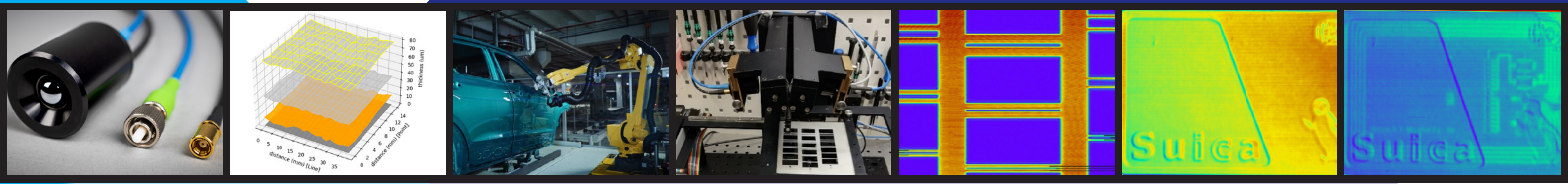


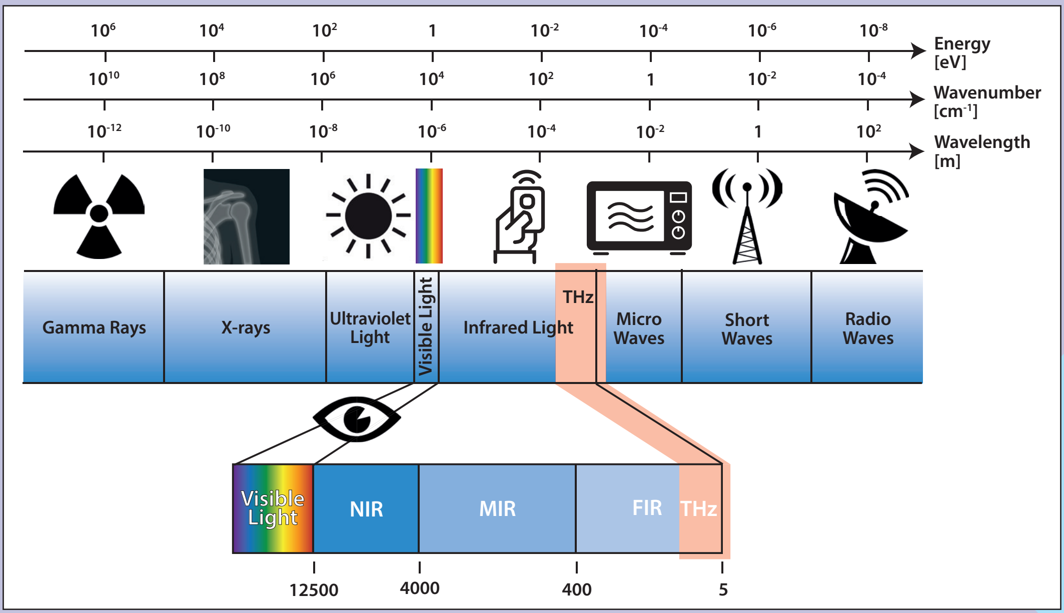
Terahertz technologies for non-destructive testing and condition monitoring

What is terahertz and why use it?

Terahertz (THz) technologies employ electromagnetic radiation in the band lying between infrared and microwave, at frequencies between 100 GHz and 10 THz or wavelengths between 30 µm and 3 mm (a similar wavelength to ultrasound). Radiation within this band is known as terahertz radiation and is non-destructive and non-hazardous.

When propagating through materials, terahertz is sensitive to variations in complex permittivity (via dispersion and absorption) and to structural inhomogeneities (via scattering and interface reflections).

Terahertz propagation through materials is modified by compositional variations (for example degradation, contamination and moisture intrusion) and by structural discontinuities (for example layer boundaries, voids, disbonds, delaminations and foreign inclusions).



Terahertz radiation is therefore a powerful tool for material characterisation. It can detect features on the meso-scale and reveal material properties, such as characteristic vibrational modes (phonons), permittivity, conductivity and porosity. Measurements are non-contact, avoiding damage and contamination, and allowing stand-off detection.

