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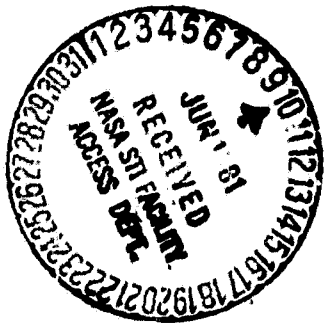

Annual Report

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ROTATIONAL CARS APPLICATION TO SIMULTANEOUS AND MULTIPLE-POINT TEMPERATURE AND CONCENTRATION DETERMINATION IN A TURBULENT FLOW

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by

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During the first year of this research, both experimental and calculational results were achieved sooner than anticipated in the proposal. A broad bandwidth CARS system was used to obtain the entire N_2 gas rotational spectrum with a single pulse of 10 - 15 nsec duration. A computer program performed a least squares comparison of the measured rotational CARS spectrum with calculated spectra. The CARS-deduced N_2 temperature was compared with thermocouple temperatures over a temperature range of 135 to 296 K. Emphasis was placed on the quantitative evaluation of the single-pulse rotational CARS technique for temperature measurement of N_2 gas for temperatures at room temperature and below.

Significant results achieved in this first year of research are reviewed below.

1. Broadband CARS System

The broadband Stokes radiation was provided by a broadband dye laser source (designed and constructed at Yale) of approximately 40 Å bandwidth at the half-power points. The THG of a Nd:YAG laser was used to pump the broadband dye laser while the SHG of the same Nd:YAG laser provided the CARS pump radiation. Both the Stokes and pump radiation were brought into a windowless N_2 gas cell (coolable to 135 K) in a noncoplanar phase-matching configuration. The resultant spatial resolution within the gas cell was about $0.2 \times 0.2 \times 3$ mm . The broadband anti-Stokes signal emerged up out of the horizontal plane defined by the two pump beams nearly at angle θ, where θ is the angle at which the Stokes beam is

directed into the horizontal plane from below. Consequently, the CARS signal could be spatially isolated from the two pump and Stokes beams. Using a single-grating spectrograph to disperse the broadband CARS signal, we found that spatial isolation of the CARS beam from the pump and Stokes beams was essential for suppression of the elastic scattering caused by the latter three beams.

A low-light-level SIT television camera was used in the conventional optical multichannel analyzer (OMA) mode with one exception. The entire CARS signal from the variable temperature N_2 gas cell was imaged onto the top half of the OMA, while the entire CARS signal from a reference N_2 gas cell was imaged onto the bottom half of the OMA. The reference cell was filled with N_2 at STP and provided a convenient wavelength converter and intensity normalizer for the two pump and Stokes beams. The CARS spectrum from the N_2 reference cell had peaks at the same wavelength as the N_2 gas in the variable temperature cell. The two spectra could therefore be compared on the basis of the strength of corresponding CARS peaks, rather than on the basis of the signal intensities in corresponding channels of the OMA. Spatial distortions in the OMA and in the spectrograph optics made the latter comparison inaccurate. Furthermore, because the two cells were placed right after each other, both CARS signals were produced by the same two pump and Stokes beams. It was not necessary to separately monitor the intensity of the broadband dye laser at each wavelength and of the two pump beams, since an automatic calibration of spectral intensity and mode fluctuations of the laser beams was contained in the CARS signal from the N_2 reference cell. Thus, division of the CARS

intensity wavelength data of the unknown temperature N_2 gas by the CARS intensity wavelength data of the STP N_2 gas produced a normalized CARS spectrum from which a least squares fit with computed CARS spectra at various temperatures could be made.

2. Computer Program

A computer program including J-dependent and temperature-dependent rotational linewidths, nonresonant background susceptibility, and finite linewidth of the pump laser (about 1.0 cm^{-1}) was written to calculate the theoretical spectra at 1 K increments from 300 K down to 130 K. To accommodate N_2 pressure changes, a pressure-dependent rotational linewidth approximation was also included. Comparisons between experimental and calculated CARS spectra at 1 atm (but variable temperature) were made in the range of 135 to 296 K. Furthermore, comparisons between experimental and calculated CARS spectra at room temperature (but variable pressure) were made in the range of 0.13 to 15.3 atm.

Our results after one year are encouraging for rather accurate instantaneous temperature determination. The accuracy of pressure determination needs further investigation, which is currently underway. Extension of temperature determination to flame temperatures is also in progress. The main objective for the second year is for multipoint spatially resolved CARS spectra providing simultaneous temperature and pressure values along a line defined by the noncoplanar phase-matching geometry.

Personnel

In addition to the principal investigator, Daniel V. Murphy worked on this project since its inception in connection with his graduate studies. A copy of his Ph.D. thesis (completed last December) was submitted to NASA, and a copy of the abstract for this work can be found on the next page.

A visiting scientist, Jia-Biao Zheng, has been working on this project since January.

Publication

D. V. Murphy and R. K. Chang, "Single Pulse Broadband Rotational CARS Thermometry in Cold N_2 Gas," Appl. Opt. 6, 233 (1981).

Preprint of this paper was sent to NASA and reprints will be forwarded upon receipt. A copy of the abstract can be found on page 6.

Presentation

A talk on this project was presented by the principal investigator at the Gordon Research Conference on Vibrational Spectroscopy in Wolfeboro, New Hampshire, in August 1980.

ABSTRACT

BROAD-BAND ROTATIONAL CARS THERMOMETRY IN NITROGEN GAS

Daniel Vincent Murphy

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1981

Coherent anti-Stokes Raman scattering (CARS) from the pure rotational Raman lines of N_2 is employed to measure the instantaneous ($\sim$ 10 nsec) rotational temperature of N_2 gas at room temperature and below with good spatial resolution (.2 x .2 x 3.0 mm^3). A broad-bandwidth dye laser is used to obtain the entire rotational spectrum from a single laser pulse; the CARS signal is then dispersed by a spectrograph and recorded on an optical multichannel analyzer. A best-fit temperature is found in several seconds with the aid of a computer for each experimental spectrum by a least squares comparison with calculated spectra. The model used to calculate the theoretical spectra incorporates the temperature and pressure dependence of the pressure-broadened rotational Raman lines, includes the nonresonant background susceptibility, and assumes that the pump laser has a finite linewidth. Temperatures are fit to experimental spectra recorded over the temperature range of 135 to 296 K, and over the pressure range of .13 to 15.3 atm. Emphasis is placed on the quantitative evaluation of single-pulse rotational CARS as a temperature measurement technique.

Single-Pulse Broad-Band Rotational CARS Thermometry of Cold N_2 Gas

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Abstract

Coherent anti-Stokes Raman scattering (CARS) from the pure rotational Raman lines of N_2 gas is employed to measure the instantaneous (10 nsec) rotational temperature of the gas at room temperature and below. An entire rotational CARS spectrum is generated by a single laser pulse using a broad-bandwidth dye laser and is recorded on an optical multichannel analyzer. A best-fit temperature is obtained for individual experimental spectra by comparison with calculated spectra. Good agreement between CARS temperatures and thermocouple temperatures is observed.