Hand-Held Terahertz Imaging

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In-Space NDI Technology Workshop
Gillruth Center – NASA / JSC
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Picometrix, LLC

• Formed in 1992 in Ann Arbor, Michigan

• Subsidiary of Advanced Photonix, Inc. since 2005
  – NYSE: AMEX listed (API)
  – Leading supplier of TD-THz instrumentation and optical receivers utilizing Si, GaAs and InGaAs
  – Industrial, military, homeland security, medical and telecom markets

• Picometrix 50,000 sq. ft. with four TD-THz application labs

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www.advancedphotonix.com
T-Ray 4000® Modular Product Line

- Imaging Station™
- Motion Controller
- Custom Gantry
- T-Scanner™
- New for 2010!

- T-Ray 4000® Control Unit
  100 Hz and 1KHz

- Spectroscopy Station™

- T-Ray® Explorer™ Software
- New for 2010!

- T-Ray® T-Gauge™
- New for 2010!

NDE and Imaging

Lab and Custom Configured R&D

Industrial Online Measurement

NDE and Imaging
Evolution of T-Ray® Instrumentation Platform

1996 PhD-Built Discrete Component Lab Setup (Bell Labs)

1999 Picometrix T-Ray® 2000 Patented Freely Positionable Fiber Optic Driven THz Modules and Sensor Technology

2002 Picometrix TMIS™ and 2004 QA1000™ All-In-One Control Unit

2007 Picometrix T-Ray 4000® Industrial 19 in. Rack Mount Portable Control Unit
Vertically Integrated

- Grow custom epitaxial structures for high speed photoconducting antennas
- Microfabricate T-Ray® antennas
- Assemble rugged fiber-coupled transmitters and receiver modules
- Engineer and manufacture control unit and high-speed optical subsystems
- Program control / analysis software
Common Control Unit: Flexibility & Expansion

- Imaging Station™
- Motion Controller
- Custom Gantry
- T-Scanner™
  - New for 2010!
- T-Ray® Computed Tomography
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- T-Ray® Transmitter and Receiver
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Industrial Online Measurement

NDE and Imaging

Optoelectronic Solutions
T-Ray 4000® Control Unit

- Interchangeable plug-in sensors
- Multiple sensor heads available
- Transmission or reflection
- Two measurement channels
- Remote sensors up to 50 m
- High-speed waveform acquisition (A-Scan)
  - 100 Hz 320 ps
  - 1000 Hz 80 ps
- Stable measurement
- Dedicated software packages
  - THz waveform acquisition and analysis
  - Imaging
  - Spectroscopy
- Portable, 19 in. rack mountable
- Robust packaging
- 0 – 35 °C
- Low RF emission
Industrial Requirements

- Compact, reliable, robust
- Tolerant of the environment
  - Temperature, dust, explosive atmosphere (sensors)
- Non-interfering with the environment
  - Low RF emissions, certifications (UL, CE, FCC)
- High speed
  - Waveform acquisition, processing
  - Imaging and process control
- Easy to use
  - Familiar to industrial personnel
Software for Data Acq., Spectra & Imaging

Imaging Station™
Motion Controller
Custom Gantry
T-Scanner™

T-Ray 4000®
Control Unit
100 Hz and 1KHz

New for 2010!
T-Ray® Computed Tomography
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T-Ray® Spectroscopy Station™

T-Ray® Explorer™
Software

New for 2010!

T-Ray® T-Gauge™

NDE and Imaging

Lab and Custom Configured R&D

T-Ray® Transmitter and Receiver

Optoelectronic Solutions
Terahertz pulse (TD-THz)

- Time Domain
  - Time of flight
  - Weighing
  - Thickness
  - Index
  - Scattering

Frequency 0.05 – 4 THz
Wavelengths 6 – 0.1 mm
          cm$^{-1}$  1.7 - 100
Water Vapor Spectrum

Rapid scan resolution: 2-3 GHz (less than the pressure broadening at STP)
Solutions for NDE and Imaging

- Imaging Station™
- Custom Gantry
- T-Scanner™

New for 2010!

