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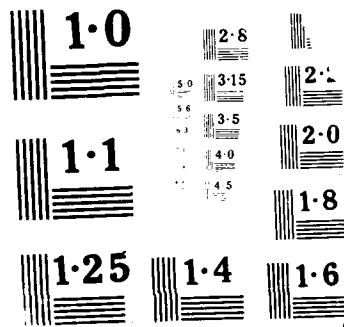
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<p>During the past year, work was continued developing novel advanced laser spectroscopy plasma diagnostic methods. The methods are based on observing the doppler shift in the absorption lines of ionic species. Two methods under study are Velocity Modulated Laser Spectroscopy and Two-Beam Doppler Shift Laser Spectroscopy. The scientific goal of the work is to increase understanding of plasmas by making in-situ measurements of ion drift velocities, concentrations and temperatures in a non-intrusive fashion. The scientific approach is to combine conventional laser spectroscopies with velocity detection. Using a method such as Rayleigh, fluorescence, or Raman scattering, one probes the Doppler profile of the specie of interest, observing shifts in the Doppler profile that arises because of the presence of a electric field. The shift may be related to the ion mobility, and thus conductivity, if the electric field is known, or to the electric field if the mobility is known. Temperature and concentration may be recovered by the conventional means.</p>			
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1 Abstract

During the past year, work was continued developing novel advanced laser spectroscopy plasma diagnostic methods. The methods are based on observing the doppler shift in the absorption lines of ionic species. Two methods under study are Velocity Modulated Laser Spectroscopy and Two-Beam Doppler Shift Laser Spectroscopy. The scientific goal of the work is to increase understanding of plasmas by making in-situ measurements of ion drift velocities, concentrations and temperatures in a non-intrusive fashion. The scientific approach is to combine conventional laser spectroscopies with velocity detection. Using a method such as Rayleigh, fluorescence, or Raman scattering, one probes the Doppler profile of the specie of interest, observing shifts in the Doppler profile that arises because of the presence of a electric field. The shift may be related to the ion mobility, and thus conductivity, if the electric field is known, or to the electric field if the mobility is known. Temperature and concentration may be recovered by the conventional means.

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2 Introduction

The purpose of our work has been to develop advanced laser spectroscopy methods to diagnose partially ionized plasmas. We have focused on methods that are based on observing the Doppler shift in ionic spectra due to the presence of an ion drift velocity. Two particular methods we are working with are Velocity Modulated Laser Spectroscopy (VMLS) and Two Beam Doppler Shift Laser Spectroscopy (TBDSLS).

The scientific goal of our work is to increase understanding of the role of flow non-uniformities and plasma/wall interactions in plasma devices by making in-situ measurements of electric field strength, ion mobilities, concentrations and temperatures in a non-intrusive fashion that allows point, one, and two dimensional imaging.

The scientific approach is to use conventional laser spectroscopic methods such as Rayleigh scattering, Raman scattering, or fluorescence, to probe ion absorption line profiles. If there is an electric field present, the ions will experience a net force and undergo drift, resulting in a shift in the position of the line profile. If the ion mobility is known, then the electric field component along the probe direction can be calculated. If the electric field driving the plasma is modulated, one will observe an oscillating shift in the line profile that arises because of the oscillating force imposed on the ions. The shift may be related to the ion mobility, thus conductivity.

Temperature and concentration may be recovered by conventional laser spectroscopic means. The methods are species and state selective, allowing one to make measurements on more than one species and to study the effect of internal mode nonequilibrium.

The merit of the methods lies in their ability to provide simultaneous measurements of important parameters in plasmas. The methods are well suited to multi-dimensional imaging. One may use an array detector to image lines and planes in addition to the more conventional point configuration.

During the first year of the program, the theoretical basis of the method was developed and our experimental facility modified for the purpose of demonstrating its effectiveness. These results were reported in last years annual report. During the past year we have worked mostly on understanding the plasma environment that we have chosen to use in the demonstration experiments. In the following we describe the plasma facility and report on the work accomplished.

3 Plasma Considerations

The selection of a plasma environment in which to demonstrate the Doppler shift methods is somewhat complicated by the fact that the plasmas of ultimate interest are quite complex and not well understood. Thus the approach we have taken is to select a plasma environment which may be fairly well characterized and which displays simple limiting behavior.

After some consideration, it was decided to work with a flame assisted plasma. The concept behind such a choice is that flame assisted plasmas, that are seeded with a dominant ionizable specie, often remain collision dominated at quite large values of electric field, and may be designed to offer uniform properties over fairly large spacial extent.

Once selected, other practical constraints limit the choices of configuration, fuel and seed specie. The seed specie must be both readily ionizable and the ion's absorption lines must be accessible for laser excitation. In addition, one seeks to achieve as high a temperature as possible so as to obtain the maximum degree of ionization. Given these constraints, barium was chosen as the seed specie and oxygen and acetylene as the oxidizer and fuel, respectively. The use of oxygen and acetylene limits the choice of a burner configuration to non-premixed.

4 Plasma Theory

The advantage of utilizing a collisionally dominated plasma is that the theoretical description of the plasma is simplified considerably. Such a simplified description has been formulated by Lawton and Weinberg [1] expressly for flames. Our approach has been to use their theory in conjunction with experiments to ensure that we have a reasonable understanding of the plasma conditions.

