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RESEARCH ARTICLE

Plasma Diagnostics of Low Pressure Helium Glow Discharges at Different Working Voltages

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Abstract

In addition to measurements of, the neutral gas temperature, the electron density and electron temperature plays a vital role in a low-pressure helium plasma characterization and processes. For instance, in biological and mass spectroscopy applications .In this paper, low pressure plasma of helium gas was generated between a flat planar anode and cathode electrodes. A cylindrical probe was constructed and employed to analyze plasma parameters of a structure discharging glow in a negative glow region. Electrons and ions currents of helium plasma have been measured at different discharges voltages and currents. Langmuir probe results at working pressure of 0.5 mbar indicate the electron temperature decreases and density increases as applied voltage increases which can be traced to the fact that electrons collide more frequently with plasma species.

Keywords: *Plasma diagnostics; Helium gas; Glow discharge; Langmuir probe.*

Introduction

Due to their inherently high-energy, plasmas are typically sustained in high temperature or low-pressure conditions. As a consequence of the needed energy input to maintain the gas ionization and discharge, it is difficult to sustain a low-temperature plasma at atmospheric pressures. Over the last three decades, however, a few techniques have been developed to generate and diagnostics such plasmas. Recently, modeling and diagnosing the parallel plate discharge reactors under vacuum with exciting dc and rf, has been acquiring an ever increasing significance thanks to the vast use this approach finds in plasma processing [1-6].

On lab scale, in the area of low-density plasma, Langmuir probes are applied to measure density and temperature of the electron as well as to measure the potential of the plasma [3-7]. In low density plasma the ion sheath around the probe is magnified and the need may arise to take into consideration the effects of collision which can hardly be defined accurately enough. Named after the physicist who invented it, American Irving Langmuir (1881-1957), the Langmuir probe is merely a small metal wire. Among the very first group of scientists who searched into the field of plasma state, Langmuir has the privilege of granting the plasma its name [1-3]. It would be perfect for the plasma to be investigated by the Langmuir method, if the particle mean free path were by far larger than Debye length. In such a case, it is reasonably justifiable to believe that the characteristic of Langmuir probe current-voltage is in harmony with this theory of Langmuir. The current-voltage (*I-V*) characteristic of single probe in absence of magnetic field is typically as shown in Figure1.

The *I-V* characteristics are the measured currents according to the applied probe voltage. The *I-V* graph is divided into three regions: ion collection (ion saturation), transition (electron retardation), and electron saturation (electron collection) region [4, 5] .The work is done under the assumptions that the current of the probe causes no disturbance to the plasma balance, the probe is smaller in its diameter than the mean free path of the electron, and that at a temperature T_e, thermal balance is established among the electrons themselves with such a distribution that is in harmony with the kinetic energy of Maxwell. Region I: With the probe granted a negative potential bias, electrons suffer repulsion while ions gather. The ion currents in the ion saturated regions were utilized to determine the ion current running through a selected area *A* in the plasma based on probe theory of the orbital motion limit (OML) [6].The OML approach provides the possibility to determine the ion density regardless of the electron temperature. Under the assumptions of the isotropy of plasma, that the electron is hugely hotter than the ion (Te>>Ti), and that the probe sheath is thick and non-collisional. Given a Maxwellian energy distribution in the plasma that is undisturbed, the equation hereunder for cylindrical probe is used to calculate the ion current in the OML regime [5].

$$I_i = A_p n_i e\left(\frac{-eV_p}{8M_i}\right)^{1/2} \text{ ..... (1)}$$

, where I_i is the probe current (ion current), *Amp.*, A_p is the probe surface area. , M_i is the ionic mass (atomic mass unite, $1_{amu}= 1.67 \times 10^{-27} kg$ for proton).

n_i is the ion density (cm^{-3}).