- T-Ray 4000® Control Unit
  100 Hz and 1KHz

Lab and Custom Configured R&D

- T-Ray® Transmitter and Receiver
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- T-Ray® T-Gauge™

Industrial Online Measurement

NDE and Imaging

- Spectroscopy Station™
- T-Ray® Computed Tomography

New for 2010!
Aerospace applications

Picometrix T-Ray 4000®

- Radome delamination and water intrusion; with Hill AFB
- F35 Intake Specialty Coating thickness measurement; with WPAFB and NGC Palmdale
- Space Shuttle: ET tank foam NDE; Orbiter TPS Tiles-hidden corrosion detection; Next Gen Orion and Ares Applications: NASA
- Aeroturbine Thermal Barrier Coating measurement; with Navy STTR
Deployed Application
Shuttle ET Tank SOFI

Reflection Imaging
1.5 mm pixels  0.2 m/s
~ 1m x 1m

Youtube Video of NASA Scanning Tank with T-Ray 4000®
http://www.youtube.com/watch?v=nRrZU_c5zN8
TD-THz Reflection Imager

- T-Ray 4000 control unit, imaging station, motion controller, and laptop computer.
- Co-linear reflection adaptor with 3 in. f.l. 1.5 in. diam. lens, F/2. Snub bow-tie transmitter to bow-tie receiver.
**TUFI Tile TD-THz C-Scans**

- Tile dimensions L6 in. x W6 in. x H1.72
- Mounted on L12 in. x W12 in. 1/32 in. thick aluminum sheet
- Aluminum mounting sheet metal was deformed into a bulge and punctured/torn.
- Front: Power integration between 0.3 and 2 THz
- Back: Centroid delay with 0.3 to 0.8 THz bandpass filter.
TUFI Tile TD-THz B-Scan

• B-Scan shows discontinuity across puncture.
• Concave deformity of impact into substrate indicated.
• B-Scan shows material compacted from impact onto surface of the substrate on the bottom of the hole. Confirmed visually.
T-Ray® Computed Tomography

NDE and Imaging

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Motion Controller
Custom Gantry
T-Scanner™

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Control Unit
100 Hz and 1KHz

Spectroscopy Station™

T-Ray® Explorer™ Software

T-Ray® Transmitter and Receiver

T-Ray® T-Gauge™

New for 2010!

Lab and Custom Configured R&D

NDE and Imaging

T-Ray 4000®
Base System

New for 2010!

Industrial Online Measurement

New for 2010!

T-Ray® Computed Tomography

Optoelectronic Solutions
CT TD-THz Setup

- TD-THz Transmission CT Sinogram Collection
- Beam Focused Through Side of Tile
- Path through tile is approx 6 in. to 8.5 in, depending on angle.
- Z-Axis is Height
- Collected 3 slices
Example Sinogram of TUFITILE

- Collected over 360 degrees
- Analysis is time-of-flight computed by centroid with a bandpass pre-filter between 0.3 and 0.8 THz
TUFI TILE
CT TD-THz Slice Reconstruction

- Impact hole clearly visible in all slices with high contrast.
- Top to slices show higher density at edges due to glaze/ceramic overcoat. Not present on bottom half of tile.
Phase II TD-THz CT Setup

- TD-THz Transmission CT Sinogram Collection
- Beam Focused Through Side of Tile
- Path through tile is approx 6 in. to 8.5 in, depending on angle.
- Z-Axis is Height
- Collected 20 slices at 2 mm
Preliminary TD-THz CT Slice Reconstruction

- Middle slice showing middle hole and deep hole
- Analysis is time-of-flight computed by centroid of the deconcolved TD-THz pulse. No bandwidth filter.
- Plan to reanalyze, excluding low frequencies to possible improve resolution of small features.
Montage of Slices

- Shows middle hole bottoms before deeper hole.
- Slice spacing is 2mm.
- Excluded the top and bottom 2 slices showed reconstruction artifacts due to the air and substrate. Developing and analysis to minimize.
- The shallowest hole is excluded due to these artifacts.
Volume and Surface Renderings

- Using 3D doctor (limited experience)
T-Ray™ Computed Tomography
TD-THz CT Example
Box of ice cream cones
TD-THz CT Example
Cat Skull
TD-THz CT Example
Honeycomb  (more transparent shows dead bees)
TD-THz Reflection Computed Tomography Setup

- **RX**
- **TX**
- **Rotation Stage**
- **SOFI Block**
- 30 mm wide collimated beam
- Fixed Angle of 12 deg
Reflected Wavefield
(Sinogram)
SOFI Block Reconstruction
Inverse Radon Transform/Filtered Back Projection

Visible
THz

Void bored in foam visible.
Single Sided Reconstructions
Inverse Radon Transform/Filtered Back Projection

180 deg (full single sided)  150 deg (partial single sided)
Hand-Movable Real Time Imager

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Imaging Speed
Limitations of Gantry

• Maximum pixel rate typically limited by waveform acquisition rate
  – Standard option: 100 Hz
  – High speed option: 1 kHz

• Increase the number of sensors
• Maximize the scanning rate
• Collect less than all the pixels
  – Advanced algorithms and modulators

• Develop alternative to traditional single sensor X-Y raster scan gantries
T-Scanner™
Portable High Speed Reflection Imager

