DOE Plasma Science Center

Visiting Graduate Student/Post-Doctoral Researcher Fellowship Report

Title of Project:	Development of a Versatile Plasma Source for Laser Diagnostics	
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Institution Visited:	Sandia National Laboratories	
Host:	Dr. Ed Barnat	
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Dates of Visit:	**Start: 6/2/14**	**End: 6/27/14**

I. Description and Importance of Research Issues Investigated During Visit

Measurements of electron number density (n_e) and electron energy distribution function (EEDF) are of great importance in the study of weakly ionized plasmas. Improved measurement capabilities, especially in the range of ~10^{10}-10^{12} cm^{-3}, would benefit applications including processing plasmas for surface and bio-treatment, electric propulsion, as well as atmospheric pressure plasmas for combustion and flow control. In many cases physical probes perturb the plasma or can be damaged, leading to the use of optical diagnostics such as Laser Thomson Scattering (LTS). Adam Friss, a PhD candidate in Professor Yalin's group at CSU, is working on a new approach for LTS, termed cavity enhanced Thomson scattering (CETS). The technique uses a high (average) power intra-cavity beam to increase the scattered photon counts and signal levels. The build-up cavity is based upon injecting a high-power narrow linewidth laser into a high-finesse cavity, and frequency-locking the two together. In this way, relatively simple setups should allow a beam power as high as ~10-100 kW. Simulations, based on expected experimental parameters and including noise, indicate that the diagnostic will allow measurements down to densities of ~10^9-10^{10} cm^{-3}. Concurrently, Dr. Barnat is continuing the development of Laser Collisional Induced Fluorescence (LCIF) including extension to higher pressure plasma systems, which are of interest in biological and surface treatment (interface) applications. Both diagnostic techniques share a common need for a custom source operating over a range of plasma conditions and with extensive optical access.

<u>The specific objective of the research visit was to develop a plasma source capable of spanning a large density range (~10^{10}-10^{14} cm^{-3}) and large pressure range (~1-300 Torr) at Sandia National Laboratory. The plasma source will serve as a test bed to develop and validate laser diagnostic techniques (CETS and LCIF).</u> Initial characterization of the plasma source was performed with microwave-based techniques.

II. Discussion of Research Outcomes and Findings Resulting from Visit

The research visit resulted in the development of a plasma source capable of a wide range of electron densities (~10^{10}-10^{14} cm^{-3}) and served to familiarize the student with a microwave density measurement technique. A variety of source configurations, gas pressures, and modes of operation were experimentally measured using a resonant microwave cavity. Microsecond and nanosecond pulse discharges as well as continuous (CW) DC discharges with and without electrodes present were investigated. The source (Fig. 1a) consists of a cathode and anode assembly connected via a half inch OD glass tube. A gas feed system enters and exits through the anode. Although the flow arrangement is not ideal, by placing the gas feed and return on the anode side issues with plasma formation inside the gas line were eliminated. Future source designs will incorporate a gas feed on the cathode side with a high degree of isolation to eliminate the unwanted plasma formation.

While Argon and Helium plasmas were investigated, the data presented is for Helium operation only as it resulted in higher densities, more stable operation, and reduced electrode sputtering. All data is summarized in table 1. The microsecond pulse discharge (Fig 1b) produced maximum electron densities of 7 x 10^{12} cm^{-3}. The cathode was held at -3kV and the anode was grounded. The plasma was very stable and typical operation conditions were 20 μs pulses at a repetition rate of 20 Hz and pressures in the range of 1 to 20 torr. Adjustment of pulse length and repetition rate did not significantly influence maximum electron density. The addition of electrodes also did not result in any significant gain in density but did localize the plasma to the region of the tube between the electrodes. However, after extended operation (~1 hour) the aluminum electrodes began to sputter coat the inside of the tube, which caused some errors in the microwave measurement due to broadening of the signal.

CW DC operation resulted in maximum electron densities of 2.4 x 10^{11} cm^{-3} but the plasma was very unstable and caused significant noise in the data. DC density increased linearly with power delivered to the plasma. The maximum density value occurred at a power of 23.5 W. For the current plasma source to achieve electron densities of 10^{14} cm^{-3} approximately 11 kW of power would be required. The DC mode of operation is not well suited for use in characterizing the CETS technique due to instabilities in the plasma, which resulted in random electron density fluctuations across the volume of the tube, and therefore the majority of the time at Sandia was spent investigating pulsed modes of operation.

