Next Generation of Terahertz Sources and Detectors

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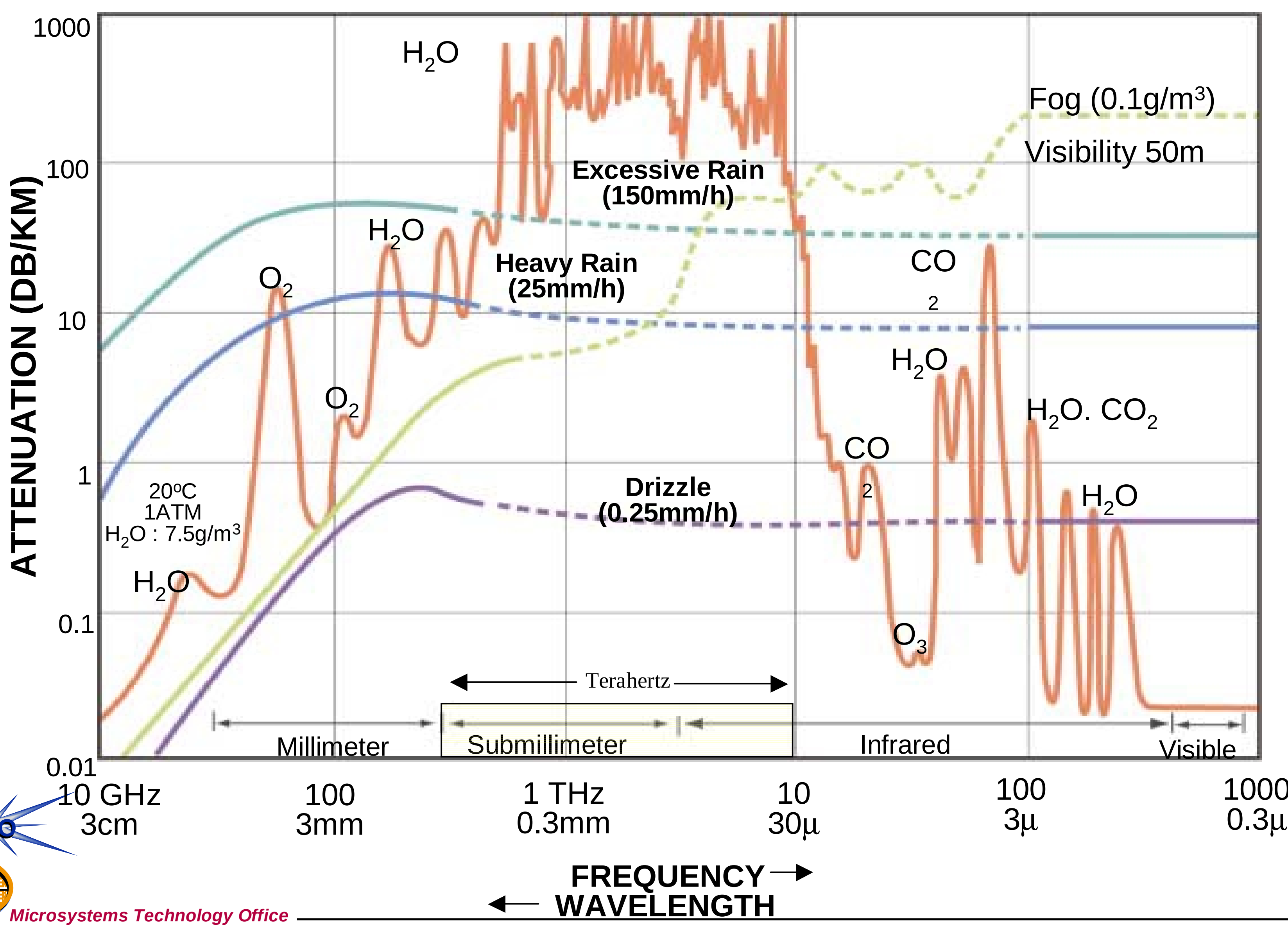
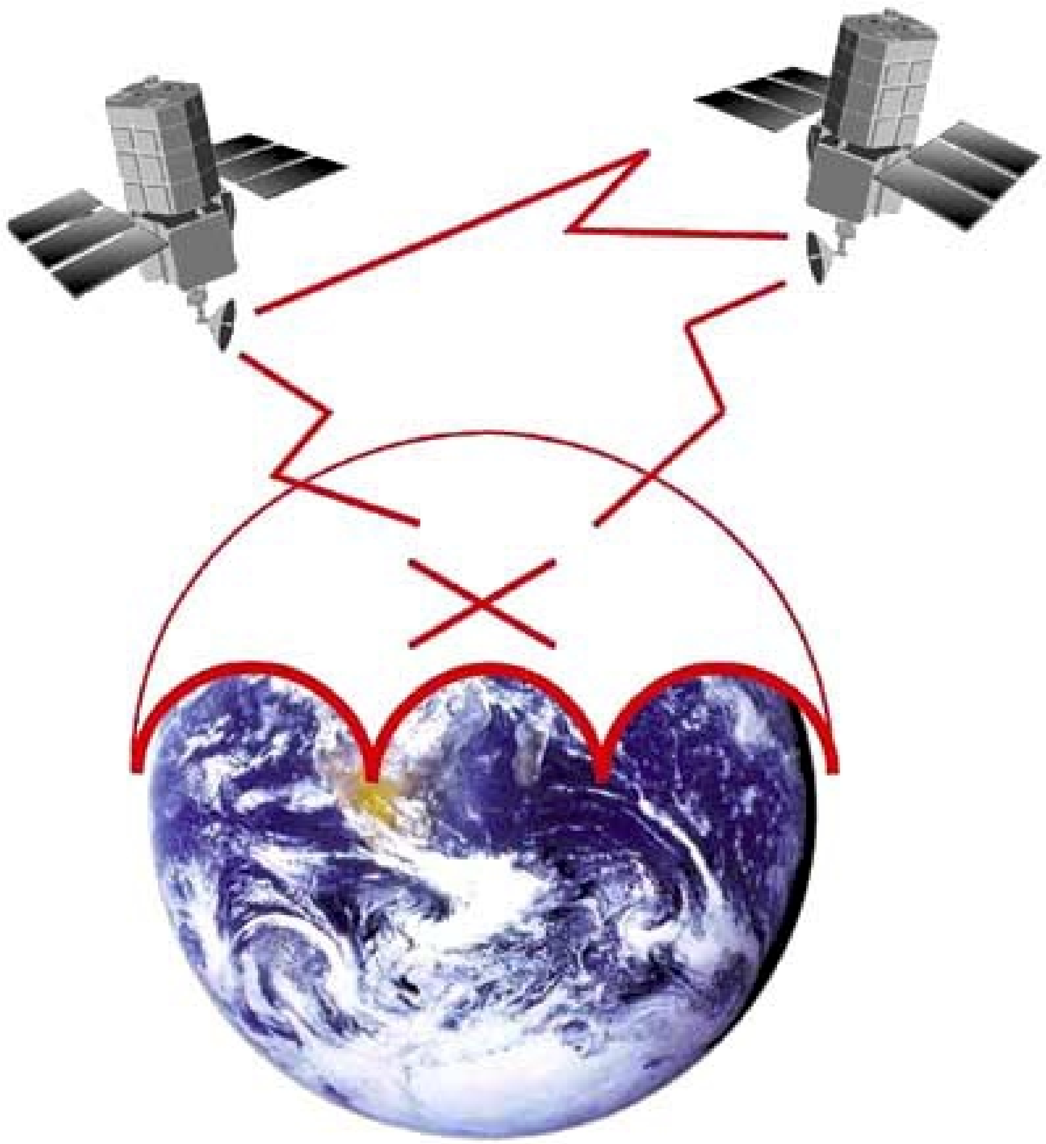
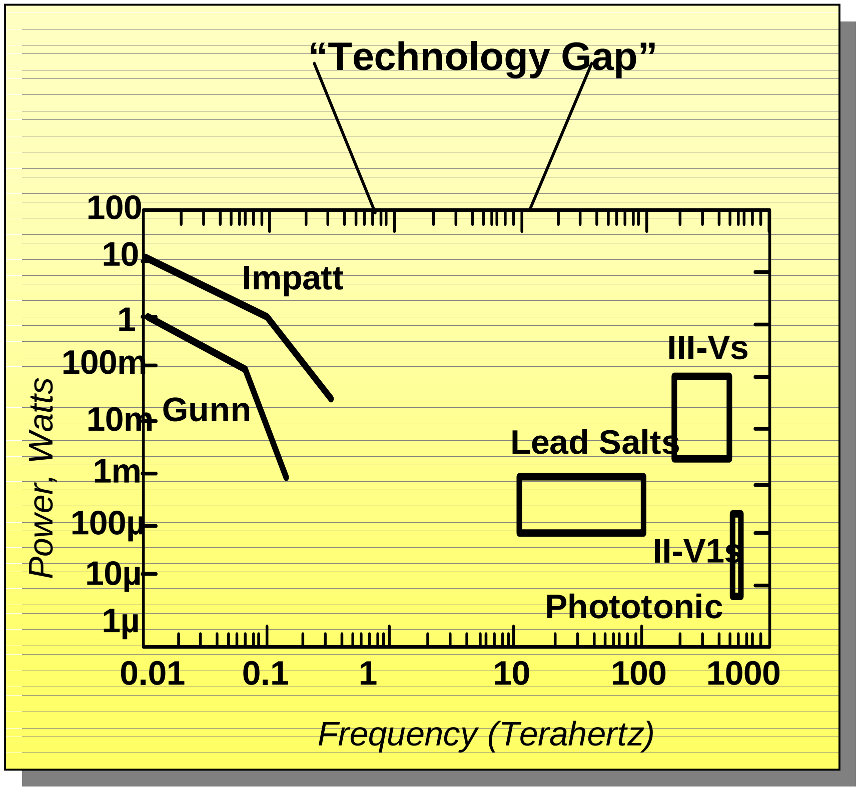
E/M Attenuation vs Frequency Limitations of Current Technology



