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High-power GaAs/AlGaAs quantum cascade lasers with emission in the frequency range 4.7–5.6 THz

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1. Introduction

Terahertz (THz) frequency radiation has many potential applications, ranging from imaging and chemical sensing through to high-speed and high-capacity optical wireless communications. However, one of the principal challenges is to develop compact, low-cost, efficient THz sources. In this respect, the development of the THz frequency quantum cascade laser (QCL) has provided a potential solid-state solution. Since their first demonstration in 2002, THz QCLs, based on the GaAs materials system, have become important compact sources of coherent radiation in the 1.2–5.4 THz band, with maximum operating temperatures of 199.5 K and peak pulsed output powers >1 W being demonstrated [1–3].

THz waves in the 5–12 THz frequency range are of interest for applications such as high-resolution spectroscopy of gaseous species and the study of shallow donor transitions in isotopically enriched semiconductors [4, 5]. However, owing to strong absorption caused by electron-longitudinal optical (LO) phonon interactions in GaAs materials, it is difficult to develop GaAs-based THz QCLs in this frequency range. Indeed, deteriorating device performance has been observed as the emission frequency is increased beyond 5 THz [2, 3]. To date, the highest emission frequency observed from GaAs-based THz QCLs is 5.4 THz. However, this device only worked in pulsed mode, with a maximum operating temperature of 55 K and a maximum peak output power of 6 mW at 5 K [2]. As an alternative, group III-nitride semiconductors, having much larger LO phonon energies than those in GaAs, have been proposed and examined as potential materials for THz QCLs. However, owing to the relative immaturity of this material system, lasing action has not yet been observed at temperatures above ~5 K [6].

Here, we demonstrate GaAs/AlGaAs THz QCLs emitting over a spectral range of 4.7–5.6 THz. The devices operate in pulsed mode with a maximum working temperature of 107 K, and a peak output power from a single facet in excess of 170 mW at 10 K.

2. Experimental details

The QCL active region design is based on a bound-to-continuum transition with a single-well injector, similar to those reported in Refs. 1 and 7, but with rescaled layer thicknesses to enable higher frequency emission. The QCL structure was grown by solid-source molecular beam epitaxy on a semi-insulating GaAs substrate. After growth, the QCL wafer was processed into surface-plasmon ridge waveguide structures using standard photolithography and wet chemical etching techniques before the substrate was thinned to ~165 µm. For measurement, devices were cleaved and indium-soldered onto copper sub-mounts. They were characterized in pulsed mode, with a repetition rate of 10 kHz and a duty cycle of 2 %, in a liquid-helium continuous-flow cryostat. The radiation was collected from a single facet and the average power was measured using an absolute terahertz power meter (Thomas Keating). Peak output power was then calculated from the measured average power and duty cycle. Unlike some earlier reports, neither a light-pipe nor a Winston core was used to improve collection efficiency from the devices. Furthermore, no correction was made to account for the collection efficiency or for absorption in the polyethylene windows, although these factors have been considered elsewhere [8-10].

3. Results and discussions

Fig. 1 shows the LIV curves of an as-cleaved Fabry-Përot (FP) cavity device with a ridge width of 150 µm and a cavity length of 1.8 mm at different heatsink temperatures (left panel). Also shown are typical lasing spectra from the same device with different injection currents at 10 K (right panel). The device operates with a maximum temperature of 107 K. At 10 K, a peak output power of ~170 mW is obtained from a single facet. Even at 77 K, the device still delivers a peak output power of ~50 mW. If a larger dimension device is fabricated, then the peak output power should be much higher, as shown in Ref. 1. The device emits over a spectral range of 4.7–5.6 THz with dominant peaks at ~5 THz. It should be noted that this broadband emission is observed across almost the whole injection current dynamic range. For example, the highest emission frequency of ~5.6 THz is preserved with increasing injection current up to the peak maximum, and additionally, it is still observed even with a working temperature of 90 K (data not shown). To the best of our knowledge, this is the highest frequency emission observed to date from GaAs/AlGaAs THz QCLs. To obtain single mode emission, after characterization of the FP-cavity device, a photonic lattice (PL) with only 20 defect sites was patterned on the ridge of the same device using a focused ion beam (FIB) [11]. The device emits a single mode of 4.98 THz at 10 K (inset to right panel) with a maximum working temperature of 88.5 K and a peak output power up to 33.5 mW (data not shown). Since there is sufficient gain, with further refinement and optimization of the PL design and processing, it should in principle be feasible to engineer single mode emission of ~5.6 THz from this QCL structure.

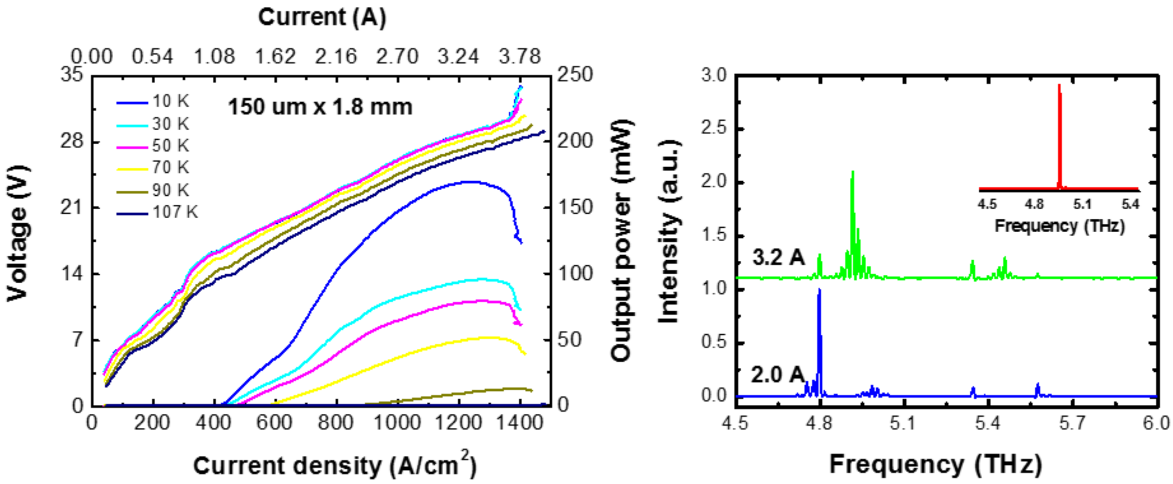

Fig. 1 Left panel: LIV curves of an as-cleaved FP-cavity device with a ridge width of 150 µm and a cavity length of 1.8 mm at different heatsink temperatures. The power only takes emission from a single facet into account. No correction is made for the collection efficiency or for absorption in the polyethylene windows. Right panel: Typical lasing spectra for the same device with different injection currents at 10 K. Inset: the typical lasing spectrum at 10 K of a PL laser fabricated by post-packaging FIB processing of the same device.

4. References

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