

QCL-Based Applications

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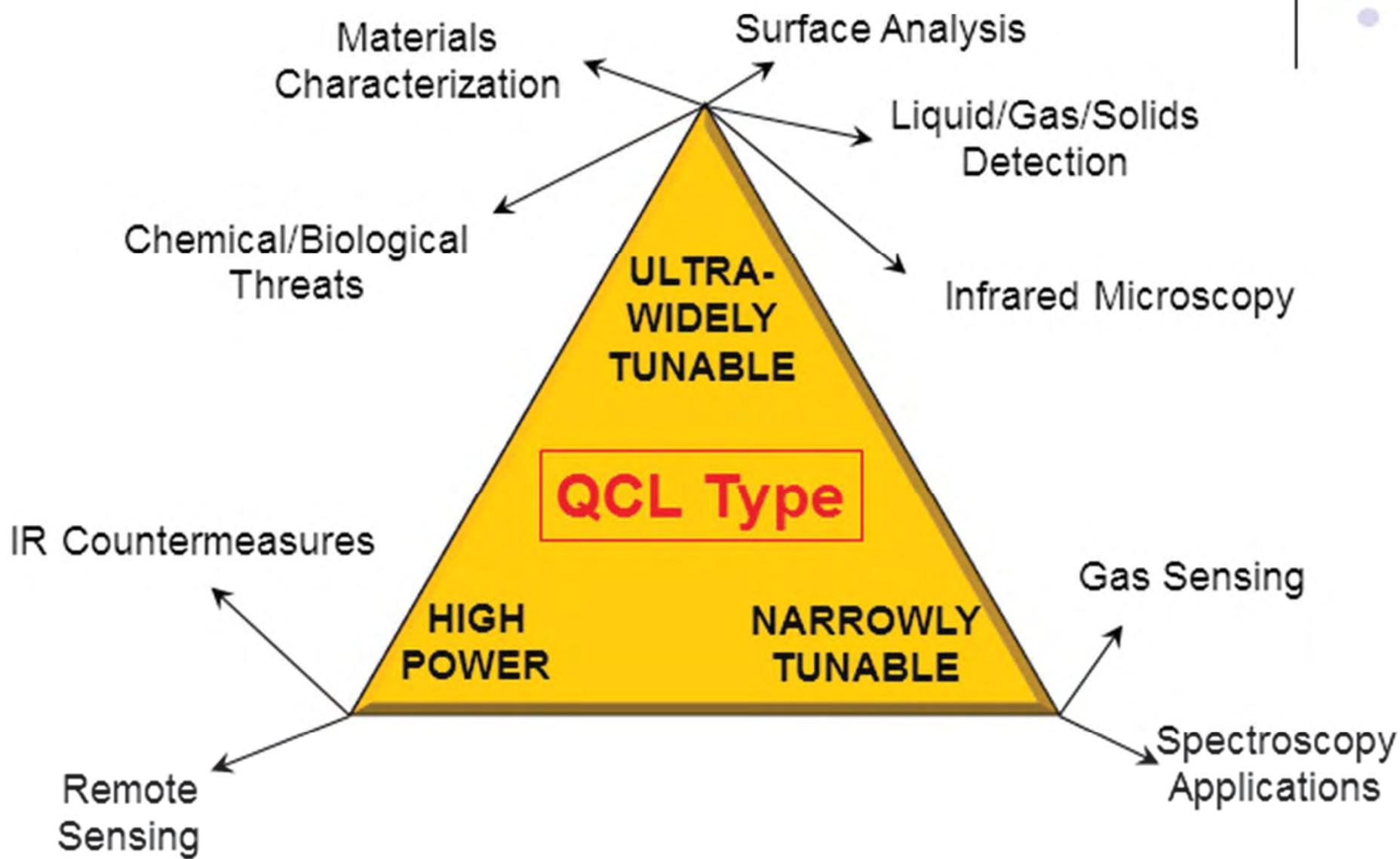
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October 2012





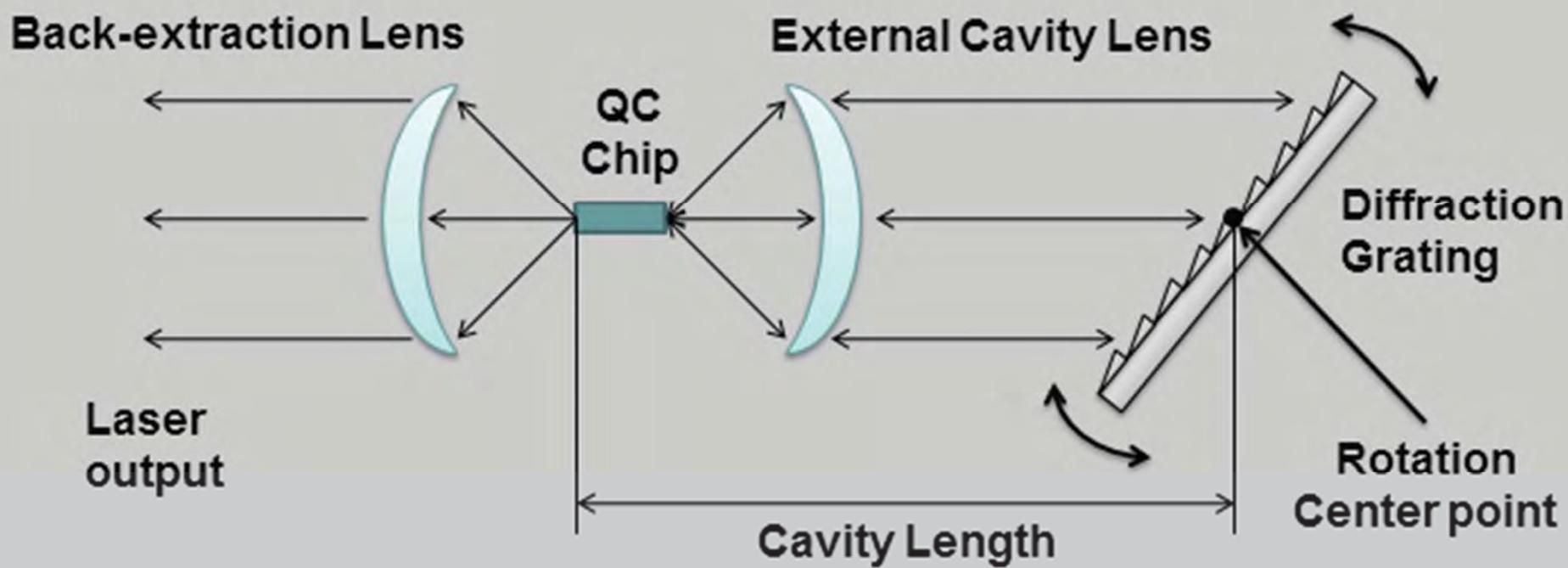
QCL Classification



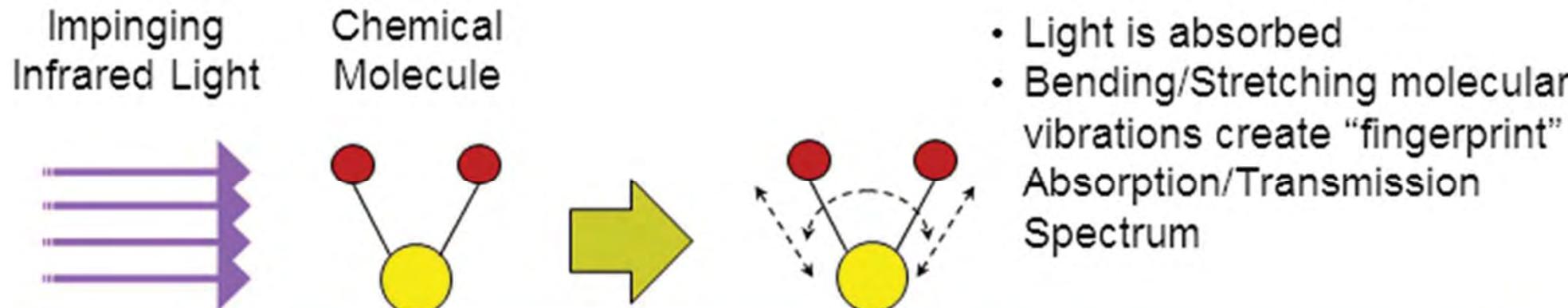
Basic Laser Configuration of Ultra-Widely Tunable QCLs



External Cavity QCL Back Extraction

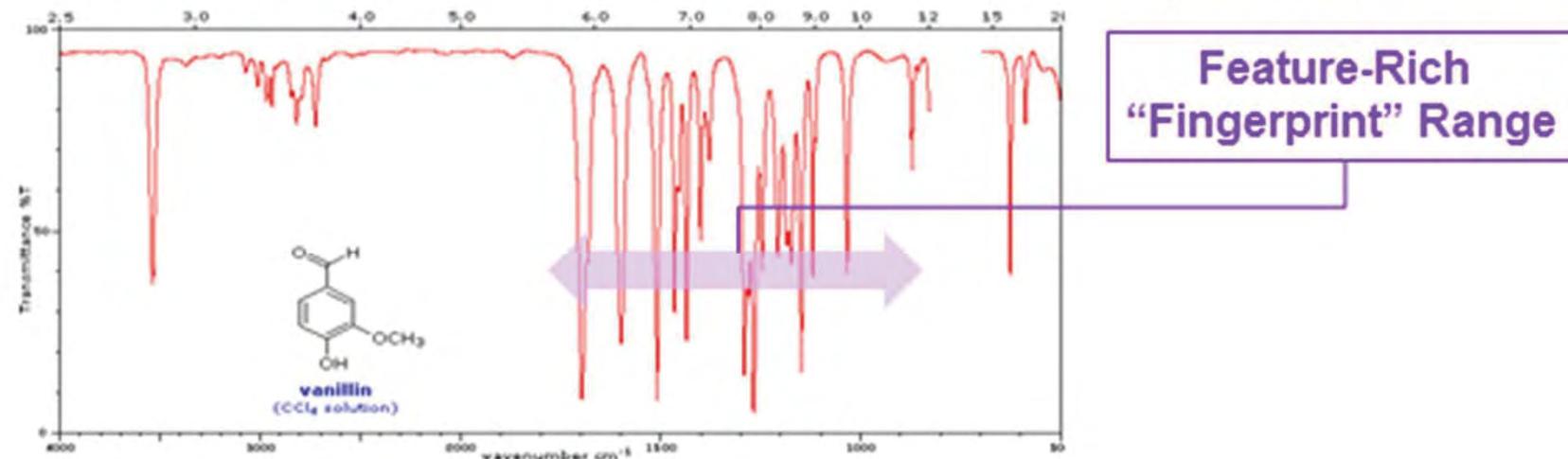


What is Infrared Absorption Spectroscopy?