In short, the I^2 vs V_p ,plot for the ion-collection range ($V_p<0$) , the inclination of the linear segment of the curves involving I^2 vs V_p was used to determine the density of the ion, without knowledge of the electron temperature according to the relation:

$$n_i = 1.24\times 10^{15}\frac{M_{amu}^{1/2}(slope)^{1/2}}{A_p} \text{ .. (2)}$$

The increasing of probe negative bias leads to repel all electrons and the current becomes pure ion current. Region II: With the reduction of negative probe potential V_p, the probe cause ions as well as electrons to gather (high thermal energy). As the potential (probe bias) is taken further to the positive domain, the gathering ion and electron currents merely cancel out. At this point, the floating potential V_f is established. For thermalized plasma, this voltage value attains nearly *1/2KT* and is expressed in *(eV)*. Going with the probe potential further beyond V_f causes an acute leap to occur on electron current. The mathematical relation between this current and the probe bias voltage is of an exponential degree. Finally, the current becomes saturated at the plasma space potential value (*Vp*) because of space charge limitation in current gathering. In region II the electron current is given by [8]:

$$J_e = \frac{I_e}{A_p} = \frac{n_e \cdot e \cdot v_{th}}{4}\cdot \exp\frac{-eV}{kTe} \text{ ... (3)}$$

$$I_e = \frac{A_p \cdot n_e \cdot e \cdot v_{th}}{4}\cdot \exp\frac{-eV}{kTe} \text{ .... (4)}$$

So, it is possible to determine the temperature of the electron straightforward from the *I-V* characteristic of the probe. The slope yields the electron temperature:

$$Slope = \frac{-e}{kTe} \text{ ..... (5)}$$

, where T_e in (K^o).

$$Slope = \frac{1}{T_e} \text{ .... (6)}$$

, where T_e in (eV)

The approach used to determine the electron density can be summarized as follows: In region III, when positively biased, the probe totally collects electrons and repels ions, whereas the current of electrons collected is almost constant. Being called the electron-saturation current I_s, from it the electron density can be determined via equation [8]:

$$I_s = \frac{n_e e A_p}{4}\left(\frac{2kT_e}{m_e}\right)^{1/2} \quad .... (7)$$

The electron density is given by:

$$n_e = 3.73\times10^{13}\frac{I_{sat}}{A_p T^{1/2}} \quad .... (8)$$

where T_e is the electron temperature and n_e is the electron number density. It is possible to determine the floating potential through the following equation, for the case of the bias voltage at which $I_i+I_e = 0$,

$$I_{is} = I_{es}\exp\left[\frac{e(V_f - Vp)}{kT_e}\right] .... (9)$$

$$V_f = Vp + \left(\frac{kT}{e}\right)\ln\left[0.6\left(\frac{2nm_e}{m_i}\right)\right] ... \quad (10)$$

This work aims to study the effect of the changes in discharge current on the electrical characteristics of He plasma and also, determine n_e and T_e using single Langmuir probe technique at different plasma discharge voltages.

