Trace gas spectroscopy using a guided wave difference frequency sensor

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Abstract

We report sensitive spectroscopic detection of formaldehyde using a guided wave difference frequency spectrometer with tunable output near 3.5 μm. A dual-beam, rapid-scan measurement system allowed real-time acquisition of normalized direct absorption spectra.

Motivation

Need for compact room-temperature mid-IR sources:

Trace gas detection	**Chemical analysis**
Industrial process control	**Environmental monitoring**
Combustion diagnostics	**Atmospheric chemistry**
Rural emission studies	**Medical diagnostics**

Output: > 10 μW at 2 to 5 μm (room temperature), diffraction-limited, linewidth < 100 MHz

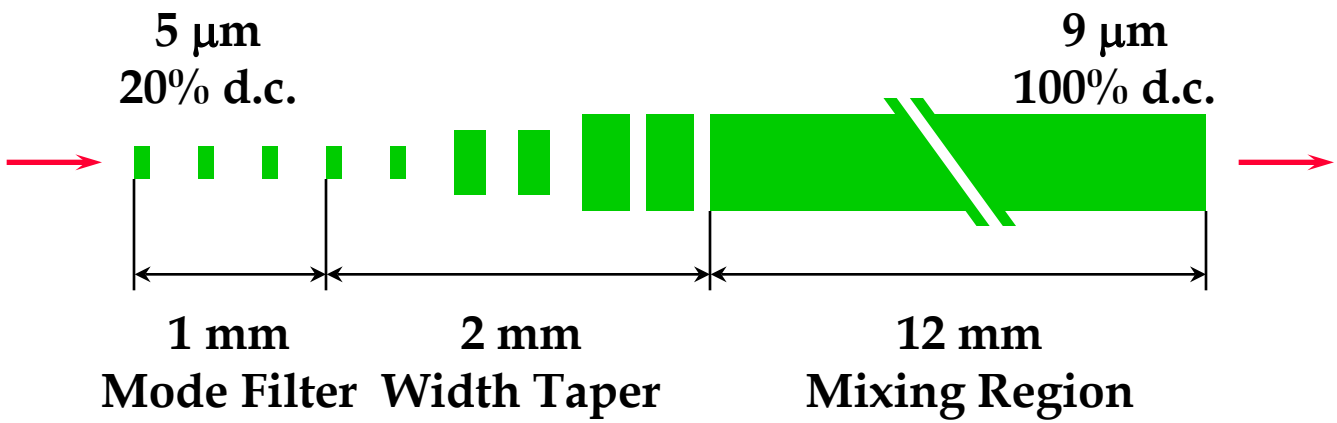
Absorption sensitivity: 2×10^{-4}

Introduction

Mid-infrared laser absorption spectroscopy is a promising technique for environmental trace-gas detection because many important air contaminants have strong absorption bands in that spectral region. To access the 3 to 5 μm spectral region a convenient technique is difference frequency mixing in a nonlinear optical material, which allows the frequency shifting of readily available near infrared diode lasers. Periodically poled $LiNbO_3$ (PPLN) has desirable characteristics for such difference frequency mixing, including engineerable phase matching and a high nonlinear coefficient (d_{eff}). The use of a tapered waveguide in PPLN, leads to an enhancement of the DFG conversion efficiency of PPLN [1,2] compared to bulk PPLN

(0.6 %. W^{-1} :WG PPLN [3] vs 0.1 %. W^{-1} Bulk PPLN [4]).

Waveguide design



PPLN GRATING PERIOD: 19.2 μm
PROTON EXCHANGE: 36 hours at 160°C in benzoic acid
ANNEAL: 38 hours at 340°C in air

