



THz Imaging

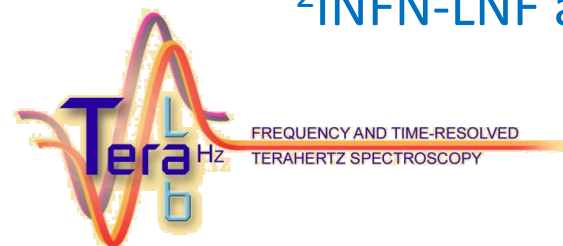
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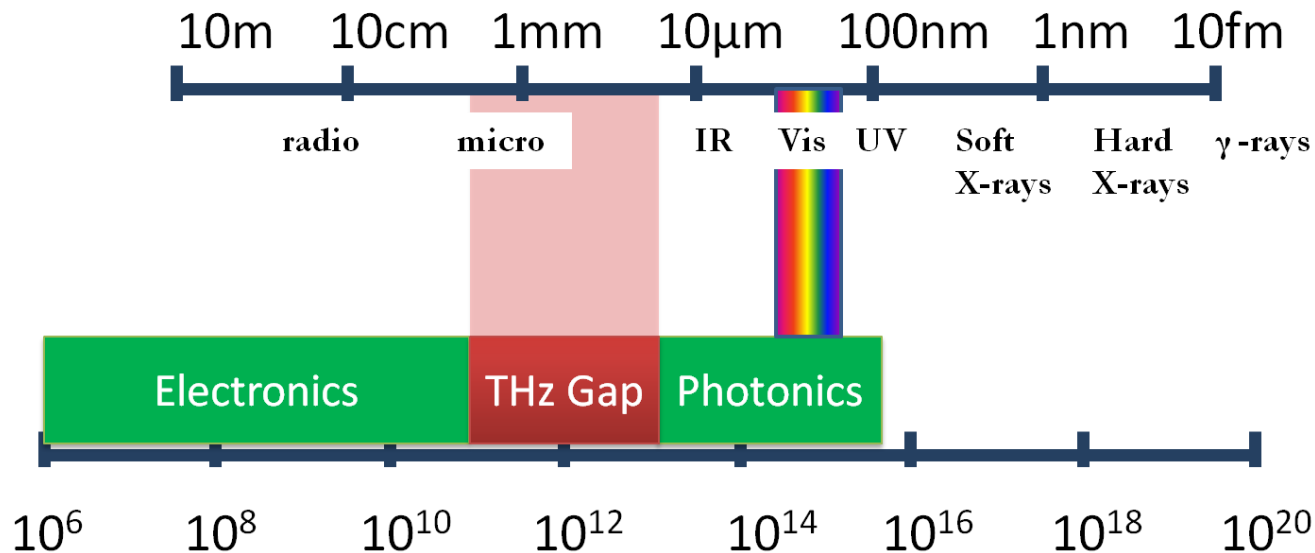
²INFN-LNF and Department of Physics, Aquila University

³INFN-LNF

F. Giorgianni



Terahertz Light



Frequency: **0.1 – 10 THz** ?

Wavelength: **3 mm – 30 μ m** ?

Energy: **0.41 – 41 meV**

Wavenumber: **3.3 – 333 cm^{-1}** ?

