Falcon Analytics

*Yehoshua Socol*

# Terahertz (THz)

# Technology and Applications

16.07.2008

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- Introduction
- Commercial systems and components
- Spectral signatures
- Case study: Avnet-37 project
- Summary and Outlook

# Acknowledgements


- Prof. B. Kapilevich — Ariel UC
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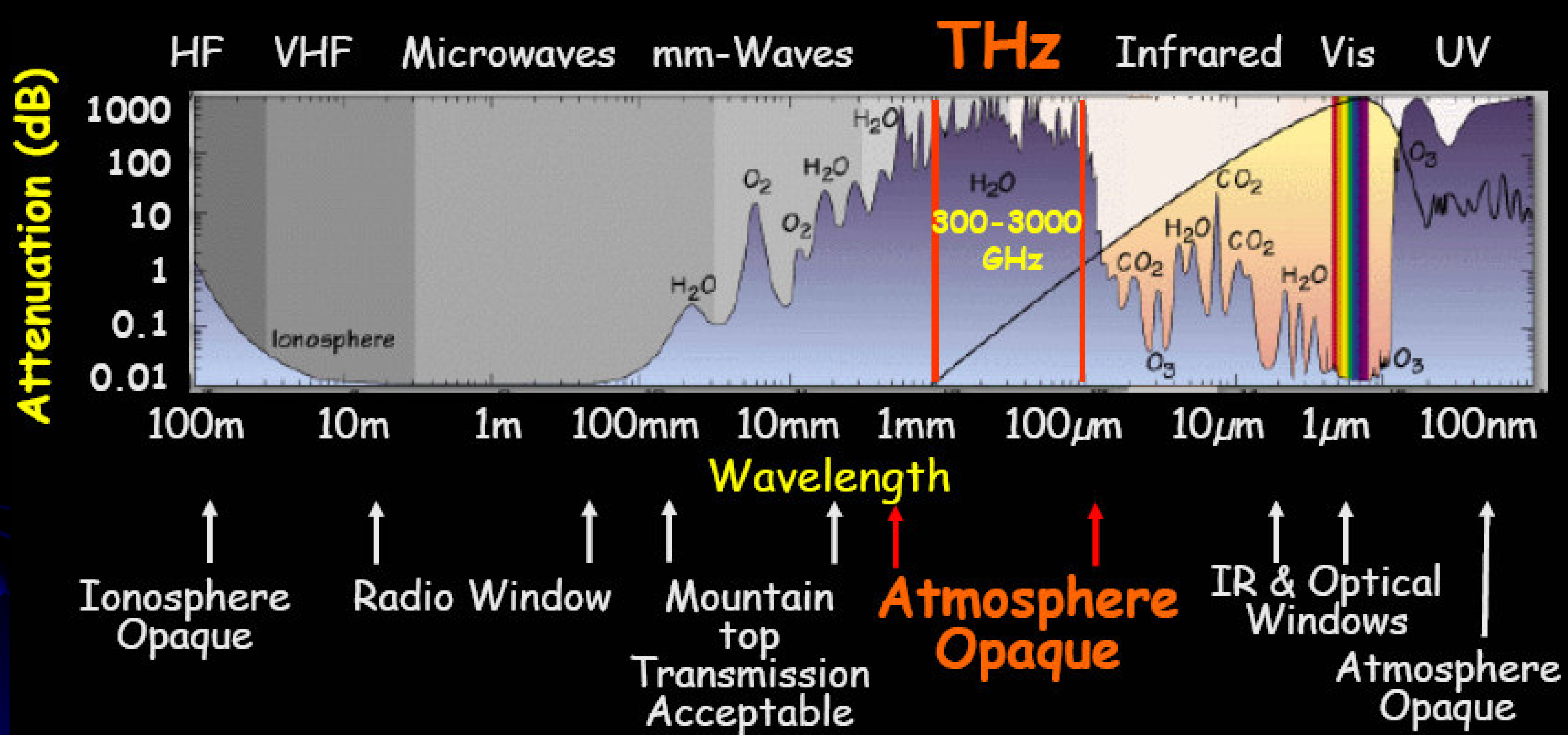
- Mr. M. Lebel — Ministry of Industry & Trade, Israel

# THz radiation




Attenuation (typical): 0.1 dB/ m

50-100 m – still measurable

# THz radiation

## Present Applications

- ☐ Solid-State physics: Spectroscopy
- ☐ Astrophysics & Planet Science: Molecular Spectroscopy
- ☐ Earth science: Upper atmosphere sensing from satellites

# THz radiation

## Potential Applications (after P. Siegel, Caltech)

- ☐ Biochemistry: Composition of Biomaterials, Spectroscopy
- ☐ Biology: Changes of Conformational State
- ☐ Chemistry: Molecular Binding States/Fast Reactions
- ☐ Electronics: High speed circuits, Visualizing Charge
- ☐ Genetics: Gene Sequencing
- ☐ Mathematics: Scattering (RADAR Cross-Section & Modeling)
- ☐ Medical Diagnostics: Disease States
- ☐ Pharmaceuticals: Isomer identification/Tablet integrity
- ☐ Physiology: Tissue Identification/Distinguishing Disease
- ☐ Reconnaissance: Imaging through smoke
- ☐ Safety: Chem & Biohazard Identification/Plume Detection
- ☐ Security: Hidden Weapons/Contraband detection

# Contents

# THz

## Sources

- Thermal Radiation
- BWO
- RF up-converter
- Beat frequency
- Pulse laser
- Free Electron Laser

## Detectors

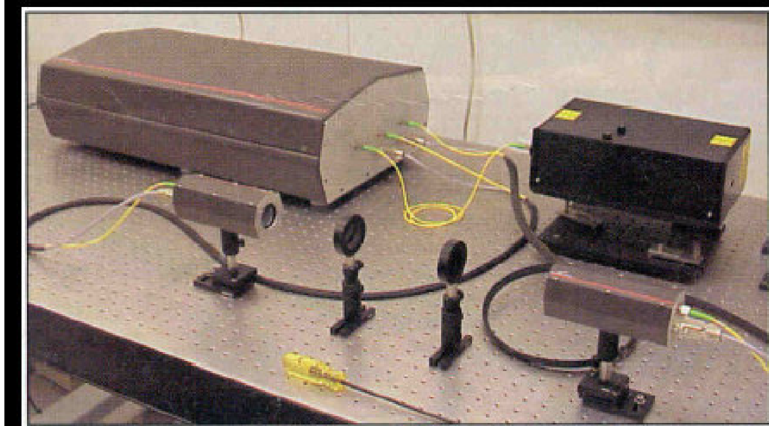
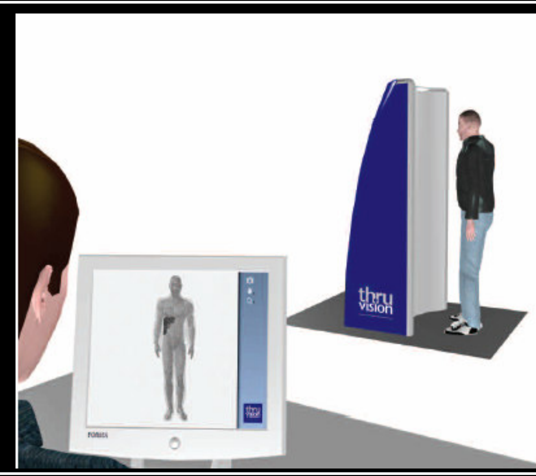
- Thermal

  (pyro-, bolometers)

