# Terahertz Microelectronic Transceiver

LDRD
LABORATORY DIRECTED RESEARCH & DEVELOPMENT

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## The Grand Challenge:

- THz offers innovative and potentially disruptive capabilities in applications such as:
  - "See-through" imaging for high resolution concealed object detection & identification
  - Chemical detection & identification via highly distinctive THz absorption/emission signatures
  - High spatial resolution radar / High data rate secure wireless telecommunication
- Unlike microwaves & infrared, THz lacks a solid-state microelectronic technology base
  - Continuous wave THz sources of sufficient power tend to be big, finicky tube-based oscillators
  - Strong atmospheric absorption makes THz signal-to-noise requirements very difficult
- ***This project seeks to build a foundational integrated microelectronic technology for THz***

Replace big tube technology:

THz Molecular Gas Tube Laser

with microelectronics:

6 QCLs on a chip

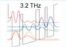
## All Solid-state Approach

- Compact, reliable, & scalable to high-volume, low marginal cost fabrication
- Multidisciplinary team needed: device physics, spectroscopy, rf engineering, material science…
- Resource intensive: state-of-art semiconductor growth & microfab, computational modeling & design, rf & optical test…

## THz Quantum Cascade Lasers:

Solid-state paradigm for high-power coherent THz transmission source

QCL cross-section

QCL band diagram

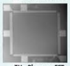
- ONLY solid-state source capable of >> 1 mW average power above ~ 2 THz
- Excellent spectral sharpness

- Requires high purity, high precision III-V MBE synthesis
- Requires advanced microfab capabilities
- Better computer modeling & design tools desired

## THz Solid-state Receivers:

Established & new detection technologies

THz Schottky diode

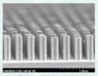

THz Plasmon FET

- State-of-art Schottky mixer (partnered with NASA/JPL)
- New THz plasmon transistor detector

- Explore sensitivity limits & new detection functionalities
- Test compatibility with QCL sources

## Nanotechnology for THz:

Exploring tomorrow's potential THz technology


GaAs nanowire array


Si nanowires on high-frequency waveguide

- Nanosize = very small parasitics, large thermal response to small absorbed EM power
- Very high speed/sensitivity quantum effects possible
- Cost-effective directed self assembly

- Fundamental electrodynamic properties still unknown
- Materials synthesis, quality issues need improvements

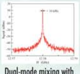
## Major Accomplishments

- First study of QCL compatibility with room-temperature monolithic Schottky diode mixer for solid-state THz heterodyne receiver
- Innovative designs & prototypes of waveguide & monolithically integrated QCL-based TμTs
- Advances in new THz QCL and detector devices

## QCL - Schottky TμT Prototyping:

Can a THz QCL function as local oscillator (LO) for a monolithic Schottky diode?


Schottky Receiver


Dual-mode mixing with very sharp linewidth

- Room-temperature Schottky most practical THz receiver
- Schottky needs > 5 mW LO power to work as radiometer: a stringent test of QCL capability
- Heterodyne mixing gives high-precision characterization of QCL frequency properties

- Non-Gaussian QCL beam prevents coupling sufficient power for Schottky to work as radiometer

- Mixing of dual QCL modes works & shows very sharp free-running QCL emission linewidth
- QCL frequency can be measured with very high absolute precision by using Schottky to mix QCL against known molecular gas laser lines

## Integrated TμT Approaches:

Put QCL transmitter & diode receiver together


Micromachined THz Waveguide Horn Antenna


Monolithically Integrated TμT

- Integrated TμT will maximize QCL/diode coupling efficiency & minimize size/weight
- Micromachined THz waveguide integration extrapolates microwave approach, but is less efficient & compact
- Innovative monolithically integrated QCL/diode is most compact & efficient, but very difficult to make work

- Developed processes & prototypes of micromachined THz waveguide components
- Fabricated initial prototype of monolithically integrated TμT

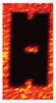
## Significance

- TμT will be a core technology making THz practical outside the laboratory
- All solid-state THz technology will improve reliability, reduce size/weight, reduce cost
- Opens up major new capabilities of interest to Sandia & Sandia customers

## "See-thru" Non-invasive, Non-hazardous Imaging:


Razor obscured by packing foam

See-thru image of razor using 2.9 THz QCL illumination

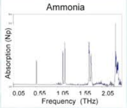


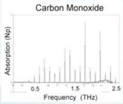

Actual razor

- Many materials, fabrics opaque to IR/visible or microwave are (semi)transparent in THz
- Metals are highly reflective in THz
- THz wavelengths enable < 1 mm image resolution for clear object identification
- THz radiation energy is non-ionizing; no known health hazards associated with mW exposures
- Must have illumination power & detector sensitivity overcome atmospheric attenuation

- Unobtrusive, non-hazardous concealed weapons detection
- Sealed package inspection
- Non-destructive parts & materials damage evaluation

## Chemical Sensing & Identification:




- Many molecules have rotational mode absorption & emission resonances in THz that are strong & distinctive
- THz may be best spectrum for high-sensitivity, high-specificity detection & identification of molecular species in vapor
- TμT chemical sensor must be tuned to known signature frequencies & overcome attenuation

- Real-time chemical vapor assay with very low probability of misidentification
- Point, portal, and (limited) remote chemical sensing
- Hazardous/toxic chemical early warning

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