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## RESEARCH ARTICLE

# COMPARATIVE STUDY OF PLASMA PARAMETERS BY USING MOVABLE LANGMUIR SINGLE AND DOUBLE PROBE IN ARC PLASMA

***Ghanshyam Thakur, [1]Raju Khanal and [2]Bijoyendra Narayan**

[1]Central Department of Physics, Tribhuvan University, Kirtipur, Kathmandu, Nepal
[2]Dr. S. K. S. Women's College, Motihari (B. R. A. Bihar University, Muzaffarpur), Bihar, India

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## ABSTRACT

In this work, plasma is produced by arc discharge between two copper electrodes and is characterized by using a movable Langmuir probe. It is a simple way to measure plasma parameters such as electron temperature, electron density, ion density, Debye length, floating potential, etc. A movable Langmuir single probe technique has a reference point since it is biased with reference to one of the electrodes of the plasma producing system. In some situations such as radio frequency discharges, no reference point is available to bias the movable single probe. Hence, a single probe technique is not applicable and hence, the movable double probe technique is more appropriate. In this method, each probe is biased with respect to the other. The two probes in a vertical plane are biased with a potential and allowed to move through the arc plasma. Depending on the magnitude of biasing potential charges are collected by the probes and hence current flowing to the probe circuit is estimated. The plasma thus produced in laboratory has various applications which include gaseous discharge, plasma torch, sputtering, laser produced plasma as well as to Tokamak plasma.

## INTRODUCTION

In laboratory, plasma is produced by discharge between two copper electrodes using high voltage DC source [1]. The simplest way for measuring plasma parameters is the Langmuir technique [2]. This technique was developed by Langmuir in 1924 [3]. It is simply a small metallic electrode in the form of a wire inserted into plasma [4]. The probe is connected to a DC power supply capable of biasing it at various voltages, positive or negative, relative to the plasma. The characteristic of the Langmuir probe can be easily understood by plotting the $I$-$V$ curve. From the plot of probe current versus probe voltage, which is known as 'characteristics', provides facts about plasma parameters such as electron temperature, electron density, ion density, floating potential, etc. In single probe method, a large amount of current is drained from discharge resulting into disturbance to the plasma. But in double probe method, current collected by probes is about 15-20 times less than as collected in single probe in the single probe method [5]. Although the experimental set up and the measurement procedure are simple but theoretical treatments to the study are extremely complicated. The complexity in the probe theory comes mainly from the interaction among particles in the plasma and their behavior in the sheath regions. The treatment becomes relatively simple for low pressure regions less than 0.1 Torr in which $\lambda$ (mean free path of the charged particles) are larger than the probe size i.e. $\lambda >> L_D$. For higher pressure (say atmospheric pressure) probes of smaller dimension should be chosen, but the size is limited by mechanical stability [6].

### Theory

There are two different methods like single probe and double probe which are used to study arc plasma at atmospheric pressure.

### Single probe method

In deducing the theory for single probe it has been assumed that both electrons and ions obey Maxwell Boltzmann distribution law [7]. Further, the sheath thickness should be small compared to the lateral dimension of plane probe so that edge effect may be neglected [8].

The current drawn by the probe is so small that it does not alter the state of plasma; hence the dimension of the probe should be as small as possible [9]. The probe current can simply be given by

$$I_e = I_{oe}^{eV/kTe} \qquad \text{……………………………………….(1)}$$

After taking log and differentiating, we get

$$T_e = \frac{e}{kd(\ln I_e)/dV} \qquad \text{……………………………………….(2)}$$

Equation (2) is used for the determination of electron temperature,$T_e$ *by* drawing tangent to the curve lnIe versus V of the probe. Since probe current mainly depends upon electron current it can provide better information about electron temperature in comparison to ion temperature [10]. Once the electron temperature is known, the electron and ion densities can be determined [3].

$$n_e = \left(\frac{I_e}{eA}\right)\sqrt{\frac{2\pi m_e}{2kT_e}} \qquad \text{………………………………………...(3)}$$

and

$$n_i = \left(\frac{2.5I_i}{eA}\right)\sqrt{\frac{m_i}{2kT_e}} \qquad \text{………………………………………..(4)}$$

