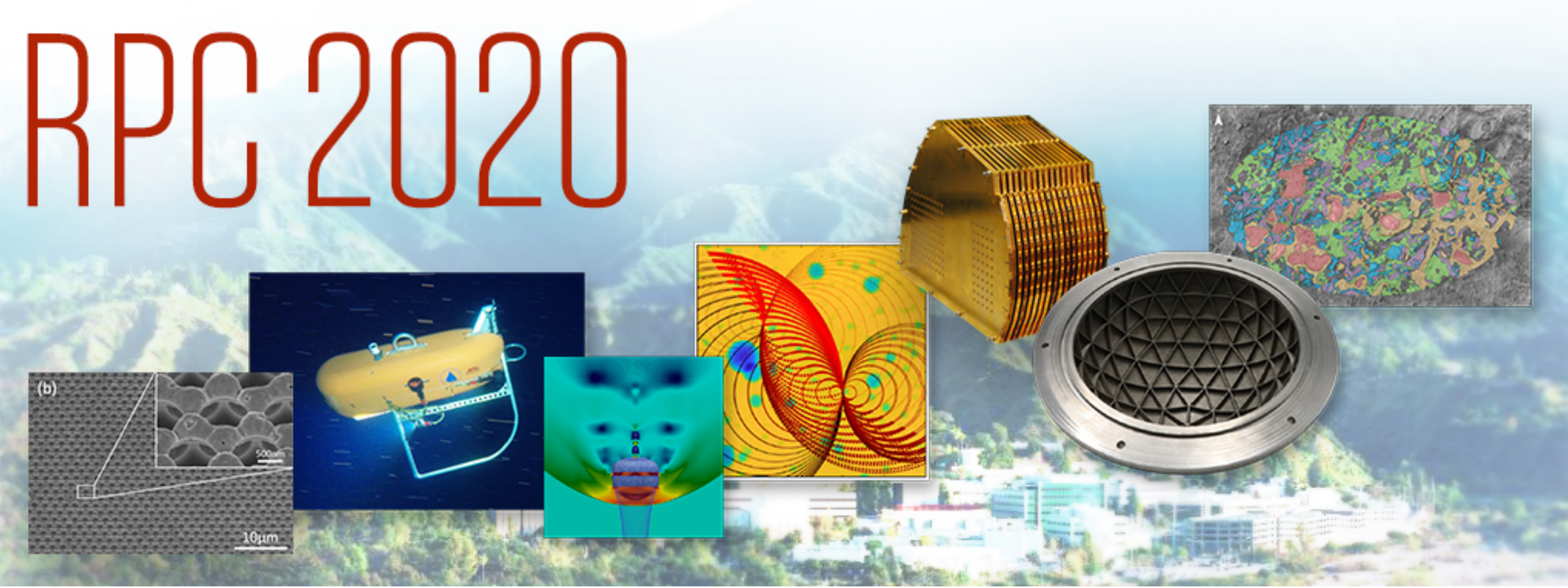

Virtual Research Presentation Conference

In-house Development of THz Quantum Cascade Lasers

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Program: Spontaneous Concept

Assigned Presentation # RPC-147

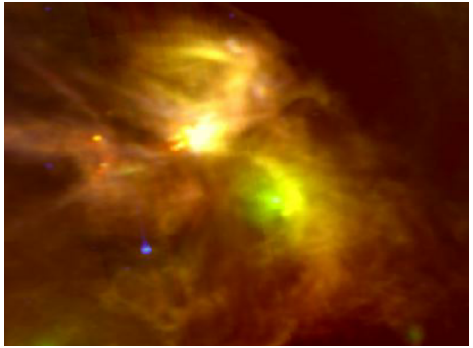
Jet Propulsion Laboratory
California Institute of Technology

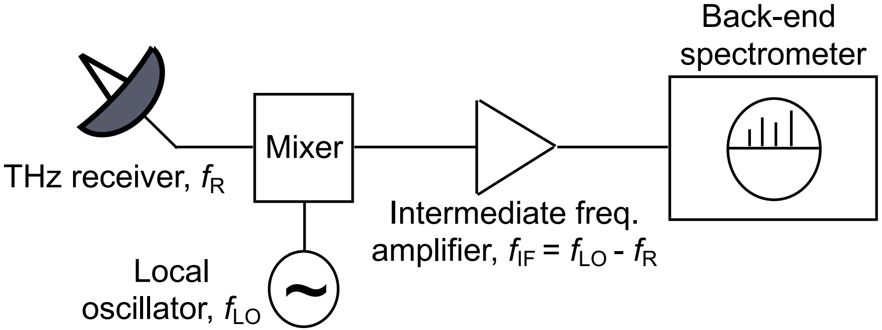
Tutorial Introduction

Heterodyne spectroscopy at terahertz (THz) frequencies is used to study the composition and dynamics of the interstellar medium between galaxies. This technique requires the mixing of collected radiation with a frequency reference, referred to as a **local oscillator (LO)**.

THz quantum cascade lasers (QCLs) make excellent LOs since they are spectrally narrow, stable, and produce relatively high output power; however, THz QCLs are specialty devices that require low operating temperature and are not readily available for integration with spectrometer assemblies.

With this effort, we completed the initial steps toward developing a process to design, fabricate, and test THz QCLs at JPL for LOs in heterodyne receivers.





Problem Description

Context: Next generation balloon- and space-based astronomy instruments can leverage heterodyne spectroscopy to probe the structure of the interstellar medium as well as water content in our own galaxy at THz frequencies. This requires high-performance THz local oscillators (LOs) with reduced size, weight, and power consumption.