The 3-14 μm spectral region is the most desired region by spectroscopists

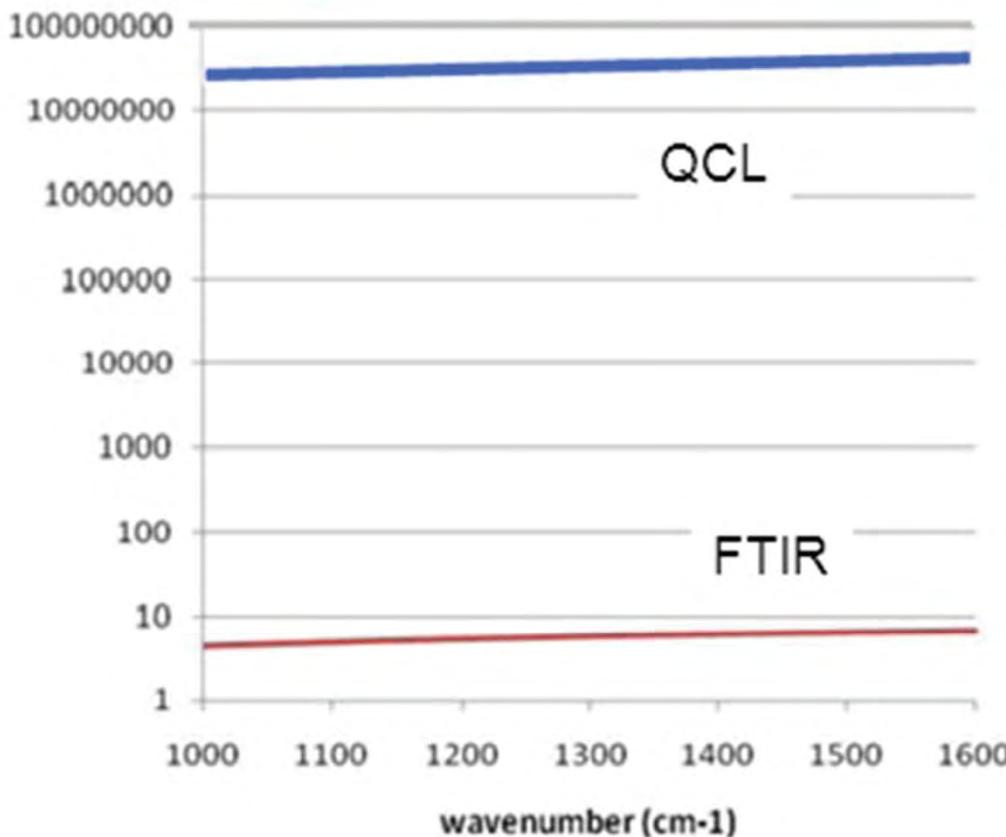
Resultant Transmission Spectrum – Mid-Infrared Radiation (3-20 μm)



Spectral Radiance Comparison QCL vs FTIR



Source Spectral Radiance Comparison



- ✓ Spectral radiance is radiance per wavelength – QCL is a high brightness, very small dimension source
- ✓ A lot of power can be focused to a small area

Radiance is defined by

$$L = \frac{d^2\Phi}{dA d\Omega \cos \theta} \approx \frac{\Phi}{\Omega A \cos \theta}$$

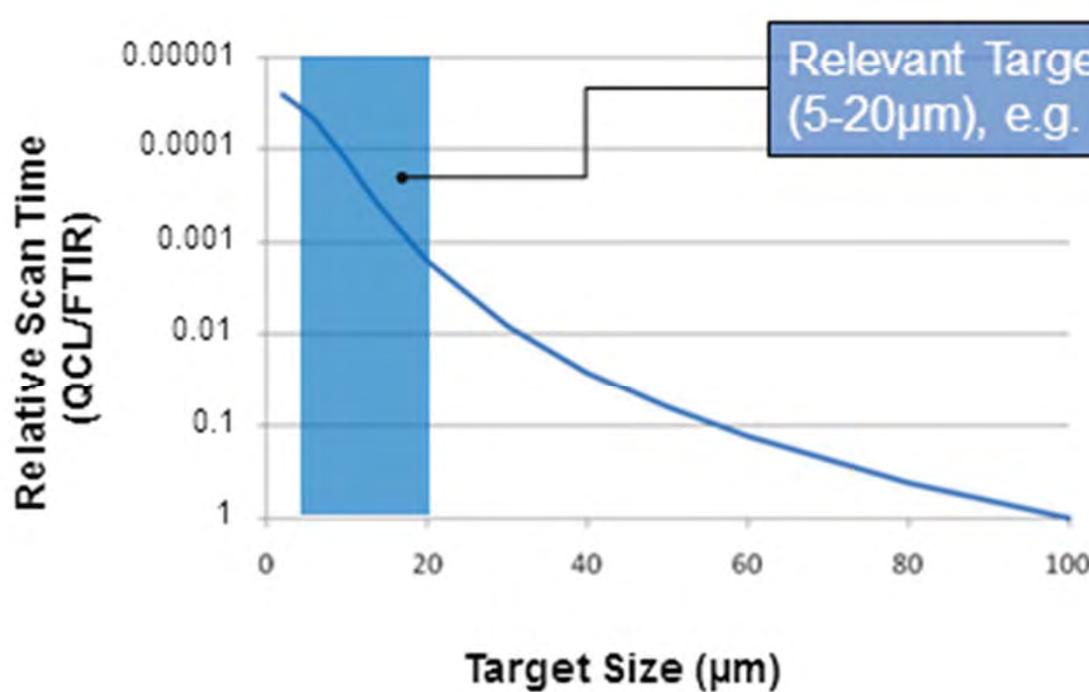
where

L is the observed or measured radiance ($\text{W}\cdot\text{m}^{-2}\cdot\text{sr}^{-1}$), in the direction θ ,
 Φ is the total radiant flux or power (W) emitted
 θ is the angle between the surface normal and the specified direction,
 A is the area of the source (m^2), and
 Ω is the solid angle (sr) subtended by the observation or measurement.

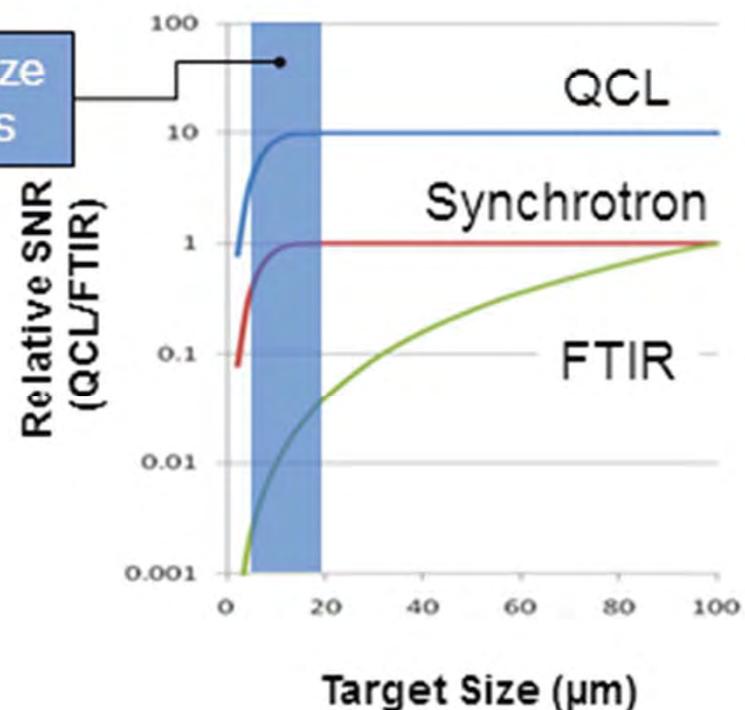
Specific Advantage over FTIR for Small Targets



Up to 10^3 Faster Measurements
for Small Targets (fixed SNR)



Up to 10^3 Higher SNR
for Small Targets



QCL technology offers dramatic SNR and/or Speed improvements for small targets enabling rapid micro-analysis

