DOE Plasma Science Center

Visiting Graduate Student/Post-Doctoral Researcher Fellowship Report

Title of Project:	Control of Electron Energy Distribution Functions Using a Dual Tandem Plasma Source	
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Host:	Demetre Economou	
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Dates of Visit:	**Start: 09/16/13**	**End: 09/19/13**

I. Description and Importance of Research Issues Investigated During Visit

During the visit I investigated sources of discrepancy between results obtained experimentally for an argon discharge and results obtained through simulations. This was important in enabling further refinement of my modeled system and in allowing accurate comparisons between modeled and experimental results. Having an accurate and validated model of the experimental system allows for investigation of interesting effects, including those which would likely be difficult to analyze experimentally. The experimental system being investigated provides additional ways to control the electron energy distribution function (EEDF) in inductively coupled plasma (ICP) systems, which could lead to increased control of plasma generated species for etching and deposition purposes.

One source of discrepancy between the results of the model and the experimental data was the increase in electron temperature with time in the afterglow of a pulsed ICP with the secondary ICP on in continuous (cw) mode. In this case the primary (lower) ICP source was pulsed and the secondary (upper) source was on in cw mode with and without a +60 V bias on the boundary electrode (BE) at the top of the system. The model saw a much smaller increase in electron temperature with time in the afterglow as compared to the experimental data.

Another source of discrepancy was the generation of a third ionization region at the top of the system initiated near the BE when a large positive bias (≥ 60 V) was applied. This also led to pulsing of the plasma potential with time in the modeled results. Neither of these results was observed experimentally.

This visit enabled further research collaboration as I was able to present my results and get direct feedback on what was observed in the experimental system and get feedback on possible reasons for these discrepancies. I was also able to observe the actual setup of the system when experiments were run (as opposed to potentially inaccurate or misinterpreted schematics) and see how data was collected. This would prove very valuable in developing a more accurate model of experimental conditions.

II. Discussion of Research Outcomes and Findings Resulting from Visit

As a result of my visit to the University of Houston I modified my system to more accurately reflect the experimental setup. For instance, I was under the mistaken belief that either the stage or the Langmuir probe was used in the system during experiments but not both. This turned out not to be true as the cylindrical stage was in the system at the same time as the Langmuir probe. The stage was donut shaped centered about the center axis of the chamber and the Langmuir probe would rise along this axis to take measurements. The stage has an inner radius of 1 inch and an outer radius of 2 inches. During etching experiments, where I mistakenly believed the Langmuir probe was switched for the stage, the probe would remain in its rests position near the bottom of the chamber and a small 2 inch wafer would be put on top of the stage. The outer diameter of the stage was grounded stainless steel, the inner radius was Teflon, and the top surface was anodized aluminum. This had a noticeable effect on the spatial profiles of species densities and the azimuthal electric field.

I also modified my model to shift the position of the coils of the main ICP source as they were lower in height than the experimental setup. From discussion with Prof. Economou's research group I decided to make my representation of the biasable grid separating the two sources more open in my model. It was believed that I may have been preventing the high energy electrons from the secondary ICP source to pass through the grid into the primary ICP region in the afterglow when the primary ICP was pulsed. This turned out to be correct and I saw an increase in electron temperature with time in the afterglow that was much closer to the experimental data.

Running an experiment with both ICP sources on in cw mode with the bias ramped up to + 80 V, we did not observe a third ionization region spread across the top of the chamber as in the model, nor did we observe the pulsing of the plasma potential as in the model. It was observed however that as the bias on the boundary electrode was ramped from 0 V to +80 V, that a third discharge developed inside the gas inlet and spread into the chamber, with higher voltage causing an increased spread into the chamber near the inlet. My old model did not include the actual tube by which the gas flowed into the chamber, and instead represented gas injection as being from a small nozzle area along the chamber wall. Including this inlet tube turned out to be the key to resolving the discrepancy of the third ionization region between the model and experiment. A third ionization region at the top of the chamber was produced in the experiment as predicted by the model, however it originated in the inlet tube and only spread a short distance from the inlet into the actual chamber. In the model the lack of this inlet tube forced the ionization region to be spread across the top of the chamber. I would not have discovered this had I not gone to visit Prof. Economou at the University of Houston and seen the experiments run with my own eyes.

