Deployment of a Quantum Cascade Laser Open- Path Gas Sensor for Water Vapor and Wood Smoke Analysis

Ekua N. Bentil[1], Charles Amuah[1,2], Anna P. M. Michel[3], Moses J. Eghan[2], James A. Smith[4], and Claire F. Gmachl[1]

[1]Department of Electrical Engineering, Princeton University, Princeton, NJ 08544 USA
[2]School of Physical Sciences, University of Cape Coast, Cape Coast, Ghana
[3]Princeton Institute for the Science and Technology of Materials, Princeton University, Princeton, NJ 08544 USA
[4]Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ 08544 USA
Author email: eanane@princeton.edu

Abstract: We present results from a widely tunable (296 cm^{-1}) Quantum Cascade laser based-sensor used in sensing water vapor and target gases found in wood smoke in the rural fishing village of Elmina, Ghana.

OCIS codes: (010.0280) Remote sensing and sensors; (140.5965) Semiconductor lasers, quantum cascade

1. Introduction

In areas of Ghana where fishing is a leading occupation, most women spend many hours smoking fish. Fish smoking serves as an alternative to cold stores and also as a variation in fish processing. In these communities, several types of wood are used for such smoking and other cooking activities. The wood when burned releases gases that are detrimental to one's health if inhaled .Therefore, novel sensors capable of measuring these gases and other contributors to poor air quality are needed. Most gases have unique absorption signatures in the mid-infrared (mid-IR) region. Quantum Cascade (QC) lasers [1,2] are tunable, semi-conductor light sources in the mid-infrared region and are therefore useful in gas spectroscopy. QC laser-based sensors possess several desirable qualities. They are portable, highly sensitive, fast, non-invasive and allow real time data analysis.

In this work, a third-generation sensor, a QC laser open-path system (QCLOPS) is used for multi-species sensing. The sensor was deployed in Elmina, Ghana, in the summer of 2010, during the peak fishing season. In addition to water vapor, the two gases from the wood smoke that were targeted during this deployment were 2-methyl phenol and benzyl alcohol. These gases were chosen because they are harmful, prevalent in all ten wood species targeted and have fingerprints in the emission region of the available QC laser (965 – 1260 cm^{-1}).

2. System design and mode of operation

This model of QCLOPS is a two tier laser system (Fig. 1a), and a modification of a previous design [3]. The system employs a Daylight Solutions Inc QC laser which is external cavity tuned, thermoelectrically cooled and operated in pulsed mode. Due to the broad absorption features of the two wood smoke gases, the laser is tuned across the entire tuning range of 296 cm^{-1} wavenumbers in steps of 1 cm^{-1}. The laser radiation is transmitted through the air where it interacts with the water vapor and wood smoke. The radiation is reflected back by a retro-reflector to a thermoelectrically cooled Vigo detector. The round trip path length of the laser radiation is about 58 m. The signal from the detector is digitized (NI PXI-5105) and saved to a file using LabView software (Fig. 1b). Alignment is aided with the help of a HeNe laser.

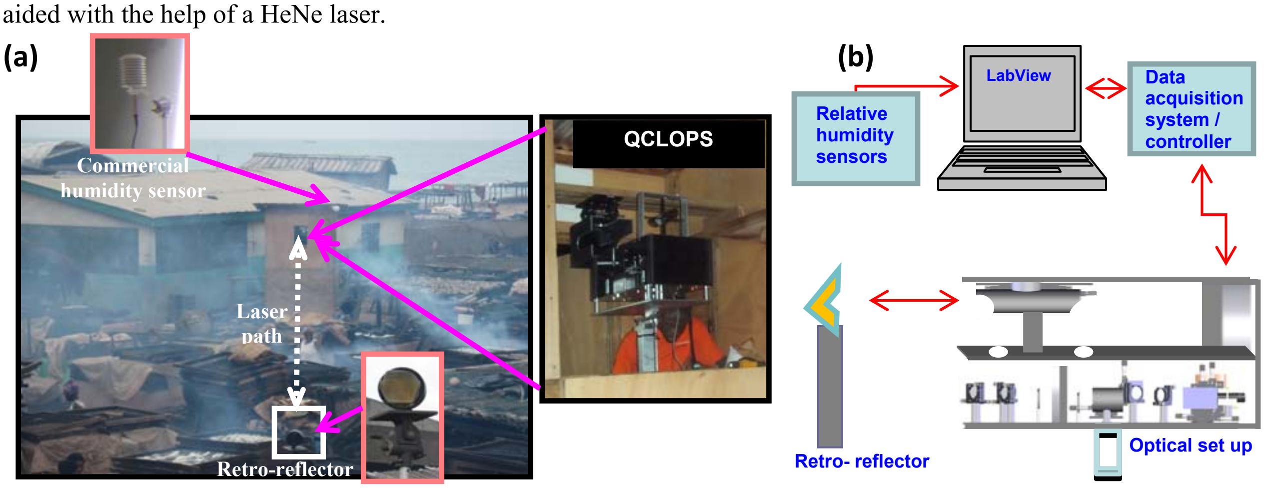

Fig. 1a. Deployment site in Elmina, on a day when many of the women were smoking fish: The picture shows the kiosk (housing the sensor), the retro-reflector and the humidity sensor. **b.** Schematic diagram of the sensor.

