 14662C

The University of Texas at Austin

Temperature measurements in the plume of an inductively coupled plasma torch using CARS

Dan Fries, John S. Murray, Rajkumar Bhakta, Sean Kearney, Noel Clemens, Philip Varghese

74th Annual Meeting APS DFD · Nov. 21-23, 2021 · Phoenix, AZ

ODEN INSTITUTE

PECOS Predictive Engineering & Computational Science

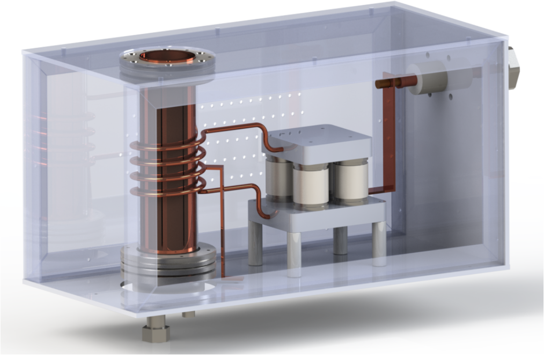
Sandia National Laboratories

PSAAP III

ICP Torch

Inductively coupled plasma torch produces bright air plasma plume, expect 5000-7000 K on centerline.

- Emission spectroscopy is line-of-sight averaged.
- Need enough signal and background rejection to perform spatially resolved measurements.
- Laser Induced Fluorescence → minor species
- Coherent Anti-Stokes Raman Scattering → major species[a].



[a]Gülhan et al. (2018), "Characterization of High-Enthalpy-Flow Environment for Ablation Material Tests Using Advanced Diagnostics".

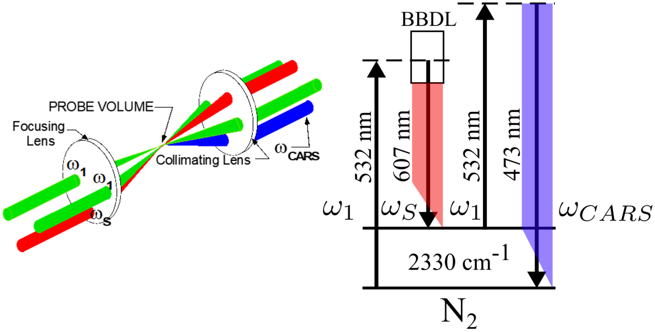
ICP Torch

Inductively coupled plasma torch produces bright air plasma plume, expect 5000-7000 K on centerline.

- Emission spectroscopy is line-of-sight averaged.
- Need enough signal and background rejection to perform spatially resolved measurements.
- Laser Induced Fluorescence → minor species
- Coherent Anti-Stokes Raman Scattering → major species[a].

[a] Gülhan et al. (2018), "Characterization of High-Enthalpy-Flow Environment for Ablation Material Tests Using Advanced Diagnostics".

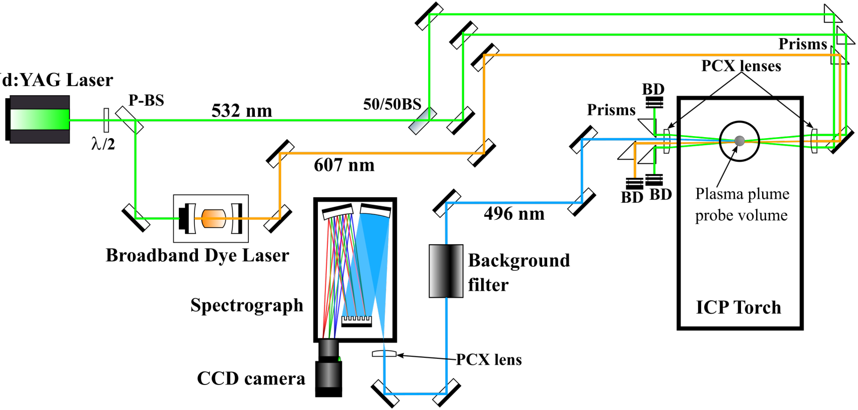
CARS-Setup



- Four-wave mixing process.
- BOXCARS beam configuration.
- $\lambda_{pump} = \lambda_{probe} \approx 532$ nm, degenerate pump waves.
- $\lambda_{Stokes} = 607$ nm with $\Delta\bar{\nu} = 140$ cm$^{-}1$ at FWHM.
- Measurement volume: 4.7 mm (5-95% glass slide)
- Measuring rotational-vibrational equilibrium temperature.

