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Selective Emission of a THz QCL using a Magnetic Field

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Quantum cascade lasers (QCLs) utilize intersubband (ISB) transitions to emit in the mid- infrared and terahertz regime, the chemical fingerprint region [1]. The optical transitions can be designed through bandgap engineering [2]. Whereas THz QCL are the only solid state lasers which emit in the range below the reststrahlen band (5–20 meV). When using magnetic fields parallel to the growth direction, ISB transitions and scattering mechanisms can be investigated due to the suppression of non-radiative relaxation channels.

A high-temperature three-well GaAs/AlGaAs THz QCL was studied. It exhibits two upper laser levels $|4\rangle$ and $|3\rangle$ and a lower laser level $|2\rangle$ with optical transitions $|3\rangle \rightarrow |2\rangle$ and $|4\rangle \rightarrow |2\rangle$ labeled as LT_{32} and LT_{42}. Level $|1\rangle$ is the extractor level, coupled to the LO-phonon transition $|2\rangle \rightarrow |1\rangle$. The design is identical to the $GaAs/Al_{0.21}Ga_{0.79}As$ active region that reached a T_{max} of 196 K at a frequency of 3.8 THz [3]. The QCL is processed into a 2550 μm × 120 μm ridge with the metal-metal waveguide geometry with 15 μm Ni side absorbers added in the processing to suppress higher order lateral modes.

At 12.2 kV cm^{-1}, the LT_{42} transition around 3.8 THz has a larger matrix element and thus stronger emission than the LT_{32} transition. At 12.5 kV cm^{-1}, the LT_{42} and LT_{32} transitions have similar matrix elements and at higher biases the LT_{32} transition is stronger. The temperature dependent L-J-V device behavior is as follows: The lasing threshold J_{th} increases typically with the heat sink temperature, while the peak output power and dynamic range decrease. Emission spectra were taken at 5, 80, and 140 K for different current densities. At all temperatures, the LT_{42} is the first emission, due to the greater dipole matrix element z_i. With increasing bias, the LT_{32} emerges at low temperatures, while it is largely suppressed at higher temperatures. To determine whether the two laser states occur next to each other in the same active region or in neighboring periods, a magnetic field of 0−7.5 T was applied to the QCL. Here, smaller laser ridges (1900 μm × 90 μm, with 10 μm Ni side absorbers) were used. The threshold current density J_{th} decreases with increasing magnetic field, which is due to the reduction in scattering processes. Above 6 T, the J_{th} increases again and the output power falls, due to continued suppressed scattering. Applying the magnetic field results first in the reduction in emission of LT_{32} and then at higher fields reduction in the emission of LT_{42}. The magnetic field is hindering the scattering from level $|4\rangle \rightarrow |3\rangle$. Due to the low energy separation between $|4\rangle$ and $|3\rangle$, this is an efficient scattering process without the magnetic field. The LT_{42} emission increases with the applied magnetic field up to 4.1 T, as the scattering to level $|3\rangle$ is suppressed.

References

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