Plasma Gas Identification Using the Single Langmuir Probe

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ABSTRACT

A novel method to identify mass composition of plasmas was discovered at Polytechnic University of Puerto Rico Mirror Cusp (PUPR-MC) plasma machine using a Single Langmuir probe characteristic. This is a comparative method similar to a mass spectrometer. Argon, nitrogen, hydrogen and residual gas (no gas injected) characteristics can be compared using the Single Langmuir probe. Different gases will produce different plasma parameters. Using the mass spectrometer we can identify the elements present in the chamber and relate probe characteristic curve to its respective element. Each gas has its own characteristic appearance. By looking at the shape of the curve it is possible to identify the must abundant gas in the plasma chamber. Plasma parameters may vary due to a number of factors. Probe position, microwave power, magnetic confinement, gas and pressure are factors that can be controlled. In order to compare gases, using a Microwave source at 198 W to heat the gas and initiate ionization, a coil current of 390 A operating in mirror mode was used. It means that the current flows in the same direction through the two parallel solenoid magnets (coils) used to confine plasma. Distance between coils was fixed at 60 cm. At Mirror mode, plasma is confined to a hot electron ring produced between the coils. The ring contains the highest plasma density in the chamber; therefore the center remains at a lower density. The probe was immersed into plasma at 110cm from the flange, the collector (disk) was placed at 14cm from the center of the chamber, and 18.12cm apart from the electron ring. Low power (4% of 5KW microwave generator) was used to protect probes from burning at close range. The pressure chamber was 2.9x10-4 Torr. Averages of plasma parameters for each gas were obtained using a Single Langmuir probe. After studying results, every curve showed the respective characteristic for each gas. Without a mass spectrometer, it was possible to identify a gas used to produce plasma with only the I-V obtained from a Single Langmuir probe.

INTRODUCTION

A novel method to identify mass composition of plasmas was discovered at PUPR-MC plasma machine using a Single Langmuir probe characteristic. A Single Langmuir Probe, named after Nobel Prize winning physicist Irving Langmuir, is a device used to determine electron temperature, electron density and plasma potential. These plasma parameters can be determined by the I-V characteristic of the probe when a voltage ramp is applied to the collector of the probe.

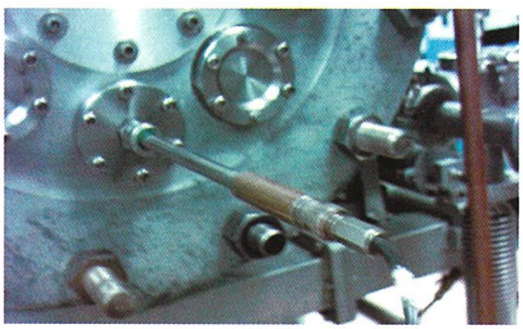

Figure 1: *Single Langmuir Probe Inside PUPR-MC Plasma Machine*

A Keithley source meter is used to acquire data from the Single Langmuir probe. The data is analyzed using a program developed in the Labview environment.

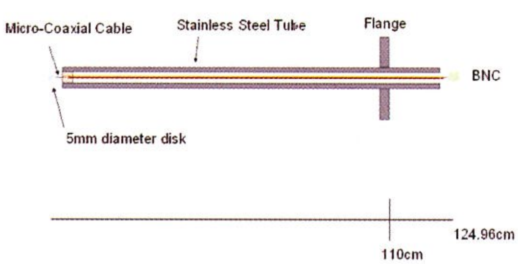

Figure 2: *Composition and size of the probe, placed at 110 cm from the flange, disk located at 18.12 from electron ring.*

The program computes graph and instant measurements of plasma parameters with collected data. By comparing the different plasma parameters with the mass of the gas being studied, it was found that the plasma floating potential has linear correlation with the mass of the gas. With this finding the gas inside the chamber can be identified using a Single Langmuir Probe. A mass spectrometer was used to verify data obtained from the relation between the plasma floating potential and the mass of the element inside the chamber. A quadrupole mass spectrometer allows for the identification of masses of individual atoms and molecules that have been converted to ions inside the vacuum chamber. When the selected gas is injected into the plasma chamber, the mass spectrometer can corroborate the plasma being produced.

