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Operation of a Monolithic Planar Schottky Receiver Using a THz Quantum Cascade Laser

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Outline

- A little history & motivation
- The Schottky receiver
- The THz quantum cascade laser
- The THz QCL + Schottky receiver

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(Recent) History & Motivation

- Continuing search for better LO sources > 2 THz
  - FIR molecular gas laser most common
  - Solid-state sources preferable but have power issues
- THz quantum cascade lasers demonstrated in 2002
  - Continuous improvements in power, efficiency, frequency coverage, operating temperature
  - Only solid-state source capable of > 1 mW CW above 2 THz
- 2.5 THz QCL used successfully as LO for Nb HEB mixer
  - ~ 10 μW LO power [Hübers, *et al*., Optics Exp. (2005)]
- Dual-mode mixing of THz QCL with point-contact Schottky
  - Low conversion gain [Barbieri, *et al*., Optics Lett. (2004)]
- Planar Schottky mixer has more stringent LO requirements
  - Need 5 to 10 mW CW with excellent frequency stability
- Can a THz QCL be used successfully with a planar Schottky receiver?

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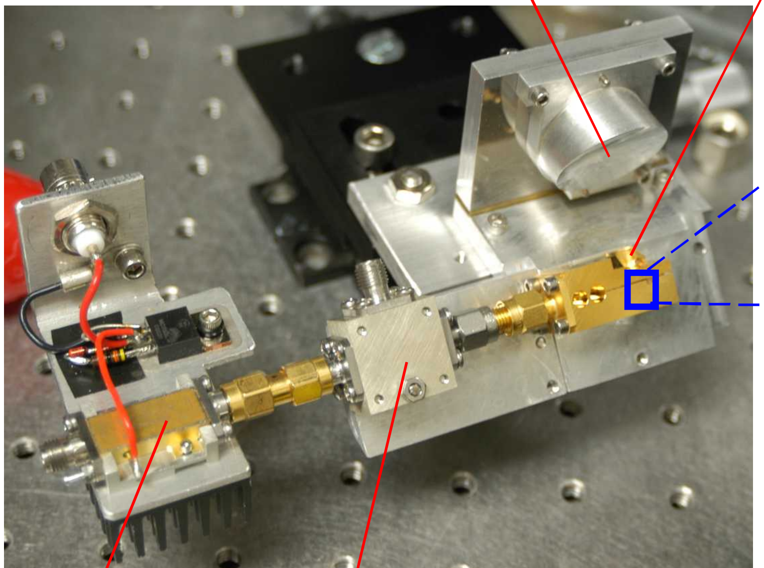
The JPL Schottky Receiver



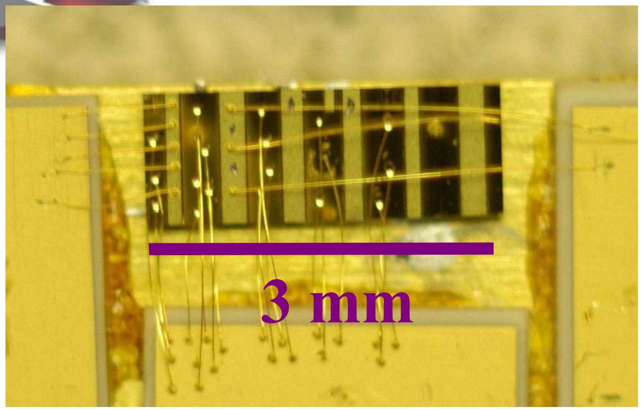
- GaAs monolithic membrane diode mixer in waveguide block
- Designed for 2.5 THz, works to at least 3.1 THz
- T_N = 11,000 K at 2.5 THz with ~ 5 mW LO power
- $T_N \approx$ 20,000 K at 2.9 THz with ~ 6 mW LO power