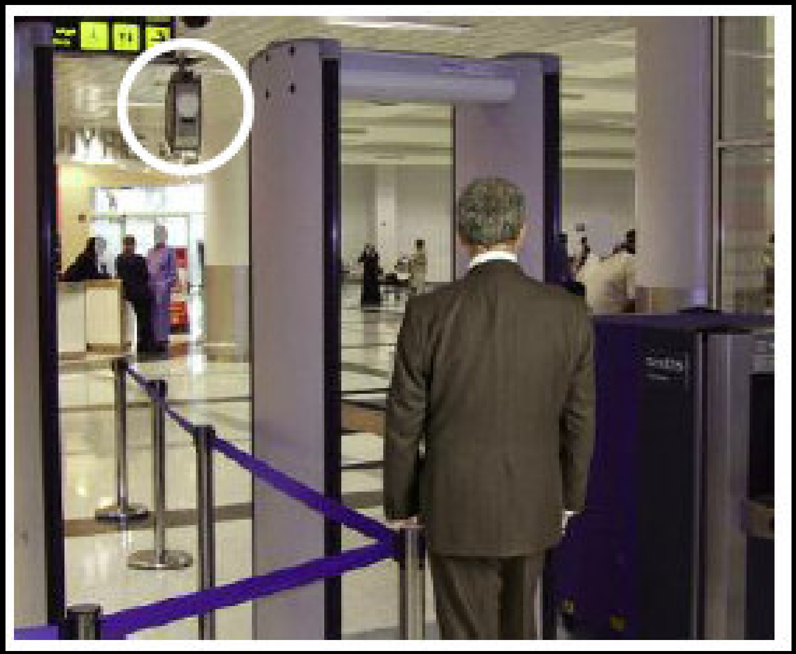
- RF down-converter
- Quantum

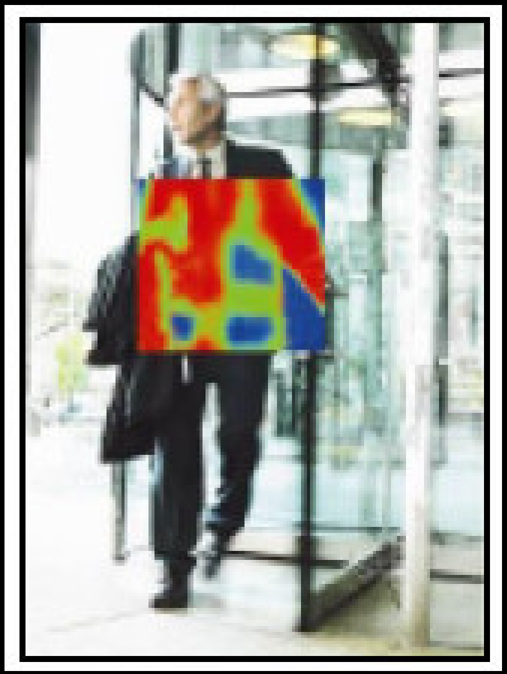
# THz systems evolution

Considerable progress 2005-2008

| | Picometrix (US) | ThruVision (UK-US) |
|---|---|---|
| 2005 |  |  |
| 2008 |  |  |

# THz systems performance





**ThruVision**

Distance: 3-25 m

Resolution: ~ cm

Numerical example:

$\lambda$ = 0.3 mm (1 THz)

F# = 1

d = 5 m f = 5 cm

Resolution = $\lambda$ F# d / f = 3 cm

# THz Components: Sources

| | Vendors (sample) |
|---|---|
| Thermal Radiation | (passive) |
| BWO | Microtech Instr. |
| RF up-converter | Virginia Diodes |
| Beat frequency | Topica |
| Pulse laser | Picometrix |
| Free Electron Laser | NL,DE,US,RU |

# THz Source - example

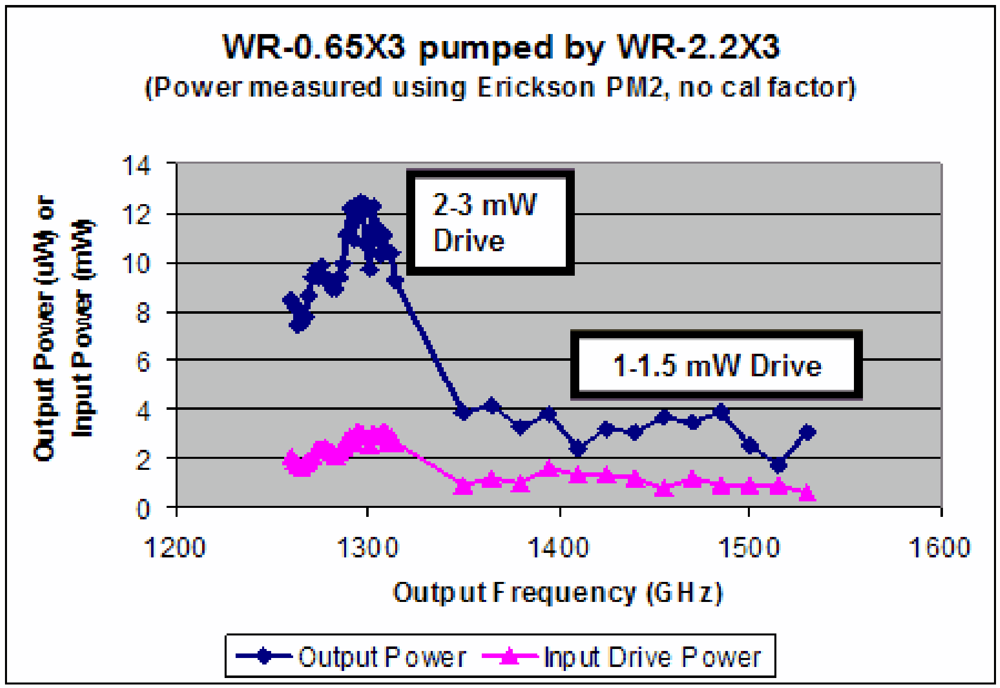
## Tripler up to 1.7 THz

**VDI Virginia Diodes, Inc.**

VDI Model: WR0.65x3

**1100-1700 GHz Output, Full-band Frequency Tripler**

- 0.3-0.5% Efficiency
- No Bias
- Planar construction
- Input flange: WR-2.0
- Output flange: Feedhorn
- Size: 1.2 x 0.8 x 0.25 inch

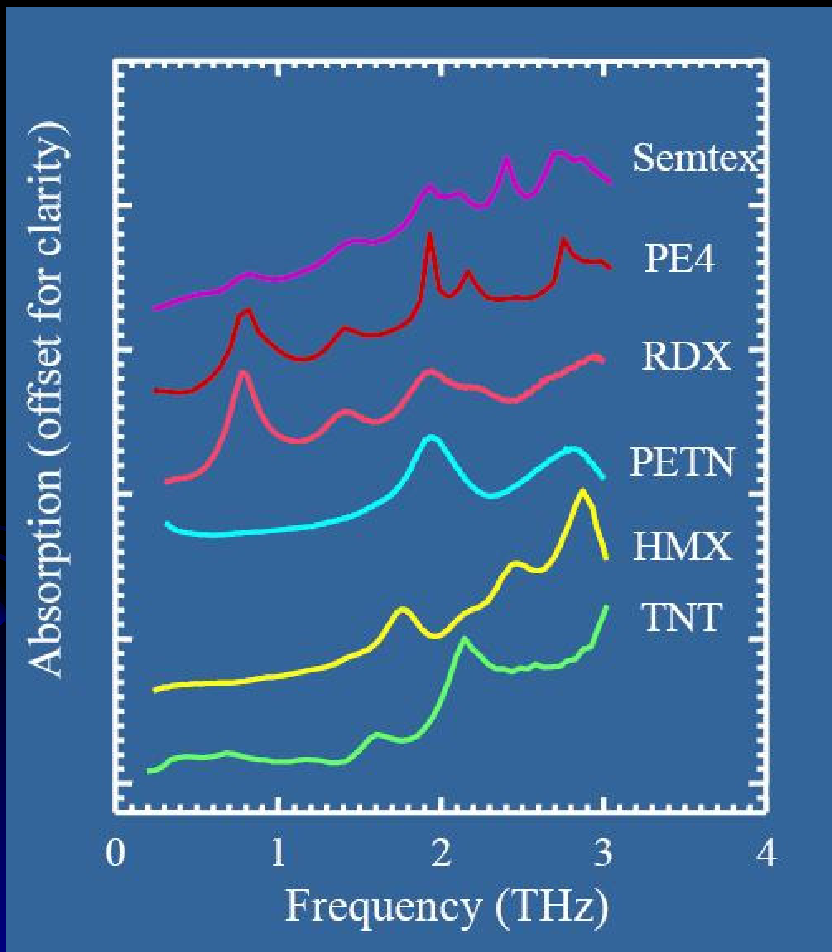


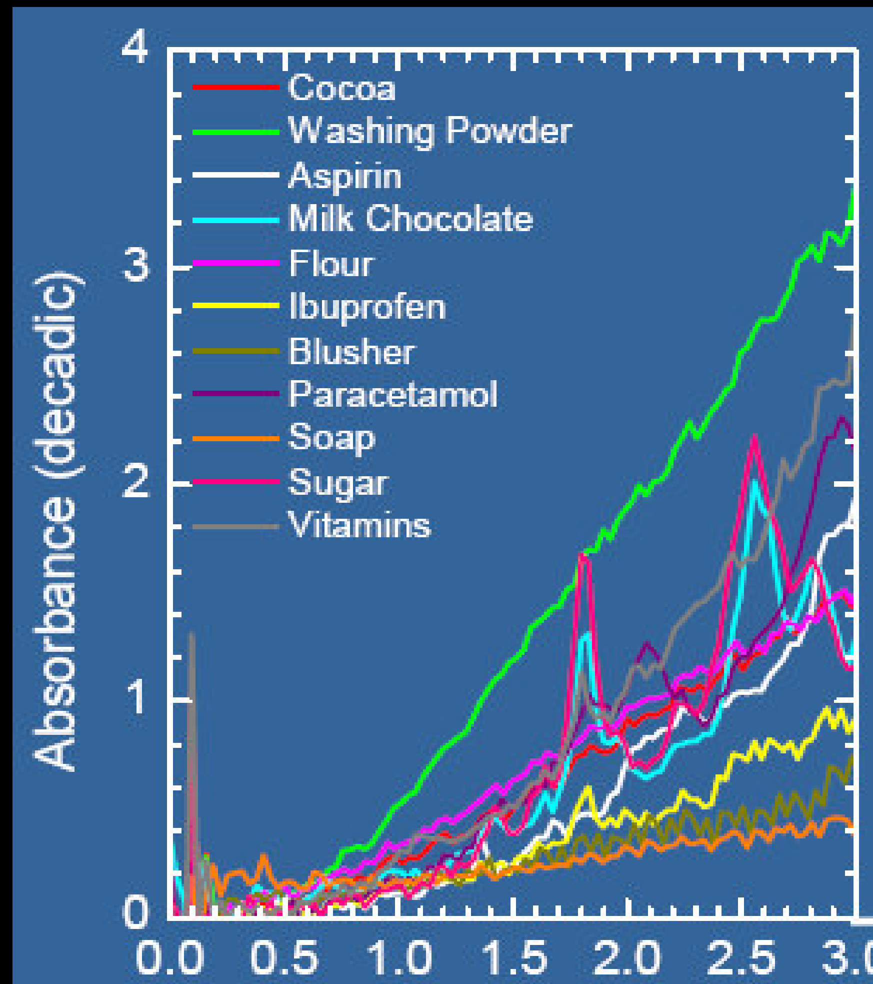

**Contact VDI today for specifications and quotation details.**

Virginia Diodes, Inc., Ph:434.297.3257, FAX:434.297.3258, www.virginiadiodes.com, VDIRFQ@virginiadiodes.com

