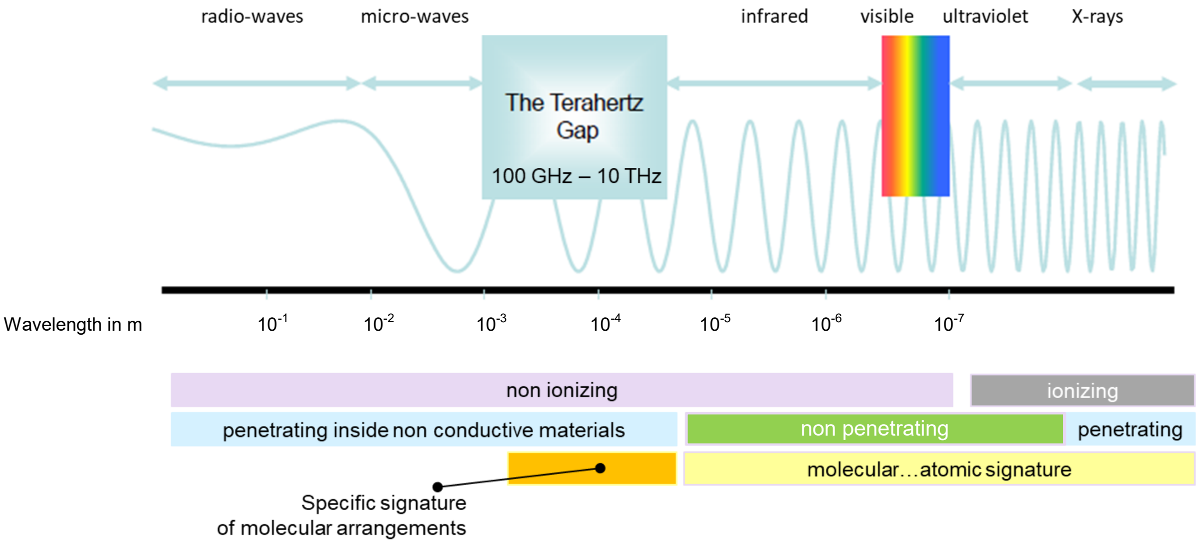
NON-DESTRUCTIVE ANALYSIS & CONTROL
INTO THE MATTER

PRINCIPLES, SYSTEMS & APPLICATIONS

TERAKALIS

▶ A new domain of electromagnetic waves with huge potential of applications



▶ Relevant capabilities for analyzing the matter in different phases

SOLIDS

- Until 1 THZ, relative transparency of dielectric material (ex. plastics 80-90% of transmission).
- Between 1 and 10 Thz, specific vibrations linked to inter-molecular bondings.

GASES

- < 9 THz, rotations of the molecule or one part of it or according to the size, vibrations of the whole molecule.
- Good transmission through the air even moist.

LIQUIDS

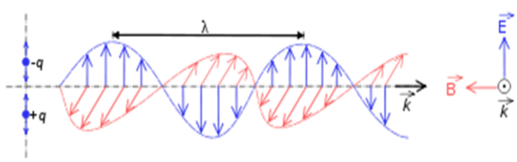
- Relative transparency for non polar liquids.
- Absorption is proportionnal to the intensity of the dipole moment.
- High sensitivity to the water content.

ELECTRONS PLASMAS

- Collective excitation of free electrons.
- The difference between the energy levels can be located in the THz domain.

▶ TeraHertz measurement systems for in-heart non destructive testing of the matter

These active systems consist of an emitting source and a sensor ; they allow to measure the amplitude, the phase and the polarization state of the TeraHertz waves. This measurement can be punctual, linear or matrix one depending if the spatial distribution analysis is required.

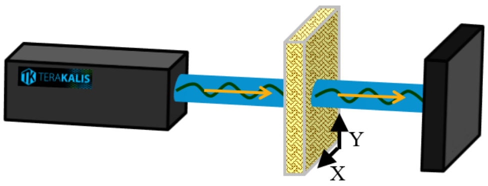


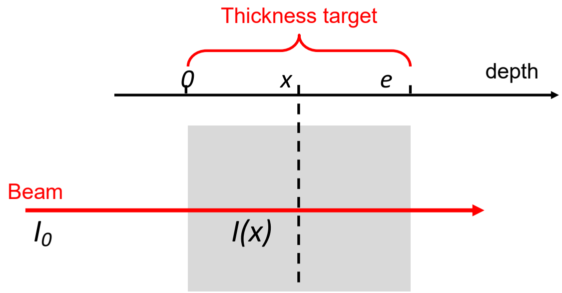
The opto-mechanical system configuration must be adapted according to the type of control problem to solve and also to the level of performances expected in terms of spatial resolution, time of acquisition and detection or characterization sensitivity. Parameters such as emitting frequency, polarization state, focal distance, analysis beam size, incident angle must be selected for system effectiveness optimization.

