Macalester Journal of Physics and Astronomy

Volume 2
Issue 1 *Spring 2014*

Article 5

May 2014

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Abstract

In the field of thin-film research, there exists a novel method of film growth called Plasma Enhanced Chemical Vapor Deposition or PECVD. This technique utilizes the energetic electrons released from a plasma discharge to help catalyze chemical reactions in the deposition chamber that are essential to the film-growth process. Because plasma dynamics are not very well understood, much research goes into developing techniques to characterize a plasma's properties. In our research, we examined techniques used to measure the current versus voltage characteristic of an Argon plasma by use of a Langmuir Probe with the ultimate goal of determining the plasma's electron energy distribution.

Keywords

Langmuir Probe, plasma, plasma potential, probe characteristic

Langmuir Probe Measurements of an Argon Plasma

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(Dated: May 12, 2014)

In the field of thin-film research, there exists a novel method of film growth called Plasma Enhanced Chemical Vapor Deposition or PECVD. This technique utilizes the energetic electrons released from a plasma discharge to help catalyze chemical reactions in the deposition chamber that are essential to the film-growth process. Because plasma dynamics are not very well understood, much research goes into developing techniques to characterize a plasma's properties. In our research, we examined techniques used to measure the current versus voltage characteristic of an Argon plasma by use of a Langmuir Probe with the ultimate goal of determining the plasma's electron energy distribution.

INTRODUCTION

The rationale behind our research in Langmuir Probe measurements was the long term goal of better understanding the PECVD film growing process. Because a plasma (glow discharge) is an integral component in a PEVCD deposition system, it is important to have a good understanding of plasma dynamics in order to be well educated and informed about the reactions that grow the film, and to know what plasma parameters to change in order to improve aspects of the film growth process.

The plasma's main purpose in the deposition is to provide high energy electrons that dissociate reactant molecules and catalyze reactions. For example, a common PECVD reaction done in laboratories uses a gaseous Silicon compound called Silane gas (SiH_4). Because film growth requires free Silicon radicals, the Silane molecules must be broken apart before the film can grow. Electrons produced by a plasma in the system will help to dissociate the Silane and in turn grow the film. Because only electrons above a particular energy threshold can dissociate any particular reactant, it is helpful to determine $f(\epsilon)$, the plasma's Electron Energy Distribution Function (EEDF). This function is simply the statistical distribution of electron energies in the plasma. Fortunately the EEDF can be derived from certain probe measurements of the plasma, as seen in the following relation.[1]

$$\frac{\partial^2 I}{\partial {V_B}^2} = \frac{2\pi e^3 S}{m_e^2} f(\epsilon)|_{\epsilon=e(V_p-V_B)}$$

where:
I is the current through the probe
V_B is the probe voltage
m_e is the mass of an electron
S is the surface area of the probe
$f(\epsilon)$ is the EEDF
V_P is the plasma potential

Luckily, both the current versus voltage curve and the plasma potential are measureable by use of a Langmuir Probe [FIG. 1.]. This probe is simply a conductive wire mounted such that it lies in the center of the discharge. The probe is connected to both a voltage source and current meter for measurement.

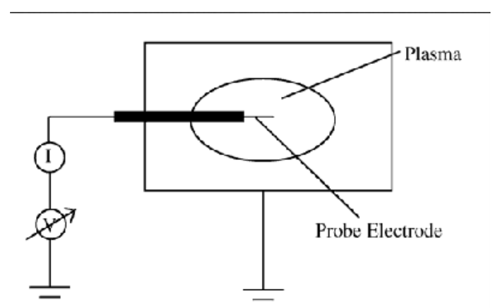

FIG. 1. Langmuir Probe

This paper will discuss our efforts to measure a suitible probe characteristic (I-V curve) of an Argon discharge in both DC and RF driven plasmas. I will also briefly offer some insight towards a possible analog measurement technique that uses a voltage ramp and oscilliscope.