<u>Duplicate of Aura receiver</u>

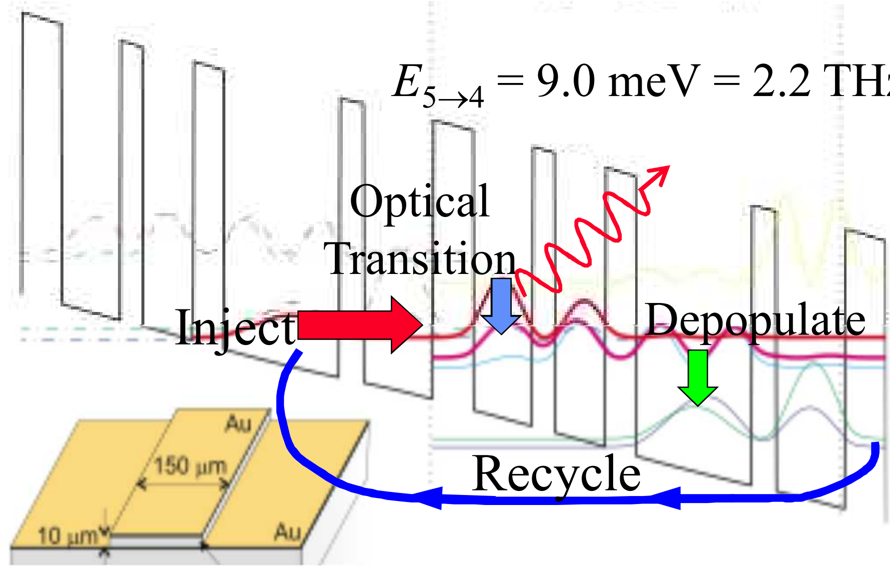
Siegel, *et al*., IEEE Trans. Microw Th & Tech. (1999)

Gaidis, *et al*., IEEE Trans. Microw Th & Tech. (2000)

THz Quantum Cascade Lasers

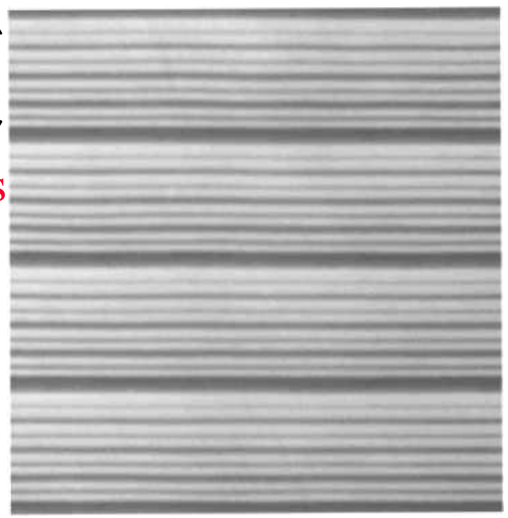


6 QCLs integrated on chip



50 nm

200 reps



TEM cross-section of QCL stack

- *Tour-de-Force of Bandgap Engineering*
  - Requires ultra-precise, clean MBE growth
  - Many designs successfully grown at Sandia
- Can output > 1 mW CW power
  - Beam profile problematic
- Ongoing research into:
  - Higher power & operating temperature
  - Expanded frequency coverage
  - New designs need 6 Å layers repeated 10^3x!

