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LANGMUIR DOUBE PROBE FOR PLASMA PARAMETERS MEASUREMENT

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ABSTRACT

This paper reports the measurement of electron temperature (T_e) and electron density (n_e), Debye length (λ_D) and plasma frequency(f_p) in a low pressure DC glow discharge in air using Langmuir double probe. Three different methods namely: Double slope, Dote and Interception were used to evaluate the electron temperature (T_e) and mean value of T_e obtained from the above three methods was used to calculate the electron density, Debye length and plasma frequency.The main objective of the study is to investigate the effect of discharge voltage and pressure on the plasma parameters at low pressure and low voltage. Experiment showed that (T_e), (n_e) and (f_p) gradually increased but (λ_D) decreased on increasing the voltage from 550V to 700V respectively. Similarly, on increasing the pressure from 0.10 to 0.16 mbar, there were decrease in electron temperature and Debye length whereas increase in electron density and plasma frequency.

Keywords: Langmuir Double Probe, Electron temperature, Electron density, Debye length, Plasma frequency etc.

INTRODUCTION

The DC glow discharges have been extensively used in the gas laser, thin film deposition, etching and surface modification of the materials [1,2]. For understanding, developing and maintaining such processes, it is desirable to determine the basic plasma parameters [3]like electron temperature, plasma density and their dependence on the discharge voltage and operating gas pressure. One of the most widely used method for the plasma diagnostic in the electrical method is the Langmuir single probe and it was used by Irvin Langmuir in 1924. However, to overcome the limitations caused by the single probe, Johnson and Malter in 1950, introduced double probe method for the plasma characterization over a wide range of plasma densities [4,5]. In which electron current is completely controlled by the ion saturation current so that probe draws very little amount of current without disturbing the plasma condition. It also enables the performing of the time as well as the space resolved measurements of plasma parameters and even it can be used to the electrode less discharge like microwave discharge. Other importance of the double probe is that it measures local parameters of studied plasma but almost all other techniques give information averaged over a large volume of plasma [6,7] and the simplicity of the used equipment that allows us to receive result quickly, without high experience. In the double probe method, we have used three different methods namely: Double derivative, Dote and Intercept method to measure the electron temperature and their average value is used to evaluate the electron density, Debye length and plasma frequency.

MATERIALS AND METHOD

The photograph of the plasma reactor used for the characterization of the low pressure dc glow discharge in air is shown in Fig.1 in which vacuum is created at 0.10, 0.14 and 0.16mbar pressure and voltage is changed from 550V to 700V. Two identical cylindrical probes are inserted in the discharge region and it is powered by the digital voltage sweep of ±50V over 2500 points. The data are taken from Tektronix TDS 2014C oscilloscope and it is transferred to the personal computer through data storage device for the further analysis.All other specifications of the double probe for its operation is given in Tab.1.

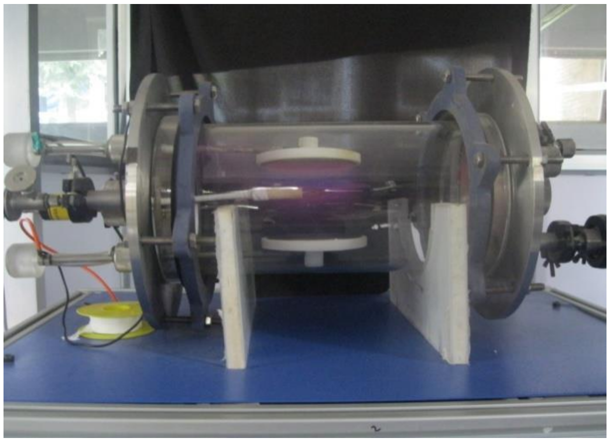

Fig.1 Photograph of low temperature plasma reactor with langmuir double probe.

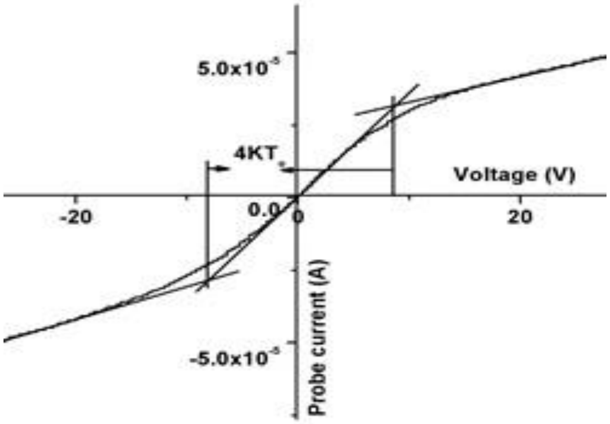

Fig.2 Measurement of electron temperature from double slope method

Tab. 1 Specifications of the double probe system

S.N	Specifications
1	Probe material: Tungsten
2	Length of the probe: 6mm
3	Diameter of the probe: 0.5mm
4	Diameter of the electrode: 10 cm
5	Distance between two electrodes: 8cm
6	Maximum voltage across electrodes: 1000V
7	Biased voltage range: -30V to +30V sweep over 2500 points
8	Current sensing resistor: 10KΩ
9	Maximum probe current:500μA