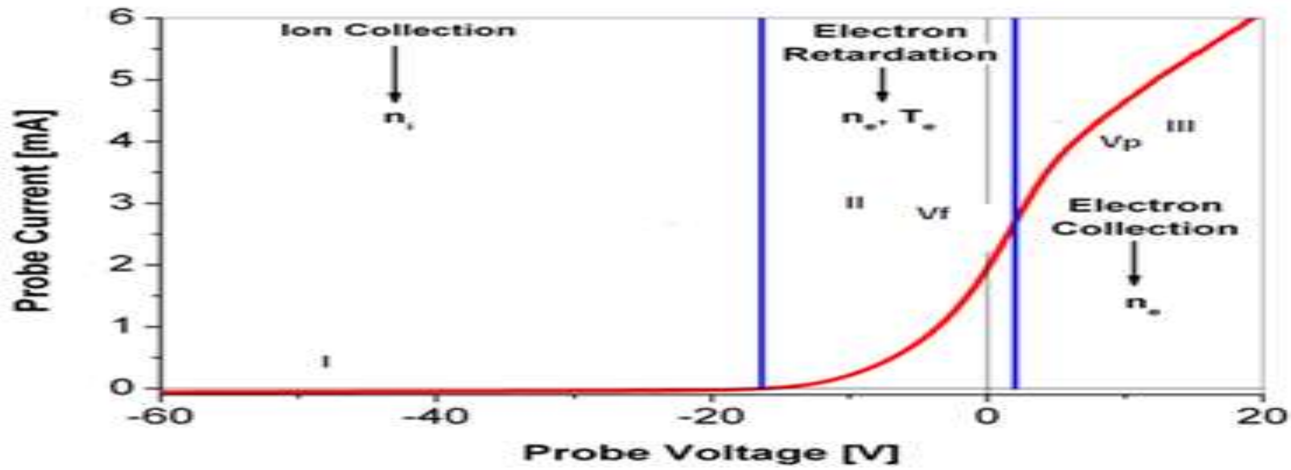

Fig.1: I-V characteristics of single Langmuir probe [4]

Experimental Procedure

As a discharge vessel, a 46mm long cylinder with a diameter of 100mm was used. The cylinder accommodated two discs (anode and cathode) of stainless steel connected by 1.5kV power supply as shown in Fig.2. Home-made-single probe of tungsten, being cylindrical of 0.5mm in diameter and 2.0mm in length (Fig.3) .The Langmuir probe was located near the cathode electrode center with spacing of 14mm in the longitudinal vector. The discharge chamber was vacuumed to 1×10^{-5} mbar using a diffusion pump (380L/sec.) together with a rotary pump of $14m^3/h$ and the purities of working discharge helium gas is 99.99%. The obtained discharge currents were of: 8.0, 10.9, 12.4 and 16.9mA and were varied from 1.2-1.5kV. Figure 3b illustrates the probe circuit capable of sweeping the probe potential in the range from -100 to +100V relative to earth while measuring the probe current .All probe voltages were taken relative to earth.

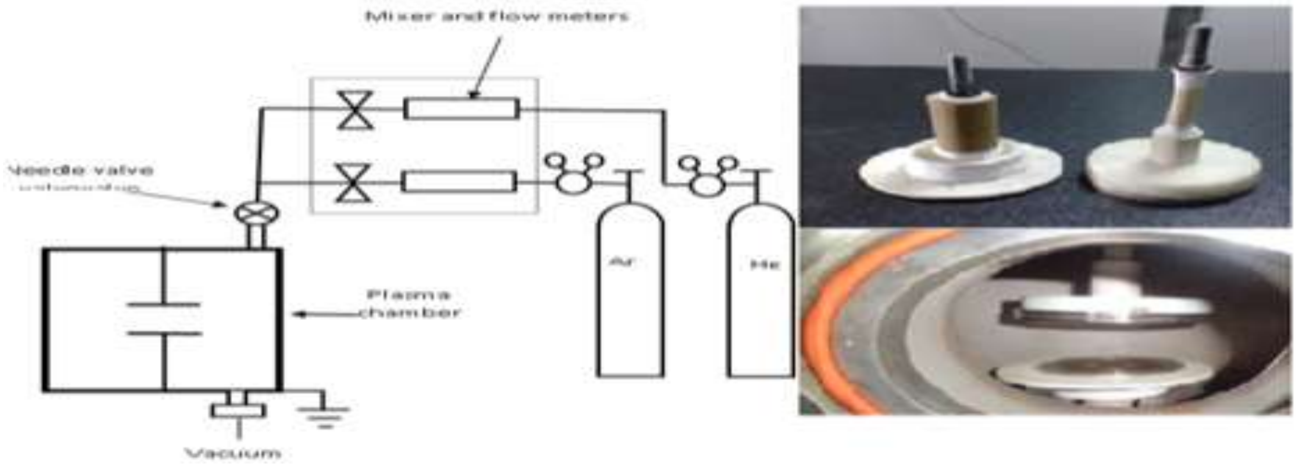

Fig.2: A schematic diagram of home-made plasma system (a) and discharge electrodes (b)

