Chapter Title:

Instrumentation for Bench- and Large-scale Test Fixtures

Kevin L. McNesby

U. S. Army Research Laboratory

Aberdeen Proving Ground, MD.

Erik Johnsson

NIST

Gaithersburg, MD

NEXT GENERATION FIRE SUPPRESSION TECHNOLOGY PROGRAM

Project working title:

3.C - Laser-Based Instrumentation for Real-Time, In-Situ Measurements of Combustible Gases, Combustion By-Products, & Suppression Concentrations

Kevin McNesby, Erik Johnsson, George Mulholland,
Reed Skaggs, Andrzej Miziolek, Edwin Lancaster, Robert Daniel,
Bill Bolt, Craig Herud, Brian Kennedy

Army Research Laboratory (APG, MD)

NEXT GENERATION FIRE SUPPRESSION TECHNOLOGY PROGRAM

Working Description:

OPTICAL SPECTROSCOPIC TECHNIQUES FOR ARMY APPLICATIONS

Kevin McNesby, Reed Skaggs, Andrzej Miziolek,
Erik Johnsson, George Mulholland, Edwin Lancaster, Robert Daniel,
Bill Bolt, Craig Herud, Brian Kennedy, Bill Jackson, Ian McLaren, Don Horton,
Steve Modiano

Army Research Laboratory (APG, MD)

NEXT GENERATION FIRE SUPPRESSION TECHNOLOGY PROGRAM

- joint, effort at ARL (Army Research Laboratory), ATC (Aberdeen Test Center), NIST Using Optical Spectroscopy

•(FY97-02)

- work focussed on needs pertaining to armored vehicles

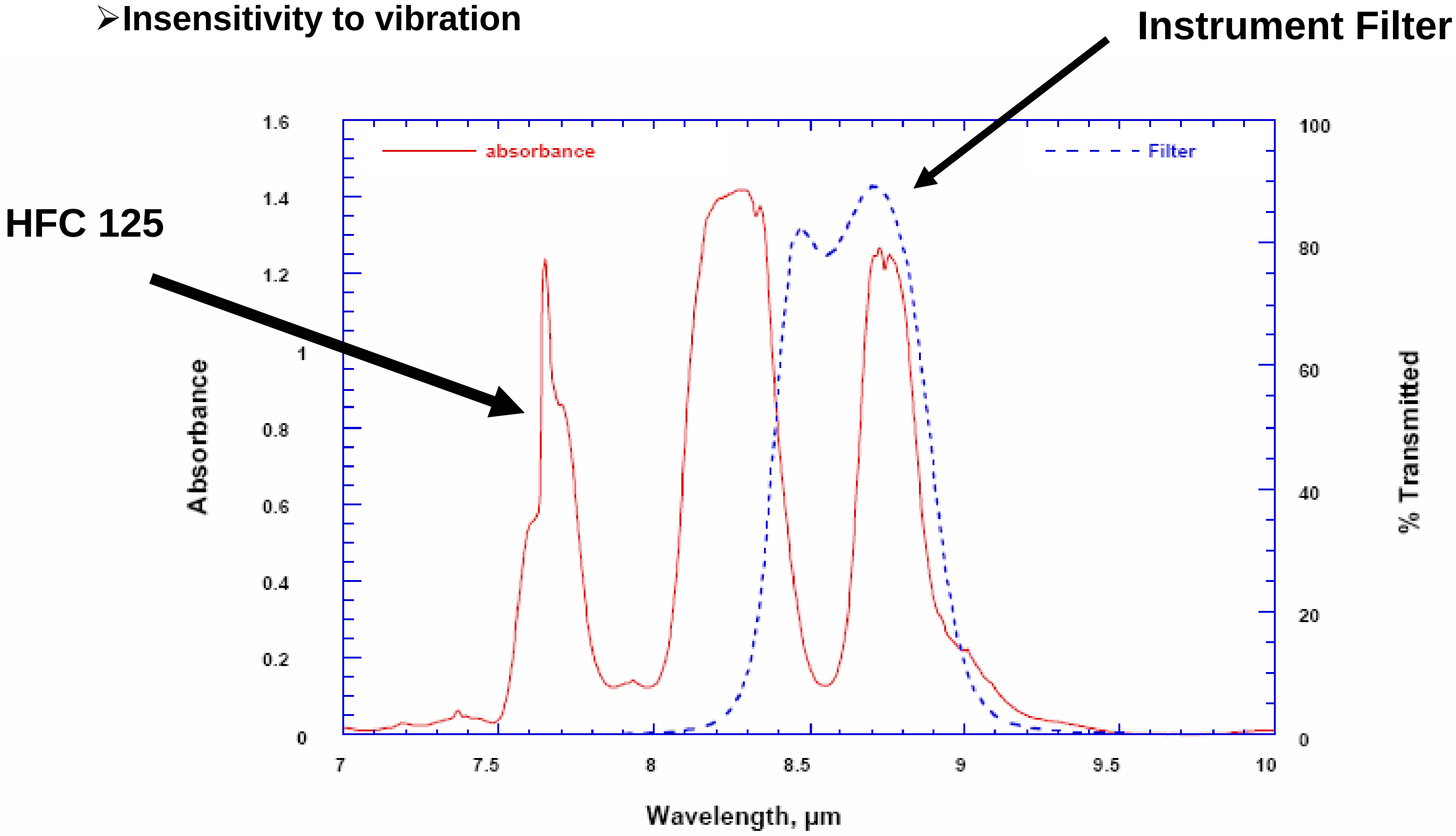
- field-scale to laboratory scale environment

Talk Outline

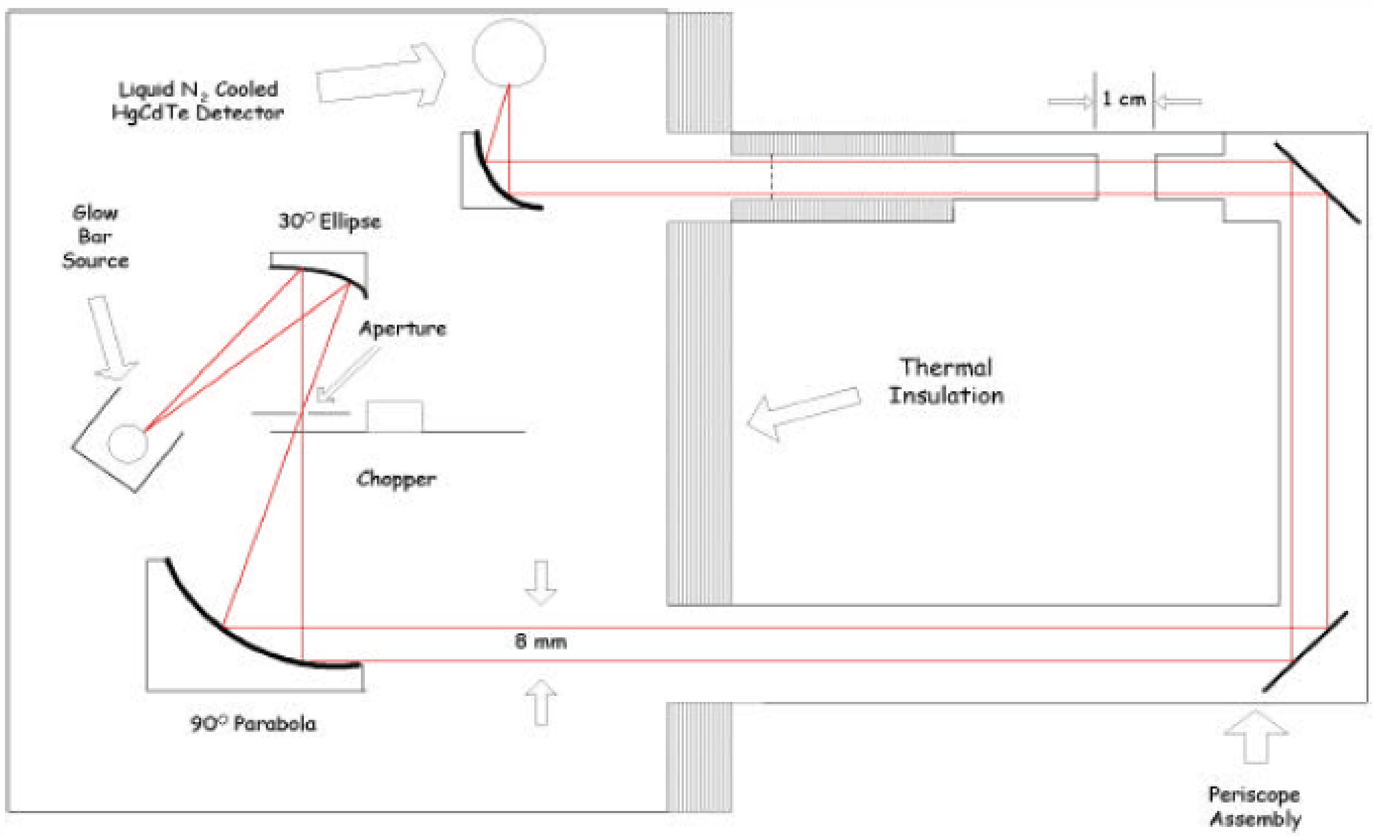
- Introduction – Tanks
- Species **(Suppressants; Toxic By-products; Fuels; Oxidizers)**
- Fast Vibrational/Visible Spectroscopy
- Differential Infrared Rapid Agent Concentration Sensor (DIRRACS)
- Laser Induced Breakdown Spectroscopy for Fire and Explosive Suppressant Measurement
- Diode Laser Spectroscopy for Toxic and Combustible Gas Measurement

Differential Infrared Rapid Agent Concentration Sensor (DIRRACS)