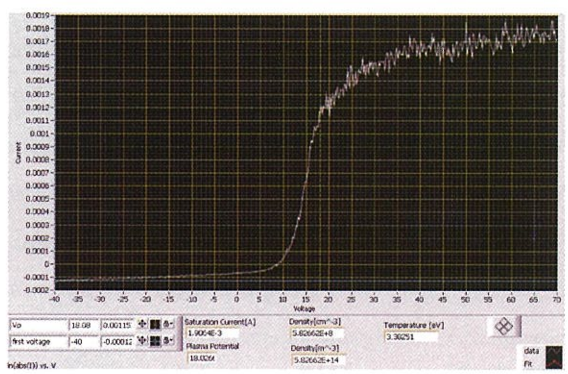

Figure 3: *Data Acquisition & Analysis Program (Trace of Hydrogen Gas with Some Residual Nitrogen)*

PROCEDURE

To ensure quality of data obtained from the Single Langmuir probe, a 5 mm disk was used as collector. The probe was placed at a dense plasma area. The microwave power used to ionize the different gases was 198 W at 2.45 GHz. The magnetic field produced by the current flowing through two parallel coil magnets was used to confine plasma. The coils were configured to operate in Mirror mode. In Mirror mode, plasma is confined to a hot electron ring between coils. The ring contains the highest plasma density present in the chamber. Plasma density decreases as it gets farther from the ring. By changing the distance between the parallel coils, plasma density inside the chamber can be controlled. By moving parallel coils closer to each other, plasma density increases in the hot electron ring leaving the rest of the chamber with a much lower density. As the coils are separated, the magnetic field that affects the electron ring decreases, and thus the density in the electron ring decreases too. In our studies the coils were separated by 60 cm. The same separation was used for all gasses to ensure identical conditions for each gas. The current on each coil was set at 390 A. The pressure in the chamber was set at $2.9\,\mathrm{E}^{10x-4}$. When injecting a gas in the chamber, the mass spectrometer was used to read the elements in the chamber. Ten measurements per gas were taken and mean values of the acquired plasma parameters were calculated. With this information, parameters obtained from the Single Langmuir probe can be associated with the gas used to produce plasma.