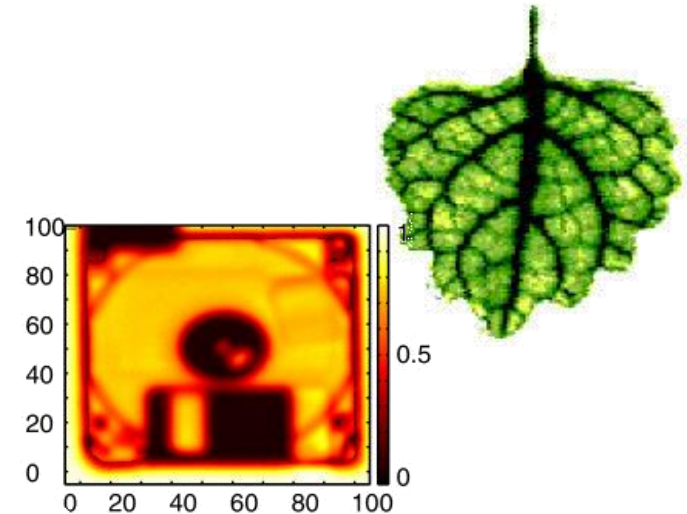
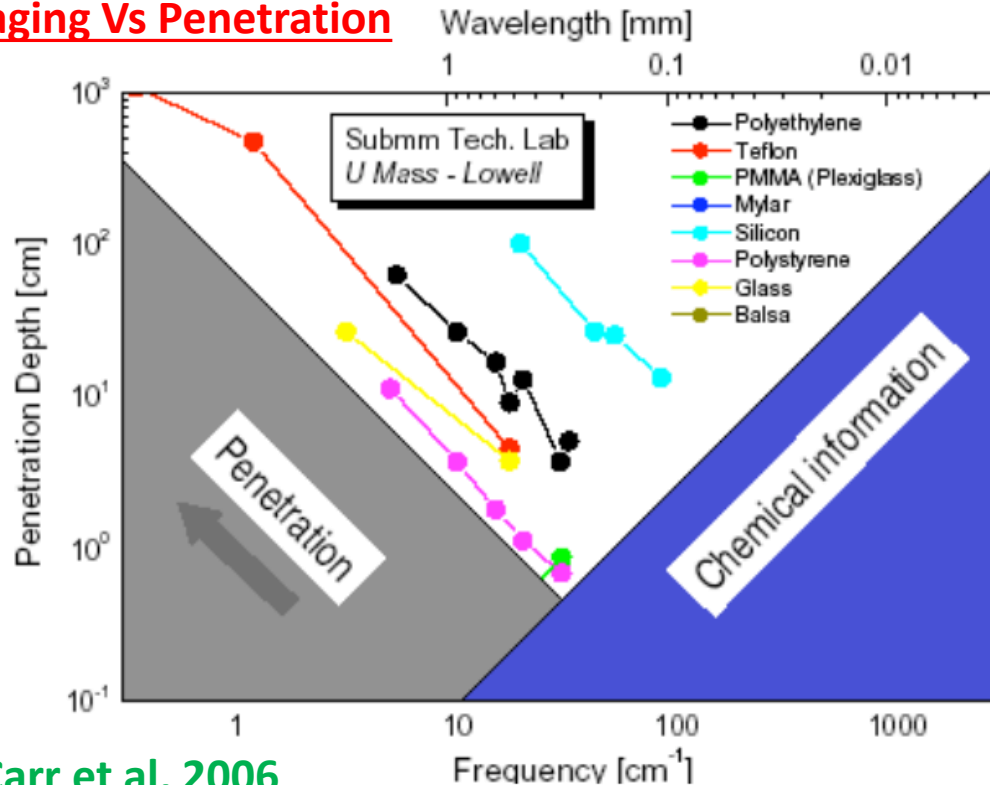
Temperature: **1 – 100 K**

Technology Review (MIT) 2004:

THz selected as one of “10 emerging technologies that will change your world”

THz Imaging and Spectroscopy

Imaging Vs Penetration



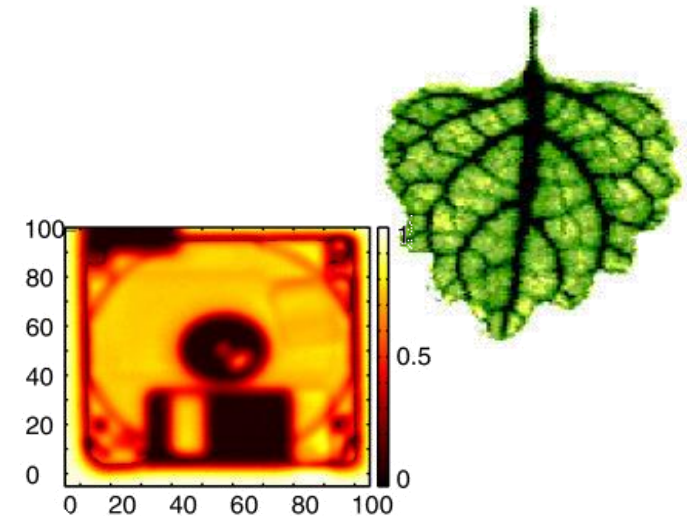
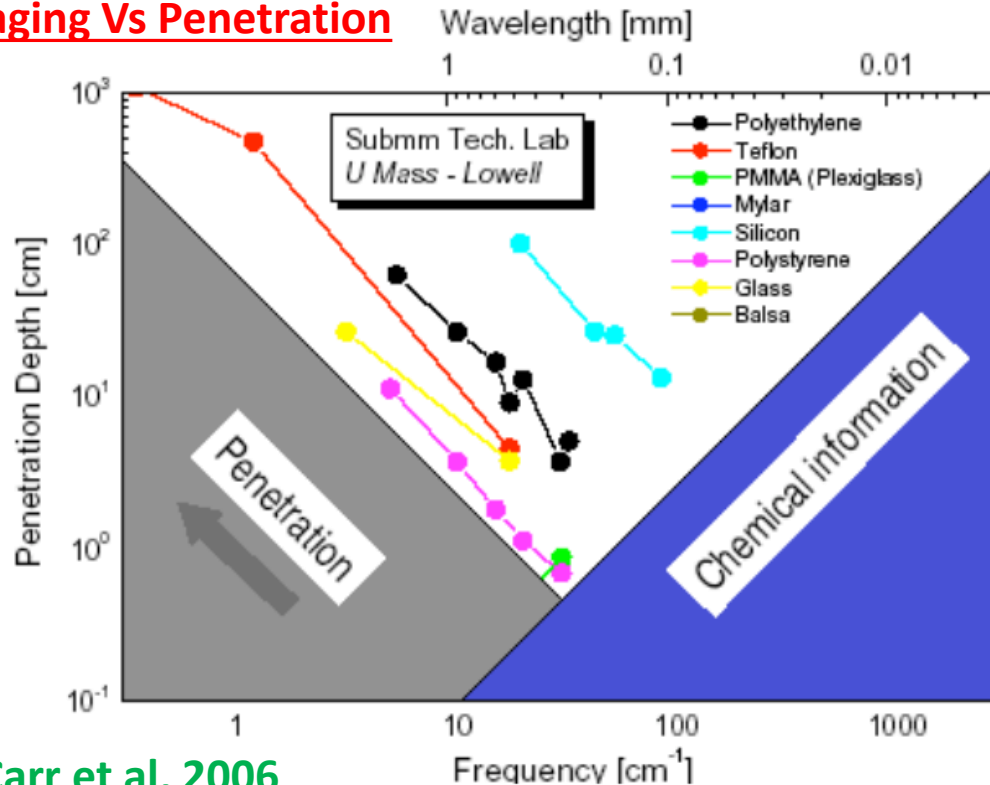
Why TeraHertz?

