Advanced Infrared Semiconductor Laser based Chemical Sensing Technologies

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Abstract: Recent advances in the development of sensors based on the use of both infrared diode lasers and quantum cascade lasers (QCLs) for the detection, quantification and monitoring of both small and large molecular gas species with resolved and unresolved spectroscopic features respectively will be reported.

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1. Introduction

Ultra-sensitive, selective and fast response chemical analysis of gases based on molecular absorption laser spectroscopy is a well-established technology [1]. The architecture and performance of several sensitive, selective and real-time gas sensors based on infrared semiconductor lasers will be described. To date we have detected 16 gases (CH_4, H_2S, N_2O, CO_2, CO, NO, H_2O, SO_2, NH_3, C_2H_2, OCS, C_2H_4, H_2CO, C_2H_5OH, C_2HF_5 and CH_3COCH_3) at the ppm to ppt level [1,2]. High sensitivity requires sensitivity enhancement schemes such as a multipass gas absorption cell, cavity absorption enhancement, or photoacoustic spectroscopy. These methods can measure absorption coefficients as low as 10^{-9} cm^{-1} for field deployable gas sensors. A novel technique called Quartz-Enhanced Photoacoustic Spectroscopy (QEPAS), which was first reported in 2002 [3,4] will be emphasized. Our progress in QEPAS optimization has now resulted in a 60 fold increase in detection sensitivity as a result of incremental improvements in optical coupling, acoustic design and electronics (see Table 1). QEPAS allows a breakthrough in size, weight, robustness and cost as well as wireless sensor network nodes [5] for laser-based chemical sensing applications (see Fig 1). Applications include the monitoring of single and multiple gas species for applications in such diverse fields as in environmental monitoring, industrial process control, medical diagnostics and homeland security [1, 2]

2. Infrared Semiconductor Laser based trace gas platforms and measurements

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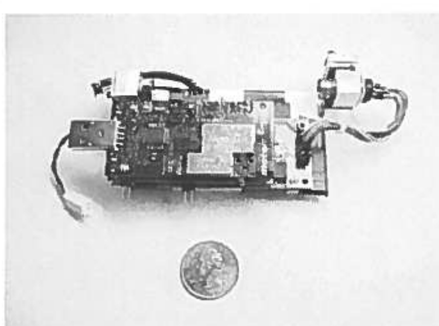

Fig. 1: Miniature laser absorption spectroscopy (LAS) based CO_2 sensor.

Molecule (Host)	Frequency, cm^{-1}	Pressure, Torr	NNEA, $cm^{-1}W/Hz^{½}$	Power, mW	NEC (τ=1s), ppmv
H_2O (N_2)**	7306.75	60	1.9×10^{-9}	9.5	0.09
HCN (air: 50% RH)*	6539.11	60	$< 4.3\times10^{-9}$	50	0.16
C_2H_2 (N_2)*	6523.88	720	4.1×10^{-9}	57	0.03
NH_3 (N_2)*	6528.76	575	3.1×10^{-9}	60	0.06
C_2H_4 (N_2)*	6177.07	715	5.4×10^{-9}	15	1.7
CH_4 (N_2)*	6057.09	950	2.9×10^{-8}	13.7	2.1
CO_2 (breath ~100% RH)	6361.25	150	8.2×10^{-9}	45	40
H_2S (N_2)*	6357.63	780	5.6×10^{-9}	45	0.20
CO_2 (N_2+1.5% H2O) *	4991.26	50	1.4×10^{-8}	4.4	18
CH_2O (N_2:75% RH)*	2804.90	75	8.7×10^{-9}	7.2	0.12
CO (N_2)	2196.66	50	5.3×10^{-7}	13	0.5
CO (propylene)	2196.66	50	7.4×10^{-8}	6.5	0.14
N_2O (air+5%SF_6)	2195.63	50	1.5×10^{-8}	19	0.007
C_2H_5OH (N_2)**	1934.2	770	2.2×10^{-7}	10	90
C_2HF_5 (N_2)***	1208.62	770	7.8×10^{-9}	6.6	0.009
NH_3 (N_2)*	1046.39	110	1.6×10^{-8}	20	0.006

* - Improved microresonator
** - Improved microresonator and double optical pass through ADM
*** - With amplitude modulation and metal microresonator

NNEA – normalized noise equivalent absorption coefficient.
NEC – noise equivalent concentration for available laser power and τ=1 s time constant, 18 dB/oct filter slope.

Table 1: QEPAS Performance for 12 Trace Gas Species

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