

Terahertz Sensing for NDE Applications

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https://www.npl.co.uk/research/electromagnetics/terahertz-radiation



- ➤ What is Terahertz (THz)?
- > Why use THz for non-destructive evaluation?
- How does it work?
- Examples of applications for NDE





Why use THz for NDE?



- Non-contact, non-ionising, non-destructive
- Terahertz waves can <u>penetrate through materials</u> that are opaque in the visible and near-infrared
- Sensitive to <u>structural inhomogeneities</u>
- Multiple layers can be measured
- Complex internal structures can be imaged
- Hidden defects can be observed
- Can detect <u>corrosion under insulation</u>
- Porosity can be accurately measured
- Moisture levels can be accurately measured, and moisture distribution can be imaged

Why use THz to examine materials? NPL

- Sensitive to variations in <u>complex permittivity</u>
- Sensitive to variations in <u>composition</u>
- Sensitive to variations in <u>density</u>
- Sensitive to variations in molecular structure and configuration
- ✤ Sensitive to <u>crystallinity</u>
- Sensitive to polymerisation / curing
- Sensitive to <u>additive content</u>
- Sensitive to <u>contamination or impurities</u>
- Sensitive to <u>degradation / wear</u>



- Plastics, composites
- Foams
- Paints, adhesives
- **Glass, ceramics**
- Hydrocarbons
- Conductive films
- Semiconductors
- *Metamaterials
- Paper, card, wood, textile
- Pharmaceuticals
- Food and agriculture

Why use THz to examine coatings? **NPL**

Coating thickness

Coating uniformity

Car paint inspection



Checking pipe integrity



Multiple coating layers
 Layer adhesion / delamination
 Corrosion or damage under coatings
 Conductivity of thin films



Why use THz to examine plastics, composites and foams?

Composition
Density
Additive content
Porosity
Crystallinity
Polymerization / curing
Defects





- Cracks and faults
- *Debonding
- Moisture content / penetration
- Degradation / wear

Why use THz to examine hydrocarbons – fuels and lubricants?



Composition

- Moisture content (down to 0.01%)
- Contaminants
- ***Oxidation products**
- Calorific value
- Ethanol content in fuels
- Viscosity of lubricants
- *Sediments



How does THz work? Time-domain spectroscopy (TDS)



TDS is the <u>predominant</u> platform for THz measurements: * photonic * pulsed * broadband * coherent

Measures

- Amplitude
- Phase
- Time-of-flight



TDS performance

- Broadband operation
- One-shot spectral acquisition
- Bandwidth: 0.1 6 THz
- Frequency resolution 1-10 GHz
- Polarised beam and polarisationsensitive detection



Amplitude and phase spectra obtained via Fourier Transform.



Example: lactose monohydrate





Examples of using THz for NDE – polymers and adhesives

Differentiate grades of PVC





Measure crystallinity





Crystallinity of HDPE

Sommer et al, J Infrared Milli Terahz Waves (2016) 37:189–197



Crystallinity of polybuthylene terephthalate (PBT)

Fischer et al, IEEE Trans THz Sci Tech, 3/3, 2013

Adhesive setting





Sommer et al, Polymer Science, Series B, 58 (2016) 769–776



Radome inspection





- a) A typical radome.
- b) Mobile terahertz radome scanner
- c) Delamination
- d) Water intrusion

Irl Duling and David Zimdars, Nature Photonics, Vol 3, 2009



Examples of using THz for NDE – multilayer coatings

How does it work?





Trans THz Sci Tech 4 (2014): 432-439

Car paint layers





Picot, M., H. Ballacey, J. P. Guillet, Q. Cassar, and P. Mounaix. *Proc 15th Asia Pacific Conf NDT (APCNDT2017),* 13-17. 2017.

Corrosion under insulation



THz Waveform



Fuse et al., Electronics and Communications in Japan, Vol. 99, No. 8, 2016



Taday & Portieri, The International Photonics and Optoelectronics Meeting (POEM) 2019



THz Waveform

20.0

Optical Delay /ps

Middle of corrosion

30.0

0.06

0.04

0.07

0.0

-0.06

-0.08

10.0

-0.02





Area B





Coating thickness of pharmaceutical tablets





Layered structure



PVC pipe with foam core



J. Jonuscheit, Opt & Photon 11 (2016): 30-33.

Conductive thin films



Measuring sheet resistance of conductive thin films



Comparison of 3 techniques



Wafer No.





Naftaly et al., Electronics 10 (2021): 960

240

300

380



Examples of using THz for NDE – electronics

Authenticating microchips



Reflection imaging



Authentic INTEL chip



Fake chip



Ahi et al., Opt. Lasers Eng. 2018, 104, 274–284

Imaging microcircuits



Probe-based techniques required to achieve sub-wavelength spatial resolution



THz probe



Spinelli et al., Energy Procedia 2016, 92, 218-224



Examples of using THz for hydrocarbons – oils & fuels



Alkanes





Refractive index increases with chain length

Alkanes have high THz transparency

Nickel et al., Chem Phys Lett, 592 (2014) 292–296











Al-Douseri et al., Int J IR & MM Waves, 27 (2006) 481-503

Ethanol in gasoline





5% ethanol is clearly detected

Arik et al., J Phys Chem A, 118 (2014) 3081–3089

Contaminants in fuel





Sulphur in gasoline

Methyl methacrylate in diesel

Zhan et al., J. Phys. D: Appl. Phys. 49 (2016) 395101

Water in diesel





0.1% water is detectable

Abdul-Munaim, Trans ASABE 59 (2016): 795-801

Engine oil oxidation





Abdul-Munaim et al., Lubricants 2019, 7, 18

Gasoline in engine oil





4% gasoline is detectable

Abdul-Munaim et al., Tribology International 119 (2018) 123–130



Water in oil



Gorenflo et al., Chem Phys Lett 421 (2006) 494–498

Water in crude oil





BINDT THz User group



https://www.bindt.org/branches-and-committees/User-Groups/terahertz-user-group/







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https://www.npl.co.uk/research/electromagnetics/terahertz-radiation