**Double probe method**

Since electron velocities are much higher than ion velocities, the probe must be negative with respect to space to prevent a net electron current flowing to the whole system. This situation can be avoided if one probe is so much larger than other, so that the ion current to this larger probe can cancel the saturation electroncurrent to the smaller probe[8]. The biasing voltage on the probes are varied from negative to positive potential for obtaining an *I-V* characteristic of the probe. This provides ion saturation current in the negative ($I_{1i}$) as well as in positive direction ($I_{2i}$). This curve passes through the origin (I=0) where current is linearly varying with applied voltage [11]. The rate of change of current with respect to voltage in the linear range can be expressedas.

$$(dI/dV)0=(e/kTe)[I1i\times I2i/(I1i+I2i)] \qquad \text{……………………………………………(5)}$$

From this $kT_e$ can be computed from the slope at the origin and the measured amplitudes of

$I_{1i}$ and $I_{2i}$. Once $kT_e$ is known, the plasma density can be calculated as [4]

$$n_i = \frac{2I_I(m_i)^{\frac{1}{2}}\left(\frac{e}{kT_e}\right)^{\frac{1}{2}}}{e^{\frac{3}{2}}A} \qquad \text{……………………………………………….(6)}$$

**In Experimental Setup**

A high voltage DC is prepared by rectifying a 3-phase AC supply using an arrangement of diodes of 6A and 100V each. A movable system is made from a body of Dot Matrix printer, which moves to and fro uniformly through the arc. A cylindrical platinum wire is inserted into a ceramic hollow tube and insulated using clay except on the tip of the probe [12, 13, 14]. The schematic diagram for single probe method and double probe methods are shown in Figures 1 and 2.

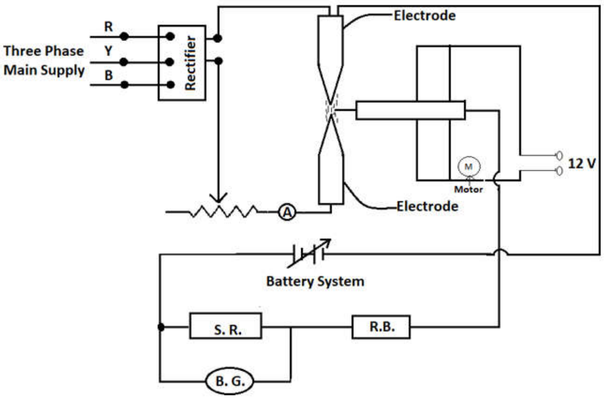

**Figure 1. Schematic diagram of single probe circuit for determination of plasma parameters**

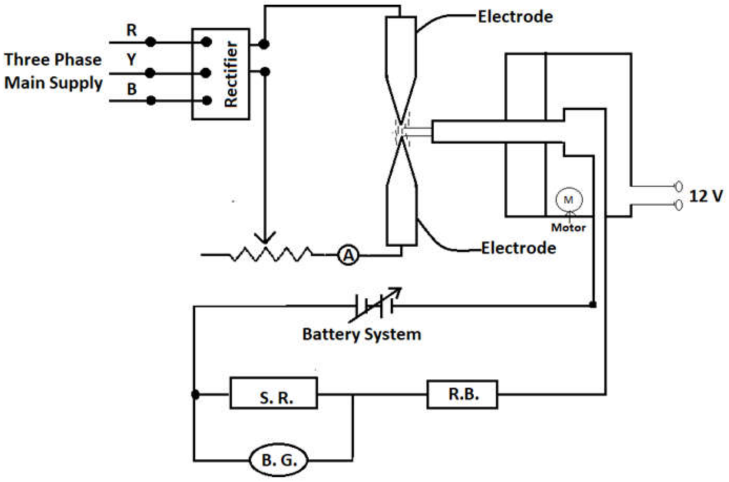

**Figure 2. Schematic diagram of double probe circuit for determination of plasma parameters**

## Observation

**Table 1. Probe biasing potential and corresponding probe current for copper electrodes arc current at 3.6 A by single probe method**

