Compact fiber coupled gas sensor tunable from 3.3–4.4 μm

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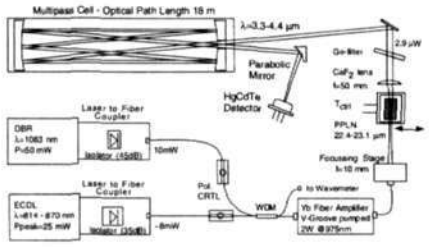
In trace gas detection based on absorption spectroscopy there is a need for widely tunable



CTuS4 Fig. 1. Optical set-up of a fiber coupled widely tunable DFG spectrometer.

narrow bandwidth mid-infrared light sources. Diode lasers which have desirable operating characteristics for field based laser spectroscopy, are presently only available in the spectral region from 0.63 to 1.6 μm. However, these can be frequency shifted into the mid-infrared spectroscopic fingerprint region by nonlinear difference frequency mixing.

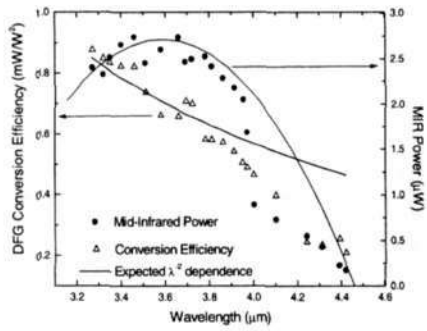
The recent development and characterization of a portable fiber coupled difference-frequency spectroscopic source tunable from 3.3 to 4.4 μm will be reported. This device uses as pump sources an external cavity (ECDL, 25 mW peak, 814–870 nm) and a distributed Bragg reflector (DBR, P = 50 mW, λ = 1083 nm) diode laser seeded Ytterbium doped fiber amplifier pumped by a 975 nm, 2W diode laser (Fig. 1). The fiber amplifier boosts a seed power of 10 mW at 1083 nm to 540 mW.[1] Both pump lasers are coupled into single mode fibers and combined by a wavelength division multiplexer (WDM). The linear polarization output from the fiber for a $e + e \rightarrow e$ difference frequency generation (DFG) process in a periodically poled lithium niobate (PPLN) crystal is maintained by using two polarization controllers in the fiber delivery system. Coarse frequency tuning of the ECDL is achieved by rotation of its diffraction grating relative to the optical axis of the laser cavity. Fine tuning and repetitive scanning over single or multi-component absorption lines of up to ~25 GHz is accomplished by current modulation of the DBR diode laser. The sensor is 50 × 50 × 15 cm^3, weighs 25 kg, and has been packaged in an aluminum suitcase for portability.

An achromat lens (f = 10 mm; 0.25 NA) was used for imaging the fiber output (×8 magnification) into the 19 mm long PPLN crystal resulting in a DFG conversion efficiency of 0.74 mW/W^2 (at 3.5 μm). The theoretical DFG conversion efficiency yields 1.4 mW/W^2.[2] Optimal conversion is not achieved because of different pump-beam mode field diameters in the fiber leading to incomplete overlap of the pump beams in the crystal, and a low NA (0.25) of the imaging lens.

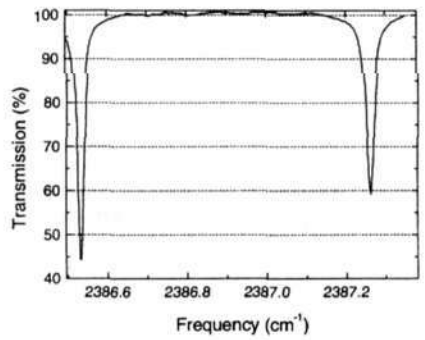
Figure 2 shows the conversion efficiency and power as a function of the generated mid-IR wavelength with a maximum power of 2.9 μW (@ 3.7 μm). The expected λ^{-2} power conversion efficiency is also plotted in Fig. 2.

The discrepancy between experimental results and the theoretically expected wavelength dependence at longer wavelengths is a result of absorption losses in the $LiNbO_3$ crystal beyond 4.0 μm, and a strong CO_2 band from 4.1 to 4.4 μm responsible for absorption in the air between the crystal and IR detector.

The DFG process was quasi-phase matched



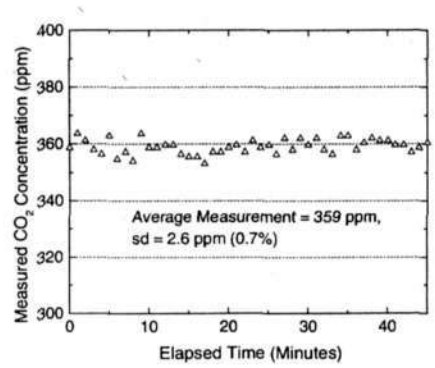
CTuS4 Fig. 2. Conversion efficiency and tuning characteristics of a DFG spectrometer.



CTuS4 Fig. 3. CO_2 spectrum near 2387 cm^{-1} (4.2 μm).

(QPM) in a multi-channel PPLN crystal (Λ = 22.4–23.1 μm; 0.1 μm steps). For wavelength tuning of the mid-IR radiation from 3.25–3.65 μm, the PPLN crystal was translated perpendicular to the optical axis of the QPM channels at a constant temperature of 24.5 °C. DFG wavelengths of 3.65 to 4.4 μm were phasematched using the 23.1 μm QPM channel and crystal temperatures ranging from 24.5–110 °C. In fact, using a combination of temperature and grating period, any wavelength in the mid-infrared tuning range of the DFG based gas sensor can be conveniently accessed.

Sensitive and selective detection of CO_2, N_2O, CH_4 and H_2CO was realized. Figure 3 shows a spectrum of two lines of a fundamental CO_2 band near 2378 cm^{-1} at a pressure of 96.4 Torr. Calibration of the sensor was achieved by monitoring a CO_2 line at 2387.258 cm^{-1} using a calibrated 359 ppm mixture of



CTuS4 Fig. 4. CO_2 concentration measured using a calibrated 359 ppm CO_2 in air mixture.

CO_2 in air.[3] Over a 45 minute period (45 measurements), the gas sensor operated with a measurement standard deviation of ±0.7% (±2.6 ppm), (4s averaging/measurement). A sensor linewidth of ~40 MHz was inferred by comparing the FWHM of an experimentally acquired CH_4 spectrum (not shown) to the predicted Voigt linewidth FWHM.

In conclusion, a robust, compact and widely tunable fiber coupled mid—infrared sensor suitable for the sensitive, selective and real-time detection of various trace gases will be described. Issues such as power scaling, portability and high-resolution spectroscopy will also be discussed.

1. D.G. Lancaster, L. Goldberg, J. Koplow, R.F. Curl, F.K. Tittel, Electronics Letters, **34,** 13, pp. 1345–1346 (1998).
2. D. Richter, D.G. Lancaster, R.F. Curl, W. Neu, F.K. Tittel, Applied Physics B, **67,** 3, pp. 347–350 (1998).
3. Courtesy of E. Dlugokencky, NOAA, Climate Monitoring & Diagnostic Laboratory, Boulder CO.