In the double slope method, one tangent is drawn at the point of inflection and another tangent in the ion saturation current region. The ordinate of the intercept gives the ion saturation current. The electron temperature (T_e) can be obtained by using the relation [8]

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

In Dote method, electron temperature can be obtained by using following relation[9]

$$T_e = \frac{\sum I_{po}}{4\left[\left(\frac{di}{dV_d}\right)_{V_d=0} - 0.82S\right]} \dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

where, $\left(\frac{di}{dV_d}\right)_{V_d=0}$ = slope of the current voltage characteristic at the point of inflection
S= slope at the positive ion saturation current
And $\sum I_{po}$ = total ion saturation current

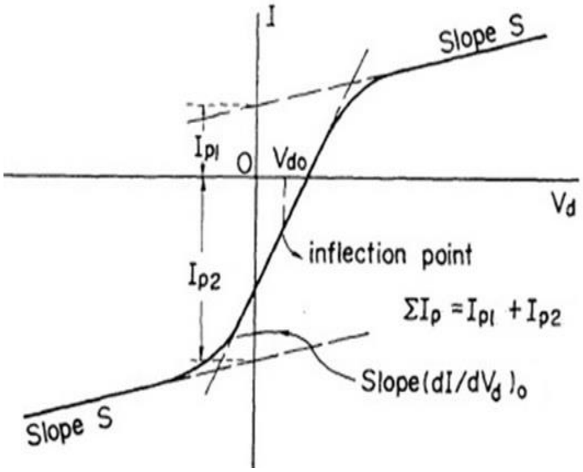

Fig.3 Schematic diagram of the double probe characteristic to determine T_e in Dote method

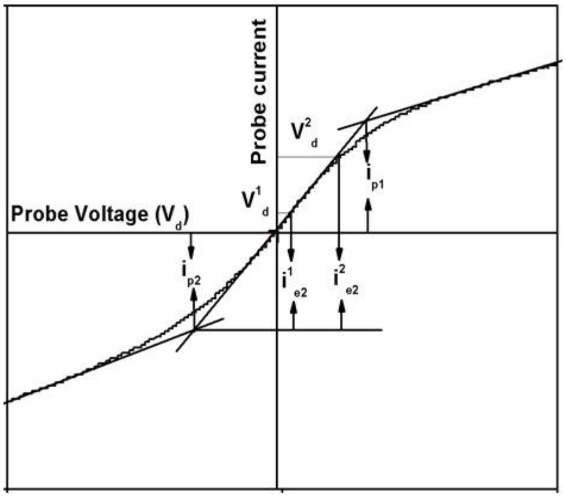

Fig.4 Schematic diagram of the double probe characteristic to determine T_e in Intercept method

Similarly, in the Intercept method the electron temperature can be obtained by using following relation [4]

$$T_e = \frac{V_d^2 - V_d^1}{ln\left[\left(\frac{F-1}{D-1}\right)\right]} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.(3)$$

where $F = \frac{\sum i_p}{i_{e2}^1}$and $D = \frac{\sum i_p}{i_{e2}^2}$

In our experiment we have chosen V_d^2 and V_d^1 as around 2V and 5V respectively

While the electron density can be measured from the ion saturation current and electron temperature using the following equation.

$$\mathrm{T_e} = 0.6\mathrm{eAn_e}\sqrt{\frac{\mathrm{KT_e}}{\mathrm{M_i}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots .(4)$$

The factor 0.6 is due to the reduction of the ion density in the presheath region over which the ions areaccelerated up to the Bohm velocity[10,11].

Similarly, Debye length (λ_D) and the plasma frequency (f_p) can be obtained by using following relations respectively

$$\lambda_D = \sqrt{\frac{\epsilon_0 K T_e}{n e^2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots ..(5)$$

And

$$f_e = \frac{1}{2\pi}\sqrt{\frac{e n_e}{\varepsilon_0 m_e}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

RESULTS AND DISCUSSION

In Double derivative, Dote and Intercept method the electron temperature is evaluated by using Eq.1, Eq.2 and Eq.3 respectively and the graphical representation of the mean value of electron temperature obtained from above mention three methods as a function of the discharge voltage at different constant pressure is shown in the Fig.3. It is observed that with the increase in discharge voltage at a fixed pressure, the ($\mathrm{T_e}$) graduallyincreases. The increasing trend in $\mathrm{T_e}$ under the influence of rising discharge voltage might be due to increase in kinetic energy of the electrons gained from the electric field [12,13]. Fig.3 also shows that there is decrease in $\mathrm{T_e}$ on increasing the pressure at constant voltage. The reason behind it can be explained from the Eq.7.

