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Laser Level Selection in Terahertz Quantum Cascade Lasers using a Magnetic Field

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Quantum cascade lasers (QCLs) utilize unipolar intersubband (ISB) transitions to emit in the mid-infrared (3-30 μm) and terahertz (60-300 μm), covering the molecular fingerprint region [1]. The optical transitions can be designed through bandgap engineering [2]. THz QCL are the only solid-state lasers which emit in the range below the reststrahlen band (5—20 meV). By using an applied magnetic field 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, with two upper laser levels |4⟩ and |3⟩ and a lower laser level |2⟩ with the optical lasing transitions |3⟩ → |2⟩ and |4⟩ → |2⟩, labeled as LT_{32} and LT_{42}. Level |1⟩ is the extractor level, coupled to the LO-phonon transition |2⟩ → |1⟩. 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 [3,4]. The QCL is processed into a 2550 μm × 120 μm ridge in the metal-metal waveguide geometry with 15 μm Ni side absorbers to suppress higher order lateral modes.

At 12.2 kV/cm, 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, 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 current density 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. The 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 hinders the scattering from level |4⟩ → |3⟩. Due to the low energy separation between |4⟩ and |3⟩, 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⟩ is suppressed.

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III-7 **Andrea Barone, University of Pavia**
Photonic Crystal Cavities with comb-like spectrum for integrated nonlinear optics in silicon

III-8 **Natalia Fiuczek, Institute of High Pressure Physics "Unipress", PAS Warsaw**
Nanoporous metamaterials for nitride DBRs

III-9 **Maximilian Beiser, TU Vienna, Institut für Festkörperelektronik**
Interband Cascade Laser Frequency Comb generation and high-speed detection

III-10 **Hanh Hoang, TU Vienna, Institut für Festkörperelektronik**
Fabrication of ZnO/ZnMgO-based optoelectronic devices

III-11 **Marcin Siekacz, Institute of High Pressure Physics "Unipress", PAS Warsaw**
Vertical integration of nitride based edge emission laser diodes by tunnel juncti

III-12 **Edgar David Guarin Castro, Universität Würzburg**
Electroluminescence emission in a GaAsSb/AlAsSb resonant tunneling diode with emitter prewell

III-13 **Aaron Maxwell Andrews, TU Vienna, Institut für Festkörperelektronik**
Laser Level Selection in Terahertz Quantum Cascade Lasers using a Magnetic Field

III-14 **Dohyun Kwak,TU Vienna, Institute of Photonics**
Hybrid InP Quantum Dots-Black Phosphorus Photodetector

III-15 **Martin Kainz, TU Vienna, Institute of Photonics**
Thermoelectrically Cooled THz Quantum Cascade Lasers

III-16 **Michael Jaidl, TU Vienna, Institute of Photonics**
Multi-mode emission from a THz Quantum Cascade Ring Laser

III-17 **Julia Slawinska, Institute of High Pressure Physics "Unipress", PAS Warsaw**
Arrays of nitride micro-LEDs defined by ion implantation

III-18 **Mikołaj Chlipała, Institute of High Pressure Physics "Unipress", PAS Warsaw**
Efficient nitride LEDs for application in cryogenic temperatures

III-19 **Alexander Reiner, Universität Augsburg**
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III-20 **Dominik Theiner, TU Vienna, Institute of Photonics**
Spectrally Resolved Gain Dynamics in Heterogeneous Terahertz Quantum Cascade Lasers

III-21 **Zbig Wasilewski, Uni Waterloo, Canada**
Room Temperature THz Intersubband Transitions in Continuously Graded AlxGa1-xAs Parabolic Quantum Well Arrays

III-22 **Grzegorz Muziol, Institute of High Pressure Physics "Unipress", PAS Warsaw**
Observation of efficient optical transitions in wide InGaN quantum wells despite the piezoelectric field

III-23 **Ulrich Czopak, Universität Innsbruck**
Towards an Unconventional Photon/Polariton Blockade

III-24 **Nikola Opačak, TU Vienna, Institut für Festkörperelektronik**
Theory of frequency modulated combs in semiconductor lasers