Development of a terahertz heterodyne receiver front-end with quantum cascade laser and hot electron bolometric mixer in a pulse tube cooler

H.-W. Hübers[a,b], H. Richter[a], S.Pavlov[a], A. Semenov[a], L. Mahler[c], A. Tredicucci[c], H. E. Beere[d], D. A. Ritchie[d], K. I'lin[e], and M. Siegel[e]

[a]Institute of Planetary Research, DLR, Rutherfordstr. 2, 12489 Berlin, Germany
[b]Institut für Optik und Atomare Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany
[c]NEST-INFM and Scuola Normale Superiore, Pisa, 56126, Italy
[d]Cavendish Laboratory, University of Cambridge, Bb3 OHE, United Kingdom
[e]Institute of Micro- and Nano-Electronic Systems, University of Karlsruhe, Hertzstr. 16, 76187 Karlsruhe, Germany

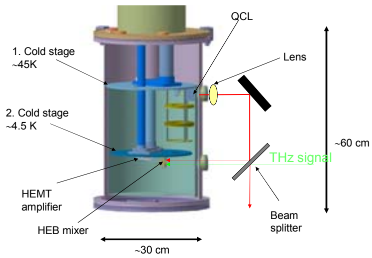
1. Summary

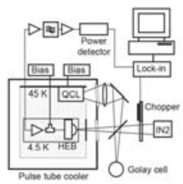
At DLR a liquid cryogen free terahertz (THz) heterodyne receiver front-end in a pulse tube cooler (PTC) is under development. The basic features are:

- Operating frequency: 2.5 THz (planned: extension to 4.7 THz);
- Quantum-cascade laser (QCL) as local oscillator and superconducting hot electron bolometric (HEB) mixer;
- QCL mounted on first cold stage (~50 K) and HEB mounted on second cold stage (~ 4 K) of the PTC;
- DSB noise temperature: 2000 K (uncorrected), ~ 800 K (corrected for optics loss);
- Frequency stabilization to a molecular absorption line (accuracy < 300 kHz);
- Easy-to-operate ("turn-key");

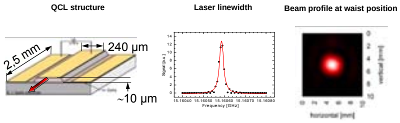
This design can be the basis for as facility heterodyne spectrometer on board of SOFIA (e.g. as 2nd generation instrument).

2. System

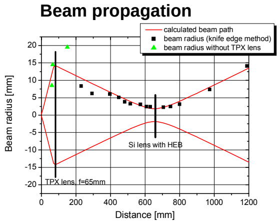




QCL

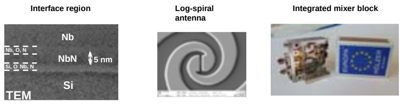


The QCL structure is based on a GaAs/AlGaAs superlattice and a plasmon-type waveguide. The active medium is formed by 110 repeat units of the superlattice (total thickness ~10 µm) covered on top by a Cr/Au layer. The laser works up to 58 K and the maximum output power is 5 mW in continuous wave mode. The short term linewidth is about 30 kHz (measurement time 4 ms) [1].

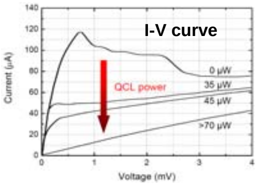


The beam waist is located 650 mm from the QCL. A fit of a second order polynomial expression to the data obtained with the knife-edge method yields a beam radius at the position of the waist of 1.8±0.1 mm and an M^2 of 1.1 in direction vertical to the layers of the superlattice of the QCL [3].

HEB

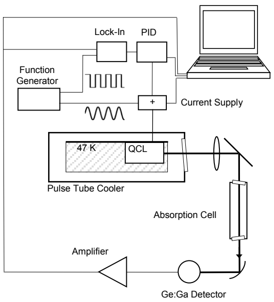


The hot electron bolometer (HEB) were manufactured by means of electron-beam lithography from 4.5 nm thick NbN film, which were grown on Si substrate by magnetron sputtering (deposited at University Karlsruhe [2]). Radiation was coupled to the bolometer by an extended hemispherical Si lens. The mixer, the lens and the bias-T are integrated in an compact mixer block.

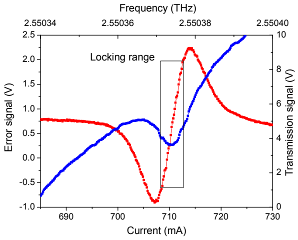


I-V curves of an HEB mixer pumped with the QCL LO at 2.5 THz. The arrow indicates increasing LO power. The absorbed power in the HEB is ~300 nW (isothermal method), the power required to pump the HEB ~13 µW (corrected for vacuum window, quartz filter, Si lens). The system noise temperature is $T_{SYS,DSB}$ ~800 K (corrected for optical loss, no AR coating, vacuum window, cryo filter, and air) [3] .

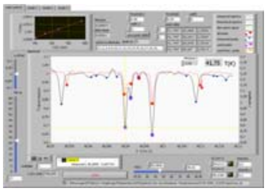
3. Frequency stabilization



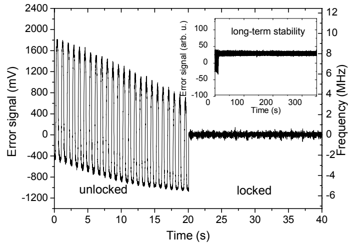
The diverging QCL beam is focused and guided through a 52 cm long absorption cell. The cell is filled with $^{12}CH_3OH$ at a pressure of 1–2 hPa. Methanol was chosen, because it has many absorption lines in the frequency range covered by the QCL. The particular absorption line which was used as a reference for the stabilization is a transition at 2.55025 THz. The signal transmitted through the absorption cell is detected with a Ge:Ga photoconductor, followed by a low noise amplifier.



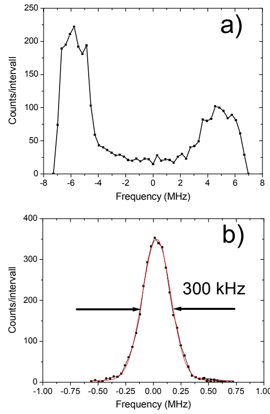
Absorption line of methanol at 2.55 THz and 1.7 hPa. The QCL is locked to the center of the derivative-like signal, which is the error signal of the PID loop [4].



Fingerprint-like identification of the absorption line by comparing the measured spectra with FTS data. This allows also to determine the tuning rate of the QCL [4, 5].



Error signal of the PID control loop in the unlocked and in the locked state. The control loop was activated after 20 s. The variations in the unlocked state are caused by temperature and current fluctuations in the QCL. The 1.2 Hz variation is related to the temperature variation on the first cold plate of the PTC which is 0.1 K. The thermal drift is due to current heating of the QCL. In the locked state the 1.2 Hz component and the thermal drift are eliminated [4].



Number of counts in a given frequency interval when the QCL is operating in the unlocked (a) and locked (b) state for 10 seconds. For longer time intervals the peaks in the upper diagram become much broader, while the width and shape of the peak in the lower diagram remains unchanged [4].

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