Development of Combined Dual-Pump Vibrational and Pure-Rotational Coherent anti-Stokes Raman Scattering Technique

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Motivation and Background

• CARS in reacting flows primarily used for temperature and species concentration measurements

• High Accuracy and Precision in Complex Environments
• Multiple Species
Introduction to CARS

- CARS is a third order, four-wave mixing, parametric process

\[ \omega_{\text{CARS}} = \omega_p - \omega_{\text{St}} + \omega_{\text{pr}} \]

- Time resolved and Spatially resolved
- Species specific and Transition specific
- Relatively insensitive to collisions

Comparison between CARS and known Temperature in a Calibration Burner

![Graph showing comparison between CARS and known temperature. The x-axis represents the equivalence ratio, and the y-axis represents flame temperature (K). The graph includes data points for adiabatic temperature, VCARS, and temperature difference.](image)
Two-beam PRCARS

Pump $\omega_1 +$ Stokes $\omega_2$

Probe $\omega_3$

Signal $\omega_4$

$\omega_4 = \omega_1 - \omega_2 + \omega_3$

$k_1, \omega_1$

$k_2, \omega_2$

$k_3, \omega_3$

$k_4, \omega_4$

$k_1 + k_3 = k_2 + k_4$
Combined VCARS and PRCARS System

BLUE: 473 nm (N₂ VCARS SIGNAL)
GREEN: 532.2 nm + 528 nm (PRCARS SIGNAL)
Energy Level Diagrams

Combined DPVCARS and PRCARS System

CL: Camera Lens
ND: Neutral Density Filter
SWP: Short-Wave-Pass Filter
P: Polarizer ; L: Lens (+ 180 mm)
BD: Beam Dump
CCD: Charge-Coupled Device Camera
DM: Dichroic Mirror
DG: Diffraction Grating
BPF: Bandpass Filter
200 Shot Averaged PRCARS Spectra

Temp. = 295 K
$O_2/N_2 = 0.266$

Temp. = 613 K

Temp. = 911 K

Temp. = 1189 K

200 Shot Averaged DPVCARS Spectra

Temp. = 295 K
O$_2$/N$_2$ = 0.265

Temp. = 681 K
O$_2$/N$_2$ = 0.23
CO$_2$/N$_2$ = 0.11

Temp. = 2081.5 K
H$_2$/N$_2$ = 0.07

Temp. = 2441.7 K

Single-shot Precision of the Combined CARS System

Temp. = 2107.56 K  
$H_2/N_2 = 0.089$

Std. Deviation of 3% . Average  
Temperature = 2087 K
Measurements and 1-D Simulations in Laminar Premixed Flames

- Comparison of various chemical mechanisms against CARS measurements.
- Assess influence of fuel composition and strain rate on flame structure.
- Assess Influence of transport properties such as thermal diffusion on flame structure.
- Assess Influence of radiation model on flame structure.

1-D Numerical Solution of Premixed Flame Structure

Major and important minor species at Eq. Ratio = 1.4 using San Diego chemical mechanism.
CH₄/Air Premixed Flame with varying Equivalence Ratios

Comparison of Flame temperature for Eq. ratio = 1.31

Comparison of H₂ and O₂ mole-fraction for Eq. ratio = 1.31
Other DPVCARS Possibilities

DPVCARS: $\text{N}_2, \text{H}_2,$

DPVCARS: $\text{H}_2, \text{O}_2, \text{CO}_2$
Acknowledgements

Yifan Weng for assisting with COSILAB simulations

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