Society of Physics Students
Eastern Michigan University
303 Strong Hall
Ypsilanti, MI 48127

2005-06 Sigma Pi Sigma Undergraduate Research Award Recipient

Investigating Experimental Parameters in a New Plasma Source

Final Report

Primary Participants:

Stephanie Sears

Jeremy

Faculty Advisor:

Dr. James Carroll

SPS Chapter Advisor:

Dr. Diane Jacobs

Prepared By: Stephanie Sears

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from the chamber by a nylon sheet. The probe we used to collect our data was a small sphere mounted on a conducting rod. The rod was shielded from the plasma by a glass tube surrounding it. The probe was connected to its controller via an electrical feed-through in the side of the chamber. The probe was also mounted on a motorized slide so that plasma characteristics can be measured spatially. A grounded washer was placed between the source and the probe in order to control electrical discharges and direct the plasma toward the source. A schematic drawing of the experimental set up is shown below.

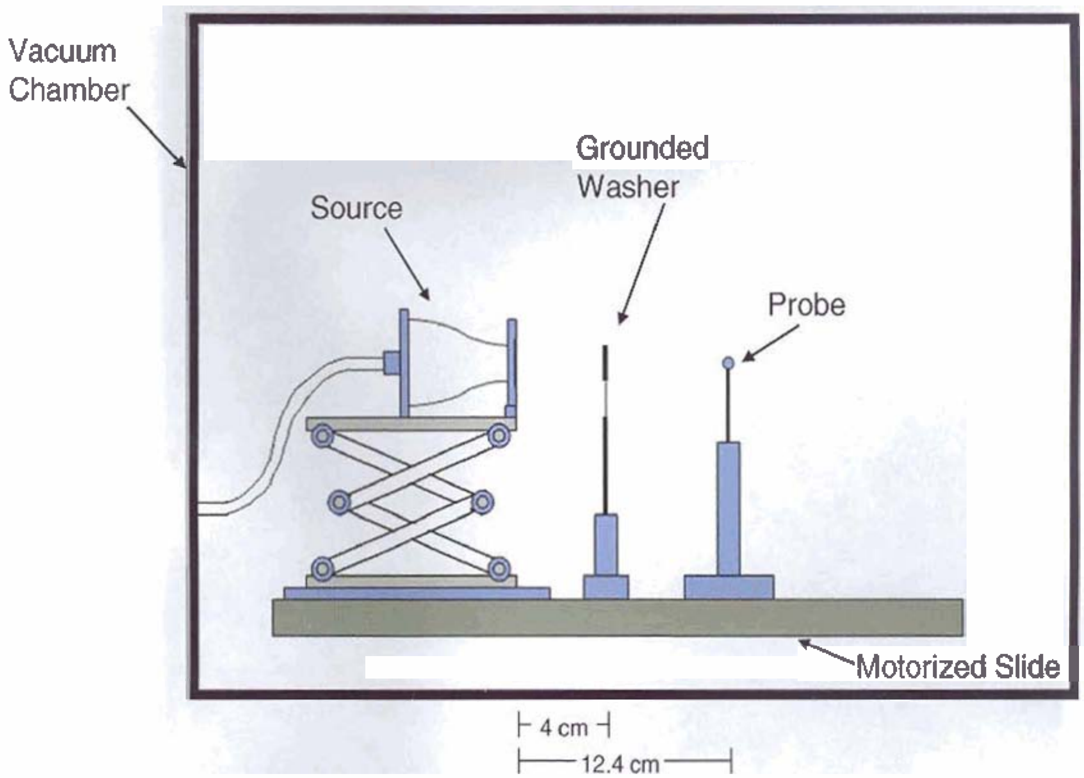

Figure 2: A schematic drawing of the experimental set up. The probe and the ground washer are isolated from each other and only the probe is movable.

Once all of the components were in place the chamber was sealed and pumped down to vacuum. We then adjusted the argon flow using a needle valve until there was enough gas in the chamber to generate a plasma. A picture of the source in operation is shown below.

