Illuminating a spectrum of new possibilities
Emerging Diagnostic & Therapeutic Applications of Terahertz Technology

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Terahertz Primer

• Properties
  • Unambiguous identification of molecular species (fingerprint)
  • Able to penetrate clothing, and non-metallic packaging up to 100 meters distant (normal air, fog and sandstorm conditions)
  • Non-ionizing radiation, low human safety risk

• Applications
  • Security detection imaging
  • Medical diagnosis, ablation & imaging
  • Subcutaneous heating – non-invasive wrinkle smoothing
  • Secure Short Range Communications – high bandwidth
  • Spectroscopy & substance identification

• Currently Available THz Sources
  • Low power
  • Low efficiency
  • Large
  • Costly

Needed: An inexpensive practical source
**Relevant Properties of THz Radiation**

- Harmless nonionizing radiation
- All warm bodies naturally emit THz radiation
- THz radiation enables imaging through clothing, bandages, and packaging materials
- Complex molecules such as chem/bio agents and pathogens can be unambiguously identified in real time by their resonant signatures in THz band at stand-off distances
- Distinctively different propagation of THz in different types of human tissue enables cancer detection
- Selective heating below surface of the skin will enabling wrinkle smoothing
- High frequency implies broad bandwidth and very high wireless data transmission rates
### Example Application Areas with Significant Commercial Potential

#### Application Areas

- **Security**
  - Standoff detection of concealed contraband
  - Standoff detection and identification of explosives/CBAs
  - Real time detection of harmful substances concealed in mail

- **Medical/Biological Diagnostics**
  - Cancer detection
  - Bacteria & Pathogen Detection
  - Wound Healing/Monitoring

- **Non-Destructive Testing**
  - Chemical Mapping/3D Imaging of Pharmaceuticals
  - Micro-defect detection in micro-electronics

- **Cosmetic Surgery/Tissue Enhancement**
  - Accelerated wound healing
  - Reduction of scarring
  - Wrinkle smoothing

#### THz Technology

- THz Imaging/Spectroscopy
- Spectroscopy
- Spectroscopy/THz Imaging
- THz Imaging
- Spectroscopy/THz Imaging
- THz Imaging
- Heating due to THz exposure
- Heating during wound healing
- Interaction of with sub-dermal collagen
Current State of THz Technology

• TeraView Ltd., based in Cambridge, England

• Since 2000 the company has developed systems and methods for utilizing THz

• In many areas the company has demonstrated best known examples of THz technology with commercial potential
  – Breast cancer detection
  – Skin cancer detection
  – Detection of concealed weapons
  – Chemical detection and identification of explosives
  – Materials characterization
  – 3D chemical mapping of constituents in pharmaceuticals
  – Non-destructive testing and defect detection in microelectronics
Unique Properties of THz Radiation
Homeland Security - Imaging

Sub-millimeter (THz) wave radiation would provide high resolution imaging of concealed weapons/contraband.

Millimeter-wave image of a concealed weapon hidden in newspaper (Jefferson Labs).
Security & Defense

From TPS spectra 1000

From TPI image 1000

• Imaging semtex (in red) below 6 layers of clothing, including 2 sweaters and 4 shirts

Absorption

0 1 2 3 4
Frequency (THz)

Semtex

PETN

RDX

HMX

TNT

TeraView
Security, forensics, & defense

Detecting explosives

- HMX
- PETN
- RDX
- PE4
- TNT
- Semtex

Absorbance vs. Frequency/THz and Wavenumber/cm

TeraView
Thickness Map for Outer Layer of “Coated” Tablet

Good Tablet

Bad Tablet

Holes in Coating

coating thickness (um)

60.0 84.0 108. 132. 156. 180.
Polymorph Identification
Differentiating polymorphs non destructively in final product

Can clearly see differences between the two polymorphs
Non-invasive detection and characterization of cancerous skin tissue. (DoE, NSF, NIH Terahertz Workshop, Feb., 2003)
Medical - intra-operative probes & precancerous screening

Skin cancer

Visible

Surface

Below Surface

Breast cancer

Visible

Terahertz images

Oral cancer

Visible

TeraView
Unique Properties of THz Radiation

Bioscience/Medicine - Spectroscopy

THz spectroscopy enables real-time unambiguous identification of airborne molecules, chem-bio agents, pathogens.
**Biology/medical**

**Amino acids**

- Leucine (LEU)
- Glycine (GLY)
- Glutamine (GLN)
- Tyrosine (TYR)

Absorbance vs. Wavenumber/cm$^{-1}$

Frequency/THz

0.7 1.3 2.0 2.7 3.3

- Tyrosine (TYR)
- Glutamine (GLN)
- Leucine (LEU)
- Glycine (GLY)

TeraView
Terahertz spectra of 4 different di-peptides

Fig. 1. Far-infrared spectra of four dipeptides recorded at room temperature. Prototyped after spectra displayed in Fig. 1 of Kutteruf et al. [28]. The spectra have been vertically offset for clarity. The amino acids are coded as Leu, leucine; Gly, glycine; Pro, proline; and Ala, alanine.

from Johnson et al., Chem Phys Lett.
Terahertz spectra of different polypeptides

![Terahertz spectra diagram]

- Absorbance vs Frequency/THz
- Polypeptides: gly-gly-leu, leu-gly-gly
Terahertz spectra of different bacteria