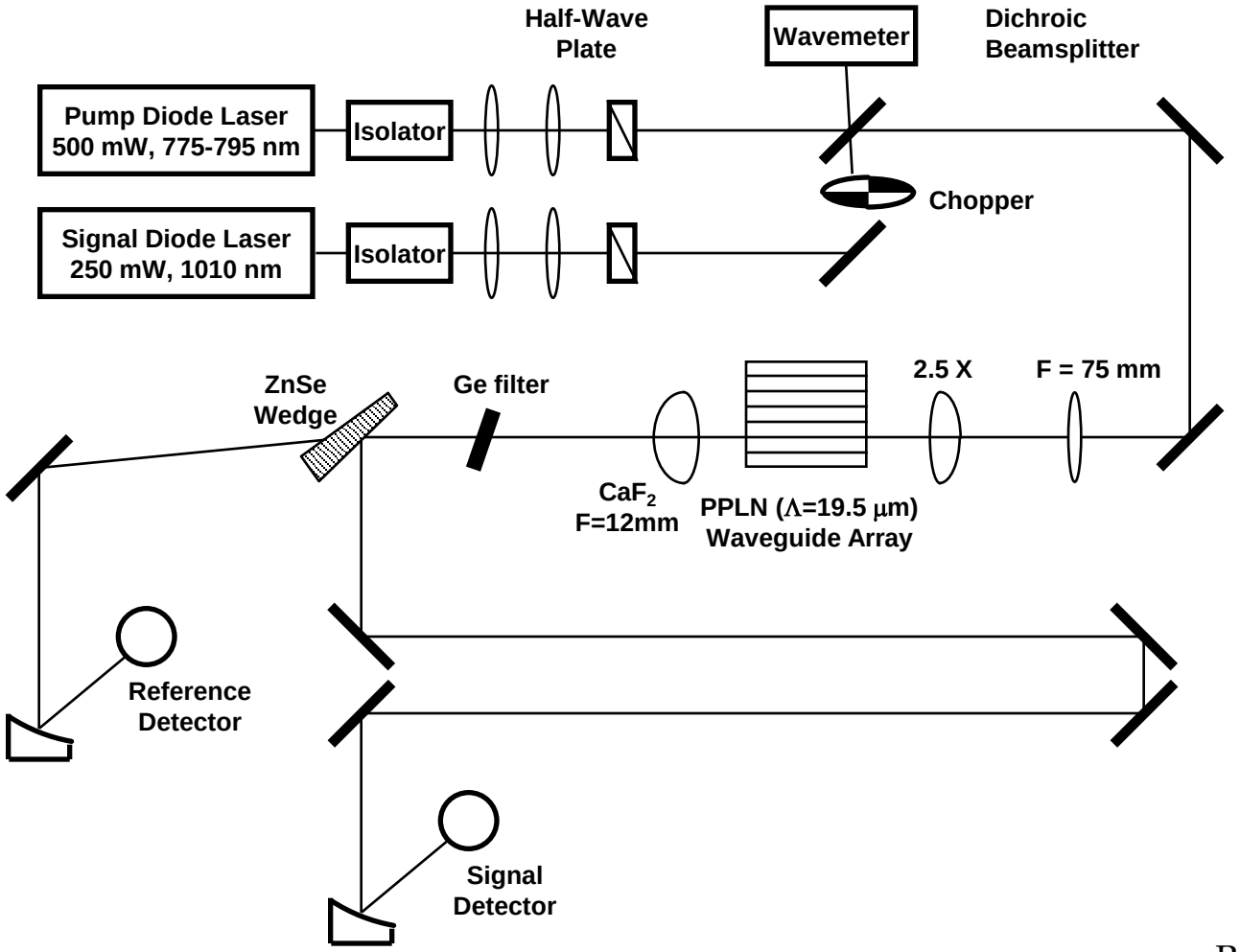
NUMBER OF SPATIAL MODES (ESTIMATED)

	INPUT	OUTPUT
at 790 nm	3	27
at 1096 nm	1	12
at 2830 nm	0	1

DFG spectrometer configuration

The DFG spectrometer employed in this work uses two commercial semiconductor lasers: a master oscillator power amplifier tunable from 775 to 795 nm ('pump'), and a grating-stabilized tapered high-power oscillator at 1010 nm ('signal'). To simulate operating conditions expected of a compact low-power instrument, both lasers were operated at power levels below 150 mW. Each laser beam passed through an optical isolator, a half-wave plate and a telescope, emerging as a collimated, vertically polarized beam of near circular symmetry. The telescopes were adjusted such that the emerging beam diameters were roughly equal (~2.2 mm) for optimal simultaneous coupling into a waveguide. The laser beams were combined by a dichroic beamsplitter and focused at the input face of a channel waveguide array by a microscope objective.