Using a limitation to our advantage!!!



Program Objectives



Explore innovative semiconductor device and circuit concepts for the demonstration of high power sources and high sensitivity detectors for the region of the electromagnetic spectrum between 0.3-10 THz (1 - 0.03 mm)

Technical Challenges

THz Sources

- Achievement of high output power (at least mWs)
- Efficiency
- Compactness
- Tunnability for certain applications

THz Detectors

- High Sensitivity and Detectivity
- Quantum Efficiency
- Compactness

Technical Approaches

THz Sources

Electrical

- InP-and Sb-based HEMTs
- GaN-based Gunn diodes
- Sb-based Stark Ladders and Quasi-optic Combiners
- Passives and Wave-guides

Optical

- Optical Photomixing
- SiGe VCSELs

THz Detectors

- RTD-based
- Electro-acoustic Detectors (HEMTs)
- Photon assisted tunneling in QWs

Department of Physics Microwave Laboratory

Raytheon Systems Company

Quantum Device Technologies for THz Communications and Imaging

OBJECTIVE:

Develop monolithic integrated circuits capable to generate power at 0.33 THz, 0.66 THz, 1 THz and 3 THz.

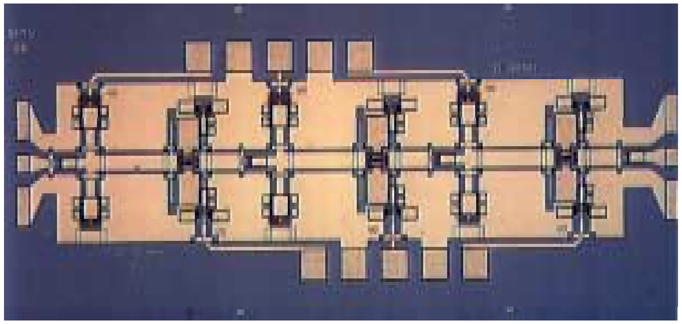
APPLICATIONS:

•Remote sensing
•High resolution imaging
•High data-rate space communication

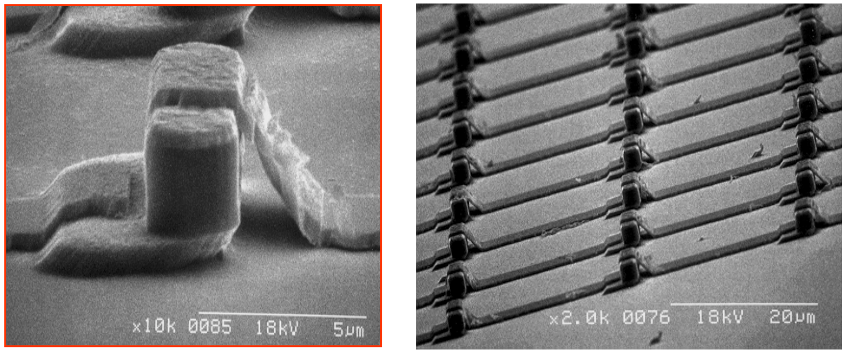
APPROACH:

• Develop high performance HEMT MMIC sources with integrated antennas for 0.3 THz to 1 THz frequency range

• Develop novel superlattice oscillators and multipliers for 1 THz to 10 THz frequency range