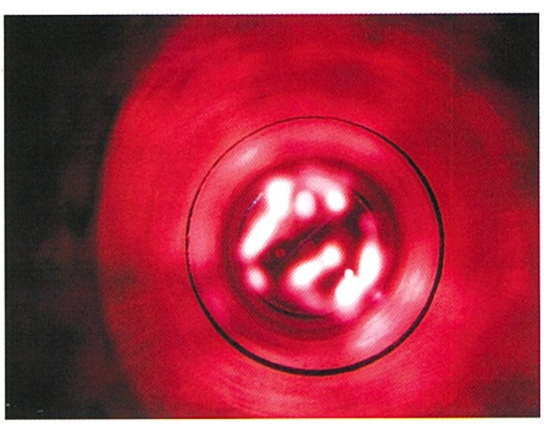

Figure 4: *Nitrogen Plasma*

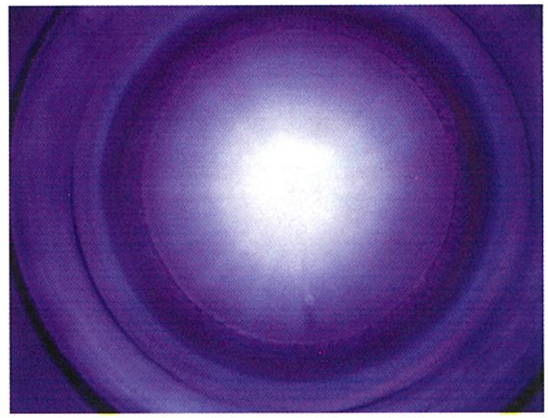

Figure 5: *Argon Plasma*

Figure 6: *Residual Gas Plasma*

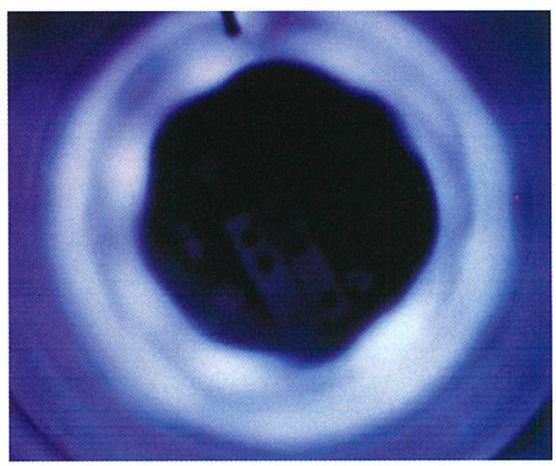

Figure 7: *Hydrogen Gas Plasma*

RESULTS

ARGON

The Single Langmuir probe characteristic for argon (Figure 9) shows low noise with a plasma potential at 32 V and a floating potential of 15.6 V. The mass spectrometer shows the respective mass of Argon 39.9 amu. Notice on Figure 10 a low quantity of Nitrogen in the chamber.

Nitrogen

At first glance the Single Langmuir probe characteristic for nitrogen (Figure 13) looks noisy. Nitrogen has a single Langmuir probe characteristic of low plasma potential and a near flat tail. The noise for voltages greater than the plasma potential is characteristic of nitrogen. The mass spectrometer data (Figure 16) shows a peak at 14 amu.

Hydrogen

The Single Langmuir probe characteristic for hydrogen (Figure 11) is a very clean one. Notice the clearly identifiable floating potential and plasma potential. Figure 14 shows the mass spectrometry for hydrogen.

Residual Gas

With no gas injected, residual gas can be ionized. The spectrometer (Figure 15) shows water vapor at around 18 amu, and some nitrogen and a small amount of argon. The Single Langmuir probe characteristic for residual gas (Figure 12) also reflects some nitrogen at the noisy tail that resembles I-V curve for nitrogen.

