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Applications of TeraHertz Radiation (T-ray)

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Outline

TeraHertz Radiation (THz) or T-ray

The Interaction between T-ray and Matter

*****Generation of Terahertz Pulses

Applications of THz in Imaging and Science



This is the so-called 'terahertz gap'. It has historically been defined by the relative lack of **convenient and inexpensive** sources.

Application in science and industry, offering **complementary** or even **alternative methods** of **material characterization**.

Photo-Physical Processes



Motions of Molecule





Various Molecular Interactions in the THz frequency Region



Parrott et al., Journal of Molecular Structure 1006 (2011) 66-76

The Interaction Between T-ray and Matter

Internal Molecular Vibrations and Far-IR Absorption Spectra



The Far-IR region of DNA and RNA absorption spectra (2 - 300 cm⁻¹) reflects Low-Frequency molecular internal motions.

The resonant Frequencies of such motions – **phonon modes**- are strongly dependent on the **weak Hydrogen Bonding** of the double-helix base-pairs and **non-bonded Interactions** between different functional groups.



Characteristic Vibrational Bands for Organic Compounds

There are two main vibrational modes:

Stretching - change in bond length (**higher** frequency) **Bending** - change in bond angle (**lower** frequency) ex: CH₂ stretching

ex: CH₂ bending--rocking, scissoring, wagging, and twisting



Origin of Absorption

Infrared active vibrations (those that absorb IR radiation) must result in a *change* of *dipole moment*

ex: OH with permanent dipole IR active O_2 , N_2 , Cl_2 w/o IR inactive frequency(energy) versus peak intensity(amplitude)



Dipole moment must change during vibration excitation (absorption)



Specific mid-IR photon energy is absorbed by a vibration motion of a molecule.

http://www.azosensors.com/Article.aspx?ArticleID=544

Generation of Terahertz Pulses

Free Electron Laser





When light is absorbed by a material such as a <u>semiconductor</u>, the number of free electrons and <u>electron holes</u> increases and raises its electrical conductivity. To cause excitation, the light that strikes the semiconductor must have enough energy to raise electrons across the <u>band gap</u>, or to excite the impurities within the band gap. When a <u>bias voltage</u> and a load resistor are used in series with the semiconductor, a voltage drop across the load resistors can be measured when the change in electrical conductivity of the material varies the current through the circuit.





Laser-based THz Imaging Technologies



(a, b): Time Domain Spectroscopy (TDS), (c) Direct (passive) Imaging, and (d) Heterodyne Imaging.



The Potential of THz Imaging Technology

The Modes of THz Tomography

Schematic illustration of a CW THz imaging system in transmission geometry.



Schematic illustration of a pulsed THz imaging system with reflection geometry.



Applications of THz in Imaging and Science



Molecular Identification in THz Range



DL-malic acid molecule showing representative types of (a) intramolecular and (c) intermolecular vibrational modes. (b) mid-IR spectrum and (d) terahertz spectrum of DL-malic acid are also shown.

THz Reflection Time-Domain Pulses



THz reflection time-domain pulses of a single sheet of paper (blue solid line) approximately 0.1 mm thick, and a single sheet of plastic (red dashed line) approximately 0.5 mm thick. In both cases, two distinct reflections can be determined from the time-domain traces.



THz waves penetrate a wide variety of non-conducting materials such as polymers, paper, textiles, ceramics, composite materials, chemical powders...

B. B. Hu and M. C. Nuss, "Imaging with terahertz waves," Opt. Lett. 20, 1716-1718 (1995)



High-speed THz Reflection 3D imaging for non-destructive Evaluation





(a)



(b)



(a) 2D and (b) 3D images of a floppy disk, acquired using the THz imaging system. Jin et al., Optics Express, 20, <u>23</u>,25432-25440(2012).

https://www.osapublishing.org/oe/fulltext.cfm?uri=oe-20-23-25432&id=244728

THz Spectroscopy Promises Better Diagnosis and Safer Drugs

With THz imaging systems getting smaller and cheaper – and performing better – applications are stacking up in cancer imaging as well as drug detection and development.

