Emerging, Trace Gas Detection Techniques: Concepts and Environmental Applications

Frank K. Tittel

Electrical and Computer Engineering Department,
Rice University
Houston, Texas

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OUTLINE

- Motivation, Design, and Technology Issues
- Performance Characteristics of Compact IR Sensors
- Detection of Pollutants and Trace Gas Species
- Outlook and Summary

Applications of Trace Gas Detection

- Urban Emission Measurements
  - Industrial Plants
  - Combustion Sources
  - Automobile
  - Waste Dumps
- Rural Emission Measurements
  - Agriculture
  - Forest Fires
- Environmental Monitoring
  - Atmospheric Chemistry
  - Volcanic Emissions
- Spacecraft and Planetary Surface Monitoring
  - Crew Health Maintenance & Life Support
- Chemical Analysis and Process Control
  - Semiconductor Industry
- Medical Applications
- Aircraft Identification

Tunable CW IR Coherent Sources

- Solid State Lasers
  - Color center lasers, tunable (1-4 μm), low temperatures
- Lead Salt Diode Lasers
  - Tunable (3-30 mm), each diode ~100 cm^{-1}
  - Undesirable discontinuities, low temperatures needed
- CO and CO_2 Sideband Lasers
- Optical Parametric Oscillators (OPO)
  - Tunable 2-14 μm ($LiNbO_3$, KTP, BBO, $AgGaS_2$,
  - $AgGaSe_2$, $ZnGeP_2$), Pulsed and CW
- Tunable III-V Semiconductor Diode Lasers
  - Single Frequency: InGaAs / AlGaAs 620 nm - 2.1 μm;
  - GaSb based lasers 2-6 μm
  - DFB quantum cascade lasers (3-17 μm) pulsed at RT
- Difference Frequency Generation (DFG)
  - Tunable & RT: QPM BPM $LiNbO_3$ (2-5.3 μm)
  - $AgGaS_2$ (3-9 μm); $AgGaSe_2$ (>8-20 μm);
  - GaSe (7-18 μm); GaAs (2-16 μm)

Advantages of Diode Laser Pump Sources

- Broad wavelength coverage (630 nm to 2 μm, with gaps)
  - Tunability (0.3 nm / C, or 2 MHz / μA typical)
  - High efficiency (n_{elec} ≥30%, 0.1-1 W/A)
  - FP, DBR, DFB, ECDL, VCSEL
- CW single mode power (1 to 500 mW)
  - With amplification: ≥ 1W (MOPA, Fiber)
- Narrow linewidth (≤ 15 MHz)
- Amplitude and frequency stability
- Direct frequency modulation (f≤ 0.1 GHz, 10 GHz range)
- Room temperature or TE cooled operation
- Convenient Fiber Pigtailing
- Reliability (> 10,000 hrs.), small size, and low cost

