Mid-IR Optoelectronics: Materials and Devices
Room Lecture Hall, Nielsen Hall - Session MIOMD-WeM2

Sensing

Moderator: Gerard Wysocki, Princeton University

10:30am **MIOMD-WeM2-14 Mid-Infrared Trace Gas Detection Enhanced by Tuning Fork, Optical Cavity and Hollow-Core Fiber***, Wei Ren,* The Chinese University of Hong Kong **INVITED**

Mid-infrared trace gas detection plays a significant role in many sectors such as energy systems, transportation, environmental monitoring, agriculture, safety, and security. With quantum cascade laser (QCL) and interband cascade laser (ICL) used as the light source, it is promising to develop high-resolution mid-infrared laser-based spectrometers with a portable size and low power consumption. Photoacoustic spectroscopy (PAS) and photothermal spectroscopy (PTS) are two highly sensitive methods for chemical analysis by detecting the absorption-induced acoustic wave and refractive index change, respectively. However, there is still room for improvement compared to the most sensitive spectroscopic techniques such as cavity ring-down spectroscopy (CRDS) or noise-immune cavity-enhanced optical-heterodyne molecular spectroscopy (NICE-OHMS).

In this talk I will discuss recent advances in the development of ultra-sensitive PAS enhanced by tuning fork and optical cavity, as well as PTS enhanced by hollow-core fiber and phase-sensitive interferometry. PAS signal is proportional to the overall incident laser power (W). The most recent innovation of PAS with a double opto-acoustic resonance enables ultra-sensitive and wide-dynamic-range gas detection [1]. The merging of a high-Q-factor acoustic resonator (i.e., quartz tuning fork) with a high-finesse optical resonator leverages on a double standing wave effect. By using a mW-level QCL, the doubly resonant QEPAS sensor demonstrates ppt-level CO detection in the mid-infrared. In comparison, PTS signal is proportional to the light power density (W/m^2), which can be readily achieved in a hollow-core fiber [2]. By taking advantage of mid-infrared fiber technology, I will present our recent innovation of mid-infrared-pump near-infrared-probe PTS for trace gas sensing [3-5]. The variation of refractive index caused by the pump-laser can be sensitively detected by agile interferometric methods such as the Mach-Zehnder interferometer, heterodyne interferometer, Fabry-Pérot interferometer, and fiber mode interferometer.

11:00am **MIOMD-WeM2-17 Highly Selective Toluene Detection using Quartz Enhanced Photoacoustic Spectroscopy at λ = 13.71 µm***, Kumar Kinjalk,* IES, University of Montpellier, CNRS, France*; G. Menduni, A. Zifarelli, M. Giglio,* PolySense Lab, Dipartimento Interateneo di Fisica, University and Politecnico of Bari, Italy*; R. Teissier,* MirSense, France*; A. N. Baranov,* IES, University of Montpellier, CNRS, France*; A. Sampaolo,* PolySense Lab, Dipartimento Interateneo di Fisica, University and Politecnico of Bari, Italy

Among anthropogenic and natural volatile organic compounds (VOCs), benzene, toluene, ethylbenzene, and xylene isomers (commonly called BTEX) are the main sources of air pollution. The World Health Organization has classified BTEX compounds as highly aggressive cancer-causing agents, and therefore there is a high interest in developing efficient techniques for their detection.

Although optical sensors proved high performances in terms of sensitivity and selectivity, there is a lack of suitable sources emitting in the 13-15 µm wavelength range, where BTEX exhibits strong absorption features. This work demonstrates a custom-built InAs-based QCL operating at 13.71 µm and its employment in a quartz enhanced photoacoustic spectroscopy (QEPAS) sensor for detecting toluene. The fabricated QCL allowed the excitation of the absorption lines of toluene at 729.39 cm^{-1}. The QEPAS sensor employs a quartz tuning fork (QTF) excited by sound waves generated via a photoacoustic effect to detect gas traces. The QTF has a fundamental resonance frequency of f_0=12.457 kHz and a quality factor Q=22,197 at 200 Torr. A 2f-wavelength modulation detection scheme is implemented by modulating the QCL current with a frequency of $f_0/2$ and acquiring the f_0 component of the QTF using a lock-in amplifier. Starting from the obtained calibration curve and the measured noise level, a minimum detection limit of 592 ppb at 0.1s of integration time is achieved. Using the Allan deviation analysis, a detection limit of 150 ppb can be obtained at 10 s of integration time. Furthermore, the study of gas mixtures revealed no spectral interference from benzene or ethylbenzene.

11:20am **MIOMD-WeM2-19 Quartz Enhanced Photoacoustic Spectroscopy Exploiting Beat Frequency Approach for Environmental Monitoring of Pollutants***, Giansergio Menduni,* PolySense Lab - Dipartimento Interateneo di Fisica, University and Politecnico of Bari, Italy

Fast and accurate monitoring of pollutant gases in the environment is critical to safeguard public health. Among different sensing solutions, quartz enhanced photoacoustic spectroscopy (QEPAS) is a highly sensitive optical technique, implementing quartz tuning forks (QTFs) to convert sound waves, produced by gas molecules when modulated light is absorbed, into an electric signal. The slow signal acquisition speed depends on the long scan time of the gas absorption feature, requiring few minutes. Furthermore, the real-time monitoring of the QTF resonance frequency (f_0) and quality factor (Q) cannot be carried out during the laser tuning range scan. In this work, the beat frequency-QEPAS (BF-QEPAS) approach was employed to both overcome these limitations and detect NO, using an interband cascaded laser emitting at a central wavelength of 5.263 µm and a 12.4 kHz custom QTF. In BF-QEPAS, a staircase ramp with a rising time of ~1s and a sinewave detuned with respect to f_0 allow exciting the QTF with an acoustic pulse. Considering the typical BF-QEPAS signal, i) the gas concentration is retrieved from the value of the first peak, ii) f_0 is measured from the time difference between the detectable peaks, and iii) Q is determined by the decay time, evaluated with an exponential fit of the detectable peaks. We achieved a minimum detection limit and a normalized noise equivalent absorption of 180 ppb at 5 ms of the lock-in time constant and $2.5 \cdot 10^{-9}$ $cm^{-1}WHz^{-1/2}$, respectively. Furthermore, the BF-QEPAS signal allows determining the f_0 with an accuracy of 0.1 Hz and the Q with a relative error of ~1%.

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