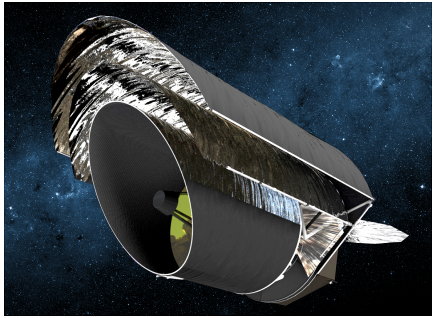
State-of-the-art THz LOs are Schottky-diode-based multipliers, which suffer from low efficiency and low output power at frequencies above 2 THz (wavelengths shorter than 150 μm).

Relevance to NASA and JPL: Heterodyne receivers in the THz regime would enable measurements with unparalleled resolving power ($R \sim 10^7$) for ongoing and future NASA missions, including the balloon-based ASTHROS and the space-based Origins Space Telescope.

ASTHROS high-altitude balloon concept

Credit: NASA GSFC

Origins Space Telescope concept



Credit: NASA/Caltech

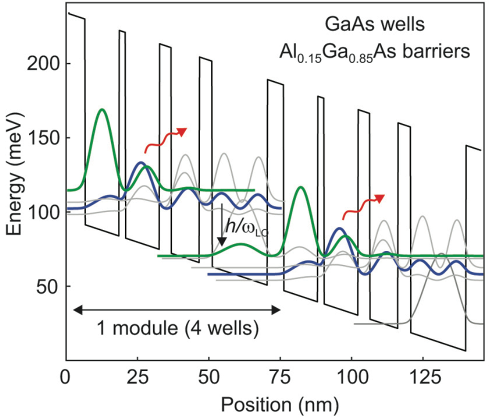
Methodology

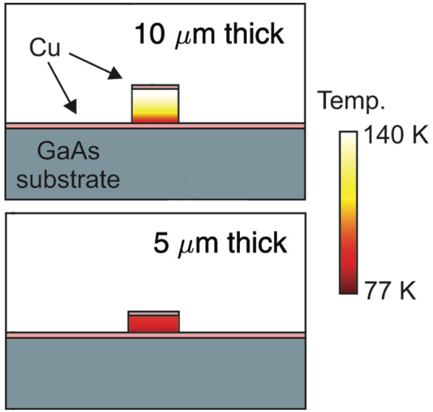
- We designed quantum cascade lasers (QCLs) emitting at 2.7 THz and operating at liquid-nitrogen temperatures (77 K)
- QCL structures were grown on GaAs substrates by molecular beam epitaxy (MBE)
- We also procured a beamsplitter and detector for an existing Fourier transform infrared (FTIR) spectrometer at JPL to expand spectral measurement capability to the 1.5 to 21 THz range (15 to 200 μm wavelength)

Advancement:

- Compared with previous THz QCLs, our current designs are expected to operate ~50 K cooler, enabling higher output power and improved efficiency
- With QCL wafers in-hand at JPL, we can fabricate THz QCLs as LO sources for heterodyne spectrometers

THz QCL band structure design and thermal modeling





Results

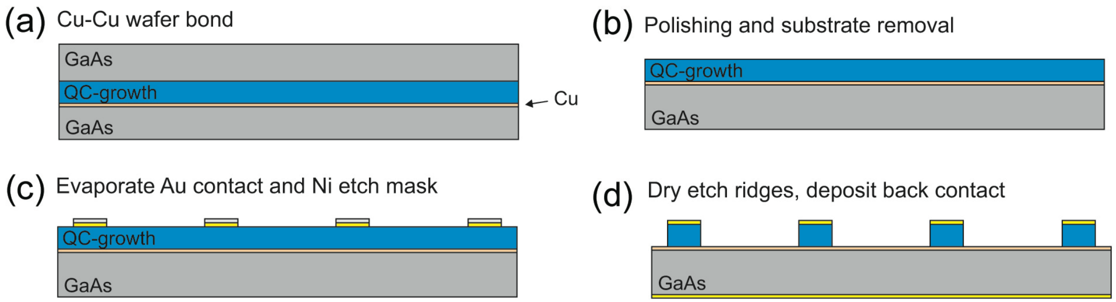
Accomplishments:

1. Design of high-performance QCL gain structures
2. Growth of semiconductor QCL structures by molecular beam epitaxy (MBE)
3. Lithography mask design for QCL resonators and metasurfaces for efficient generation and extraction of THz radiation
4. Procurement of spectrometer parts required for THz QCL spectral characterization

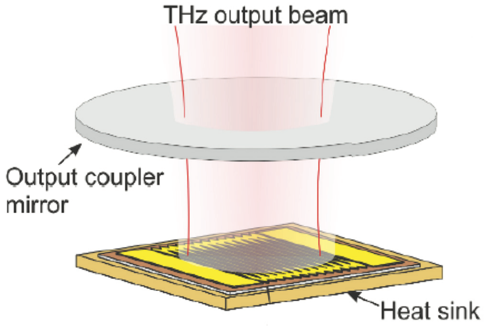
Significance: With QCL wafers in-hand at JPL, we can fabricate and characterize THz QCLs as LO sources for heterodyne spectrometers

Next steps: In the next year, we will demonstrate and validate a fabrication process for THz QCLs in the JPL Microdevices Laboratory using the wafer material designed and grown under this effort

Fabrication process for vertical-external-cavity surface-emitting QCLs



Surface-emitting LO source



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