Low-Temperature Plasma Measurements Using a Langmuir Probe 3P03

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1 Abstract

Plasma is a fourth state of matter with fascinating characteristics. This Experiment aims to measure some current-voltage relationship of two plasmas with a Langmuir Probe to seek for some parameters to describe a plasma. The space potential, which is thought as the average potential among the space in the plasma was measured to be 9(1)V for the 2.07mA plasma and 24(2)V for the 3.57mA plasma.

2 Introduction

Plasma is thought as a fourth state of matter for having distinct features from the other three states Solid, Liquid and Gas. It can be produced from ionization of atoms in a gas. Deferring from a gas it is highly electrically conductive due to it's special structure.

The objective of this experiment is to discover some characteristics that defines a Plasma. In this experiment Plasmas will be generated by ionizing argon gas filled in tube with a 2.07mA discharge current and a 3.57mA discharge current. A Langmuir Probe will be used to measure different characteristics of the plasma. To do this, a bias will be applied to the probe causing the amount of ions or electrons colliding with the probe to change, resulting in different measurements of different currents(calculated from voltage across a 1000 Ohm resistor) corresponding to probe biases.[1] Both of the measurements in this experiment were done using standard multi meter, the uncertainty is estimated as 0.01 in this report.

3 Data Analysis

Regression analysis

To start with, the assumption of a Maxwellian distribution will be used to provide an expression to describe the probe current in regime 2. [1]

$$I_e = I_{es} exp(-e(V_{sp} - V_p)/T_e) \tag{1}$$

Taking the natural log on both side, equation (1) can be showed in this form, clearly showing the relationship between probe bias and the measured current.

$$lnI_e = lnI_{es} - \frac{e}{T_e}(V_{sp} - V_p) \tag{2}$$

As shown in Figure.1, plotting the natural log of current over probe potential.There is an exponential decline in the curve, meaning the transition from regime 2 and regime 3 where the probe bias increases from negative to positive.

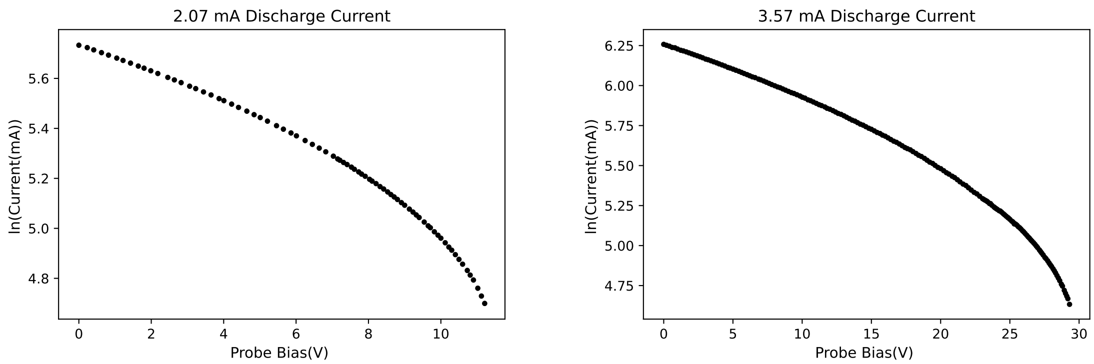


Figure 1: Semi-log plot of 2 Plasmas

Regime	Voltage Range (V)	Number of Data Points
2	10.22 to 11.21	11
3	0 to 6.25	32

Regime	Voltage Range (V)	Number of Data Points
2	27.41 to 29.31	20
3	0 to 10.22	102

Table 1: The data selected to define regime 2 and regime 3 the above one shows that of 2.07mA

Select data from the two regimes, linear fits can then be applied to each regime.

