Impedans Application Note

# Measurement of Plasma Parameters in Low & Medium Pressure Discharges with the Automated Langmuir Probe - ALP System™

## Introduction

A Langmuir Probe system can provide the following parameters: floating potential, $V_f$, plasma potential, *V*p, electron density, *N*e, ion density, *N*i, electron temperature, *kT*e, and electron energy distribution function (EEDF).

The probe can obtain data as a function of position with a resolution of a fraction of a millimeter and in time with temporal resolution of less than microseconds.

## Electron Density

The Electron density is measured from the electron current at the plasma potential and the exact nature of the sheath expansion is not required as there is no sheath at the plasma potential. However Ne is very sensitive to the plasma potential measurement.

## Plasma Potential

The plasma potential is measured from the maximum in the first derivative as seen in the figure below

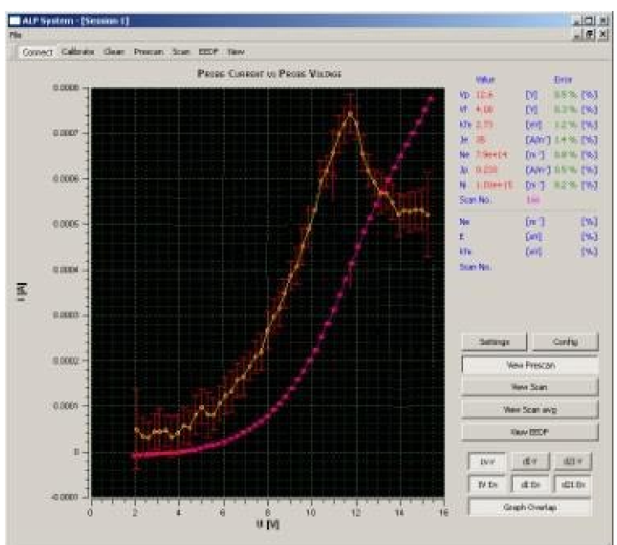


**Figure 1: Langmuir Probe trace and derived parameters (Impedans Ltd. ALP System Software)**

This method is also referred to, and is equivalent to, the zero second derivative method. In a noisy plasma where the second derivative method is more prone to noise, the plasma potential can be determined by extrapolating the current from the retarding region and electron saturation region. This is known as the intersecting slopes method.

## Floating Potential

The floating potential is measured by biasing the probe until zero current is drawn, this presents a large (infinite) impedance to the probe and prevents problems with loading.

## Ion Density

The ion density is measured using Laframboise Theory and in electropositive gases should equal the electron density. The ion current *Ii* collected by a spherical or cylindrical Langmuir probe can be expressed with excellent accuracy as

$$I_i = I_0 a(-X)^b$$

where

*Io* is the ion flux at the sheath edge

*X = (Vb - Vp)/kTe* is the dimensionless probe potential,

*Vb* and *Vp* are the probe bias and plasma potential espectively,

*kTe* is the electron temperature

*a* and *b* are parameters depending on the ratio of the probe radius *rp* to Debye length.

In general, ion density measurements are modified by collisions in the sheath and pre-sheath. If the ion mean free path for collisions is known, a correction is applied to Laframboise theory. In this way ion density measurements using the Langmuir probe can be extended from the ideal collisionless case to 10Torr with a single theory.

Figure 2a below shows a typical measured probe characteristic in an Argon plasma at a pressure of 2.25mT.

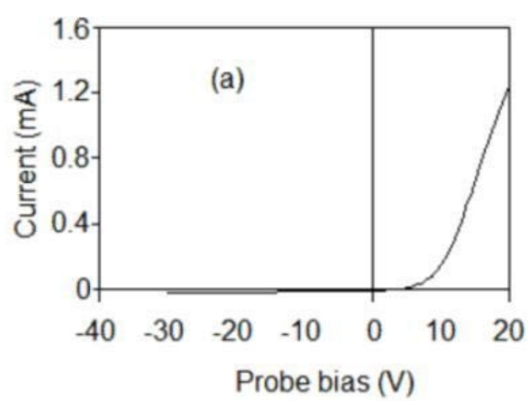


**Figure 2a: Complete Langmuir Probe IV characteristic**

Figure 2b shows the calculated ion current (dotted line) against the measured current (solid line). Note that the difference between the calculated and measured curves can be assumed to be due to electron collection on the probe.

