The EGEN model shows distinct trends, and it is now apparent that for the production of the highest possible shock speed, the driver arrangement must be tailored to give the proper timing for energy delivery to the driver gas without completely exhausting the gas from the chamber prior to the full deposition of the available energy.

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Unified Spontaneous Raman and CARS System

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Introduction

A HOPE of every experimentalist involved in fluid-dynamics or combustion research has been to find a universal probe capable of simultaneously providing with reasonable accuracy parameters of interest, in a nonintrusive, instantaneous, and remote manner. It appeared for a while that such a probe could be provided by the utilization of the spontaneous Raman scattering techniques. As is well known[1-3] these techniques can provide almost all of the important measurables in a flowfield or flame. Indeed, if a short-time duration high-power laser pulse technique is utilized some of the derived parameters of major importance in turbulent combustion modeling or chemically reacting flows can be obtained easily.

While the preceding is still true for clean flowfields and flames[4-6] in cases where carbon particles or soot is present the appearance of fluorescence, incandescence, and other interfering radiation may make the utilization of the spontaneous Raman scattering techniques very difficult. While certain data acquisition techniques, such as gating, and the utilization of some field polarization properties, etc., may help in improving the signal to noise ratio under difficult conditions, the low scattering cross section of the spontaneous Raman effect has made it necessary to reach into the nonlinear wave mixing phenomena to develop a technique based on the Raman effect that is capable of providing a diagnostic probe several orders of magnitude more efficient in terms of signal strength. This technique, the coherent anti-Stokes Raman scattering technique (CARS) while providing larger signals is not capable of replacing the spontaneous Raman scattering technique in terms of generality. In addition, it generally requires two lasers to provide a single specie or temperature measurement.

In order to provide a more universal diagnostic apparatus, a novel arrangement, based on a simultaneous LDV and spontaneous Raman diagnostic system utilized in Ref. 7, is described here. This arrangement, in its simplest configuration, utilizes a Q-switched ruby laser and a Raman cell filled with a gas of particular interest, whereby stimulation of the Stokes line of the particular gas is caused, and when collinearly mixed with the primary beam generates a CARS signal in a given flowfield. A part of the incident ruby laser is simultaneously utilized to obtain spontaneous Raman signals. Thus, one is able to avail himself of the advantages of both the spontaneous and CARS techniques utilizing only one ruby laser. The system can also be operated using a doubler on the ruby laser. A broadband dye laser, pumped with part of the doubled ruby laser to provide the desired Stokes line when combined with the remainder of the doubled 3471 Å laser line, results in a CARS system. The bulk of the undoubled ruby laser is used to drive a spontaneous Raman system. These systems are described and some preliminary data are shown.

Theoretical Background

The basic theoretical background of the formulation and operation of both the spontaneous Raman techniques and CARS have been discussed abundantly in the literature. It is therefore sufficient here just to cite some of the references,[1-7] and point out some of the major differences between the spontaneous Raman and the coherent anti-Stokes Raman scattering (CARS) systems.

1) Spontaneous Raman is single ended, CARS is not.
2) Spontaneous Raman can resolve any number of Raman active species in a mixture simultaneously, CARS can not.
3) Spontaneous Raman can provide the temperatures of any number of Raman active species in a mixture simultaneously and simply, CARS can not.
4) Spontaneous Raman can provide a measure of the fluctuation of a number of species in a flowfield and thus a measure of turbulent intensity, CARS can not.
5) Spontaneous Raman can provide a measure of the mixedness parameters, autocorrelation or correlation of parameters of importance in a flowfield, CARS can not.
6) Spontaneous Raman is linear, CARS is not.

These are some of the advantages of spontaneous Raman scattering over CARS.

However, one of the major drawbacks of spontaneous Raman is its extremely low differential scattering cross section. This feature is responsible for very low signal levels and therefore limits the application of spontaneous Raman scattering diagnostics to well-behaved, clean, low noise systems, particularly systems containing essentially no carbon particles or carbon soot. In those cases that are most important in a majority of combustion systems, CARS with its coherent signal, several orders of magnitude higher than the spontaneous Raman signal, is highly preferred in spite of its other limitations.

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Experimental Apparatus

To take advantage of the positive properties of both systems, a unified diagnostic system utilizing a single Q-switched ruby laser has been designed, built, and tested. A schematic diagram of the system is shown in Fig. 1. Here the Stokes line of the specie of interest is generated in a stimulated Raman cell, which together with the primary pumping wave (6943 Å) is collinearly focused on the flowfield under investigation. The primary power of the ruby laser is sufficient here to provide the necessary power for the CARS and, in addition, to provide sufficient intensity to provide the excitation for the spontaneous Raman signals, from the same point in the flowfield.