Key QCL Advantages Lead to Breakthrough Applications



ADVANTAGE	ENABLING...	APPLICATION EXAMPLE
High Photon Energy	<ul style="list-style-type: none">• Noncontact, standoff• Faster measurements• Testing of Highly Absorbing Material• Use of TEC-cooled detectors (no liquid nitrogen)	<ul style="list-style-type: none">• Pharma cleaning verification• Heterogeneous catalysis• Tribology• Characterization of lubricants• Trace detection of explosives
Ultra-Miniature Source	<ul style="list-style-type: none">• Excellent fiber optic coupling• Analysis of miniature targets• Higher sensitivity microscopy	<ul style="list-style-type: none">• IR assisted Atomic Force Microscopy• ID of cancerous cells• Chemical reaction monitoring• Forensics
Wide Spectral Range	<ul style="list-style-type: none">• Detection & ID of chemicals• Characterization of materials	<ul style="list-style-type: none">• Detection/ID of CWAs/NTAs• Metrology of surface layers• Coatings, paints characterization
Compact, Rugged Design	<ul style="list-style-type: none">• Handheld instruments• Field-hardened devices	<ul style="list-style-type: none">• Battlefield detection of IEDs• On-line detection of silicone residue• Point-of-Need detection of biothreats
Good Beam Quality	<ul style="list-style-type: none">• Focusing to small spots• Long standoff operation	<ul style="list-style-type: none">• Perimeter monitoring• Coatings analysis of highly curved surfaces (e.g. knee replacement parts)

Example of COTS QCL-Based Handheld Spectrometer



LaserScan™ Analyzer



Lasers are eye safe

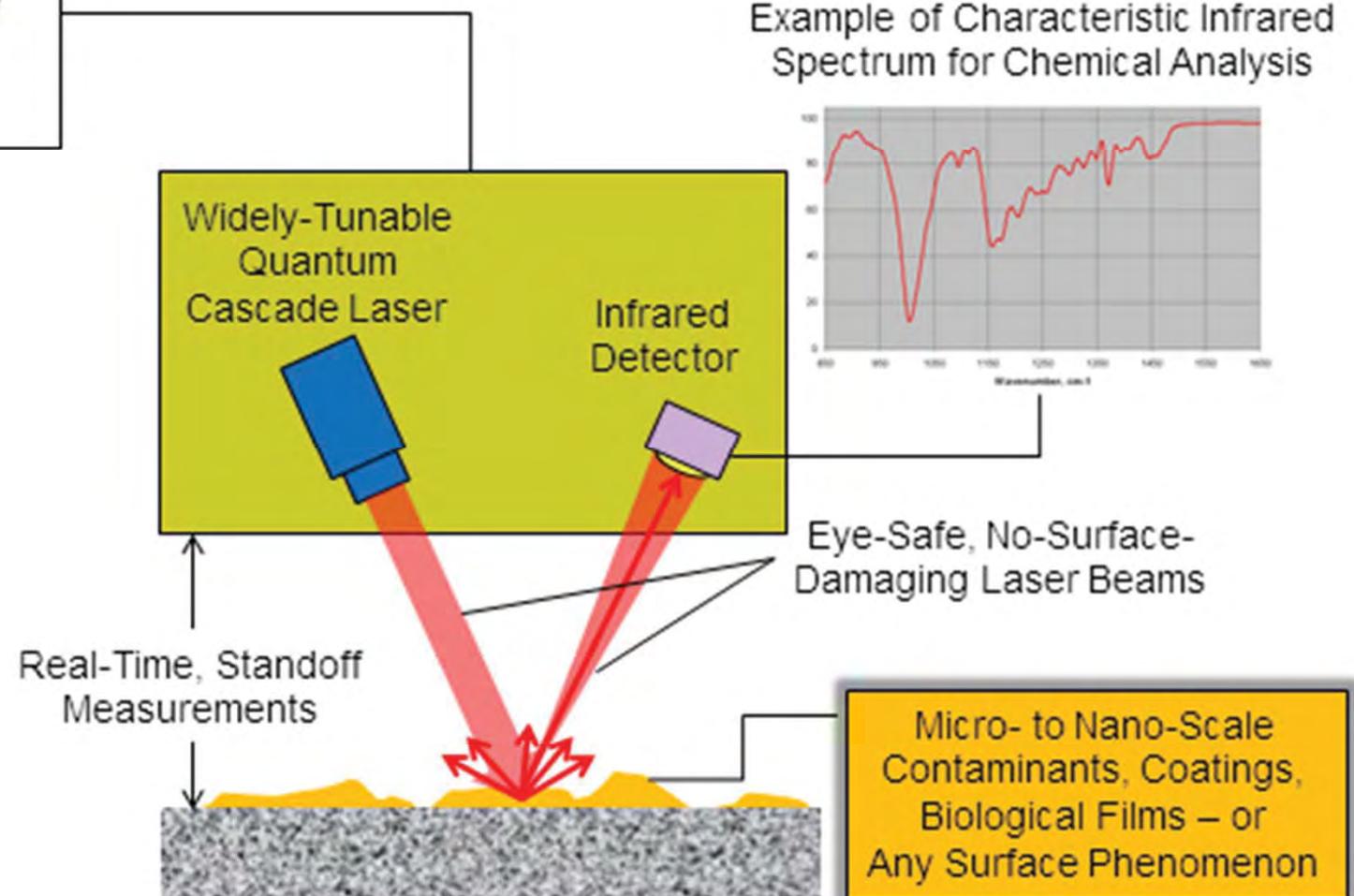
- Quantum Cascade Laser Source
 - 6-12 μm
 - 1667-833 cm^{-1}
- 0.5 cm^{-1} spectral resolution
- Short standoff (6 inches to 3 feet)
- Detects sub-micron to 50 micron films
- Detects concentrations $\sim 1 \text{ }\mu\text{g}/\text{cm}^2$
- Off-the-shelf accessories for point detection
 - Gases/Liquids/Solids



Compared to Other Handheld Techniques

Detects	Standoff/Noncontact			Sampling		
	Solid	Liquid	Gas	Solid	Liquid	Gas
LaserScan	✓	✓	✓	✓	✓	✓
FTIR	✗	✗	✗	✓	✓	✓
Raman	✓	✓	✗	✓	✓	✗
IMS	✗	✗	✗	✗	✗	✓
Gas Chromatography	✗	✗	✗	✗	✓	✓