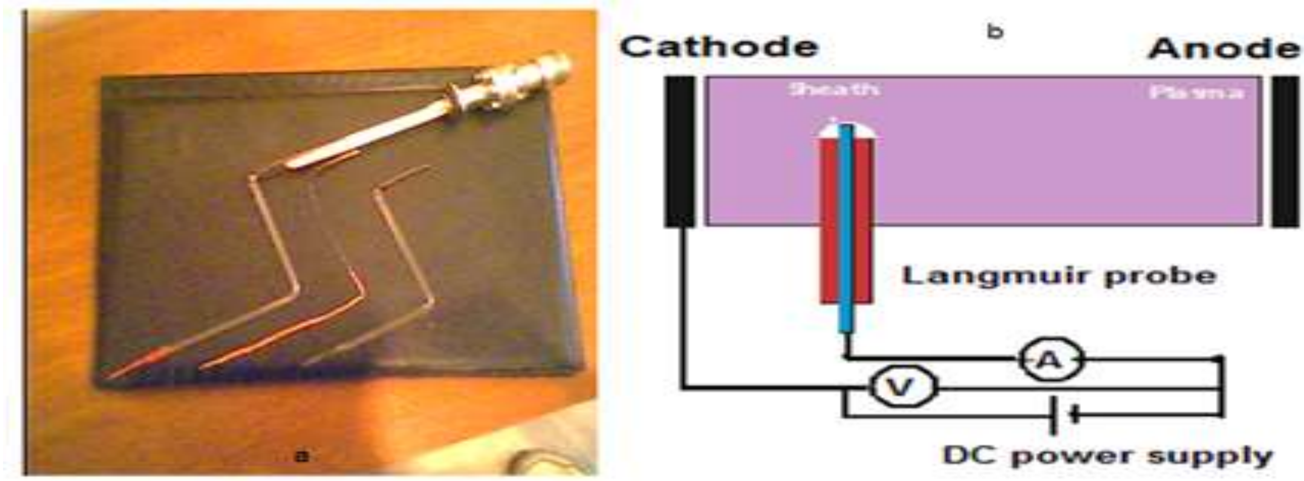

Fig 3: Langmuir probe assembly (a) and its circuit (b) in planer glow discharge experiments

Experimental Results

Paschen curve for helium gas discharges is obtained by measuring the breakdown voltages of gas within a stainless steel vacuum chamber with two planar electrodes .Data is taken at various pressures and electrode separation of 46mm.The breakdown voltage has to do with the spacing of electrode pd (Paschen law) [8], where p is the gas pressure and d is the inter- electrode gap spacing as illustrated in Fig. (4) Of the previous section. The minimum breakdown voltage $V_{b\ (min)}$ was found 205 V at pd_{min} of 5mbar.cm. When the amount of Pd is low, the breakdown voltage is high due to the fact that collisions are too few (low pressure or small gap). At high pd values, however, the breakdown voltage is high because there are too many collisions (high pressure or large gap). For Pd values larger than 5mbar.cm), the rise on breakdown voltage becomes - basically- of a linear shape relative to Pd.