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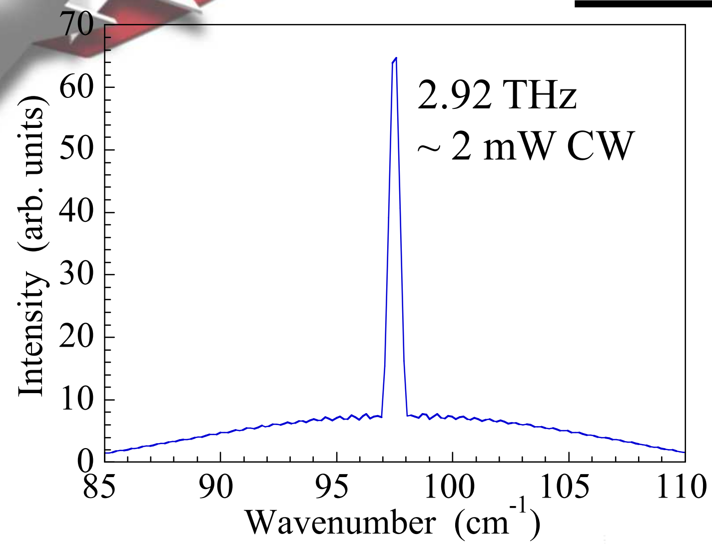
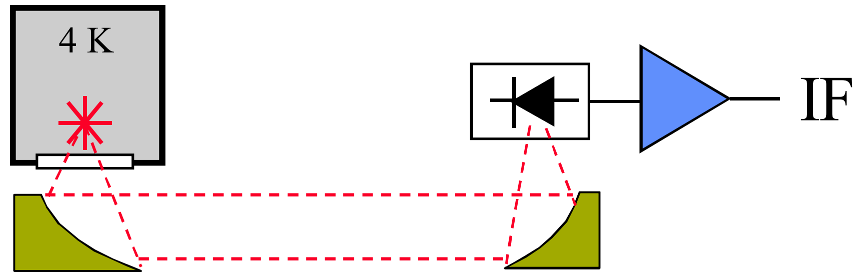
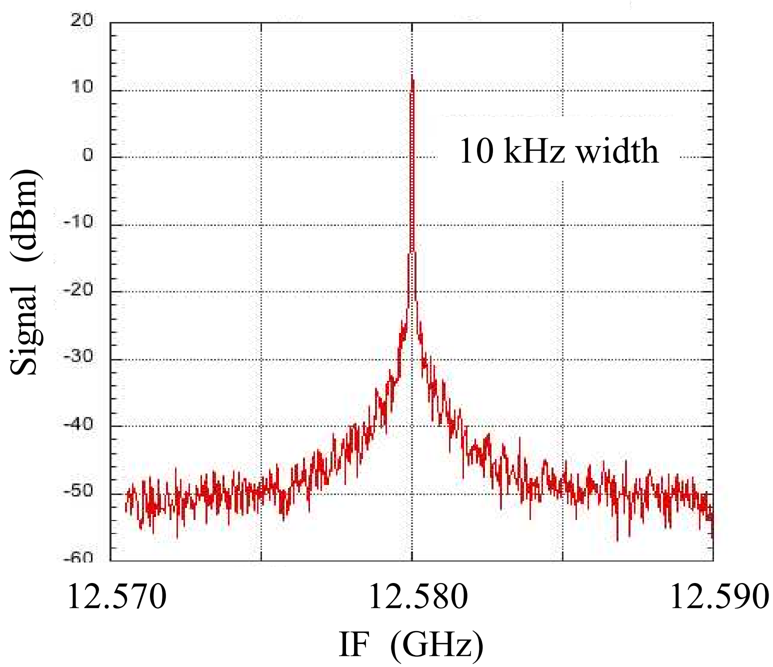
Dual-mode Mixing





- 2.92 THz <u>free running</u> QCL
- ~ 2 mW CW total power in non-Gaussian divergent beam
  - Collimated with paraboloid mirror
  - Estimate ≤ 0.4 mW coupled to receiver
  - Insufficient to measure noise temperature
- Above threshold bias, dual F-P modes split by 12.58 GHz
- Dual mode difference frequency signal width ≤ 10 kHz