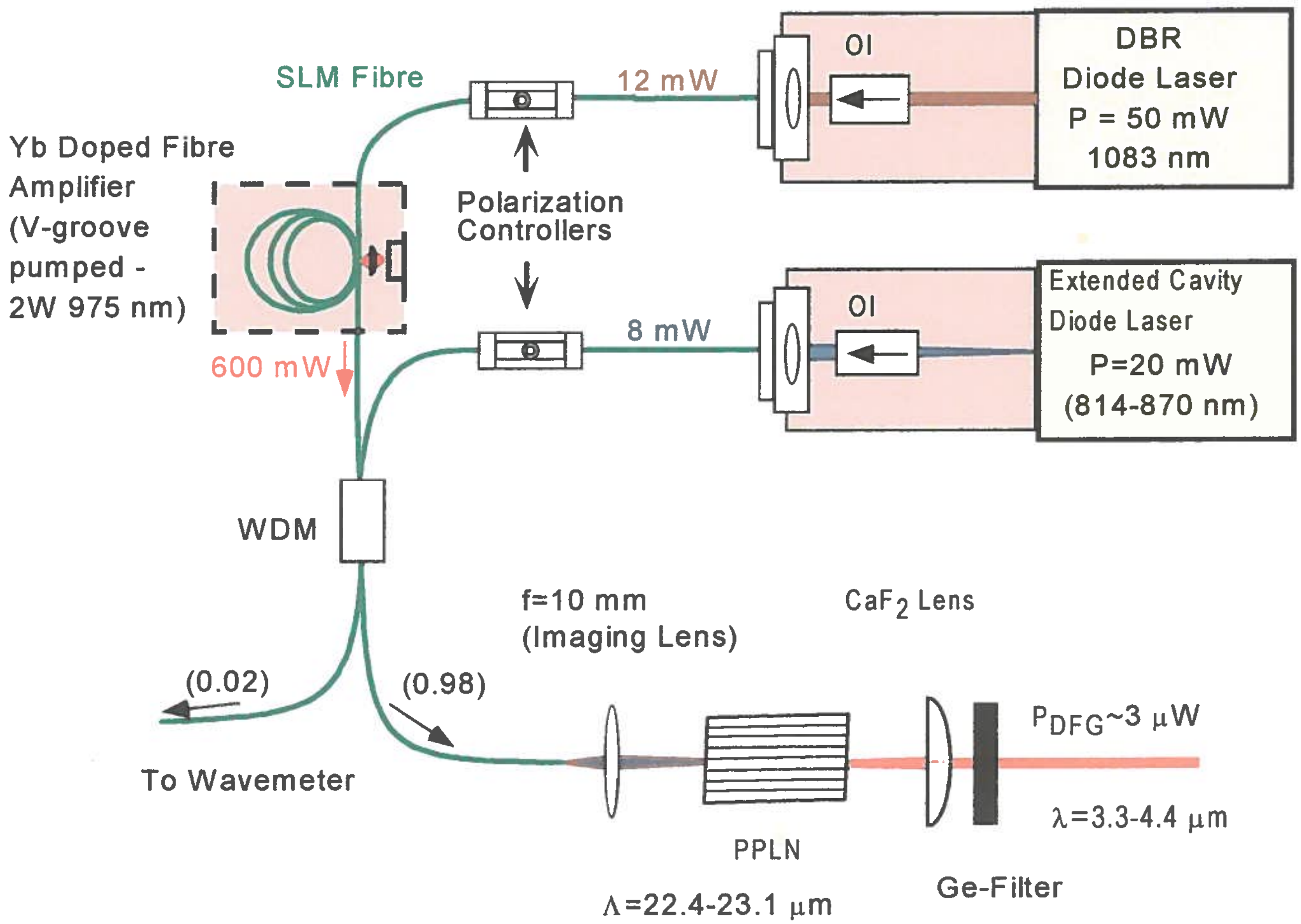
Nonlinear Optical Material Requirements

- Reasonable Nonlinear Coefficient
- Transparency (i.e. low optical loss)
- Adequate Optical Damage Threshold
- Practical Growth / Fabrication Technology
- Thermal & Chemical Stability
- Birefringence for Phase Matching
  - Strong preference for noncritical
- Quasi-Phase Matching

High Resolution Difference Frequency Generation Experiments

- $LiNbO_3$ (1974)
  - A. Pine at NIST
  - Single mode Ar^+ and dye laser
  - Coverage to 4 μm
- $LiIO_3$ (1980)
  - T.Oka at University of Chicago
  - Coverage to 5.2 μm
- $AgGaS_2$ (1991)
  - Rice Group
  - 2 tunable single mode lasers
  - Coverage to 10 μm
- QPM - $LiNbO_3$ (1995)
  - Rice, NRL, Stanford
  - Coverage to 5.4 μm
  - All-solid state pump sources
- $AgGaSe_2$ and GaSe (1996)
  - Rice, NRL, and Aerodyne
  - Coverage from 7 to 18 μm

DFG sensor schematic



- Fiber coupling has reduced alignment requirements
- Fiber amplifier has eliminated the requirement for a high-power narrow bandwidth pump