# Contents

# THz Spectral Signatures




TeraView - APS March meeting 2005

W. R. Tribe *et al.* *SPIE 5354*, 168 (2004)

# Signatures' Representations
## Dielectric Characteristics

Theory: dielectric properties fully described by
complex dielectric constant $\varepsilon = \varepsilon' + i\,\varepsilon''$ ($D = \varepsilon\, E$)

Practice: other characteristics are more convenient

Complex refraction index $n' + i\, n'' = n + i\,\kappa = \sqrt{(\varepsilon' + i\varepsilon'')}$

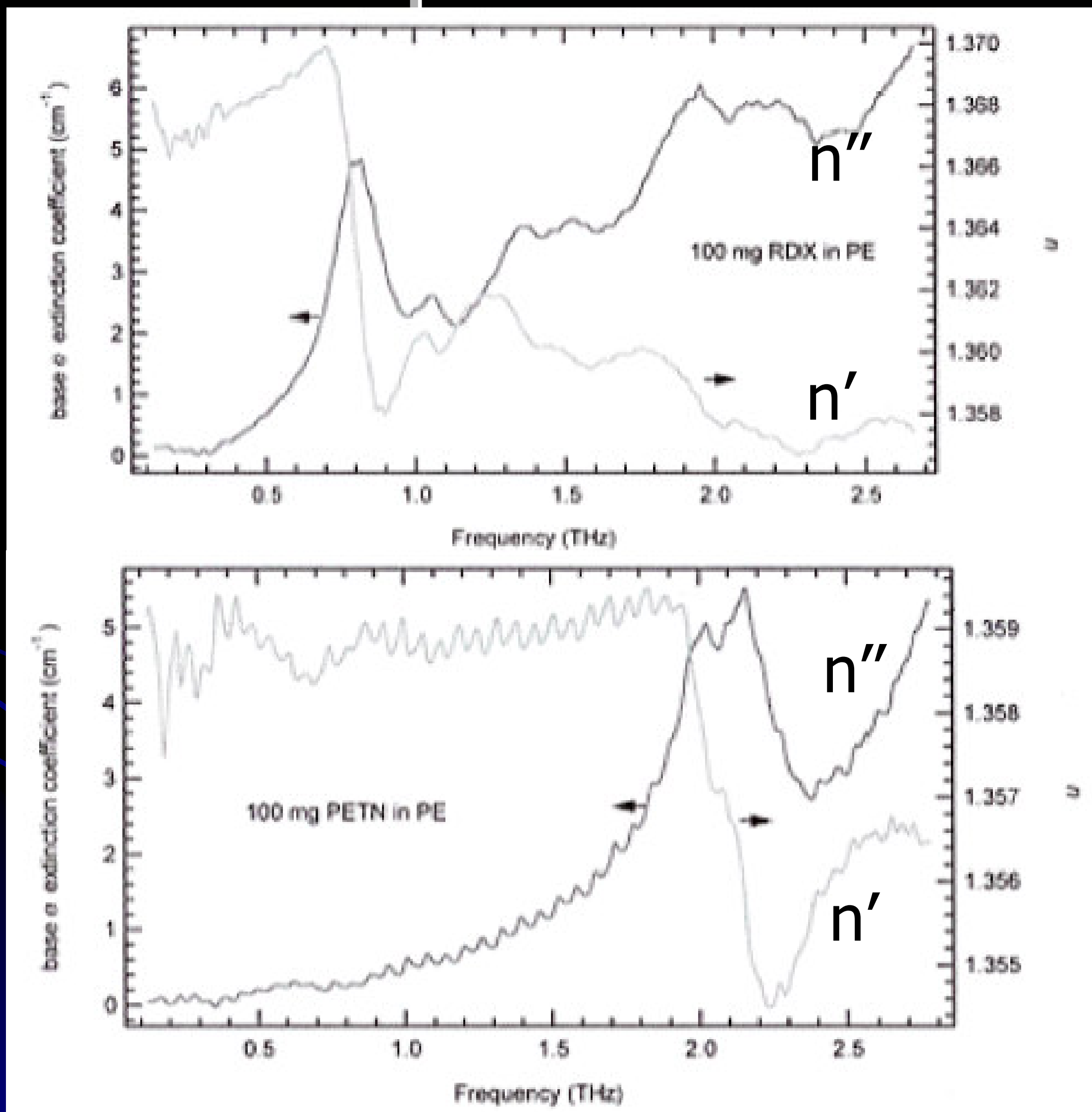
Intensity $I(x)$ decay with depth $x$ $I(x)=I(0)\, exp(- a\, x)$
Absorption coefficient $a = 4\,\pi\,\kappa\,/\,\lambda$

$n'' = \kappa = a\,\lambda\,/\,4\pi$

$\lambda$ radiation wavelength (in vacuum)

# "Vector" THz spectra

## complex refraction index



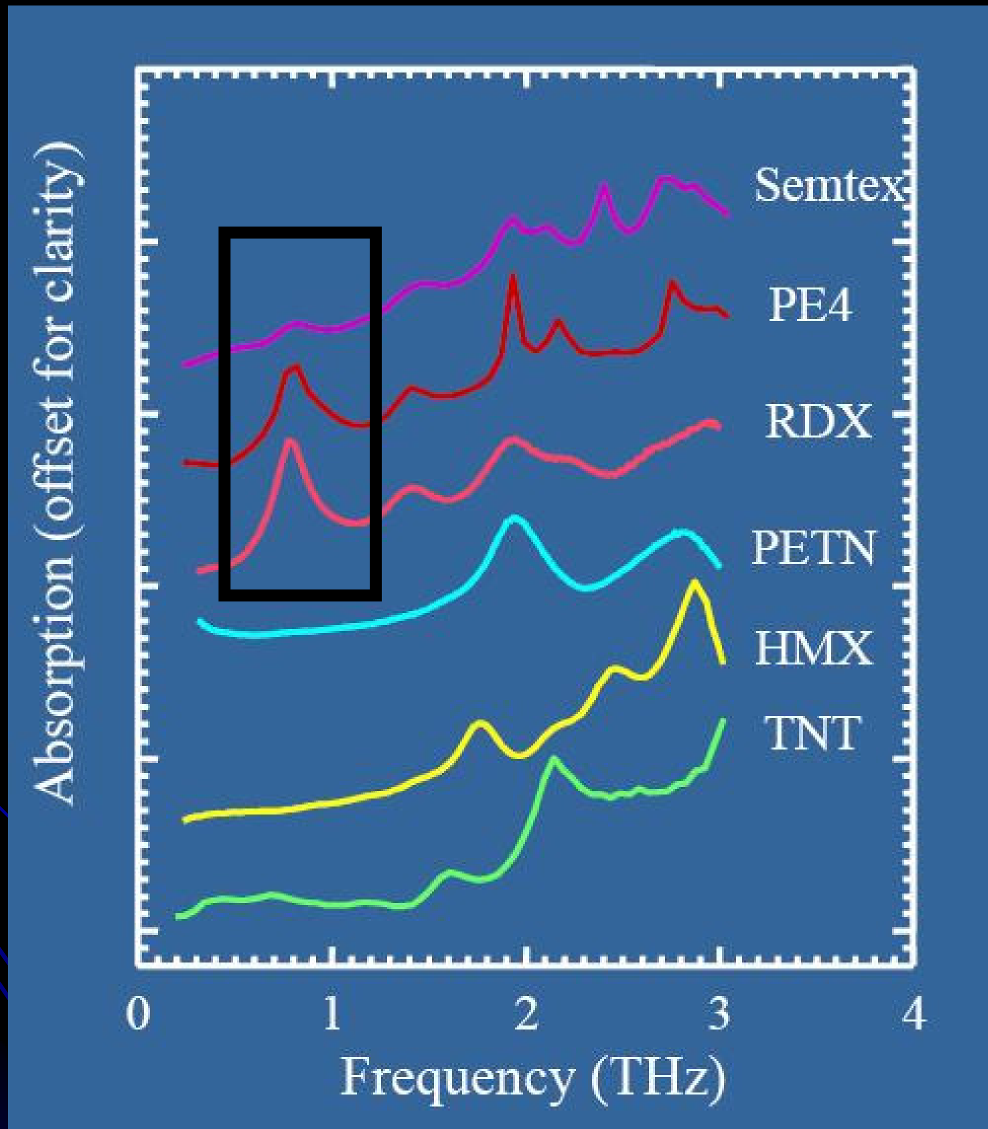

**Difficult to measure**

**Very rare in literature**

D.J.Cook, B.K.Decker and M.G.Allen *PSI-SR-1196* (2005)