Abstract

The objective of this research project was to investigate the properties of a prototype plasma source similar in nature to an ion thruster. We were able to operate this new source and successfully generate a plasma. We built two new plasma probes to study the properties of this plasma, such as its size, density, and temperature. We also updated and enhanced the equipment available in the plasma lab to encourage more active undergraduate research at Eastern Michigan University.

Experimental Procedure and Set Up

The prototype plasma source used in our experiments is shown below. The source is 11.4 cm long, 8 cm high, and 8 cm wide. The glass chamber of the source has a diameter of 6.4 cm at the large end and 4.1 cm at the small end. The back of the source has a gas inlet with an inner diameter of approximately 0.5 cm while the front of the source has a small hole (0.8 mm in diameter) where the plasma exits the source. We used an argon plasma for our experiment.

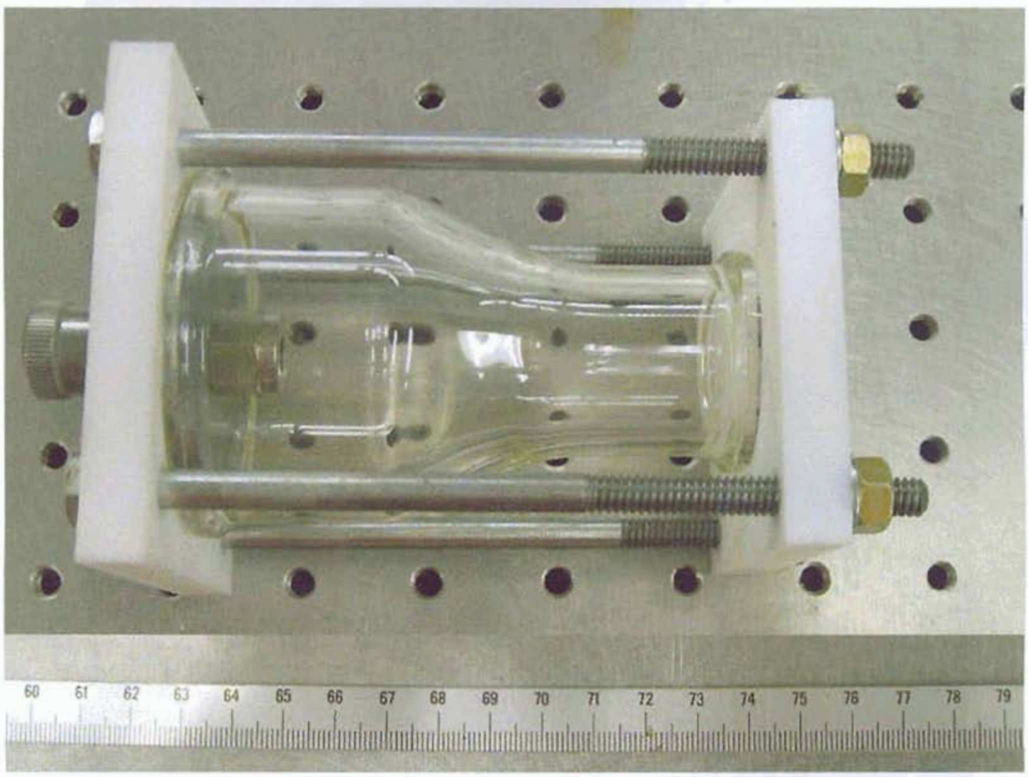

Figure 1: The prototype plasma source used in our research. The ends of the source are electrically isolated from each other by the white nylon.