Figure 8: *PUPR-MC Plasma Machine*

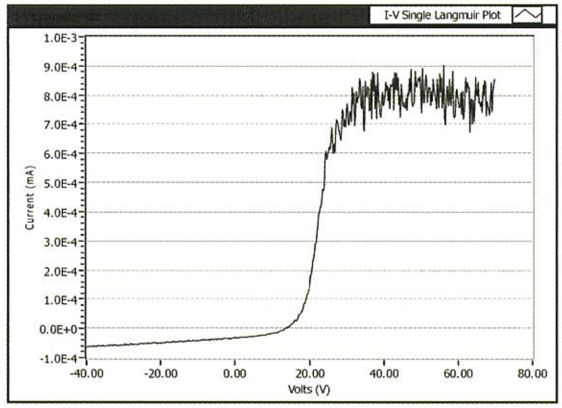

Figure 9: *Argon Single Langmuir I-V*

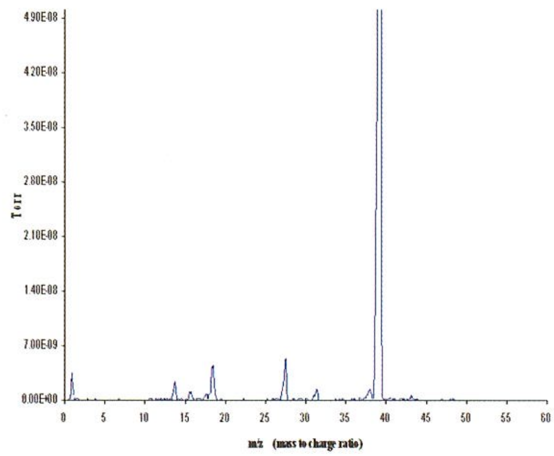

Figure 10: *Argon Mass Spectrometer Reading*

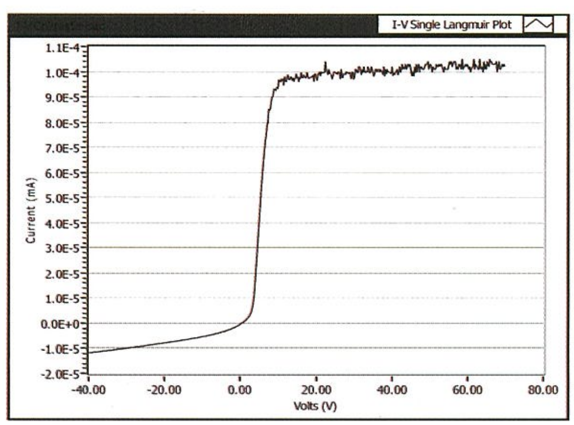

Figure 11: *Hydrogen Single Langmuir I-V*

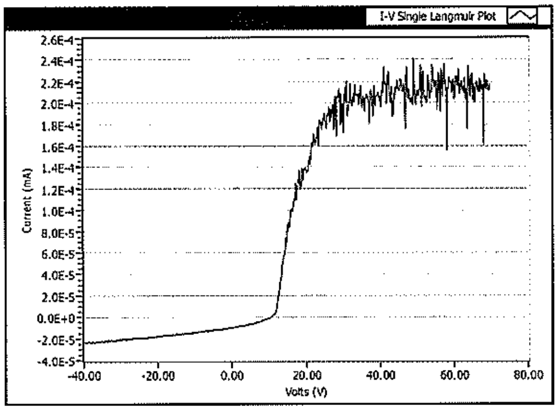

Figure 12: Residual Gas Single Langmuir I-V

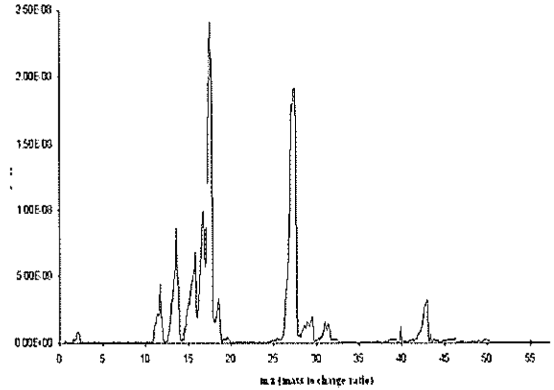

Figure 15: Residual Gas Spectrometer Reading

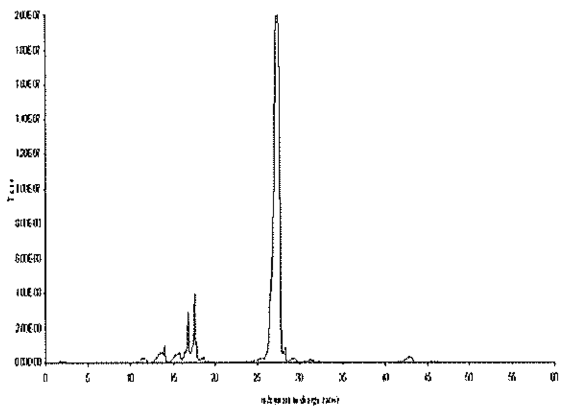

Figure 16: Hydrogen Mass Spectrometer Reading

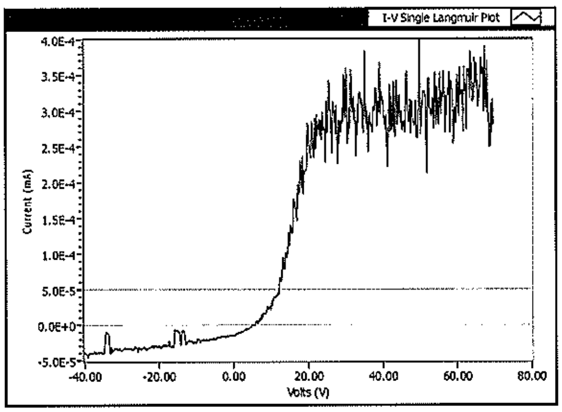

Figure 13: Nitrogen Single Langmuir I-V

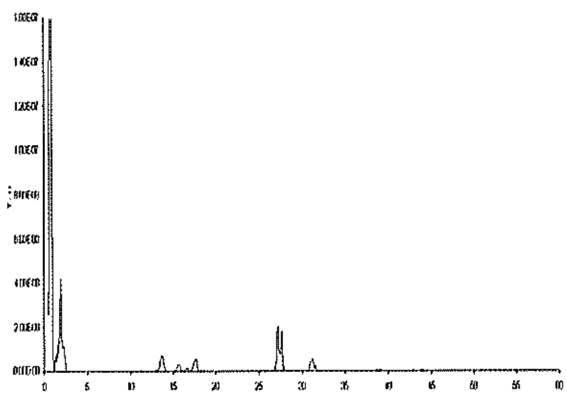

Figure 14: Hydrogen Mass Spectrometer Reading

DATA ANALYSIS