- 150 mm (6 in.) wide scan
- 2 mm spot size
- Scan rate up to 15 Hz
- Video rate B-Scan
- Push by hand to sweep out C-Scan

- Trade-off between scan rate, waveform acquisition speed and pixel size
- Current controllers are designed to collect waveforms at either 100 Hz or 1000 Hz.
T-Scanner™ Setup

- Computer Control / Display
- T-Ray 4000 TD-THz Control Unit
- Umbilical
- T-Scanner
Water intrusion into composite laminate panel degrades radar performance. Current solution: Tap Testing
Ground-Based Radome Scan

- Scan width 150 mm
- Maximum rate 15 Hz
- Maximum pixel rate 800 pixels per second
Scan of C-130 Radome

- Large defect identified
- Plan images and cross-sections can be produced
F-35 Manufacture and Repair

- Panel fit and placement
- Coating thickness
- Explosive environment

This work sponsored by the Air Force Research Laboratory (AFRL).
Phase II TD-THz Step/Gap Measurement Prototype

Hand-Held Interface Unit

Hand-Held Scanner

T-Ray 4000 Controller

Adjustable Step/Gap Testing Jig
Phase II hand-held T-Ray 4000 plug-in sensor

- Line-scan width 3 in.
  - Gap > 500 mils
  - Step 0 to > 250 mils
- Stand-off approx. 3 in.
- 4 to 10 B-scans per second
- Laser projection reticule aids operator positioning
- 3.5 in. high, 5.25 in. wide, 6 in. long (handle 4.2" high)
- 240 x 320 pixel backlit color LCD touch-screen, 3.78" diagonal
- 15 m umbilical
- Weight 3 lbs.
Panel offset (step and gap)

THz can look through the coating to the underlying metal to adjust fit. Also deployed in the paint booth to control the thickness.

This work sponsored by the Air Force Research Laboratory (AFRL).
Making A Measurement

Touchscreen Seam Selection
Making A Measurement
Scanning and Results
T-Ray 5000 platform

- Touchscreen
- Internal processing
- Integrated umbilical
- 35 lbs
- 0 – 50 °C
### Identification and Significance of Innovation

- Picometrix’s time-domain terahertz (TD-THz) non-destructive evaluation (NDE) systems can be used to inspect space flight structures such as inflatable space habitats, thermal protection systems (TUFi-type tiles, SOFI TPS), and other components for voids, disbonds, and damage such as tearing and micro-meteorite impact.
- However, the COTS TD-THz control unit is too large and heavy and require too much electrical power for space based use.
- The Phase II project will develop and construct a TD-THz reflection tomography NDE instrument < 1/3 the mass and volume of the COTS control unit.

### Expected TRL Range at the end of Contract: Phase I 3, Phase II 6-7

### Technical Objectives and Work Plan

#### Phase II Feasibility

- Construct a higher efficiency all-in-one TD-THz transceiver which reduces the laser optical drive requirements from the control unit based on the Phase I design.
- Construct a compact all-fiber-optic chirped fiber Bragg grating group velocity dispersion precompensator to replace the macroscopic opto-mechanical GRISM (grating/prism) design used in the COTS control unit based on the Phase I design.
- Reconfigure the laser optical drive subsystem design into a miniaturized all-in-one power stabilized unamplified femtosecond fiber laser/chirped fiber Bragg grating GDC/fiber optic delivery.
- Construct and deliver a prototype compact TD-THz reflection tomography NDE instrument < 1/3 the mass and volume of the COTS control unit.

### NASA and Non-NASA Applications

- In-space inspection of TPS, TUFFI, SOFI, and inflatable habitats.
- Inspection of composite aerospace components during manufacture and after aging.
- Material examples include ceramics, foams, Kevlar, Zylon, glass, and other non-conductive polymer matrix composites.
- Automotive composites, transmission and clutch plates, pipe insulation, circuit boards, homeland security – packages, mail, luggage.

### Firm Contacts

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T-Gauge™ for Industrial Measurement

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**NDE and Imaging**

**Lab and Custom Configured R&D**

**Industrial Online Measurement**
Nondestructive Testing of Pipeline Repairs

- Petrochemicals
  - Pipe patch inspection
  - Extends lifetime
Extruded Material Manufacturing Plant

Nuclear gauge
  - total thickness only

T-Gauge™
  - individual layers

Two layer laminate with cloth reinforcement

No method to measure second layer thickness
Paper coating pilot line

- Coat weight down to 1.5 lbs/ream measured
- Caliper thickness to .25 micron

Two channel coat weight measurement
Organic coating on plastic

Coating thickness: 60 microns
Accuracy: better than 5%
Web speed up to 1 m/sec

On a moving web
Thank you

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