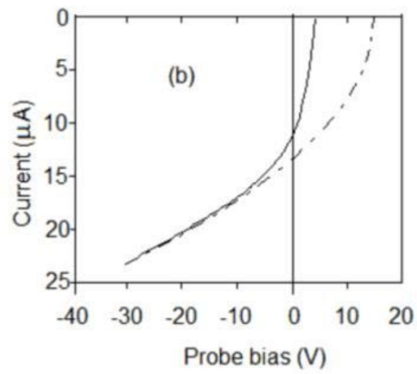


**Figure 2b: Negative current portion of measured characteristic Passive Probe RF Compensation**

In symmetrical RF discharge, both the electrodes are the same area and a balanced or symmetrical voltage with reference to ground is applied to the electrodes. The area of the grounded electrode often includes the chamber walls and Faraday shields and thus the grounded electrode greatly exceeds the area of the driven electrode. The asymmetry in the plasma source is important as it determines the level of RF fluctuations of Vp relative to ground. More asymmetry leads to lower RF fluctuations in plasma potential. RF fluctuation in Vp relative to ground can be removed by means of the Passive Compensation Probe method first developed by Gagne and Cantin. The probe is ‘‘forced’’ to float at the RF potential by ensuring that the probe-plasma impedance, Zp, is much less than the probe-ground impedance, Zs.

## Automated Probe Cleaning

The probe surface is made of refractory metal. This is so that the probe can be cleaned by heating to white hot by electron bombardment. This is achieved by pulse biasing the probe to a large positive voltage and drawing an electron current of up to 100mA during the on period of the pulse. The power on the probe surface is calculated and maintained by varying the duty cycle so that the probe is not damaged. The probe is maintained in a clean condition by biasing at a negative potential so that the probe is under ion bombardment.

## Probe Geometry

The diameter of the probe tip is typically 0.05 to 0.4 mm, and the probe holder should be as small as practical. The probe length is typically 1-10 mm and is designed to prevent any increase in probe collection area by a sputtered conductive layer by having a recessed gap between probe tip and insulator.

## Plasma-Ground Sheath Resistance (Rsh)

The resistance between the plasma and the grounded electrode is not negligible and this resistance is part of the probe circuit. The plasma potential is set by a balance between the ion current to both electrodes and ground. The probe, when drawing electron current, upsets this balance and alters the plasma potential. The change in Vp as a function of current drawn by the probe can be measured and a correction made. Without this correction the electron temperature is overestimated.

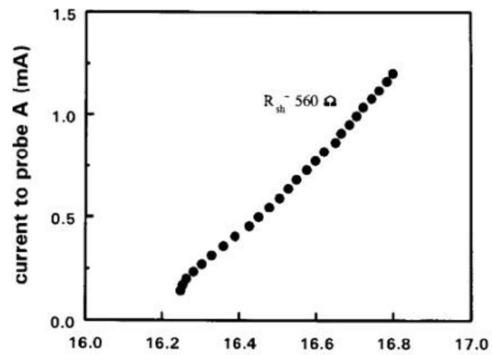


**Figure 3: Rsh measured in a medium pressure capacitively coupled discharge**

## Electron Energy Distribution Function

The calculated ion current to the probe is subtracted from the current-voltage characteristic to leave the total electron current. The EEDF is then calculated from the second derivative of the electron current to the Langmuir probe at biases below the plasma potential:

$$\frac{f(\varepsilon)}{\sqrt{\varepsilon}} = \left(\frac{d^2 I_e}{dV^2}\right) \frac{2m_e}{e^2 S} \sqrt{\frac{2e}{m_e}}$$

where

*f(ε)* is the EEDF, *ε* is the electron energy,

$d^2I/dV^2$ is the second derivative of the probe current-voltage characteristic,

$m_e$ is the electron mass,

*e* is the electronic charge

*S* is the probe area.

The distribution in the form f(ε)/√ε  is known as the electron energy probability function (EEPF).