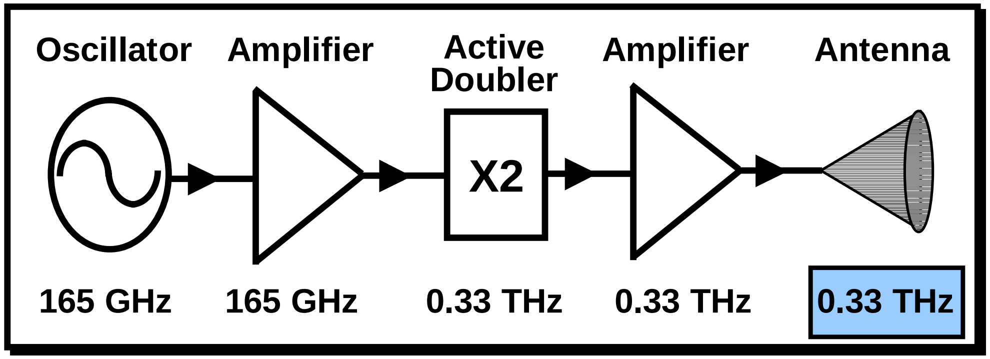


State of the art HEMT MMIC



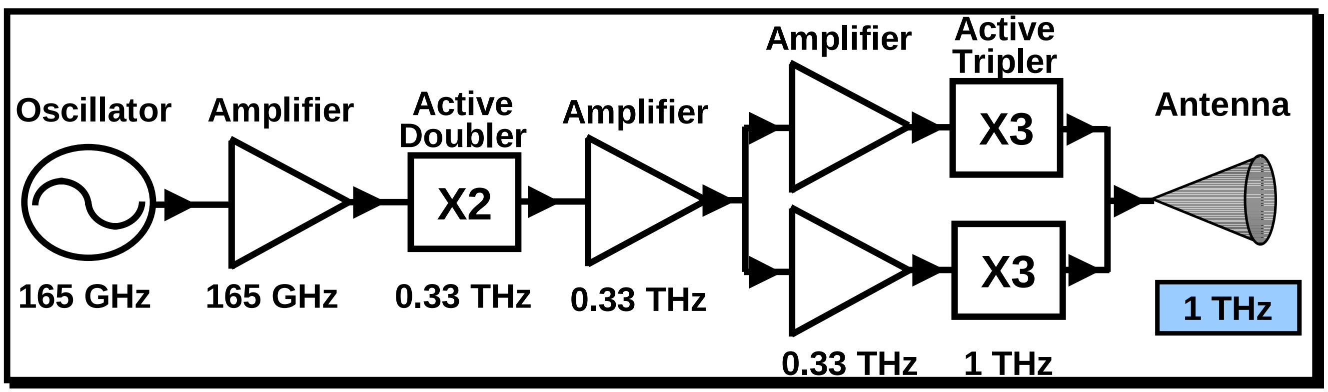
Quasi-optical superlattice array for harmonic generation

0.3 THz to 1 THz SOURCES



CHALLENGES

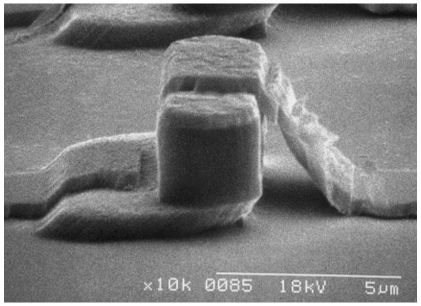
- MMIC design
- Low-loss passive components
  - Antennas
  - Transmission lines
  - Power combiners
- Spatial power combining
- Packaging
- Testing

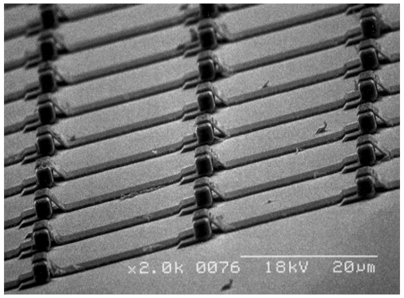


InAs/AlSb/GaSb Materials Effort

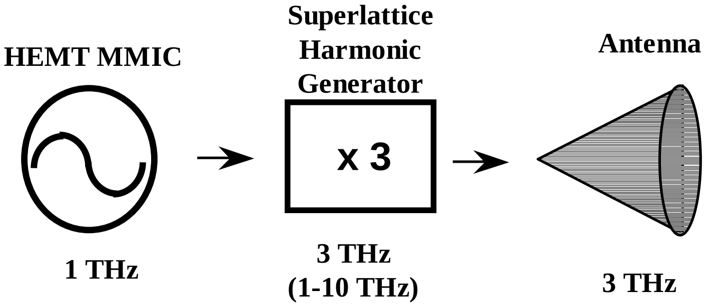
- 1-10 THz source development
  - collaboration with UCSB (Allen)
  - InAs/AlSb superlattice devices
  - emphasis on harmonic generation

- Materials support for Raytheon (Frazier)
  - RTD structures
  - High Jp
  - IMSC MBE Capability





Quasi-optical superlattice array for harmonic generation



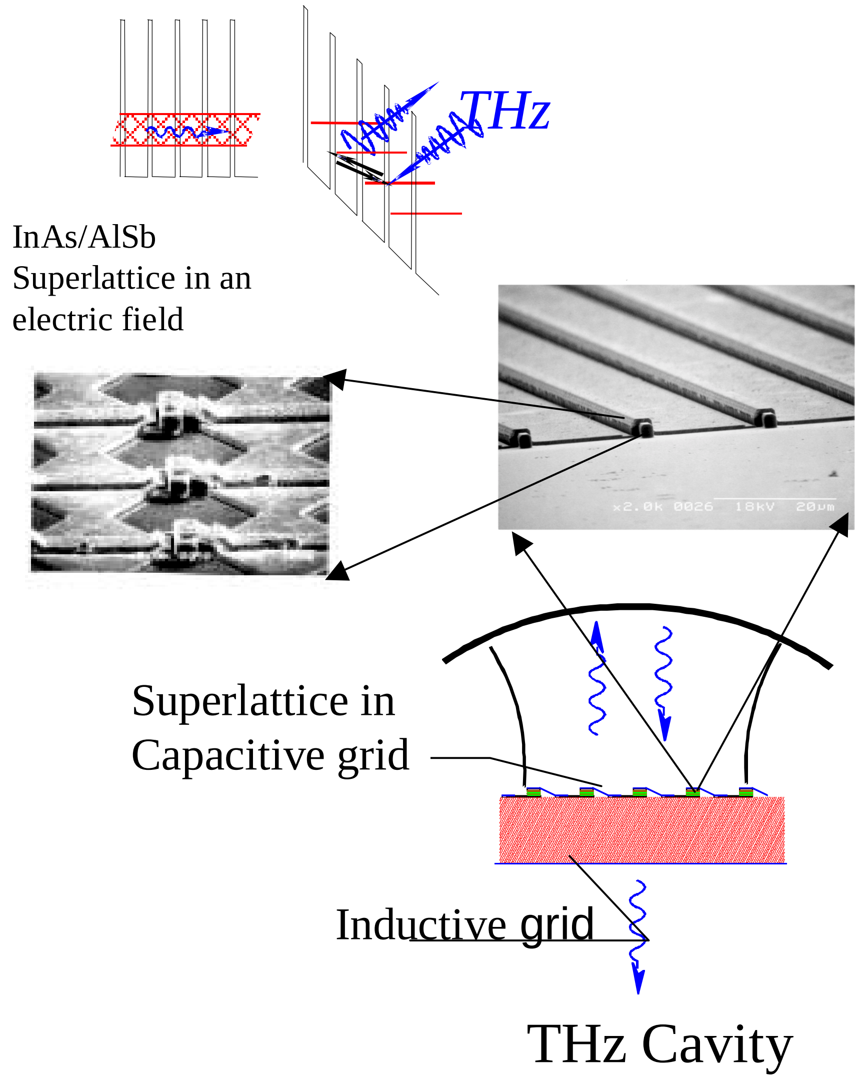
Solid State Terahertz Sources for Sensing and Satellite Communications

