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Gas spectroscopy – Editorial special issue photoacoustics

Photoacoustic spectroscopy is one of the most powerful techniques for gas sensing that covers a broad range of applications, including atmospheric monitoring, industrial process control, security and biomedical applications. Based on the photoacoustic effect, the detection of acoustic waves generated from gases exposed to light allows a precise measurement of gas concentration. From the visible to the terahertz spectral range, photoacoustic spectroscopy can be employed with all kinds of light sources. Several different detection methods to pick up photoacoustic waves have been implemented over the years, among them: quartz tuning forks, membrane microphones in the resonant cell, and cantilever and bridge acoustic sensors for miniaturized detectors. Specific sensor designs have been proposed to enhance performance, for example, the use of optical resonance cavities to enhance the light-gas interaction. This Special Issue plans to review a collection of high-quality research articles focused on new developments in photoacoustic sensors for applications as well as novel technologies, with a focus on the study of the fundamentals and methodology of photoacoustic detection.

In terms of applications, the focus on photoacoustic gas sensing is mostly aimed at applications in environmental monitoring. This Special Issue illustrated this direction with several papers like "*Humidity enhanced N2O photoacoustic sensor with a 4.53 μm quantum cascade laser and Kalman filter*" by Yuan Cao and coauthors [1]. In this manuscript, it was demonstrated the realization of a high-sensitivity N2O photoacoustic sensor using a 4.53 μm quantum cascade laser with a minimum detection limit of 28 ppbv in 1 s and a measurement precision of 34 ppbv by implementing a Kalman adaptive filtering to remove the shot-to-shot variability related to the real-time noise. In "*Compact and portable quartz-enhanced photoacoustic spectroscopy sensor for carbon monoxide environmental monitoring in urban areas*" by Fabrizio Sgobba and coauthors [2] a 19-inch rack-mounted 3-unit sized Quartz Enhanced Photoacoustic Spectroscopy (QEPAS) trace gas sensor has been designed and realized for real-time carbon monoxide monitoring in ambient air, and the sensor was tested outdoors in a trafficked urban area for several hours. In "*Compact quartz-enhanced photoacoustic sensor for ppb-level ambient NO2 detection by use of a high-power laser diode and a tuning fork*" by Shangzhi Li and coauthors [3] a compact quartz-enhanced photoacoustic sensor for ppb-level ambient NO2 detection was demonstrated. By implementing a high-power blue laser diode module with a small divergence angle and a custom grooved quartz tuning fork with 800-μm prong spacing a minimum detectable concentration (1σ) of 7.3 ppb with an averaging time of 1 s has been achieved and continuous measurements covering a five-day period have been performed to demonstrate the stability and robustness of the reported NO2 sensor system. In "*Integrated near-infrared QEPAS sensor based on a 28 kHz quartz tuning fork for online monitoring of CO2 in the greenhouse*" by Yihua Liu and coauthors [4] a highly sensitive and integrated near-infrared CO2 sensor was developed based on quartz-enhanced photoacoustic spectroscopy. The QTF, acoustic micro resonator, gas cell, and laser fiber are integrated, resulting in a super compact acoustic detection module. At atmospheric pressure, a 5.4 ppm detection limit at a CO_2 absorption line of 4991.25 cm^{-1} was achieved with an integration time of 1 s. This portable CO_2 sensor system was tested for 24 h continuous monitoring of CO_2 in the greenhouse located in Guangzhou city. Finally, in *Mid-infrared intracavity quartz-enhanced photoacoustic spectroscopy with pptv – Level sensitivity using a T-shaped custom tuning fork* by Jakob Hayden and coauthors [5] the sensitivity of quartz-enhanced photoacoustic spectroscopy has been boosted by implementing a resonant optical power buildup inside a high-finesse cavity, reaching an optical power amplification of ~100 and detection limits of 260 ppt and 750 ppt for CO and N2O, respectively.

Photoacoustic gas sensing biomedical applications have also been demonstrated in "*Quartz-enhanced photoacoustic NH3 sensor that exploited a large-prong-spacing quartz tuning fork and an optical fiber amplifier for biomedical applications*" by Zhijin Shang and coworkers [6]. They demonstrated a sensor system for exhaled ammonia (NH3) monitoring exploiting quartz-enhanced photoacoustic spectroscopy (QEPAS). A NH3 minimum detectable concentration of 14 ppb at 1 s averaging time was achieved, and continuous measurements of the NH3 level exhaled by healthy volunteers were carried out to demonstrate the potentiality of the developed sensor for breath analysis applications. In "*Photoacoustic heterodyne breath sensor for real-time measurement of human exhaled carbon monoxide,*" Biao Li and coworkers [7] reported on a breath sensor for real-time measurement of human exhaled carbon monoxide by combining the conventional PAS with a beat-frequency detection algorithm. A detection sensitivity of 26 ppb was achieved with an integration time of 1 ms. Test results from the eight volunteers confirm that the exhaled CO concentration levels of the smokers were significantly higher than those of the nonsmokers.

This Special Issue also contains papers associated with a novel QTF-based sensitive trace gas detection technique called light-induced thermoelastic spectroscopy (LITES). In "*Ultra-highly sensitive HCl-LITES sensor based on a low-frequency quartz tuning fork and a fiber-coupled multi-pass cell*", Shunda Qiao and coauthors [8] demonstrated an ultra-highly sensitive LITES-based hydrogen chloride (HCl) sensor with a minimum detection limit (MDL) of 148 ppb at an integration time of 200 ms. In "*Quartz tuning forks resonance frequency matching for laser spectroscopy sensing*", Yufei Ma and coworkers [9] reported on the performance of quartz tuning fork (QTF) based laser spectroscopy sensing architecture employing two sensing modules, one based on

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quartz-enhanced photoacoustic spectroscopy (QEPAS) and one on light-induced thermoelastic spectroscopy (LITES) technique. In *"Highly sensitive HF detection based on absorption enhanced light-induced thermoelastic spectroscopy with a quartz tuning fork of receive and shallow neural network fitting",* Xiaonan Liu and coworkers [10] reported on a highly sensitive hydrogen fluoride (HF) sensor based on LITES technique. A Herriott multi-pass cell (MPC) with an optical length of 10.1 m was selected to enhance the laser absorption. At an integration time of 110 s, the minimum detection limit (MDL) achieved was 71 ppb. Finally, in "*Quartz tuning fork-based demodulation of an acoustic signal induced by photo-thermo-elastic energy conversion*", Ziting Lang and co-workers reported on a gas sensing method based on LITES, also reported as quartz-enhanced photothermal spectroscopy (QEPTS), demodulated by a quartz tuning fork (QTF) [11]. The method proposed in this paper utilizes the second QTF to sense the acoustic wave produced by the first QTF owing to the vibration resulting from the photo-thermo-elastic effect. The measured results indicate that this technique had an enhanced signal-to-noise ratio (SNR) of 1.36 times when compared to the traditional LITES.

In conclusion, the papers in this Special Issue cover a diverse range of photoacoustic gas sensing applications. We hope that these works will also be interesting to the readers in the research communities.

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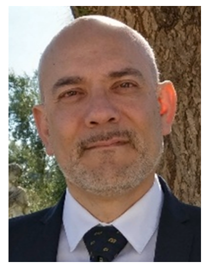

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