# Understanding spectral shapes

## Optical Resonances



# Understanding spectral shapes

## Optical Resonances

$$\varepsilon = 1+(N_f e^2 / \varepsilon_0 m [\omega^2 - \omega_0^2 - i \gamma \omega])$$

$n = \sqrt{\varepsilon}$

$n = n' + i n''$ — Complex refraction index

- $n'$ — refraction
- $n''$ — absorption

$\varepsilon = \varepsilon' + i \varepsilon''$ — Complex dielectric constant

m,e – electron mass, charge

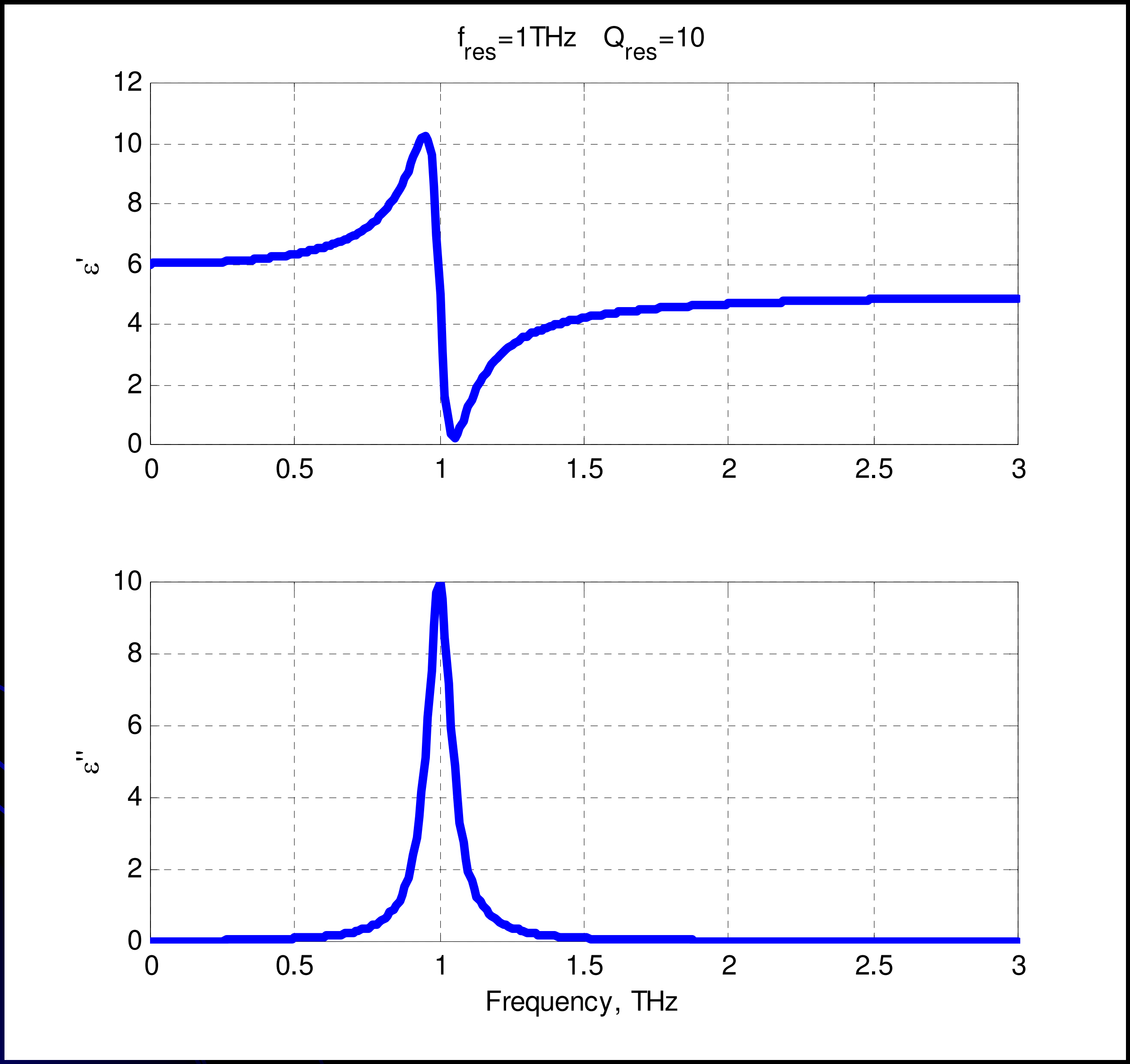
$N_f$ – resonance strength

$\gamma = \omega_0 / Q$ (analog of Q-factor in RF)

# Theory – complex ε

ε'

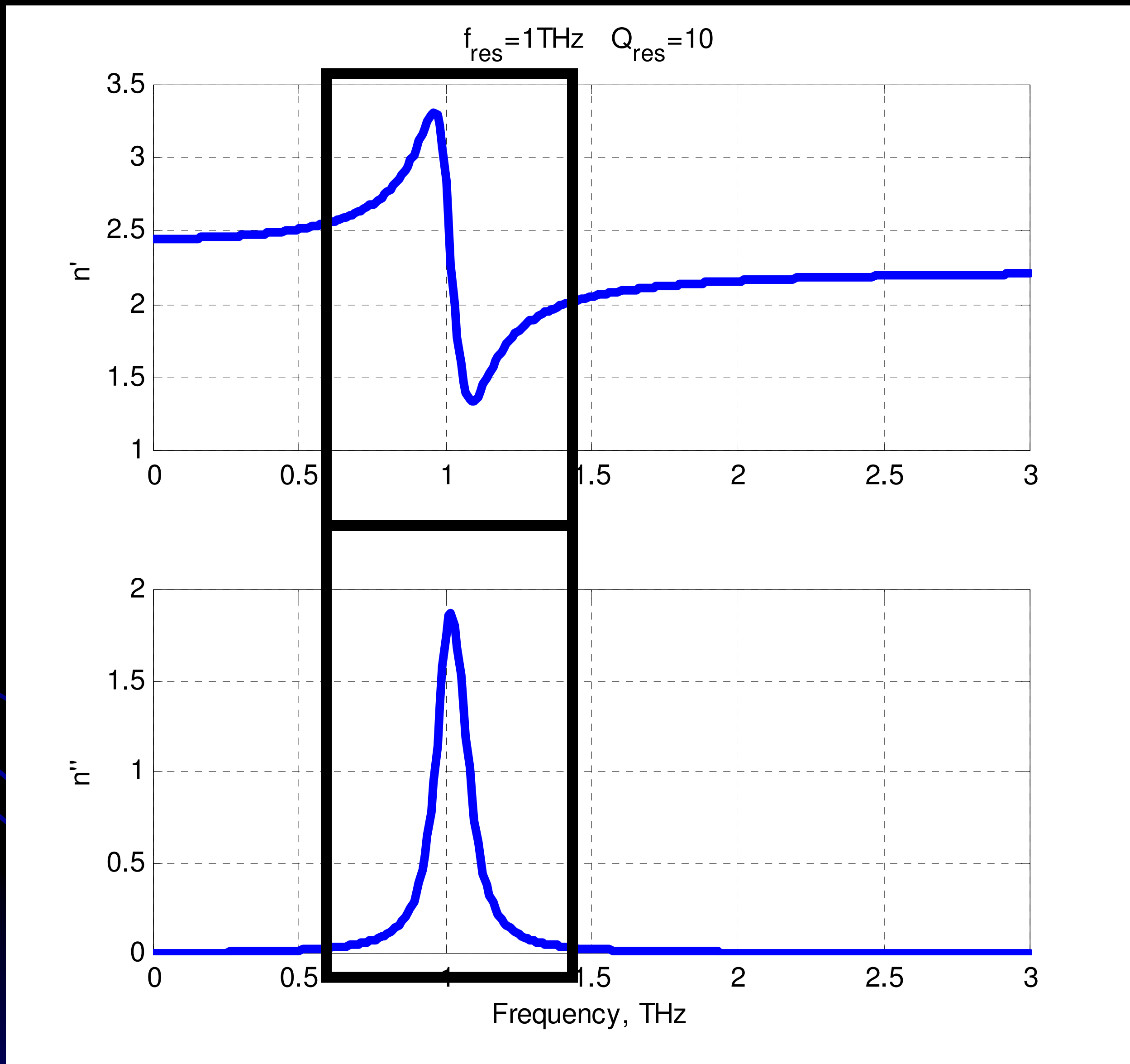
ε''