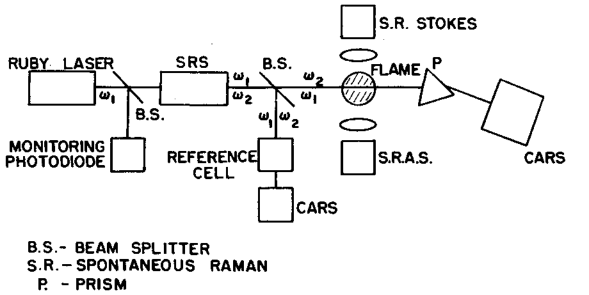

Fig. 1 Spontaneous Raman CARS configuration utilizing a stimulated Raman scattering cell (SRS).

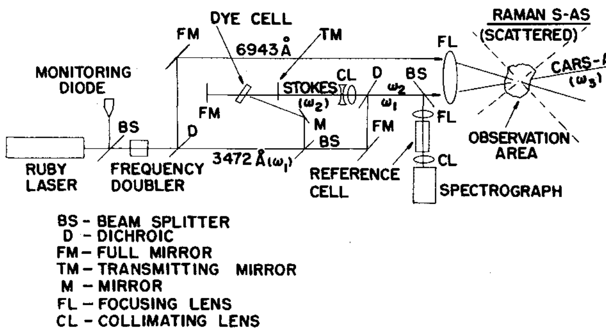

Fig. 2 Spontaneous Raman-CARS configuration utilizing doubler and dye cell.

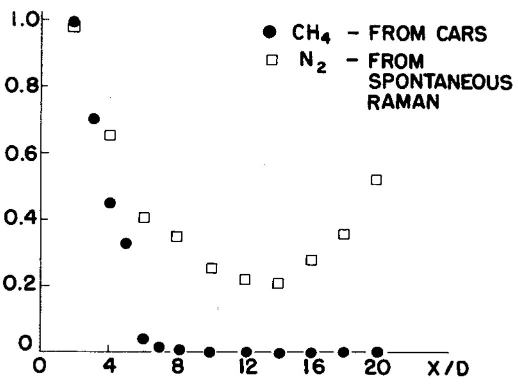

Fig. 3 Normalized axial methane and nitrogen concentration profiles.

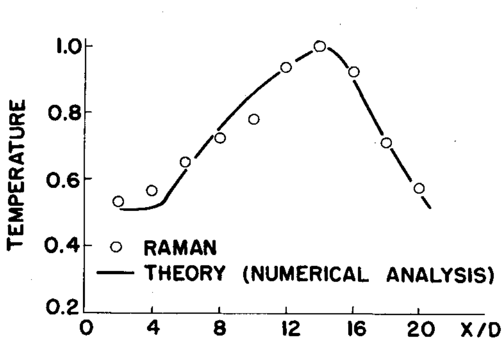

Fig. 4 Normalized spontaneous Raman axial temperature profile.

Figure 2 indicates a different version of the same apparatus. Here a doubler converts part of the ruby pulse at 6943 Å to a 3471 Å wave which is then separated by a dichroic mirror from the fundamental. Part of the 3471 Å laser energy is used to pump a broadband dye laser, which is then combined coaxially with the rest of the 3471 Å laser energy and focused at a point in the working fluid to obtain CARS. The total energy of the second harmonic (3471 Å) is approximately 500 mJ. Since the original ruby laser pulse energy was over 3 J, well over 2 J of laser light is available after separation by the dichroic mirror to be focused on the working fluid to be used to excite spontaneous Raman scattering.

Experimental Results and Conclusions

Preliminary experiments using these systems have been conducted on a methane diffusion flame. The purpose of these experiments was the demonstration of their feasibility, practicality, and advantages in terms of making this a more universal diagnostic system.

As is well known, the concentration of the unburned methane in an air methane flame is generally very low, and its measurement at a point of about 1 mm^3 is almost impossible using spontaneous Raman scattering. On the other hand, the measurement of all the products of combustion, and their temperatures, simultaneously is impossible using CARS. This combined apparatus permits a complete diagnosis of the flame simultaneously and instantaneously.

Figure 3 indicates a preliminary survey of the concentration of the unburned methane using CARS, and the concentration of nitrogen using spontaneous Raman. Figure 4 shows the temperature of the nitrogen in the flame using spontaneous Raman.

It is clear from the preceding that this system with the addition of the LDV capability which has been included previously into the diagnostic system using only spontaneous Raman[7] fulfills the requirements for a universal diagnostic system. It can provide data on most practical flowfields of interest, be they "clean," or "contaminated," be they environmentally "friendly" or "hostile." A system like this which is portable and adjustable with respect to the flowfield of interest should be very useful.

Acknowledgment

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