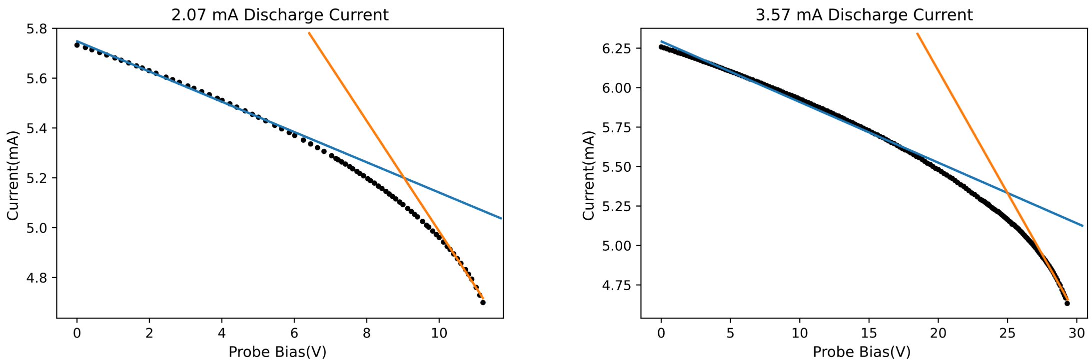


Figure 2: Plots of 2.07mA Plasma and 3.57mA Plasma with fits in both regimes

The residual of each plasma in the 2 regimes is shown below in Figure 3 and Figure 4.

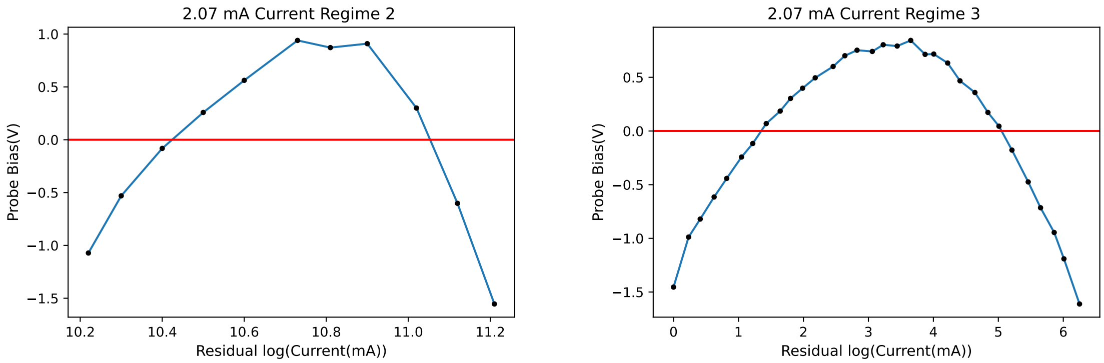
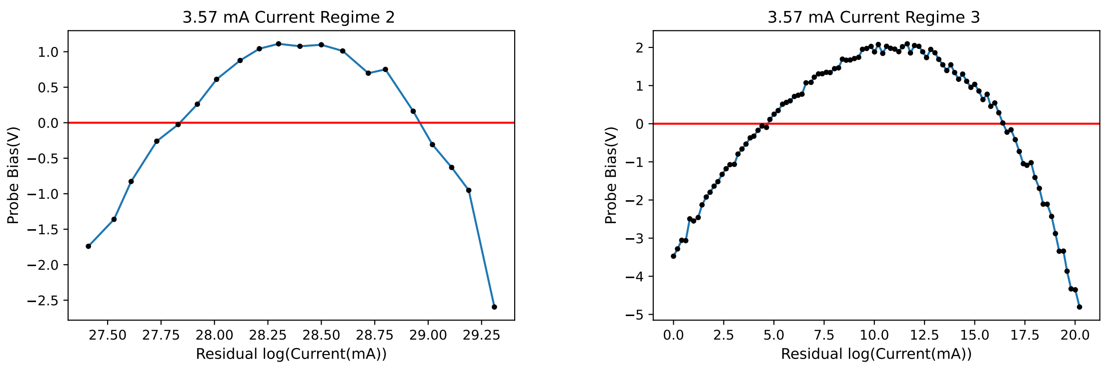


Figure 3: 2.07mA Plasma in Regime 2 and Regime 3

Figure 4: 3.57mA Plasma in Regime 2 and Regime 3



Electron Temperature

Formula of electron temperature can be obtained from Equation 2, where m is the slope of fit:

$$T_e = -\frac{e}{m} \tag{3}$$

And thus, it can be calculated from the linear fits.