3.33 - 3.73 μm DFG spectrometer



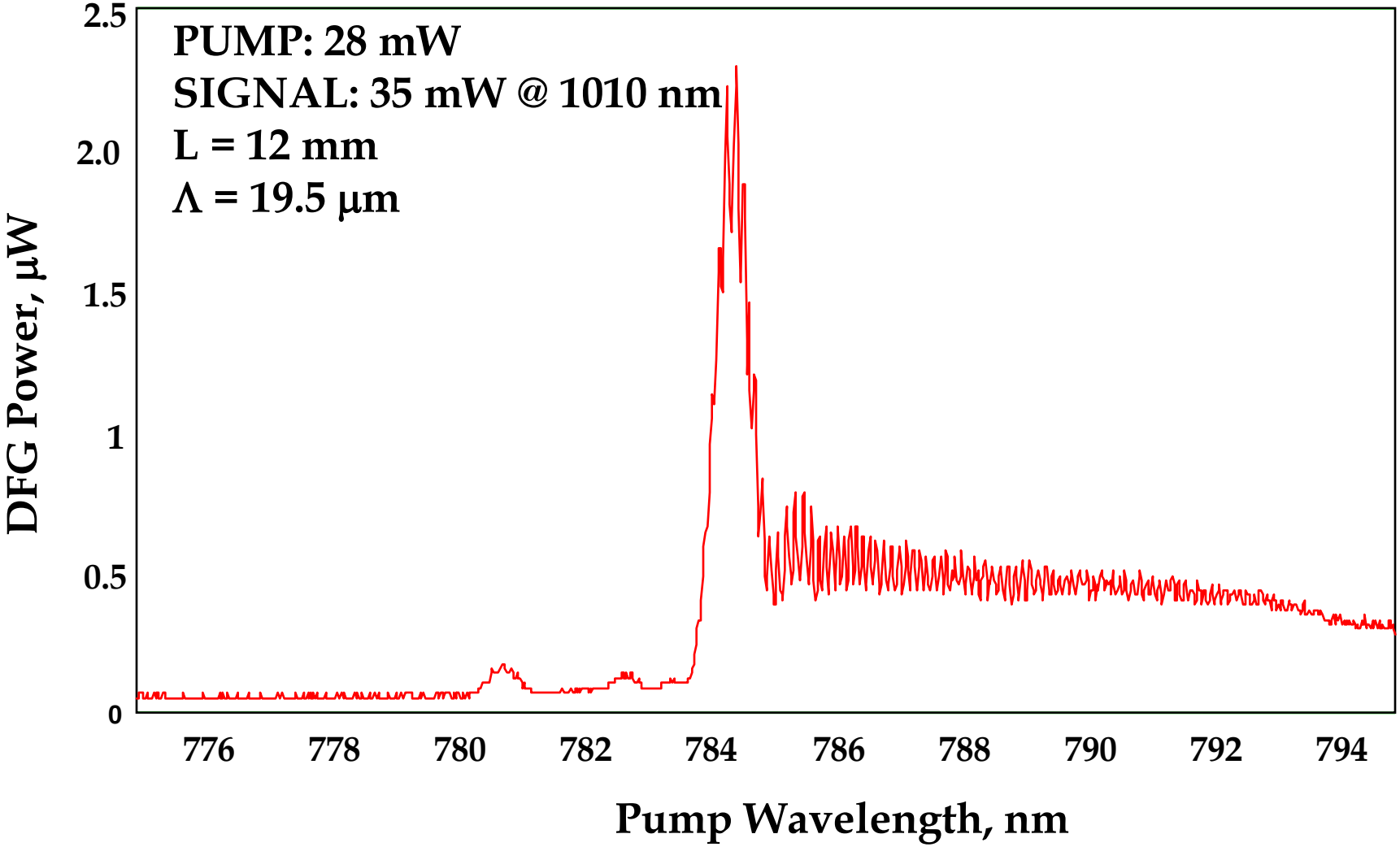
Refs [5,6]