The collected plasma parameters were tabulated and are presented in Table 1. Each of the parameters was compared to the mass of each gas.

Table 1: Mean Values of Plasma Parameters for Each Gas Obtained From a Single Langmuir Probe

Gas	Density, n part./cm^3	Temperature, kTe [eV]	Electron Saturation Current, Ies [A]	Plasma Potential, Vp [V]	Plasma Floating Potential, Vf [V]
Hydrogen	3.18E+08	11.41	9.55E-04	18.02	-1.5
Argon	6.53E+08	9.53	1.65E-03	32.69	15.6
Nitrogen	3.13E+08	1.99	3.61E-04	10.74	4.8
Residual Gas (Air)	1.83E+08	4.51	7.04E+04	24.75	12.1

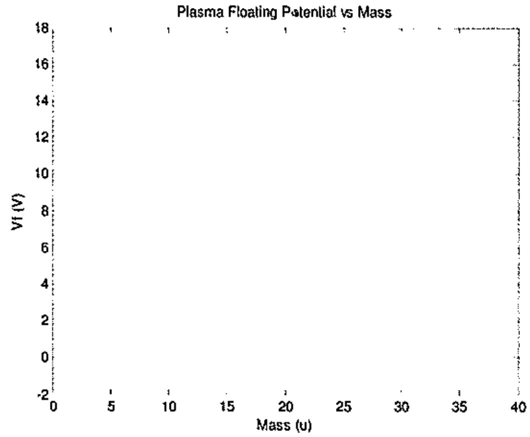

Figure 17: Plasma Floating Potential (V) vs. Mass (amu)

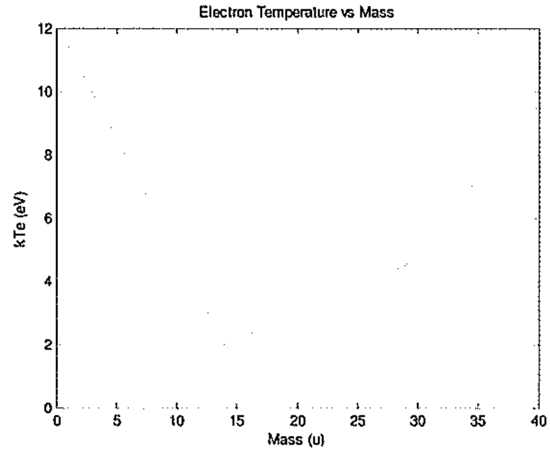

Figure 19: Electron Temperature (eV) vs. Mass (amu).