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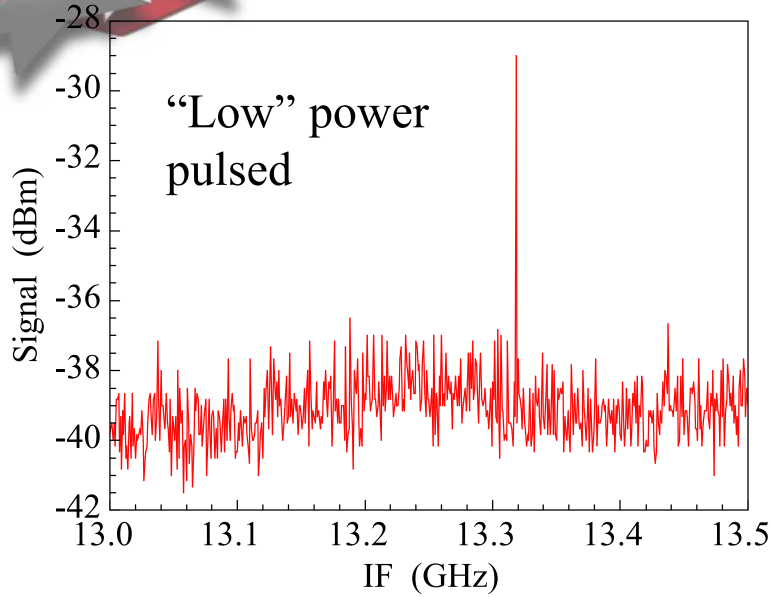
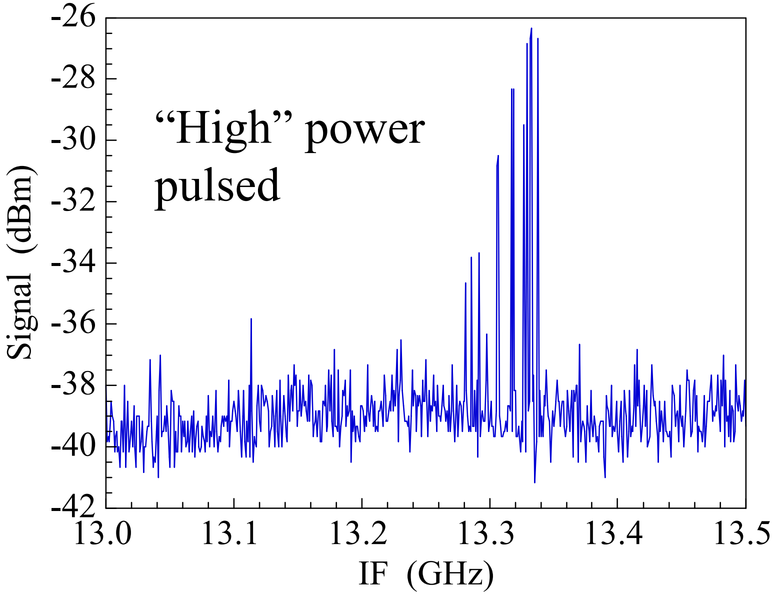
QCL Mixing Against FIR Laser