Dual beam spectroscopy

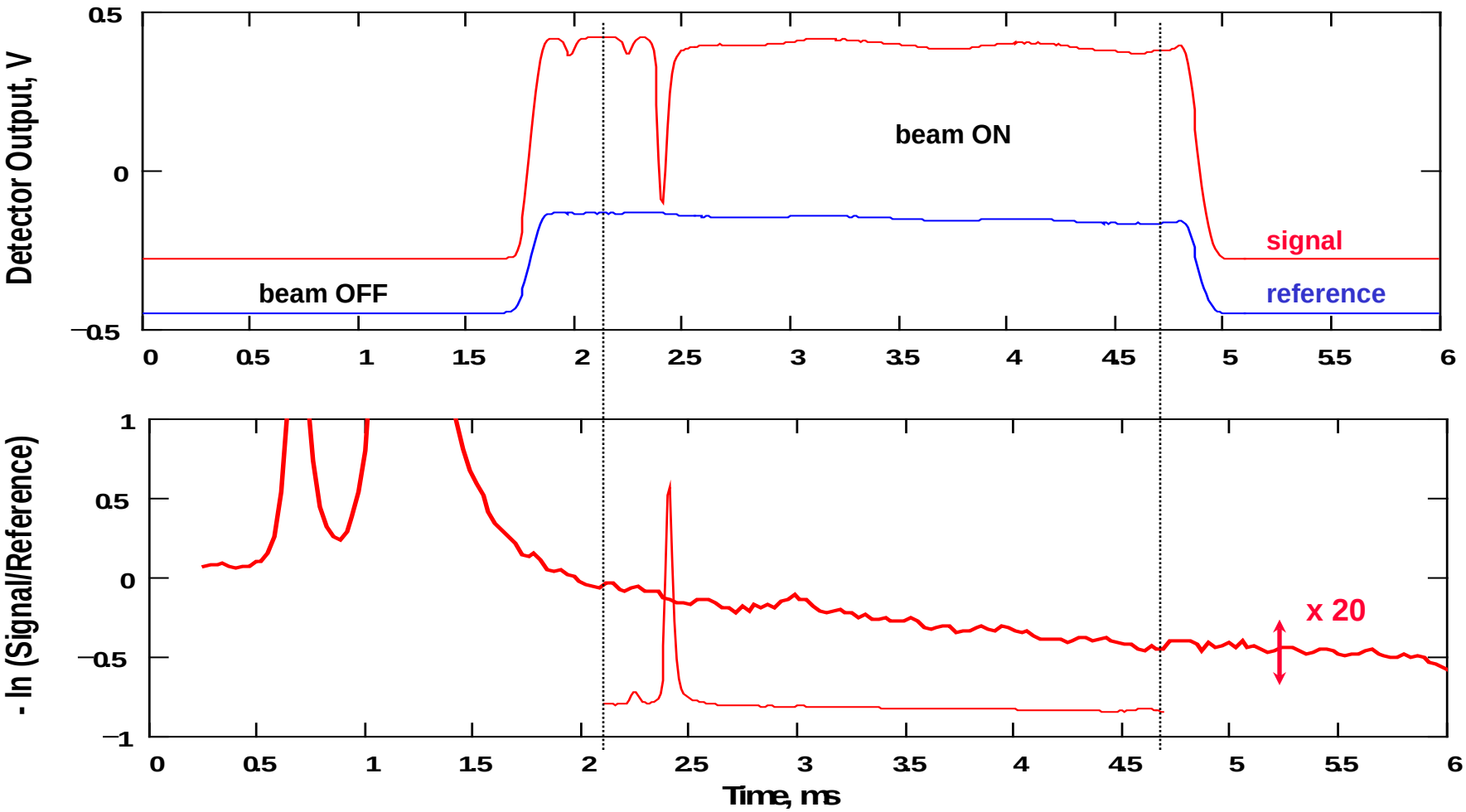
Dual beam spectroscopy was used to acquire high sensitivity absorption spectra. To acquire the reference and signal channels a beam splitter and two photovoltaic InSb detectors were used.

Repetitive frequency scanning of 0.4 cm^{-1} was achieved by the use of a 200 Hz triangular wave voltage modulation applied to the piezo element of the external cavity diode pump laser. Data was acquired by the use of two miniature PCMCIA 16 bit A-D cards with a sampling rate of 120 kHz. To allow simultaneous acquisition of the detector dark voltages in every frequency sweep, a beam chopper was operated synchronously with the frequency modulation.