All of our experiments were conducted under vacuum. The gas line connected to the back of the source was grounded to the chamber while the front of the source was kept at a negative bias which we controlled from an adjustable voltage source outside the chamber. The source itself was placed on a movable stand so its height could be adjusted as needed. The stand was isolated

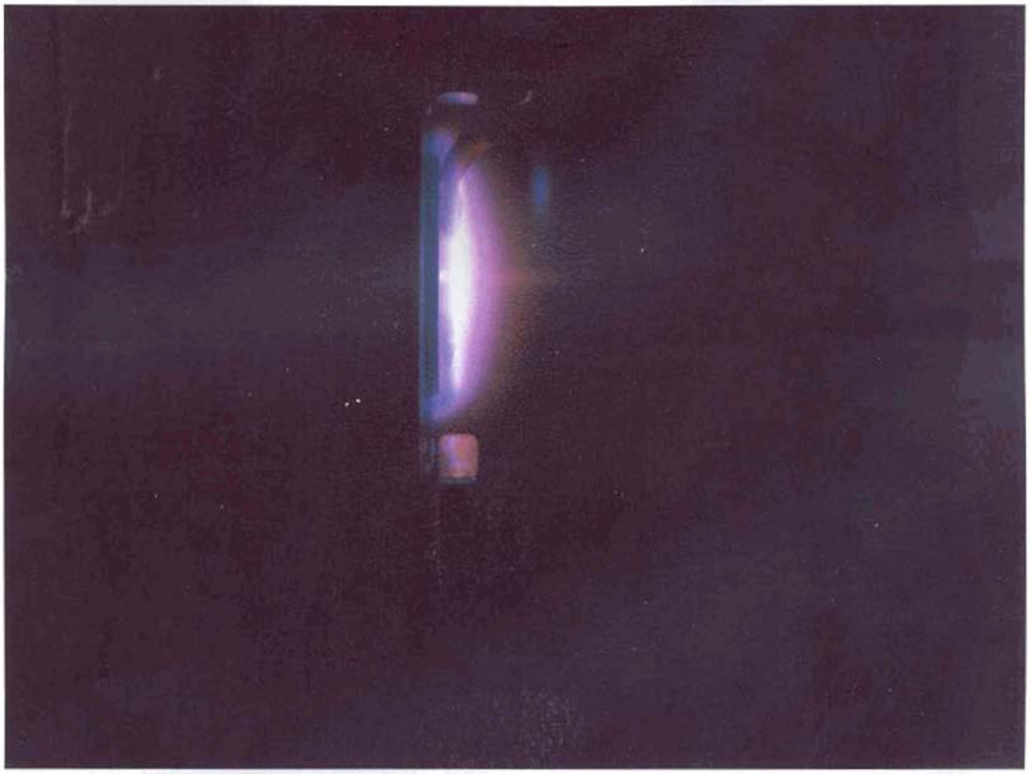

Figure 3: A picture of the plasma source in operation, taken through a side window of the vacuum chamber. Notice the narrow pink jet of plasma extending from the very center of the source.

Results

The data from our plasma source was taken in the form IV traces using the probe shown above. In this procedure the potential on the probe was swept from -40 volts to +40 volts in 0.25 volt steps. The current being collected was recorded at each point and the final result is an IV trace like the one shown below. This particular trace was taken with a 650 volt potential difference across the source.