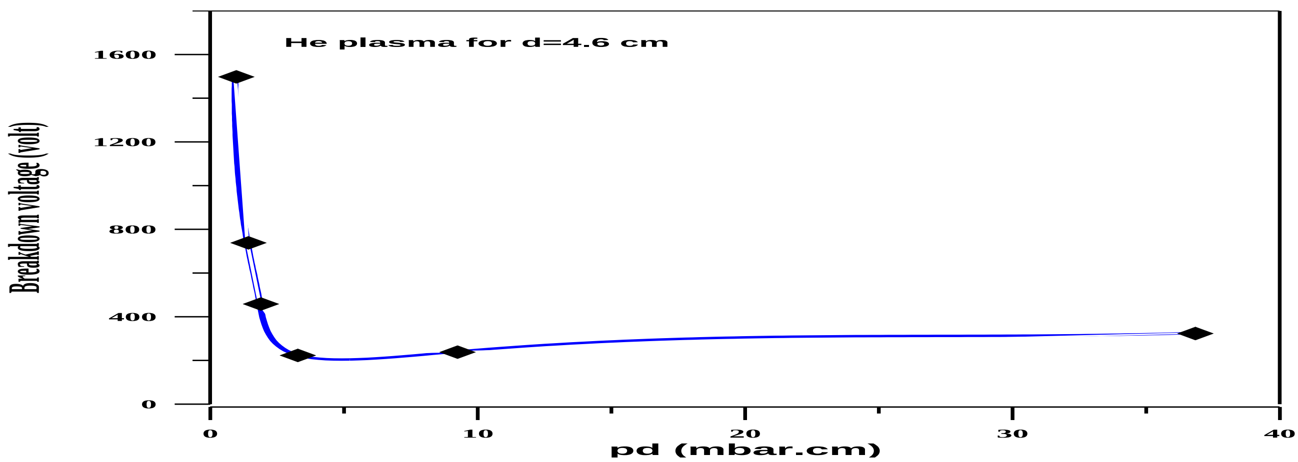

Fig.4: The breakdown voltage of helium gas at various pressures and electrode separation of 46 mm

Figure (5) illustrates how the discharge current changes with the change of the voltage applied, for gas vacuum values of 0.3, 0.5 and 0.7 mbar, subsequently. As expected, the diagram reveals that the higher the applied voltage is the higher the discharge current is, whereby the non-linear nature of current variation is noticed, however. As the chamber pressure increases, so bigger amounts of ions, electron, and free species increases in glow column, i.e. the probability of secondary electron emission gets higher. So the total current measured is, indeed, the summation of ions and emitted electron currents. The current density after short transient evolves into a child low sheath with time-varying current density and sheath thickness. The Child law current density J_c for applied voltage V_o across sheath of the thickness d is given by [10]:

$$J_e = \frac{4}{9} \cdot \frac{\in_o (2m_e)^{1/2} \cdot V^{3/2}}{d^2}$$

, where εo is the free space permittivity, d is the inter-electrode spacing and e and M is the charge and particles mass.

