A compact, continuous wave terahertz source for spectroscopy and imaging based on a quantum cascade laser

H. Richter[a], M. Greiner-Bär[a], S. G. Pavlov[a], A. Semenov[a], M. Wienold[b], L. Schrottke[b], M. Giehler[b] , R. Hey[b], H. G. Grahn[b], H.-W. Hübers[a,c]

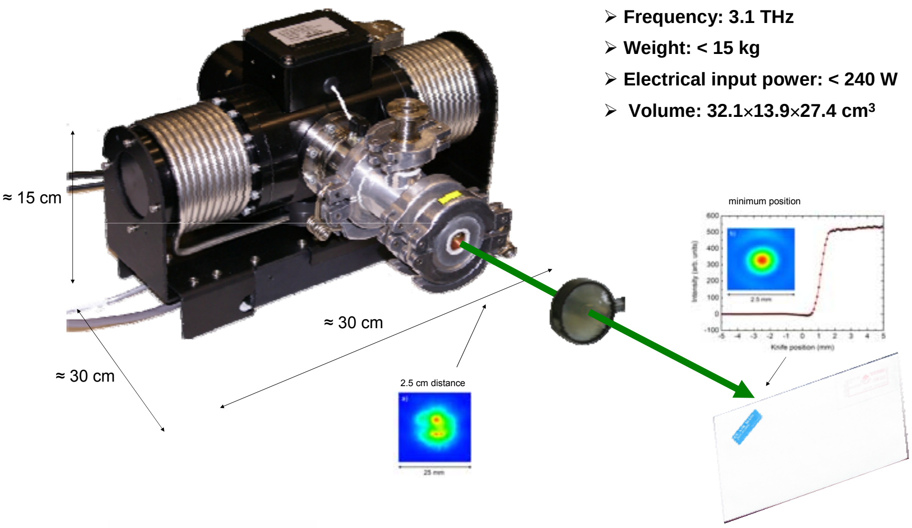
[a]Institute of Planetary Research, DLR, Rutherfordstr. 2, 12489 Berlin, Germany
[b]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5−7, 10117 Berlin, Germany
[c]Institut für Optik und Atomare Physik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

1. Motivation

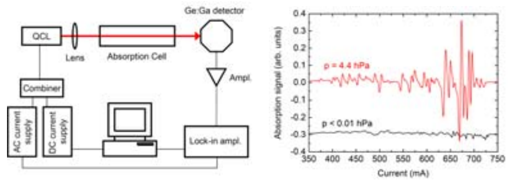
The Terahertz (THz) spectral range has a unique potential for many applications. One example is high-resolution spectroscopy of rotational transition in molecules which are relevant in atmospheric research or astronomy. Another example is imaging for security applications, biomedicine or non-destructive testing. For such applications radiation sources which are compact, easy-to-use and with low input power are required. THz quantum cascade lasers (QCLs) have the potential comply with these requirements [1-7]. However, until now, THz QCLs are operated either with liquid-helium cooling or with large cryo-coolers. While these cooling approaches might be acceptable for scientific experiments, they are unacceptable for most practical applications. We report on the development of a compact, easy-to-use THz source, which is based on a QCL operating at 3.1 THz and a compact, low-input-power Stirling cooler.

2. Compact cw THz-source for imaging and spectroscopy

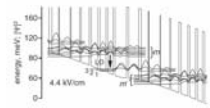
Twin Piston Integral Stirling Cryocooler



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

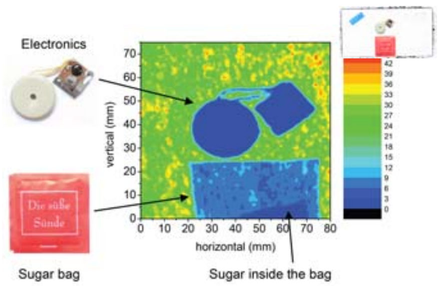


Absorption of $^{12}CH_3OH$, measured with high spectral resolution around 3.1 THz. The lock-in detection yields a signal-to-noise ratio, which is as large as 1500 despite the short measurement time (320 ms). The rather complicated absorption structure is due to the multimode operation of the laser, because each mode generates its own spectrum.



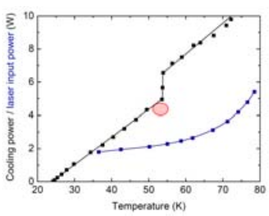
Conduction band profile and squared moduli of wavefunctions at 4.4 kV/cm, where m and m_0 denote quasi-minibands of different cascades [8,9].

- two-miniband design: intersubband transition resonant to energy of longitudinal optical phonons
- low operating voltage, low current density (several 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

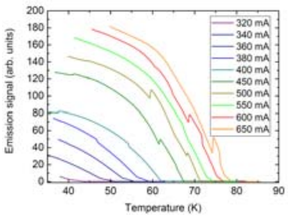


THz image of a sugar bag and the electronic components of a music greeting card inside an envelope. The envelope was raster-scanned in steps of 1 mm through the position of the minimum waist. The legend shows the intensity of the transmitted signal (in arbitrary units).

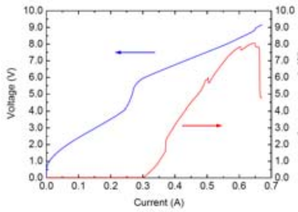
3. System Performance



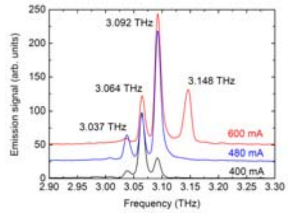
Electrical input power at lasing threshold of the QCL and cooling power available from the Stirling cooler as a function of temperature. The step at 54 K occurs because the internal temperature stabilization of the cooler does not function below this temperature. The red ellipse indicates the region of maximum output power.



Cw laser output signal as a function of temperature for several driving currents. Across the whole range, the electrical input power at the temperature threshold is much less than the available cooling power.



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. The maximal output power is 8 mW.



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.

4. Summary

We have realized a compact, cw THz source based on a QCL and a miniature cryo-cooler. Imaging and spectroscopy experiments show promising results. Further improvements are envisaged. The broad frequency coverage of almost 10% of the emission frequency makes it attractive for implementation into an external cavity. This will allow for tuning of the emission frequency across a broad range as required for a spectrometer. Along with frequency stabilization by for example locking to an external reference such as the emission from a multiplied microwave source or to a molecular absorption line, this source is an attractive option for a THz local oscillator. The results indicate that future developments may result in many scientific or commercial applications.

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in der Helmholtz-Gemeinschaft

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