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THz quantum cascade lasers with output power over 1 W

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1. Introduction

Terahertz (THz) frequency radiation has many potential applications, ranging from imaging and chemical sensing through to telecommunications. However, one of the principal challenges is to develop compact, low-cost, efficient THz sources. In this respect, the development of the THz quantum cascade laser (QCL) has provided a potential solid-state solution [1]. Nonetheless, for many remote sensing and imaging applications, high THz powers are desirable, in part owing to the significant attenuation of THz radiation by water vapour in the atmosphere. THz QCLs have been demonstrated with peak pulsed output powers (P_{peak}) of up to 470 mW per facet [2], using a direct wafer-bonding technique to stack two separate THz QCLs together. This approach, however, requires the QCL to have a symmetric active region, limiting widespread applicability of the technique. In general, increased output powers in semiconductor lasers can be obtained by using longer and/or broader area cavities [3]. Indeed, in long-cavity 4.7-THz QCLs, a P_{peak} of up to 875 W (from both facets) was recently achieved. [4] Here, we demonstrate THz QCLs with a P_{peak} of 1.01 W from a single facet at 10 K by using broader area device. The devices operate in pulsed mode with an emission frequency of around 3.4 THz. To the best of our knowledge, this is the first demonstration of THz QCLs with P_{peak} exceeding 1 W. [5]

2. Experimental details

The QCL active region design and complete structure used here are very similar to those reported in [6]. The active region consists of an $Al_{0.16}Ga_{0.84}As$/GaAs heterostructure with a layer sequence of **52**/103/**17**/107.5/**36**/88/**39.5**/<u>172</u> (starting from the injector barrier) where the thicknesses are in Å, $Al_{0.16}Ga_{0.84}As$ barriers are in bold, and the Si doped layer (3×10^{16} cm^{-3}) is underlined. The whole 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. The substrate was then thinned to ~180 μm by wet chemical etching. For characterization, the devices were cleaved and indium-soldered to copper submounts. They were driven by a pulsed current source, 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), which was butted against the cryostat window. P_{peak} was then calculated from the measured average power and duty cycle.

3. Results

Fig. 1 shows the LIV curves of the as-cleaved devices with different ridge widths but a fixed cavity length of 1.5 mm at 10 K. The P_{peak} scales linearly with ridge width, similar to the observations in [3]. The scaling factor, dL/dw ~ 0.98 mW/μm, where L is the emitted power. Similarly, the emitted power scales with the cavity length.

However, there is a trade-off between P_{peak} and device heat-dissipation owing to the increase in cavity length/width. At a certain size it became difficult to further increase P_{peak} by simply scaling cavity length/width. We noticed that a P_{peak} of up to ~780 mW could be obtained from an as-cleaved device with a 3-mm-long cavity and a 425-μm-wide ridge. To further increase the emitted power, we coated the rear facet of selected devices with SiO_2(150 nm)/Ti(10 nm)/Au(150 nm)/SiO_2(200 nm). Fig. 2 shows the output power as a function of current density from a 425-μm-wide, 4.2-mm-long, facet-coated device. A P_{peak} of ~1.01 W (at 10 K) is obtained from the front facet, at a frequency of ~ 3.4 THz (inset). It should be noted that this lasing frequency is ~0.5 THz and 1.3 THz lower than the THz QCLs reported in [2, 4], respectively. A decrease in the emitted power would have been expected if the QCL design was scaled to lower frequencies [7], owing to the increased free-carrier losses and the reduction in optical confinement within the single-metal waveguide. In contrast to this expectation, the single-facet output power from this device is approximately two times higher than that reported in [2, 4]. The responsible mechanism will be discussed in detail. With increasing current, the lasing spectra show multimode behavior, and both broaden significantly and shift to higher frequencies. Owing to the wide ridges, lateral modes are also present in the lasing spectra.

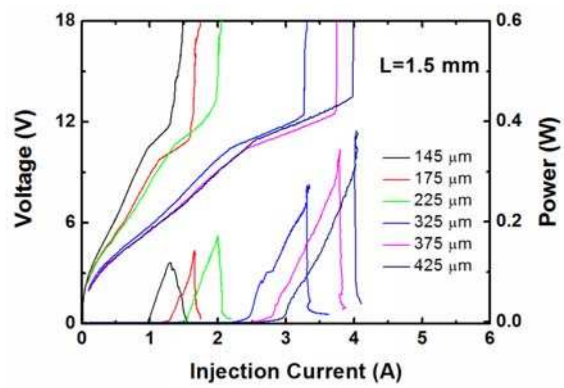

Fig. 1 LIV curves of the as-cleaved devices with different ridge widths but a fixed cavity length of 1.5 mm at 10 K. The light was collected from one facet.

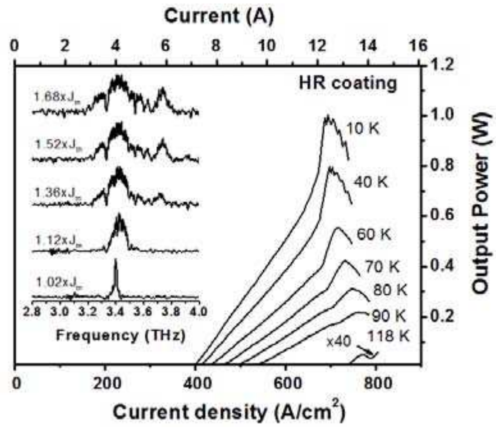

Fig. 2 Output power as a function of current from a rear-facet coated device (4.2 mm × 425 μm). Inset: Typical lasing spectra for different device current densities at 10 K.

4. References

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