Regime	Parameter	Values
2	Slope	-0.22(1)
2	Intercept	0.3(1)
3	Slope	-0.060(3)
3	Intercept	-1.146(6)

Regime	Parameter	Values
2	Slope	-0.157(5)
2	Intercept	2.3(1)
3	Slope	-0.0384(7)
3	Intercept	-0.601(5)

Table 2: Fit parameters in regime 2 and regime 3, the above one shows that of 2.07mA

Discharge Current (mA)	Electron Temperature (eV)
2.07	4.5(3)
3.57	6.4(2)

Table 3: Estimated Electron Temperatures

Space Potential

The plasma space potential can be represent as the intersection of linear fits in regimes 2 and regime 3 for each current as shown in figure 2 above. And the result is in the table below.

$$V_{sp} = -\frac{b_3 - b_2}{m_2 - m_3} \tag{4}$$

Discharge Current (mA)	Space Potential (V)
2.07	9(1)
3.57	24(2)

Table 4: Estimated Space Potential

Saturation Current

The equation for Saturation Current can also be determined from equation 2, where b is the intercept of fits:

$$I_{es} = e^{b + \frac{eV_{sp}}{T_e}} \tag{5}$$

The result is shown below:

Discharge Current (mA)	Electron Saturation Current (mA)
2.07	0.317(2)
3.57	0.539(3)

Table 5: Estimated Saturation Current

Electron Density

Now, the electron density can be determined:

$$n_e = \frac{I_{es}}{eS}\sqrt{\frac{2\pi m_e}{T_e}} \tag{6}$$

Here, m_e is the mass of an electron, and S is the surface area of the probe:

$$0.76\pi \times 2.54 = 6.06 \times 10^{-6} m^2 \tag{7}$$

The result is given by the table.

Discharge Current (mA)	Electron Density(m^{-3})
2.07	3.6(2) x 10^8
3.57	5.25(9) x 10^8

Table 6: Estimated Electron Density

4 Discussion

It can be observed from above, the resulting plasmas diverse largely in all aspects. The space potential of the plasmas differ by a factor of 2.7 just by applying 1 mA of current. To explain this, I suggest that a thresh hold amount of current is required to overcome to start generating a plasma. And when above this barrier, increasing amount of current will contribute exponentially towards ionizing argon, resulting in a more fully ionized argon in the tube.

The I-V curve is not symmetric about 0 or the floating point. This can be clearly seen from equation 1. Before reaching the floating point it rises slowly with the probe bias being negative. In regime 2, after passing the floating point, it then grows exponentially until it transits to regime 3 and slow down again, but different from that in Regime 1 as the plasma potential is positive.

The Maxwell-Boltzmann distribution can be used to determine proportion of ion and electron that can overcome a 2V barrier. Here n is the electron density T is electron temperature m is the mass of electron and v is the velocity:

$$f(v) = n_e(\frac{m_e}{2\pi T_e})^{\frac{1}{2}} exp[-\frac{m_e v^2}{2T_e}] \tag{8}$$

The density and temperature of the ion and electron can be assumed to be equal. The Proportion that can overcome the 2V barrier for both electron and ion are determined by:

$$\frac{1}{2}mv^2 \geq eV \tag{9}$$

$$v \geq \sqrt{\frac{2eV}{m}} \tag{10}$$

5 Conclusion

In conclusion, the features Electron Temperature, Space Potential, Saturation Density, and Electron Density that can be used to well define a plasma have been discovered, from the I-V relation obtained using a Langmuir Probe in this experiment. The space potential has been estimated to be 9(1)V for a plasma generated from a 2.07mA discharge current and 24(2)V from a 3.57mA discharge current.

6 Refrences

[1] D. FitzGreen, Plasma Physics. McMaster University Department of Physics and Astronomy, October 2020.