There are two main analysis mode : transmission and reflection, depending on the material context and the application targeted.

▶ 1st principle : attenuation of the amplitude of the wave

⇒ Example of transmission mode :





The attenuation of the TeraHertz wave amplitude, through a material, is influenced by several interaction phenomena : reflection at each interface, scattering and internal absorption. The local heterogeneities of the material create amplitude variations of the transmitted wave according to their types and dimensions.

Detects/characterizes the heterogeneities of the material

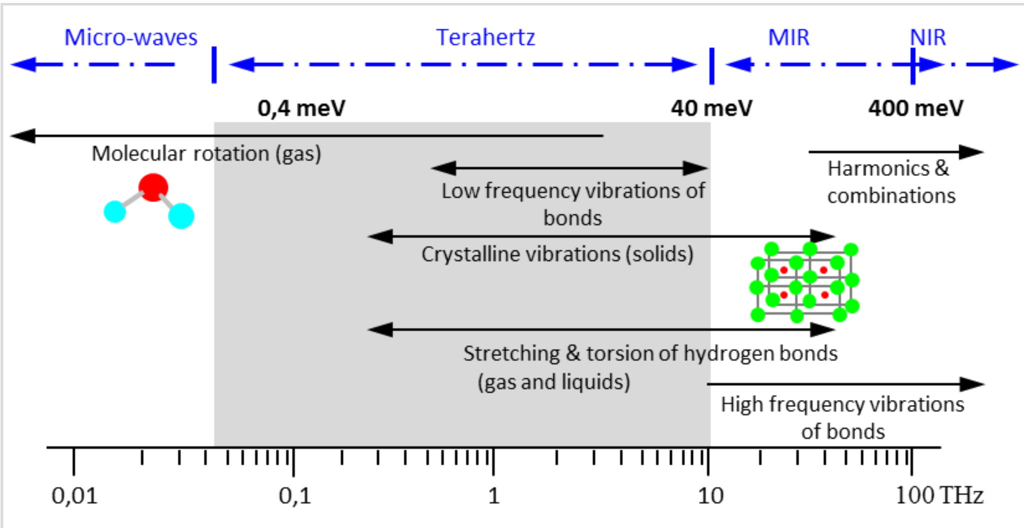
porosities, delaminations, fibers breakages, inclusions, contaminations ...

Simplified attenuation law :

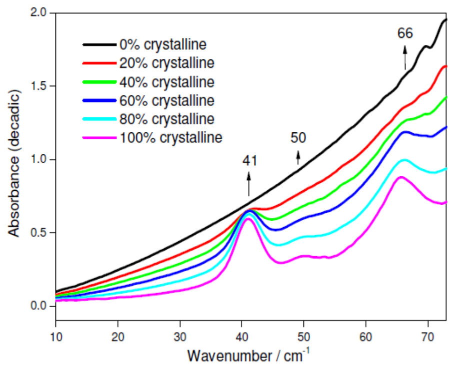
$$I(x) = Io \, * \, e^{-\sigma x}$$

x = depth inside the sample
I_o = Intensity of the incident beam
$I_{(x)}$ = Intensity of the beam at the depth x
σ = absorption coefficient

▶ 2nd principle : resonance of the matter at specific frequencies



According to the frequency, the TeraHertz wave interacts with the matter based on different excitation modes described in the graph above ; the level of the values of the absorbed or reflected wave is indicative of the structural properties of the matter such as crystallinity displayed in the graph on the right side.



Characterizes the structure of the matter

crystallinity, polymorphism, type of inter-molecular bondings...

▶ 3rd principle : optical activity of the matter

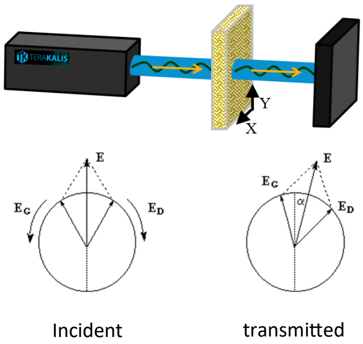
The optical activity of a material is the property owned by a asymmetrical molecular structure to interact with an electromagnetic radiation.