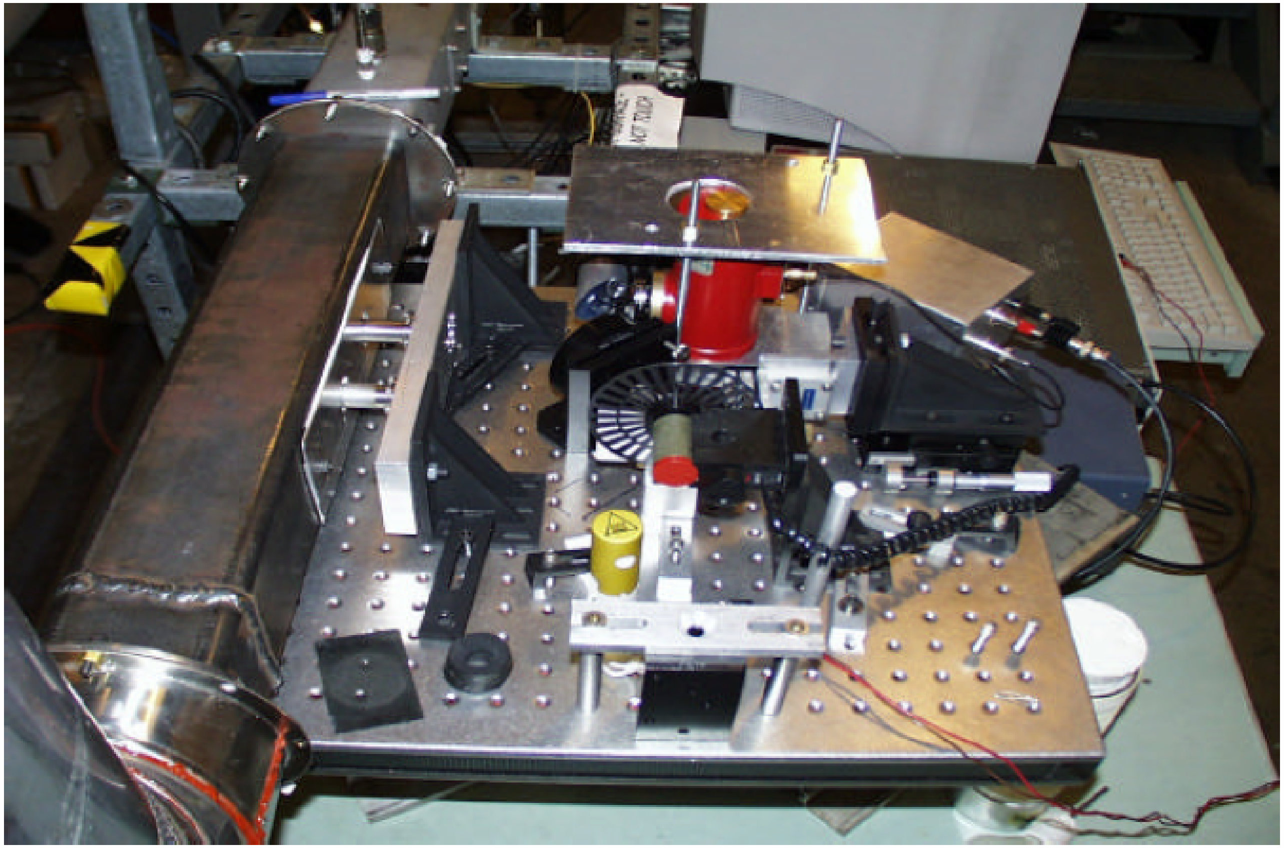
- **Measurement of suppressant concentration**
- **Previous instrument response time ~ 200 ms (viscosity sensor)**
- **1 ms response time**
- **Infrared absorption**
- **Insensitivity to vibration**



DIRRACS II Schematic

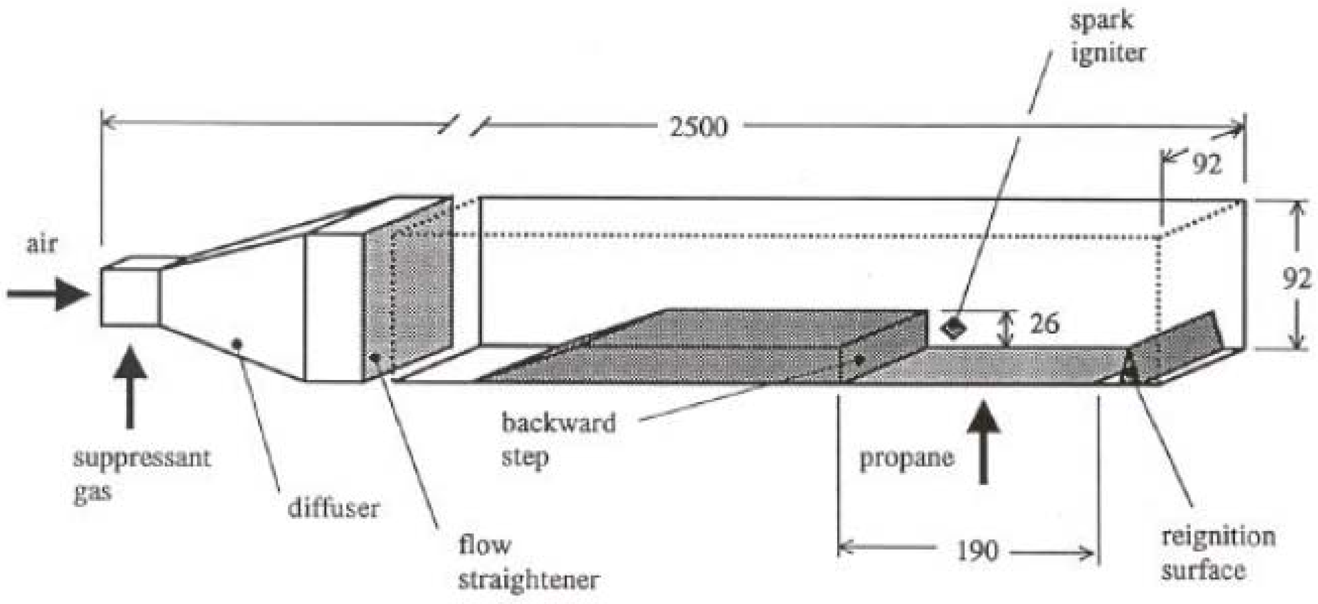


DIRRACS II Instrument



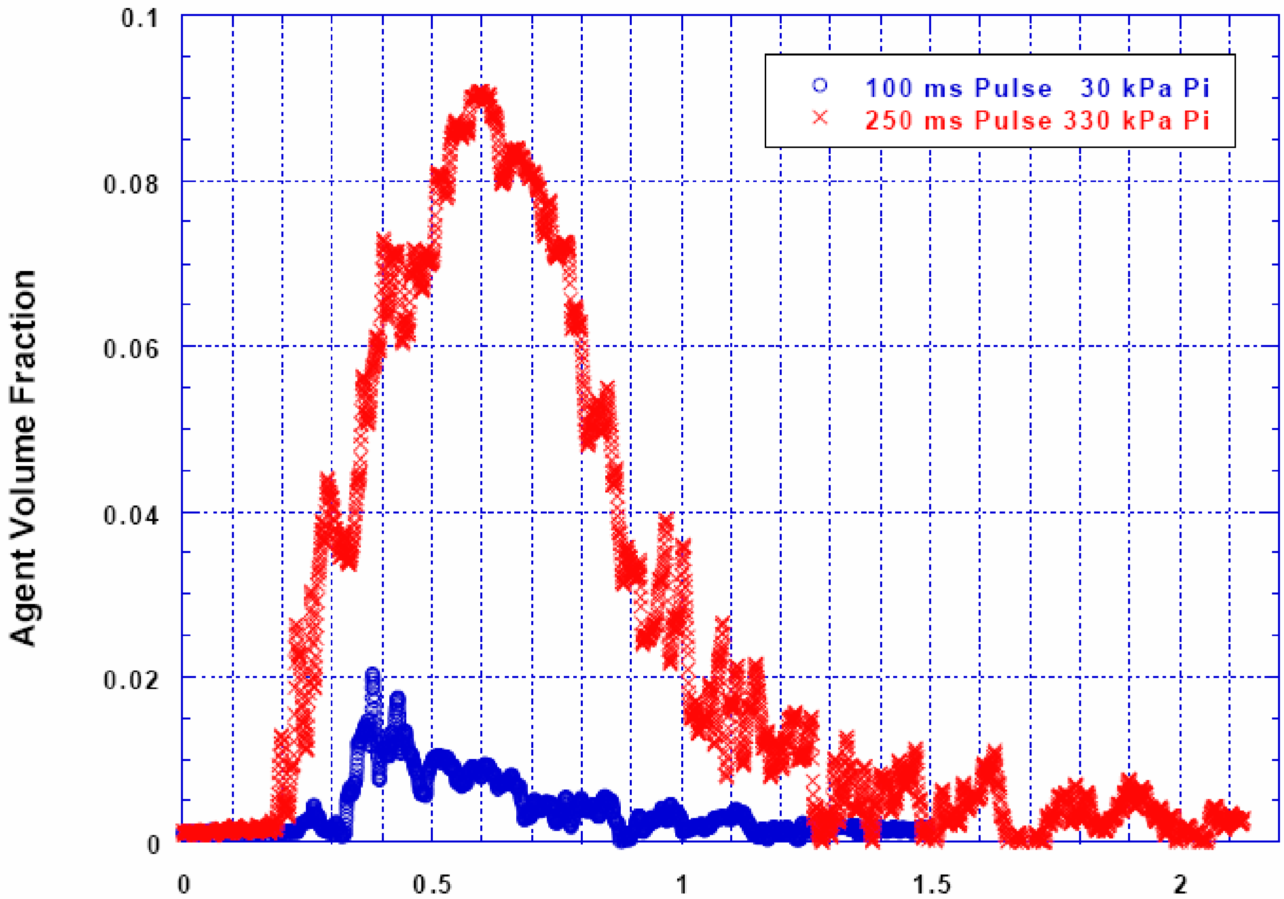
DIRRACS II Test Rig

Transient Application
Recirculating Pool Fire
(TARPF) Facility at NIST.



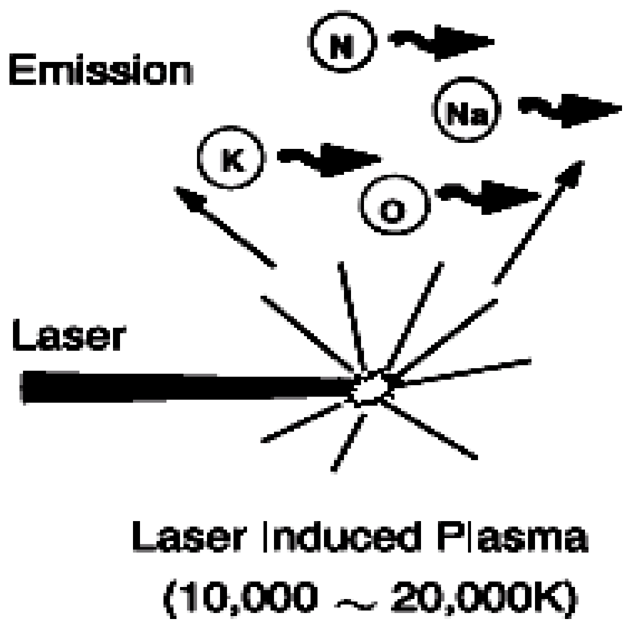
DIRRACS Testing

Time Response < 10 ms
Sensitivity < .005 volume fraction



HFC 125 agent volume fraction versus time for two releases of HFC-125 in the TARPF facility.