The Lawton and Weinberg theory is based on the assumption that diffusion of ions and electrons can be neglected in comparison with drift. Under this assumption, and assuming that the plasma is one-dimensional with uniform properties, the governing equations are electron and ion continuity

$$\frac{dJ_{\pm}}{dx} = r_{\pm}$$

and Poisson's equation

$$\frac{dE}{dx} = \frac{e}{\epsilon}(n_{+} - n_{-})$$

J_{\pm} is the ion or electron current density in units of molecules per unit area and time, r_{\pm} the collisional ionization rate in units of molecules per unit volume and time, E the electric field, e the charge of an electron, ϵ the permittivity of free space, and n_{\pm} the ion or electron number density. The current density is given by

$$J_{\pm} = \pm \mu_{\pm} n_{\pm} E$$

where μ_{\pm} is the ion or electron mobility, and the electric field is related to the potential by

$$\frac{dV}{dx} = -E$$

These equations have particularly simple limiting solutions. The first is the zero-field limit. In this case it is assumed that the electric field is sufficiently small so that the imposed ion and electron currents are insignificant in comparison to the ionization rate. In this limit, the ion and electron number densities remain at approximately their equilibrium values and the source term in Poisson's equation remains zero. Thus the electric field is constant and given by

$$E = \frac{V_0}{L}$$

where V_0 is the potential across the electrodes, and L is the electrode spacing.

The other simple limit occurs at large field strengths and is called the saturation limit. If the field becomes large enough, then the current is limited by the ionization rate. In this limit the current becomes

$$J_{sat} = r_c L$$

where r_c is the collisional ionization rate. The electric field is given by

$$E = 2 \frac{V}{L} \left(\frac{x}{L} \right)$$

In between these two limiting solutions, the current density depends on the square root of the voltage drop across the plasma

$$\frac{J}{J_{sat}} = \sqrt{\frac{V}{V_{sat}}}$$

If the theory is correct, then the drift velocity of ion we are observing in the experiment can be calculated directly. This gives a basis of comparison with the Doppler shift measurements. Furthermore, the theory allows one to determine the ionization rate and the equilibrium ion number density from the current-voltage characteristics of the plasma.

5 Experimental

The flame assisted plasma is generated inside a low pressure vessel. The vessel is constructed from stainless steel and is mounted with windows and instrumentation ports.

The burner we have chosen is a capillary, diffusion flame burner obtained from the University of Florida. The non-premixed burner allows a wide range of operating conditions without the normal difficulties associated with using acetelyne and oxygen as reactants, and can be operated down to about 20 Torr. Barium tetrachloride is seeded into the flame using a Perkin-Elmer aspirator modified to operate at lower pressures.

Electrodes are mounted adjacent to the flame. A combination of a DC power supply and audio power amplifier/signal generator allows delivery of up to several hundred volts DC or AC.

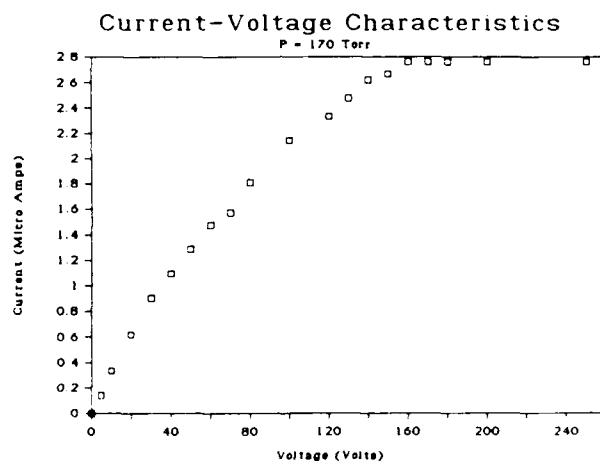


Figure 1. Current Voltage Characteristics

Typical current-voltage results are shown in Figure 1. The curve displays the square root dependency and the linear and saturation regimes. This particular case is for a very low level of seeding. As the level of seeding is increased, the saturation current increases. Thus by varying the seeding rate, one can significantly change the domain of behavior.

6 Current Status

At present we are in the final phases of the plasma characterization work as reported above. Once this work is finished we will begin spectroscopic measurements in the plasma environment.

7 Publications

a) AFOSR sponsored publications appearing or accepted during the past grant period:

M. Sassi, C. Lee, and J. W. Daily, "Doppler Shift Methods for Plasma Diagnostics," AIAA Paper 87-1528 (1987).

M. Sassi, and J. W. Daily, "Doppler Shift Methods for Plasma Diagnostics," Journal of Quantitative Spectroscopy and Radiative Transfer, In Press.

b) Papers in progress

Daily, J. W., "Laser Induced Fluorescence Spectroscopy in Flames," Invited review for Progress in Energy and Combustion Science.

Lee, C., J. Hwang, M. Sassi, and J. W. Daily, "Characteristics of a Flame Assisted Plasma for Laser Plasma Diagnostics."

c) Report

Lee, C., "Current-Voltage Characteristics of a Flame Assisted Plasma for Plasma Diagnostics," University of California, Master Degree Project Report (1987)

8 Personnel

The principle investigator is Professor John W. Daily. Professor Daily is currently an Associate Professor of Mechanical Engineering (with tenure.)

At present two graduate students are working on the project. These are Mohamed Sassi, a Ph.D. student, and Jungho Hwang, also a Ph.D. student. Carolyn Lee, a Masters student, finished her degree in December.

9 Interactions

a) Meetings

M. Sassi, C. Lee, and J. W. Daily, "Doppler Shift Methods for Plasma Diagnostics," AIAA 22nd Thermophysics Conference, Honolulu, Hawaii, Paper 87-1528 (8-10 June 1987).

b) Other

We have had numerous visitors and interactions with other workers at meetings.

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