Nanosecond discharges with electrodes were also investigated (Fig. 1c) and resulted in maximum electron densities of 1 x 10^{14} cm^{-3}. Nanosecond operation resulted in a dense filament of plasma that formed between the electrodes. Operation was possible over a much larger range of pressures (1-200 torr) in comparison to microsecond and DC operation. The filament attachment points on the electrodes drifted in time and at high pressures (~200 torr) the filament would attach to the wall of the tube. Significant sputter erosion of the electrodes was encountered and required the glass tube to be replaced after several hours of operation to ensure the accuracy of the microwave density measurements. The nanosecond mode of operation is the most promising from a density standpoint and relatively easy to implement in the lab assuming an appropriate pulse generator is available.

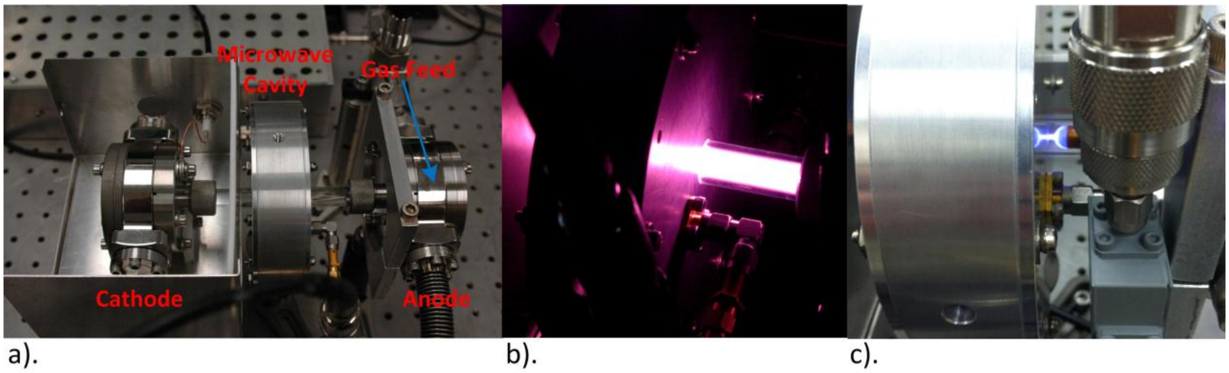

Figure 1. Plasma Source and Operation. *a).Plasma source and individual components. b). Microsecond discharge operation. c). Nanosecond discharge operation.*

Mode of Operation	Pressure (Torr)	Pulse Length (μs)	Max n_e (cm^{-3})
CW DC (10.2 W)	4	NA	1.2×10^{11}
CW DC (19.2 W)	4	NA	2.09×10^{11}
CW DC (23.5 W)	4	NA	2.44×10^{11}
Microsecond Pulse	10	20	6×10^{12}
Microsecond Pulse	12.5	20	7×10^{12}
Microsecond Pulse	15	20	6.9×10^{12}
Microsecond Pulse	17.5	20	6.1×10^{12}
Nanosecond Pulse	50	0.02	5×10^{13}
Nanosecond Pulse	200	0.025	1×10^{14}

Table 1. Summary of Density Measurements for Various Modes of Operation

III. Ongoing and Future Work

A pulsed plasma source will be built at CSU for development and validation of the CETS technique. The source will be similar in construction to the Sandia source but will be designed with a cross so a high finesse optical cavity can be placed orthogonal to the plasma column or filament. The CSU source will be initially characterized using the resonant microwave technique learned during the visit to Sandia. Additionally, lessons learned over the course of the visit will influence the design of the CSU plasma source to ensure stable operation, appropriate gas feed system, and reduced electrode sputtering. Depending on equipment limitations the source will operate as a microsecond and/or nanosecond discharge. Future conference and journal publications resulting from the CETS technique will include detailed descriptions of the plasma source and will be of benefit to the general plasma science community.