1. Low energy (meV), non-ionising radiation (unlike for example X-rays Imaging > 10 keV)
2. Many materials are transparent to THz (good penetration)
3. Many molecular rotational and vibrational absorption modes (Spectral Fingerprinting)
4. Water is strong absorber and Metals are opaque –possible contrast agents

THz imaging provides **different / new information** respect to IR, VIS, UV, X-Ray Imaging

THz Imaging and Spectroscopy

Imaging Vs Penetration



Why not TeraHertz?

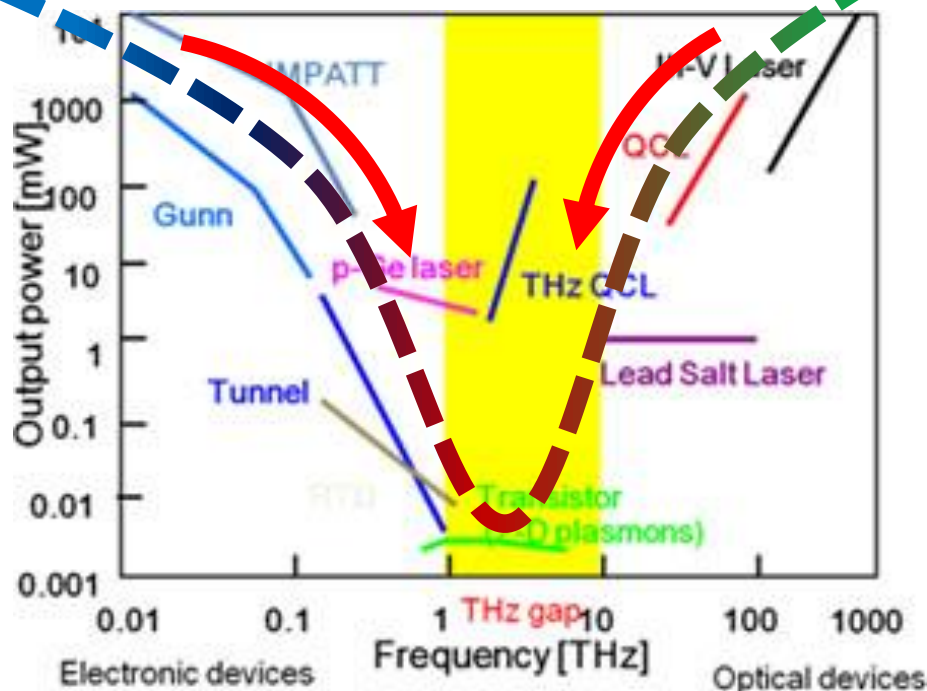
1. Difficulties in developing of high intensity THz sources and efficient detectors
2. Lack of efficient materials and devices to manipulate THz Radiation
3. Water absorption could be a problem

THz imaging provides different / new information respect to IR, VIS, UV, X-Ray Imaging