Suppressant Gas Measurement: Laser Induced Breakdown Spectroscopy (LIBS)

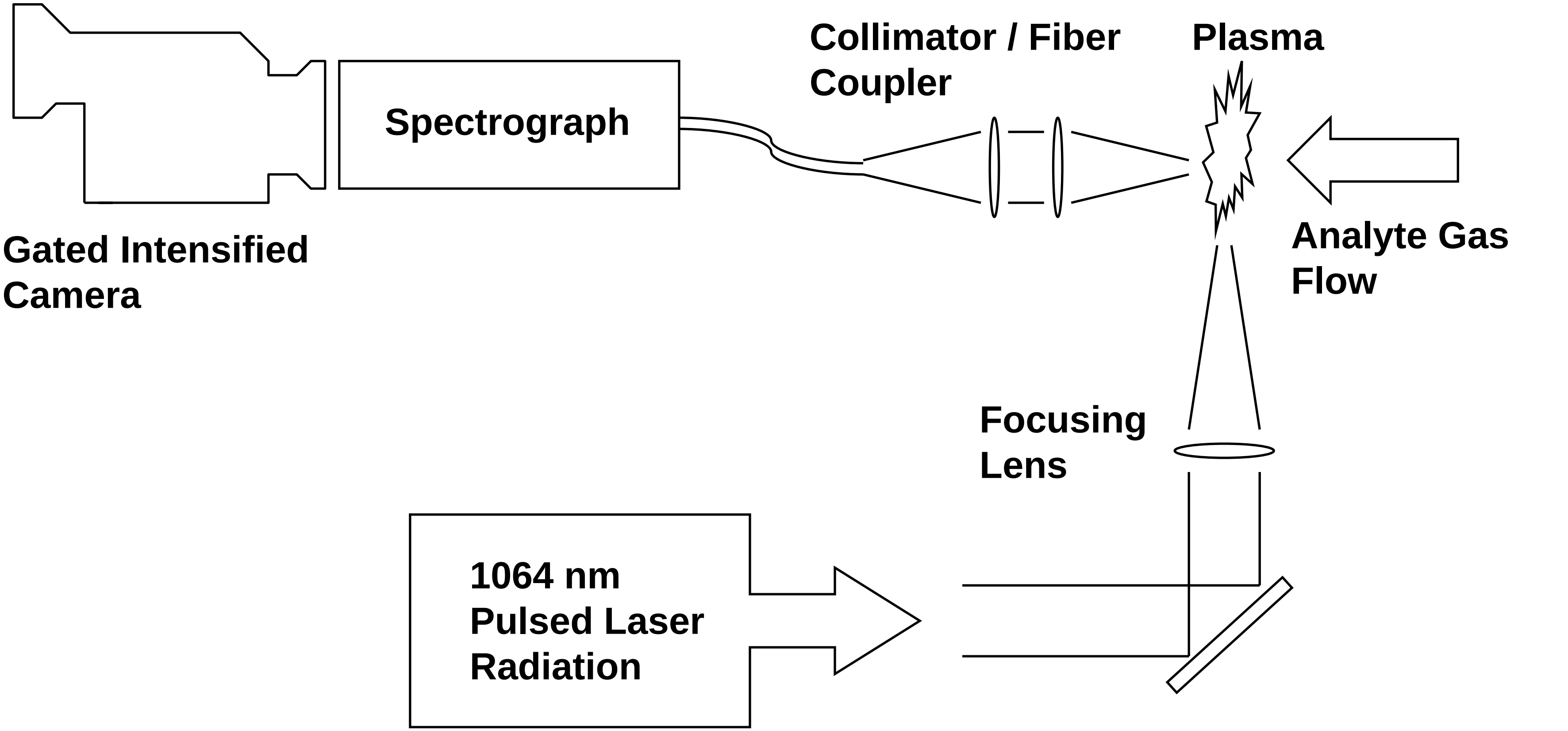


Plasma Formation

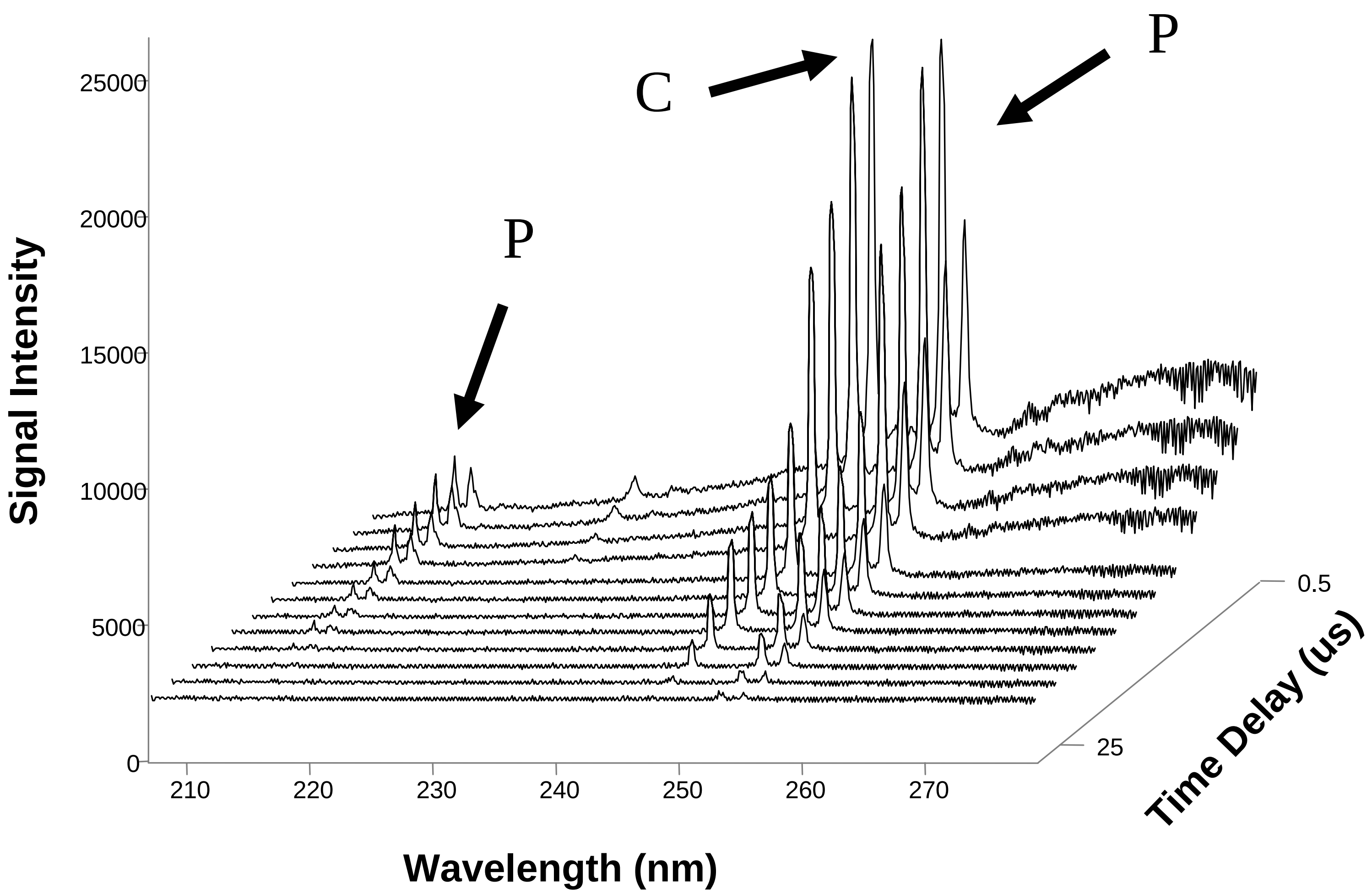
- Multiphoton Absorption --> Ionization
- Absorption of Laser Radiation by Free Electrons, i.e. Inverse Brehmstrahlung
- Electron Collisions --> Ionization --> Heating --> Breakdown
- Typical Gas Temperatures, ca. 20,000 K

Spectrochemical Analysis based on Collection of Emission of Atomic and Molecular Constituents Usually after Plasma Continuum Radiation Decays (2-100 usec).