METHODS AND DATA

All plasma experiments discussed in this paper were executed in a dedicated vacuum chamber [FIG. 2] that included: an Argon gas line, ion gauge and capacitance manometer (both pressure gauges), vacuum line, mechanical and electrical feedthroughs and porthole.

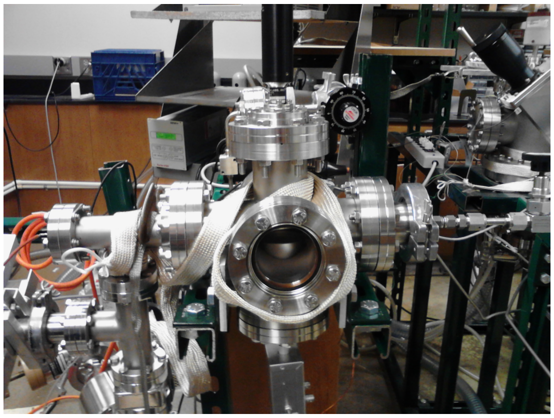

FIG. 2. the experimental chamber

DC System

The preliminary discharge was generated in a small glass cylinder [FIG. 3.] that was inserted into the vacuum chamber. This first discharge appartus was designed for a DC plasma and contained a powered cathode, grounded anode and Langmuir Probe constructed from a .10 mm diameter and .28 cm long tungsten wire mounted along its axis. The probe output as well as the electrode attached to the vaccuum chamber's feedthrough.

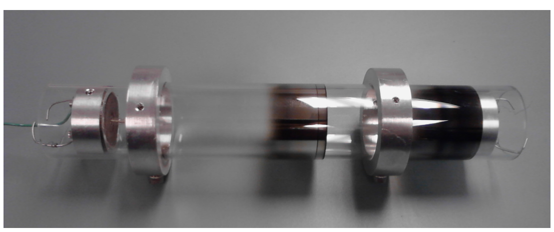

FIG. 3. the DC reaction cylinder

After the vacuum system was pumped down to about $1 * 10^{-6}$ Torr, Argon gas was introduced into the chamber and the electrodes were powered up until a discharge was optically visible. The probe lead was connected to a Keithley 2400 SourceMeter which allowed us to take probe current measurements and concurrently supply a changing voltage level to the probe. After sweeping a voltage range, the resulting data array would be exported to a lab computer for analysis. Data was collected at a variety of pressures, cathode biases, and voltage ranges. After several trials, it became evident that instability of the plasma, as well as ohmic heating of the probe were causing noise in the current measurements. This was especially problematic near what appeared to be the plasma potential, which appears as an inflection point in the probe characteristic. We believe that as current increased, significant power was dissipated in the probe tip, likely due to its very small diameter and thus non-negligible resistance. This resulted in Ohmic heating and consequent noise. An example plot of the affected data is shown below [FIG. 4.].