THz light sources

Electronics

Photonics



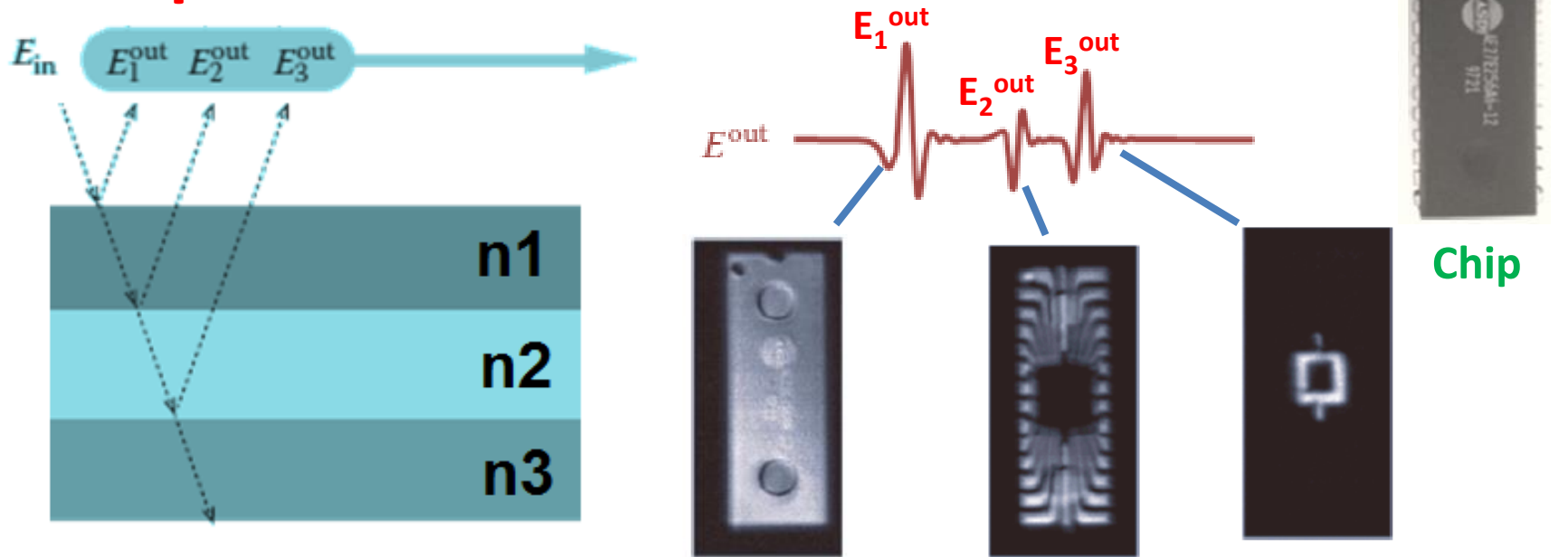
- Solid State Oscillators
- Gas and Quantum Cascade Lasers
- Free electron based sources:
 - Free Electron Laser (FEL)
 - Back Wave Oscillator (BWO)
 - Coherent Transition Radiation (CTR)
 - Coherent Synchrotron Radiation (CSR)
- Laser Based THz sources:
 - Optic Processes:
 - Optical rectification, Cherenkov Radiation (Organic/Inorganic Crystals)
 - Optoelectronic Processes:
 - Photoconductive, photo-Dember, Photoconductive Mixing

Pulsed THz Light for Imaging

Unique Properties Using Ultrafast (subpicosecond) THz Pulses

- Both frequency and time (**depth**) information
- Able to form 2+1D images with time information (**time of flight**)
- **Ultrafast** (< ps) and broadband images: possibility of implementation subpicosecond snapshot imaging (time-resolved imaging)
- **Coherent** detection to improve signal to noise ratio

Example



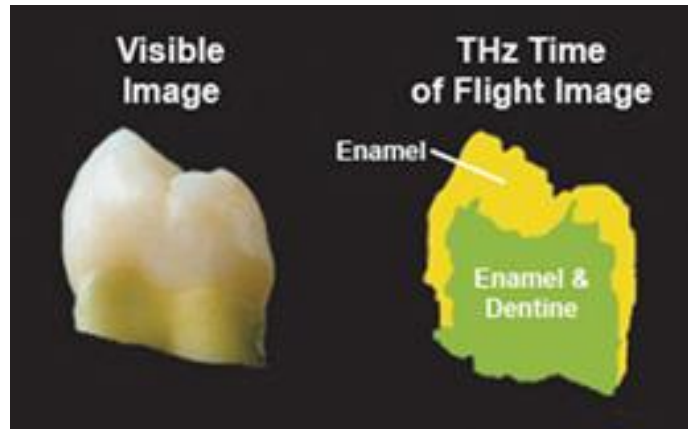
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THz image for different times of flight