LIBS Instrumentation

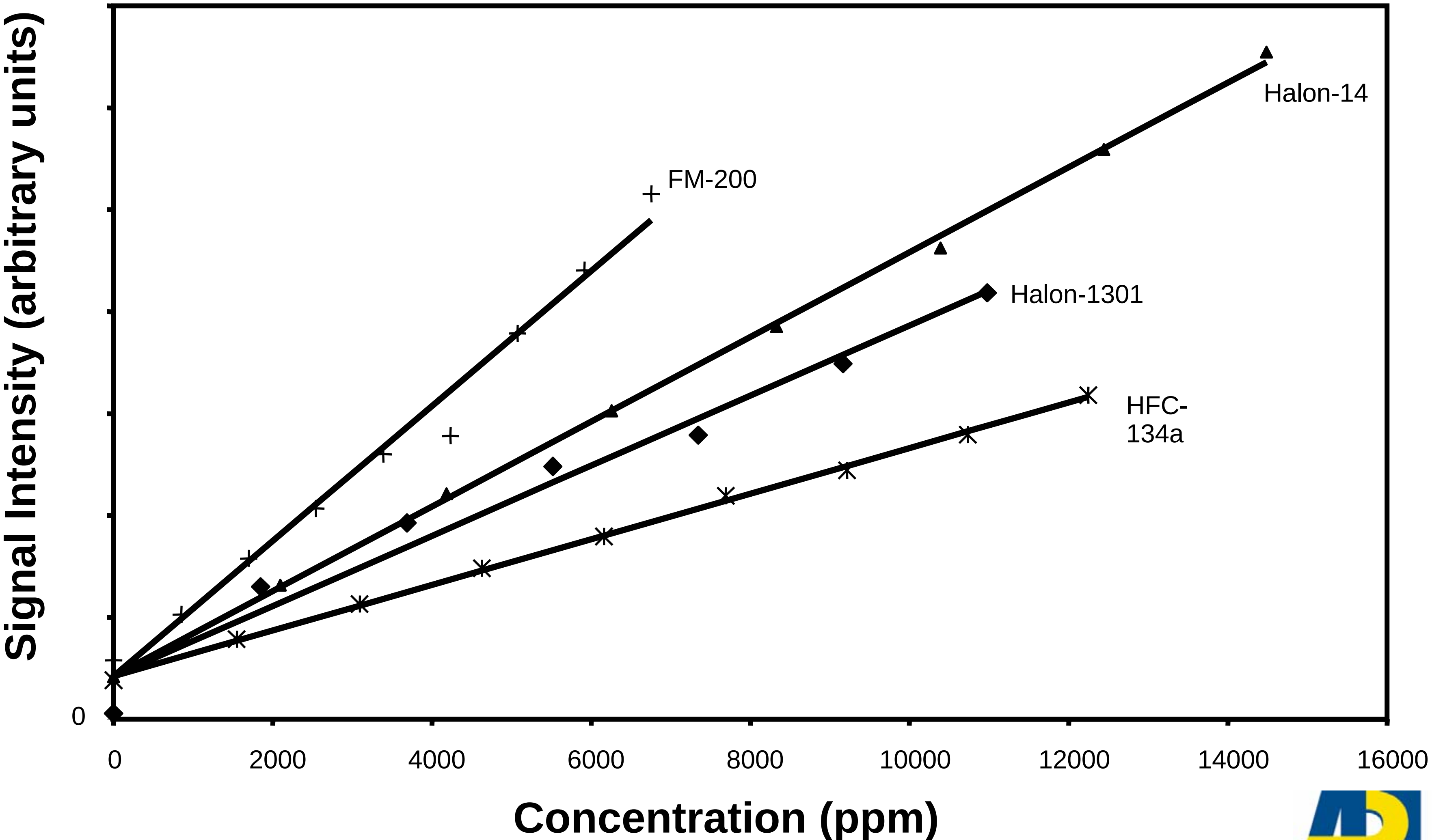


LIBS of DMMP



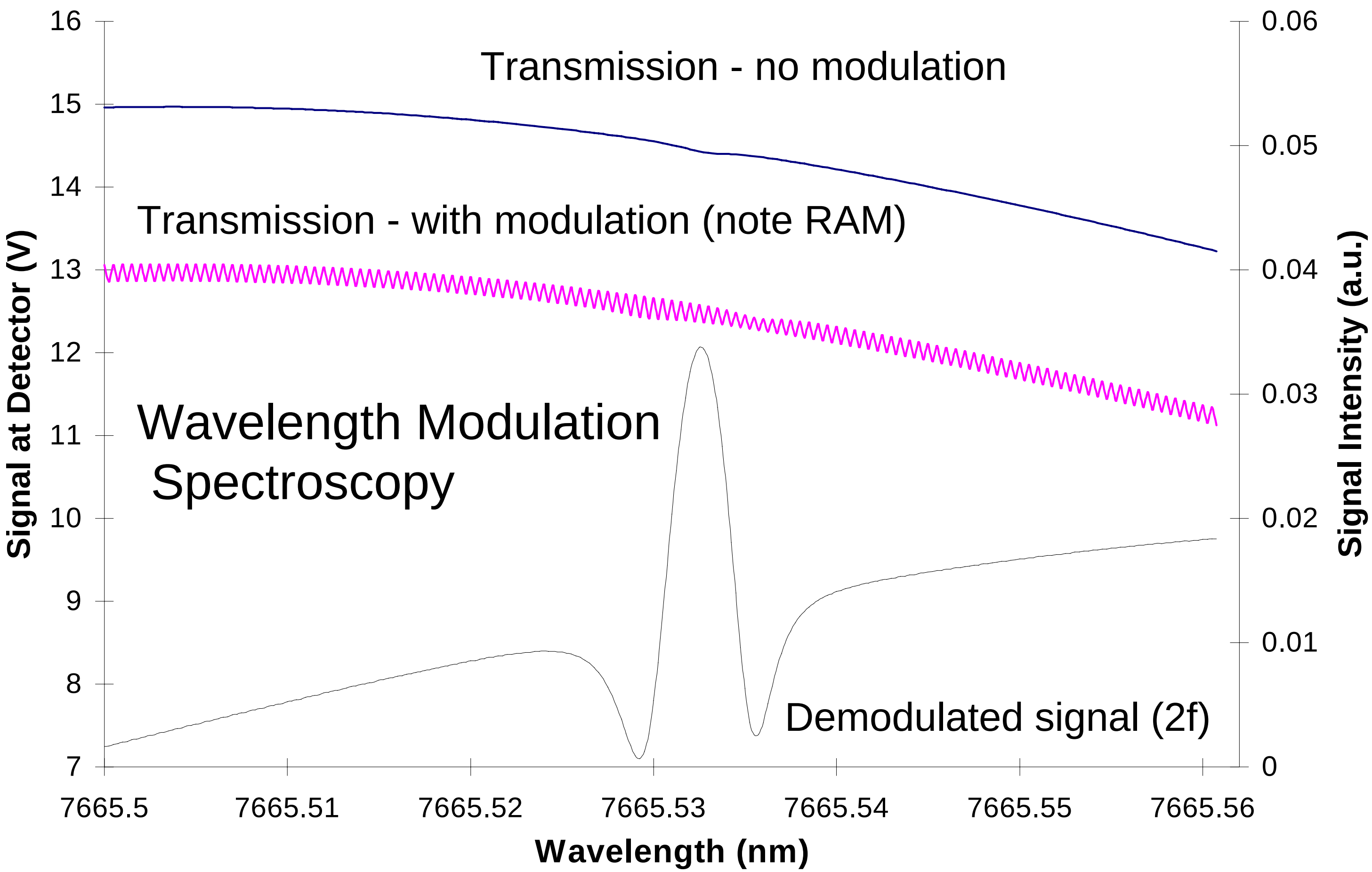
C
P
P
Signal Intensity
25000
20000
15000
10000
5000
0
210
220
230
240
250
260
270
Wavelength (nm)
0.5
25
Time Delay (us)

LIBS of Fire Suppressants

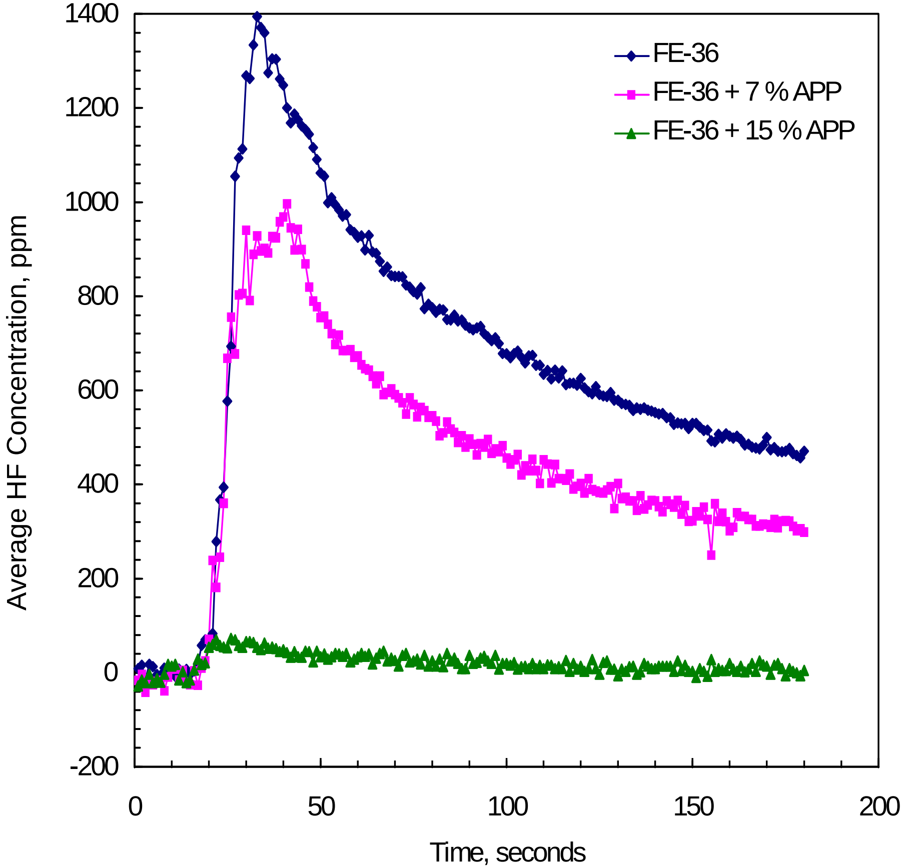


Toxic and Combustible Gas Measurement: Near Infrared Tunable Diode Laser (TDL) Spectroscopy

HF, O_2 , CO, CH_4, HCl, other small molecules



HF Gas Measurement During Suppressant Testing



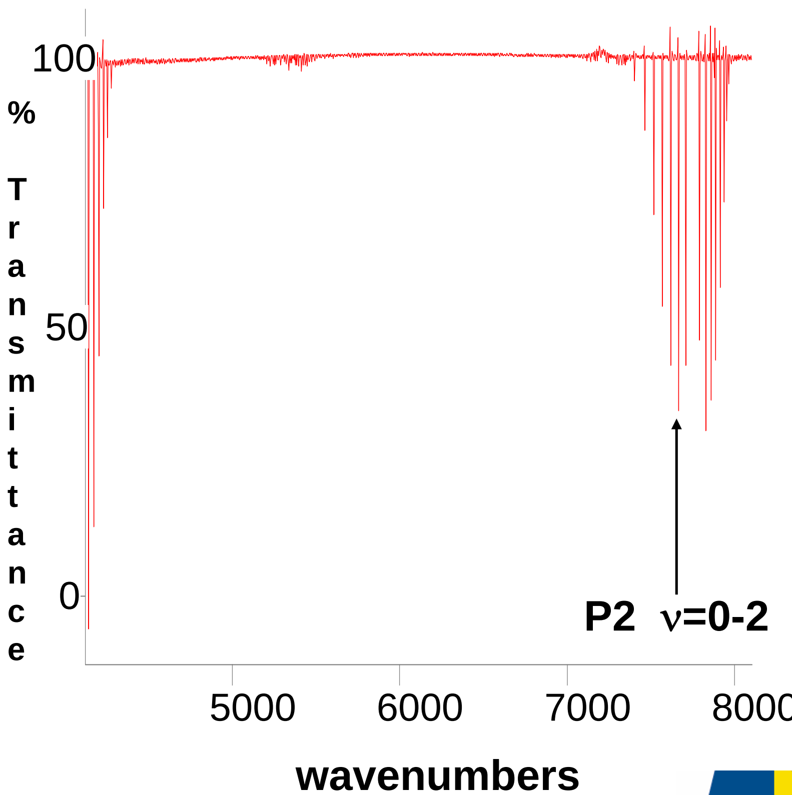
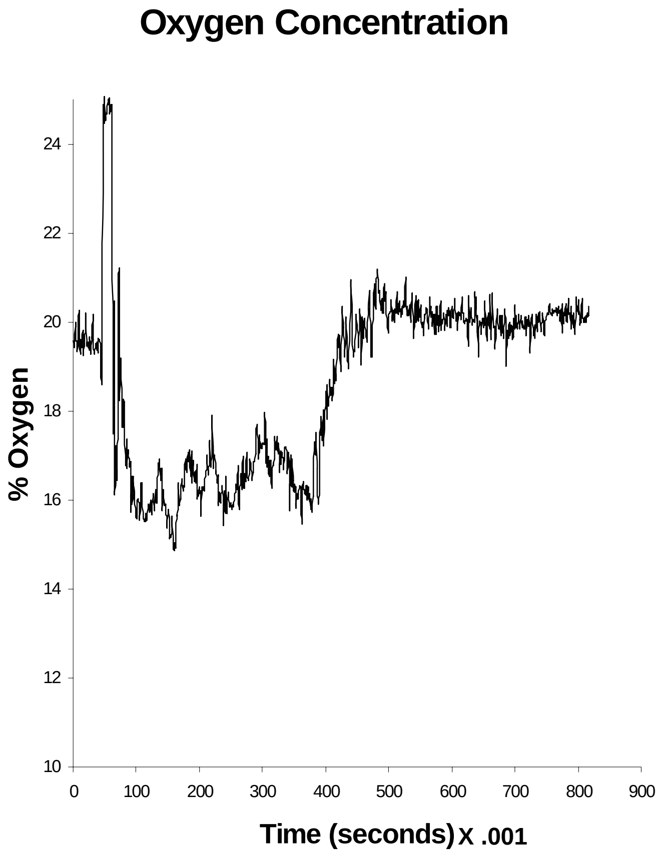


