Recent Advances in Quartz Enhanced Photoacoustic Spectroscopy for Trace Gas Sensing

V. Spagnolo¹, P. Patimisco¹, A. Sampaolo¹,², G. Scamarcio¹, F.K. Tittel²

1. Dipartimento Interateneo di Fisica, Università e Politecnico di Bari and CNR - Istituto di Fotonica e Nanotecnologie (IFN) UOS Bari, Via Amendola 173, 70126 Bari BA, Italy
2. Department of Electrical and Computer Engineering, Rice University, Houston, Texas, USA

We will report on recent advances of the quartz-enhanced photoacoustic (QEPAS) technique based on quantum cascade lasers (QCLs) in order to realize QEPAS sensors with improved sensitivity and selectivity. The QEPAS technique is based on the photoacoustic effect and exploits the enhancement of acoustic energy density provided by a quartz tuning fork (QTF), which acts as a high quality factor piezoelectric acoustic transducer [1]. An important advantage of the QEPAS technique is that no optical detection is required.

The architecture and performance of innovative and sensitive, real-time gas sensors based on QEPAS technique will be reviewed:

1) Mid-IR fiber coupled QEPAS sensors.
   The use of hollow-core waveguides allows single-mode optical coupling between external cavity mid-IR QCLs and QEPAS sensor systems. The fiber coupling system converts the astigmatic beam emitted by the mid-IR QCLs into a TEM₀₀ mode and permits the exploitation of the wide tunability of QCL sources, avoiding optical misalignment with the photoacoustic detection module produced by mechanical rotations of the external-cavity grating [2, 3].

2) Intra-cavity mid-IR QEPAS (I-QEPAS) sensor.
   Ultra-sensitive I-QEPAS spectrometers using a QCL coupled to a high-finesse optical resonant cavity which included QTF was developed and tested for gas detection. Laser optical power buildup factors of several hundreds were achieved. Comparison with standard QEPAS technique performed under the same experimental conditions confirmed that the I-QEPAS sensitivity scales with the intracavity laser power enhancement factor [4, 5].

3) THz QEPAS sensors.
   To extend the QEPAS technique into the THz spectral range we employed custom QTFs. The QTF prongs spacing is adapted to the focused THz beam waist. Normalized noise-equivalent absorption down to $2\times10^{-10}$ W cm⁻¹ Hz⁻¹/², comparable with the best results of mid-IR QEPAS systems, has been obtained [6, 7].

Furthermore, we explored new QTF designs in order to optimize resonator geometry and piezo-electric charge collection in terms of trace gas sensing performances. QEPAS sensors developed up to now were based on a standard QTF geometry, optimized for timing applications. A detailed analysis of the piezolectric properties in terms of resonance frequencies, quality factors and gas damping effects will be discussed.

References