It turns out particularly with the existence of the optical rotation (OR), the phenomenon of the optical rotatory dispersion (ORD). and the circular dichroism (CD).

The measurement of the polarization state variation between the incident wave and the transmitted one allows to characterize some structural properties of the matter such as anisotropy or enantiomeric purity. The polarization states to be considered can be of linear, circular or elliptic type.

Characterizes the structure of the matter

distribution and orientation of the fillers ou fibers, spatial arrangements of the molecules, chirality, birefringence,



Optical rotation:

$$\alpha = \pi\, l * \frac{(nG - nD)}{\lambda}$$

α = angle of rotation of the polarization plan
l = thickness of the crossed material
λ = wavelength of the light
nG, nD = optical material indexes

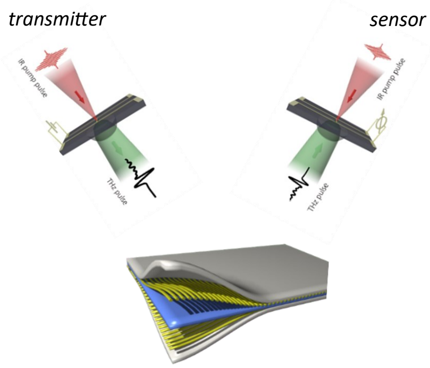
▶ 4th principle : reflectivity on interfaces of two materials

The TeraHertz waves penetrate the non conductive materials and reflect on all types of material.

The time of flight measurement is used on the basis on the emission of a TeraHertz pulse.

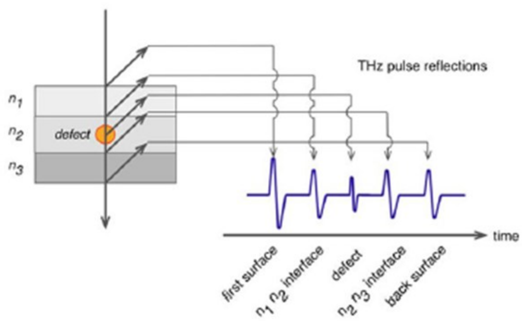
In the case of a mono or multi layer material, each interface between two materials owning different optical indexes or between the air and the material will generate a wave reflection.

After a calibration phase characterizing the optical indexes of each layer (indexes ni), the measurement of the temporal delays Δt between two pulses will provide the value of the distance between two interfaces according to the formula :



$$\Delta e = (c^* \Delta t) / ni$$

c = light celerity

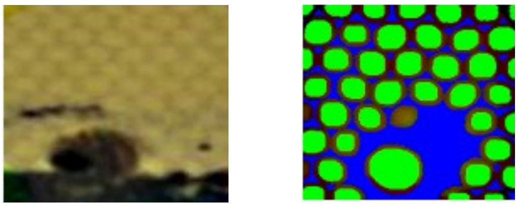


Distance measurement

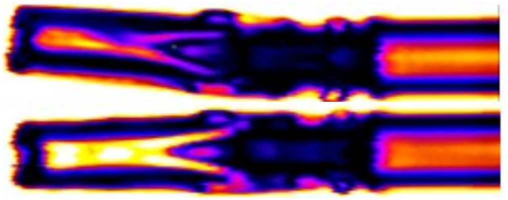
Z position of a defect inside materials
Thickness measurement