3. Pre- and postdeployment analysis and discussion

Prior to the deployment, absorption measurements were performed to test the ability of QCLOPS in sensing benzyl alcohol and 2-methyl phenol gases. Two gas cells, each containing one of the two gases (100 ppm for 2-methy phenol and an unknown concentration for benzyl alcohol), were placed in the QC laser path and the absorption features computed. The results, compared to those measured using a Fourier transform infrared spectrometer, show good agreement (Fig. 2a).

During the field deployment, a commercial relative humidity sensor (Cambell CR800) was mounted alongside the system for water vapor concentration comparison with QCLOPS. Figure 2b shows the distinct and narrow absorption features of water vapor during one complete scan. These features when compared with those obtained from the Hitran database show good agreement. This confirms that QCLOPS was indeed working well in the field. One of the biggest challenges faced during the deployment was the randomness in the selection of which wood specie was being burnt at each fish smoking unit at any given time. Since the type of wood being burnt is directly related to the type of gas being emitted in the smoke, different absorption features should be expected during the different peak fish smoking times. Preliminary data analysis confirm this to be true (Fig. 2c). Although some of the absorption peaks correspond to the gases of interest (for example, as shown in Fig. 2c(iv), x=1036 cm^{-1} for Benzyl alcohol, y=1176 cm^{-1} and z=1244 cm^{-1} for 2-methyl phenol), others are still not accounted for. Predeployment analysis of smoke from ten of the typical wood specie used in fish smoking in Elmina suggest the presence of a number of volatile and semivolatile organic gases. The presence of these additional gases are most likely responsible for the unaccounted for peaks. Additional data analysis is being done to extract the relevant features from this complex data set.

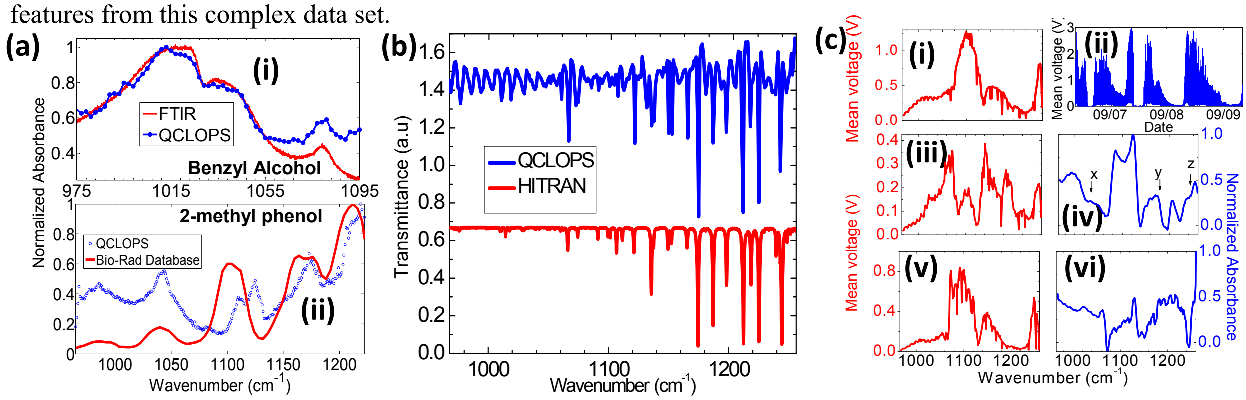

Fig. 2. a. Comparison between absorption measurements using QCLOPS and **(i)** a laboratory FTIR and **(ii)** Bio-Rad Lab's database . **b.** Comparison between absorption features of water vapor lines from the Hitran database and as detected by QCLOPS. **c.(i)** A typical reference intensity for the sensor. **(ii)** A plot of voltage vs time, showing data collected from the sensor over a period of four days in 2010. **(iii)& (iv)** Data collected over one scan and the calculated absorbance, resp., during intensive fish smoking during a day in August 2010. Points x, y and z are absoption peaks of benzyl alcohol (x) and 2 methylphenol (y,z). **(v)& (vi)** Data similar to that in c(iii) and c(iv) but collected on a fish smoking day in September 2010.

4. Conclusion

We have designed, built and successfully deployed in rural Ghana, a multi-species broadly tunable mid-IR gas sensor for the detection of complex chemicals in wood smoke. Analysis of the wood smoke data in addition to giving relevant information on the gases present could also throw some light on the scattering as a result of the particulates in the smoke.

5. Acknowledgement

The authors thank MIRTHE (NSF-ERC) and Princeton University Technology for Developing Regions for funding the project. We also acknowledge Daylight Solutions Inc. for the QC laser; Microbac Laboratories Inc. for the initial analysis of the wood samples; Bio-Rad Laboratories for the gas absorption database; and Alexandra Ritter and Richard Cendejas for helping to build the sensor.

6. References

1. J. Devenson, et al., "InAs/AlSb quantum cascade lasers emitting at 2.75–2.97 μm," *Appl. Phys. Lett., vol. 91, pp. 251102-251102-3,* 2007.
2. R. Colombelli, et al., "Farinfrared surface-plasmon quantum-cascade lasers at 21.5 µm and 24 µm wavelengths," *Appl. Phys. Lett., vol. 78, pp. 2620- 2622*, 2001.
3. A.P Michel, et al.,"Quantum cascade laser open-path system for remote sensing of trace gases in Beijing, China," *Optical Engineering, vol. 49, Issue 11*, 2010.