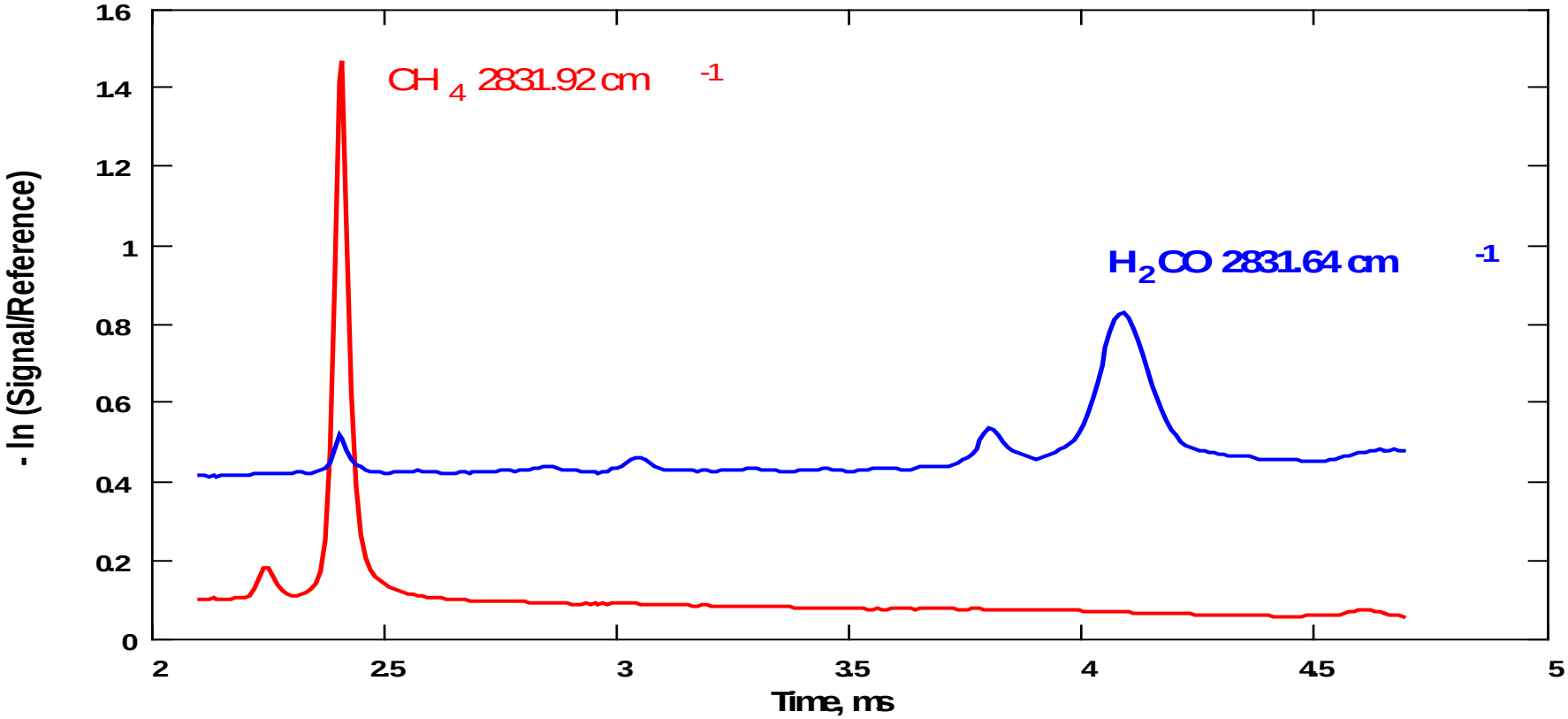
Guided and unguided idler in PPLN waveguide