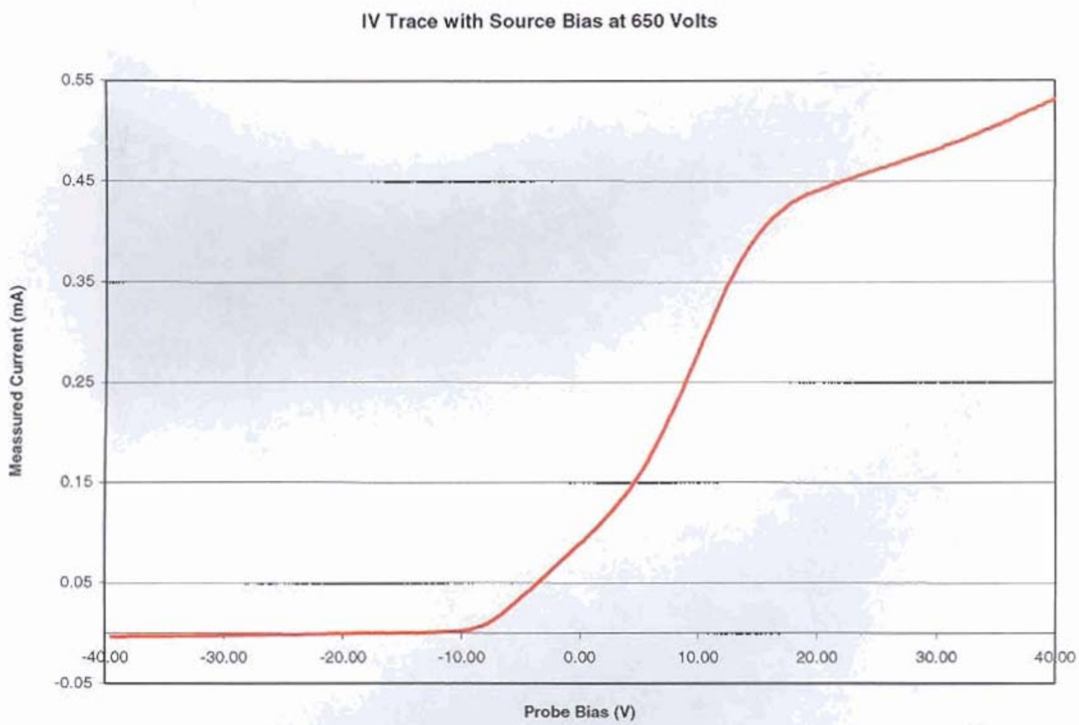

Figure 4: A typical IV trace used to analyze plasma characteristics. The most important points are the initial and final points, the slope in the very steep region of the graph, and the "knee" in the upper right. Notice the sharp change of slope that occurs around +5 volts. All of our traces had similar sharp changes, but this is not a phenomenon we expected to see.

From an IV trace we can get information about ion and electron densities, the floating potential and plasma potential, and the electron temperature. The first important point on an IV trace is the initial current. The current collected when the probe is at -40 volts is the ion current. From this data point we can get information about the ion density in the plasma. The next important point in the trace is where it crosses the x-axis. This is the floating potential of the plasma, the potential where the probe collects the same number of ions as electrons. Just after the floating potential the graph slopes up sharply before leveling out again. This region of sharply increasing slope is called the transition region. The probe potential at the inflection point, where the graph changes from concave up to concave down, gives us information about the electron temperature. The probe potential at the end of the transition region, where the graph has its maximum positive slope, tells us the plasma potential. The final point on the IV trace, when the probe is at +40 volts, is the electron current. From the electron current we get information about the electron density in the plasma.

Since the potential difference across our source is what pulls neutral gas atoms apart into ions and electrons, we would expect the ion current and electron current to increase as we increased the potential difference across the source. Since the amount of ions increases at the same time the amount of electrons increases, however, we would expect the floating potential to remain constant as the source bias increases. By taking many probe traces at different source biases, we were able to observe how the bias on our plasma source affected the ion current, electron current and floating potential. These trends are shown below.

