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Optical and Electrical Characterization of Low Pressure DC Glow Discharge

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***Abstract*- In this paper, electrical and optical emission spectroscopic method of determining electron temperature (T_e) and electron density (N_e) are used to investigate the relationship between T_e and N_e with applied voltage in the cylindrical plasmas of dc glow discharges at low pressures in laboratory. In electrical method, Langmuir Double probe is used as diagnostic tool for studying T_e and N_e at low pressure. In optical emission spectroscopy, Saha-Boltzmann method was used to determine T_e and N_e by measuring intensities of NI and NII lines at various voltages. Further, comparison of T_e and N_e calculated by both electrical and optical method in low pressure at various voltages have been made and result showed that the T_e and N_e obtained by the two methods become consistent with each other.**

***Keywords*- Electron Temperature, Electron Density, Optical Emission Spectroscopy, Langmuir Double Probe.**

I. INTRODUCTION

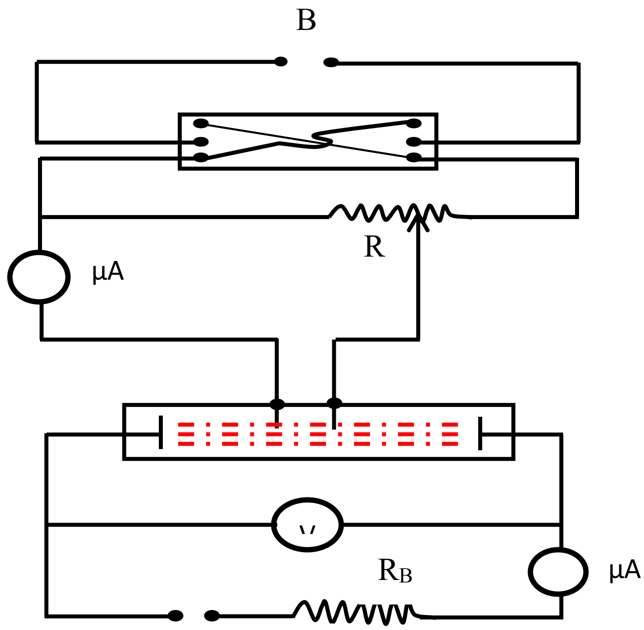
Low pressure dc glow discharge is one of the most common modes for laboratory plasma [1]. The DC glow discharges have been extensively used in the gas laser, material processing and thin film deposition, biological and chemical decontamination of media, light source, absorption and reflection of electromagnetic radiation and synthesis of nanomaterial [2]. Before applying the discharge for any purpose, it is necessary to determine the basic discharge parameters like electron temperature and electron density. The plasma properties depend on several parameters, mainly, the geometry of the electrodes, cooling system, excitation frequency, power injected, operating gas pressure and gas composition [3,4]. Various methods, such as emission or absorption optical spectroscopy, microwave interference, mass spectroscopy and Langmuir probe have been used to diagnose the plasma.

The Langmuir double probe, introduced by Johnson and Malter at 1950, is one of the most powerful and experimentally simple techniques for plasma characterization over a wide range of plasma densities. It is best suited for localized parameter measurement of the plasma because it collects very little amount of electron current without disturbing the plasma condition [5].

The electron density and electron temperature are most fundamental parameter in gas discharges and plays very important role in understanding the discharge physics and optimization of the operation of plasma [6, 7]. Different methods are available to measure the electron density and electron temperature of which the most commonly used are Langmuir probe, microwave interferometer, Laser Thomson Scattering and optical emission spectroscopy (OES) [7].

Techniques based on optical emission are clearly non-invasive, require only moderate spectroscopic equipment, are easy to implement and measurement are usually fast. The OES based technique is suitable for measurement of electron density and electron temperature. To measure electron temperature line intensity ratio method is used, in which the intensity ratio of emission lines is related to electron temperature and electron density [8, 9].