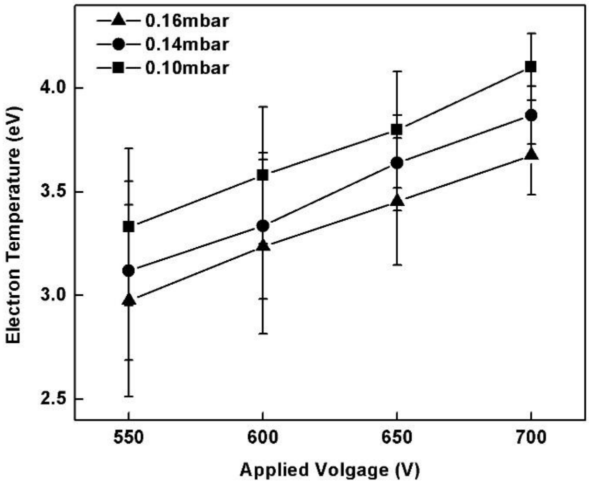

Fig.3Variation of mean value of the electron temperature as the function of the discharge voltage at different constant pressure.

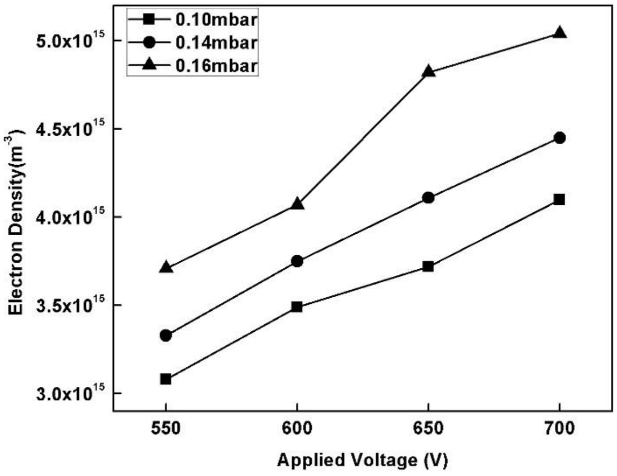

Fig.4 Variation of the electron density with discharge voltage at different constant pressure.

The mean energy of the electron is given by,

$$\bar{E} = eE\lambda_e = \frac{e\lambda_e V}{d} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (7)$$

where, V is the discharge voltage, d the inter-electrode gap, E the electric field strength and λ_e is the mean free path of the electrons.

When the discharge pressure inside the discharge chamber increases, electron collision frequency with neutral atoms also increases and the mean free path between two successive collisions decreases. Which shows that rather than gain of energy by the electrons from the electric field, more and more energy is transferred to the neutral species as a result T_e decreases.

Fig.6 shows that electron density decreases on increasing the discharge voltage as well as pressure. On increasing the pressure or voltage, there is increasing the ionizing activity inside the plasma during the inelastic collision between electrons and neutral species due to the decrease in mean free path of the electrons or by the increasing the kinetic energy of the electrons as a result, more and more energy is transferred to the neutral species and electron temperature increases [14].

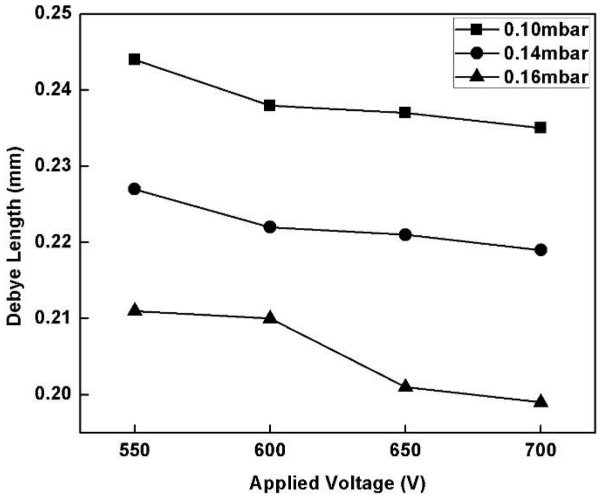

Fig.5 Variation of the Debye length with discharge voltage at constant pressure

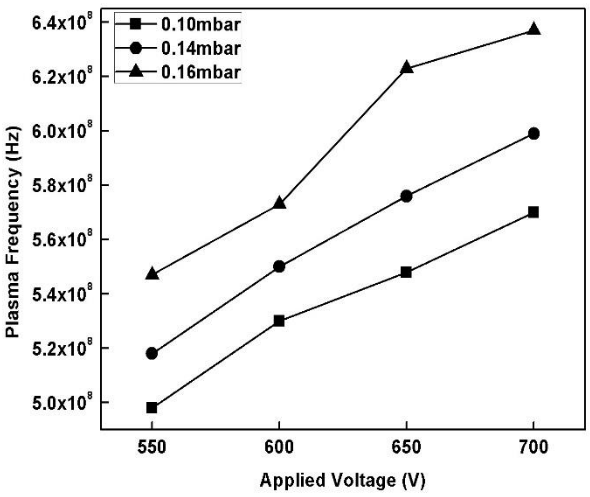

Fig.6 Variation of the plasma frequency with discharge voltage at constant pressure