LaserScan™ Analyzer Surface Analysis



Block's Family of Widely-Tunable QCL Instruments



2013

LaserScan™



Today



- Handheld, field device
- Standoff chemical detection

LaserScope™



- Fiber coupled, laboratory use
- Ultimate target, setup flexibility

LaserTune™



- QCL source
- Fiber coupled, laboratory use

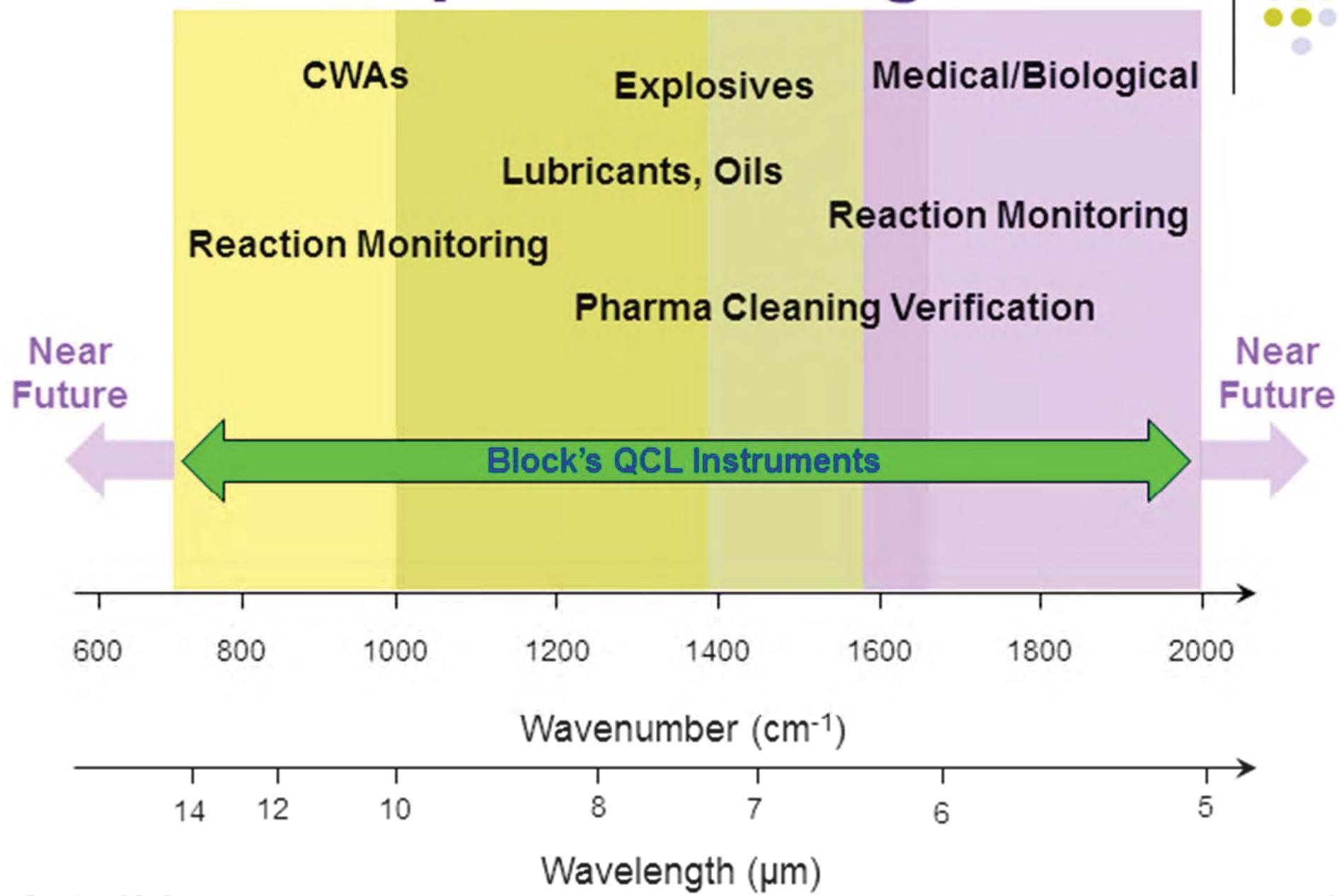
LaserBench™



- Compatible with any FTIR accessory
- Laboratory use

Block QCL Instruments

Spectral Range





Selected Surface Analysis Applications

QCL-Based Surface Analysis

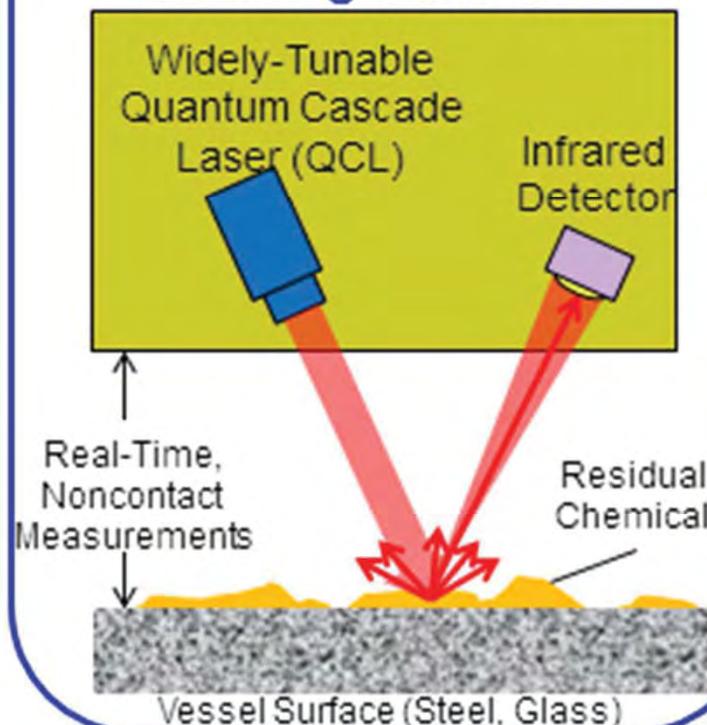
Noncontact, Real-time Cleaning Verification of Pharmaceutical Vessels



- Cleaning Verification of pharmaceutical vessels between batches is a slow, time-consuming process, due to the use of manual swabs and slow High Pressure Liquid Chromatography instruments
- Such delays lead to raw material processing delays, costing millions of dollars per year to large pharma

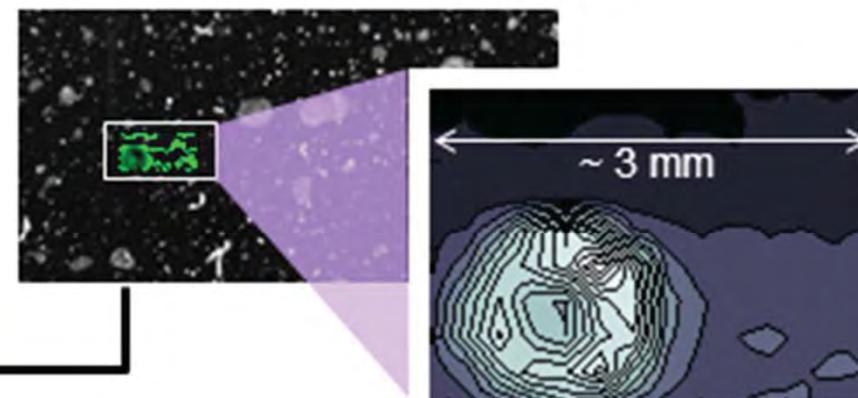


Conceptual Schematic for Cleaning Validation



Block's QCL-based technology would offer noncontact, rapid cleaning verification at detection levels close to $0.1 \mu\text{g}/\text{cm}^2$

Top view of vessel surface with "islands" of residual chemical



High spatial resolution concentration plot, using scanning QCL

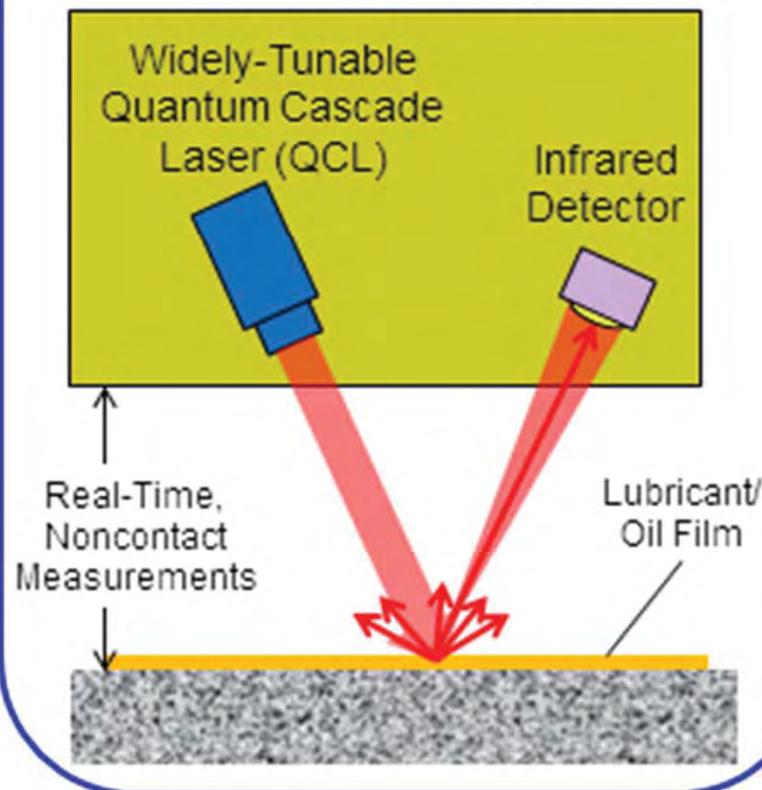
QCL-Based Surface Analysis

Noncontact, Real-time Characterization of Tribology Mechanisms



- Need for real-time, noncontact detection of:
 - Chemical changes in lubricants due to wear
 - Contaminants or lubricity additives
 - Wear-related chemical surface changes
- Targets typically sensitive to touch, optically absorbing and fast, real-time measurements needed

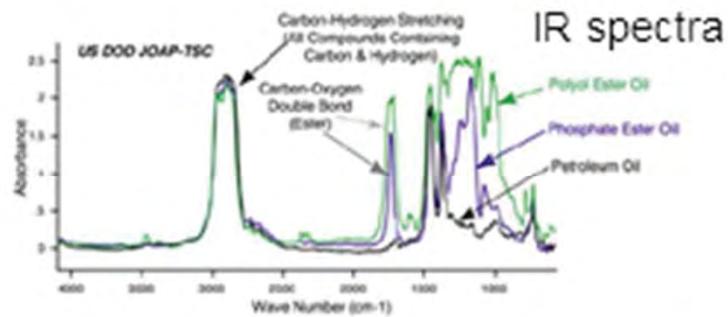
Conceptual Schematic for Tribology Analysis



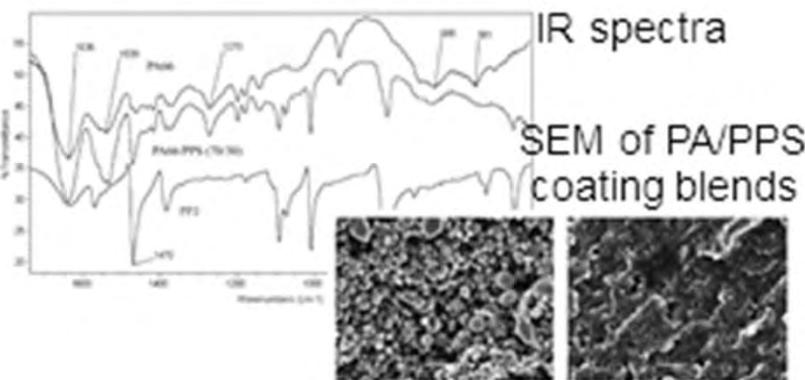
Block's QCL-based technology offer noncontact inspection and infrared spectroscopy-based, chemical analysis of lubricant/oil films and/or the wear surface

EXAMPLES

Chemical analysis of oils



Polyamide (PA),
Polyphenylene sulfide (PPS)
tribology studies



QCL-Based Surface Analysis

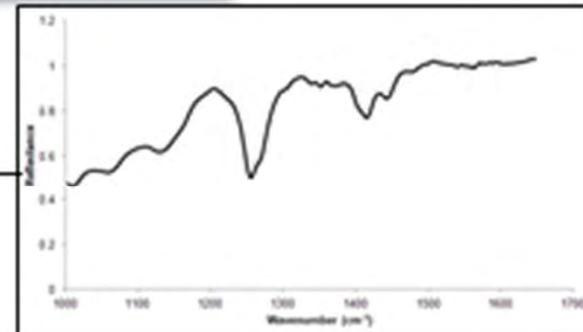
Noncontact, Real-time Detection of Residual Lubricants



- Need for real-time, noncontact monitoring of oil films, silicone contamination
- Inspection needs to be done on line, in field – handheld, quick measurements are needed

Block's QCL-based technology would offer noncontact, real-time inspection and infrared spectroscopy-based detection of oil/silicone films

Near Future (2013)