II. EXPERIMENTAL SETUP



H.V. Power Supply

Fig: 1 Schematic diagram of low pressure DC glow discharge

The photograph of the plasma reactor used for the characterization of the low pressure dc glow discharge in air is shown in Fig.1. It is made of thick glass cylinder of length 34 cm long and external diameter of 16.5 cm. The vacuum is created inside the plasma reactor at the desire pressure 0.07mbar with the help of a rotary pump and the pressure is controlled by using a needle valve and is measured by using a pirani gauge. The discharge is produced inside the chamber in between two circular electrodes made of stainless steel of diameter 10 cm separated at the distance of 8 cm and the maximum voltage that can be applied across it is 1 kV. The two identical cylindrical electrostatics probes each with radius 0.5 mm and length 6 mm made of tungsten are inserted inside the positive column of the discharge region. The double probe is connected to a power supply capable of biasing it at various potentials (positive or negative) relative to plasma and the current collected by the probe provides information on the conditions of the plasma. The system that we used to calculate the plasma parameters is automated and the probe characteristic is acquired digitally by employing a digital voltage sweep of ± 50 V over 2500 points. The probe current is taken across a 10 kΩ current sensing resistor so that a maximum 500μAcurrent can be drawn by the probe. The probe current and probe voltage are recorded digitally by using Tektronix TDS 2014C oscilloscope. The data obtained can be transferred to a personal computer for further analyses.

The Spectra of discharge in the range 190nm- 900nm were recorded by the optical emission spectrometer with focal length 140mm and typical resolution 100μm core fiber (Linear array spectrometer VS 140). The recorded spectra were analyzed to determine the electron temperature and electron density. A commonly employed convenient method of temperature determination is the two-line emission ratio methods, which yield the electronic excitation temperature T_{exc} that, can then be equated to the electron temperature T_e.

III. ELECTRICAL MEASUREMENTS

For the electrical characterization, Langmuir double probe is the best way in which two different methods, double slope and Dote method [7] have been used to calculate the electron temperature and mean value is used to evaluate the electron density.

The variation of I-V characteristics at different discharge voltage is shown in the Fig.2a. This data is used to evaluate the electron temperature and electron density. This graph shows that increase in voltage increases the ion saturation current.

In the double slope method, electron temperature can be obtained by using the relation (1) with the help of Fig.2b.

$$T_e = \frac{I_{sat}}{2\left|\frac{di}{dV_d}\right|_{V_d=0}} \quad \text{.............(1)}$$

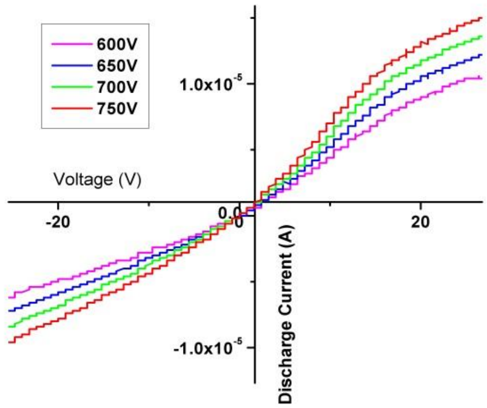


Fig. 2a. I-V Characteristic curve for different applied voltage

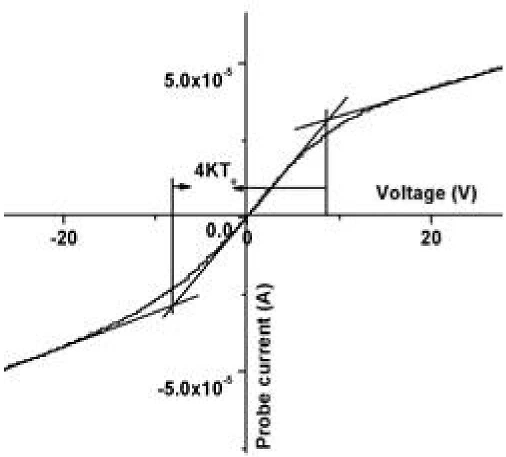


Fig. 2b. Measurement of electron temperature from Double Slope Method

In the Dote method, electron temperature can be obtained by using the relation (2) with the help of Fig.2c [2].

$$(T)_e = \frac{e}{K} \frac{\sum I_{po}}{4\left[\left(\frac{dI_d}{dV_d}\right)_0 - 0.82S\right]} \text{................(2)}$$

T_e- Electron temperature, e - charge of an electron, k- Boltzmann constant

$\left(\frac{dI_d}{dV_d}\right)_0$ Slope from current voltage characteristics at inflection

