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Integration of a 2.1-THz Quantum Cascade Laser within an IEEE WM-130 Rectangular Metallic Waveguide

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***Abstract* — A 2.1-THz quantum cascade laser (QCL) has been integrated into an IEEE standard rectangular metallic waveguide for the first time. A (130 × 65)-µm² precision micromachined channel within a metallic module was used to form a fundamental WM-130 waveguide, in accordance with IEEE standard 1785.1-2012. We show that single-mode continuous-wave laser emission is obtained, with a Gaussian far-field divergence angle of 9°.**

I. INTRODUCTION

TERAHERTZ-FREQUENCY quantum-cascade lasers (THz QCLs) are very attractive ~2–5-THz sources for industrial or satellite-based sensing applications, owing to their compact size, high output power and narrow linewidth. One key potential application is in local oscillators (LOs) for heterodyne radiometric sounding of gas species in the upper atmosphere [1]. A significant challenge, however, is in the poor quality of the far-field beam, and QCLs are typically coupled to other system elements using bulky arrangements of free-space quasi-optical components.

We have previously partially overcome this limitation by integrating 3.4–5.0-THz QCLs within precision-micromachined metallic waveguides [2]–[4]. This approach underpins future guided-mode coupling between LOs, mixers and detectors, and improves the mechanical robustness and reproducibility of THz systems. However, at these frequencies, the manufacturing tolerances for waveguides are extremely tight and it has, to date, not been possible to develop fundamental-mode waveguides.

In this work, we demonstrate the first such integration of a 2.1-THz QCL into a fundamental waveguide. This frequency band is of particular interest for atmospheric radiometry, owing to its proximity to several important atmospheric gas species (e.g., O, O_3, CO and HO_2 at 2060.0, 2060.2, 2070.6 and 2070.5 GHz respectively). The relatively low QCL emission frequency eases manufacturing tolerances. and enables the use of a fundamental WM-130 waveguide. This represents the first integration of a QCL within a waveguide meeting the IEEE 1785.1-2012 standard for rectangular metallic waveguides.

II. RESULTS

The QCL was based on a bound-to-continuum active region design [5], operating at ~2.1 THz, with a 14-µm active region height. A 90-µm-wide laser ridge was defined, using a gold–gold double-metal waveguide configuration. A 150-µm thick gold overlayer was deposited and the chip was thinned to 100 µm using mechanical and chemical etching. Finally, a 2-mm-long device was cleaved, and the ridge was diced into a ~200-µm-wide section using a wafer-saw.

Rectangular channels with cross-sectional dimensions of (130 × 32.5) µm² were precision CNC-milled into a pair of brass blocks, such that these co-registered to form an IEEE WM-130 rectangular waveguide with (130 × 65)-µm² cross-section. The waveguide was coupled into free-space using a pair of diagonal feedhorns with a (1.525 × 1.525)-mm² across-diagonal aperture at either end, and a slant angle of 5.5°. The QCL was connected to an external d.c. bias through a standard SMA connector and mounted in a liquid-helium-cooled Janis ST-100 cryostat for characterization.

Figure 1(a) shows the continuous-wave light–current–voltage (LIV) characteristics of the waveguide-integrated QCL, with a peak output power of ~40 µW and a maximum operating temperature of 60 K. Figure 1(b) shows the spectrum of the same device, indicating single-mode operation at 2.1 THz, while Figure 1(c) shows a knife-edge measurement of the far-field beam profile, obtained 39 mm from the feedhorn aperture. A Gaussian function with 9° full-width divergence is shown to give a good fit to the experimental measurement (c.f. 7° predicted for an ideal square aperture with a uniform field). Figure 1 (d) shows the assembled waveguide module attached to the coldfinger of a cryostat.

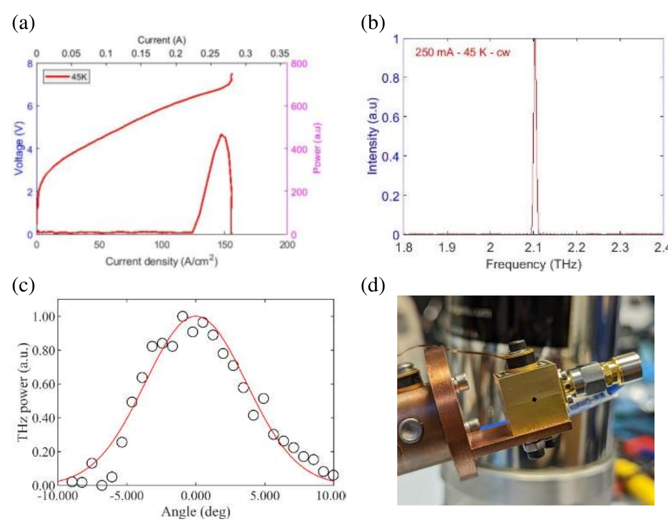

Fig. 1: (a) Voltage-current/current density and peak power–current/current density characteristics of THz QCLs at 45 K. (b) The spectrum of the device is at 250 mA and 45 K. (c) The far field beam profile. (d) Assembled module on cryostat cold-finger.

III. SUMMARY

We have demonstrated the first integration of a THz QCL within a rectangular waveguide meeting the IEEE 1785.1-2012 standard. The single-mode emission, within the 1400–2200 GHz bandwidth of the waveguide, and the single-lobed, narrow far-field emission indicate that the waveguide is operating within its intended fundamental mode. This underpins the capability for future development of fully integrated receiver systems, in which a QCL local oscillator will be coupled with a mixer for satellite radiometry applications.

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DATA AVAILABILITY

The data associated with this paper are openly available from the University of Leeds Data Repository http://doi.org/10.5518/1319.

AUTHOR DECLARATIONS

Conflict of interest

The authors have no conflicts to disclose.

Author contributions

M. Salih: writing — original draft preparation; investigation (lead); methodology (equal). S. S. Kondawar: investigation (supporting). N. Brewster: investigation (supporting). L. H. Li: investigation (supporting). E. H. Linfield: funding acquisition (supporting); conceptualization (supporting). H. Wang: funding acquisition (supporting); conceptualization (supporting); methodology (equal); supervision (supporting). P Huggard: funding acquisition (supporting); conceptualization (supporting); methodology (equal); supervision (supporting). J. R. Freeman: funding acquisition (supporting); conceptualization (supporting); methodology (equal); supervision (supporting). D. Gerber: funding acquisition (supporting); conceptualization (supporting); methodology (equal); supervision (supporting). A. Valavanis: funding acquisition (lead); conceptualization (lead); methodology (equal); writing — reviewing & editing (lead); supervision (lead).

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