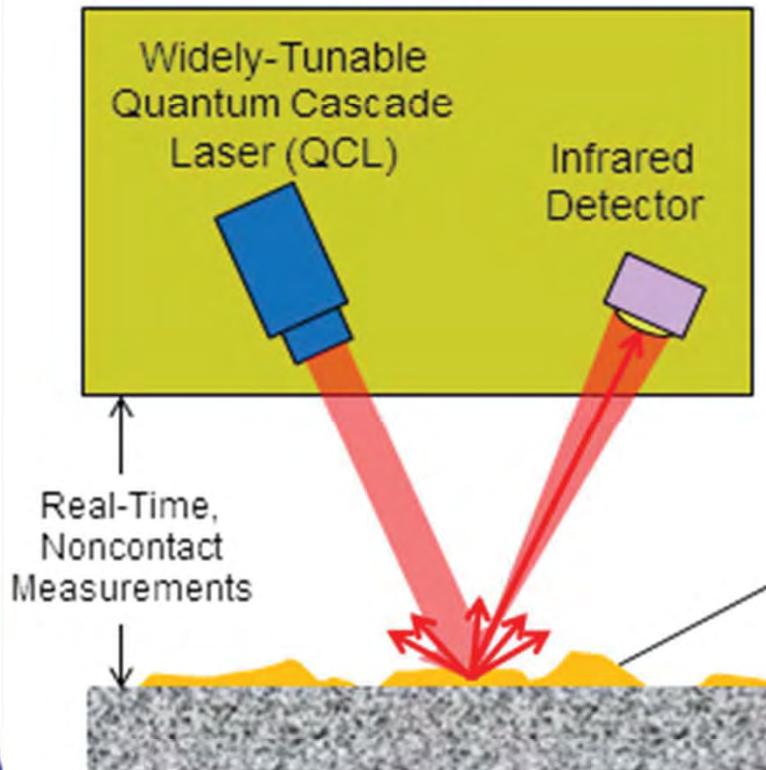
Spectrum of Silicone Film, detected by LaserScan™

QCL-Based Surface Analysis

Inspection of Coatings for Improved Orthopedic Implants



Conceptual Schematic for Coating Inspection

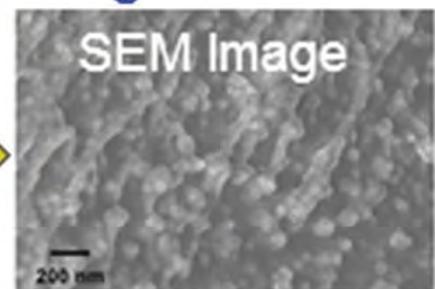
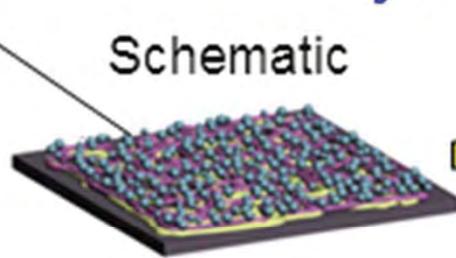


- Significant failure rate has been reported for orthopedic implants, due to cracking of the bone cement used to secure the implant
- MIT team has proposed development of new coating that instead promotes the growth of the bone itself for better adhesion

Block's QCL-based technology would offer noncontact inspection and infrared spectroscopy-based, chemical analysis of the coating

Hydroxyapatite-based, osteophilic, multilayer coating

Schematic



Source: "Osteophilic Multilayer Coatings for Accelerated Bone Tissue Growth",
Nisarg J. Shah, Jinkee Hong, Md. Nasim Hyder, and Paula T. Hammond
Adv. Mater. 2012, 24, 1445–1450, Dep. of Chem. Eng., MIT

QCL-Based Surface Analysis

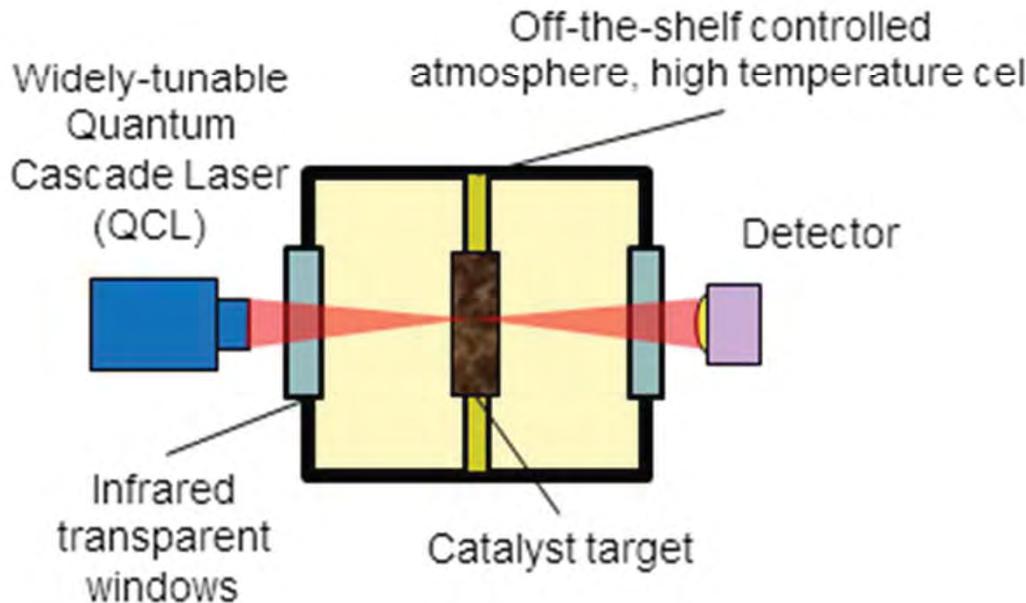
Noncontact, Real-time Characterization of Heterogeneous Catalysis



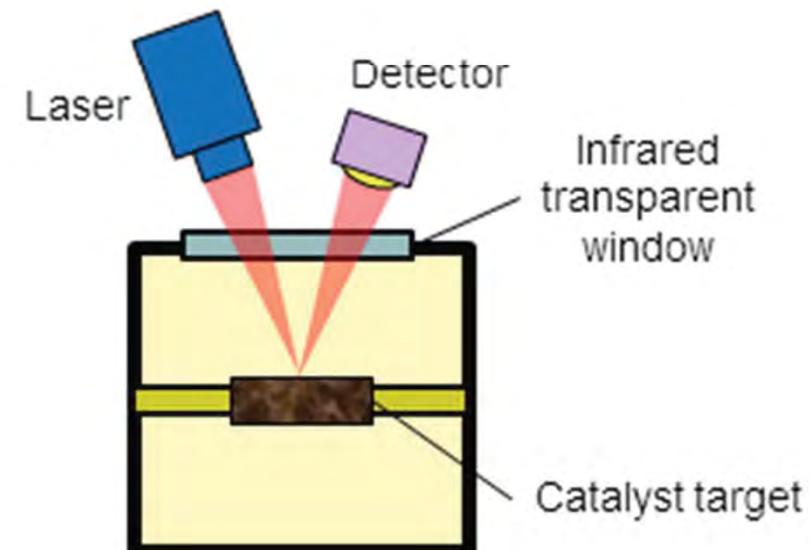
- Need for real-time, noncontact monitoring of catalytic reaction mechanisms
- Target surfaces are typically at high temperature and controlled ambient, and are dark, optically absorbing, making it difficult for conventional optical inspection techniques to be applied

Block's QCL-based technology would offer noncontact, real-time inspection and infrared spectroscopy-based evaluation of catalytic mechanisms

