Ultrafast CARS for thermometry and enhanced species detection in combustion and high-speed propulsion systems

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Designing optimal next-generation aerospace propulsion devices and minimizing the environmental impact of combustion-based transportation systems requires detailed knowledge of thermodynamic properties. In particular, temperature and gas composition are key to understanding phenomena including fuel/air mixing, reaction progress, energy release, and emission of pollutant precursors. However, realistic combustors present a number of challenges for in-situ measurements, including significant spatial variations over small scales, fast temporal dynamics, practical challenges including thick windows and limited optical access, and extreme temperatures and pressures. Although conditions are challenging, experimental measurements are critical to develop new physical insights and validate chemical kinetic and fluid dynamic models to aid in the design of new propulsion devices. To address these needs, this work discusses the development and implementation of hybrid femtosecond/picosecond coherent anti-Stokes Raman scattering (fs/ps CARS) for thermometry in dynamic combustion systems and enhanced hydrocarbon species detection for studying pre-aftertreatment engine exhaust gases.

During this presentation, fs/ps CARS results quantifying temperature and fuel distribution for a cavity-stabilized flame in a dual-mode ramjet/scramjet flowpath will be discussed. Additionally, work extending the measurement volume to study instantaneous 1D gradients in temperature and species using a three-beam planar BOXCARS phase-matching configuration targeting rovibrational transitions will be presented. Results from a quasi-one-dimensional laminar flame will be summarized, and extension of this measurement technique to shock-laden combustion systems including propagating detonations will be discussed. Finally, fs/ps CARS utilizing quantum coherent control will be presented for the improved selectivity of hydrocarbons for studying diesel engine-out emissions and the combustion of sustainable aviation fuels. For this work, a 4-*f* pulse shaper is used to produce a shaped excitation pulse through phase modulation at the Fourier plane, and a feedback-controlled algorithm is used to identify phase masks suitable for selective excitation and annihilation of specific rovibrational transitions. An example showing transition-specific excitation is included in Fig. 1 for CO_2 gas at room temperature using a static phase mask and various time delays between the two fs Raman excitation pulses.

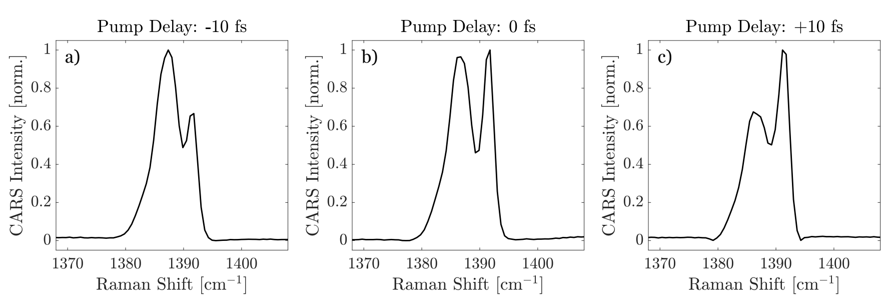

Figure 1. Experimental CARS spectra of the CO_2 rovibrational band near 1388 cm^{-1} with a constant "slit mask" applied (phase shift = π, slid width = 100 pixels, center slit location = 1200 pixels) and pump delays of a) -10 fs, b) 0 fs, and c) +10 fs.