The Debye length is a characteristic scale length in plasma and it is a measure of the distance that the potential of a charged object penetrates into the plasma. It depends upon the electron temperature and electron density. On increasing the voltage, electrons becomes energetic and some of the fast moving electrons can inter inside the positive sheath region and reduces the number of positive ions which leads to increase the Debye length but on increasing the pressure, electron density increases. The increase in electron density increases the shielding effect at short distance. The variation of Debye length with applied voltage and filling pressure is shown in

Fig.5. Overall, the decrease in Debye length in both cases is due to the increase in electron density.

The plasma frequency is the fundamental property of the plasma and represents the frequency at which the electron cloud oscillates with respect to the ion cloud and it entirely depends upon the plasma density. The variation of the plasma frequency with discharge voltage or pressure is shown in Fig.5. Both increase in voltage or pressure increases the electron density and hence the plasma frequency.

CONCLUSION

Langmuir double probe device is successfully used to evaluate the plasma parameters in the low pressure DC glow discharge in air. Result indicates that electron temperature, electron density, and plasma frequency increases but Debye length decreases on increasing the discharge voltage from 550 to 700V at different pressure 0.10, 0.14 and 0.16 mbar respectively. Similarly, on increasing the pressure from 0.10 to 0.16 mbar at different constant voltage 550V, 600V, 650V, and 700V, it is found that there is decrease in electron temperature and Debye length whereas increase in electron density and plasma frequency. The measured value of the plasma parameters is in good agreement with the expected value of the DC glow discharge and result shows that Langmuir double probe is the suitable tools to measure the plasma parameters

REFERENCES

[1] Chiad B T, Al-Zubaydi T L, Khalaf M K & Khudiar A I, Construction and characterization of a low pressure plasma reactor using glow discharge. *Journal of Optoelectronics and Biomedical Materials*, 1(3):255-262, Sept.2009.

[2] Bogaerts A, Neyts E, Gijbels R & van der Mullen J, Gas discharge plasmas and their applications. *SpectrochimicaActa Part B*, 57:609-658, 2002.

[3] Brockhaus A., Borchardt C. & Engemann J, Langmuir probe measurements in plasma *Sources Sci. Technol.*, 3:539-544, 1994.

[4] Johnson E O & Malter L, a Floating double probe method for measurements ingas discharges. *Physical Review*, 80(1), October 1950.

[5] Pilling L S , Bydder E L & Carnegle D A, A computerized langmuir probe system. *Review of Scientific Instruments*, 74(7):3341-3346, July 2006.

[6] Chen F F Electric *probe Plasma Diagnostic Techniques*. Edited by Huddleston and Leonard, Academic Press, New York, 1965.

[7] Mijovic S, Vuceljic M, Schrittwiester R, Maljkov M, Dimitriu D G & Ionita C, determination of plasma space potential from the langmuir probe by Tikhonov's regularization method. *Publ.Astron.Obs.Belgrade*, (84):313-316, 2008.

[8] Konuma M, *Film Deposition by Plasma Techniques*. Stuttgart, December 1991.

[9] Dote T, A new method for determination of plasma electron temperature in the floating double probe. *Japanese Journal of Applied Physics*, 7:964-965, 1968.

[10] Chung T H, Shin Y M & Seo D C, Comparision of two methods of interpretation of langmuir probe data for an inductively coupled oxygen plasma. *Contrib. Plasma Phys*, 46(5-6):348-353, 2006.

[11] Merlino R L, Understanding langmuir probe current-voltage characteristics, *American Journal of Physics*, 75(12):1078 -1085, December 2007.

[12] Naz,M Y, Gha_ar A, Rehman N U, Naseer S & Zakaullah M, Double and triple langmuir probes measurements in inductively coupled nitrogen plasma. *Process in electromagnetics research*, 114:113 -128, 2011.

[13] Kim C K, Analysis of langmuir probe data in high density plasmas. *Korean J. Chem. Eng.*, 21(3):746 -751, 2004.

[14] Chung T H, Yeom G Y & Kwon K H. Characterization of an oxygen plasma by using a langmuir probe in an inductively coupled plasma. *Journal of the Korean Physical Society*, 38(3):259-263, March 2001.