Spontaneous Raman Scattering Spectroscopy of a Resistojet Plume in a Vacuum Environment

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About NRL and Our Section

US Naval Research Laboratory

- opened in 1923
- plasma physics
- space physics
- material science

Combustion and Reacting Transport (6185)

- fundamental and applied fire science and suppression
- multiphase transport
- solid fuel combustion
- crude oil remediation

Spontaneous Raman Scattering Spectroscopy of a Resistojet Plume in a Low Vacuum Environment

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Motivation

• CubeSats
  • Miniaturized satellite for space research
  • Low-cost, light weight

• Micro Resistojet
  • Expansion of gas through a nozzle by electric heating
  • Extend lifespan of CubeSats

• Low Reynolds Regime
  • Viscous and heat transfer losses
  • Modeling: Monte Carlo Method

• Optimize Nozzle Geometry
  • Flow rates
  • Nozzle area ratio
  • Gas compositions
  • Temperature and number density

10 – 100 mTorr
100 – 500 K
0.1 – 10 mN

→ IEPC-2017-306: Holman et al.

→ IEPC-2017-120: Williams et al.
Spontaneous Raman Scattering Spectroscopy

\[ N_{i \rightarrow f} = N_L \ln n_0 \left( \frac{n_i}{n_0} \frac{d\sigma}{d\Omega} \right)_{i \rightarrow f} d\Omega \]

- # incident photons
- molecular number density
- differential Raman cross section
- solid angle
- length of beam segment
- population fraction in the initial state
- gas pressure

\[ n_0 \propto P \]

Theoretical spectra: CARSFT from Sandia

T = 300 K

N\textsubscript{2} rot. lines

H\textsubscript{2} rot. lines

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Multiple-pass Cell

46 total number of passes, 4 to 6 passes in probe volume
probe volume: 100 µm diameter, 172 µm length
Optical Setup

Laser: Coherent Verdi
Continuous wave, 5-W

Camera: Andor Newton EMCCD

Spectrograph: Kaiser Holographic
SuperNotch Filter
Single-pass vs Multiple-pass: **4.8 gain**
ambient air
4 – 6 passes in probe volume

Lower Pressure Limit in Single-Pass Mode:
26 Torr / 4.8 gain = **5.4 Torr**
Single mode, polarization maintaining fiber from NKT Photonics. FC/UPC connectorized by Coastal Connections.
Future Work

- Multiple-pass Approach
  - Up to 100 total number of passes
- Knobs to turn
  - Increase EMCCD camera gain
  - Reduce EMCCD camera temperature
  - Increase exposure time
- Better fiber alignment -> more laser energy transmission
- H₂ thermometry
- Establish Low Pressure Limit
Thank you for your attention.
Questions?

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Appendix A: Collecting Optics

optic fiber

100 μm pinhole

50mm doublet

30mm doublet

2-in, 100 mm achromatic doublets

probe volume
Appendix B: Fiber Launch System

The diagram shows a fiber launch system with the following components:

- Mirror
- High power 20x focusing objective
- Optical fiber
- 532 nm laser
- Coherent Verdi CW Laser
- High power beam expander (2x)
Appendix C: Theoretical Spectra

$H_2$ for temperature and number density measurements
$N_2$ for number density measurements

Theoretical Profiles from Sandia National Laboratory
CARSFT code.

- $T = 100$ K
- $T = 300$ K
- $T = 500$ K

$H_2$ rot. lines
$N_2$ rot. lines

Temperature
Appendix D: Raman vs Rayleigh

Scattering Processing

Rayleigh Scattering: elastic scattering
Raman Scattering: elastic scattering

Image from Tipping et al., Chem. Soc. Rev. 2016, 45, 2075-2089