Cavity Enhanced Optical Feedback Assisted Quartz Enhanced Photo-Acoustic Spectroscopy with a 10.4 μm External-Cavity Quantum Cascade Laser

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Introduction
The objective of this work is an extension of a recently developed method of double-resonance photo-acoustic spectroscopy (DR-PAS)1,2 to the mid-IR spectral range with a commercially available External Cavity Quantum Cascade Laser (EC-QCL).

In DR-PAS the optical power of the laser beam that is sent into a resonant photo-acoustic cell is enhanced by several orders of magnitude by optical resonance of a cavity built-up around the PAS cell. The method also produces a reliable mutual lock between the laser and the cavity as well as seamless scanning of the absorption spectrum within the entire tuning range of the laser.

In a feasibility demonstration with a low power (20 mW) telecom DFB laser we achieved a significant increase of the sensitivity of photo-acoustic detection by building up the intracavity power nearly to 300 W. This resulted in a minimum detectable absorption loss (MDAL) of 3.2 x 10^-12 cm/KHz3, which is comparable with the sensitivity of other cavity enhanced methods.

This performance can be further enhanced in the mid-IR spectral range, which is now accessible with commercially available quantum cascade lasers (QCLs), especially broadly tunable EC-QCL would result in a sub-part-per-billion detection limit of multiple gases.

EC-QCL Spectroscopic Source
A Daylight Solutions mid-IR External Cavity CW QCL with 72 mW peak power and a tuning range from 993 cm^-1 to 1096 cm^-1 (73 cm^-1) was used to study DR quartz enhanced photoacoustic spectroscopy (QEPAS) of chemical trace gas species.

- Weak absorption of H2O and CO2 – does not mask other species with lower concentrations
- Access to 7 important atmospheric molecules

Performance of DR QEPAS from H2O Measurements in Laboratory Air
With the cavity open to laboratory air it was possible to sequentially lock the cavity to the cavity modes for an unlimited period of time and thus obtain an absorption spectrum of ambient air. It was not possible to scan the laser continuously due to some technical features of our setup. The signal from an atmospheric water line at 548.26 cm^-1 was equal to 7.1 mV, which agrees with our measured response and cavity power. This sensitivity of this measurement corresponds to 1.9 x 10^-12 cm/KHz and is equivalent to a NH3 sensitivity of 0.06 ppb/v.

Results and Conclusions
- A DR-QEPAS NH3 sensor prototype based on an EC-QCL operating in the 10.34 μm range was designed, built and tested
- With 52 mW of QCL output power, 4.75 W was achieved with a built-up cavity, which corresponds to a power enhancement of 95 times
- A QEPAS sensitivity increase proportional to the power increase was achieved which resulted in DR-QEPAS sensitivity of 1.9 x 10^-12 cm/KHz
- A sensitivity increase of ~4 times should be possible by optimization of the DR-QEPAS sensor.

References

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