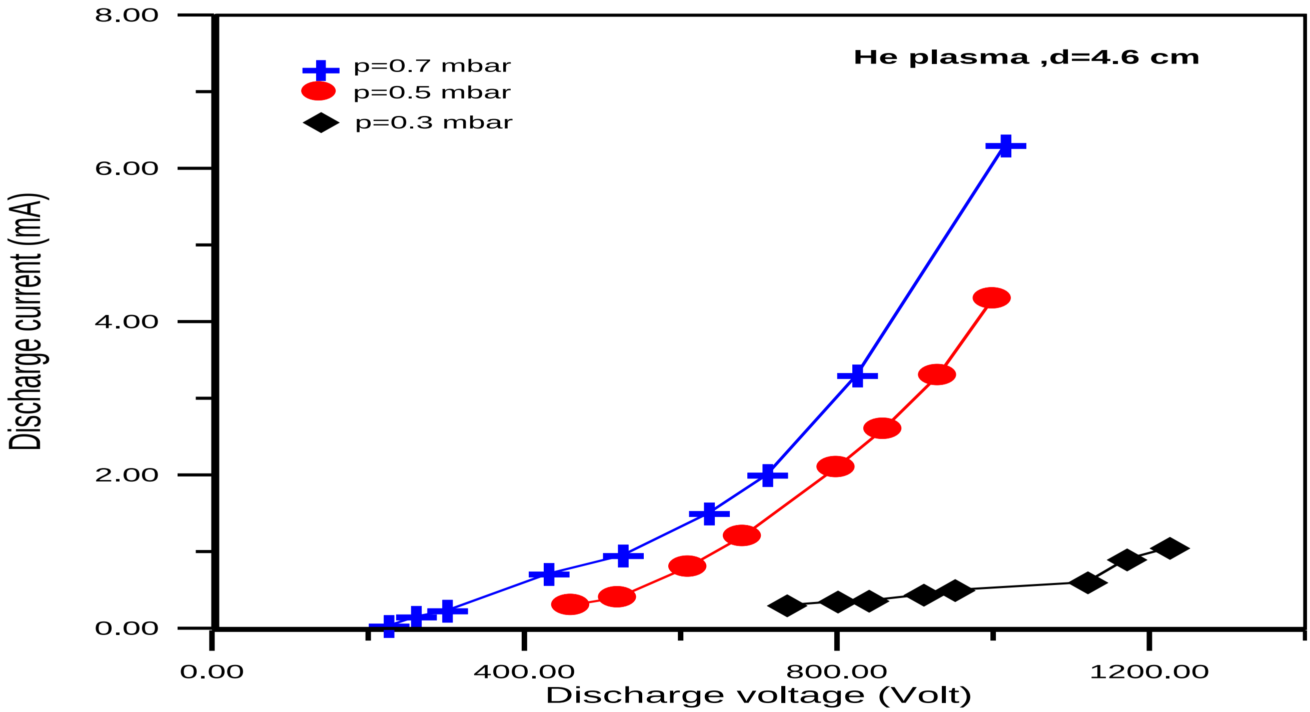

Fig. 5: I-V characteristic of helium glow discharges

Fig. 6 shows the current-voltage for our experiment of Langmuir probe obtained in helium plasma ranging at 1.2-1.5 kV, 8-20 mA and pressure of 0.5mbar. Fig. 7 illustrates how the electron temperature T_e changes with the change of the discharge cathode voltage as a function of discharge current. The electron temperature has a tendency to decrease with the increase of cathode voltage. The diagram clarifies that the higher the electron density is the higher the discharge voltage is, and that its influence is more evident under stronger vacuum, namely at values close to 0.5 mbar. It is also found that the electron temperature decreases with the increase of discharge current, and that its effect is also much more noticeable under tighter gas vacuum.

The decrease in temperature is due to a corresponding increase in electron-neutral particles collision (ionizing them and lose their energy) the presence of higher electric field (increasing of discharge voltage).The electron density shows a slight increase for the small decrease in Te in discharge voltage range of 1.2-1.5kV.Density values were determined to vary between 3×10^{10} m^{-3} and 1.5×10^{11} m^{-3} over the pressure interval. With increasing of discharge voltage and frequency of collisions become higher, the expected rise in density can be explained by the rise in ion saturation current due to sheath expansion near the probe. An expansion in the sheath increases the effective collection area and ion current measured [11, 12].