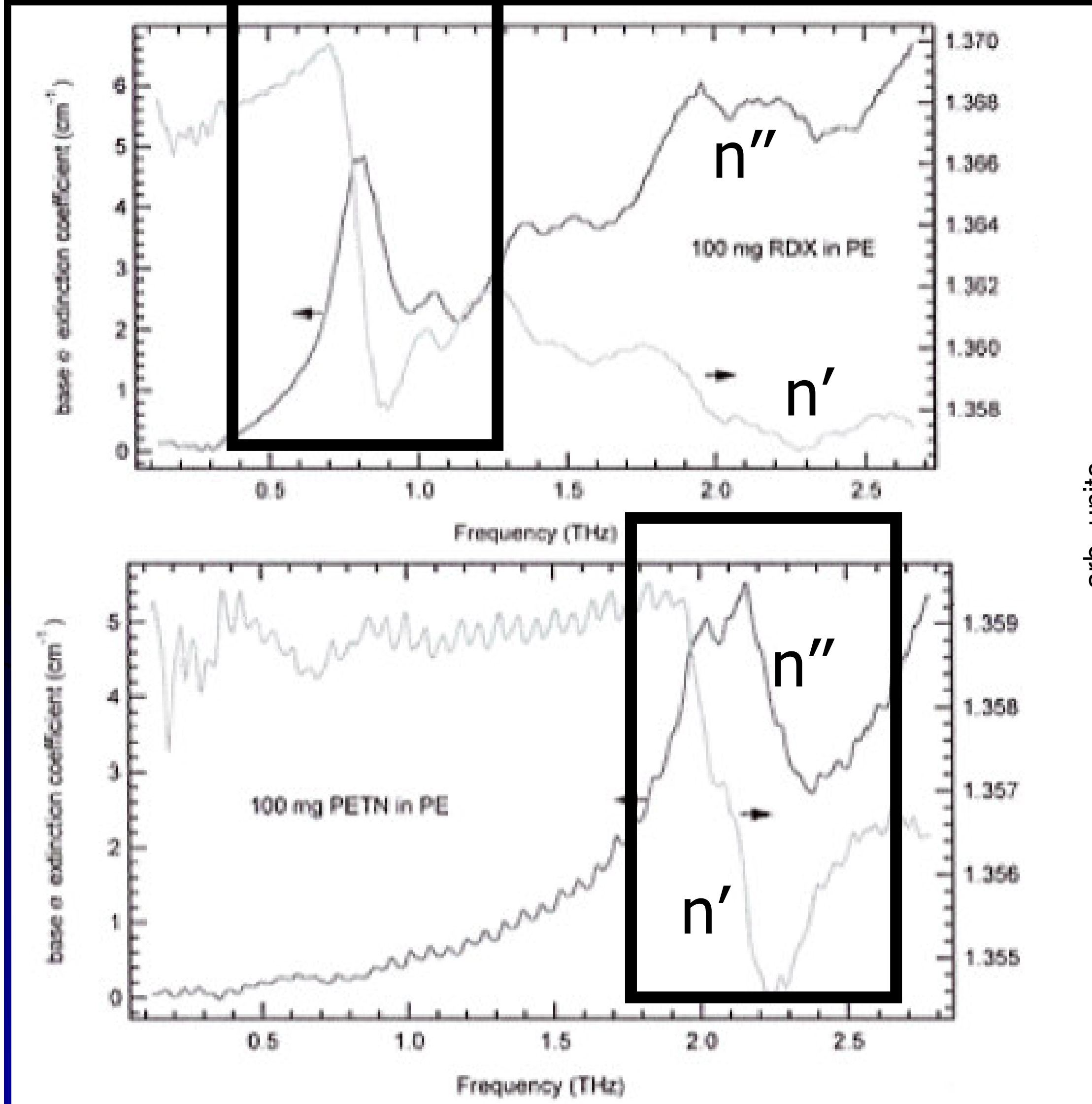
# Theory – complex n

n’

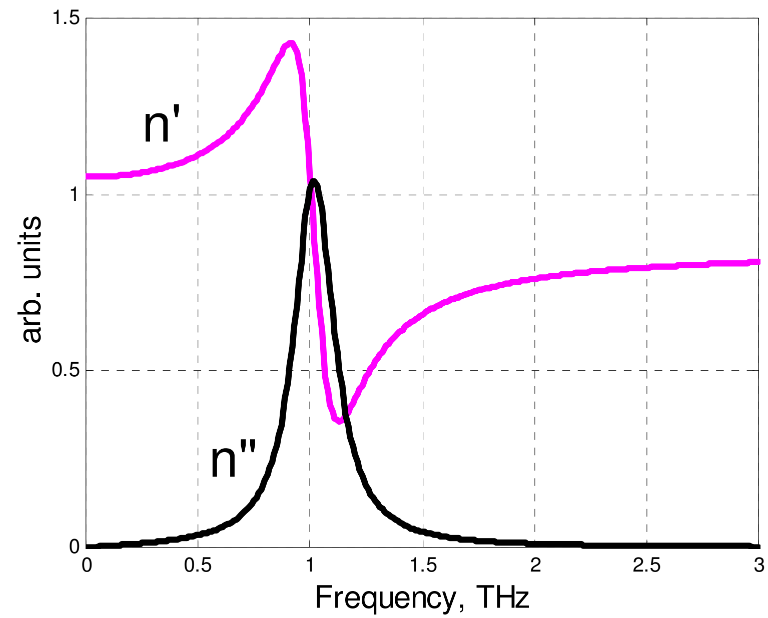
n’’