S- Slope at the positive ion saturation characteristics

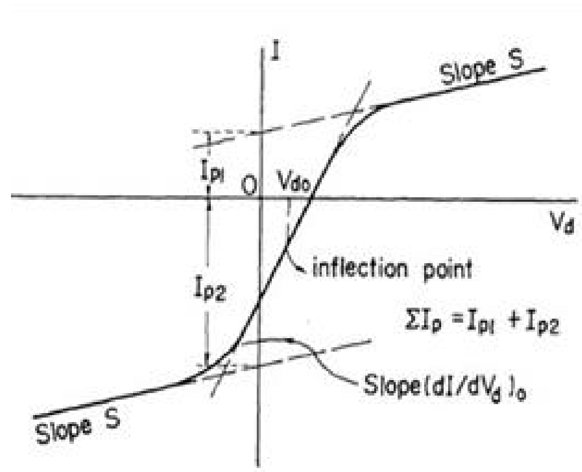


Fig: 2c Measurement of electron temperature from Dote method

From the same characteristics curve the electron density is determined by the following equation [7]

$$n_e = 4 \frac{I_{sat}}{Ae\sqrt{\frac{8kT_e}{\pi m}}} \text{ ....(3)}$$

Where

N_e-electron density

I_{sat}- Saturation current

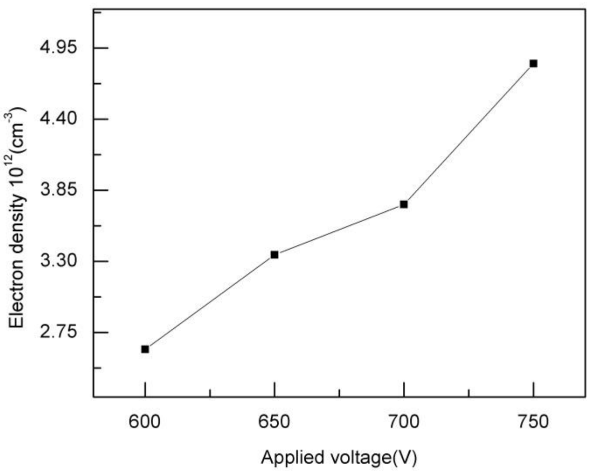
A- Area of probe

B- e- charge of electron

k- Boltzmann constant T_e- electron temperature

m- mass of electron

The mean value of the electron temperature obtained from the Double Slope and Dote method is shown in the Fig.3 and result shows the increasing trends of the electron temperature under the influence of discharge voltage at constant pressure. It might be due to the increase in kinetic energy of the electrons. On increasing the discharge voltage at constant pressure, mean free path of the electron remains same and electrons gain the energy from the electric field as a result it becomes more and more energetic increasing its electron temperature.



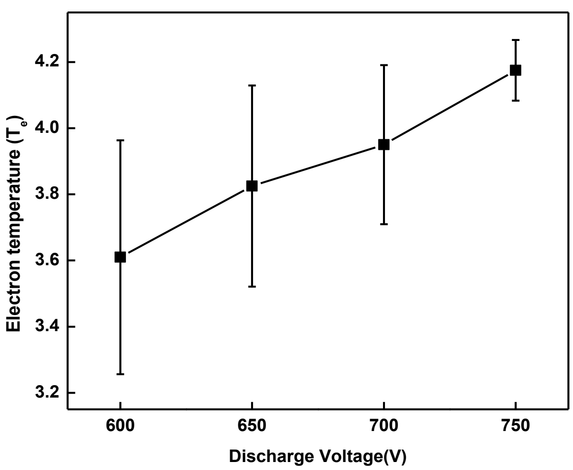


Fig.3 Variation of the electron temperature with discharge voltage at constant pressure 0.07 mbar

Similarly, the variation of the electron density with discharge voltage has been shown in the Fig.4 and there is also increasing trends of the electron density. On increasing the voltage, there is the increase in kinetic energy of the electrons and more and more energy is transferred from electron to neutral atom due to inelastic collision as a result electron density also increases.[5,6]