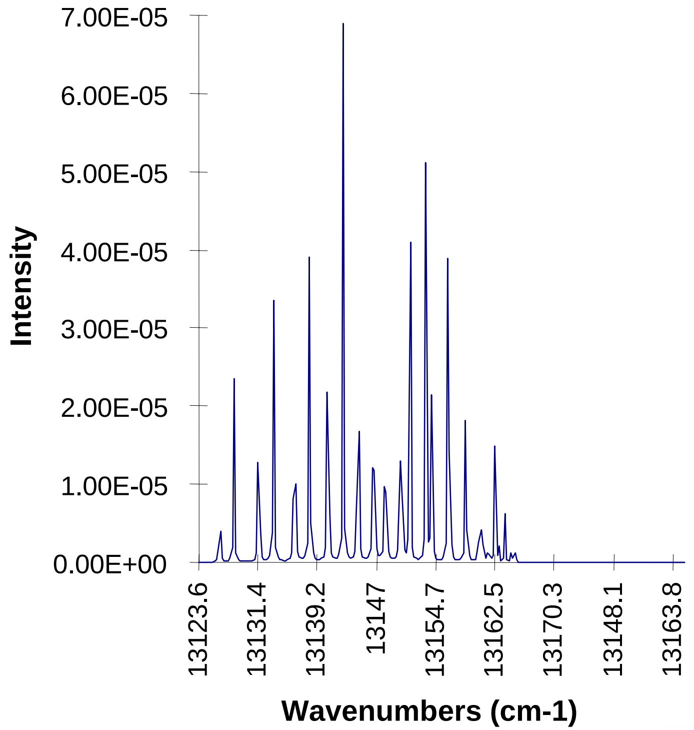
Figure 2

Oxygen Measurement Using TDL Spectroscopy

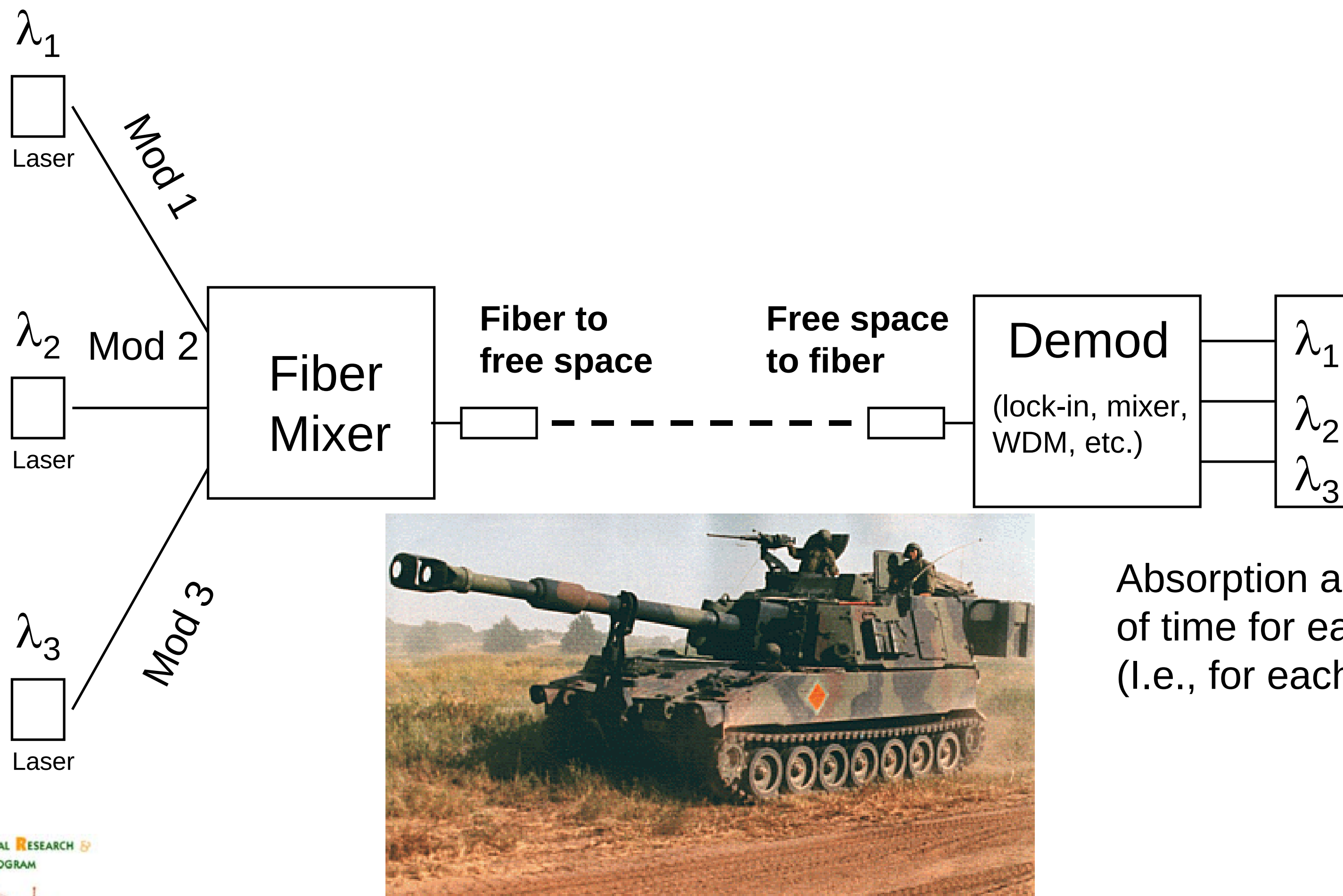


JP-8 - air fire, inhibition by C_3F_8, crew compartment test fixture, fire extinguished 150 ms after detection.

Oxygen Absorption Near 760 nm (b $\leftrightarrow$X , $^1\Sigma_g^+ \leftrightarrow {}^3\Sigma_g^-$)

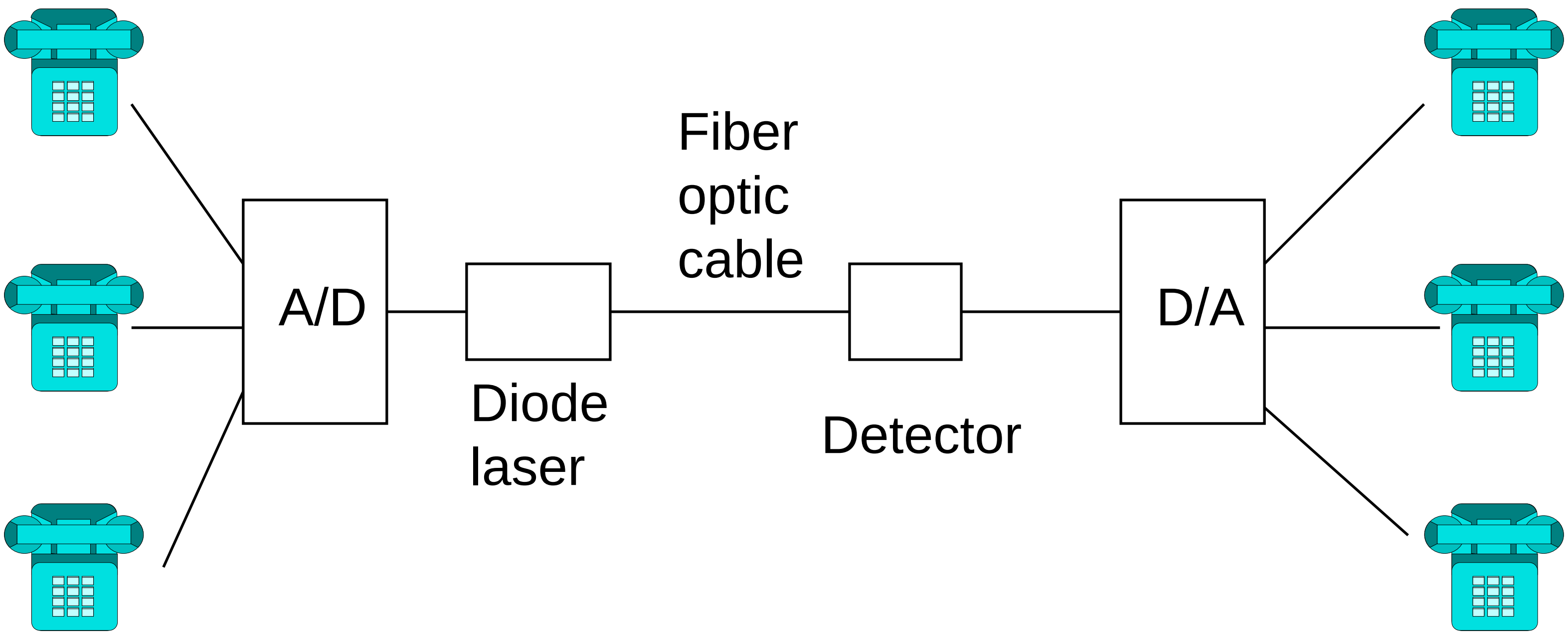


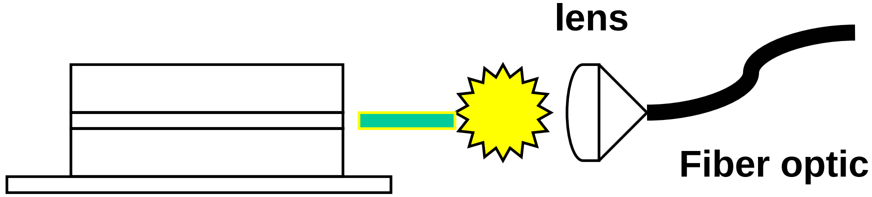
Multiple Species Gas Sensing Using Tunable Diode Lasers (TDL)



Absorption as function of time for each wavelength (I.e., for each gas)

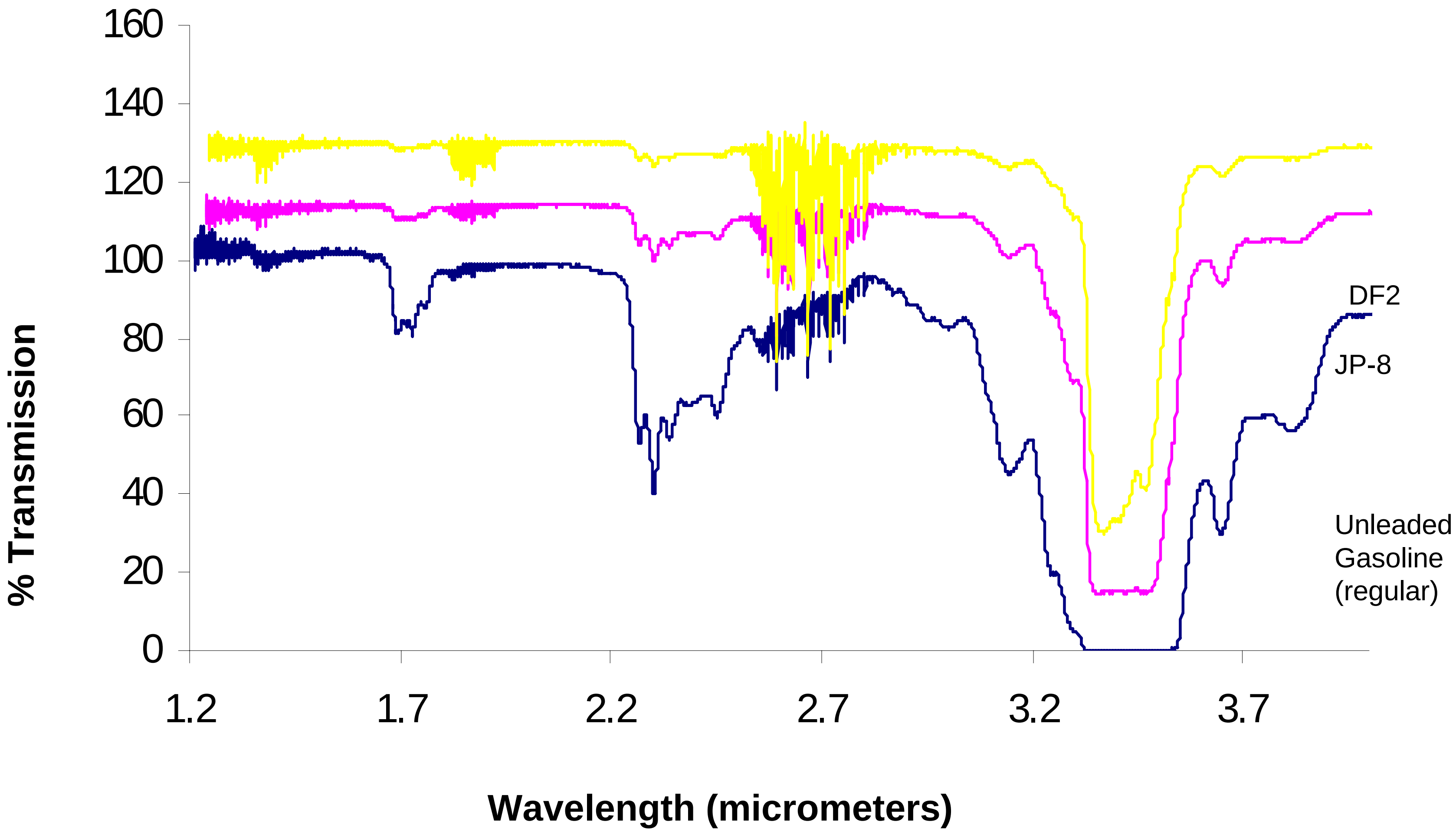
Time Division Multiplexing





Transmits best at:
780 nm
1310 nm
1550 nm

Detection and Measurement of Middle Distillate Fuel Vapors Using Tunable Diode Lasers