# Comparison with Experiment



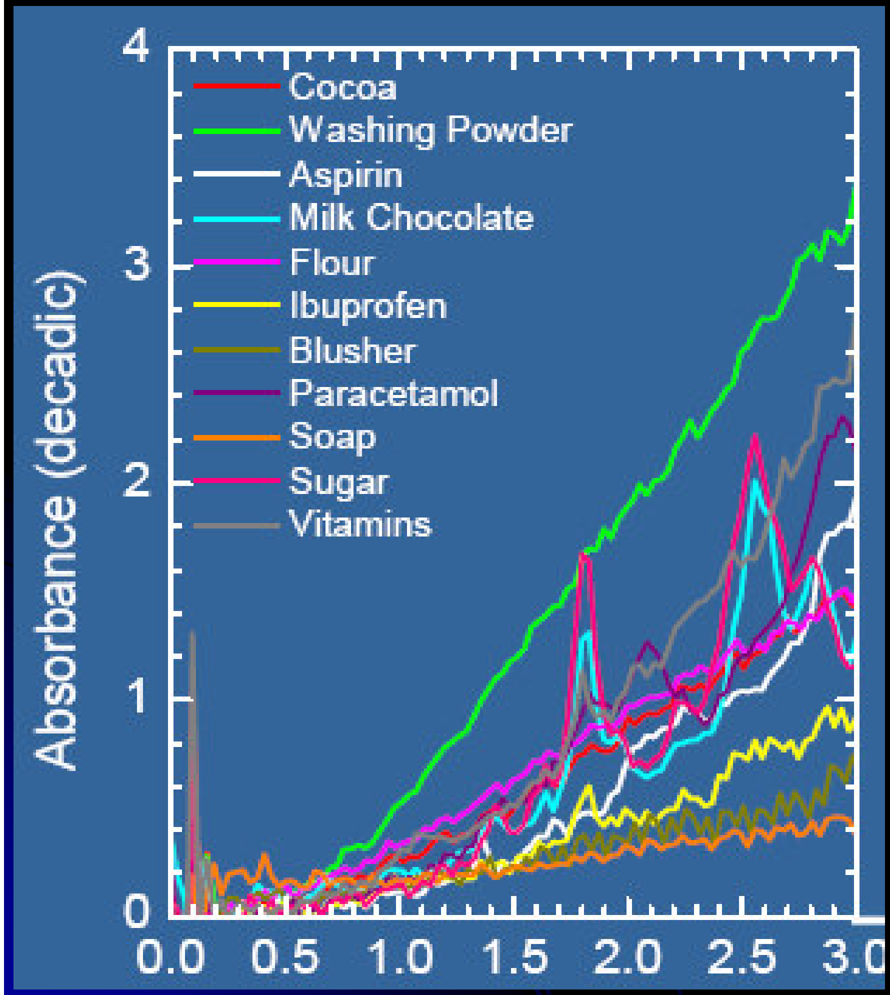

Experiment




Simulation

# Understanding spectral shapes

## Optical Resonances

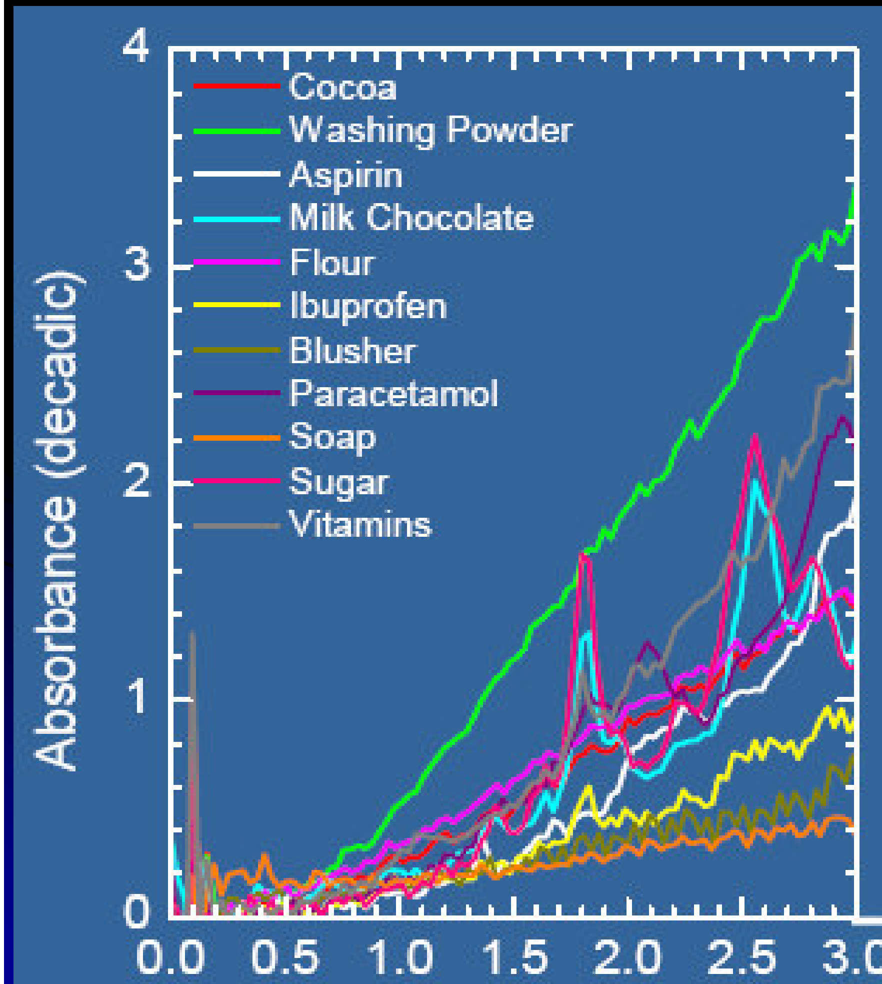



**<= n″ ~ f**

Why **linear** trend in absorption?

$\varepsilon = 1+(N_f\, e^2 / \varepsilon_0\, m\, [\omega^2 - \omega_0^2 - i\,\gamma\,\omega])$

$\omega << \omega_0$ => $\varepsilon = 1 + \ldots / (-\omega_0^2 - i\,\gamma\,\omega)$




$\varepsilon = 1 - \ldots / (\omega_0^2 + i\,\gamma\,\omega)$

<= $n'' \sim \omega$ !

“Tails” of strong IR and visible resonances

# Contents

# Avnet-37 Project

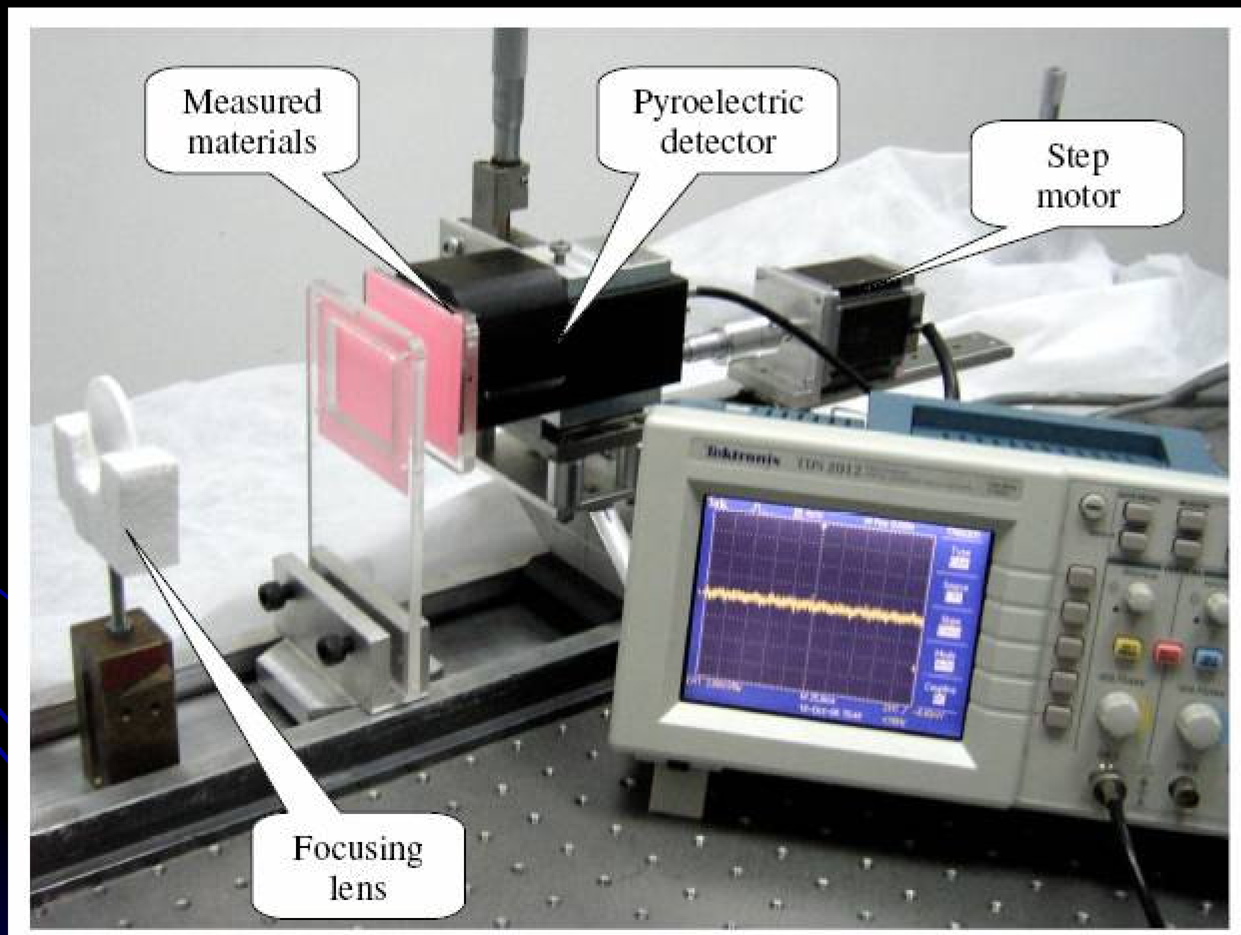
## Detection of Concealed Objects

Israeli Ministry of Industry & Trade

THz Detection sector:

Ariel UC / ELTA Systems Ltd.