OBJECTIVE:

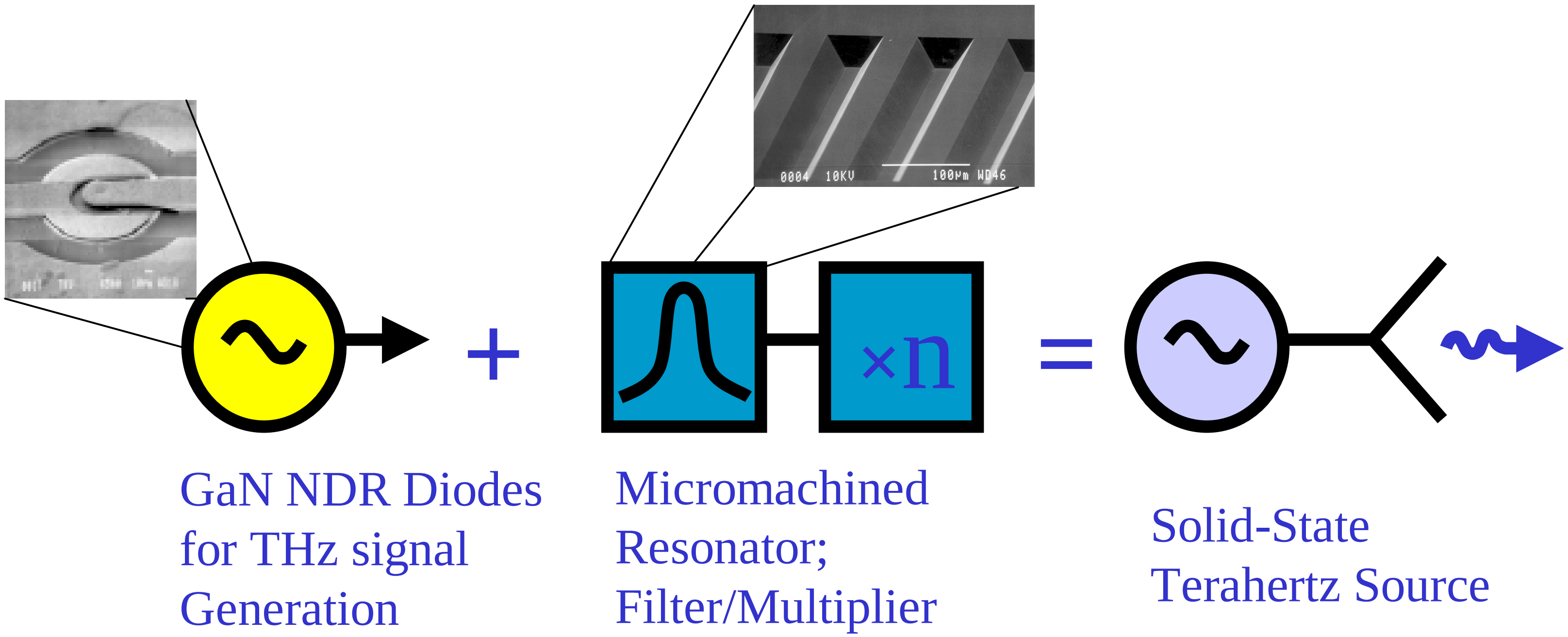
Develop and demonstrate an electrically excited solid-state Terahertz sources, capable of delivering >1 mW of power in the range above 1 THz

APPROACH:

•Implementation of InAs/AlSb superlattice, Stark ladders for THz generation
•Implementation of Quasi-optic arrays for power combining
•Demonstration of THz harmonic generation



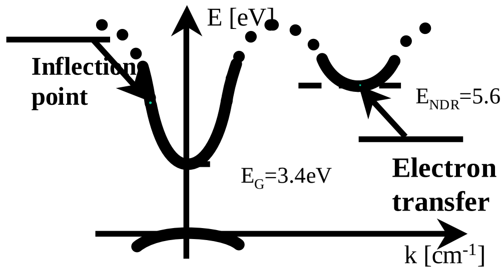
Solid-State Terahertz Sources

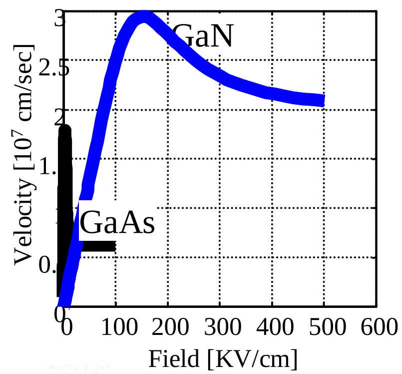


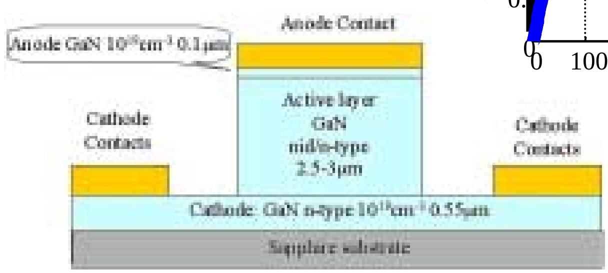
TECHNICAL APPROACH:

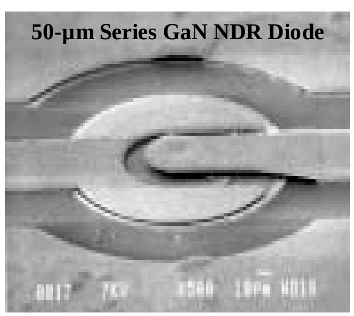
- Unique approach combining new semiconductor and micromachined concepts
- Semiconductor device potential for high-power fundamental or harmonic sources
- Possibility to apply micromachined concept to other sources developed under this program

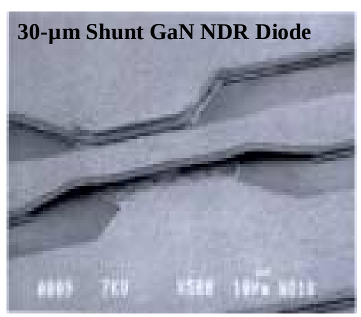
III-N Terahertz Gunn Diodes











OBJECTIVE:

Take advantage of the electron transport and material properties of III-N semiconductors for the demonstration of Gunn diode THz sources

CHALLENGES:

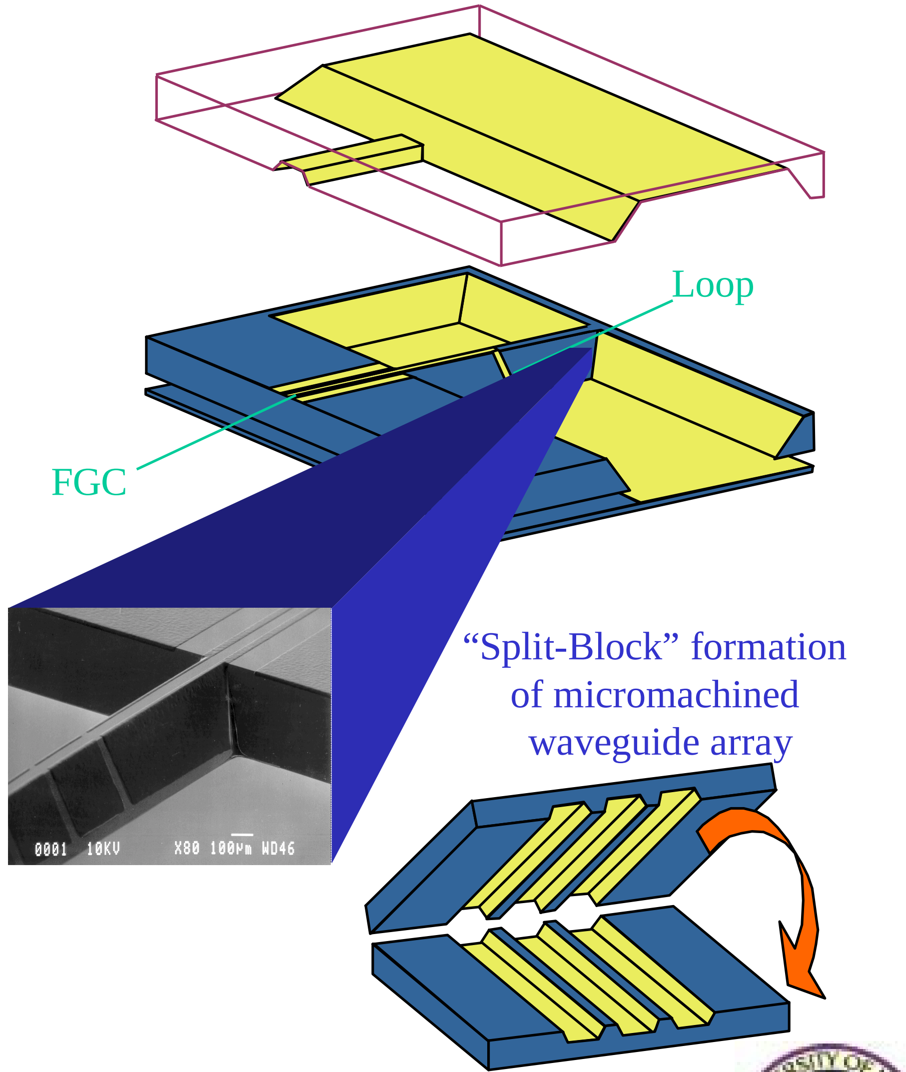
- Achieve good quality GaN materials
- Demonstrate NDR performance in WBG semiconductors
- Demonstrate generation of THz radiations

Passive Silicon Micromachined Structures for THz Applications

APPROACH:

Use Silicon Micro-machining Technology for the Development of:

- THz waveguides for high-performance low-loss circuits
- Electric and magnetic transitions from planar transmission lines to micromachined waveguides
- Transitions between waveguides and planar micromachined antennas
- Compact resonators for GaN Gunn sources

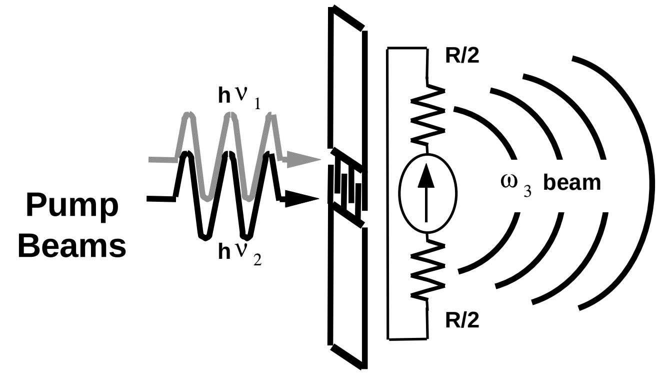


All-Solid-State Photomixing Transmitter

OBJECTIVES:

Develop a solid-state source for the THz region having up to 1 mW output power and:

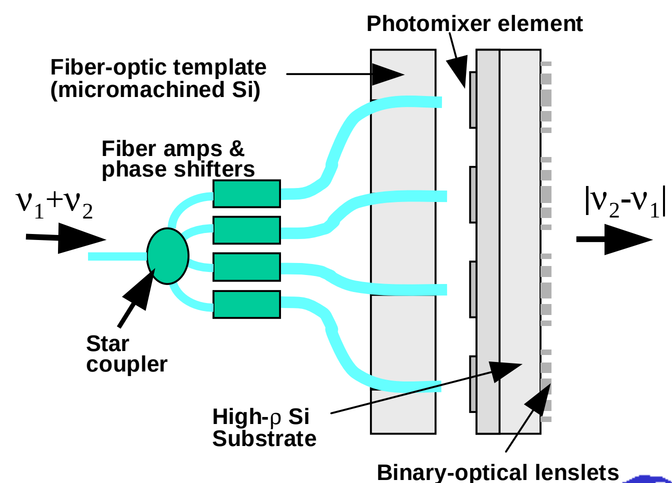
- Stable continuous-wave performance
- Room-temperature operation
- Tunability up to ~1 octave
- Instantaneous frequency stability > 1:10^6
- Phase lockability (required for comms)
- Good beam characteristics (TEM_{000} Gaussian desirable)



$$P_3 = \frac{R}{2}\eta_1\lambda_1\eta_2\lambda_2\left(\frac{eg}{hc}\right)^2 \frac{P_1 P_2}{\left[1+(\omega_3\tau)^2\right]\left[1+(\omega_3 RC)^2\right]}$$

