Version: Accepted Version

Conference or Workshop Item:
Valavanis, A, Chhantyal Pun, R, Rubino, P et al. Detector-free gas spectroscopy, with integrated frequency monitoring, through self-mixing in a terahertz quantum-cascade laser. In: UK Semiconductors 2017, 12-13 Jul 2017, Sheffield, UK.

Detector-free gas spectroscopy, with integrated frequency monitoring, through self-mixing in a terahertz quantum-cascade laser

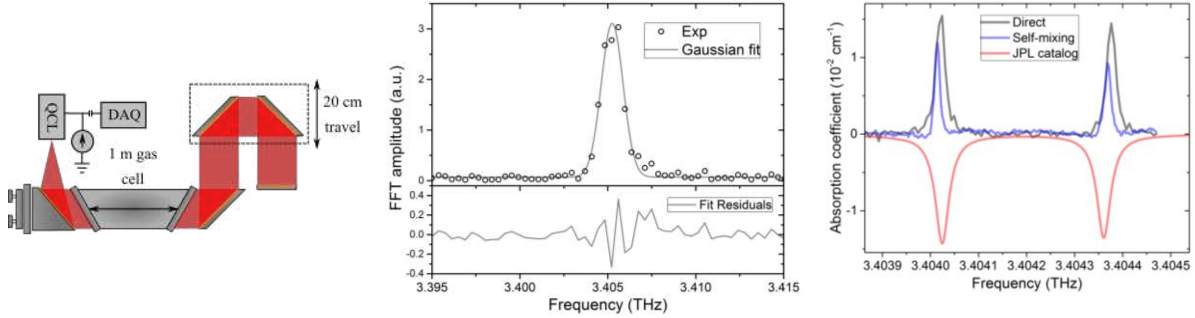
A. Valavanis, R. Chhantyal Pun, P. Rubino, J. Keeley, I. Kundu, L. H. Li, A. G. Davies, P. Dean, and E. H. Linfield

School of Electronic and Electrical Engineering, University of Leeds LS2 9JT, U.K.
a.valavanis@leeds.ac.uk

Terahertz-frequency quantum cascade lasers (THz QCLs) [1] have been used as compact, yet powerful THz radiation sources in a range of gas spectroscopy techniques, including both *in situ* active sensing [2] and heterodyne radiometry [3]. However, all such approaches require external THz instrumentation (detectors or mixers) in addition to the QCL, thus raising the system complexity and cost. A partial solution has recently been demonstrated, based on self-mixing interferometry (SMI) in a QCL [4], which occurs when radiation is fed back into the QCL from an external reflector [5]. 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 both eliminates the need for an external THz detector or mixer, doubles the interaction-length for absorption spectroscopy, and the scanning speed can potentially be raised to the time-scale of the QCL lasing dynamics (~10 GHz).

A limitation reported in the previous work is that the QCL emission frequency must be inferred from prior spectral measurements of the unperturbed laser, which introduces two principal problems: (1) additional THz instrumentation is still required, and (2) the system QCL frequency is itself perturbed by feedback effects, leading to apparent frequency shifts in the measured spectral lines. In this work, we demonstrate a technique to measure the QCL frequency directly by extending the external cavity length modulation to 400-mm using a motorised linear translation stage [Fig. 1(a)]. By 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(b)]. The QCL was shown to be tunable by adjusting the drive current over a 1.5-GHz bandwidth, around a centre frequency of 3.4052 THz. To demonstrate gas spectroscopy, a 1-m gas cell with TPX windows was filled with methanol vapour, and the transmitted QCL power was measured as a function of drive current through SMI analysis. Two absorption lines are clearly resolved, as shown in Fig. 1(c). The technique was found to be accurate to partial methanol pressures of < 10 mTorr.

In conclusion, we have demonstrated an accurate and low-cost THz gas spectroscopy technique based on self-mixing in a THz QCL, without the need for any external THz mixer or detector, or *a priori* calibration of the QCL emission frequency.



(a) (b) (c)

Figure 1 (a) Schematic of SMI system (b) Exemplar QCL emission spectrum obtained from SMI interferogram (c) Comparison of 1-Torr methanol spectra obtained using SMI, conventional direct sensing and values from the JPL molecular spectroscopy catalogue.

References

[1] R. Köhler *et al.*, *Nature*, vol. 417, pp. 156–159, May 2002.
[2] L. Consolino *et al.*, *Sensors*, vol. 13, no. 3, pp. 3331–3340, Mar. 2013.
[3] H. Richter *et al.*, *IEEE Trans. THz Sci. Technol.*, vol. 5, no. 4, pp. 539–545, Jul. 2015.
[4] T. Hagelschuer *et al.*, *Appl. Phys. Lett.*, vol. 109, no. 19, p. 191101, Nov. 2016.
[5] P. Dean *et al.*, *Opt. Lett.*, vol. 36, no. 13, pp. 2587–2589, Jul. 2011.