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Self-Mixing as a means of Spectral Characterisation of a Terahertz QCL

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Fast, sensitive and compact coherent systems for imaging and interferometry can be developed through the use of a single terahertz (THz) quantum cascade laser (QCL) device as both emitter and detector in a self-mixing (SM) scheme [1]. Here, radiation re-injected to the laser cavity interferes ('mixes') with the intra-cavity electric field, causing small variations in the fundamental laser parameters [2]. Of particular importance is the voltage perturbation induced by optical feedback. This can be used as a method of measuring the self-mixing effect through monitoring the terminal voltage of the device, and is dependent on the external cavity length and lasing frequency. As such, interferometric fringes can be acquired in a SM system by simply changing the external cavity length. In this work we demonstrate the use of SM interferometry for performing spectral characterisation of a multi-mode THz QCL in a scheme that offers much reduced experimental complexity, compared with typical Fourier Transform infrared spectroscopy (FTIR) systems.

Methodology and results

The THz QCL used in this work consisted of a 14 µm-thick bound-to-continuum (BTC) active region emitting at ~2.24 THz ($\lambda \approx 134$ µm), which was processed into a SISP ridge waveguide with dimensions of 2.2 mm×200 µm. The device was mounted on a copper carrier such that both facets of the laser could be accessed optically. The device was cooled using a continuous-flow helium cryostat and maintained at a heat-sink temperature of 25 K.

Using the experimental set-up shown in Fig. 1(a), SM interferometric fringes were measured on the QCL terminal voltage through an extension of the SM external cavity (purple) using the left-hand facet of the QCL. For direct comparison, a spectral characterisation measurement of the QCL emission was performed subsequently using the right-hand facet of the device, which was coupled to an FTIR system (green).

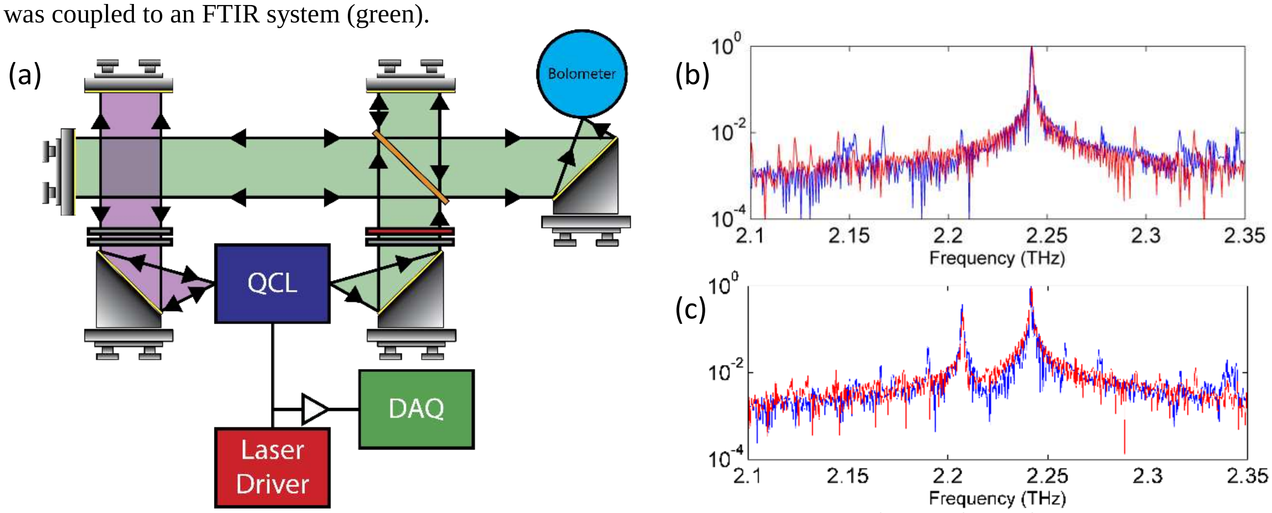

Figure 1. (a) Schematic experimental set-up to directly compare the SM system to an FTIR. Emission from one facet (left) is coupled onto an external reflector used for SM interferometry, while emission from the other facet is directed into an FTIR system. This allows both systems to be run consecutively for direct comparison. (b-c) Exemplar spectra recovered from both SM (blue) and FTIR (red) systems for both single- and multi-mode emission.

Optical polarisers (grey) were used to isolate the two systems, with a polariser in each system in cross-polarisation to the other. A quarter-wave plate (red) was used to prevent optical feedback in the FTIR system. A data acquisition (DAQ) board was utilised to measure the terminal voltage of the QCL for detection of SM interferometric fringes, and a thermal bolometer was used for detection of the FTIR interferograms.

After acquiring interferometric fringes on both systems, the same FFT analysis was performed on each measurement. Through comparison of the emission spectra acquired from both the SM and FTIR systems, good agreement can be observed for both single- and multi-mode emission regimes, as shown in Fig. 1(b). In addition the sensitivity of the SM system made it possible to resolve extra Fabry–Pérot modes not recovered in the FTIR system.

Summary

In the presented work, spectral characterisation of a THz QCL has been performed through self-mixing interferometry, offering a greatly reduced experimental complexity compared to typical methods such as FTIR.

[1] P. Dean, A. Valavanis, J. Keeley, et al., "Terahertz imaging using quantum cascade lasers-a review of systems and applications," J. Phys. D. Appl. Phys., vol. 47, p. 374008, 2014.

[2] R. Lang and K. Kobayashi, "External optical feedback effects on semiconductor injection laser properties," IEEE J. Quantum Electron., vol. 16, pp. 347-355, 1980.