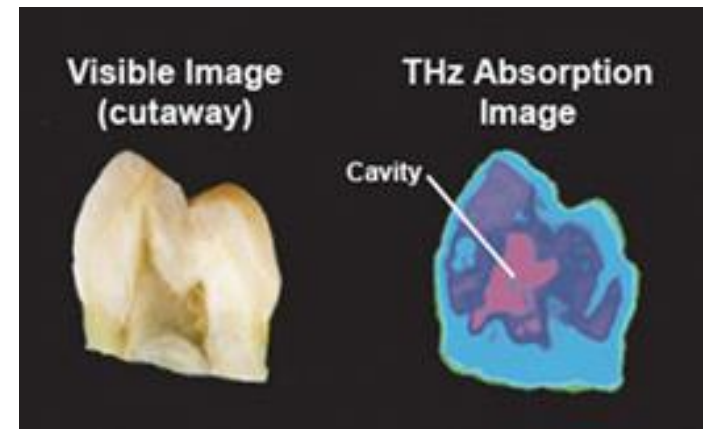
THz imaging: biomedical application

3D and Composition Information in a Single Scan

Time Of Flight Image

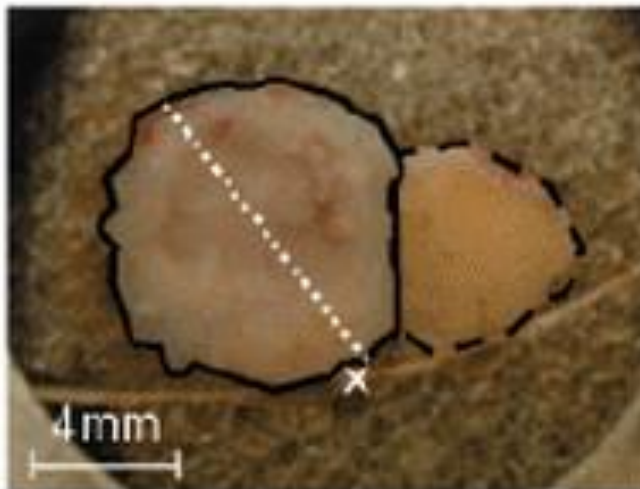


Absorption Image

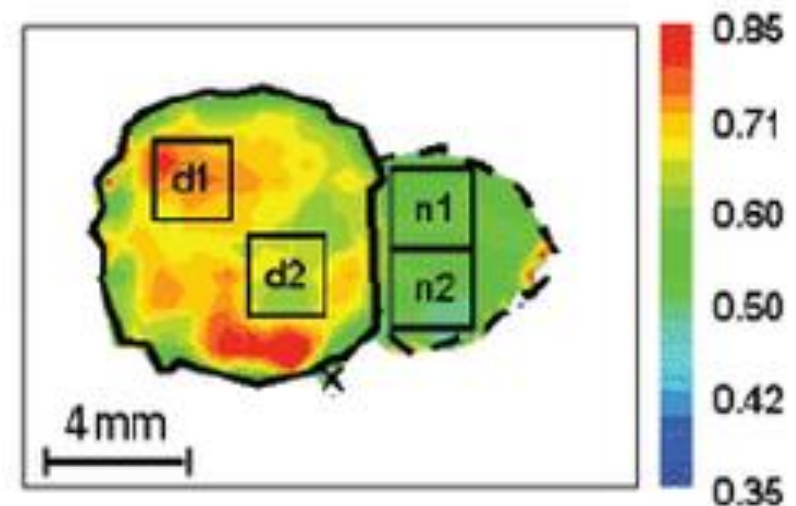


Skin Tissue

Visible Image

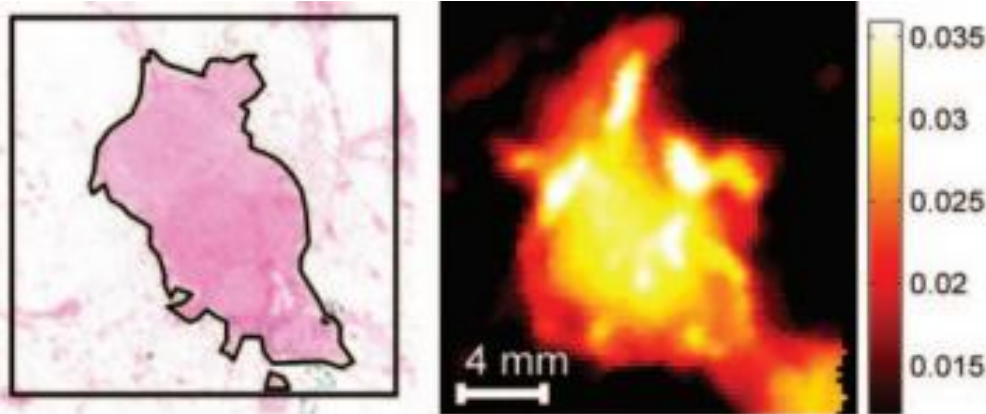
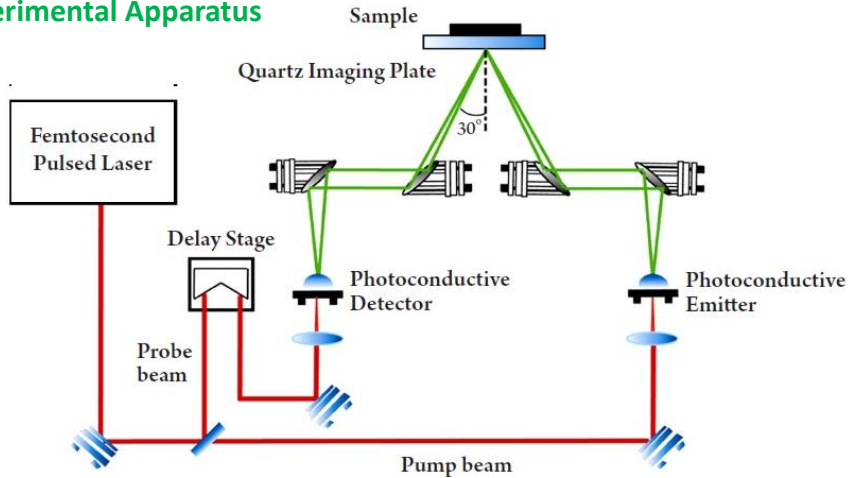


