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# Gas spectroscopy with integrated frequency monitoring, through self-mixing in a terahertz quantum-cascade laser

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Terahertz-frequency quantum cascade lasers (THz QCLs) [1] have been used as compact, yet powerful sources of THz radiation in a range of gas spectroscopy techniques [2], including both *in situ* active sensing [3] and heterodyne radiometry [4]. A novel approach has recently been demonstrated, based on self-mixing interferometry (SMI) in a QCL [5]. This effect occurs when radiation is fed back into the QCL from an external reflector [6]. The resulting interference within the QCL perturbs the terminal voltage, and the absorption spectrum of a gas within the external cavity may be inferred from the amplitude of these perturbations. This eliminates the need for an external THz detector, doubles the interaction-length for absorption spectroscopy, and the scanning speed can potentially be raised to the time-scale of the QCL lasing dynamics ( $\sim 10$  GHz).

A limitation reported in the previously published work is that the QCL emission frequency was inferred from prior FTIR measurements of the *unperturbed* laser. However, the actual system QCL frequency is perturbed by SMI feedback effects and is therefore dependent on the gas absorption cross-section, leading to apparent frequency shifts in the measured spectral lines. In this work, we demonstrate a technique to measure the frequency directly by extending the external cavity length modulation to 200-mm using a motorised linear translation stage [Fig. 1(a)]. The QCL in this system can be tuned by adjusting the drive current, over a 1.5 GHz bandwidth, around a centre frequency of 3.394 THz. Fig. 1(b) shows the transmitted radiation intensity through a 73-cm gas cell with TPX windows, filled with methanol vapour at a pressure of 2 Torr, as a function of drive current, measured using a pyroelectric detector. Two absorption lines are clearly resolved. By replacing the detector with a planar mirror, and recording the QCL voltage modulation as a function of stage position, a full interferogram can be acquired, and a Fourier transform can then be used to determine the laser frequency and the amplitude of the transmitted signal [Fig. 1(c)]. In this paper, we will demonstrate the reconstruction of the methanol absorption spectrum, with direct measurement of the laser frequency using this technique.

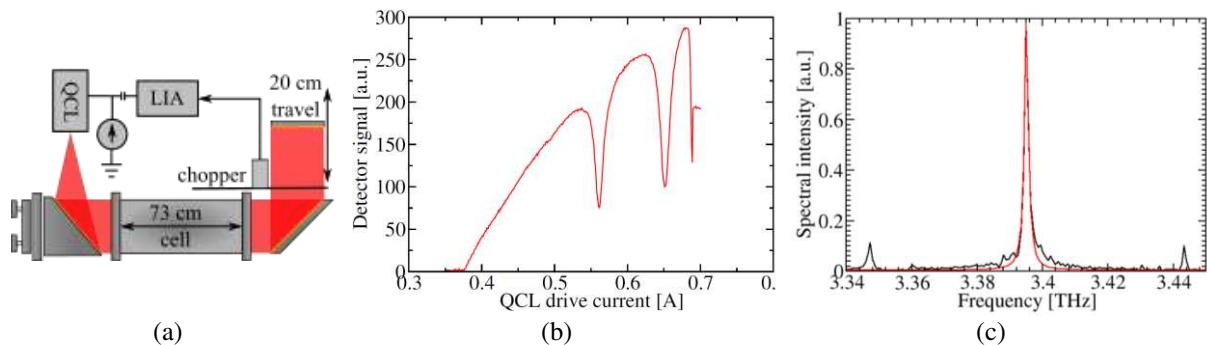


Figure 1 (a) Schematic of SMI system (LIA = lock-in amplifier) (b) transmitted THz power through methanol as a function of QCL drive current, recorded using a pyroelectric detector. (c) Exemplar QCL emission spectrum obtained from SMI interferogram

## References

- [1] R. Köhler *et al.*, *Nature*, vol. 417, pp. 156–159, May 2002.
- [2] H.-W. Hübers *et al.*, *J. Infrared Millim. Terahertz Waves*, vol. 34, pp. 325–341, Apr. 2013.
- [3] L. Consolino *et al.*, *Sensors*, vol. 13, pp. 3331–3340, Mar. 2013.
- [4] H. Richter *et al.*, *IEEE Trans. Terahertz Sci. Technol.*, vol. 5, pp. 539–545, Jul. 2015.
- [5] T. Hagelschuer *et al.*, *Appl. Phys. Lett.*, vol. 109, p. 191101, Nov. 2016.
- [6] P. Dean *et al.*, *Opt. Lett.*, vol. 36, pp. 2587–2589, Jul. 2011.