The pulsing of the plasma potential also appears to have been reduced as the inlet tube was incorporated into the model. Reasons that this pulsing may not be seen experimentally may be due to the design of the Langmuir probe to filter out high frequencies modulations of the measured currents, which might include this pulsing as the frequency is in the hundreds of kHz range. The fact that the model is a 2-D cylindrically symmetric model trying to represent a 3-D system is also a source of discrepancy that will always be there. For example the gas inlet tube is a cylindrical tube on only one side of the system however I can only model it as a disk with gas coming in from all sides.

The comparison between the modeled results and the experimental data has become quite good as a result of my visit to the University. In the figures below I will show how my model has changed from before and after my visit and how my modeled results have come to more accurately reflect the experimental data.

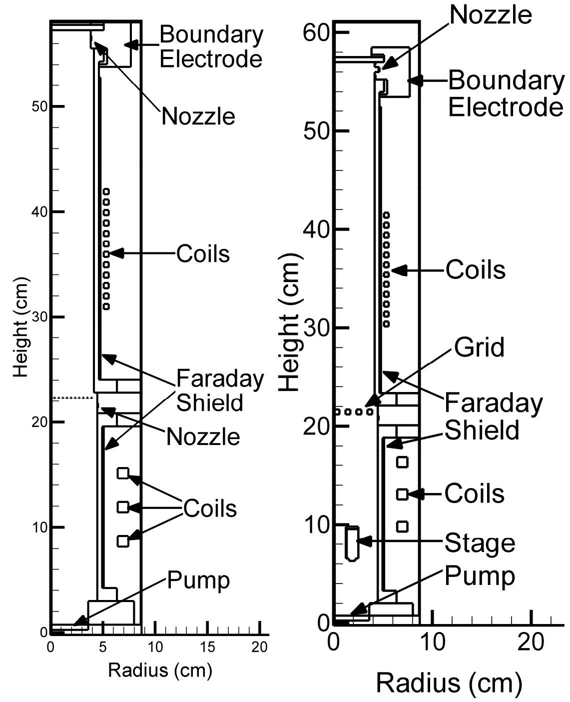

Figure 1: Model representation of Dual Tandem ICP Source System. (Left) Model before visit. (Right) Model after visit.

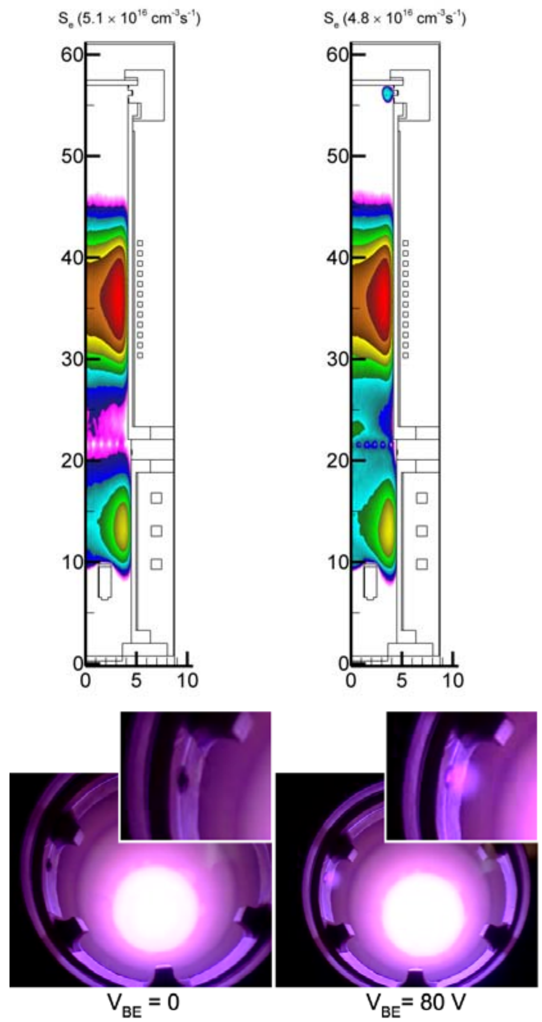

Figure 2: (Top Row) Electron source function showing ionization regions. V_{BE} = 0 V on left, V_{BE} = 60 V on right. (Bottom Row) Experiment. ICP conditions: 500 W (top source), 90 W (bottom source), both in cw mode, Ar, 10 mTorr, 80 sccm.

III. Follow-up to Visit

An oral presentation comparing updated modeled and experimental results was given at the AVS symposium on Tuesday, October 29th, 2013. A joint paper is also being developed where the results of our collaboration will be presented and discussed.