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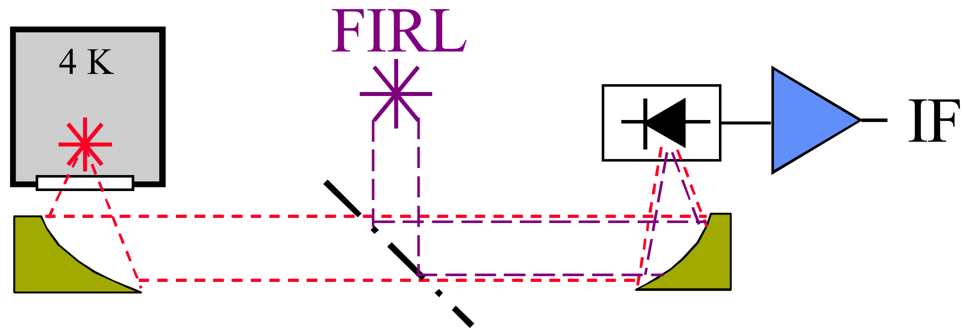
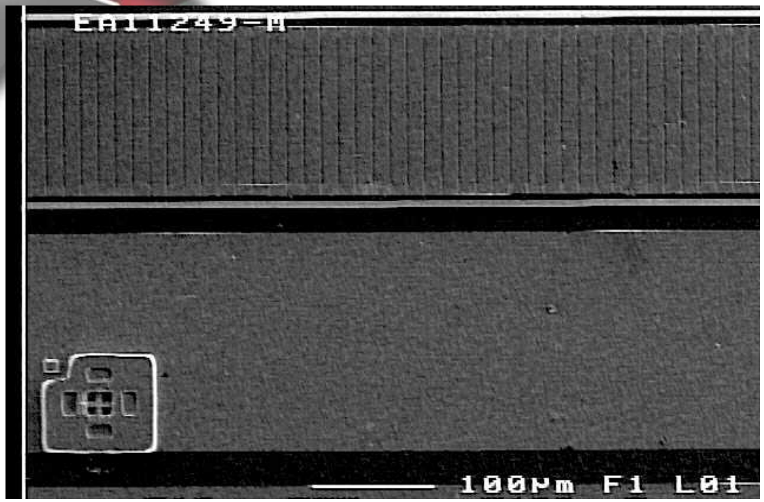
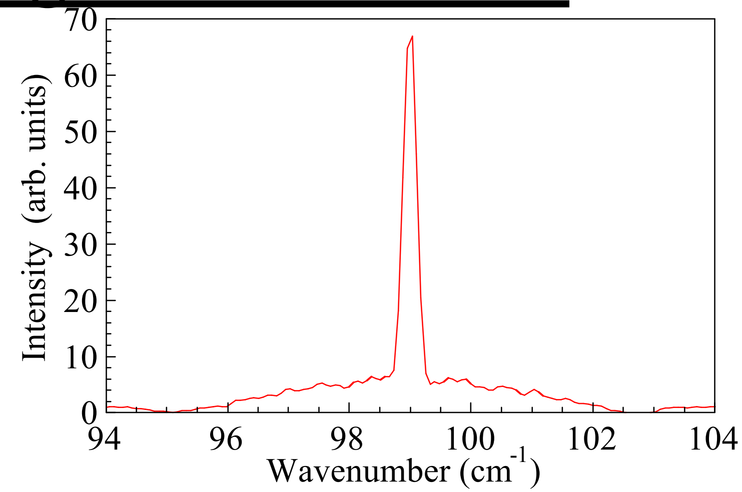
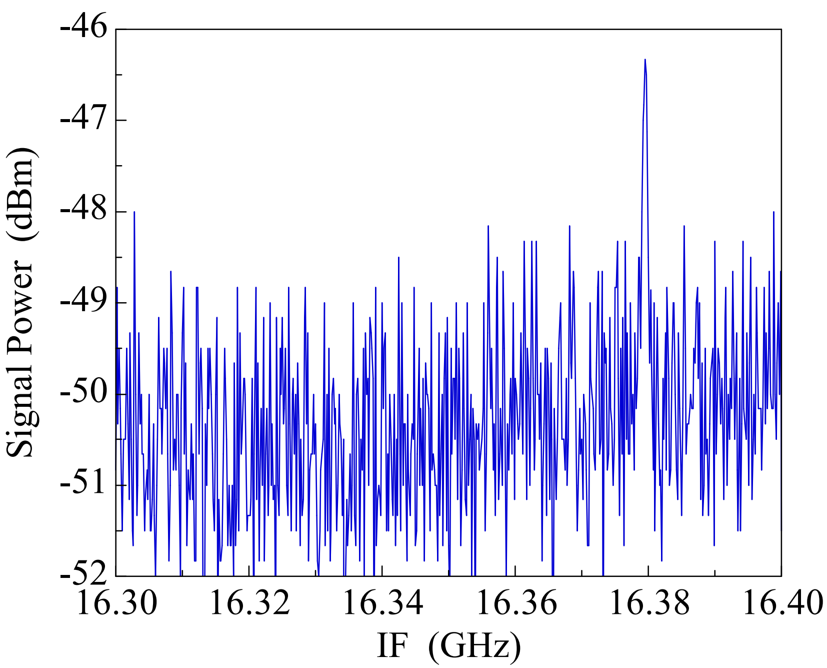


- Mix QCL with 2.9072 THz D-methanol line from FIRL
  - QCL frequency = 2.9205 THz
- QCL run pulsed, fixed current bias
  - 0.4 ms/20ms duty cycle
- Single-mode at "low" QCL power (higher temp)
- Strange multi-line emission at "high" QCL power (lower temp)
  - Frequency jumping during in 0.3 ms pulse duration?

DBR QCL Mixing Against FIR Laser







- Grating etched on top of QCL waveguide to form DBR
- Mixed with 2.951 THz D-methanol FIRL line
  - QCL frequency = 2.967 THz
- QCL run pulsed
  - Duty cycle 0.2 ms/20ms
- Only single-mode behavior seen
- Strong atmospheric absorption

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Summary & Future Directions

- Using a planar Schottky receiver with THz QCLs
  - Divergent, non-Gaussian beam from QCL causes low coupling efficiency to receiver
  - Clearly observe QCL dual-mode mixing and mixing of QCL against known molecular gas FIRL lines
  - Good way to do high-frequency-resolution characterization of QCL emission
- Currently have insufficient QCL power to do noise temperature measurements
  - Schottky needs 5 to 6 mW coupled into receiver at 2.5 to 3 THz
  - Coupling losses of –7 dB from collimating divergent beam, –3 dB from beam splitter
  - Estimate need QCL with 50 to 60 mW total CW power output to properly pump Schottky
- High-power QCLs designed, grown, and in fabrication line

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