THz spectroscopy is a fast-growing area of research with some hugely promising applications, now that <u>cumbersome</u>, <u>expensive and hard-to-use systems</u> are in the past. Its low-photon-energy radiation makes it safe for <u>tissue imaging</u>, and its high absorption in water, which is often a key indicator of <u>the presence of tumor cells</u>, makes it a hopeful weapon in fighting cancer.



(Left) Outside and inside a package of **omeprazole**. (Right) Terahertz image of the packaged **omeprazole** showing that <u>the terahertz beam can penetrate the paper</u> <u>and plastic packages to observe the inner drug content</u>. Courtesy of Applied Competence Cluster Terahertz, Ruhr University Bochum.

https://www.photonics.com/a54396/Terahertz_Spectroscopy_Promises_Better_Diagnosis

Possible Applications of THz Imaging

THz technologies starting to be important for some applications and they can be added to existing X-ray and IR technologies e.g. in:



Security Applications (detection of threats and weapons),
 Non-destructive Testing (electronics industry, corrosion analysis, agro-food control, ...),
 Medicine and Biology Diagnosis (e.g. pharmaceutical quality control, skin cancer, ...),

- Telecommunications (space)

But one of the drawbacks of THz vision technologies now is long acquisition time (up several minutes for systems with single detector). To increase the acquisition speed but be cost-effective uncooled detector arrays are needed.

Airport Scanners Hit The Road

Better than X-rays: A more powerful terahertz imaging system



http://www.thegeekr.com/2013/03/better-than-x-rays-more-powerful.html

THz Imaging and Sensing for Security Applications

Explosives, Weapons and Drugs



Illustration of a potential implementation of a THz imaging array in transmission mode (a) and reflection mode (b)

Federici et al., Semicond. Sci. Technol. 20 (2005) S266–S280

THz Biomedical Imaging

 Image: Mouse Brain

 Optical Image
 Outer Gray Matter

 Optical Image
 THz Grayscale Image

 Inner White Matter

 THz Image

 Image



THz biomedical imaging and sensing,

THz near field microscopy,

THz Metamaterials device,

THz spectroscopy of nanostructures, nanowires,

2D materials, and novel **THz devices** for generation and detection.

http://www.paultownsend.co.uk/research/fundamentals/terahertz-radiation/

New Device Converts DC Electric Field to THz Radiation

Tunable radiation source that reaches coveted THz region of spectrum could be used for tumor identification in medical imaging.



August 13, 2015 — In a step towards more widespread use of THz radiation— the **no-man's land of the electromagnetic spectrum** — researchers have designed a device that can convert a **DC electric field** into a tunable source of terahertz radiation. Their results are published this week in the *Journal of Applied Physics*.

https://www.itnonline.com/content/new-device-converts-dc-electric-field-terahertz-radiation

Tiny THz Laser Could Be Used for Imaging And Chemical Detection



http://news.mit.edu/2017/tiny-terahertz-laser-imaging-chemical-detection-0808



Flexible graphene THz detector



http://www.futurity.org/terahertz-thz-emitters-flexible-1379042-2/



THz image of a hand using arrays of carbon nanotubes. Courtesy of Tokyo Institute of Technology.

THz application in Space





https://earthzine.org/the-far-infrared-spectroscopy-of-the-troposphere-first-instrument-new-technology-for-measuring-earths-energy-balance-and-climate-change-2013-earth-science-technology-showcase/

THz Components and Systems Have Evolved over the Years



NDT = non-destructive testing

	Acquisition Time	Ease of Use	Analysis Zone	Cost
Terahertz	Several Minutes	Skilled Staff	Surface (and Subsurface, Depending on Materials)	Expensive but Decreasing
Shearography	Real Time	Skilled Staff	Surface and Subsurface	Expensive but Decreasing
Ultrasounds	Real Time	Highly Skilled Staff	Thick Samples, Not Well Suited for Surface and Subsurface	Medium
Infrared Thermography	,10 s	Skilled Staff	Surface and Subsurface Imaging (No Scan)	Expensive but Decreasing
Visual Inspection		Skilled Staff	Surface	Cheap

THz competes against other nonionizing techniques for process monitoring in the industrial field.

https://terahertztechnology.blogspot.tw/2014/04/thz-technologies-offer-varied-options.html

Security applications

Pharmaceutical applications

Terahertz food inspection: THz food scanner and THz food safety

Terahertz inspection of agricultural products

Medical diagnostics



