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A robust waveguide integration, beam shaping and heat-sinking scheme for terahertz quantum cascade lasers

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Introduction

Numerous scientific and commercial applications have been proposed for terahertz-frequency quantum-cascade lasers (THz QCLs), including their use within biomedical, security and industrial imaging and sensing, and in space science applications. However, their widespread impact has not been fully realised due, in part, to the poor far-field beam quality of standard double-metal plasmonic waveguides and the lack of a robust and reproducible scheme for integration of THz QCLs with mixers, waveguides and signal-output coupling optics. In this paper, we demonstrate a highly reproducible technique for integrating a double-metal THz QCL into a precision micro-machined waveguide channel. The far-field beam profile is shown to be approximately Gaussian with < 20° divergence and to be free of the spatial "ringing" effects that are commonly associated with double-metal QCLs. The beam divergence is comparable to that obtained using previously-demonstrated beam optimisation schemes, based on optical patterning, or assemblies of antennas or lenses attached to the device (e.g., [1]). In contrast with previous QCL integration schemes (e.g., [2]), however, our technique is based on reproducible and low-cost mechanical microfabrication processes developed to support waveguide-integrated THz-frequency mixers. This method does not perturb the optical or electronic performance of the QCL, is sufficiently mechanically robust for use in satellite-based platforms and requires no time-consuming or device-specific semiconductor-processing steps.

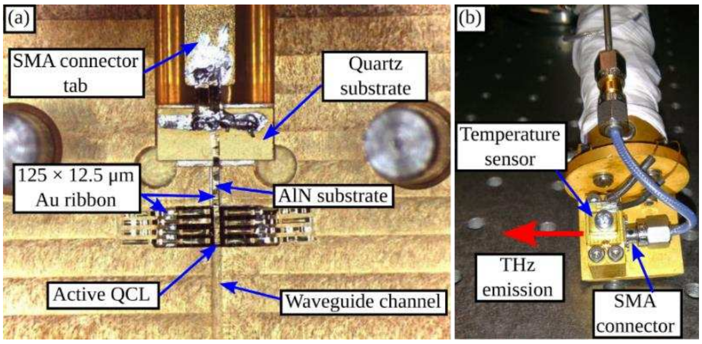

Fig. 1: (a) Photograph of interior of the waveguide block. (b) Exterior view of the QCL waveguide block, mounted on cold-finger of a helium cryostat.

1. Device fabrication

The 3.4-THz QCL used in this work is based on a 14-µm-thick GaAs/AlGaAs bound-to-continuum active region [3]. QCLs were defined in an array of 13 parallel laser ridges with 110×980 µm^2 dimensions, and 100-µm separation, using a standard Au–Au double-metal plasmonic waveguide fabrication process. A waveguide channel with 300×75 µm^2 dimensions was precision machined into a copper block, incorporating a cavity for housing the QCL array. An identical channel was machined into a second block such that the two channels co-registered to form a full-height 300×150 µm^2 rectangular waveguide. The QCL array was mounted in the lower block, using an In-film thermal-contact layer. This method enables readjustment of the QCL position, and allows the device to be potentially replaced within the block. A range of additional techniques are currently under investigation for improving the thermal management within the block. The output facet of the central device was aligned with the waveguide channel, with the other devices being left unused. A gold ribbon bond was attached between the top contact of the QCL and an electrical contact strip at the rear of the block, via intermediate quartz and AlN bonding pads, as shown in Fig. 1(a). Additional ribbon bonds were attached between the copper block and the unused devices in the array, providing mechanical compression and hence improved thermal integration between the QCL and the block. The exterior of the block [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.

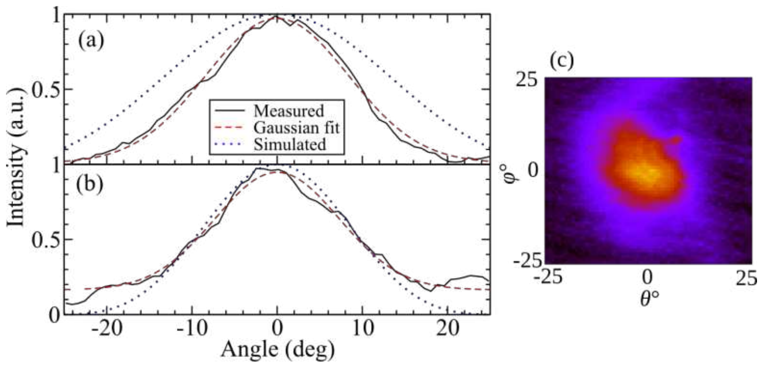

Fig. 2: Far-field beam-profile cross-sections (a) along the material growth axis and (b) in plane with the substrate. (c) a 2D image of the beam profile.

2. Optical and electronic performance

The two-dimensional profile of the emitted THz beam (Fig. 2) was measured using a Golay detector outside the cryostat window. The observed 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 ~120° divergence of unmounted double-metal devices. The threshold current at 10 K and the maximum operating temperature were measured under continuous-wave driving conditions as I_{th} = 130 mA and T_{max} = 77 K respectively for the waveguide-integrated QCL, representing only a small change compared with I_{th} = 100 mA and T_{max} = 80 K respectively for an equivalent, unmounted device. The emission spectrum, measured with an FTIR spectrometer, was also found to be unperturbed.

3. Conclusion

We have presented a robust, reconfigurable waveguide-integration technique for THz QCLs, which introduces no significant perturbation to the spectral or thermal performance. A significant improvement in far-field beam quality and reduction in divergence is observed.

References

[1] Amanti, M.I., Fischer, M., Scalari, G., Beck, M., and Faist, J., 'Low-divergence single-mode terahertz quantum cascade laser', Nat. Photonics, 3, pp. 586–590 (2009)

[2] Wanke, M.C., Young, E.W., Nordquist, C.D., Cich, M.J., Grine, A.D., Fuller, C.T., Reno, J.L., and Lee, M., 'Monolithically integrated solid-state terahertz transceivers', Nat. Photonics 4, pp. 565–569 (2010)

[3] Scalari, G., Ajili, L., Faist, J., Beere, H., Linfield, E., Ritchie, D., and Davies, G., 'Far-infrared (λ~87 μm) bound-to-continuum quantum cascade lasers operating up to 90 K', Appl. Phys. Lett., 82, pp. 3165–3167 (2003).