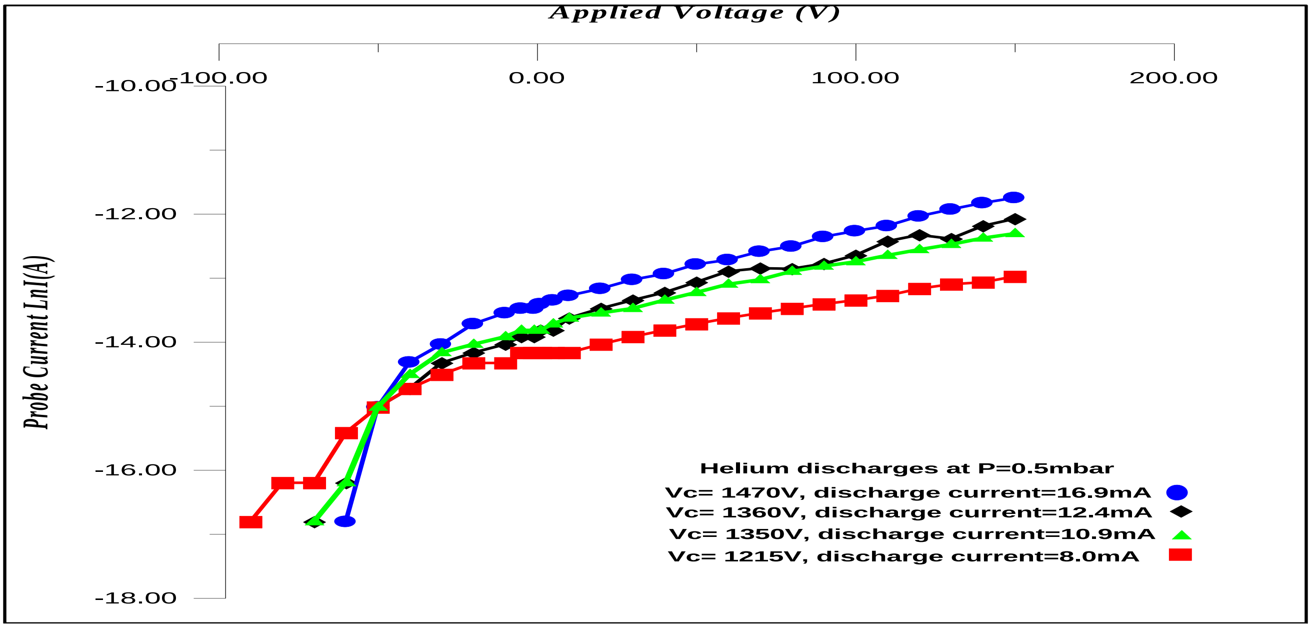

Fig. 6: The I-V characteristics of Langmuir probe for He discharges plasma at 0.5 mbar respectively for different discharge voltages

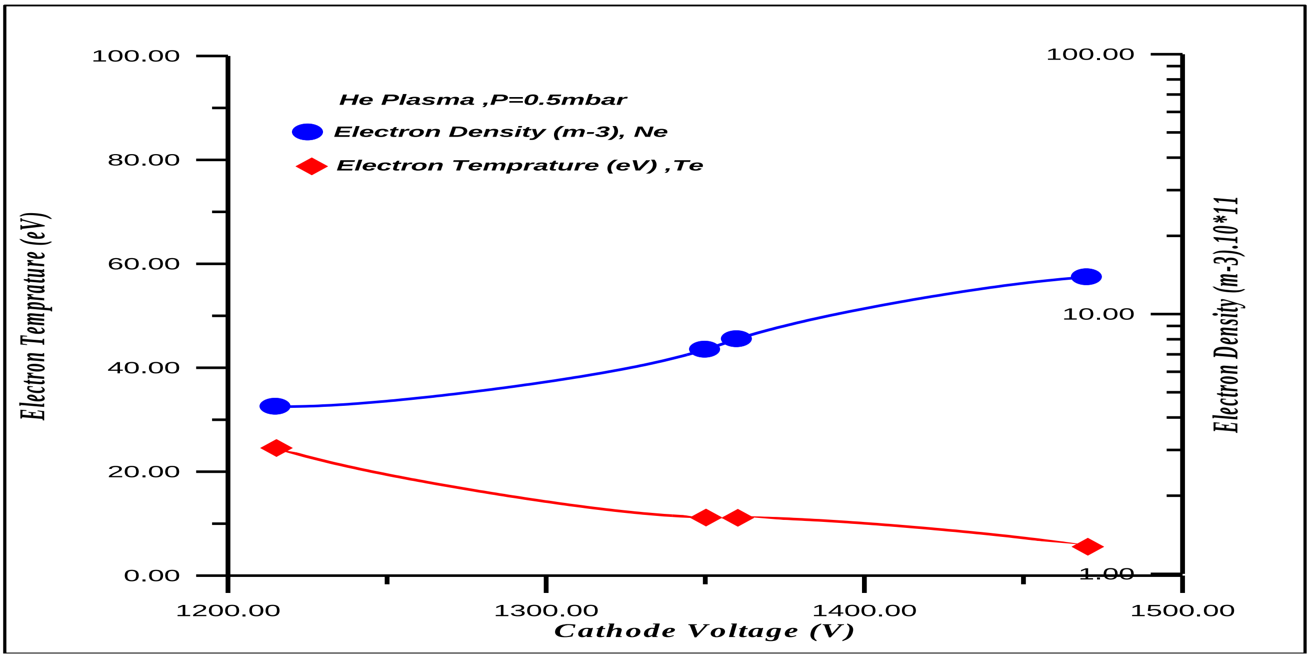

Fig. 7: Electron temperature and density of He plasma as a function of working discharge voltage

Conclusion

Langmuir probe diagnostic is practical for studying the plasma parameters for discharge under vacuum. We introduced a single electric (Langmuir) probe that is capable of measuring n_e and T_e of helium plasmas were investigated at operating pressure of home-made system. It can be wrapped up that the electron temperature and density of negative glow region depends on the cathode voltage and discharge current in lower gas pressure.

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