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WAVEGUIDE-INTEGRATED TERAHERTZ QUANTUM CASCADE LASERS FOR USE AS LOCAL OSCILLATORS

Alexander Valavanis[1,*], Yingjun Han[1], Nick Brewster[2], Paul Dean[1], Rui Dong[1], Luke Bushnell[2], Matthew Oldfield[2], Jingxuan Zhu[1], Lianhe Li[1], A. Giles Davies[1], Brian N. Ellison[2], and Edmund H. Linfield[1]

[1]*School of Electronic and Electrical Engineering, University of Leeds, Leeds LS2 9JT, United Kingdom*
[2]*Rutherford Appleton Laboratory, STFC, Harwell Oxford, Didcot OX11 0QX, United Kingdom*
[*]*Email: a.valavanis@leeds.ac.uk*

ABSTRACT

Terahertz-frequency quantum cascade lasers (THz QCLs) are compact sources of 1–5 THz radiation, which show great promise for use as local oscillators in satellite-borne heterodyne radiometers. We present a waveguide-integration scheme, in which a THz QCL is mounted in a copper heat-sink block, with radiation outcoupled into a precision micromachined rectangular waveguide. Electrical bias is provided by an integrated SMA connector and mounting points are provided for attachment to a cryocooler and a temperature sensor. The integration scheme is mechanically robust and is shown to have negligible impact on the thermal performance or threshold current of the device. The emitted beam quality is significantly improved, compared with that of a conventional device, with single-lobed profile with divergence $\lesssim 20°$.

Key words: Terahertz radiation; quantum cascade lasers; waveguides.

1. INTRODUCTION

Terahertz-frequency quantum cascade lasers (THz QCLs) [1] are compact, electrically-driven sources of coherent radiation in the 1–5 THz band. These devices are highly promising sources for use as local oscillators (LOs) in satellite-borne radiometry systems [2] owing to their small size and high output power (up to >1 W peak [3]). Aircraft-born LOs are able to integrate THz QCLs with other system components using securely-mounted discrete free-space optics [4]. However, a mechanically robust and much more compact scheme for the integration of THz QCLs with mixers, waveguides and signal-output coupling optics is needed for any practical satellite-borne system. A number of such schemes have been proposed (e.g. [5]), which are typically based on elegant yet complex semiconductor processing. In this paper, we present recent results from the characterisation of a recently-developed reproducible technique [6] in which a 3.4-THz QCL is integrated into a precision micro-machined waveguide channel. This integration scheme has previously been developed to support waveguide-integrated THz-frequency mixers.

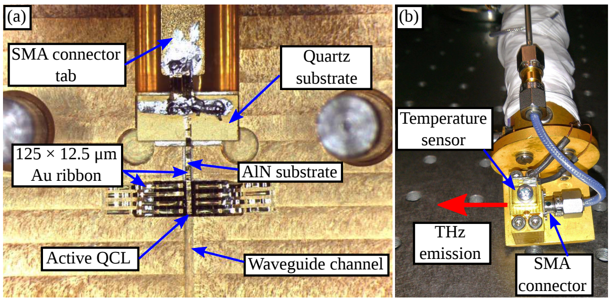

Figure 1. (a) Photograph of interior of the waveguide block. (b) Exterior view of the QCL waveguide block, mounted on cold-finger of a helium cryostat [6].

The THz QCL used in this work (prior to mounting) employs a double-metal laser waveguide, which enables operation at relatively high cryocooler temperatures, with its near-field THz mode profile closely matched to that of a rectangular metallic waveguide. However, the far-field beam profile of double-metal QCLs is typically highly divergent and of poor quality [7]. We show that our waveguide-integration scheme results in a significantly improved beam profile without the need for fragile assemblies of antennas or lenses attached to the device (e.g. [8, 9]) or complex semiconductor processing (e.g. [10, 11]). Our method does not perturb the optical or electronic performance of the QCL, and aims to be sufficiently mechanically robust for use in satellite-based platforms.

