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Waveguide-integrated terahertz-frequency quantum cascade lasers for trace-gas detection applications

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***Abstract*—We demonstrate photonic-lattice THz QCLs lasing at 2.2, 2.56, 3.5 and 4.7 THz, targeting water, methane, hydroxyl and atomic oxygen absorption lines, respectively. A robust micro-machined waveguide block improves beam quality and enables future integration of complete THz heterodyne systems including a local oscillator, mixer, and feed-horn.**

I. INTRODUCTION

The terahertz frequency band (1–5 THz) is of significant interest for atmospheric science and astronomy, owing to the strong fundamental rotational modes of relevant molecular gas species in this spectral range. However, there has been a lack of compact, robust and powerful THz sources at these frequencies, which are needed to perform high spectral resolution heterodyne gas spectroscopy. For example, THz quantum-cascade lasers (QCLs) can provide > 1 W optical power [1], with very narrow intrinsic linewidth [2], and as such are highly-promising candidates for use as heterodyne receiver local oscillators and background illumination sources. To date, however, their use has been limited (in part) by the lack of a low-cost, mechanically-robust and reproducible scheme for integration with other THz system components, control and stabilization of the emission frequency, high working temperature and far-field beam profile optimization.

We demonstrate a reliable photonic-lattice waveguide design scheme [Fig. 1(top)] for single-mode, continuous wave operation of QCLs, specifically for trace-gas detection [2.2 THz (H_2O, CH_4), 2.56 THz (CH_3OH), 3.5 THz (OH) and 4.7 THz (O)] and present a systematic optimization of their performance. The applicability of these lasers to *in situ* gas sensing is demonstrated and their use as future LO sources is described.

Furthermore, QCL devices have been integrated into precision-micro-machined waveguide blocks [Fig. 1(bottom)], which have previously been developed to support construction of waveguide-integrated THz mixers. These mechanically-robust blocks yield significant improvement in the far-field beam pattern without degradation in thermal or electrical performance.

II. RESULTS

The QCL tuning coefficients were measured with respect to heat-sink temperature and drive current (e.g, −0.7 GHz/K and −5 GHz/A respectively for a 2.2 THz QCL), and we show that this enables analysis of water and methanol lines at 2.2 and 2.56 THz respectively, in a single-pass gas cell.

The waveguide-integrated QCL was characterized in terms of emission power, far-field beam profile, threshold current and thermal performance. Compared with the performance of bare devices, we show that there is no significant change in threshold current or operating temperature, thus demonstrating good thermal and electronic integration of the QCL. The far-field beam profile has been improved significantly with a sharply reduced full-width at half-maximum (< 20°, c.f. 120° for unmounted double metal QCLs).

III. SUMMARY

We have developed single-mode THz QCLs using photonic lattice waveguides and integrated them in a robust, reproducible and low-cost package, which significantly improves the far-field beam profile. We have used these QCLs to measure the absorption line shapes of atmospheric gas species.

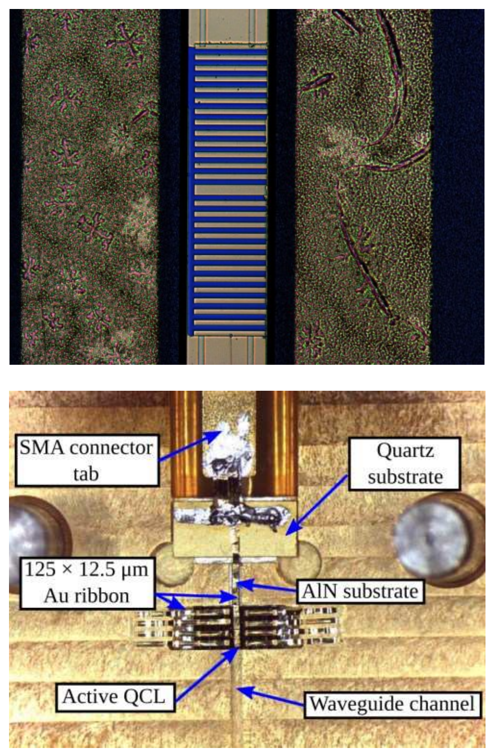

Fig. 1. (top) Single mode QCL, using a photonic lattice waveguide (bottom) structure of block-integrated device.

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