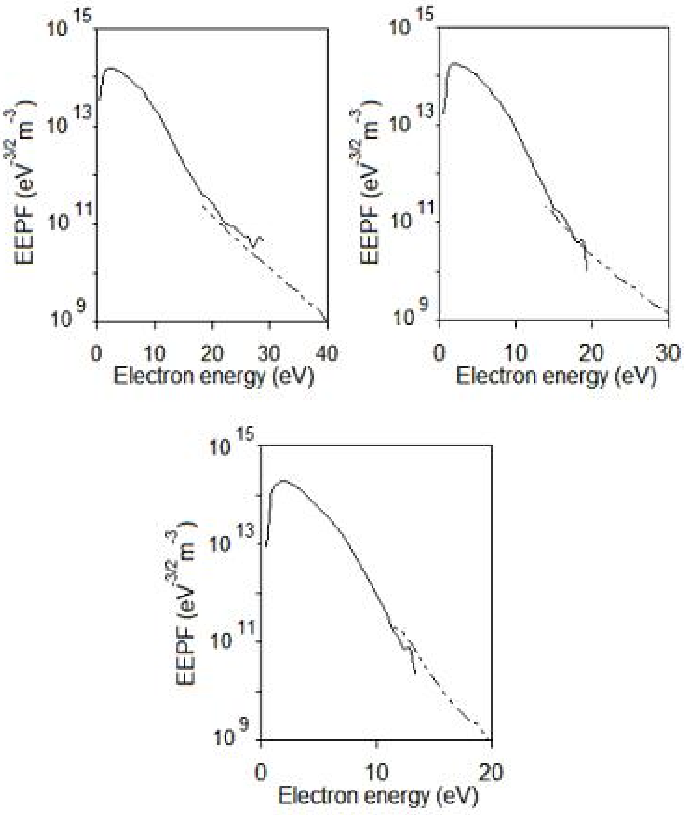


**Figure 4: EEPF's measured with the ALP Langmuir probe (solid line) and Semion RFEA (dashed) at various pressures. Top left 2.25 mTorr, top right 4.5 mTorr and bottom 7.5 mTorr.**

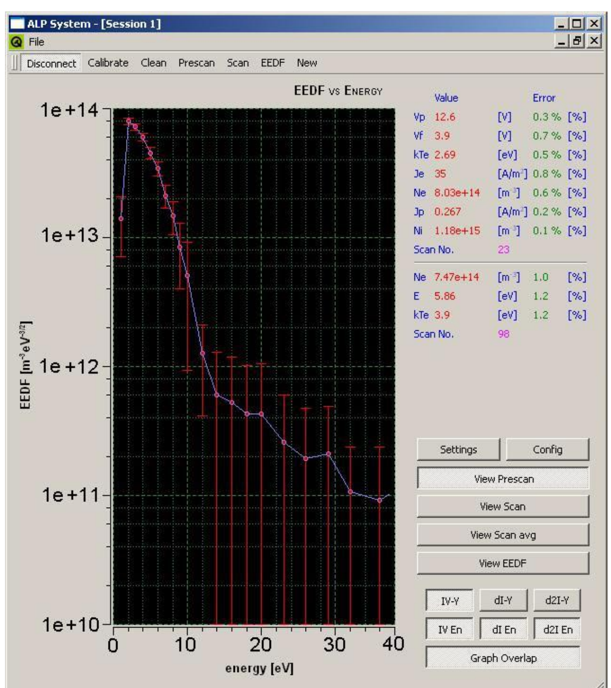


**Figure 5: ALP System™ EEDF plots**

## Impedans Automated Langmuir Probe (ALP) System™

The ALP System™ from Impedans is designed to meet the requirements of accurate probe measurements. The system software contains algorithms that automatically determine all of the key parameters as outlined in this document.

The objective of any probe system design is that the system can be operated by an inexperienced operator and give reliable results. The Impedans ALP System™ meets this requirement by providing an intuitive user interface which allows for both "one-click" measurement control for general measurements, and detailed configuration for more detailed diagnostic implementation.

The team at Impedans will be glad to help out with design issues and can provide probes for many applications. Our analysis routines are provided to the user, and provide the latest examples of best practice in probe measurement.

## ALP System™

Impedans specialises in the delivery of high performance and high resolution plasma diagnostics solutions to customers in research and industry.

Our products represent the next generation in plasma diagnostics technology, and coupled with our in-depth plasma knowledge and years of experience, our customers can be sure that they can fully characterise, optimise and monitor their plasma process with confidence.