► Examples of TeraHertz imaging application linked to industrial materials cases

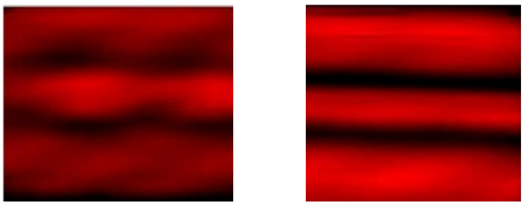
Internal Damage



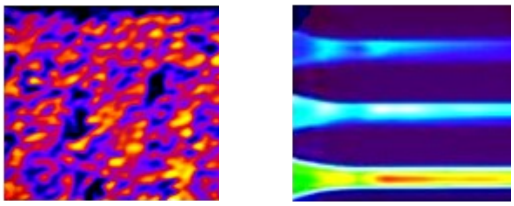
Defect Under Packaging



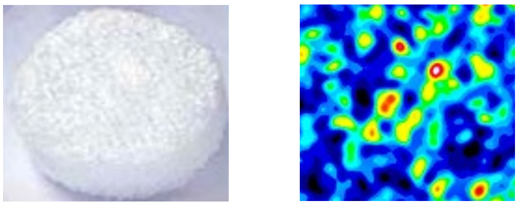
Welding Defect



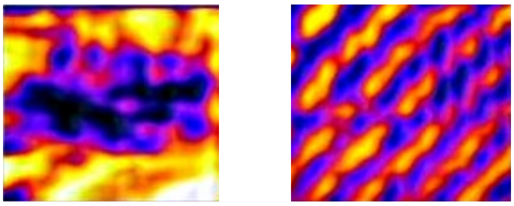
Heterogeneity



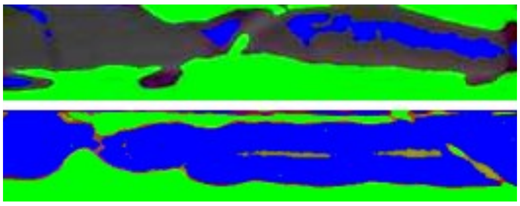
Porosities



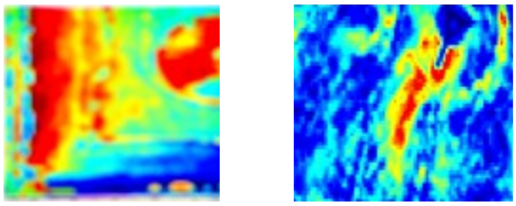
Delamination



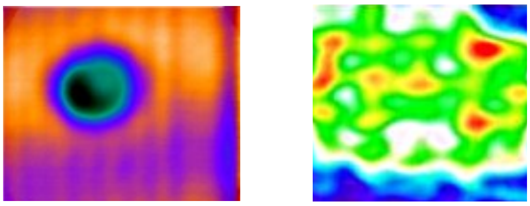
Adhesive Bonding Defect



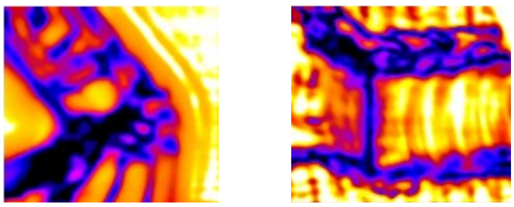
Fibers Orientation



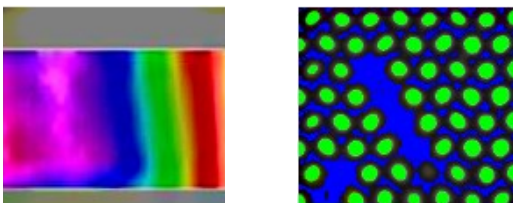
Pollution



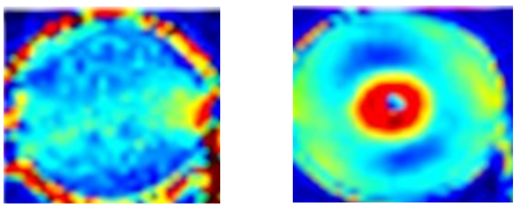
Fiber Breaks



Water Content



Stress



▶ OUR COMPETENCIES

- Opto-electronics
- Mechanical
- Physics, chemistry of materials
- Software development
- Signal & image processing
- Systems engineering

▶ OUR SOLUTIONS

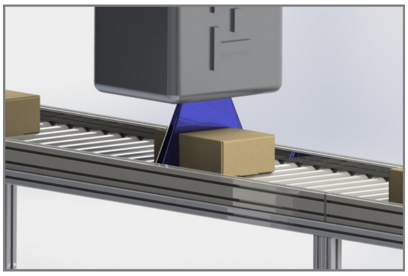
- Measurement of water content
- Measurement of filler content
- Heterogeneity imaging
- Anisotropy imaging
- Thickness measurement
- Spectrometry

▶ OUR EQUIPMENT OF ANALYSIS AND CONTROL

IN-DEPTH

TK-LAB RANGE

FAST



TK-LINE RANGE

PORTABLE

TK-FIELD RANGE

▶ OUR SERVICES

- Feasibility studies - Tests on samples
- Technical specification elaboration
- Prototyping
- Design & development
- Assistance to commissioning
- Training

▶ OUR TECHNICAL MEANS

- Multidisciplinary team
- Materials characterization platform
- TeraHertz waves simulation software
- TeraHertz multimodal analysis benches
- Oven with controled temperature and humidity

▶ CONTACT

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