Compact THz local oscillator based on a quantum-cascade laser

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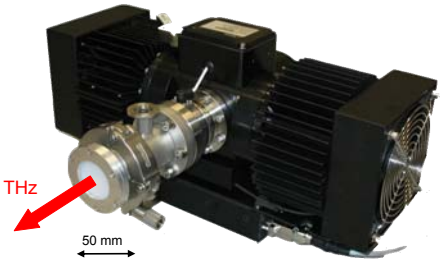
1. Summary

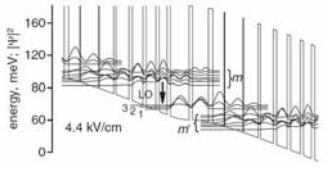
A compact, easy-to-use THz local oscillator is currently under development at DLR. It combines a quantum-cascade laser (QCL) with a compact, low-input-power Stirling cooler. This work is part of the local-oscillator development for GREAT/SOFIA. The QCL, which is based on a two-miniband design, has been developed for high output and low electrical pump power. Several lasers operating at frequencies between 2.7 and 4.7 THz have been made. Efficient carrier injection is achieved by resonant longitudinal-optical phonon scattering. The amount of generated heat complies with the cooling capacity of the Stirling cooler. The whole system weighs less than 15 kg including cooler, power supplies etc.. The output power is well above 1 mW for most of the lasers. With an appropriate optical beam shaping, the emission profile of the laser becomes a fundamental Gaussian one. Sub-MHz frequency accuracy can be achieved by locking the emission of the QCL to a molecular resonance.

2. System performance

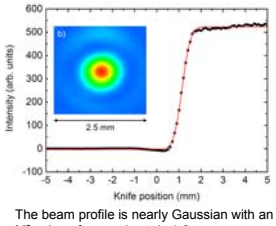
Twin Piston Integral Stirling Cryocooler



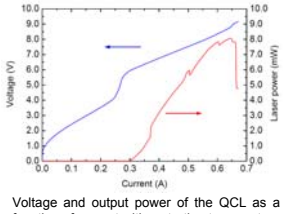
- **Frequency: 3.1 THz**
- **Power: up to 8 mW (cw)**
- **Mass: <15 kg**
- **Electrical input power: < 240 W**
- **Volume: 32.1×13.9×27.4 cm³**



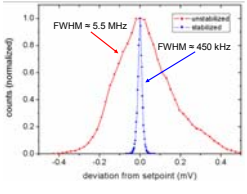
- Two-miniband design: intersubband transition resonant to energy of longitudinal optical phonons
- Low operating voltage, low current density (fewl hundred A/cm²)
- 100-µm-wide, 11-µm-thick, and 1.43-mm-long ridge
- Active region: 85 periods with each period containing nine GaAs quantum wells and nine $Al_{0.15}Ga_{0.85}As$ barriers
- Single-plasmon (SP) waveguide
- Fabry-Pérot cavity with both facets uncoated



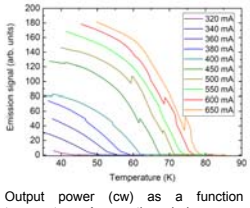
The beam profile is nearly Gaussian with an M^2 value of approximately 1.2.



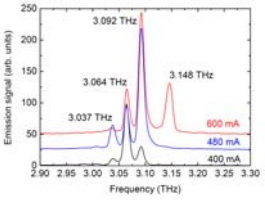
Voltage and output power of the QCL as a function of current with a starting temperature of 24 K and an end temperature of 43 K. The steps in the output power are probably caused by electric-field domains.



Frequency stabilization to a molecular absorption line yields a linewidth of 450 kHz. With some improvements a linewidth below 100 kHz will be achieved.

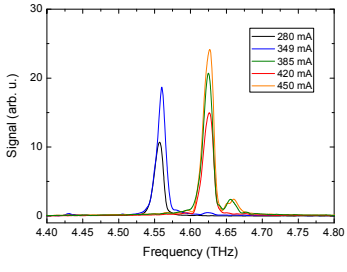


Output power (cw) as a function of temperature. Across the whole range, the electrical input power at the temperature threshold is much less than the available cooling power.



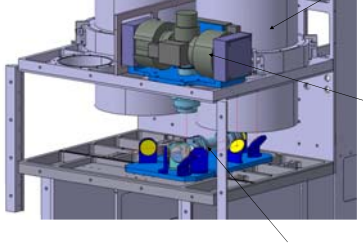
Emission spectra of the QCL measured with a Fourier transform spectrometer. The spectral resolution is approximately 10 GHz. Several longitudinal modes of the Fabry-Pérot laser cavity separated by 28 GHz appear.

3. Towards a 4.7-THz local oscillator for GREAT/SOFIA



First laser for 4.7 THz:
- Fabry-Pérot cavity with both facets uncoated
- 100-µm-wide, 11-µm-thick, and 1-mm-long ridge
- CW operation in compact Stirling cooler achieved
- ~50 µW output power (CW)
- Gain profile of of the active medium approxi-mately correct (gain maximum about 100 GHz (=2%) too low)
- next steps: adjust gain medium to 4.7 THz, DFB grating, frequency stabilization with gas cell

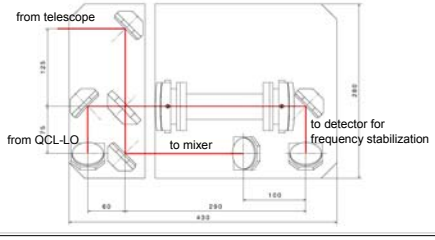
Integration into GREAT

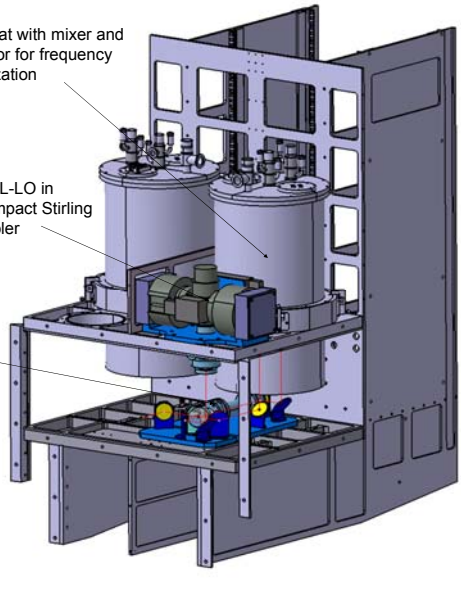


Cryostat with mixer and detector for frequency stabilization

QCL-LO in compact Stirling cooler

Gas cell for frequency stabilization





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[4] H.-W. Hübers, S. G. Pavlov, A. D. Semenov, L. Mahler, A. Tredicucci, H. E. Beere, and D. A. Ritchie, Appl. Phys. Lett. **89**, 061115 (2006).

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