Transmission Configuration



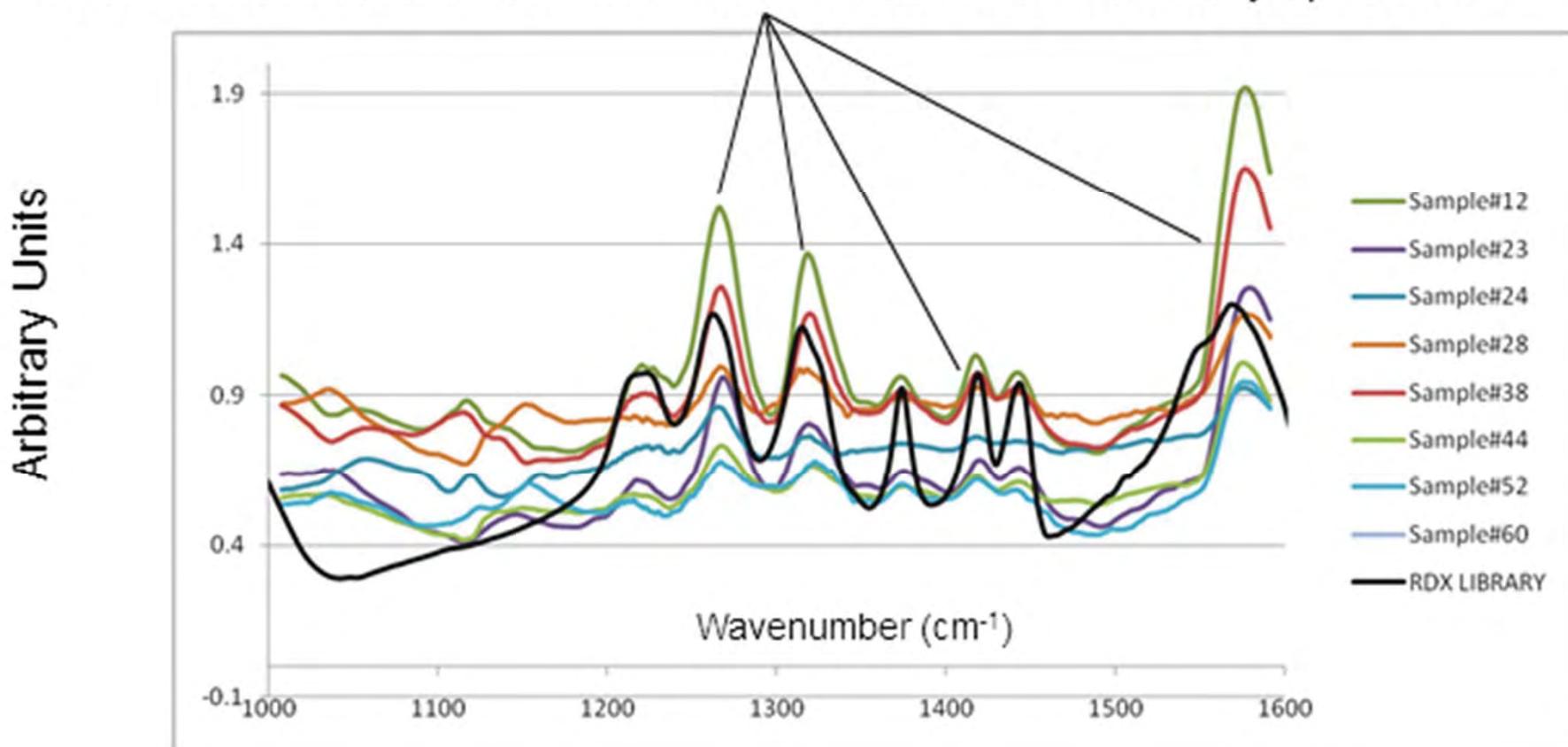
Diffuse Reflectance Configuration



TSA Provided Samples Standoff RDX Detection



Characteristic RDX Peaks Detected – match with the library spectrum

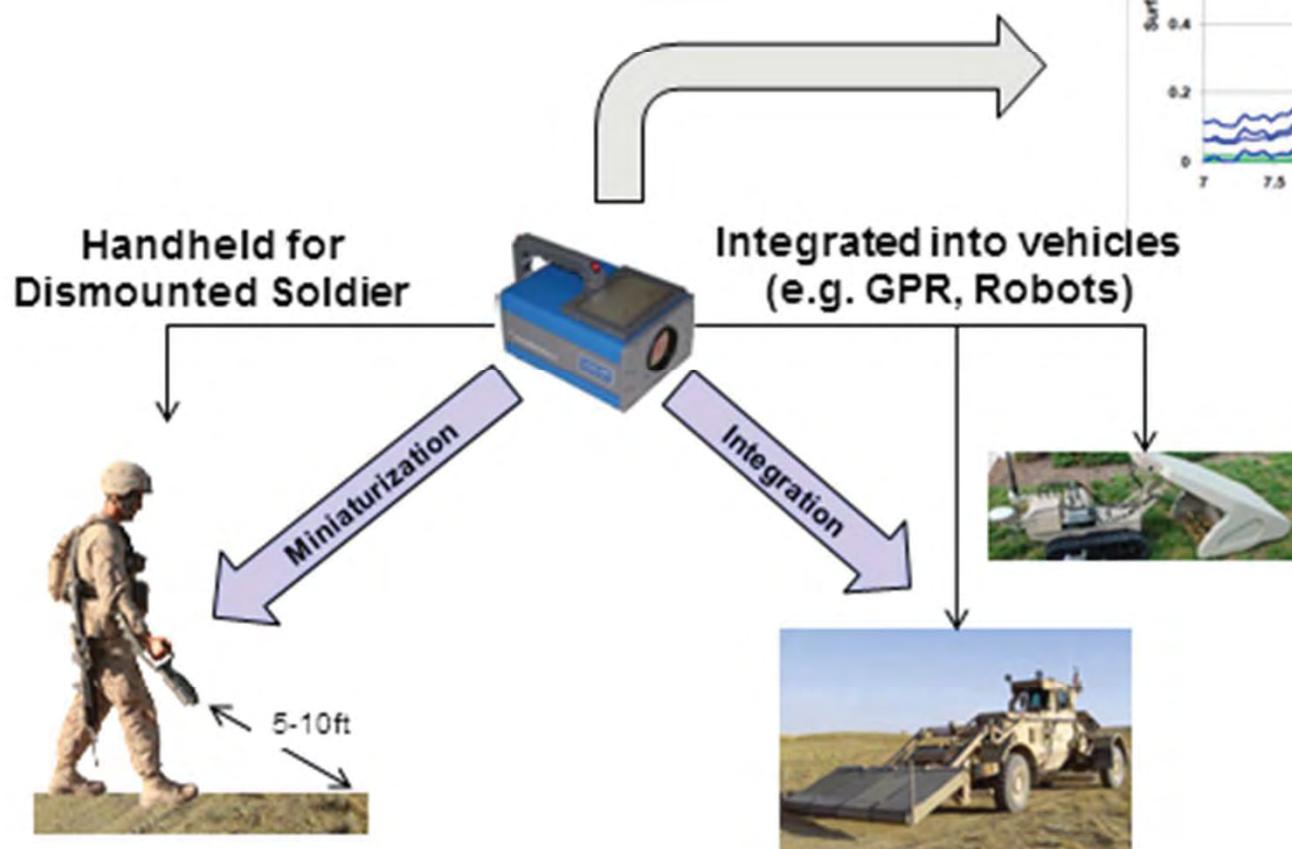
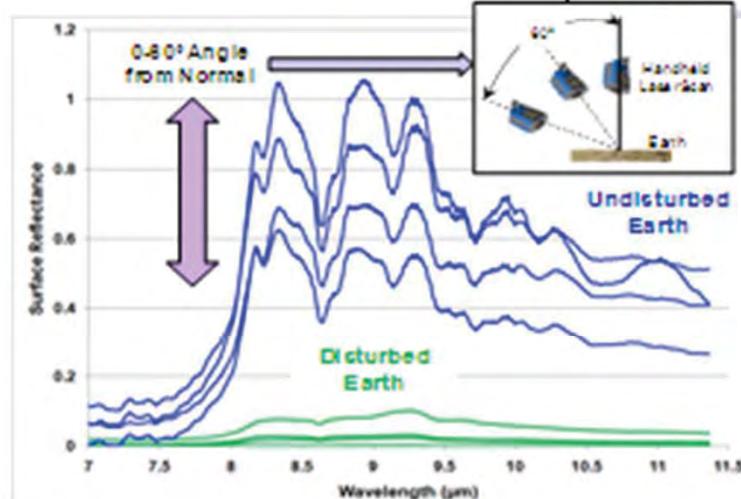


- Samples were placed ~2 ft away from instrument
- Measurements in a few seconds per sample
- Various vehicle-simulating substrates: Gray & black painted metallic, white painted plastic

Standoff Disturbed Earth & Buried IED Detection



Detection of strong “Reststrahlen Effect”
due to changing soil characteristics
during disturbing process