TECHNICAL APPROACH:

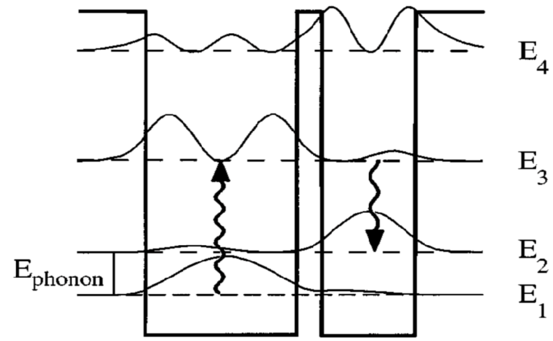
- Optical mixing in an ultrafast photoconductor (LT-GaAs)
- Couple internal THz photocurrents to a THz load (antenna)
- Implementation of power combining techniques



THz Sources Based on Intersubband Transitions in SiGe Quantum Wells

OBJECTIVE:

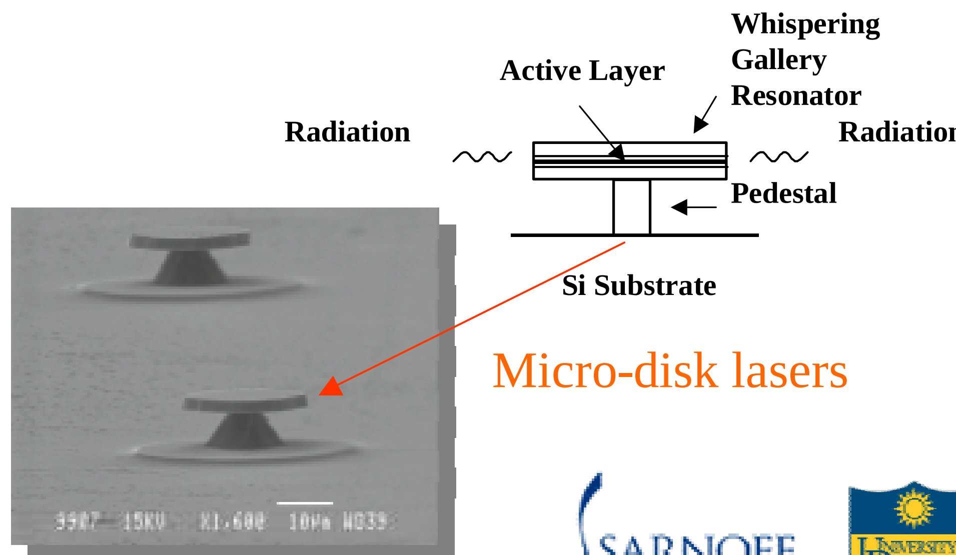
To demonstrate a SiGe, micro-disk cavity, intersubband laser suitable for communication systems



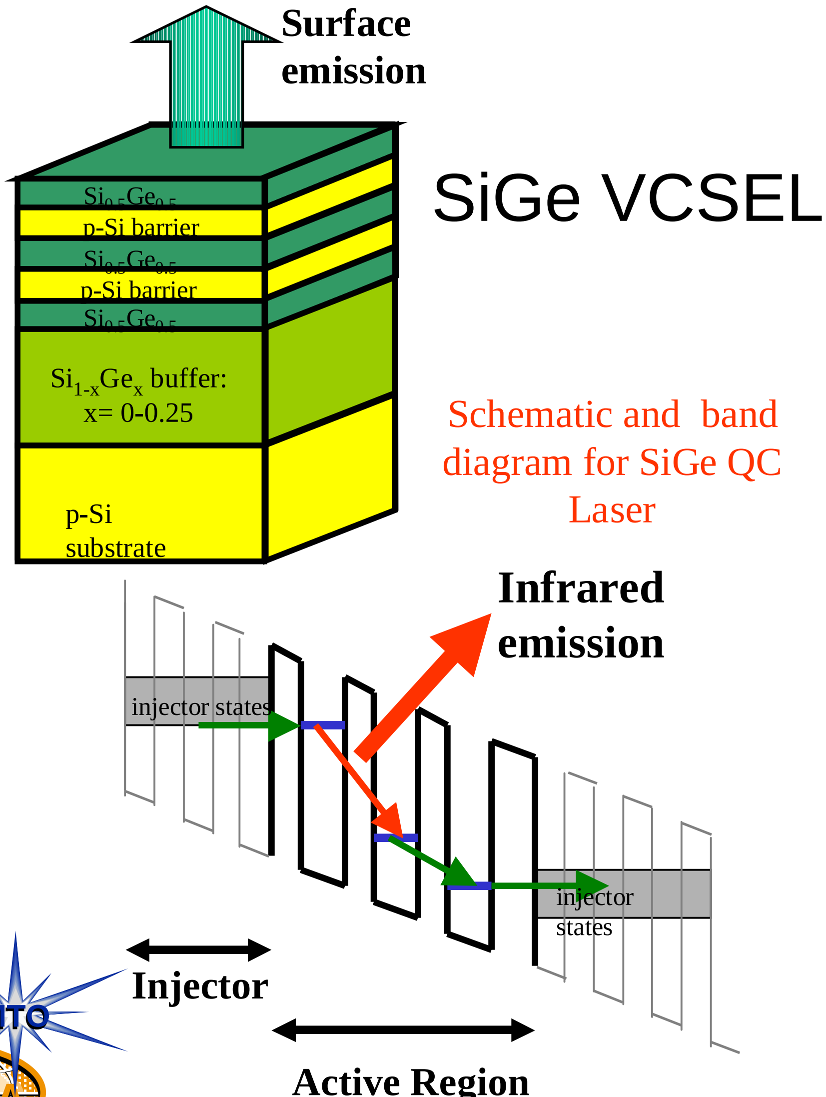
Quantum well transitions between E_3 and E_2. Proposed device will use SiGe quantum wells and hole intersubband transitions.