Spectrum of dry air saturated at 294K with vapor from unleaded gasoline, JP-8, DF2. Spectra offset for clarity.

Limitations of TDL Spectroscopy For Measurement of High Molecular Weight Vapors

- Absorption features are unstructured.
- Can't use traditional wavelength or frequency modulation techniques to measure big molecules (e.g., middle distillate fuels - JP-8, DF-2, etc.). Unable to scan on and off resonance with single DFB laser.
- Develop a near-infrared diode laser-based sensor capable of measuring hydrocarbon fuel vapor concentrations with a time resolution of 10 msec per measurement point; maintain S/N advantages of WMS.

Measurement Technique

- uses laser diode absorption spectroscopy in the near-infrared spectrum (1.3 microns and 1.71 microns)
- Emission intensity from two lasers is varied sinusoidally, with emission from first laser 180 degrees out of phase with emission from second laser.
- Measurement is made in situ.
- Phase sensitive detection is used to measure differential absorption at the two laser emission wavelengths.
- 10 msec response time

Laser Mixing Apparatus

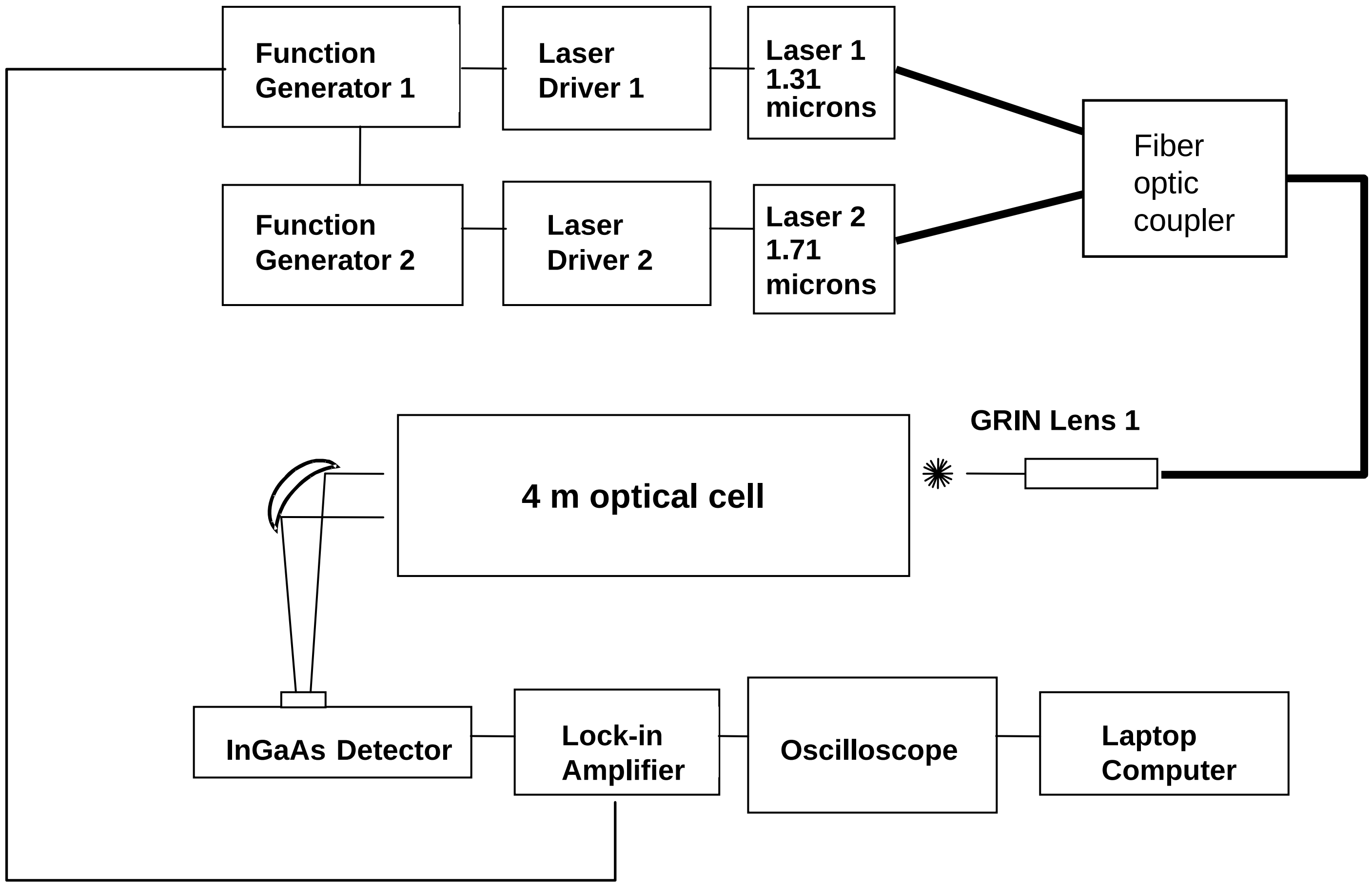


Figure 3: The experimental apparatus used to measure vapors from middle distillate fuels.

Overlap of Fuel Absorbance Spectra and Mixed Laser Probe Beam

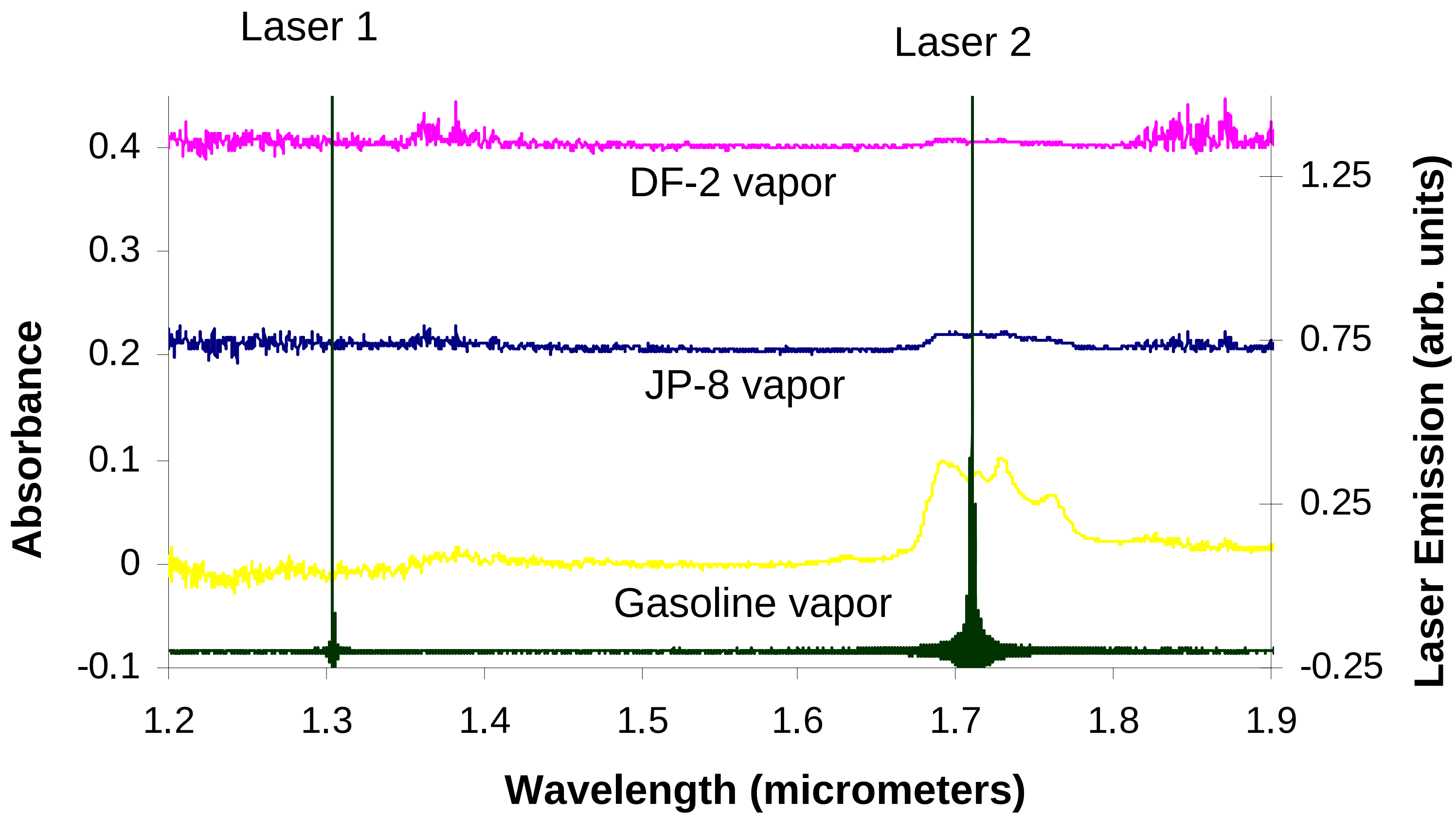
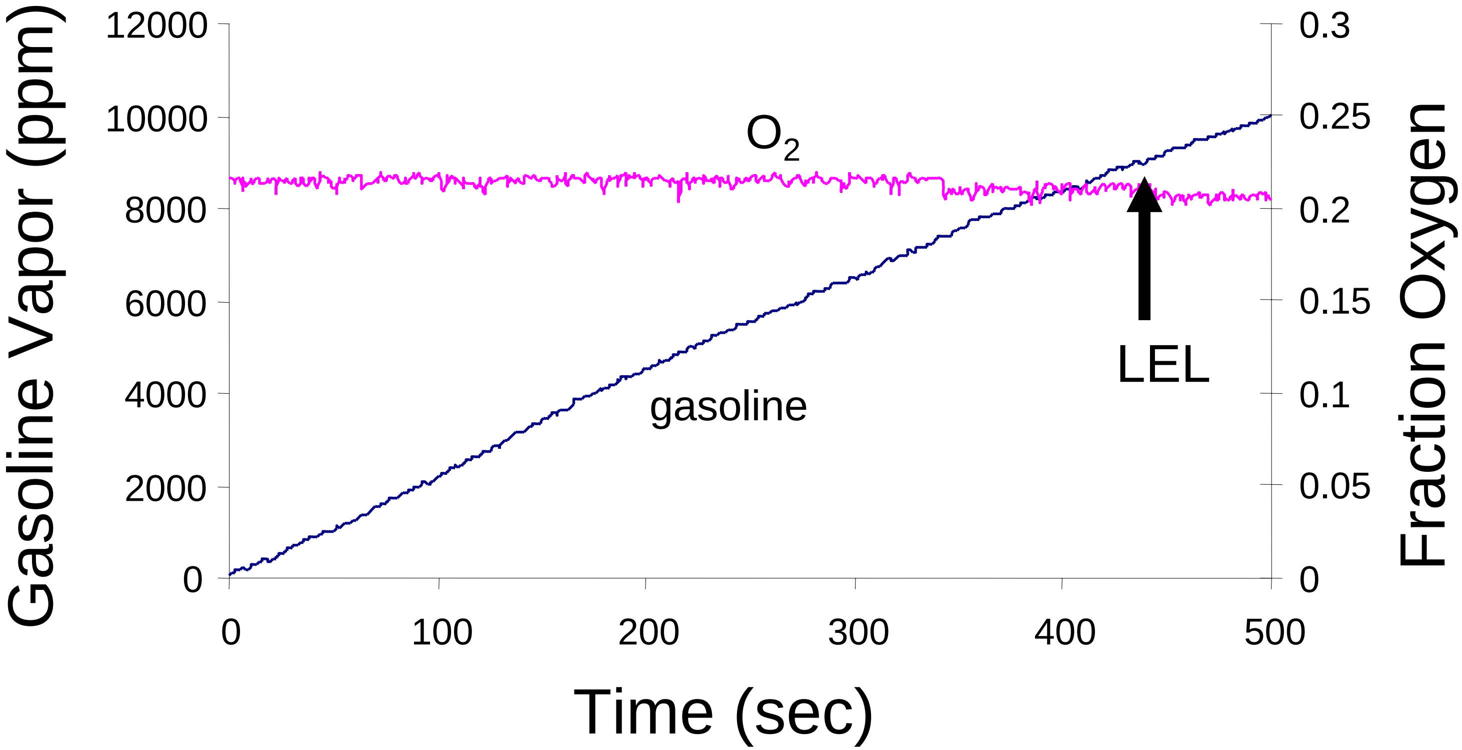