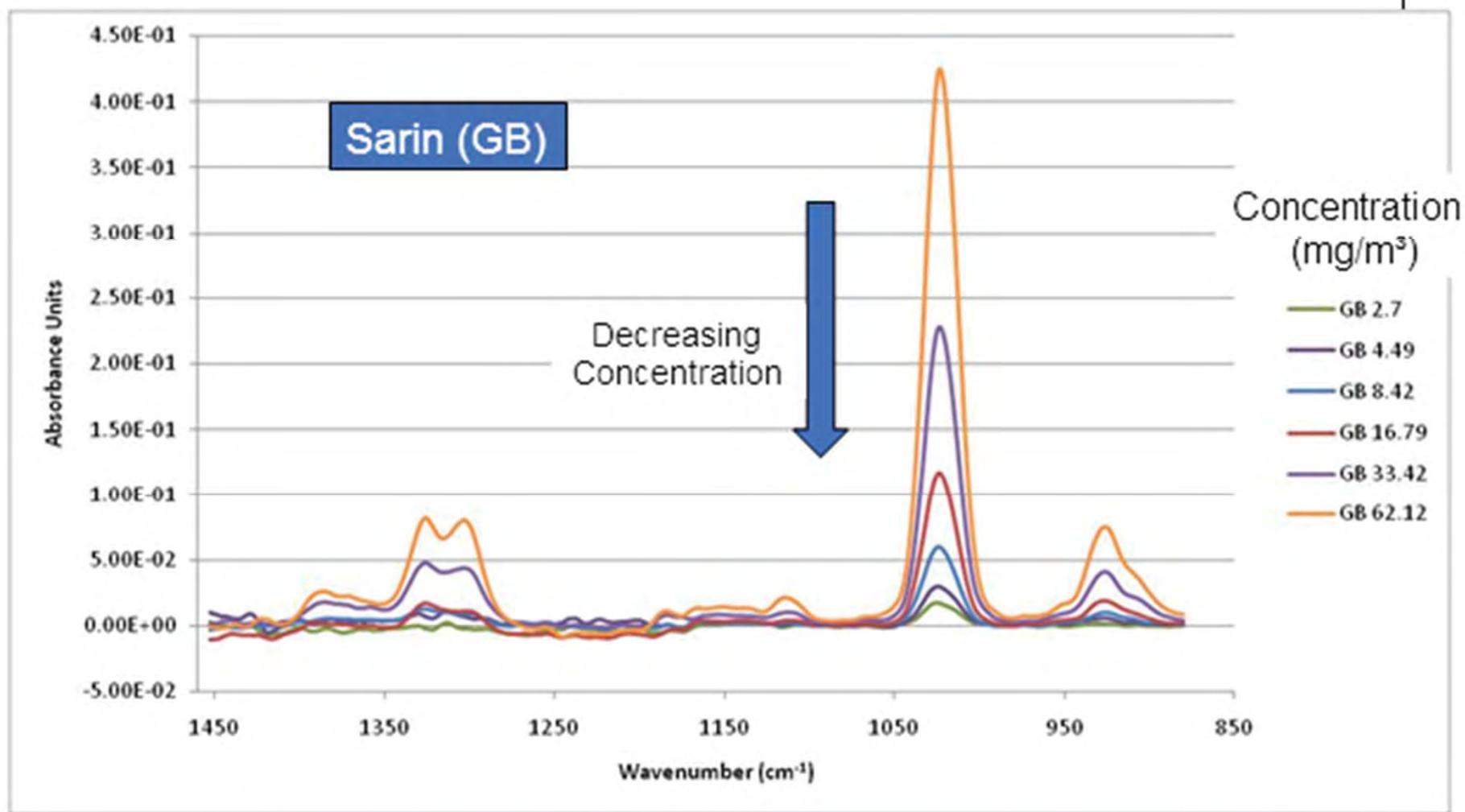




Selected Gas/Vapor Applications

LaserScope™ Analyzer

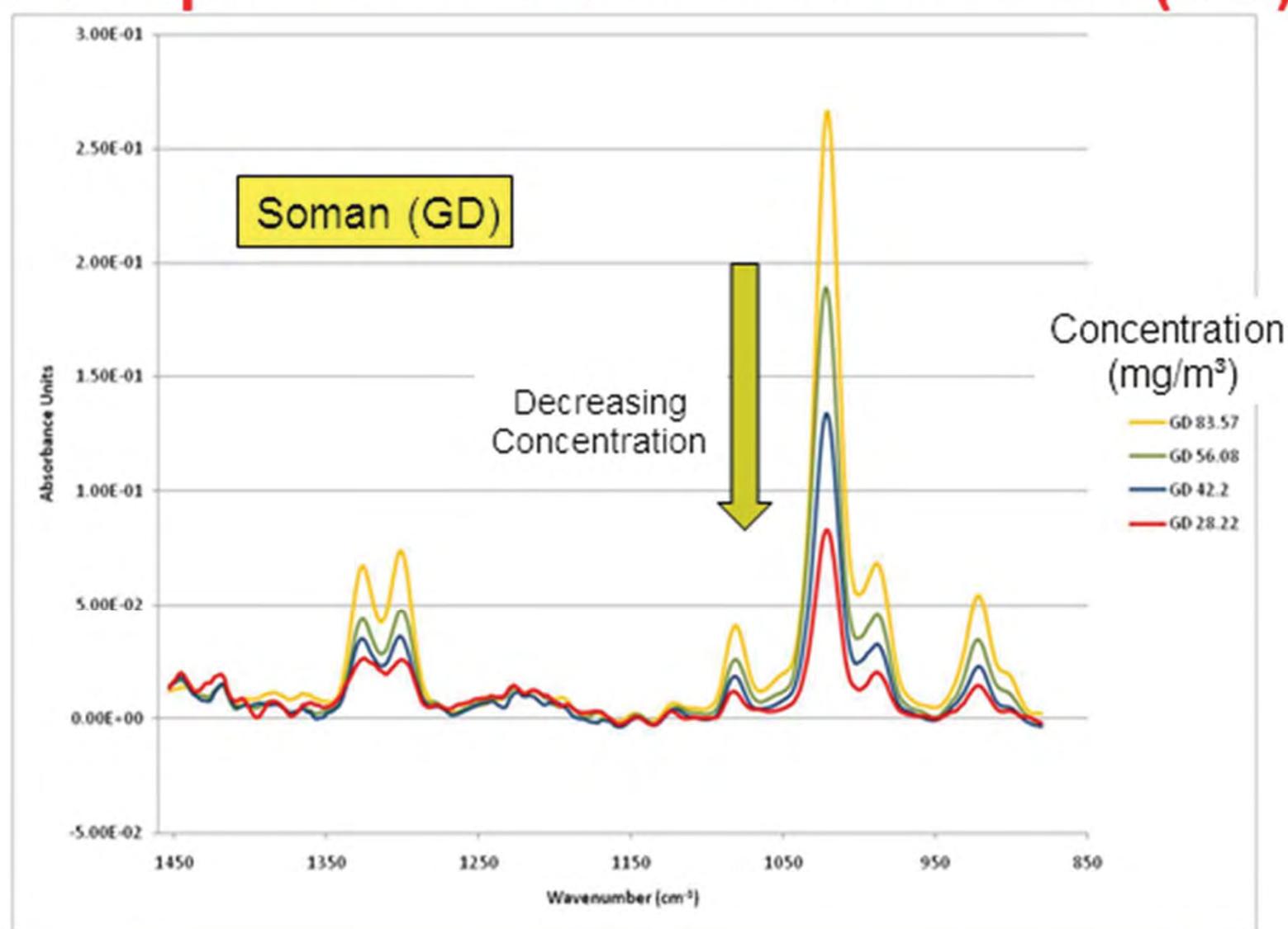
Gas/Vapor Point Detection of Sarin (GB)



Tests conducted at ECBC by government personnel

LaserScope™ Analyzer

Gas/Vapor Point Detection of Soman (GD)

