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


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1. Motivation

The terahertz (THz) spectral range has a unique potential for many applications. One example is high-resolution spectroscopy of rotational transitions in molecules which are relevant in atmospheric research or astronomy. Another example is imaging for security applications, medicine or non-destructive testing. For such applications cooling sources are required. THz quantum cascade lasers (QCLs) have the potential to provide 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

- 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

Conduction band profile and squared moduli of wavefunctions at 4.4 kV/cm, where m and m₀ 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 Al₀.₃5Ga₀.₆5As barriers
- single-plasmon (SP) waveguide
- Fabry-Pérot cavity with both facets uncoated

Absorption of 12CH₃OH, 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.

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.

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).

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 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.