroesen, & Sram, 1991). that can be examined in the experiment as well. Therefore, the volume of the plasma beam decreased. This causes to increasing of electron density in high background pressure. By increasing of the pressure, the neutral density increases, the mean free path for the electron-neutral impacts decreases, that means the electron gained energy from the excitation field decreases due to the increase in collisions rate, therefore, the number of excited neutrals decreases and then the intensities of spectral lines are decreasing.

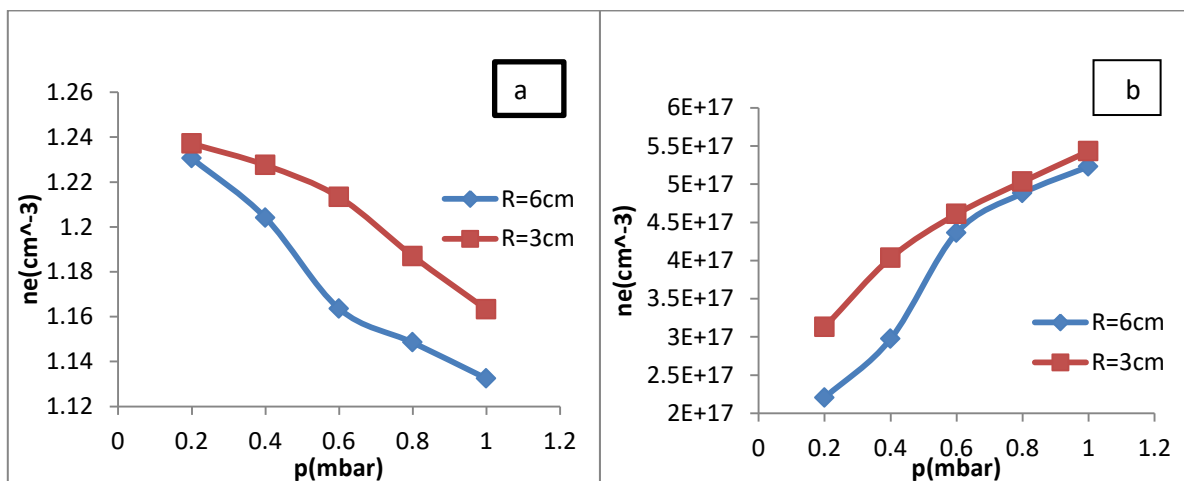


Figure 7. Affect the changing cathode diameter on both temperature and density of electrons as a function of pressure.

a. T_e (eV) as a function of pressure (mbar), b. n_e (cm^{-3}) as a function of pressure (mbar).

4- CONCLUSION

The OES method was used for studying nitrogen plasma, the measurements of electron temperature and electron density was performed by this method in N_2 plasma under a pressure

of 1 mbar. In this experiment, applied voltage (V), flow rate and gas pressure were changed. Found that T_e range from (0.8-1.3 eV) using different operation parameters was found

in correlation with the background pressure / applied voltage. The plasma maintains partial local thermodynamic equilibrium characteristics, which is in accordance with others studies $T_e(0.8-1.3 \text{ eV})$, $n_e(2.8 \times 10^{15} \text{ to } 7 \times 10^{17} \text{ cm}^{-3})$.

The higher electron densities ($>10^{15} \text{ cm}^{-3}$) obtained in the plasma may be assigned to electron impact collisions and reaction rate coupled with high input energy. These are initial results, when the optical emissions from the discharges are assembling. This method is very suitable to use, which may

inflict huge problems for Langmuir probe measurements. To use this technique for a specified discharge, a careful collection of the pertinent levels and a thorough examination of the processes are essential to evaluate the validity of the models and to emphasize the reliance of the line proportion on the parameter to be calculated, while allowing the line proportion to be insensitive to other unidentified restrictions. If these circumstances are met, line-averaged or volume-averaged electron temperature and density might be achieved with logical precision in these discharges.

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