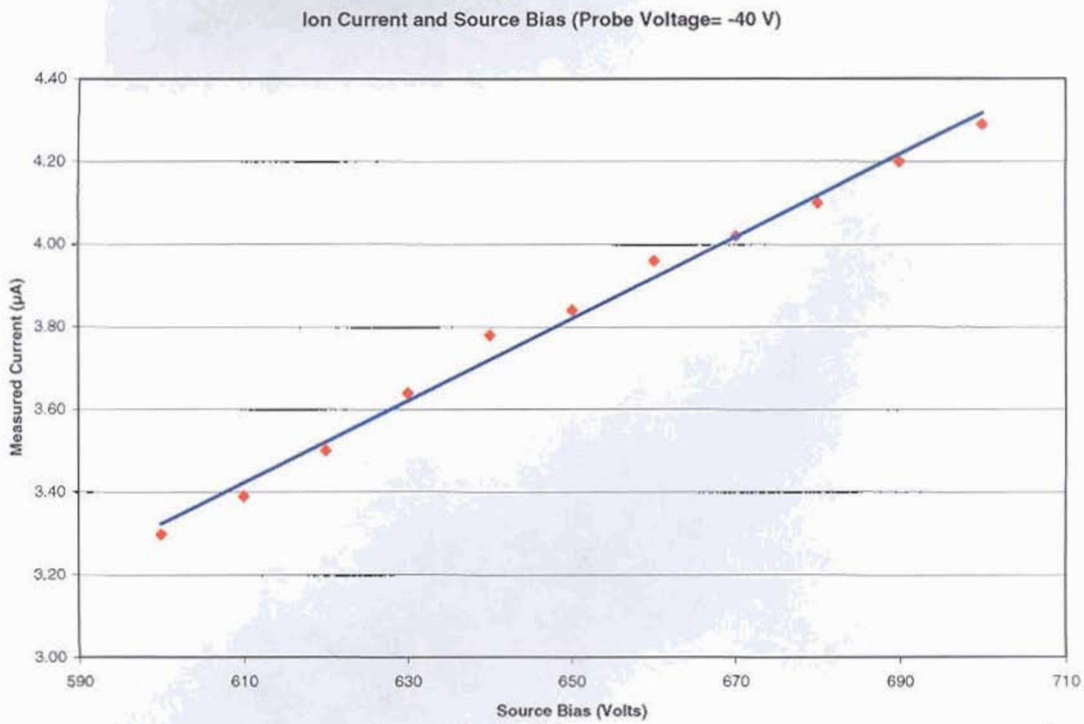

Figure 5: A plot of the ion current as a function of source bias. Note the strong linear correlation between the two. The current is measured in µA because so few ions make it all the way to the probe.

Figure 6: A plot of the electron current as a function of source bias. Notice there is a strong correlation here as well but that many more electrons are collected than ions; the current is measured in mA. Electrons are much lighter then ions and so they are much more mobile, resulting in more of them reaching the probe.

