National Aeronautics and Space Administration

# THz quantum-cascade laser sources for space science


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Program: FY22 R&TD Topics
Strategic Focus Area: Direct/Coherent Detectors and Arrays

## Objectives:

The objective of this work was to develop terahertz (THz) quantum-cascade lasers (QCLs) primarily for use as local oscillators in THz heterodyne receivers, and potentially for in-situ laser absorption spectrometers. More specifically, we were developing a new, high-performance QCL design called a QC-Vertical-External-Cavity Surface-Emitting-Laser (QC-VECSEL). Our objective was to develop devices that have acceptable SWaP characteristics for a space-based instrument, and frequency stable enough to provide the necessary spectroscopic resolution for the science objectives. We established the following performance objectives for a QC-VECSEL that can be used for a heterodyne receiver in a SmallSat configuration (e.g., Microsat/ESPA – Blue Canyon Technologies or 24U), which could eventually enable future space-based THz interferometers:

- Produce between 0.3 – 1 mW of THz power.
- Can operate on a miniature Stirling cryocooler requiring <20 W input power (~0.5 W of cooling power at 80 K).
- Are phase-locked and frequency tunable (>10%).
- Operate around important gas lines at 2.7 THz ([HD]) and 4.7 THz ([OI]).

Upon development of the lasers LOs, our objective was to perform an in-lab demonstration of a heterodyne gas cell using an HEB mixer.

## Background:

The purpose of this work is to expand upon JPL's heterodyne detector capabilities in the 2-6 THz frequency range needed for mapping atoms and molecules in the interstellar medium and Solar system bodies (planet atmospheres, comet comae, geysers, volcano plumes, etc.). Currently capabilities at JPL are limited by a lack of local oscillator (LO) sources at THz frequencies. Frequency multiplier chains (FMC) have served well at lower frequencies, but the power drops to unusable levels above 2 THz. QCLs are a leading candidate to fill the technology gap at higher THz frequencies, providing milliwatt power levels from a semiconductor source. However, QCLs are largely unavailable commercially, and existing designs have relatively poor beam qualities and limited frequency tunability. JPL has recently hired a QCL expert (Curwen) who (while a graduate student at UCLA) developed a new, external cavity QCL design that produces excellent beam qualities, and can be frequency tuned over a broad bandwidth (~10% fractional). In-house development of these new QCLs, called QC-VECSLs, will build on JPLs leadership in THz spectroscopic instruments.

## Approach and Results:

Our milestones and results are as follows:

1. ***Design of THz reflective amplifiers at 2.7 THz and 4.7 THz optimized for <1W power draw***.
2. ***Fabrication of devices at MDL and testing in a liquid nitrogen cryostat***. 4.7 THz molecular beam epitaxy (MBE) grown wafer material was designed and purchased from a commercial vendor. 2.7 THz VECSELs were constructed and tested. Devices dissipating ~3 W produced ~1 mW of THz power at 80 K, and ~4 mW of power at 50 K (Fig. 1). The 4.7 THz wafer material has been fabricated into ridge waveguides, which are used to test characterize the performance of the new wafer material (lasing frequency, operating temperature, power consumption, etc., see Fig. 2).
3. ***Heterodyne measurement of gas cell using HEB mixer***. Phase locking to an RF reference was achieved using two techniques: 1) down conversion with a diode harmonic mixer and locking to 100 MHz reference using the laser a voltage tunable oscillator, and 2) directly injection locking the laser using the output of a 2.5 THz diode frequency multiplier. The phase-noise of the locked devices is plotted in Fig. 3..

## Significance/Benefits to JPL and NASA:

THz QC-VECSEL provides a long-sought solution for large heterodyne arrays as a single QCL device can now pump multiple THz mixers (~ 100). Also, the scalability of the design and the high efficiency allows the laser to operate with a small dc power thus making it suitable for deployment on SmallSats. The most significant results in FY22 are:

1. Acquisition of MBE grown QC gain material at 4.7 THz.
2. Phase locking of the 2.5 THz QC-VECSELs using JPL made SOA diode mixers and sources.