Measured Signals; typical case



Interference-free window for simultaneous detection of CH_4 and H_2CO

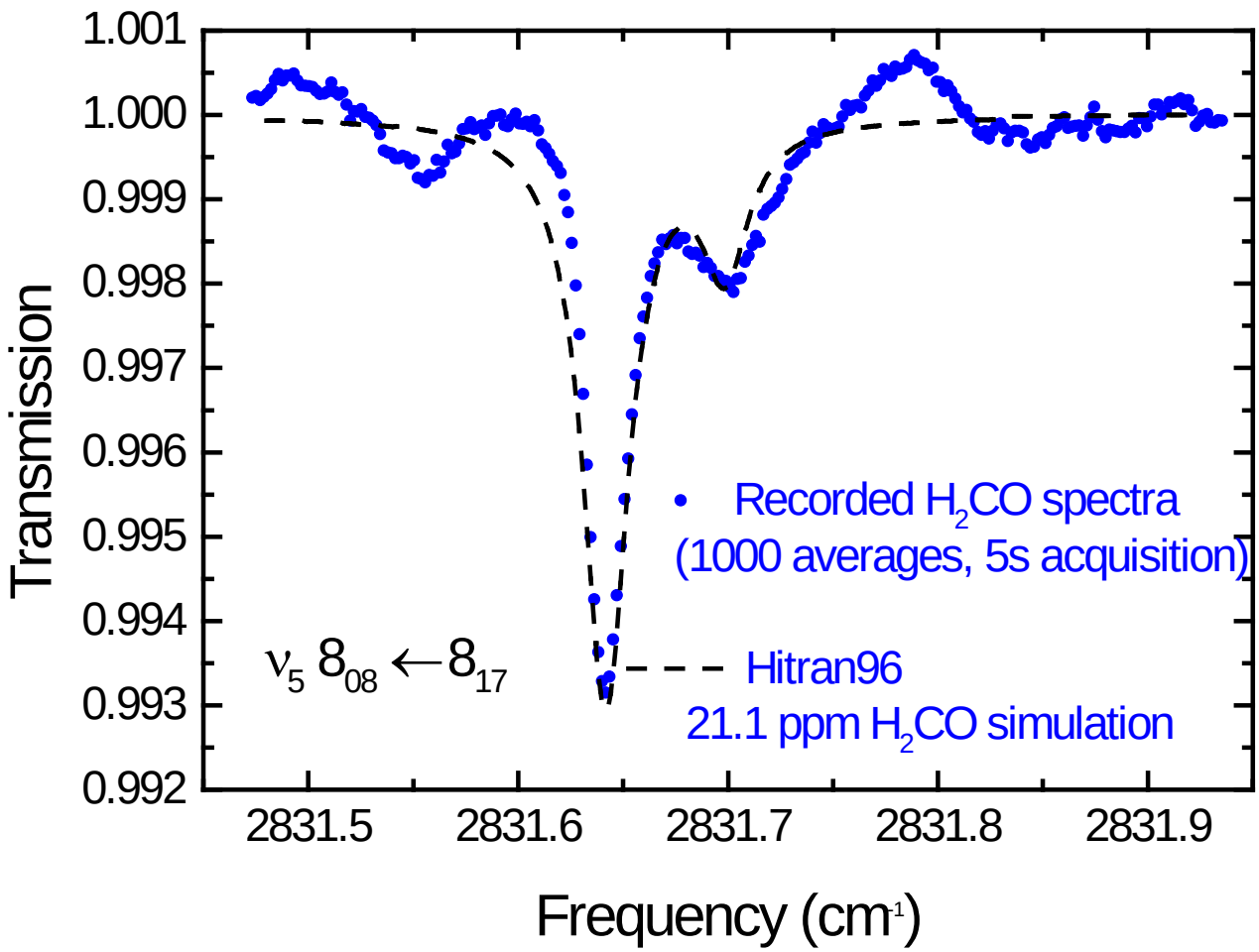


CH_4: 27 cm path, 20 torr, 30 averages, S/N=1600 (64 dB)

H_2CO: 5 cm path, 0.5 torr, 30 averages, sweep rate 190 Hz

Low-level detection of formaldehyde

(detection limit 540 ppb*m)



Conclusions

- Results demonstrate the feasibility of using diode-pumped guided-wave difference frequency generation for trace-gas detection

- A waveguide DFG conversion efficiency of 0.25 % $W^{-1}cm^{-2}$ has been demonstrated

- A high-resolution, real-time dual beam spectrometer system has been realized

- H_2CO detection sensitivity of 540 ppb.m

References

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[6] K.P. Petrov, A.T. Ryan, T.L. Patterson, L.Huang, S.J. Field, D. Bamford, "*Mid-infrared spectroscopic detection of trace gases using guided-wave difference-frequency generation*", Appl. Phys. B **67**, 357 (1998)