At first glance, the relation of the plasma floating potential to gas mass (amu) (Figure 13) seems to be linear. From the linear regression of VF-mass we obtain the relationship $V_f = 0.44703 \times \text{mass} - 1.6109$ with an average error of $\pm 1.12\,\text{V}$. As it can be seen in Figures 18, 19 and 20, there is no clear relationship of the atomic mass to any of the other of the studied plasma parameters. Additional work has to be done in order to establish any new relation.

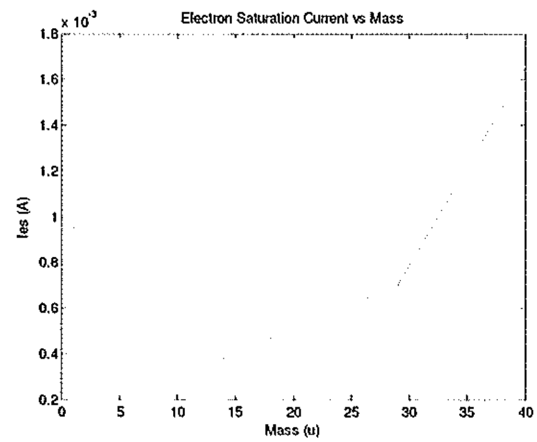

Figure 20: Electron Saturation Current (A) vs. Mass (amu).

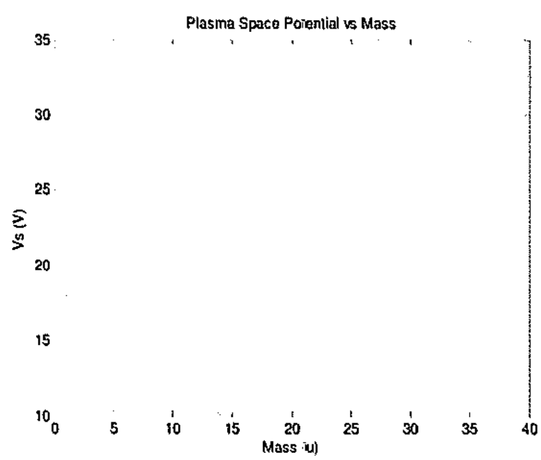

Figure 18: Plasma Space Potential (V) vs. Mass (amu).

CONCLUSIONS

In conclusion, the Single Langmuir probe can be used to effectively identify hydrogen, argon and nitrogen gases in the PUPR-MC plasma machine. From the mean values of the plasma parameters for each gas, Hydrogen was the hottest gas with 11 eV. Argon has the highest plasma potential out of the gases under study. Every gas has a unique Single Langmuir probe I-V characteristic. Without a mass spectrometer it is possible to identify a gas used to produce plasma, not only by the color of the light it radiates, but also using the I-V characteristics from a Langmuir probe.

BIBLIOGRAPHY

Langmuir, I. (1928). Oscillations in ionized gases. *Proc. Nat. Acad. Sci. U.S.*, *14*, 628.

Leal-Quirós, E. (1989). *Novel Probes and Analyzers for RF Heated Plasmas and Microwave Heated Plasmas for Controlled Fusion Research: The Hyperbolic Energy Analyzer, The Magnetic Moment Analyzer, The Double Energy Analyzer, and The Variable Energy Analyzer.* PhD thesis, University of Missouri-Columbia.

Leal-Quirós, E., Prelas, M. A., & García, E. (1990). Electron Population in the Hot Electron Ring Region of Mirrors and Cusps, Measured by Hyperbolic Energy Analyzer. *Rev. Science Instrum*, *61* (10), 3304.

Peratt, A. L. (1966). Advances in Numerical Modeling of Astrophysical and Space Plasmas. *Astrophysics and Space Science*, *242* (1 / 2), 93-163.

Wei, W. (1989). *WeM4X Plasma Diagnostics using the double Langmuir Probe.* University of Missouri-Columbia.