IV. OPTICAL CHARACTERISATION

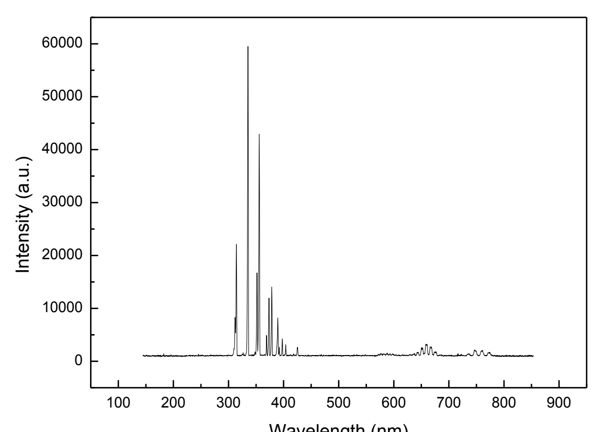
In order to evaluate the performance of the plasma, the plasma parameters (Electron temperature T_e and electron density n_e) are estimated from the intensity af atomic emission lines of the DC glow discharge. The emission line intensity of spectral line is dependent electron temperture and is proportional to the population density of the excited state. So, T_e can be determined from the emission spectrum using the Boltzmann plot: [8]

$$KT_e = \frac{E_2 - E_1}{Log\left[\frac{I_1}{I_2}\frac{\lambda_1}{\lambda_2}\frac{g_2}{g_1}\frac{A_2}{A_1}\right]} \quad ....(4)$$

In equation (4), Indices 1 and 2 refer to the first and second spectral lines, I is the measured intensity of selected spectral line, k is the Boltzmann constant, E is the excited state energy, g is the statistical weight, and A is the transition probability.

The Boltzmann plot method is valid if the discharge plasma under study is in complete local thermodynamic equilibrium (LTE). Therefore, this method may not be used for the exact determination of T_e and n_e. It can only provide us estimated values of these plasma parameters under varying working condition of discharge plasma.

Optical emission spectra of low pressure DC glow discharge are shown in the Fig: 5(a,b,cand d)



5a

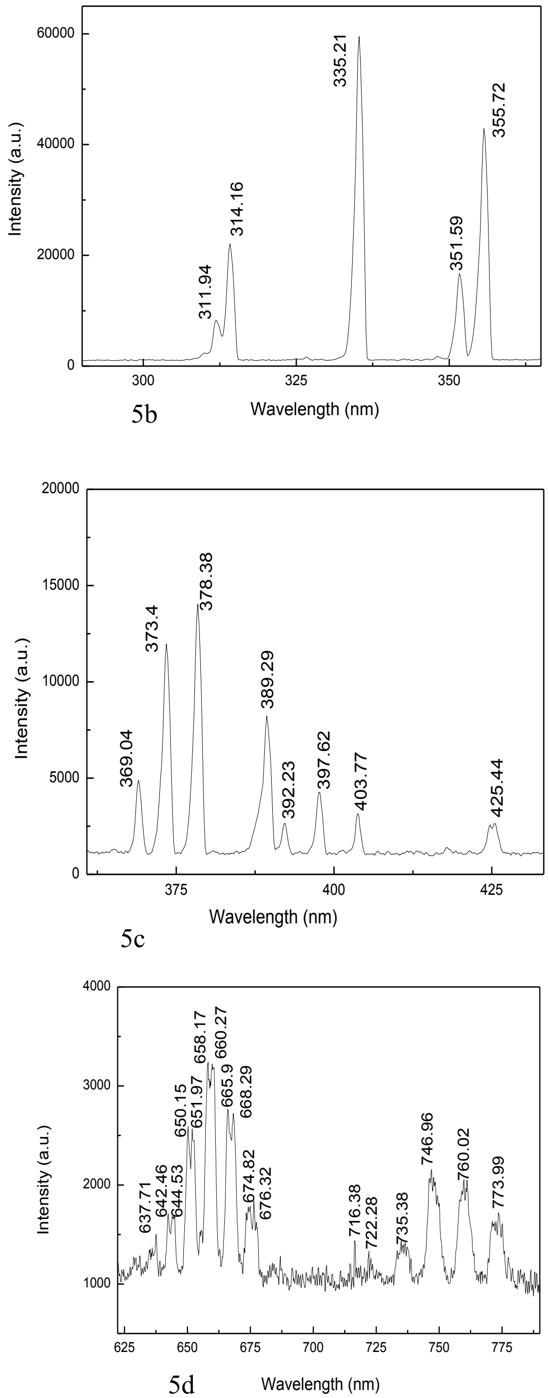


Fig. 5 OES of low pressure DC glow discharge at pressure =0.07mbar and applied voltage = 750v

