A customized THz quantum-cascade laser as the local oscillator for a heterodyne receiver at 4.745 THz

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Motivation

Quantum-cascade lasers (QCLs) for the THz spectral region

Potential for several applications
- imaging (security and medical purposes)
- absorption spectroscopy (chemical analysis)
- heterodyne spectroscopy (astrophysics)

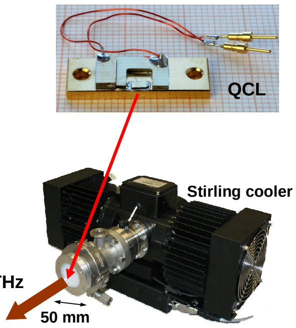
From proof-of-principle level toward customized solutions:

Local oscillator in a heterodyne detector for the oxygen (OI) line at 4.745 THz in an airborne spectrometer

Requirements:

- single-mode operation at 4.745 THz (tuning range of 5 GHz for a single mode)
- optical power on mW level
- Gaussian beam profile
- continuous-wave (cw) operation
- pumping power in compliance with Stirling cooler

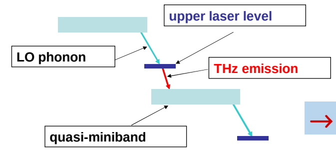
Approach



(cooling power increases from 0 to 10 W for temperatures between 25 and 70 K)

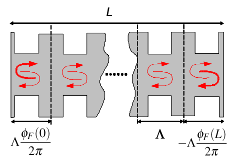
Hybrid design: BTC-RP

BTC: bound-to-continuum
RP: resonant-phonon



→ high-gain laser medium

Distributed-feedback (DFB) laser



→ single-mode operation

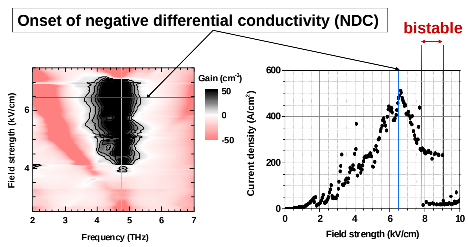
Λ: grating period, ϕ_F: facet phases, L: cavity length

Tuning of the DFB laser modes: by adjusting heat sink temperature and operating current
→ sufficient gain at target frequency for a larger range of current densities

Design and fabrication

Simulation of gain medium:

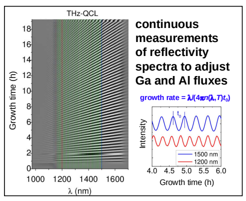
- multiple scattering processes
- predictive model: Schrödinger-Poisson equations, transport model with self-consistent scattering rates
- reasonable level of numerical expense



- gain maximum at 4.75 THz
- large dynamical range: 200 – 500 A/cm²
- negligible shift of gain spectrum over dynamical range

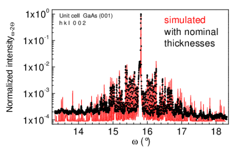
Growth of QCLs: Molecular beam epitaxy

- more than 1000 layers
- whole thickness about 10 µm
- growth time: 15–20 h



In-situ closed-loop control of growth rate

X-ray diffraction analysis: thickness of cascade

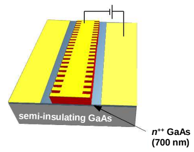


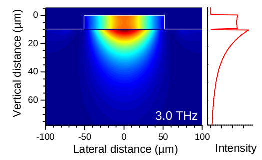
Deviation from nominal thicknesses < 1 %

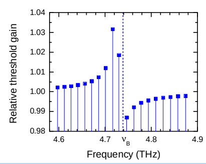
Improvements:
- band-gap monitoring to adjust substrate temperature
- closed-loop control of As flux

Distributed-feedback lasers

Single-plasmon waveguide: optical confinement by top Au and bottom n^{++} contact





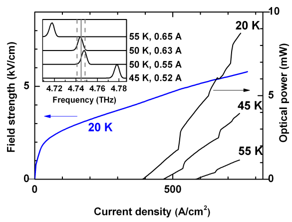


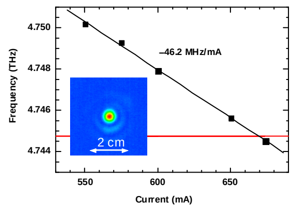
Single-plasmon waveguides with first-order lateral DFB gratings

- fabrication by dry etching
- simulation by rigorous solution of Maxwell equations for grating unit cell

Results

- single-mode lasing at target frequency (4.745 THz)
- optical power on mW level in cw operation
- maximum cw operating temperature about 60 K
- input power (< 5 W) suitable for operation in Stirling cooler





Operation in Stirling cooler:

- required tuning range* achieved
- good beam profile using one lens
- coupling of laser radiation into hot-electron bolometer for SOFIA** achieved

* 5 GHz above or below 4.745 THz: determined by maximum of intermediate frequency of detection system and expected Doppler shift of the OI line
**Stratospheric Observatory for Infrared Astronomy

Delicate balance between many processes — nominally identical samples may exhibit significant variations of operating parameters

Optimization with respect to wall-plug efficiency and dynamical range in progress

Conclusions and Outlook

Development of customized THz QCLs possible but demanding with respect to design, growth, and processing

Challenge: identification of complex interplay between large number of parameters
- improvement of model
- improvement of growth control

Mid-term objectives:
- increase of maximum operating temperature
- THz QCLs with wide tuning range
- optical gain in the THz spectral region generated by quantum coherence and interference

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