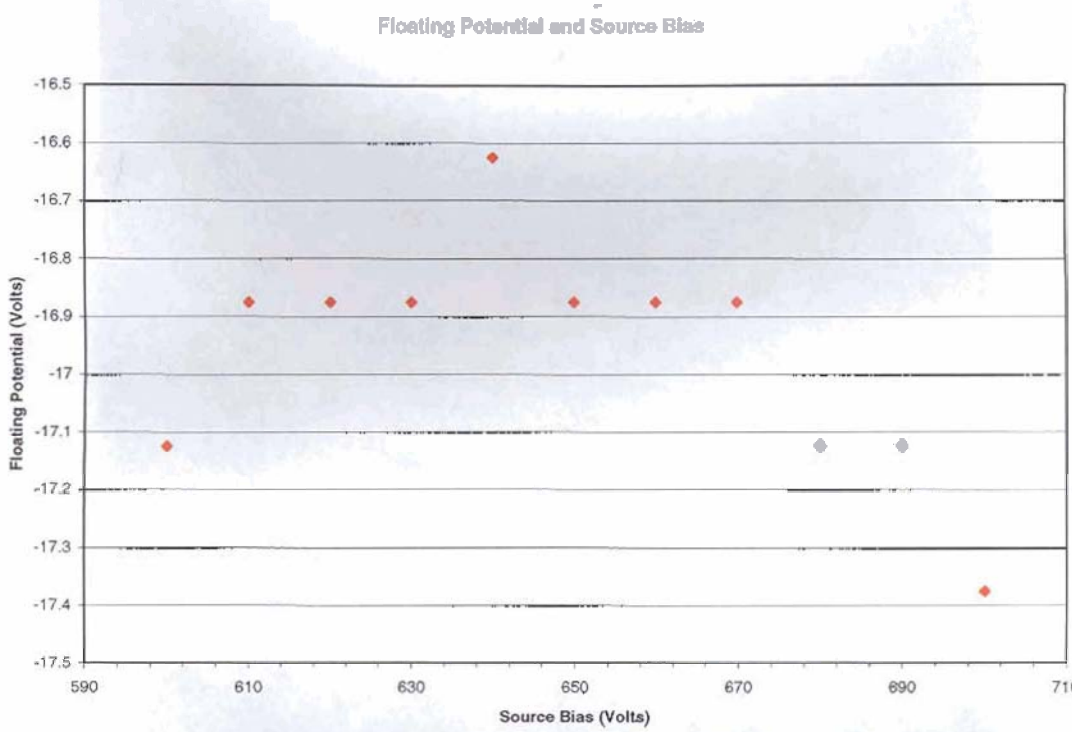

Figure 7: A plot of floating potential as a function of source bias. Notice that there is only a difference of 0.75 volts between the highest and lowest point. This supports our prediction that the floating potential of the plasma does not depend on the source bias.

Conclusions

The data we have collected shows a strong correlation between the source potential and plasma properties such as ion and electron current, as we expected. Also as expected, the floating potential of the plasma is relatively constant in spite of changes in source bias. Further analysis of the data is needed in order to characterize ion and electron density, as well as electron temperature and plasma potential in terms of source bias. Given the current trends, we expect that both ion and electron density will increase with source bias while electron temperature and plasma potential will remain constant. An interesting observation is that although the shape of the IV traces are consistent, the traces themselves are not as smooth as we expected them to be in the transition region. In all of the IV traces a sudden change in the slope is observed around when the probe bias reaches 5 volts. This change could be due to the large size of the probe disturbing the plasma. We hope that IV traces taken with the smaller probe under similar conditions will have smoother transition regions.

Another aspect of the project that needs to be addressed is the size of the plasma. While the probe was successfully mounted on a motorized slide to move axially in relation to the source, reliable spatial data has not been collected. A future research project would be to study how the plasma characteristics change as distance from the source increases. This would give us an idea of how far from the source the plasma extends and how ion and electron density, as well as electron temperature, depend on distance from the source.

Once these measurements have been made and data has been analyzed, the apparatus could be modified to take data radially. This would give us more information about the size of the plasma and how its characteristics depend on radial distance from the center of the source. We have just scratched the surface of this experiment; there are many dimensions that still need to be explored in order to understand the whole picture. All of these dimensions provide on-campus research opportunities for present and future undergraduates in our department.
In conclusion, we were able to meet our goals for this project. We successfully operated the plasma source and took several sets of data. We were able to analyze this data to get information about the plasma's floating potential, ion and electron current, and how these characteristics change with changes in the source potential. Further analysis of our data will give us information about the plasma potential and the electron temperature. Although we have some information about the plasma generated by our source, there are many questions still to be answered.

Accounting of Funds
The original funding request included funds for valves, power supplies, and vacuum fittings. Half way through the project it became obvious that the power supplies would be the important aspect of controlling the device. As our power supplies became current-limited, the voltage across the device would drop, and the plasma would cut-off. The funds were then used to purchase 2 power supplies to drive the plasma. The Department of Physics and Astronomy matched the SPS Research grant funds 2:1, and the lab purchased:

Matsusada Precision High Voltage Power supply Model : S/N 039480L (20 kV, 15 mA)		$2810
Matsusada Precision High Voltage Power supply Model : S/N 039598L (1 kV, 600 mA)		$2980
	Total:	$5790 + shipping
Funding:		
SPS Grant:		$1970
Dept. Match:		$3820 + shipping
	Total:	$5790 + shipping

These power supplies will be used by future students and have greatly increased the capabilities of the laboratory. This semester (Fall 2006), a sophomore SPS member will be applying for a Michigan Space Grant Undergraduate Fellowship to use the device and equipment related to this project. This application would not be possible without this research grant.