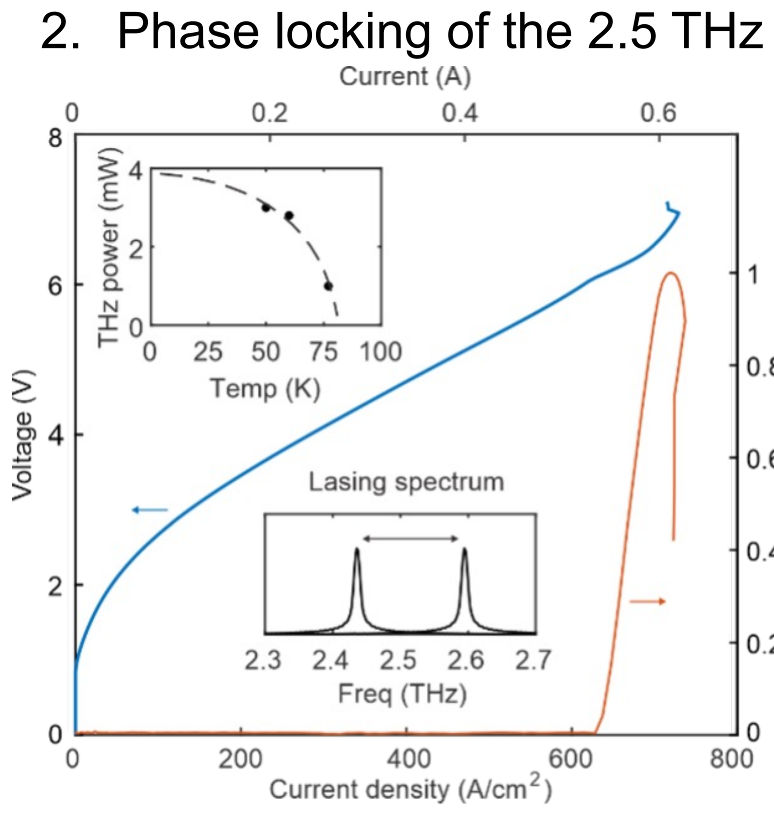


**Figure 1.** Current, voltage, and output power data for a QC-VECSEL that is continuously tunable from 2.43 – 2.6 THz.

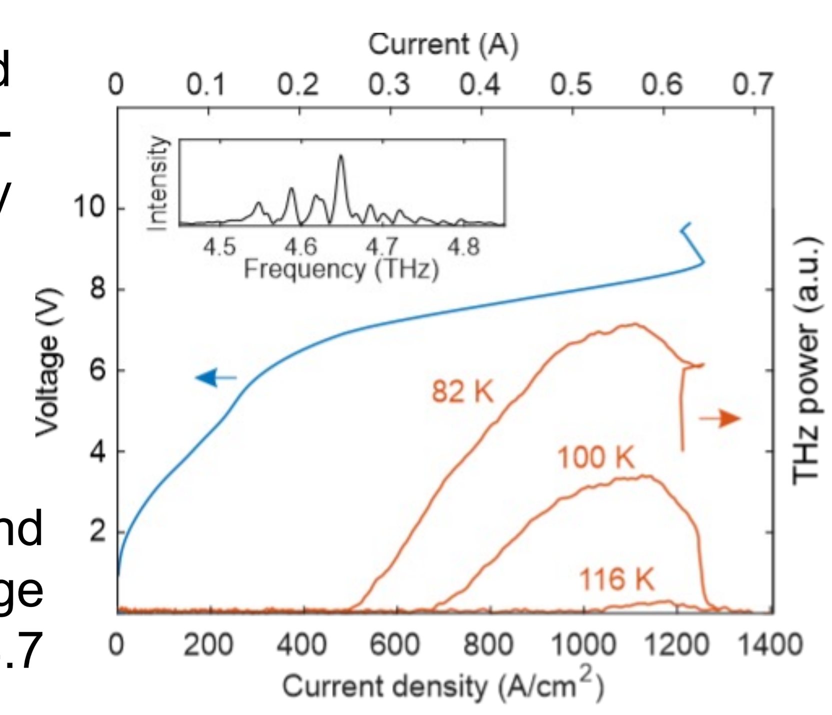


**Figure 2.** Current, voltage, and output power data for a ridge waveguide operating around 4.7 THz.

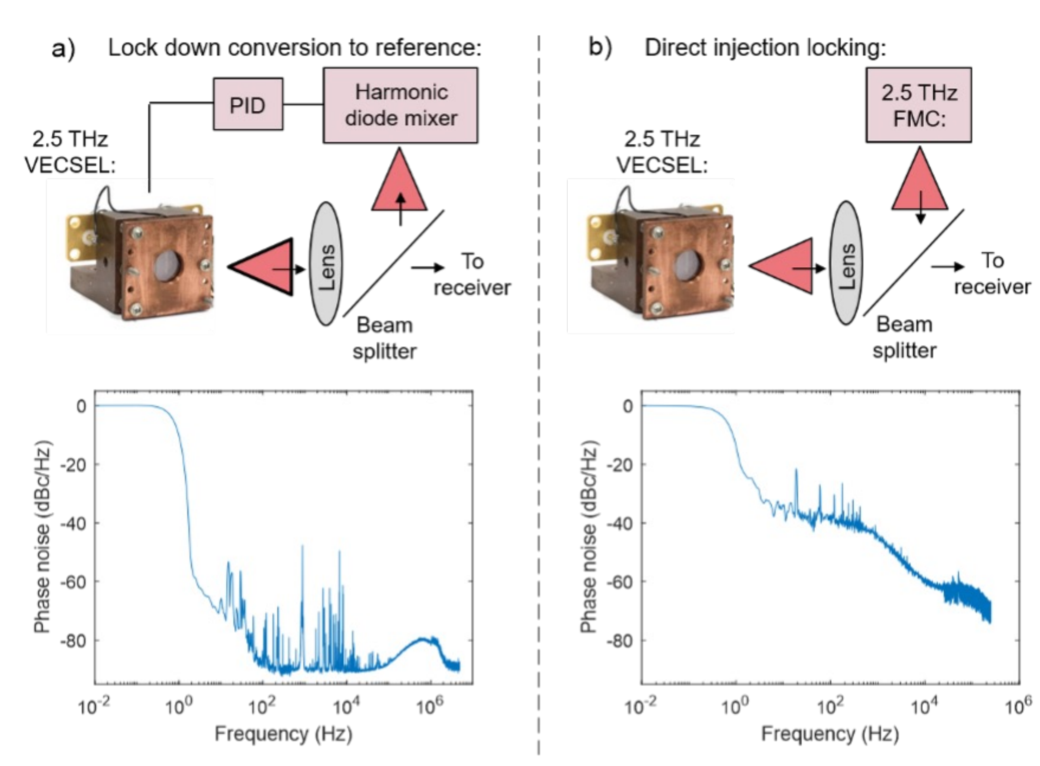


**Figure 3.** Phase locking QC-VECSEL by a) down conversion with a harmonic diode mixer, and b) injection locking using a 2.5 THz FMC.


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## Publications:


[A] C. A. Curwen et al., "Thin THz QCL active regions for improved continuous-wave operating temperature", *AIP Advances* **11**, 125018 (2021).

[B] C. A. Curwen et al., "Measurement of gain and absorption of a THz quantum-cascade metasurface free-space amplifier", *AIP Advances, submitted.*

[C] C. A. Curwen et al., "Terahertz quantum-cascade VECSELs local oscillators for heterodyne receivers," *Proc. SPIE PC12190, Millimeter, Submillimeter, and Far-Infrared Detectors and Instrumentation for Astronomy XI*, PC121900A (26 August 2022).


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