APPROACH:

•Silicon micromachining for novel resonator design
•SiGe unipolar architecture
•E/M simulation for device optimization
•1-10 THz operation



Vertical Cavity Silicon-Germanium Quantum Cascade Lasers for Terahertz Emission



Schematic and band diagram for SiGe QC Laser

OBJECTIVE:

Develop and demonstrate a vertical cavity SiGe quantum cascade laser capable to operate in the THz region of the electromagnetic spectrum

APPROACH:

- Characterization of ISB lifetimes in p-SiGe QWs
- Demonstrate FIR emission in p-SiGe tunnel barrier structures
- Demonstrate surface emission in p-SiGe quantum cascade structures
- Demonstrate vertical cavity SiGe quantum cascade device

Solid-State Terahertz Detector Technology

OBJECTIVE:

• Develop high-sensitivity, solid-state RF detector MMICs for the 0.3 - 3 THz frequency band.

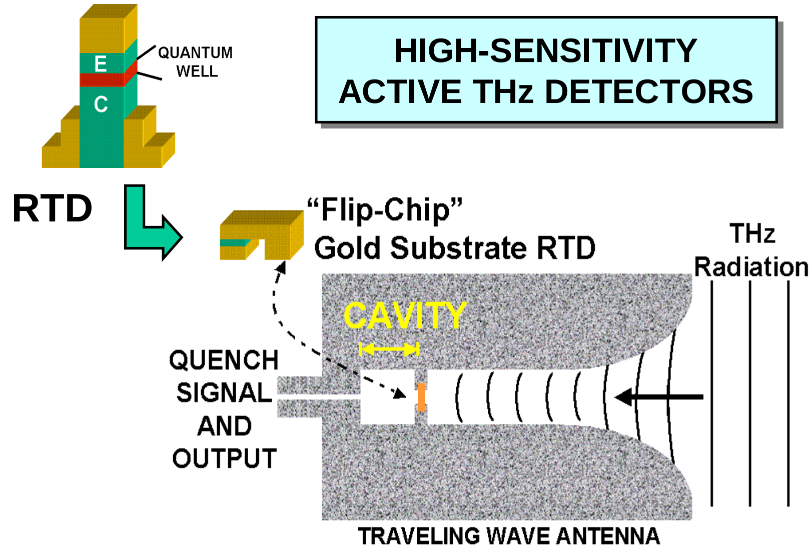
APPROACH:

•Design and develop low-parasitic InP & GaSb resonant tunneling diodes (RTDs)

•Use epitaxial transfer to integrate RTDs with low-loss THz antenna structures.

•Demonstrate passive and super-regenerative RTD detector-antenna MMICs

•Demonstrate simplex THz communication link. (with HRL & UCSB)

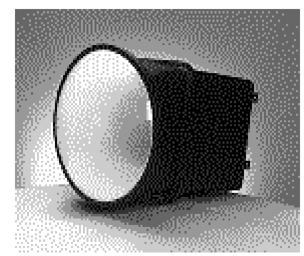


DOD FUTURE USES:

• Man-portable, ultra-secure THz communication links

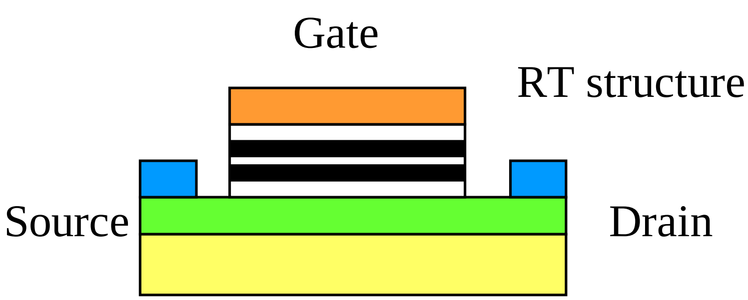
• Space-based imaging of upper atmosphere

• Phased array missile seekers/munitions

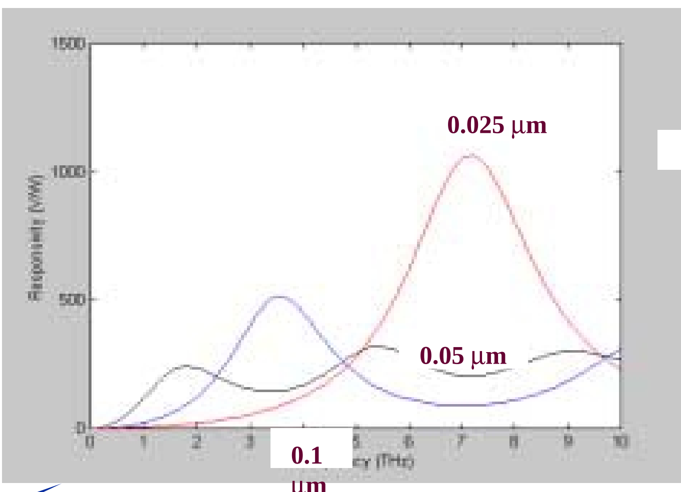


Raytheon

Plasma Wave Terahertz Electronics



Enhanced detectivity in sub-micron HEMT structures



OBJECTIVES:

- Demonstrate resonant terahertz detector with high sensitivity
- Observe terahertz radiation from a field effect transistor
- Explore applications of plasma wave electronics to silicon

APPROACH:

- Implement detectors using GaN based HEMTs
- Increase the growth of plasma waves using resonant tunneling structure
- Use "light" electrons in deep submicron silicon

THz Molecular Interactions

OBJECTIVE:

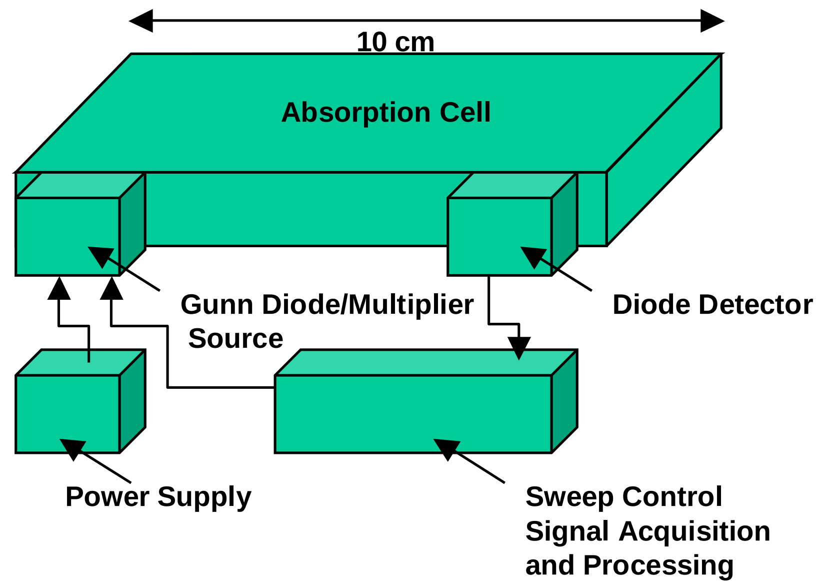
Build test bed for compact THz sources and detectors.

