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Three-section terahertz quantum cascade lasers with externally biased photonic lattices

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Single-mode (SM) operation of terahertz (THz)-frequency quantum cascade lasers (QCLs) is essential for gas sensing [1] and for their use as local oscillators. Whilst such SM operation has been demonstrated previously using distributed feedback gratings [2] and photonic lattices (PLs) [3], an ability to tune SM THz QCLs electronically would be highly desirable for many applications.

This work investigates the electronic properties of multiple segment QCLs, and explores possible electronic tuning mechanisms. We have fabricated THz QCLs with PL gratings. Our THz QCLs, based on a bound-to-continuum active region design [4], were processed into 150-μm-wide surface-plasmon ridge waveguides with lengths 2.5–4.5 mm. The upper waveguide was then patterned into three sections. The outer sections were fully metallised with gold. In the central 530-μm-long section, however, the top *n*-doped layer was etched away and metallic PLs fabricated using electron-beam lithography, with grating pitch between 14.60 and 15.65 μm. In each device, both the PL and the outer sections were bonded separately to allow independent biasing [Fig. 1(a)].

Devices were cooled in a continuous-flow helium cryostat and emission spectra measured using a Fourier-transform infrared spectrometer. Standard (unpatterned) devices lased with multiple Fabry–Pérot modes in the range 2.70–2.83 THz, whilst single mode emission was observed for devices patterned with a PL (Fig. 2). The emission spectra recorded from devices with PLs of different grating pitch showed stop-band behaviour [5], with the experimentally-determined stop-band bandwidth of around 25 GHz agreeing with the value of 23 GHz calculated using finite-element modelling.

Light-output–current–voltage (LIV) characteristics were acquired under different configurations, including the central PL sections both biased and unbiased. An equivalent circuit model describing the electronic properties of the three-section devices was developed [Fig. 3(a)], and was found to reproduce the experimental observations well. Figure 3(b) shows current–voltage (IV) simulations from the model along with experimentally observed data. This electronic model also allows prediction of the carrier modulation under different biasing conditions, and will be optimised to simulate the modulation of carriers in novel cavity geometries suitable for electronic tuning.

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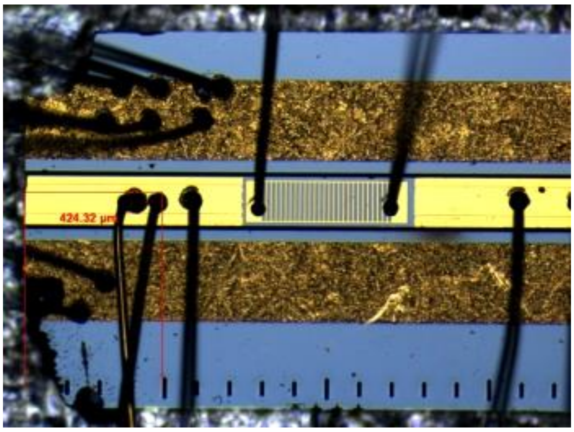

Figure 1: (a) Optical image of a fabricated device.

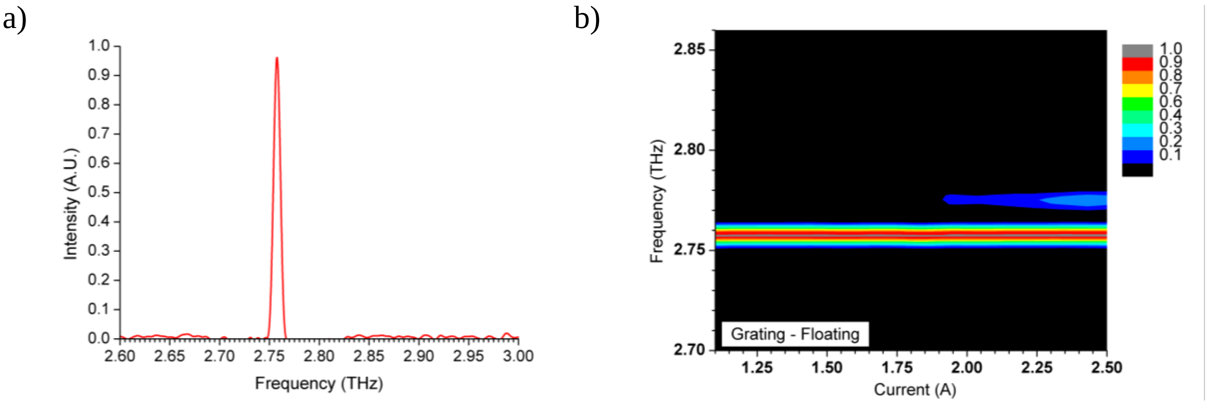

Figure 2: (a) Single mode emission. (b) Spectra map showing single mode emission across a range of bias applied to the outer waveguide sections with the PL left unbiased.

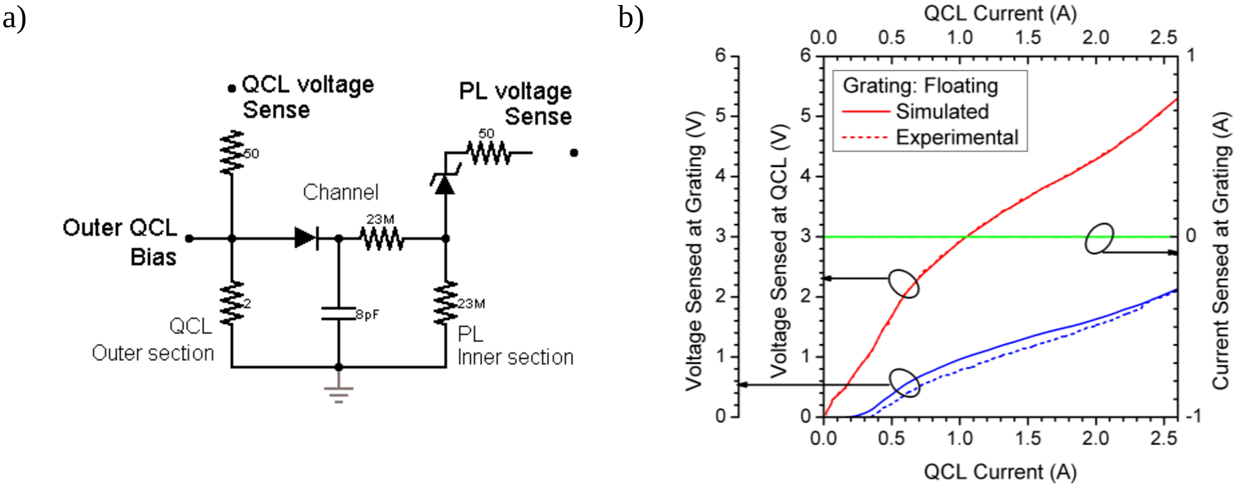

Figure 3: (a) Equivalent electronic model of three–section QCL. (b) Simulated (solid) and experimental (dashed) voltages measured across the outer sections (red) and the central section (blue) of the device. Although no separate bias is applied to the central section, a characteristic offset is observed in the voltage of the central section.