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Terahertz (THz) and its Applications in Remote Sensing

GEOG 632

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What is Terahertz (THz)?

- Far-infrared, aka "sub-millimetre region"
- 1 THz = 10^{12} Hz (Visible light ~ 10^{14} Hz)
- Wavelength: ~0.3mm = 300μm
- Useful range: 0.3 – 3 THz (1mm → 0.1mm)
- Recall: microwave → 1mm – 1m (mostly 1cm - 30cm)
  thermal → 3-14μm

Region	Wavelength
TIR	3-14μm
THz	300μm
Microwave	10e3-30e4μm

Table 1. Comparing EM regions in micrometers

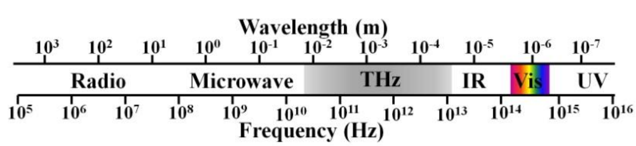

Figure 1. The location of the THz regime within the electromagnetic spectrum with respect to wavelength and frequency.

Properties of THz

- Similar to microwaves, but offer better spatial resolution
- Transparent to most non-conductive dry materials
- Many molecules have rotational energies at THz frequencies
- Non-ionizing radiation:
  - Safer than X-rays
  - Longer wavelength = less energy carried
  - Good for biological systems & non-destructive imaging
- Main limitation: highly attenuated by water vapour (but there are ways to compensate!!!!)

Why hasn't it been used before?

- Research began in 1970's due to lack of technology
- Slow start due to lack of perceived need
- First commercial THz system became available in 2000
- Need to **combine** electronics and photonics

- Now THz is easy to produce
- Shift focus to applications!!!!

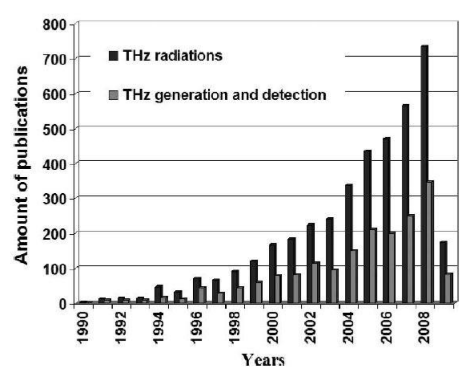

Figure 2. Publications per year in THz science and technology [3].

Applications in Remote Sensing

- Can have active and passive sensors
- Applications include but are not limited to:
  - Security
  - Imaging
  - Manufacturing
  - Communications
  - Remote Sensing
- Focus on:
  - THz in wood/wood composite industry
  - THz in aerospace industry
  - THz in environmental monitoring
  - THz in space remote sensing

Figure 3. THz applications in security imaging (http://thznetwork.net/)

THz in the wood/wood composite industry

- Why:
  - Polarization sensitive to fibrous structures
  - Commercial systems are approaching industrially relevant speeds
  - Can fibre-couple emitters/detectors to keep sensitive electronics & optics out of harsh environments
- Advantages:
  - THz radiation can penetrate wood and probe material density, moisture content, and fiber orientation

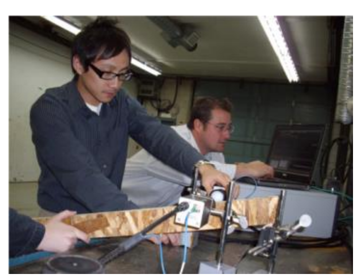

Figure 4. Dr. Matt Reid, Dian Wang, and Jonathan Schneider looking at THz applications in OSB production

THz in the wood/wood composite industry

- Oriented Strand Board (OSB)
  - Used in roofing, siding, and flooring applications
  - Chips of wood pressed together with resin
- Orientation of these chips is important in strength of OSB board
- Largest cost in wood/wood composite industry is fiber
- Want to maintain maximum strength while minimizing amount of wood used

Figure 5. Oriented strand board (www.mrbcontracting.com)

THz in the wood/wood composite industry

- Test a real-time THz scanner at Ainsworth OSB facility in 100 Mile House, BC from June 2009 – Feb. 2010
- Mapped density profiles to see where they are exceeding or not meeting minimum requirements.
- Used the Picometrix T-Ray 4000
  - Produces 1000 waveforms per second
  - 80ps window with scanning heads moving at 500mm/s
  - Resolution of 1mm

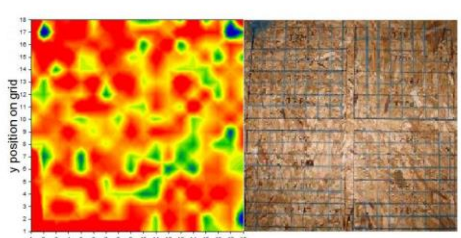

Figure 6. Density map of OSB compared to OSB at visible wavelengths (right). Darker areas correspond to more attenuation (higher density) [4]

THz in the aerospace industry

- Need for quality control of fiber composites for aerospace design after NASA Columbia disaster & crashes
- Use glass fiber reinforced plastics & carbon fiber reinforced plastics
- Can be weakened due structural defects, stress, and heat damage
- THz can provide non-invasive & non-contact quality control method