| S.N. | Probe potential Volt | Deflection $\theta$ cm | Current through BG $I_G = \theta \times 1.5\ \mu$A | Probe Current $I = 201 \times I_G\ \mu$A | lnI |
|---|---|---|---|---|---|
| 1. | 0 | 5.0 L | 7.50 | 1507.50 | -6.50 |
| 2. | -3 | 3.5 L | 5.25 | 1055.25 | -6.85 |
| 3. | -6 | 2.5 L | 3.75 | 753.75 | -7.20 |
| 4. | -9 | 2.5 L | 3.75 | 753.75 | -7.20 |
| 5. | -12 | 1.5 L | 2.25 | 452.25 | -7.70 |
| 6. | -15 | 1.7 L | 2.55 | 512.55 | -7.58 |
| 7. | -18 | 1.0 L | 1.50 | 301.50 | -8.10 |
| 8. | -21 | 2.0 L | 3.00 | 603.00 | -7.40 |
| 9. | -24 | 1.2 L | 1.80 | 361.80 | -7.92 |
| 10. | -27 | 0.5 L | 0.75 | 150.75 | -8.80 |
| 11. | -30 | 0.5 L | 0.75 | 150.75 | -8.80 |
| 12. | -33 | 0.2 L | 0.30 | 60.30 | -9.70 |
| 13. | -36 | 0.0 | 0.00 | 0.00 | 0.00 |
| 14. | -39 | 0.0 | 0.00 | 0.00 | 0.00 |
| 15. | -42 | 0.1 R | 0.15 | 30.15 | -10.40 |
| 16. | -45 | 0.1 R | 0.15 | 30.15 | -10.40 |
| 17. | -48 | 0.2 R | 0.30 | 60.30 | -9.70 |
| 18. | -51 | 0.2 R | 0.30 | 60.30 | -9.70 |

**Table 2. Probe biasing potential and corresponding probe current for copper electrodes arc current at 3.6 A by double probe method**

| S.N. | Probe potential Volt | Deflection $\theta$ cm | Current through BG $I_G = \theta \times 1.5\ \mu$A | ProbeCurrent $I = 167.6 \times I_G\ \boldsymbol{\mu A}$ |
|---|---|---|---|---|
| 1. | 0 | 0.4 L | 0.60 | 100.60 |
| 2. | 3 | 0.6 L | 0.90 | 150.80 |
| 3. | 6 | 0.6 L | 0.90 | 150.80 |
| 4. | 9 | 1.0 L | 1.50 | 251.50 |
| 5. | 12 | 0.6 L | 0.90 | 150.80 |
| 6. | 15 | 0.5 L | 0.75 | 125.70 |
| 7. | 18 | 0.0 | 0.00 | 0.00 |
| 8. | 21 | 0.3 R | 0.45 | -75.40 |
| 9. | 24 | 0.6 R | 0.90 | -150.80 |
| 10. | 27 | 0.6 R | 0.90 | -150.80 |
| 11. | 30 | 0.3 R | 0.45 | -75.40 |
| 12. | 33 | 0.6 R | 0.90 | -150.80 |
| 13. | 36 | 0.7 R | 1.05 | -176.00 |
| 14. | 39 | 0.6 R | 0.90 | -150.80 |
| 15. | 42 | 0.8 R | 1.20 | -201.10 |
| 16. | 45 | 0.7 R | 1.05 | -176.00 |
| 17. | 48 | 0.4 R | 0.60 | -100.60 |
| 18. | 51 | 0.5 R | 0.75 | -125.70 |

## RESULTS AND DISCUSSION

Figure 3 a shows the performance of electron current in (ln $I$) versus probe voltage ($V$), where $I$ is probe current ($\mu$A) for copper at 3.6 A arc current. All twelve readings are taken to study the decrease of electron current. Hence, the decreasing pattern of probe current with probe voltage follows $lnI \propto V$ rule instead of $I \propto V$ rule. The thirteenth reading shown at x-axis, where current is zero, found at (-37.5 V) probe voltage. This voltage or potential is called ‘floating potential’. Physically this is the situation at which the drift velocity of electron abruptly vanish. In other words everything is in the steady state. This nature indicates the possibility of ion current at high probe voltage.

