Radial Cavity Quartz-enhanced Photoacoustic Spectroscopy

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Abstract— This paper introduces Radial-cavity Quartz-Enhanced Photoacoustic Spectroscopy (RC-QEPAS) as a novel method for enhanced trace gas analysis, particularly focusing on hydrogen cyanide (HCN) detection. This technique employs a radial cavity coupled with a quartz tuning fork (QTF) to amplify the QEPAS signal and simplify optical alignment.

Summary: Photoacoustic Spectroscopy (PAS) has emerged as a high-sensitivity and high-selectivity optical gas sensing technology. The invention of Quartz Enhanced Photoacoustic Spectroscopy (QEPAS) in 2002 marked a significant advancement in this field. Traditional QEPAS configurations, however, are limited by the need for long resonators and precise alignment, making them unsuitable for long wavelength sources like quantum cascade lasers and THz sources.

RC-QEPAS was developed to address these limitations. Unlike longitudinal resonators, the radial cavity in RC-QEPAS facilitates easier alignment and stronger signal enhancement. Theoretical analysis and experimental research were conducted to optimize this configuration. Finite Element Method (FEM) simulations were used to analyze acoustic pressure distributions and optimize the cavity's geometry.

An experimental setup with a 1.39 μm near-infrared fiber-coupled DFB diode laser was used to validate the RC-QEPAS technique. Atmospheric H2O vapor was targeted for testing. The results demonstrated a significant enhancement in the signal-to-noise ratio (SNR) compared to traditional QEPAS configurations.

RC-QEPAS represents a major breakthrough in photoacoustic spectroscopy. By creating a radial resonance mode and coupling it with a QTF, this method substantially increases acoustic pressure, thereby enhancing the QEPAS signal. The radial cavity's dual role as a resonator and gas cell simplifies the sensor structure and reduces gas sampling volume, making RC-QEPAS advantageous for compact and sensitive acoustic detection modules. This innovation opens up new possibilities in gas sensing technology, especially for sources with poor beam quality.

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