B thuringiensis ssp. Kurstaki

B subtilis 49760

3THz 0THz

from Johnson et al., Chem Phys Lett.
Note: done on high noise, low sensitivity system
Airborne Agent Detection – alternative approach

Gas phase typically yields spectral fingerprints with rich structure

 Hydrogen cyanide
Airborne Agent Detection – alternative approach

Terahertz spectral signatures of ammonia (common cleaning agent) & HCl (toxic material) – different signatures reduce false alarms

- Ammonia and hydrogen chloride vapour signatures are distinct.
- Threats and common confusion agents (e.g. cleaning fluids) can be resolved.
Fig. 4. Absorbance spectrum of BG aerosol sample as measured by FTIR. The dashed lines denote two signatures also seen by photomixing spectroscopy on the concentrated and diluted BG samples given in [52].
Wound Healing Applications

• Sufficient THz molecular database exists over a broad range to indicate good potential for characterizing wounds spectroscopically

• THz radiation can be tuned for selective heating near surface to aid in wound healing.

• Potential for high-resolution imaging of wounds through bandages is well established
Medical Market Development

- Medical Research Team Organized – Dr. Maria Siemionow, Consultant
- Developing Tissue Research Program with The Cleveland Clinic
  - Initial focuses:
    - Aesthetic applications – collagen
    - Skin cancer detection
    - Breast cancer detection
    - Prostate cancer detection
- Implementation of technology will lead to better diagnostics, advanced treatment of medical conditions including higher levels of surgical accuracy and in-situ identification of harmful tissue
- Aesthetic Applications Entity Organized – Epitera Solutions, Inc.
Barriers To Commercialization

Low output power of existing THz sources, large system size and cost of ownership limit commercial applications

- All commercially available THz systems are limited in their ability to achieve goals in real world applications
  - Very low CW output power, typically 10s of nW
  - Costly systems due to high price of components and limited demand
  - Usually large in size, not easily movable
  - Slow acquisition times for explosive detection, high res images of concealed contraband, drug inspection
  - Standoff detection from safe distances is not realistic
Teraphysics High-Power THz Sources

- World’s first high power practical THz source: tunable, portable, 1000X more power than commercially available devices.

- Fabrication process and specific source design patents issued 2006

- Vacuum electronics devices utilizing modern micro fabrication processes and the incorporation of laboratory grown diamond

固态钻石慢波电路

300 GHz源装配件
Ample Power, Small Size and Low Cost Eliminates Large-Scale Commercialization Barriers

- Lack of sufficiently powerful sources has been a major barrier to large-scale commercialization of THz technology

- 10s of milliwatts of CW power, compact size and low cost is necessary to enable wide-spread commercialization of many THz applications

- Incorporation of high-power tunable sources will result in more compact imaging and spectroscopy systems with significantly improved acquisition time and standoff capability

- DARPA TIFT specified 10 mW CW power at 650 GHz to enable high resolution video-rate camera to detect concealed contraband at 35 m

- Bi-planar 650 GHz source was designed to satisfy TIFT

- Teraphysics bi-planar source satisfies performance and footprint requirements to enable Raytheon-designed real-time chemical sensor capable of standoff molecular identification in 20 s with sensitivity better than 1 part per trillion

- High-power multi-octave amplifier would make existing THz platforms commercially viable on a very large scale
Thermal-Mechanical Advantages of Diamond

- Highest known thermal conductivity
- Relatively low permittivity
- High strength
- Artificial diamond can be grown in place using chemical vapor deposition (CVD)
- CVD diamond forms intimate thermal bond with substrate
- Unique application by Teraphysics
Solid Diamond 300 GHz Structure
Two Views of Selective Metallization

SEM

Optical Microscope
Laser Dicing of Bi-planar Body Halves

Accurate repeatable process

100 mm quarter wafer after dicing

Adaptable to wafer scale production

A Bucket of BWOs
Proposed Wound Repair/Bacteria Research

• THz system would have unique 2-mode operation
  – Spectroscopic chemical analysis THROUGH bandages
  – Image wounds THROUGH bandages

• Spectroscopically Catalog Bacteria/Wound Infections

• Spectroscopic analysis of genetically engineered tissue

• Spectroscopic observation of wound evolution to catalog stages of healing
Research Collaboration – Cleveland Clinic Plastic Surgery

• THz (sub-mm) radiation is absorbed by moisture

• Research Goals - 2010
  – determine optimum operating frequencies and required exposure for elimination or reduction of unwanted cosmetic features in the skin
    • Wrinkle smoothing
    • Spider Veins
    • Rosascia
    • Psoriasis
    • Elimination or reduction in scaring

• Research Goals – 2011
  – Provide prototype system for animal studies
Future Developments

• Teraphysics and TeraView are in discussions to incorporate high-power sources into existing TeraView platforms
  – Source incorporated into TeraView breast cancer detection platform will enable significantly faster imaging over large area
  – Source incorporated into TeraView pharmaceutical identification platform will enable rapid chemical identification of drug constituents to meet assembly line monitoring requirements
  – Source incorporated into shoe-imaging security device will enable rapid-scan cost effective platform

• Teraphysics and TeraView are in discussions to develop new platforms to enable cost effective viable systems with a wide range of high value applications
  – Real-time pathogen and bacteria detection to eliminate hospital acquired infections
  – Real-time standoff detection of toxic chemicals for use by first responders and industrial settings