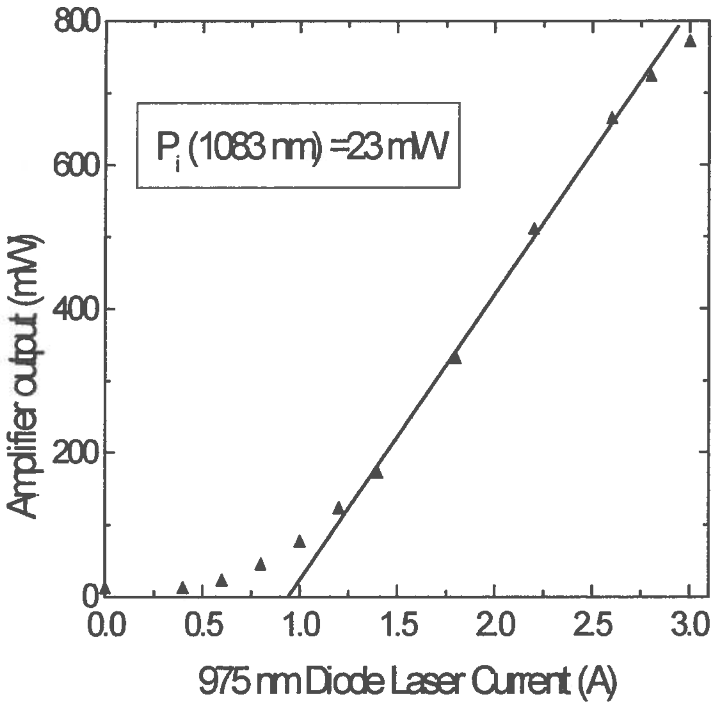
Summary . . . . Future Directions . . . . Conclusion

- Use of fiber optics for delivery/ combining has virtually eliminated alignment sensitivity
- High DFG conversion efficiency (0.88 mW/ W^2)
- 3.2 to 4.4 μm tunability demonstrated
- High sensitivity spectroscopy of 6 trace gases has been demonstrated
- Absorption sensitivity of $\pm 2 \times 10^{-4}$

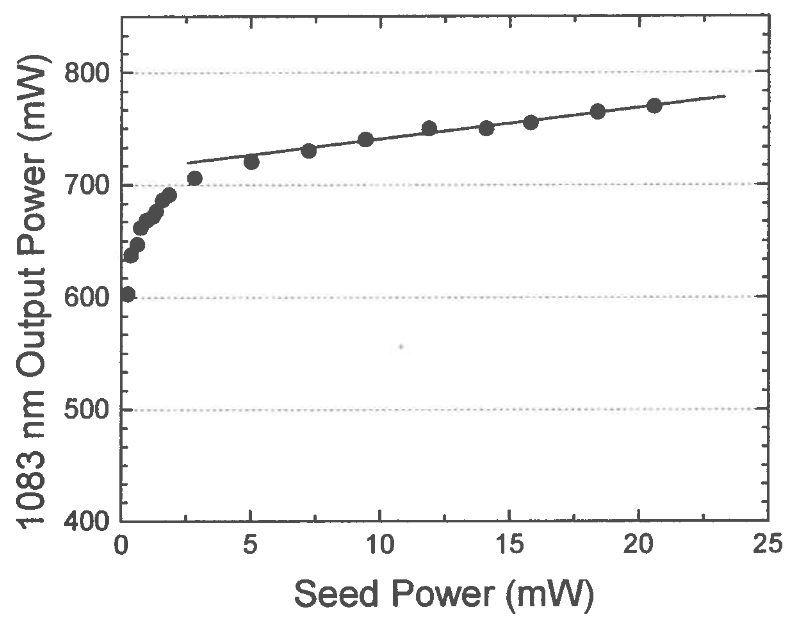
- Power Scaling (to date): demonstrated 0.54 mW at 3.5 μm (CW)
- Improved sensitivity ~ 5×10^{-5} Hz $^{-1/2}$

DFG spectroscopic sensors are now suitable for high sensitivity long term field monitoring of a range of species