THz Image



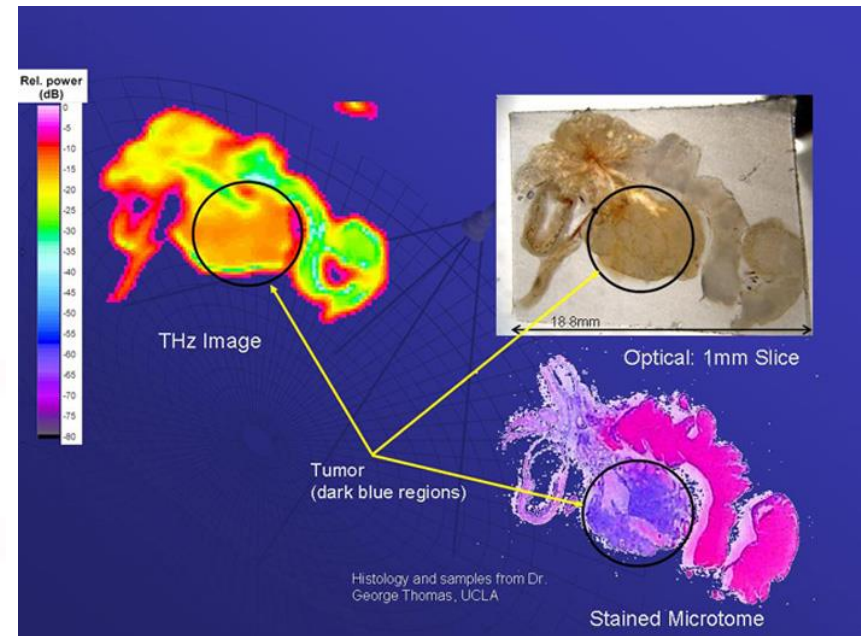
THz imaging: biomedical application

Experimental Apparatus



A. J. Fitzgerald *et al*

Human Breast Tumors



P. Siegel *et al*

A mouse prostate section with tumor tissue (circle)

THz Imaging: Cultural Heritage

THz Imaging provides new information

- **Noncontact**, nondestructive and noninvasive technique
- Chemical composition of **selective** layers
- Image of **underlying**, obscured **underdrawing**, **underpainting** and modifications
- Imaging of internal structure: to evaluate the deep of possible **cracks**

VIS Image

THz Image



Virgin of Vendome (France)

Depth-Selective Imaging

Varnish

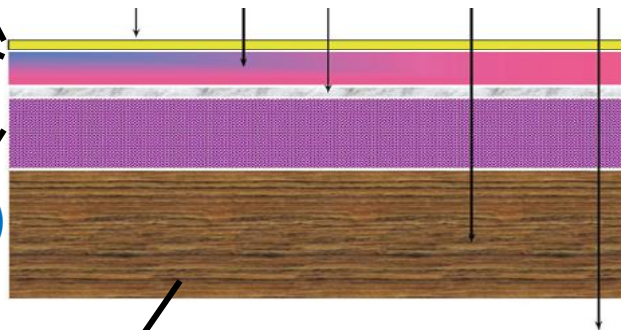
UV VIS IR THz X-Ray

Painting
Drawing

Preparation
(glue, gesso..)

Support

(wood, canvas, paper..)

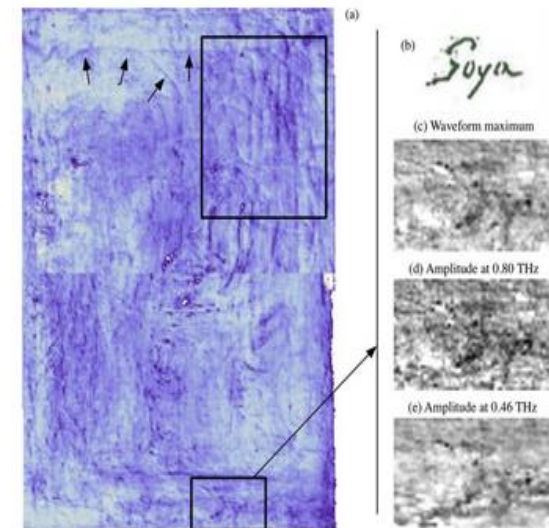


VIS Image

THz Image



F. Giorgianni



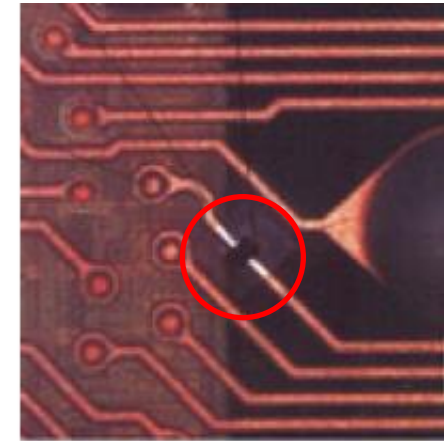
Sacrifice to Vesta (Goya)

THz Imaging: Industrial Applications

Some Applications:

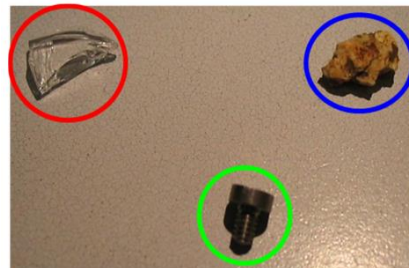
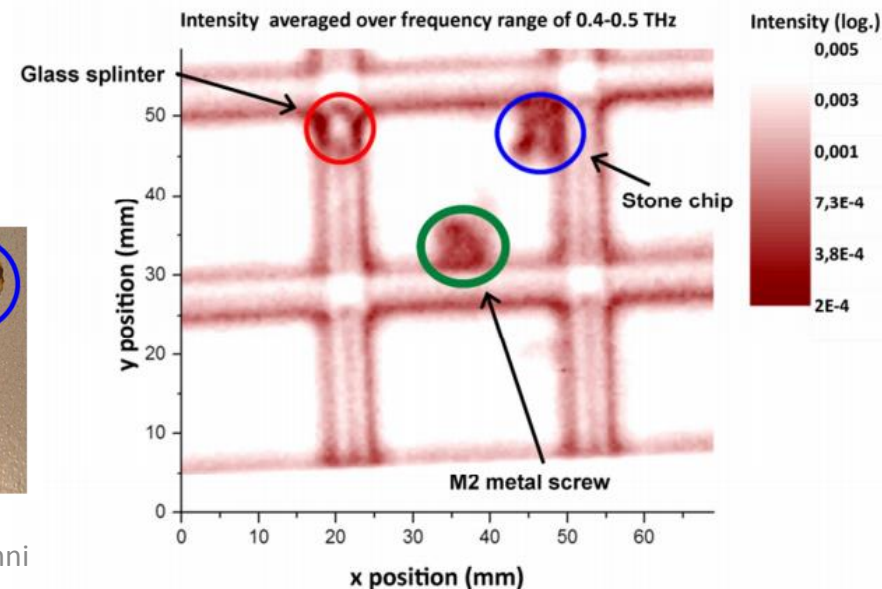
- **Noninvasive** Device Testing (Semiconductor Core Components)
- Sub-surface **cracks** and homogeneity
- **Non-destructive** and user-safe testing method for the food industry
- **Characterization** of pharmaceutical medications

THz Image



Fast Screening of Failed devices

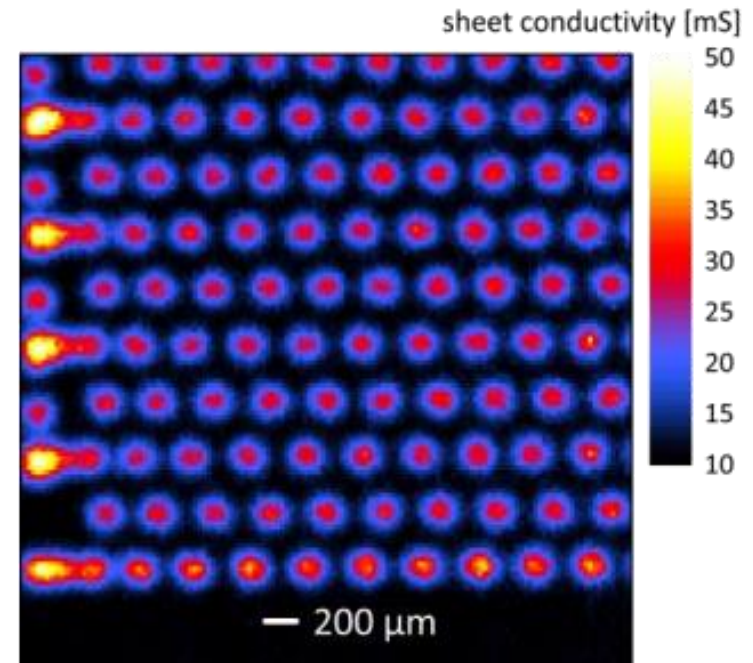
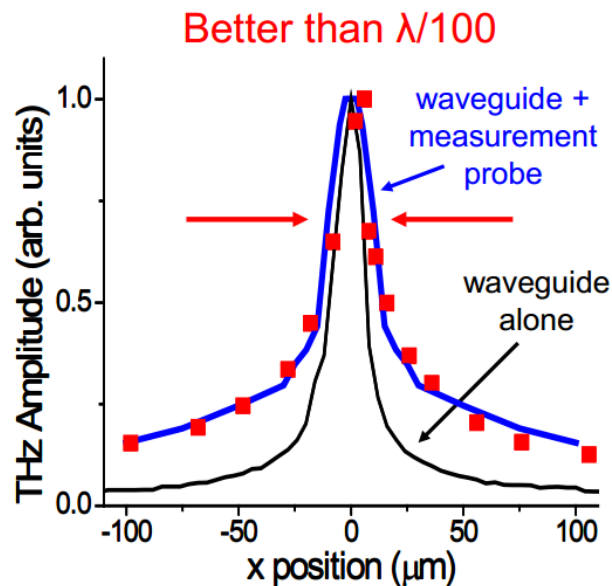
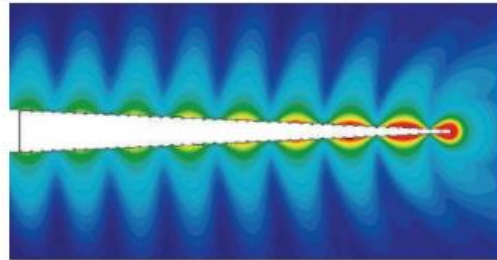
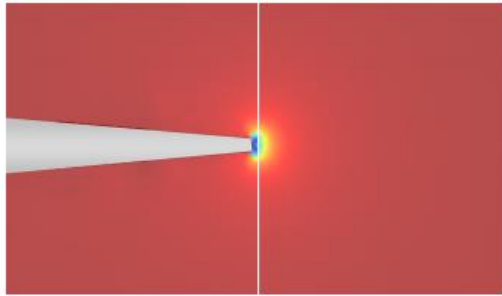
THz Image