2. WAVEGUIDE INTEGRATION

A set of 13 parallel 3.4-THz QCLs ($110 \times 980\,\mu m^2$ dimensions) was processed from an epitaxially-grown wafer using a standard Au–Au double-metal plasmonic waveguide geometry. A rectangular channel with dimensions $300 \times 75\,\mu m^2$ was defined in a copper block, using a precision-machining technique. The QCL array was located in a recess within the block, using a 20-µm-thick indium foil thermal contact. The facet of the central laser ridge was aligned with the channel in the block. The laser array was ribbon-bonded to an electrical connector and to anchoring points on the block for mechanical stability as shown in Fig. 1(a). A second copper block, containing an identical rectangular channel was used to enclose the QCL array, and to form the complete waveguide with dimensions $300 \times 75\,\mu\mathrm{m}^2$. The exterior of the block, shown in Fig. 1(b) provides a robustly mounted, and industry standard, SMA connector, an integrated temperature sensor and precision-machined mounting points for attachment to a cryostat.

3. CHARACTERISATION

The block was mounted within a helium-cooled cryostat and the QCL was driven using a d.c. current source. The beam was focused onto a Ge:Ga bolometric detector using a pair of off-axis paraboloidal reflectors, and was modulated optically using an optical chopper at a frequency of 185 Hz for lock-in amplification. The threshold current for continuous-wave emission at $10\,\mathrm{K}$, and the maximum operating temperature were $I_{\mathrm{th}} = 130\,\mathrm{mA}$ and $T_{\mathrm{max}} = 77\,\mathrm{K}$ respectively for the waveguide-integrated QCL, representing only a small change (c.f., $I_{\mathrm{th}} = 100\,\mathrm{mA}$ and $T_{\mathrm{max}} = 80\,\mathrm{K}$) compared with an equivalent, unmounted device. The emission spectrum, measured with an FTIR spectrometer, was also found to be unperturbed.

The far-field profile of the THz beam, shown in Fig. 2, was obtained by translating a Golay detector linearly in two dimensions outside of the QCL cryostat. The beam profile exhibits a near-Gaussian shape, with no evidence of spatial "ringing" effects, and a divergence $< 20°$ in all directions, representing a significant improvement over the $\sim$120° divergence of unmounted double-metal devices.

4. CONCLUSION

We have demonstrated a waveguide integration scheme for THz QCLs, which improves the output beam quality significantly without the requirement for complex semiconductor processing or discrete optical components. This scheme introduces no significant degradation in the threshold current or the operating temperature range, compared with conventional unmounted QCLs, and is based on highly reproducible micromachining techniques. Work is currently in progress to improve the quasi-optical outcoupling of THz radiation through the use of an integrated feedhorn. Subsequent designs will integrate a QCL with a planar Schottky diode mixer for heterodyne radiometry applications.

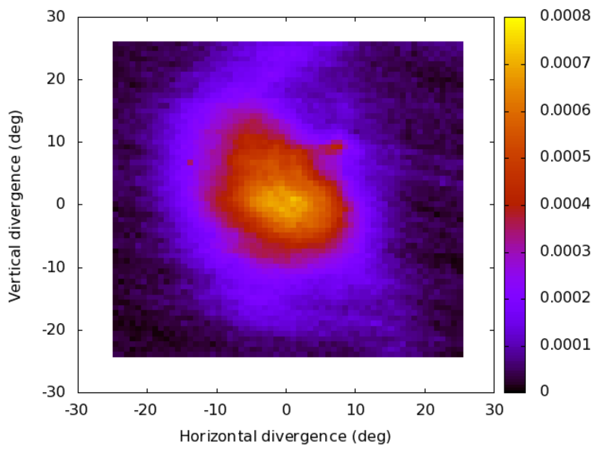

Figure 2. Two-dimensional far-field beam profile of the THz emission from the QCL integrated within a waveguide block. The colour scale represents the intensity (arbitrary units). Data as reported in [6].

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