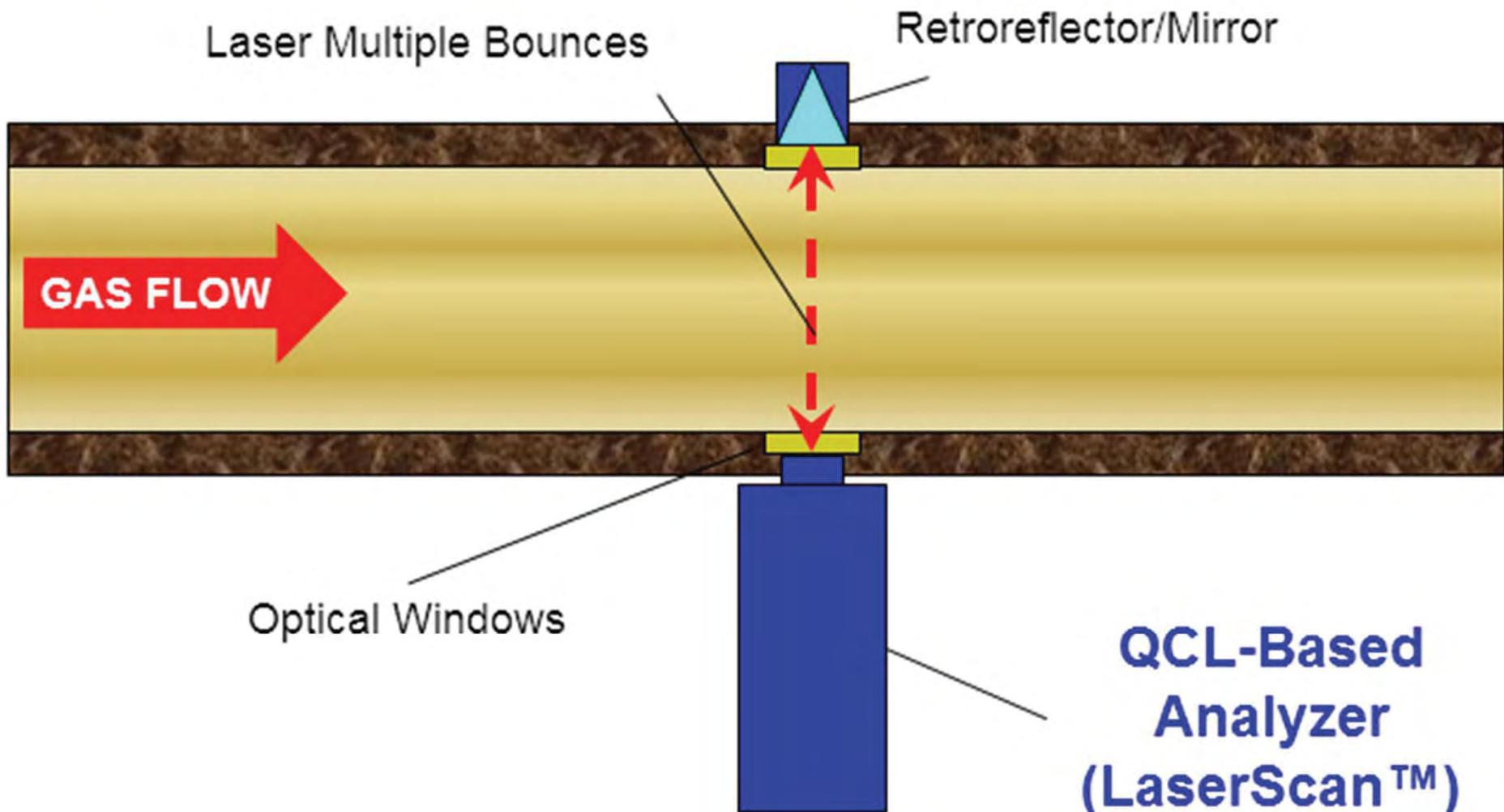


Tests conducted at ECBC by government personnel



Cross-Duct Measurement

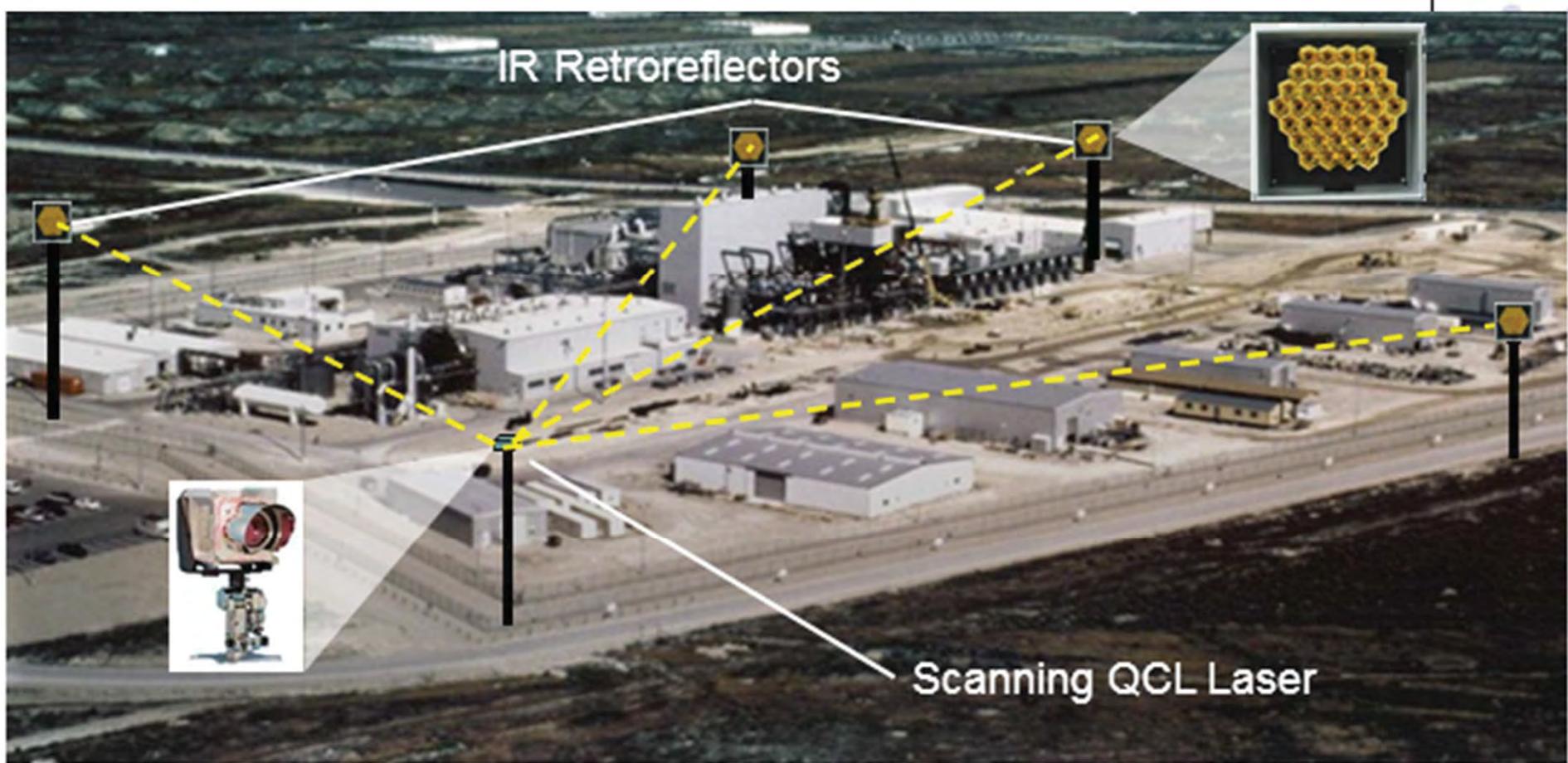
Collimated Beam makes multiple bounces possible without re-imaging





Other Potential Applications

Surveillance and Perimeter Monitoring



- Eye-safe laser beams and optimally placed retroreflectors provide real-time large area protection – high sensitivity line of sight detection
- “Sample-and-scan” modes allow for detection of chemical threats over large areas

Protection of Closed Areas



Sampling Mode



Scanning Mode



Retroreflectors



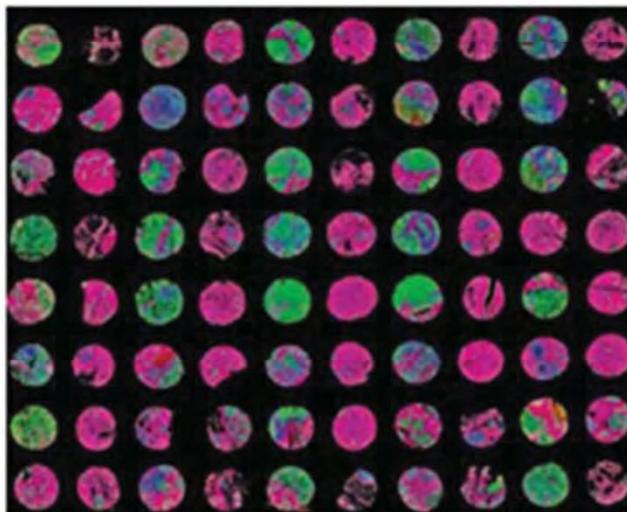
- Eye-safe laser beams allow for operation in areas with people
- Fast readings allow for quick detection and immediate warning alerts
- Sensors' cost drops strongly with volume, so it would enable wide deployment

Infrared Spectroscopy Based Cancer Detection



Breast Cancer Detection

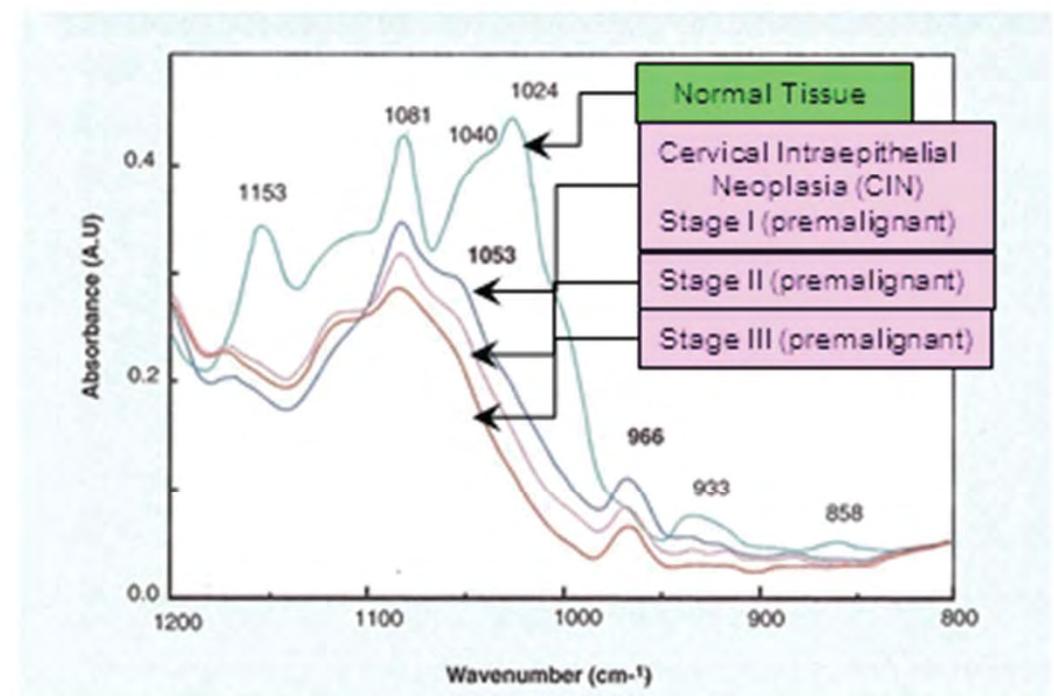
Microarray of breast tissue biopsies



Source: Prof. Rohit Bhargava, 2008

Cancerous tissue contains more epithelium (green) and lymphocytes (blue) than normal tissue (pink)

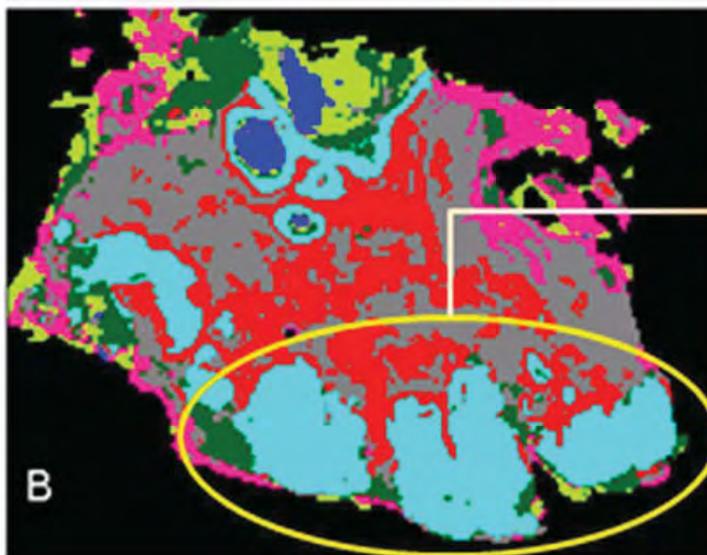
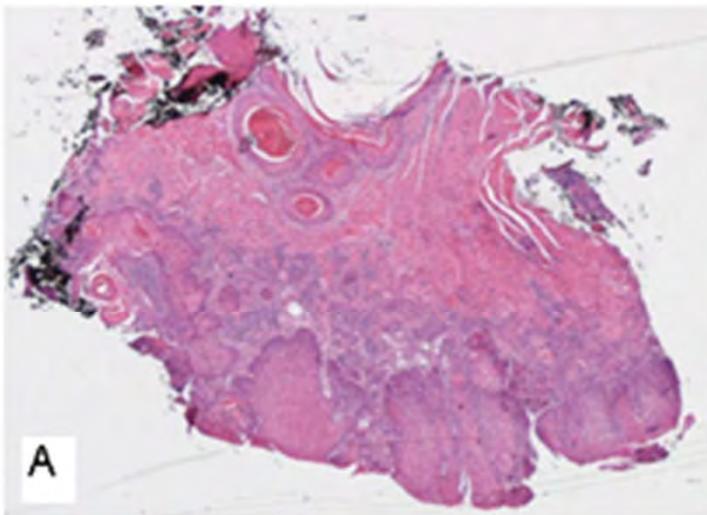
Cervical Cancer Detection



Source: Future Oncology, 2005

Pre-Malignant staging of cervical cancer demonstrated

Chemical Imaging of Cells*



Chemical cell ID to complement pathologists' visual determination

SCC Cells

- A: Stained Histopathology of Oral Tissue with Squamous Cell Carcinoma (SCC)
- B: FTIR Microscopy Measurements (light blue shows SCC cells)

*Research of Prof. Max Diem, Northeastern University



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