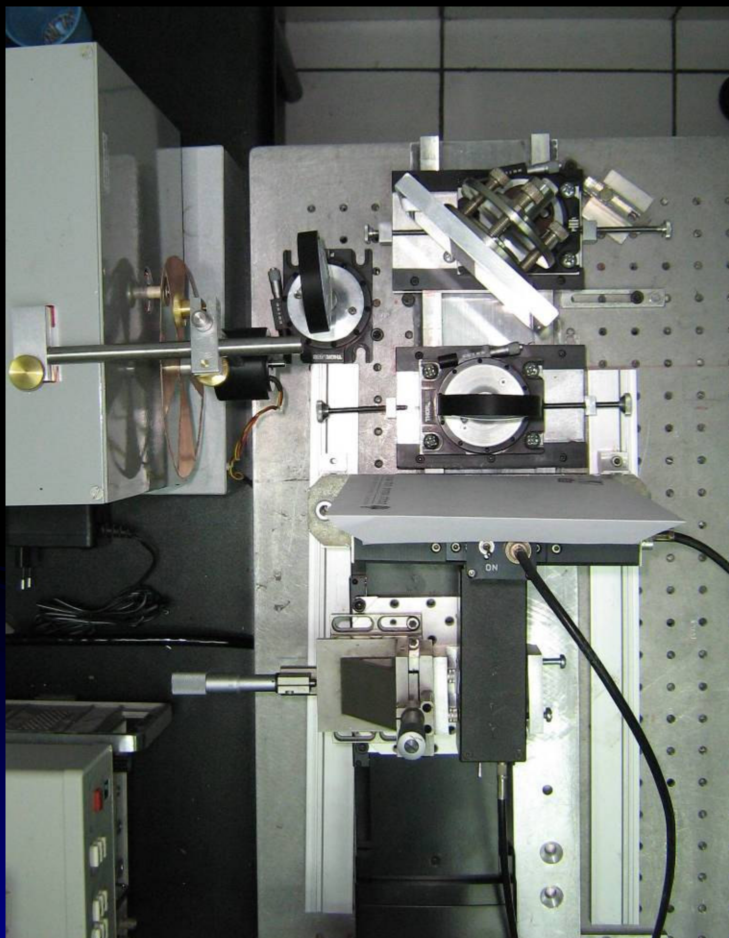
# Ariel UC THz facility



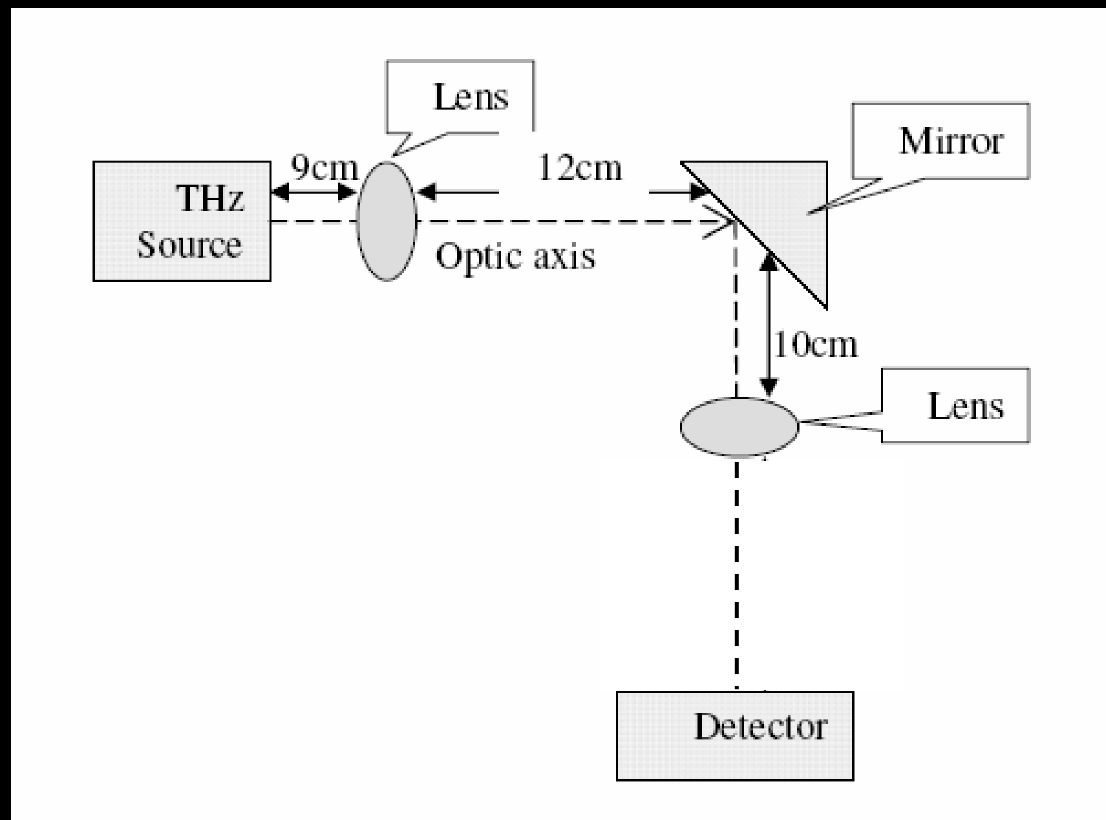
# Ariel UC THz facility

| | | *Manufacturer* |
|---|---|---|
| 1 | THz source GBWO-103<br>0.8 – 1.1 THz | GYCOM<br>Nizhny Novgorod, Russia |
| 2 | Pyro-electric Detector<br>(based on $LiTaO_3$ Crystal) | Microtech Instruments, Inc |
| 3 | High-Performance Mid-Range Travel Linear Stage ILS-100PP With Universal Motion controller ESP-300 | Newport Corporation |
| 4 | THz Absolute Power Meter System | Thomas Keating Ltd, UK |

# Experimental set-up



Top view

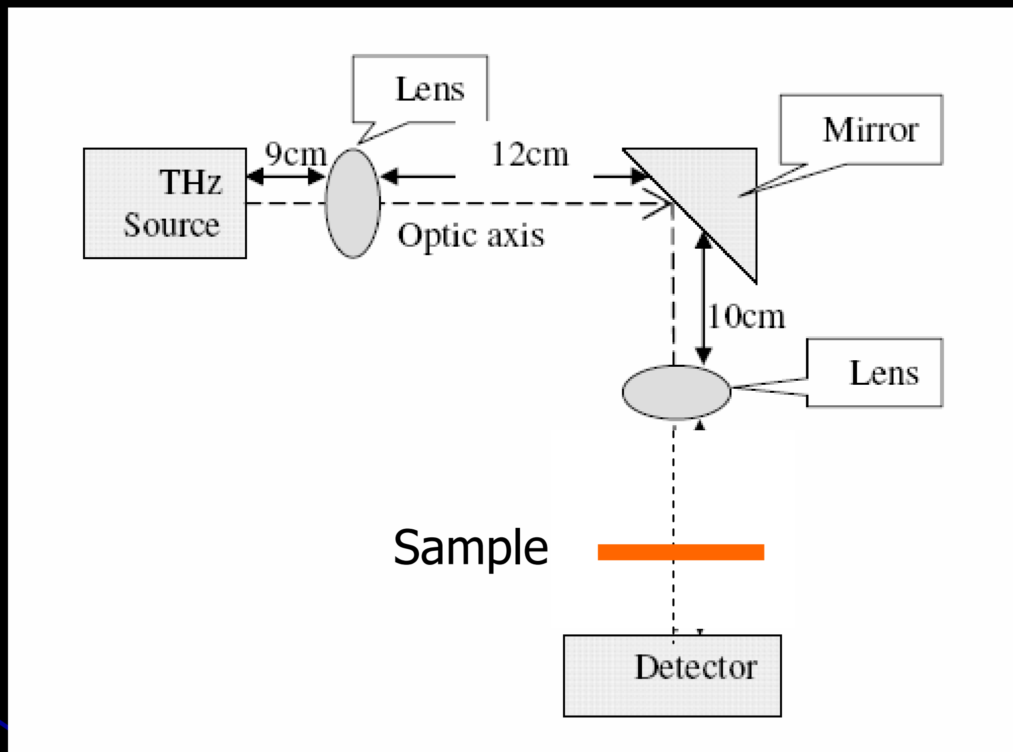



Optical scheme

# THz lenses

| | |
|---|---|
| **Material** | **Polyethylene** |
| **Cost in-house prod.** | **$ 75** |
| Cost Microtech Inc. | $ 700 |

# Experimental set-up

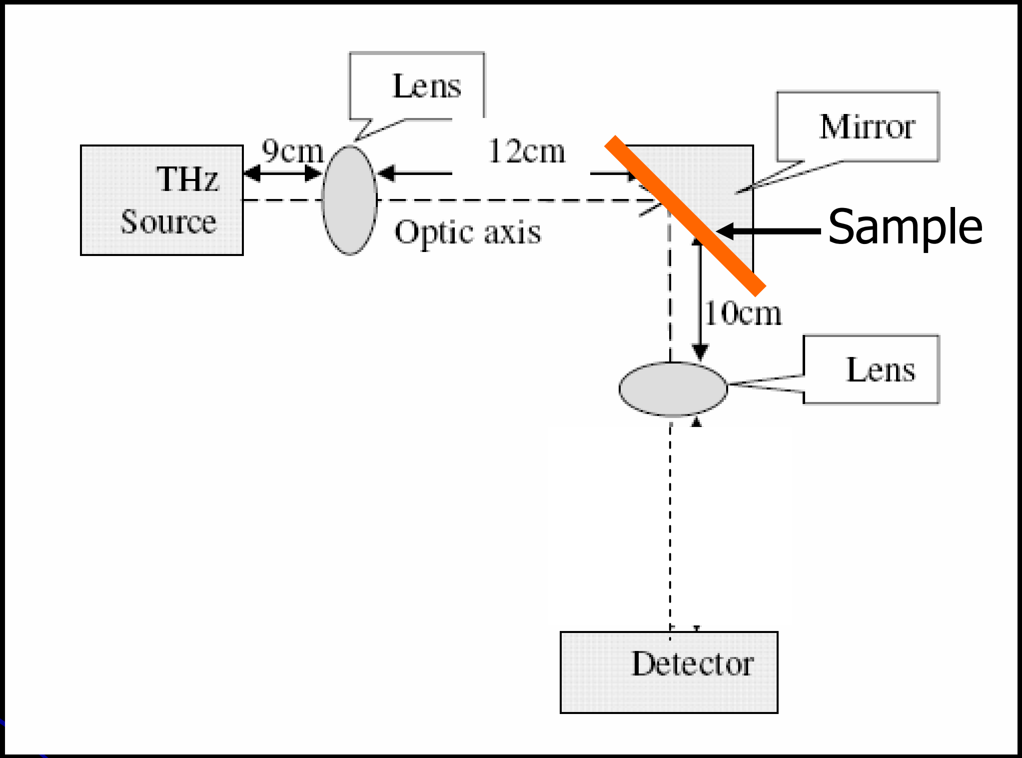



**Transmission mode**

+ : Absorption measurable

– : Impossible to measure high-loss samples

# Experimental set-up




**Reflection mode**

– : Impossible to measure absorption

+ : Possible to measure high-loss samples (refraction index)