Yb^{3+} fiber amplifier characteristics

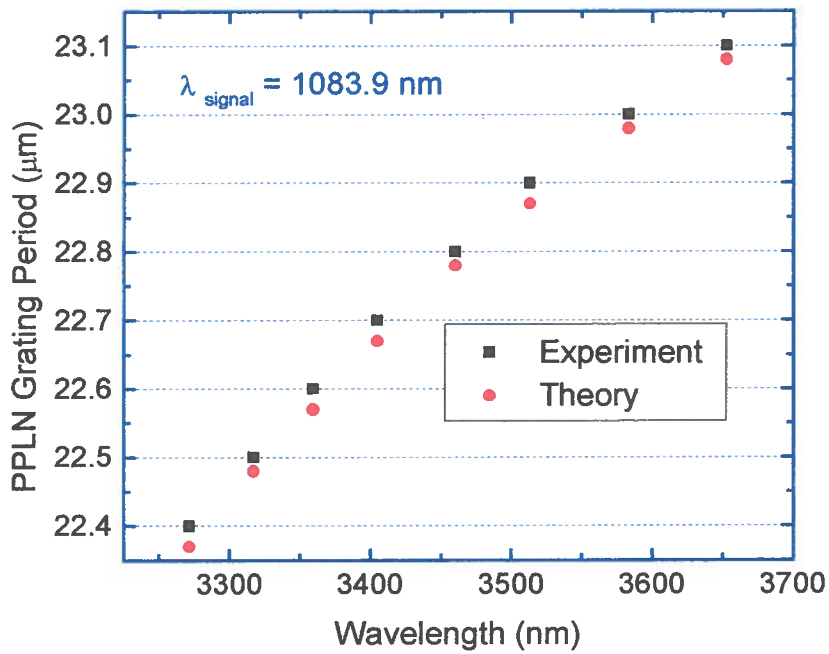


- Yb^{3+} doped doubling-cladding fiber
6 μm inner core, hexagonal
131 μm outer cladding.
Pump diode = 2W (SLI).

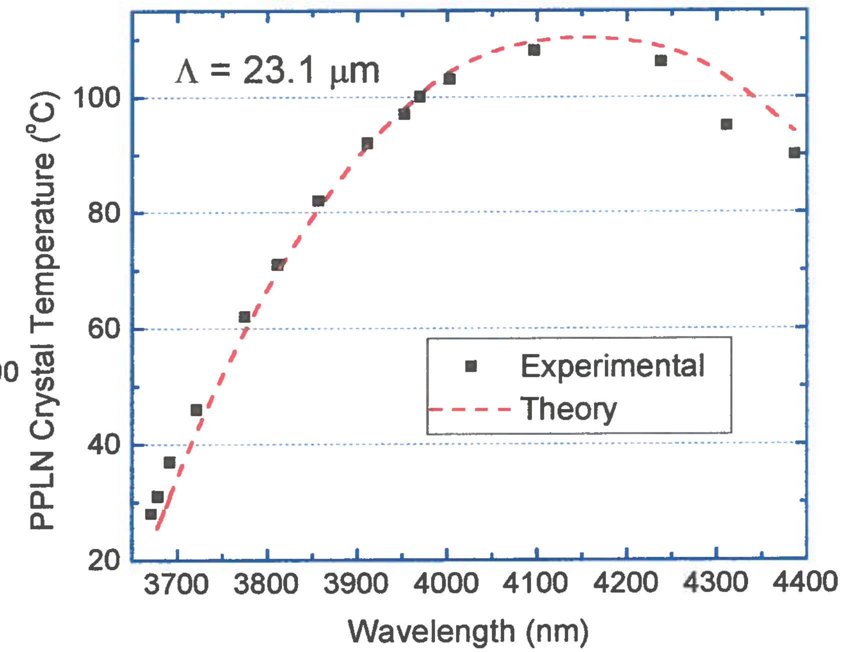


Amplifer designed by
L. Goldberg and J. Koplow
Naval Research Labs

Quasi-phasematching of PPLN



PPLN crystal 1
L = 19 mm
Λ = 22.4 - 23.1 μm



PPLN crystal 2
Λ = 22.4 - 23.3 μm
3250 nm - 4400 nm can be phasematched at T=13-43° C

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