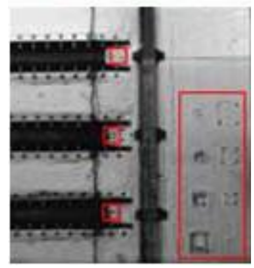

Figure 7. NASA uses THz technology to observe defects (bottom) in the foam insulation of space shuttles (top) (http://www.picometrix.com/pico_products/terahertz_app_foam.asp)

THz in emissions monitoring & detection

- THz interactions are $10^3 – 10^6$ times stronger than in the microwave region
- Each gas has a unique spectral signature that can be detected
- Similar to hyperspectral remote sensing
- **Databases**:
  - Jet Propulsion Laboratory → Sub-millimetre, millimetre, and Microwave Spectral Line Catalog (http://spec.jpl.nasa.gov/)
  - US Air Forces → HITRAN Molecular Spectroscopic Database (http://www.hitran.com)

Figure 8. Typical air pollution (http://en.wikipedia.org/wiki/Air_pollution)

THz in emissions monitoring & detection

- **My project**: preliminary studies in THz technology as a real-time emissions monitoring & particulate detection
- Identified H_2O, CO, NO, NO_2, SO_2, CH_3Cl and compared to literature
- **Next steps:**
  - See temperature & pressure effects
  - Test real-time measurements on UNBC Nexterra Gasification system
  - Optimize combustion process

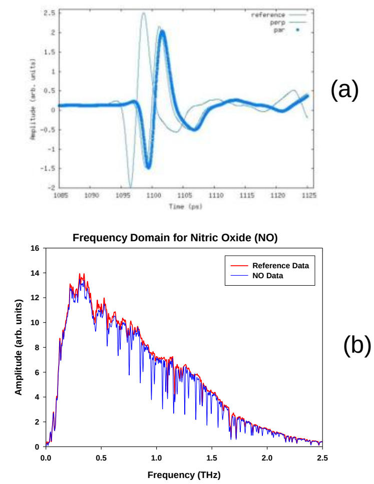

Figure 9. (a) Typical THz pulse (aspen) showing the absorbance of THz as compared to the reference scan. (b) Frequency domain showing spectral signature of NO gas

THz in space remote sensing

- Ideal location is space due to attenuation of water vapour
- 2 main purposes:
  - Look at elements in the interstellar medium (ISM) and planetary atmospheres
  - Look at gases and pollutants in Earth's upper atmosphere
- Typical frequencies range 0.1 – 2.5 THz

Figure 10. Aura satellite containing the EMLS sensor (www.jpl.nasa.gov/)

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THz in space remote sensing

- Heterodyne Instrument for Far-infrared (HIFI)
  - Developed by the Space Research Organization in the Netherlands
  - Detects light hydrides within the ISM
  - OH+, H_2O+, H_2Cl+, SH+, HF
- This type of spectral analysis requires knowledge about the frequencies and energies related to the elements' rotational (or vibrational) energies
- Can be determined quantum mechanically (Physics!!!! Eww!)

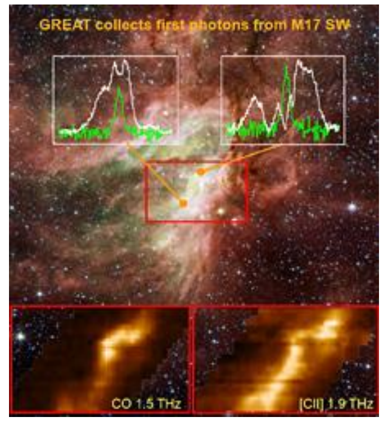

Figure 11. Spectra of CO and CH from the M17 SW nebula by the GREAT sensor on SOFIA (www.nasa.gov/)

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THz in space remote sensing

- Use THz to study planetary atmospheres
- Telescopes include:
  - SWAS (~0.5 THz)
  - Herschel HIFI (0.48-1.9 THz)
  - Odin (0.45 – 0.58 THz)
- Microwave Instrument for the Rosetta Orbiter (MIRO)
  - Measures water, ammonia, & CO from Comet 67P/Churyumov-Gerasimenko
  - Range 0.55 – 0.58 THz
  - Will rendezvous in 2014

Figure 12. MIRO (www.jpl.nasa.gov/)

THz in space remote sensing

- Using THz to probe Earth's atmosphere:
- Earth-Observing-System, Microwave Limb Sounder (EMLS) launched July 2004
  - 4 bands in GHz range (100, 650 GHz = 0.1 – 0.65 THz)
  - 1 band in THz range (~2.5 THz)
  - Measures emission in the mesosphere, stratosphere & upper atmosphere
- Data collected include:
  - Daily global maps of geopotential height
  - Ozone profile
  - Global temperature
  - Cloud ice densities
  - Detection of pollutants

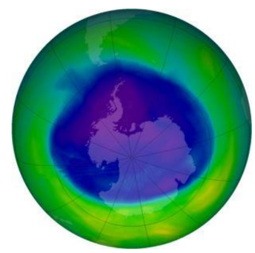

Figure 13. Data collected from EMLS to show the ozone hole over Antartica (www.sciencedaily.com)

References

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[2] D. Saeedkia, *Handbook of terahertz techology for imaging, sensing, and communications*, Woodhead Publishing Limited, 2013

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[4] J. Schneider. *Probing the Potential Applications Of Terahertz Radiation in Wood Products.* 2013

[5] B. Drouin *et al*. "Terahertz spectroscopy for space applications: 2.5-2.7 THz spectra of HD, H_2O, and NH_3", *Journal of Molecular Structure*, **1006** 2011, pp. 2-12.