# Reflection - quantitative

Fresnel formulas

$R(TE) = | r(TE) |^2$
$R(TM) = | r(TM) |^2$

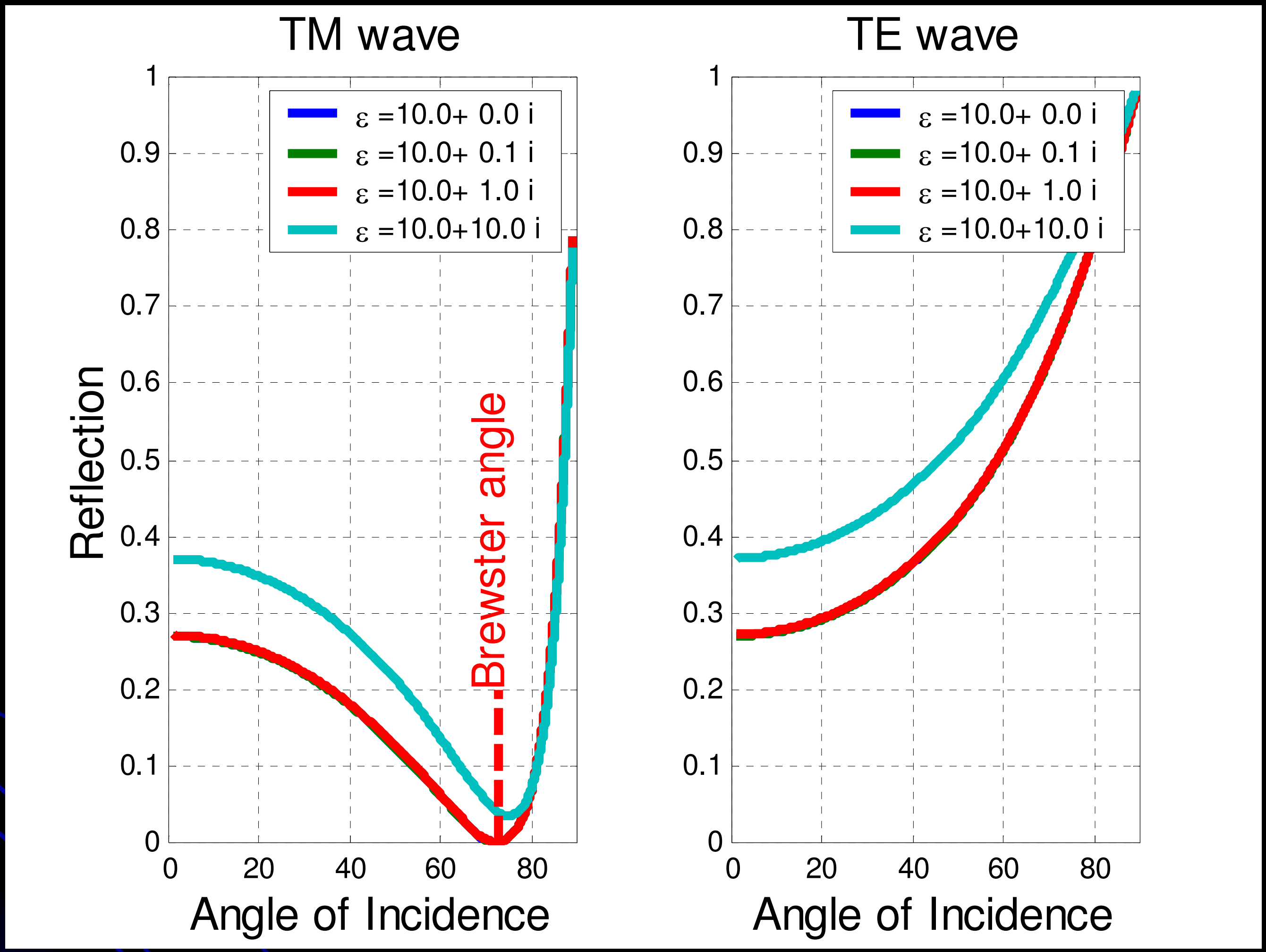
where

$$r(TE) = \{ \cos(\theta) - \sqrt{[\varepsilon - \sin^2(\theta)]} \} \; / \; \{ \cos(\theta) + \sqrt{[\varepsilon - \sin^2(\theta)]} \}$$

$$r(TM) = \{ \varepsilon \cos(\theta) - \sqrt{[\varepsilon - \sin^2(\theta)]} \} \; / \; \{ \varepsilon \cos(\theta) + \sqrt{[\varepsilon - \sin^2(\theta)]} \}$$

$\theta$ – angle of incidence
$\varepsilon$ – complex dielectric constant

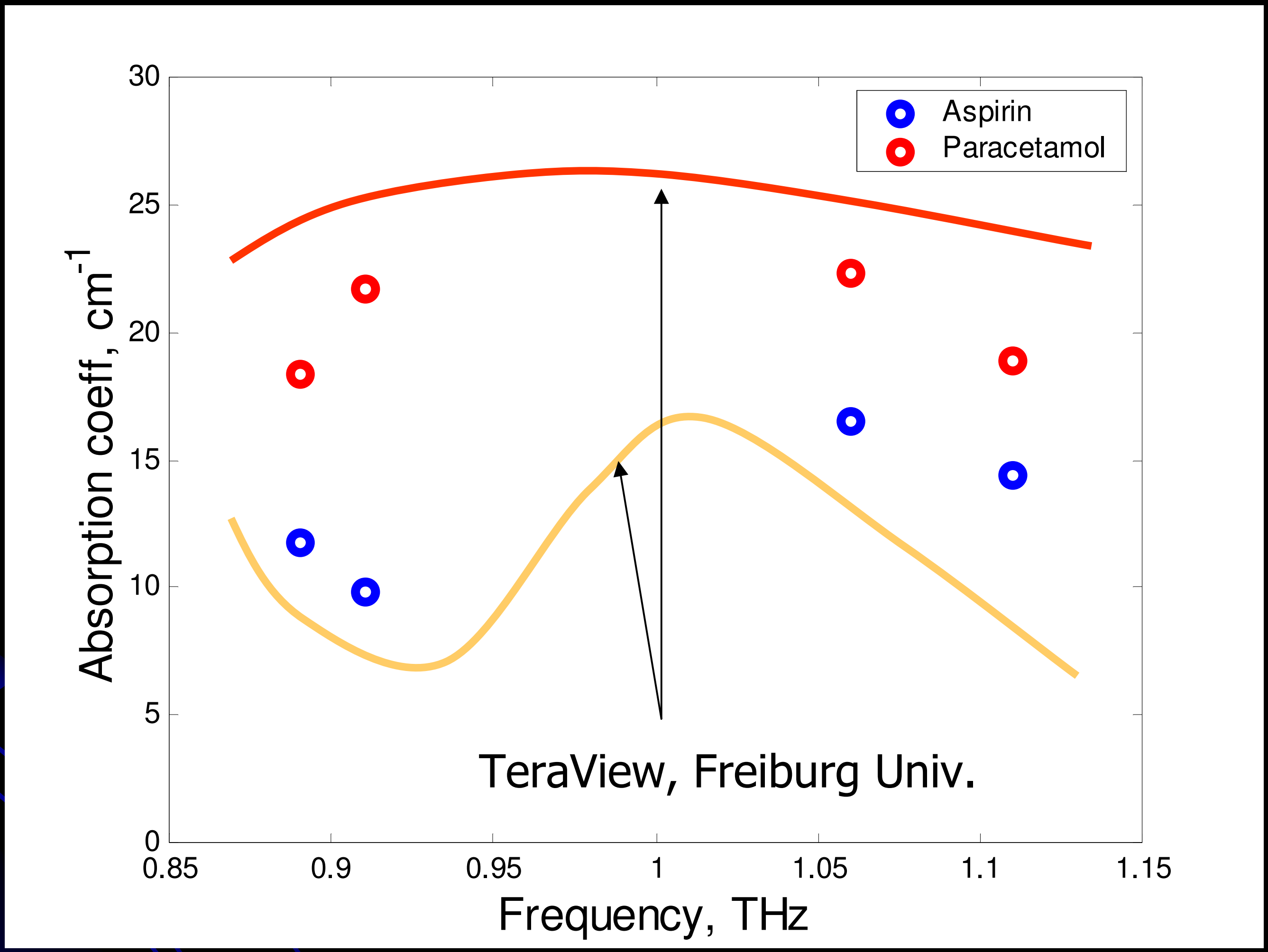
# Reflection - quantitative




Theory: reflection depends on absorption

Practice: the dependence is negligible, unless absorption unreasonably high

# Measurements : Powders



# Summary and Outlook

1. Through-clothes imaging is feasible

2. Identification of chemical hazards is feasible

"Terahertz has the opportunity to be a breakthrough technology that can be used in several large markets within non-destructive testing, homeland security and defense. It is entering the high reliability application and market development phase, which will take some time to blossom."

R. Kurtz, The Wall Street Transcript, Mar 2007