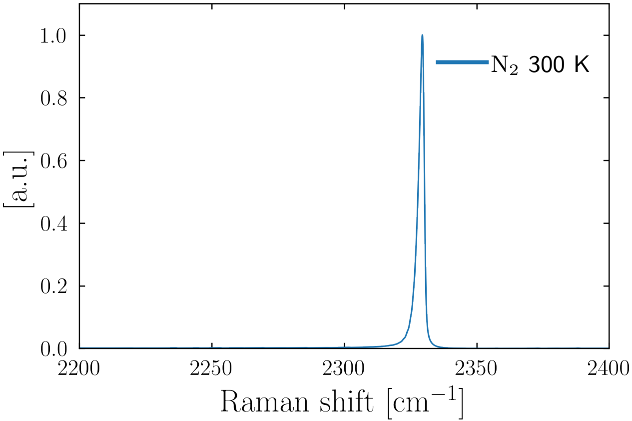
CARS-Setup

Nanosecond CARS setup with a broadband dye laser: simultaneous excitation of multiple ro-vibrational transitions.



CARS

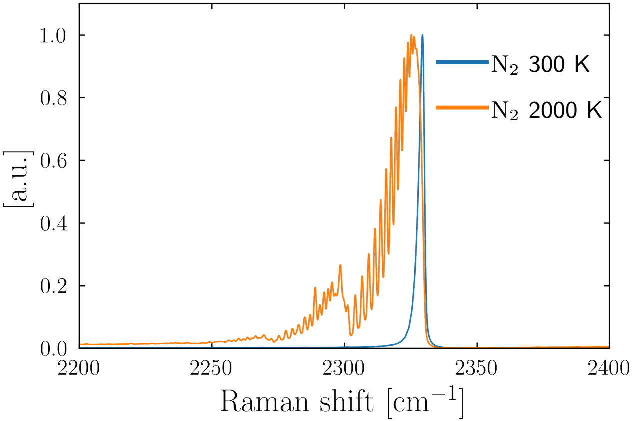
Spectral trends with Temperature



- Initially only $v = 0$ contributes.
- All particles in ground state.

CARS

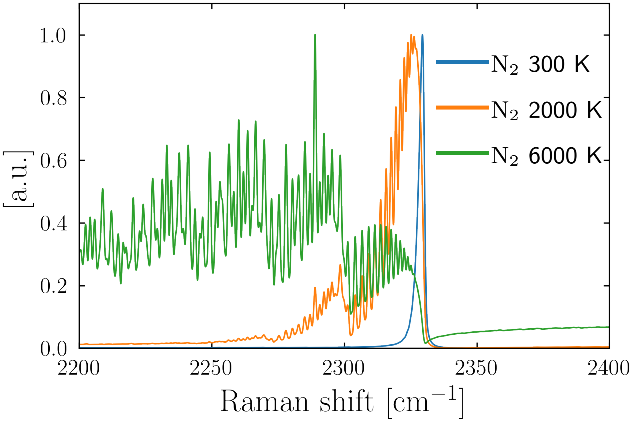
Spectral trends with Temperature



- Initially only $v = 0$ contributes.
- All particles in ground state.
- At combustion temperatures around 2000 K contributions from $v = 0 - 2$ discernible, $\Delta v = \pm 1$.