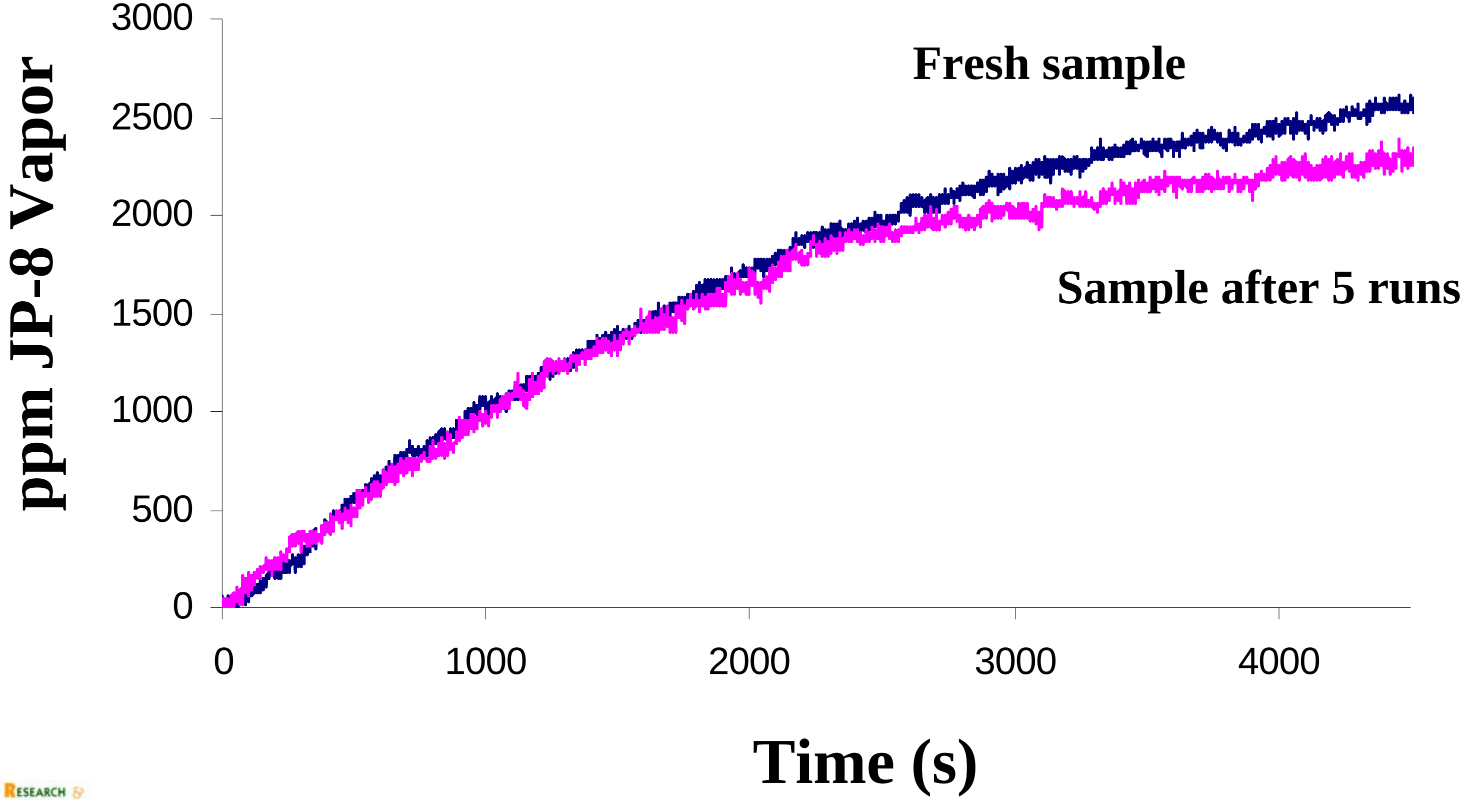
Figure 4: shows the vapor phase absorption spectrum of air saturated by vapor at 294K from JP-8, DF-2, and gasoline between wavelength values of 1.3 and 1.75 micrometers superimposed upon the emission from the optical fiber which carries the mixed wavelength probe beam.

Results: Approach to Lower Explosion Limit (LEL) in a Gasoline Fuel Tank at Room Temperature



Simultaneous measurement of fuel/oxygen concentration (by volume) during displacement of contents (dry air) of a 14 liter vessel by air saturated by gasoline vapor at 294K and 1 atmosphere total pressure. Oxygen sensor courtesy of Oxigraf, Inc.

Results: "Aging" of JP-8 Detected Using Mixed Laser Sensor



FT Diode Laser Spectroscopy

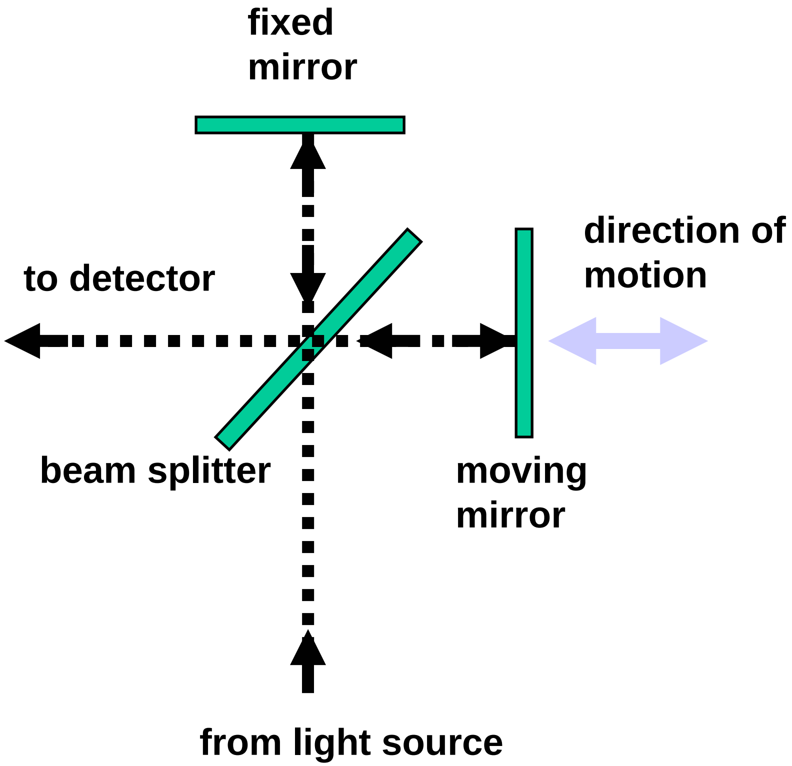
For a monochromatic source:

$$I(\sigma) = I(\nu)\cos 2\pi\, \nu\, \sigma$$

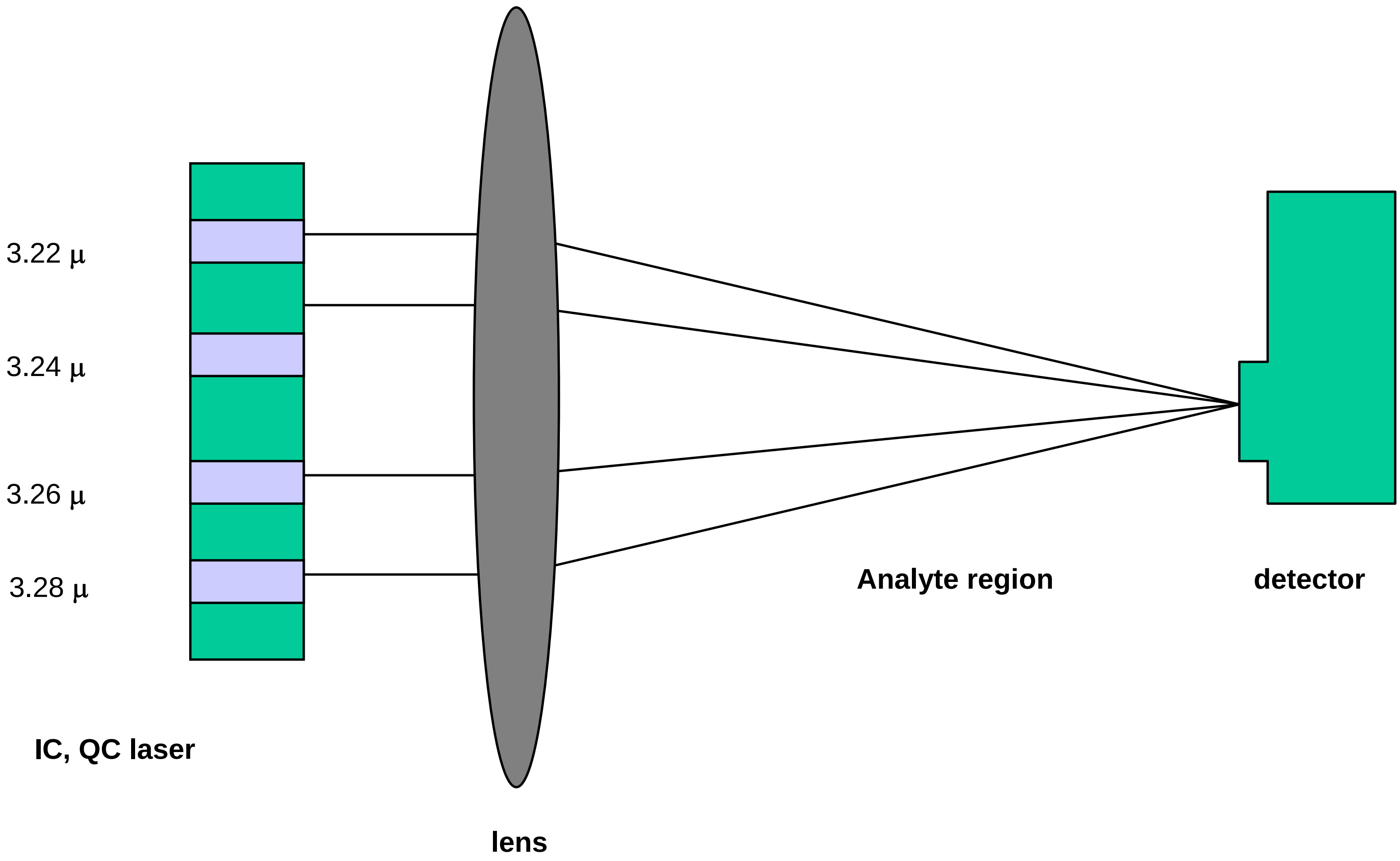
For a polychromatic source:

$$I(\sigma) = \int_0^\infty I(\nu)\cos 2\pi\, \nu\, \sigma\, d\nu$$

σ= mirror position
ν = light frequency (cm^{-1})
$I(\sigma)$ = intensity at detector
$I(\nu)$ = source intensity

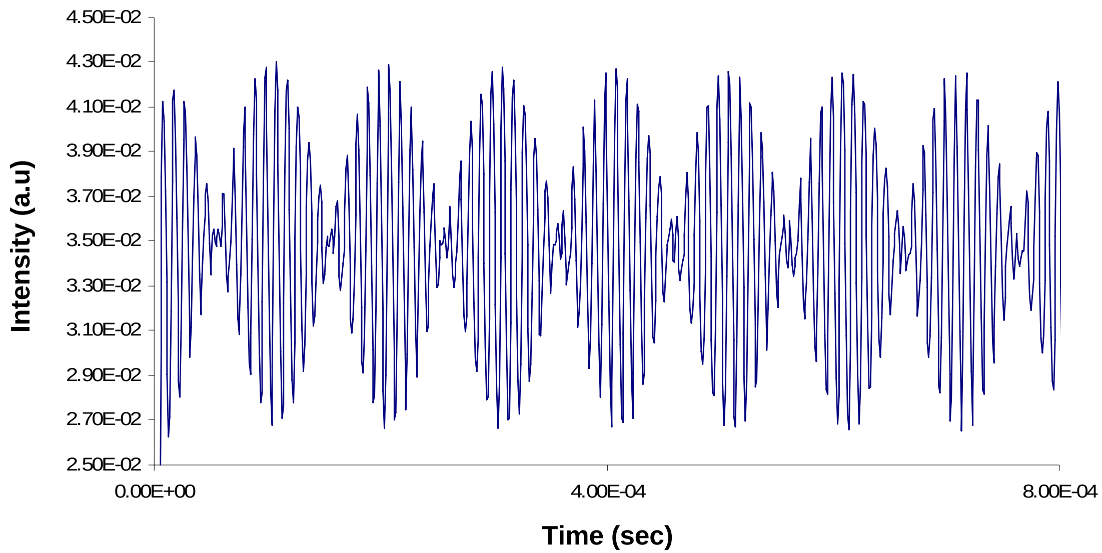


FT Diode Laser Spectroscopy

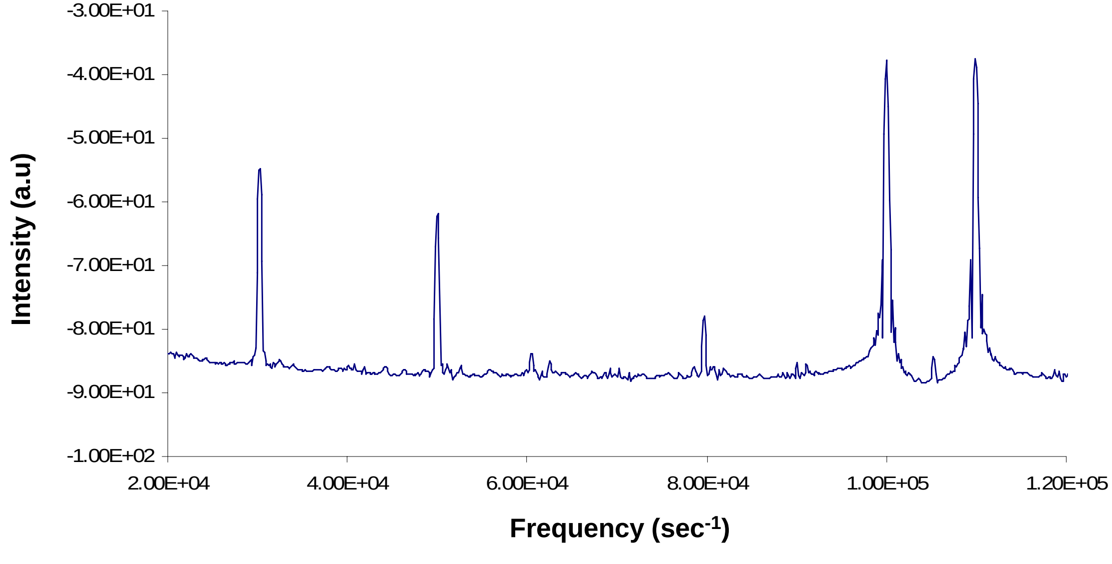


FT Diode Laser Spectroscopy

Signal at detector
Laser 1 (100 KHz) at 1.31μ
Laser 2 (110 KHz) at 1.71 μ

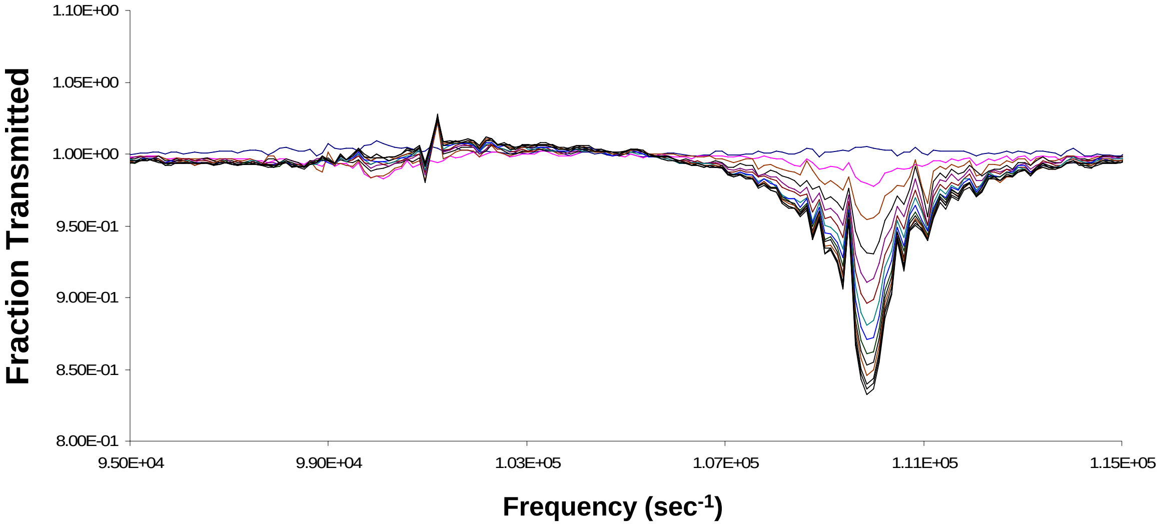


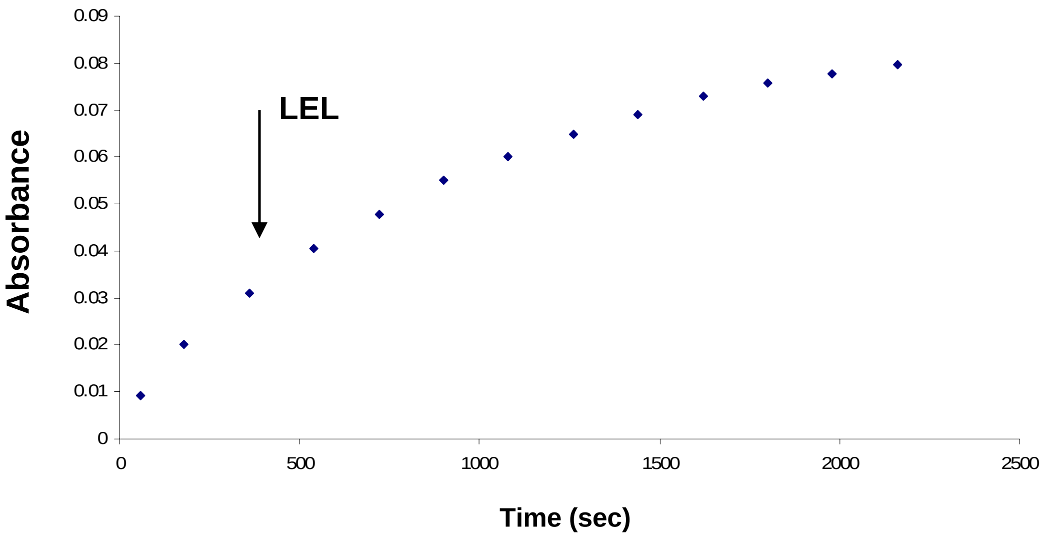
Fourier transform of signal at detector (res.= 100 Hz)



FT Diode Laser Spectroscopy

Absorption of laser radiation at 1.71μ as air in 2m cell is displaced by air saturated with gasoline vapor.





Conclusions/Successes/Failures

- Project greatly enhanced knowledge of fire suppression on board combat vehicles.
- Laser diode systems fielded at ATC/ARL for HF and O_2 .
- DIRRACS II testing at WPAFB.
- FTLS work continues.
- JP-8 sensor vibration problems
- COF_2 formation documented

Conclusions/Successes/Failures (cont.)

- Lasers outside communication bands still very expensive
- Mid-IR RT CW lasers still unreliable
- Narrow BW, broadly tunable, fast light sources still unavailable

Publications

9 open literature, 1 book chapter, 11 Gov’t Tech Reports

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- Dick Gann, NIST
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