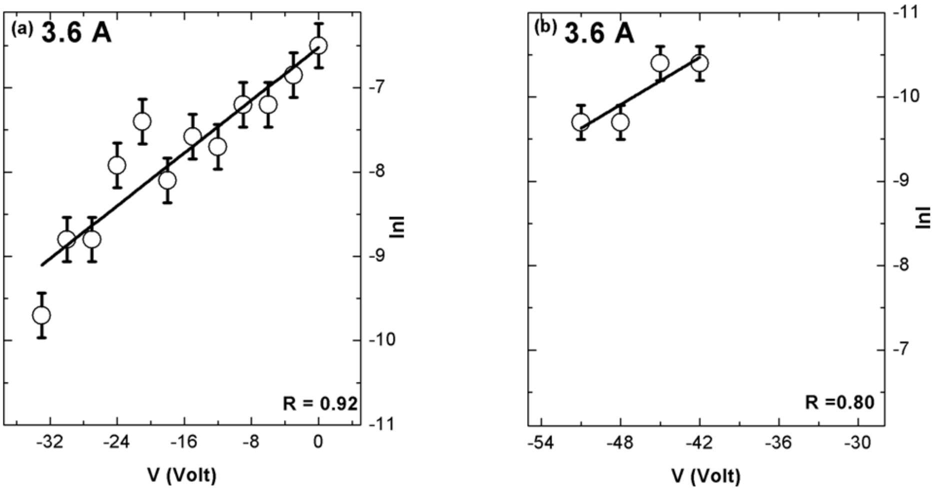

**Figure 3. Probe voltage versus probe current plot for Copper at 3.6 A arc current; (a) behavior of electrons. Here y-axis (lnI) is in the log scale. (b) behavior of ions. The best fit line represents second order polynomial. The reason is described in the text. The error bars represent the standard error of the deviation. The value of regression coefficients aregiven.**

Figure 3b suggests the performance of ion current at high probe voltage. We get only a few readings and increasing slope is found to be less as observed in the free hand graph. We have fitted the ion current polynomially due to following reason: (i) A sudden drop to show floating voltage deviates very sharply from Ohm’s law ($I \propto V$) or electron behavior ($lnI \propto V$) and (ii) there is very few observations because of the experimental constraints. It is therefore, we have fitted second order polynomial.

The best fit equations for electron current and ion current are:

$$\mathrm{Ln}\, I = 0.1V - 6.5 \qquad \text{.....................................................(7)}$$

$$\ln I = -0.002V^2 + 0.030V - 6.8$$

This is the case for copper at 3.6 A arc current. In all figures, error bar represents the standard error ($\pm 1\sigma$) of the distribution. The values of regression coefficient in Figures 3(a,b) suggests a very good agreement between observations and fittedcurves.

Taking differentiation of equation (7) with respect to $V$, we get the value of $\frac{e}{kT_e}$

The distribution of positive and negative currents for copper at arc current 3.6 A while increasing probe voltage are shown in Figures 4(a) and (b) respectively. These deflections (positive and negative

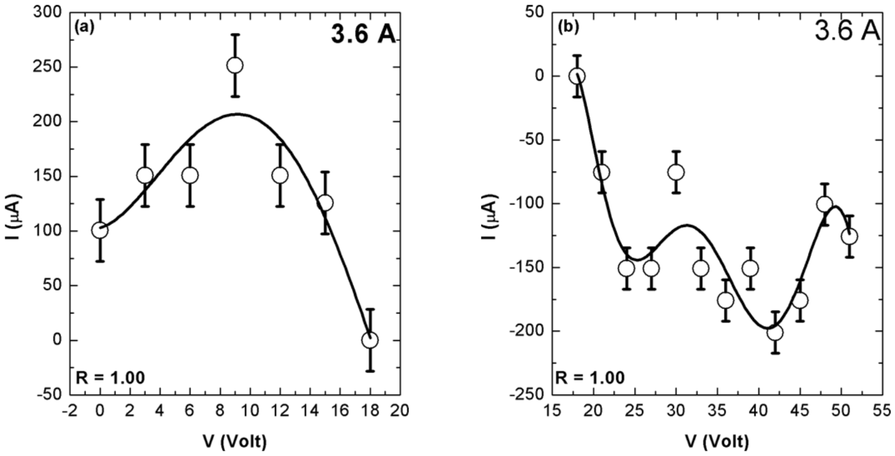

**Figure 4. Probe voltage versus probe current plot using double probes for copper at 3.6 A arc current. (a) positive probe current versus probe voltage. (b) negative probe current versus probe voltage. The hollow circle with error bar represents observed value. The standard error of the distribution is used for error bars. The solid curve represents the best fit higher order polynomial curve having highest value of regression coefficient (*R*). andvice-versa) are plotted independently to observe these distributions and hence the differences in the distribution for double probes also. Here, in both the cases the function of ions issignificant**

