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Three-well, resonant-phonon depopulation, quantum cascade lasers with thinned active regions and surface-plasmon waveguides

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Abstract: **We report, for the first time, high performance three-well, resonant-phonon depopulation, terahertz quantum cascade lasers with thinned active regions. Lasers operated at 3.1 THz in a surface plasmon waveguide. The variation of output power, maximum operating temperature, and threshold current density is presented for active regions of 10 µm, 7,5 µm, 6 µm, and 5 µm thickness, and in each case results are presented as a function of duty cycle.**

Terahertz (THz) frequency quantum cascade lasers (QCLs) [1] have many potential applications in fields ranging from security imaging, biomedicine, and spectroscopy through to astronomy [2−4]. However, a number of barriers still remain to commercial exploitation. For example: THz QCLs typically use active regions of ~10 µm thickness, which is both demanding for the molecular beam epitaxy (MBE) growth technology [5], but also requires high operating voltages to achieve the requisite threshold electric fields. The latter leads to a large total injected electrical power into the active region, resulting in device heating. This affect is compounded further, in high-performance phonon-depopulation QCLs, as a result of the large parasitic current channels inherent to such active region designs. This makes continuous-wave (cw) operation difficult to attain – a requirement for many applications.

We have studied THz QCLs with thin active regions, basing our work on GaAs/AlGaAs three-quantum well, resonant phonon-depopulation structures [6]. Such structures have recently led to lasing, in pulsed mode, up to a maximum operating temperature of 186 K for 10 µm thick active regions with double-metal waveguide confinement [7].

We present experimental results from four THz QCLs, which have active region thicknesses of 10 µm, 7.5 µm, 6 µm and 5 µm. Each active region was incorporated into a surface plasmon waveguide, and had an emission frequency of ~3.1 THz. The output powers, threshold current densities, maximum operating temperatures, and operating dynamic range of these designs were compared over a range of duty cycles from 0.5 – 100%. For each laser, the active region doping level (~5 x 10^{16} cm^{-3}) and barrier thicknesses were kept constant. All devices were processed into ridge waveguides,

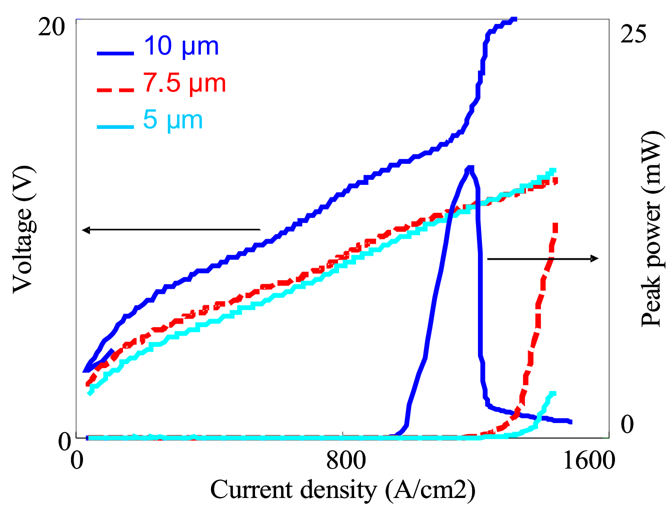

Figure 1 Voltage and output power as a function of current density for THz QCLs with 10 µm, 7.5 µm, and 5 µm thick active regions.

It was found that the threshold current density increased from ~900 A/cm^2 to ~1200 A/cm^2, as the active region thickness decreased from 10 µm to 5 µm. The maximum operating temperature correspondingly fell from 115 K to 66 K, with the

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maximum peak output power decreasing from ~20 mW to ~2.5 mW. The dynamic range for the 10 µm thick active region was ~6.6 V, whereas for the 5 µm active region, the value was ~3.5 V. Figure 1 shows typical power-current density-voltage (*LIV)* characteristics for 10 µm, 7.5 µm, and 5 µm active region thicknesses.

However, as the thickness of the active region is reduced, the required threshold voltage also falls, leading to less heating in the device and make cw operation possible. We will show how the duty cycles can be increased towards continuous-wave operation for all active region thicknesses. We will also show that the threshold current density increases less strongly with increased duty cycle for the THz QCLs with thinner active regions, which we interpret as resulting from a lower lattice temperature.

In summary, we have demonstrated the fabrication of THz QCLs, three-well, resonant-phonon depopulation, surface plasmon waveguide, for four different thicknesses of active region (10 µm, 7.5 µm, 6 µm and 5 µm) and compared their performances. This work suggests that the thinner active region makes continuous-wave (cw) operation possible to obtain from three-well, resonant-phonon depopulation, which is a requirement for many applications.

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