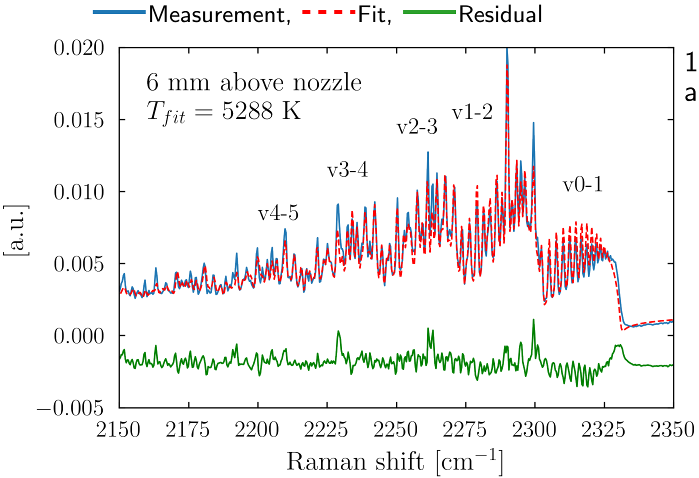
CARS

Spectral trends with Temperature



- Initially only $\mathrm{v} = 0$ contributes.
- All particles in ground state.
- At combustion temperatures around 2000 K contributions from $\mathrm{v} = 0 - 2$ discernible, $\Delta \mathrm{v} = \pm 1$.
- At plasma temperatures, significant contribution out to $\mathrm{v} \sim 5$, $J \sim 100$.
- T increases $\Rightarrow N_a - N_b$ decreases $\Rightarrow$ signal decreases.

Results in Torch Plume

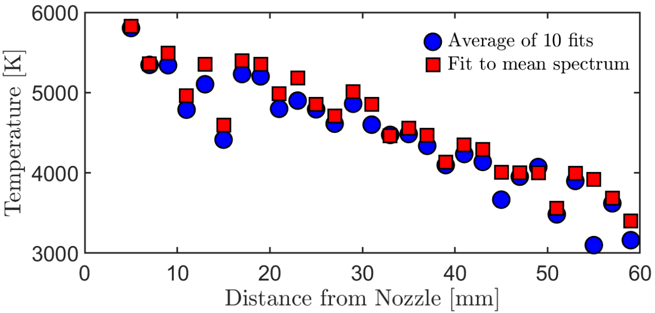


Fit to average of 500 single-shot measurements.

10 kV DC anode voltage, 30 slpm air, centerline.

- PI-MAX 4 camera.
- Isolated line model.
- Temperatures from spont. Raman scattering and emission spectroscopy: 5700-6100 K.
- Difficulties: modulation dip at bandhead, completeness of fitting model, extrapolation of semi-empirical line shape, spatial averaging, time averaging, change in torch configuration.

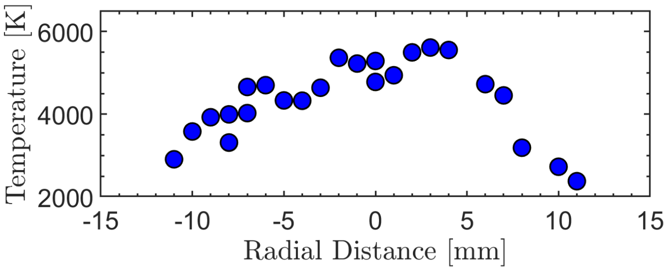
Results in Torch Plume



10 kV DC anode voltage, 30 slpm air, centerline.

- PI-MAX 4 camera.
- Isolated line model.
- Temperatures from spont. Raman scattering and emission spectroscopy: 5700-6100 K.
- Difficulties: modulation dip at bandhead, completeness of fitting model, extrapolation of semi-empirical line shape, spatial averaging, time averaging, change in torch configuration.

Results in Torch Plume



Fit to average of 100 measurements.

10 kV DC anode voltage, 30 slpm air, centerline.

- PI-MAX 4 camera.
- Isolated line model.
- Temperatures from spont. Raman scattering and emission spectroscopy: 5700-6100 K.
- Difficulties: modulation dip at bandhead, completeness of fitting model, extrapolation of semi-empirical line shape, spatial averaging, time averaging, change in torch configuration.

Conclusion

Results

- Successful average and single shot CARS N_2 measurements in ~ 6000 K environment.
- Time gating effective in rejecting plasma emissions.
- $T_{\text{CARS}} < T_{\text{OES}}/T_{\text{Raman}}$?

Future Plans

- Time filter torch background differently.
- Uncertainty quantification.
- Analysis of single shot CARS.
- Measure close to a reacting surface.

Acknowledgments

This material is based upon work supported by the Department of Energy, National Nuclear Security Administration under Award Number DE-NA0003969.

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

References I

Gülhan, A. et al. “Characterization of High-Enthalpy-Flow Environment for Ablation Material Tests Using Advanced Diagnostics”. *AIAA J.* 56.3 (2018), pp. 1072–1084.