Figure 4a indicates the distribution of positive probe current with the probe voltage. It is observed that the value of current ($\mu A$) decreases with increasing voltage. The sequence of decrease is in haphazard manner up to sixth reading, after that it suddenly declined at 18 volt. Therefore, as expected, Ohm's law is not stringently followed by the observations. We fitted higher order polynomial in such a way that its regression coefficient should be in upper limit. Here, the fifth order polynomial,

$$I=102.8+12.5V+3.6V^2-0.37V^3+8.1E-3V^4+3.4E-6V^5 \quad \ldots\ldots(9)$$

Demonstrates very good agreement with the observed distribution with regression coefficient 1.00. We intend to use constant slope of equation (16) to solve the equation (6).

Figure 4b presents the distribution of negative probecurrent with increasing probe voltage when double probes are used for the arc plasma produced by the copper electrodes at the arc current of 3.6A. Here the distribution is found to be amusive: first, the current decreases (actually increase in negative value) sharply and then it increases (actually decrease in negative value) with fluctuations. We have attempted to fit higher order polynomial to get higher value of regression coefficient. For this, the eighth order polynomial,

$$I = -54371.3 + 12554.6V - 1191.5V^2 + 60.3V^3 - 1.8V^4 + 0.03V^5 - 2.7E-4V^6 + 1.1E-6V^7 + 1.4E-12V^8 \quad \ldots\ldots(10)$$

is found to have highest value of $R(1.00)$. Therefore, an intense deviation from Ohm's law is noticed when double probe method is used. We intend to calculate electron temperature with the constant slope of equation (17) to solve the equation (6).

**Conclusions**

Atmospheric arc plasma using copper electrodes at an arc current 3.6 A were produced and characterized using a Langmuir single and double probe at CDP, TU, Kirtipur. In case of copper electrodes, at atmospheric pressure and an arc current of 3.6 A, the values of electron temperature, electron density and ion density are $5.03 \times 10^4$ K, $5.37 \times 10^{15}$ m$^{-3}$ and $2.57 \times 10^{16}$ m$^{-3}$ respectively by single probe method. Similarly the values of electron temperature and ion density are $2.15 \times 10^4$K and $3.24 \times 10^{17} m^{-3}$ respectively by double probe method. Thus the Langmuir single and double probe were successfully used to estimate the temperature and densities of plasma particles which then can be used to derive most of the plasma parameters. Such aplasma can be useful invarious applications like plasma torch, sputtering, etching, nitriding, gaseous discharge as well as to Tokamak plasma.

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## REFERENCES

1. B.Narayan *et al.*, Ind.J.of Pure and Applied Physics, 29, 506(1991).
2. I. M. Hutchinson, *Principles of Plasma Diagnostics*, Cambridge University Press, Cambridge, UK(1987).
3. R. Boyd, *The collection of positive ions by a probe in an electrical discharge*, In Proceedings Royal Society London. 201, 329 (1950).
4. V.N.Rai, *Basic Concept in Plasma Diagnostics*, Laser Plasma Division, Raja Ramanna Centre for Advanced Technology, Indore, India (2001).
5. R. M. Castro *et al.*, *(*Contrib. Plasma physics), 39, 235(1999).
6. M. Konuma, *Plasma Techniques for Film Deposition*, Alpha Science International, (2005).
7. S. N. Sen, Plasma Physics *(Plasma State of Matter)*, Pragati Prakashan, Meerut, India (2007).
8. R. H. Huddlestone and S. L. Leonard, *Plasma Diagnostic Techniques*, Academic Press, New York (1965).
9. F. F. Chen, *Mini Course on PlasmaDiagnostics*, IEEE- ICOPS meeting, Jeju, Korea (2003).
10. T. J. M. Boyd and J. J. Sanderson, *Plasma Dynamics*, Thomasm Nelson Sons, London (1969).
11. 11.R. L. Merlino, Am. J. of Phys., 75(12), 1078 (2007).
12. G. S. Thakur, R. Khanal and B.Narayan, Proceedings of PSSI Plasma Scholars Colloquium, 41(2016).
13. G.S.Thakur, R.Khana land B.Narayan,Varanasi Management Review,III(2) 27 (2017).
14. G.S.Thakur, R. Khanal and B. Narayan, Research Highlights, IV(2)20(2017).

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