

Fast, sensitive trace gas detection with a portable solid-state mid-infrared laser sensor

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The purpose of this work was to construct a portable solid-state gas sensor based on tunable laser difference frequency generation (DFG), and to achieve detection limits of < 10 ppb (parts in 10^9 , by mole fraction) for several atmospheric trace gases. Earlier feasibility tests [1, 2] indicated that this can be done with the use of periodically poled lithium niobate (PPLN). Its quasi-phase-matching properties can be tailored for 2 - 5 μm DFG with near-infrared diode lasers. This, along with large non-linearity and good optical quality, makes PPLN the ideal mixing material for DFG applications targeted at species like CO, N_2O , CO_2 , SO_2 , H_2CO , and CH_4 . Reported herein are the design, construction, and performance testing of an all-solid-state DFG sensor for carbon monoxide (Figure 1).

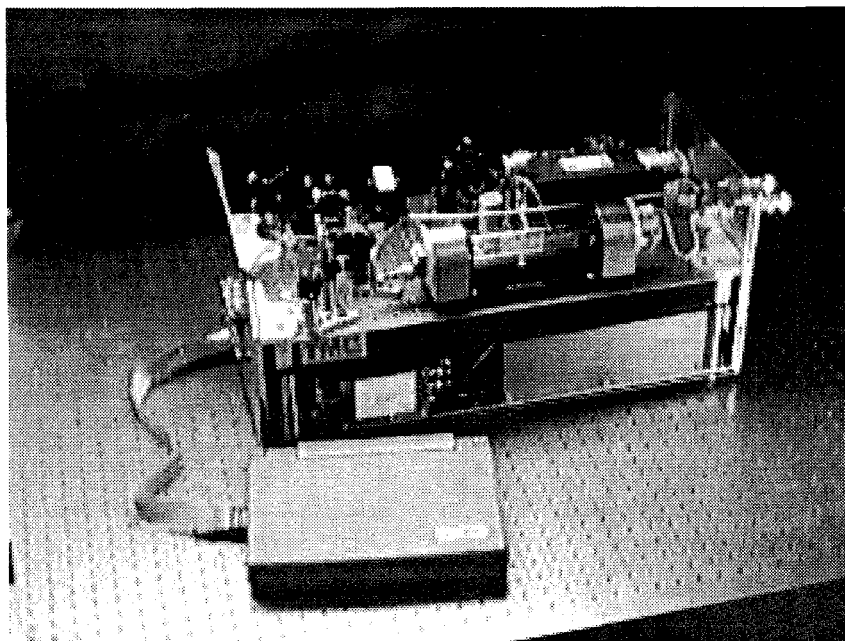


Figure 1. A photograph of the instrument with cover removed, showing the optical breadboard and the electronic components mounted below.

The sensor employs a 750 mW diode-pumped monolithic Nd:YAG ring laser at 1064.5 nm (signal), and a 100 mW Fabry-Perot diode laser at 865 nm (pump). Difference frequency mixing is performed in a 19 mm long PPLN crystal. The z-cut crystal has eight 1.3 mm wide strips with domain grating periods from 22.4 μm to 23.1 μm in 0.1 μm steps. For DFG at 4.6 μm (idler), the optimum period was found to be 22.9 μm at room temperature. With 70 mW pump power and 750 mW signal power, 4.4 μW idler power was measured. The idler beam is directed into a compact multipass cell with 18.3 m effective path length, and focused onto a Peltier-cooled HgCdTe detector. Low-drift dc coupling of the detector allowed the direct measurement of idler power necessary to determine percent optical absorption. Detector output is digitized by a 12 bit, 100 kS/s analog-to-digital converter connected to a laptop computer. A small computer-controlled shutter is used to block the Nd:YAG beam for 10 s every 3 minutes, allowing the measurement of dark detector voltage. For calibration of the DFG sensor, we measured absorption at the peak of the R(2) transition of CO in air flowing from a high-pressure cylinder. The factory-assigned CO mole fraction in the cylinder was 9000 ± 50 ppb. Measured absorption normalized to CO mole fraction in the sample is the calibration constant: $c = (5.980 \pm 0.006) \cdot 10^{-5} \cdot \text{ppb}^{-1}$. The error given here does not include the uncertainty in concentration of the reference sample, and represents uncertainty in the

measurement of absorption only. The calibration constant was used to compute the CO concentration from absorption measured in other air samples. Figure 2 shows a record of CO concentration in laboratory air over 24 hours. Each data point corresponds to a 10 second average.

