Outline

• Brief AFRL overview
• THz QCL application areas
• Mid-IR QCL application areas
• Overview of related work within Sensors (time permitting)
AFRL Overview

2nd International QCL Workshop, Brindisi, Italy 5-10 September 2006
AFRL Missions

AFOSR
- Physics & Electronics
- Mathematics & Space Sciences
- Aerospace & Materials Sciences
- Chemistry & Life Sciences

Directed Energy
- Lasers
- High-Power Microwave
- Adaptive Optics & Imaging

Information
- Dynamic Planning & Execution
- Global Awareness
- Global Information Exchange

Human Effectiveness
- Warfighter Training
- Crew System Interface
- Bioeffects & Protection
- Deployment & Sustainment
AFRL Missions

Materials & Manufacturing

Structures & Propulsion
Sensors & Survivability
Sustainment & Deployment

Propulsion

RF and EO based
Sensors & Countermeasures

Automatic Target
Recognition

Sensor Fusion

Munitions

Interdiction Target Sets

Engaged Forces Target Sets

Single Munition Against All Targets & Scenarios

Sensors

Propulsion & Power for Space Platforms

Propulsion & Power for Air Platforms

Propulsion & Power for Weapons

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AFRL Missions

Air Vehicles
- Sustaining Today’s Fleet
- Unmanned Air Vehicles
- Space Access & Future Strike Technologies

Space Vehicles
- Space Systems Protection
- Spacecraft Payloads
- Spacecraft Vehicles
AFRL Research Breakout (2005)

By Directorate/Tech Area

- Directed Energy (7%)
- Human Effectiveness (8%)
- Munitions (5%)
- Space Vehicles (10%)
- Information (9%)
- Materials & Mfg (9%)
- Air Vehicles (8%)
- Basic Research (16%)
- Sensors (11%)
- Propulsion (17%)

By Platform

- Space (27%)
- Air (48%)
- Cyber (25%)

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Application Areas for QCLs in the THz
Nondestructive Evaluation of Air and Space Craft (AFRL/MLLP)

Motivation

- Want affordable means of finding defects, possible failure points of
  - Cracks in airframes
  - Thermal protection systems (TPS)
- Current methods utilize ultrasonic or X-ray technology
- THz demonstrated to pass through some relevant paints/coatings

Tech Drivers

- Portability, FOR vs. $P_{OUT}$ (tradeoff), spatial resolution and accuracy, energy concentration at $\lambda_{DESIGN}$

Point of Contact

Mr. Adam Cooney, AFRL/MLLP
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Transmission through various films of interest in the THz region.

THz inspection of TPS structures

Karpowicz et al, APPLIED PHYSICS LETTERS 88, 054105 (2006)
Nondestructive Imaging in Engine Combustors (AFRL/PRTC)

Motivation

- Examine failure mechanisms & monitor engine performance in aircraft
- Examine moisture content in jet fuel
- Ceramic ports already in existence on such platforms transparent to THz radiation
- Low thermal noise background in this region

Tech Drivers

- Portability
- Intensity/output power
- Spatial resolution/beam control
- Cost, size, weight, and power (C-SWaP)

Point of Contact
Dr. James Gord, AFRL/PRTC
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Transient-Grating Spectroscopy in a High-Pressure Combustor

![Graph showing relative absorption vs frequency with H2O line positions]
Scale-Model Radar Cross-Section
(AFRL/SN and UMass-Lowell)

**Motivation**
- Replace bulky, extremely inefficient molecular lasers with QCLs in the UML Sub-Millimeter Wave Laboratory
- Perform scale model radar cross section measurements for phenomenology and target recognition database formation

**Tech Drivers**
- Intensity (desire 10’s mW output power, > 5 GHz bandwidth tuning range, operation at ~ 3.5 THz)
- Wavelength of operation (scale common radar wavelengths by 1/16, 1/32, etc…)
- Good modal patterns of replacement lasers (must have beam on target)

**Point of Contact**
Dr. Thomas R. Nelson, AFRL/SNDP
Thomas.Nelson@wpafb.af.mil

Concealed “Gun” – 1.56 THz Image
RCS of 1/16 scale model tank
Application Areas for QCLs in the Mid-IR
Infrared Scene Generation

Motivation

• Replace bulky, slow-response “resistor banks” with tailored design QCLs (or even QC-LEDs?) to mimic the thermal background of a given scene

Tech Drivers

• Intensity
• Wavelength of operation (multi-spectral emission, broadband, tunable?)
• Modal patterns of replacement lasers
• Dynamic range (quiescent scene to lasing)
• Formation as a projection source

Point of Contact
Dr. Thomas R. Nelson, AFRL/SNDP
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EO/IR threat simulations

Target Simulator
IR Missile

Laser IRCM Development Range

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Work within AFRL/SND
In collaboration with AFRL/MLLP and AFIT
AlGaAs/GaAs Based QCLs

Initially started with 2 tiered approach:

1. Collaboration with UMass-Lowell and Worcester Polytechnic Institute on interface-phonon mediated structures for THz emission

2. Try to mimic structures in the literature
   1. MIT/Sandia structures for THz (AFRL growth and processing, UML test)
   2. Northwestern U. designs for InP mid-IR devices (commercial growth, AFRL processing, UML test)
   3. Capasso/Faist/Sirtori/Gmachl structures for GaAs-based mid-IR (AFRL growth & processing, UML test)

To date, none of our structures have demonstrated lasing
Another new direction…

Use of multi-objective Genetic Algorithm approach for QCL design optimization

- Collaboration of AFRL/SNDP, MLLP (Cooney), and AFIT/ENG (Prof. G. Lamont)

- Utilizing in-house programs for
  - Bandstructure
  - Scattering rates (electron-electron, electron-phonon)
  - Self-consistency in Schrodinger-Poisson solver

- and integrating them with AFIT’s GenMOP Genetic Algorithm code for new designs.
Initial GenMOP Designs

THz QCL SOLUTIONS

MIT-type solutions

MIT has spent ~5 yrs optimizing this solution

GenMOP

Optimized QCL Solution (Gain, Temperature Performance)

New Family of solutions discovered

Improved solution

room for improvement?

Optimized QCL Solution

(a)

MIT solution

GenMOP MIT-type Solution

GenMOP phonon-injector

MIT has spent ~5 yrs optimizing this solution

Improved solution

room for improvement?

Optimized QCL Solution

(a)

MIT solution

GenMOP MIT-type Solution

GenMOP phonon-injector

Optimized QCL Solution (Gain, Temperature Performance)

New Family of solutions discovered

Improved solution

room for improvement?
Summary

• Many applications areas relevant to the USAF exist just at Wright-Patterson AFB for QCLs, including:
  – Mid IR: IR Scene generation (and the standard chem/bio hazard ID efforts)
  – THz
    • Sensors: Scale model radar cross section experiments
    • Propulsion: NDE of engine combustors and jet fuel
    • Materials lab: NDE of airframes
  – This doesn’t even touch on uses at other AFBs or surrounding community (Univ. Dayton, Ohio State Univ., Wright-State Univ.)
• In-house efforts have been slow but steady…
  – Recent acquisition of FTIR system for THz spectroscopy
  – MLLLP purchase of QCL driver circuitry
  – Promising outlook of GA approach to device designs