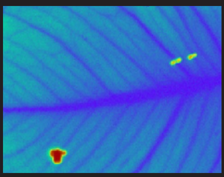
As with all types of electromagnetic radiation, terahertz penetrates through insulators and reflects from conductors.

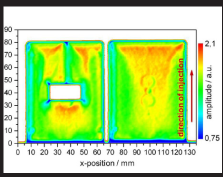
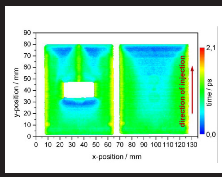
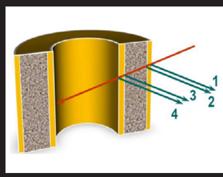
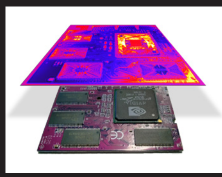
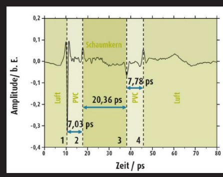
Terahertz can penetrate through many materials that are opaque in the visible and near-infrared, revealing internal structures and material properties.

The terahertz frequency band is currently unlicensed and available to users.

Capabilities of THz

- Non-destructive
- Non-contact, non-ionising
- Measurement rate <0.1 s (per single point)
- Can measure in transmission or reflection
- Can examine many non-metallic, non-conductive materials (measure complex permittivity)
- Can penetrate through materials that are opaque in the visible and near-infrared
- Can characterise complex internal structures of materials in the meso-scale (0.01 to 1 mm)
- Can measure thickness and properties of multiple layers
- Can examine thin films
- Can image complex internal structures
- Can measure low levels of moisture in materials
- Can reveal degradation, contamination and variation in properties



Types of materials that can be examined by THz

- Plastics, composites
- Semiconductors
- Foams
- Paper, card, wood, textile
- Paints, adhesives
- Glass, ceramics
- Petrochemicals
- Pharmaceuticals
- Food and agriculture
- Conductive films
- Nanostructure ensembles

NDT/CM applications of THz technologies

Coatings

- Coating thickness
- Coating uniformity
- Multiple coating layers
- Layer adhesion/delamination
- Corrosion or damage under coatings
- Conductivity of thin films
- Conductivity of nanostructure ensembles
- Carrier mobility in thin films
- Carrier mobility of nanostructure ensembles

Plastics, composites, adhesives, foams

- Additive content
- Density
- Porosity
- Crystallinity
- Polymerisation/curing
- Defects
- Composition
- Cracks and faults
- Debonding
- Moisture
- Degradation/wear

Electronics

- Imaging internal structures
- Detecting faults
- Measuring conductivity
- Measuring response time down to picoseconds
- Semiconductor properties
- Carrier mobility

Oils, fuels and lubricants

- Composition
- Moisture content (down to 0.01%)
- Contaminants
- Oxidation products
- Octane number of petrol and diesel
- Ethanol content in fuels
- Viscosity of lubricants

Pharma

- Tablet coatings
- Tablet porosity
- Particle size
- Crystallinity
- Isomers

Constraints on THz measurements

- Penetration depth is limited by material absorption: in most materials 1 to 10 cm
- Spatial resolution is limited by the minimum beam spot size (diffraction limit): 0.1 to 5 mm, depending on the frequency used
- Probe-based techniques are required to achieve sub-wavelength resolution (below 0.1 mm, down to 10 nm)
- There is a trade-off between penetration depth and spatial resolution: at higher frequencies penetration decreases and resolution improves (as for ultrasound)
- THz propagates through insulating materials and is reflected from conductors
- Limited penetration depth in conductive materials
- THz is strongly absorbed by water

Prepared by the Terahertz User Group
of the British Institute of Non-Destructive Testing
Midsummer House, Riverside Way, Bedford Road, Northampton NN1 5NX, UK
Tel: +44 (0)1604 438300 | Email: info@bindt.org | Web: www.bindt.org

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