Terahertz Near-Field Nanoscopy

THz Imaging beyond the diffraction limit

Standard THz imaging resolution $\sim 100\text{ }\mu\text{m}$



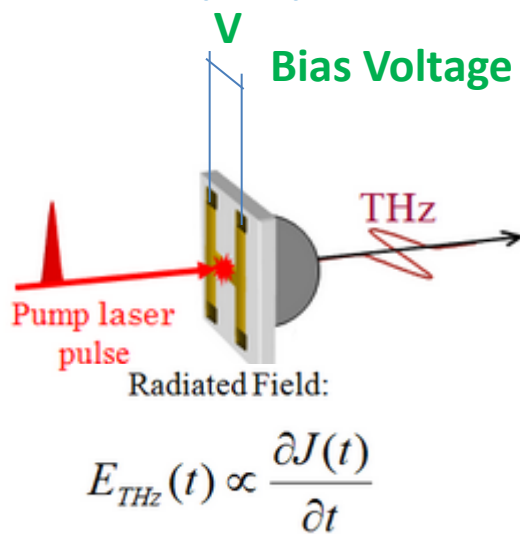
Measured sheet conductivity image of a laser-doped multicrystalline silicon wafer

Ultrafast Pulsed Sources for THz Imaging at INFN-LNF and Roma1

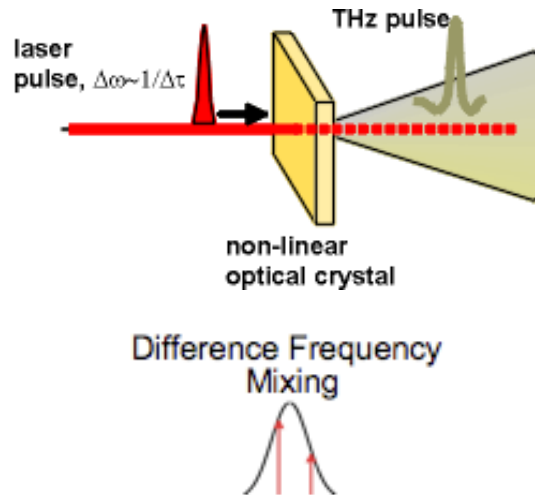


Laser based Sources:

Photoconductive Antennas (PCA)

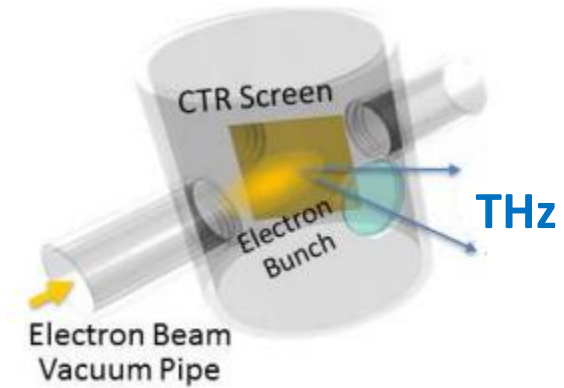


Non-linear Crystals (NLC)



Free electrons based Source

Coherent Transition Radiation (CTR)



	Average THz Power	THz Energy per Pulse	Repetition Rate	Pulse duration	Spectral Range	Lock-in Freq. Oper.
PCA	1 uW	~pJ	80 MHz	~ 1	~ 1 THz	10 KHz
NLC	1 uW	~ pJ	80 MHz	< 0.15	> 3 THz	~ 1 KHz
CTR	300 uW	>30 uJ	10 Hz	< 0.2	> 3 THz	--

Conclusions

Advantages of THz imaging:

1. **Non-ionising** radiation (unlike for example X-rays Imaging)
2. **Nondestructive** evaluation (low energy)
3. Good **penetration** in many Materials (Comparable with X-ray)
4. Possibility to implement **Time-Resolver** Imaging (subpicosecond duration)
5. Pulsed **broadband** (polychromatic) sources for imaging
6. Molecular **Fingerprint** (Chemical Imaging)
7. **Contrast** agents: Water and Metals
8. Lower resolution compared to the other techniques (100 μm) -> **Near-field** imaging

THz imaging provides different / new information