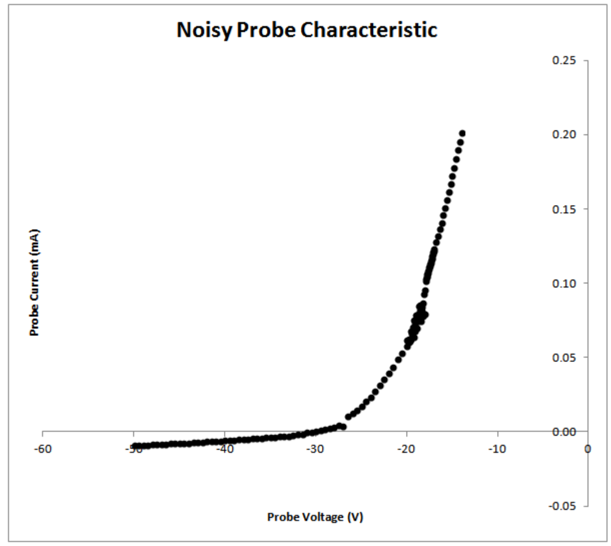

FIG. 4. example noisy data from the DC system

Because in most trials, the data started to become noisy at the same time the probe tip appeared to glow and flicker, we believe that the noise was most probably due to heating. It is also possible that, because the size of the system was small relative to the size of the probe, the electric field around the probe was perturbing the plasma to such a degree that the probe was acting as an anode and altering the plasma as well as our data. We needed to keep discharge currents low to prevent overheating and cracking of the discharge tube, and indeed measured probe currents were comparable to the discharge current near V_p. Either way, it became obvious after many trials that we needed to revise our apparatus.

RF System

Our next incarnation of the discharge apparatus was a new system designed to generate an RF plasma [FIG. 5.]. The system consisted of two seperate electrodes and a new Langmuir Probe mounted between them.

By re-designing the system we hoped to remedy a few problems we had about the existing system, notably the noise and perturbation issues. Additionally, we hoped that by switching the driving voltage from a

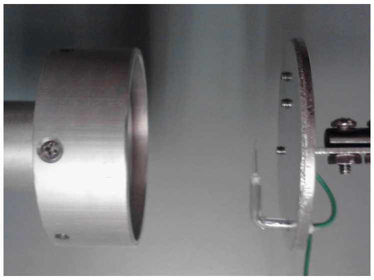

FIG. 5. the RF electrodes and Langmuir Probe

DC level of a few hundred volts to a lower-powered RF current oscillating at 13.56 Mhz, our system would better model real PECVD systems - which typically use RF driven plasmas. After a few trials, it was obvious that this system was superior to the previous design. The plasma was visually much more stable and was much more uniform even at low power. Additionally, the probe characteristic was much less noisy. There was, however, a still unavoidable problem of ohmic heating in the probe near V_p. Despite running the discharge on a multitude of different pressures, power levels, and electrode seperations, the probe characteristic was still too noisy. A plot of our best data from the RF system is shown. [FIG. 6.]

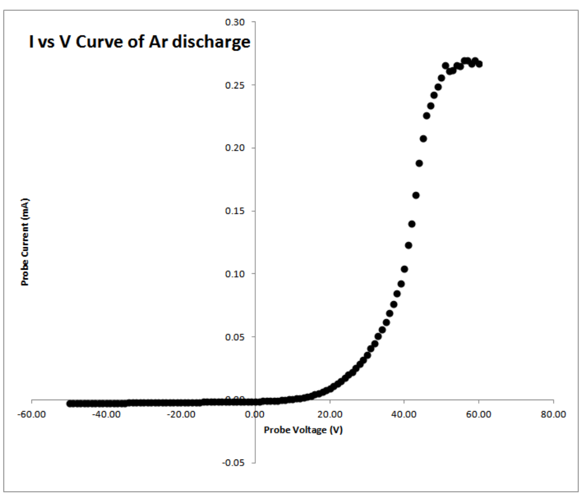

FIG. 6. example probe characteristic from the RF system

Conclusion

It became obvious, after our trials with both the DC and RF systems, that perhaps we needed to rethink the experiment as a whole. It is possible that this smaller dedicated vacuum chamber was too small for the experiment we were attempting to carry out. Similar size probes have been used in a much larger deposition system without the problems encountered here.[3] We did, however, learn that using an RF plasma made the system more stable and symmetrical. One possible solution to the heating problem would be to run the probe bias on a fast analog sweep and to read the current out on an oscilloscope. By sweeping the voltage at a high enough frequency, we could mitigate the probe heating.

ACKNOWLEDGMENTS

I'd primarily like to thank Professor Jim Doyle for welcoming me into his lab and mentoring me through the research process. Additionally, I would like to thank Ken Moffet for helping us construct the necessary equipment we needed in order to do this research. Finally, I would like to mention the Macalester Beltmann fund, which funded my research.

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