The spectrum is recorded by linear array spectrometer and emitted lines were observed in the range of 300nmto 850nm. T_e is determined from analysis of selected two NI spectral lines in the observed spectra. The intensities of these spectral lines are obtained from the observed spectrum. The values of E, g and A for the selected lines are taken from the NIST Atomic spectra data sheet. Using these values in equation (4), we can obtain the values of T_e as a function of applied voltage. The electron density n_e can be determined by using the relative intensity of atomic and ionic spectral lines in Boltzmann Saha equation from equation (5) [9]

In this Equation, (1, 2) represents the neutral and ionized atomic species; T_e is the electron temperature; E is the energy of emission level; E_i is the ionisation energy

$$n_e = 2\left(\frac{I_1}{I_2}\right)\left(\frac{\lambda_1}{\lambda_2}\right)\left(\frac{A_2}{A_1}\right)\left(\frac{g_2}{g_1}\right)\left[\frac{2\pi m_e k T_e}{h^2}\right]^{\frac{3}{2}} Exp[-\frac{E_1 - E_2 + E_i}{KT_e}] \quad (5)$$

of neutral atom; I_1 is the intensity of the NI line; I_2 is the intensity of NII line; λ_1, λ_2 are the respective wavelengths; A_1, A_2 are the transition probabilities; g_1, g_2 are the statistical weights of levels (1-neutral) and (2-ionized) respectively.

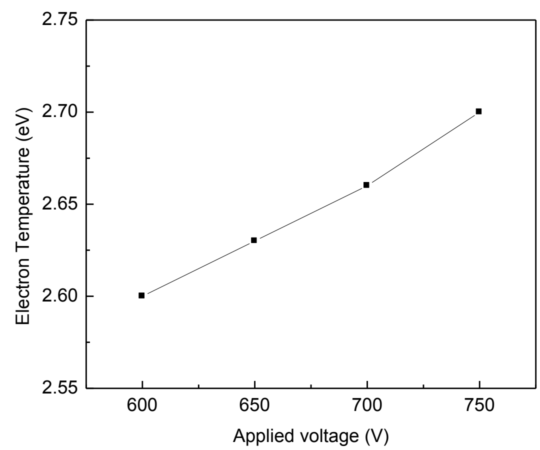


Fig. 6 Variation of the electron temperature with discharge voltage at constant pressure

The electron temperature and the electron density obtained from the optical method have been shown in the Fig.6 and Fig.7 respectively. The electron temperature increases from 2.6 to 2.7 eV and electron density from 1.44×10^{13} to 1.50×10^{13} cm^{-3} on increasing the applied voltage from 600 to 750V.

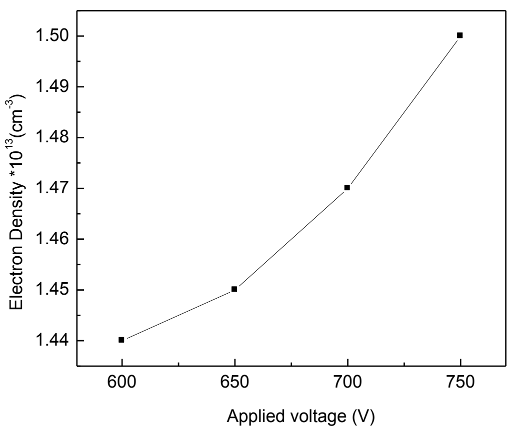


Fig. 7 Variation of the electron density with discharge voltage at constant pressure

Similarly, from electrical method, the electron temperature is found to increase from 3.6 to 4.2 eV and electron density from 2.70×10^{12} to 4.70×10^{12} cm^{-3} on increasing the applied voltage from 600 to 750 V. The result shows some discrepancy on the plasma parameters obtained from the both method and it might be due to the fact that Langmuir double probe measures the local plasma parameters around the probe whereas OES gives the average information of the T_e and n_e over the entire volume of the plasma.

V. CONCLUSION

In this paper the Langmuir double probe and optical emission methods were used to characterize the low pressure DC glow discharge in air plasma. Electron temperature and Electron density were deduced from the I-V characteristics at various input voltages from 600 V to 750 V at fixed working pressure 0.07 mbar. Both T_e and n_e increases with increase in input voltages. T_e and n_e were also determined by optical method and found that T_e and n_e increases with increase in input voltage. T_e and n_e determined by electrical and optical has been compared. It has been found that T_e and n_e determined by both methods are similar.

VI. ACKNOWLEDGMENTS

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