Experimentally determine rotational energy level spectrum of various gas phase molecules

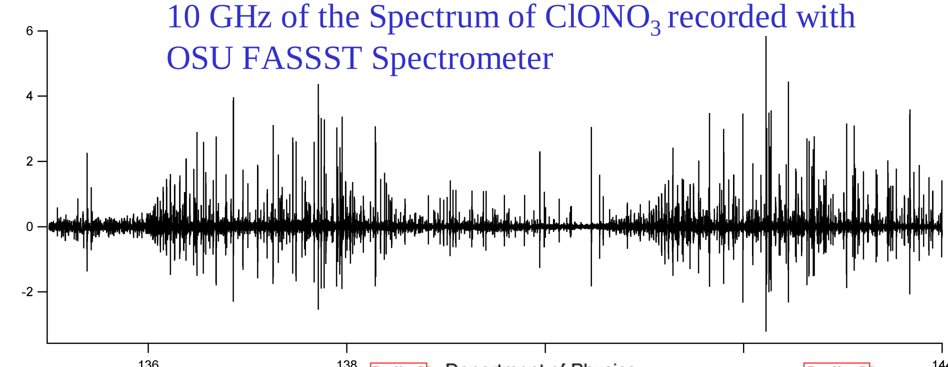
TECHNICAL CHALLENGES:

- Specific identification of chemical species
- Quick response (< 1 second)
- Small (<< 1 ft3)
- Low Power
- Simple-Based on FASSST Concept
- Potentially Inexpensive in Quantity

FASSST Point-Sensor Test Bed



10 GHz of the Spectrum of $ClONO_3$ recorded with OSU FASSST Spectrometer



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Microwave Laboratory

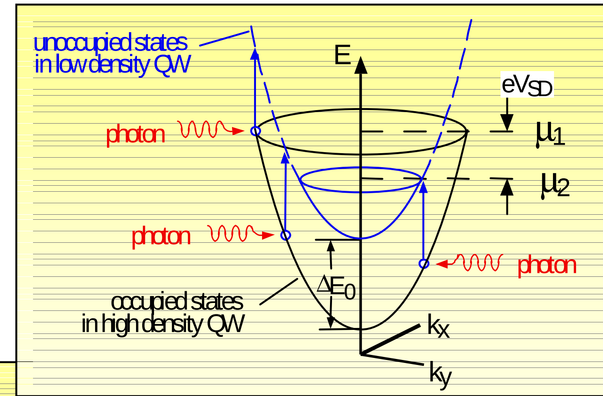
THz Detection Based on Photon-assisted Tunneling on Double Quantum Wells

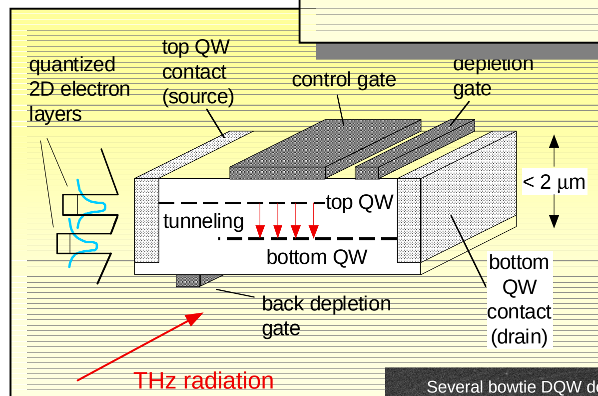
OBJECTIVE:

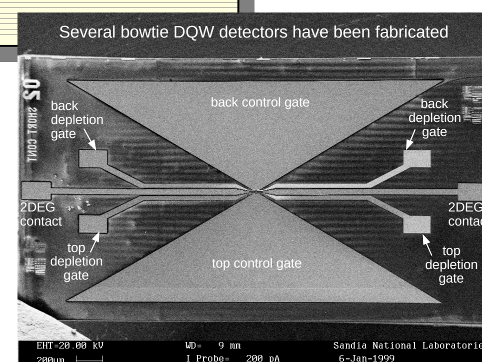
Demonstrate tunable, narrowband photon-assisted tunneling in double quantum well (DQW) heterostructures.

TECHNICAL APPROACH:

- Use bandgap engineering to optimize photodetector performance.
- Develop antenna structure compatible with THz detectors
- Bench-demonstration of THz detector system



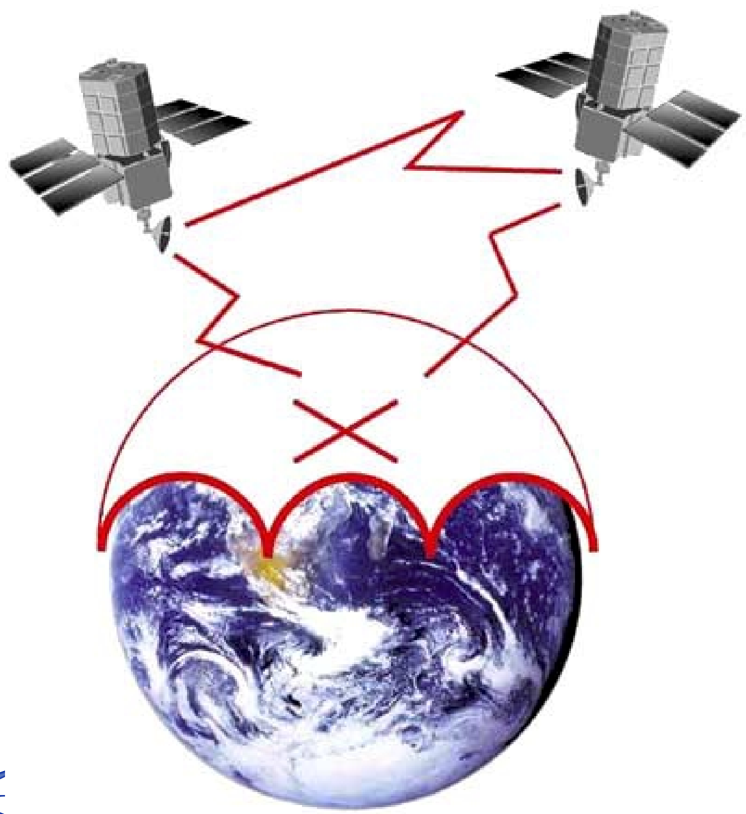




Double quantum well THz detector concept

Summary

DARPA is Creating Future Opportunities for THz Technology in:



- Environmental sensing
- Upper-atmosphere imagery
- Covert satellite communications
- Chem/Bio Detection (Near Distance)