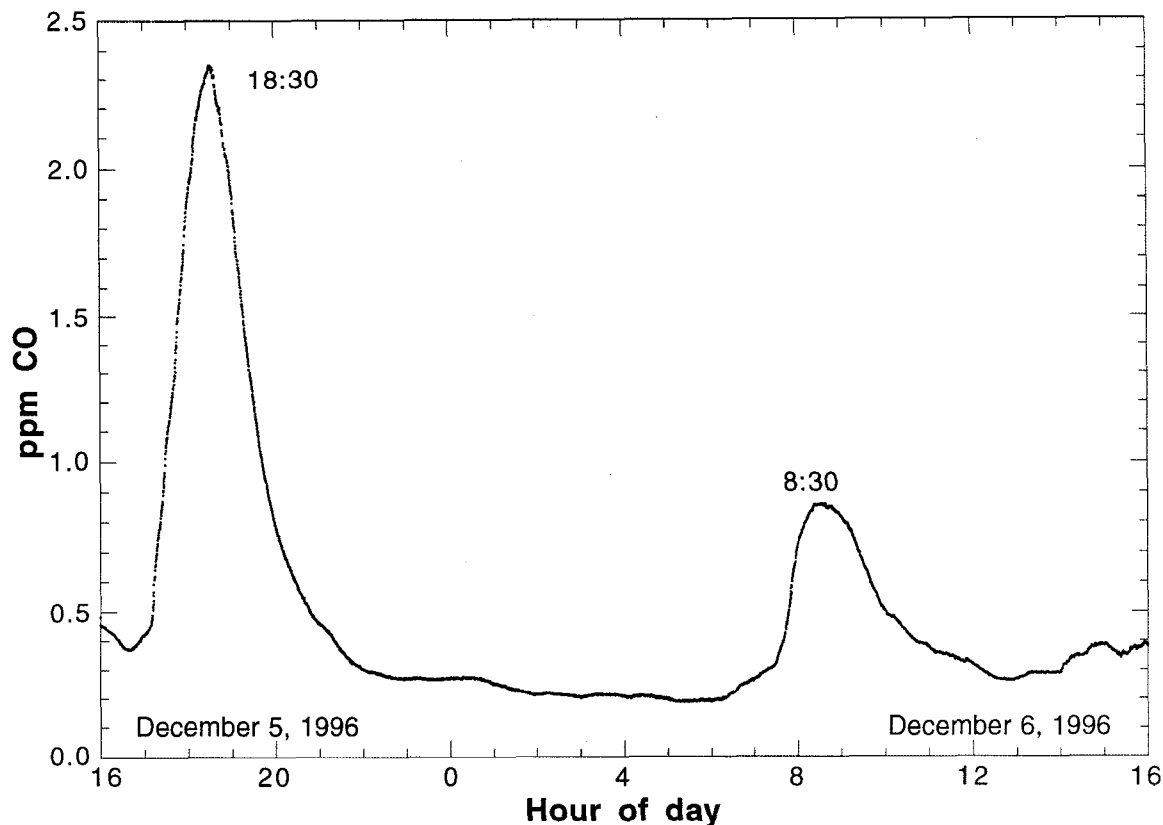


Figure 2. CO concentration in room air versus time recorded at Rice University. The multipass cell was left open to allow convective flow of air. The peaks were observed during the evening and morning rush hours.

This is the first demonstration of a portable, high-precision gas sensor based on diode-pumped mid-infrared DFG. The instrument employs no cryogenic or high-voltage components, measures $31\text{ cm} \times 31\text{ cm} \times 65\text{ cm}$, and is controlled by a laptop computer. It showed reliable unattended operation in the field for more than 16 days, without appreciable loss of output power or precision. The instrument can be modified for the detection of several trace gases. An external-cavity diode laser can provide a tuning range of $\geq 700\text{ cm}^{-1}$, allowing the detection of N_2O , CO_2 , SO_2 , H_2CO , and CH_2 . This technology has potential benefits for trace gas detection applications, since cost, power consumption, and size of the laser pump sources can be reduced further. Two fiber-coupled 10 mW diode lasers can be used as pump sources, one of the lasers being used in the external-cavity configuration for improved tuning range and predictability of wavelength. With bulk PPLN as the mixing element, reduction in pump power to 10 mW levels implies a factor of 1000 reduction in DFG power. However, DFG conversion efficiencies for PPLN waveguide devices should exceed $10\%\cdot\text{W}^{-1}$ [3], offering an excellent remedy for loss in pump power. Fiber coupling of the pump lasers into the waveguide would greatly improve stability of optical alignment, reduce sensitivity to vibration, reduce size, and lower the cost of the DFG sensor.

1. K. P. Petrov, L. Goldberg, W. K. Burns, R. F. Curl, F. K. Tittel, *Opt. Lett.* **21**, 86 (1996).
2. K. P. Petrov, S. Waltman, E. J. Dlugokencky, M. A. Arbore, M. M. Fejer, F. K. Tittel, L. W. Hollberg, *Appl. Phys. B* **64**, 567 (1997).
3. M. A. Arbore, M.-H. Chou, M. M. Fejer, *CLEO'96 Technical Digest Series* **9**, 120 (1996).