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L3 – Photothermal techniques in material characterization

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Optical Excitation

⇓

Absorption

⇓

Excited State Relaxation

⇓

Temperature Change ⇔ *Density Change* ⇔ *Pressure Change*

(*Thermal Diffusion*) (*Acoustic Wave*)

⇓

Optical Probe ⇒ *Refractive Index Change* ⇒ *Photothermal Signal*

Photothermal spectroscopy is a group of high sensitivity methods used to measure optical absorption and thermal characteristics of a sample.

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Optical Probe ⇒ *Refractive Index Change* ⇒ *Photothermal Signal*

The basis of photothermal spectroscopy is a *photo*-induced change in the *thermal* state of the sample.

Optical Excitation

⇓

Absorption

⇓

Excited State Relaxation

⇓

Temperature Change ⇔ *Density Change* ⇔ *Pressure Change*

(*Thermal Diffusion*) (*Acoustic Wave*)

⇓

Optical Probe ⇒ *Refractive Index Change* ⇒ *Photothermal Signal*

Light energy absorbed and not lost by subsequent emission results in sample heating.

Optical Excitation

⇓

Absorption

⇓

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(*Thermal Diffusion*) (*Acoustic Wave*)

⇓

Optical Probe ⇒ *Refractive Index Change* ⇒ *Photothermal Signal*

This heating results in a temperature change as well as changes in thermodynamic parameters of the sample which are related to temperature.

Optical Excitation

⇓

Absorption

⇓

Excited State Relaxation

⇓

Temperature Change ⇔ *Density Change* ⇔ *Pressure Change*

(*Thermal Diffusion*) (*Acoustic Wave*)

⇓

Optical Probe ⇒ *Refractive Index Change* ⇒ *Photothermal Signal*

Indirect measurement of the temperature, pressure, or density changes that occur due to optical absorption are ultimately the basis for the photothermal spectroscopic methods.

Optical Excitation

⇓

Absorption

⇓

Excited State Relaxation

⇓

Temperature Change ⇔ Density Change ⇔ Pressure Change

(Thermal Diffusion) *(Acoustic Wave)*

⇓

Optical Probe ⇒ Refractive Index Change ⇒ Photothermal Signal

Most of Photothermal spectroscopic methods are nondestructive, accurate, precise and reliable operating usually in real time.

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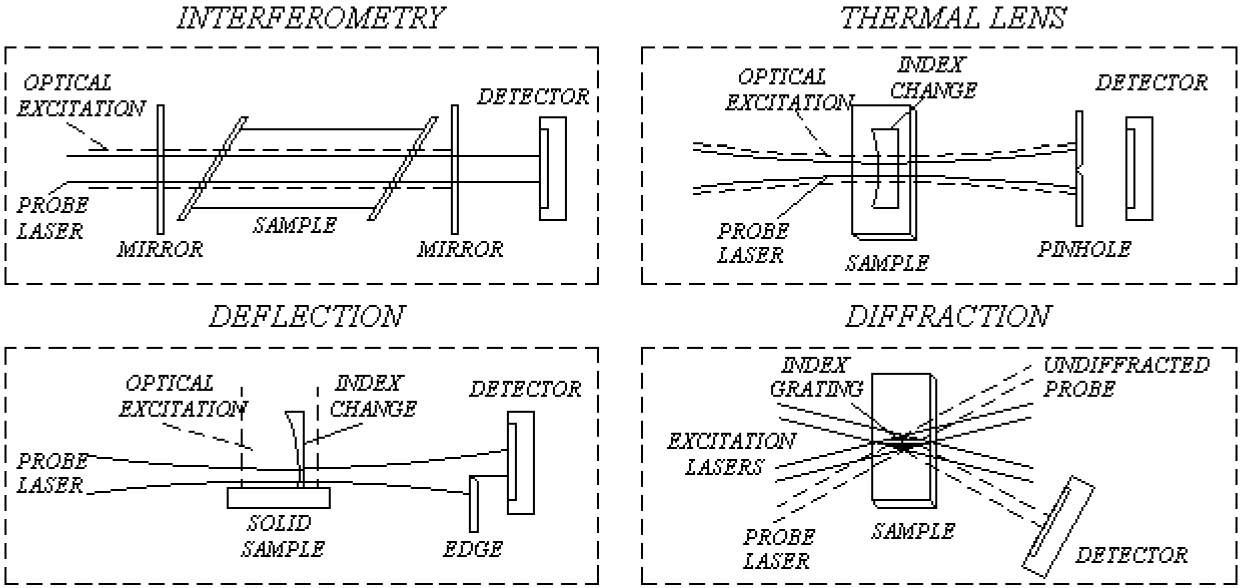

Interferometry directly measures the refractive index. Deflection measures the gradient. Thermal lens spectroscopy is based on beam focusing or defocusing. Diffraction methods measure the power of a beam diffracted by the periodic index.

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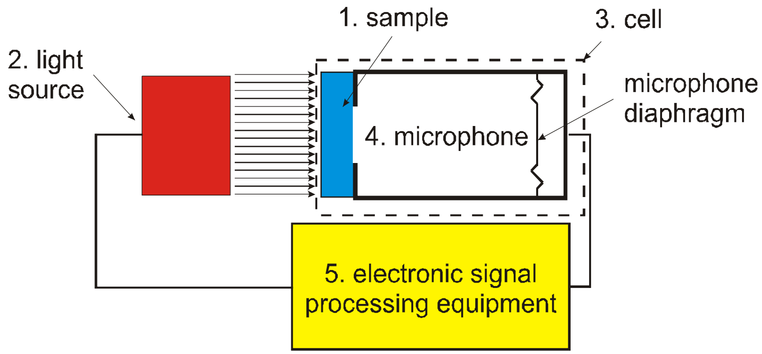

In photoacoustics modulation of the light impinging on an absorbing substance will produce a similar modulation in temperature through the photothermal effect. In a gas of restricted volume, temperature modulation produces a pressure modulation. The periodic pressure modulation is an acoustic signal.

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Temperature Distributions in Semiconductors

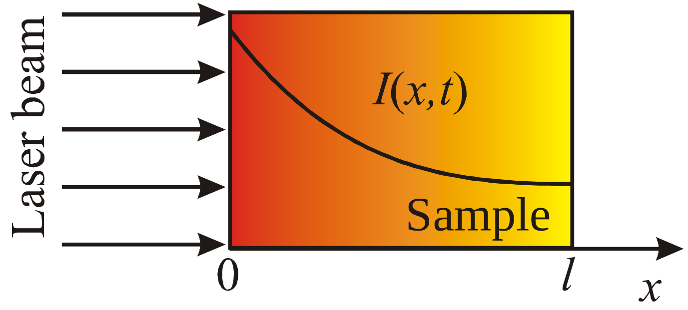
$$j_Q(x,t) = -k\frac{\partial T}{\partial x}$$

$$\frac{\partial j_Q}{\partial x} + \rho c\frac{\partial T}{\partial t} = 0$$

$$\frac{\partial T}{\partial t} = D_T\frac{\partial^2 T}{\partial x^2}$$

$$D_T = \frac{k}{\rho c}$$

Sample Heating



$$I = I_0\,\mathrm{Re}\left(1 + e^{i\omega t}\right)$$

$$T(x,t) = T_{dc}(x) + \mathrm{Re}\left(T(x)e^{i\omega t}\right)$$

Steady state

$$\frac{\partial^2 T_{dc}}{\partial x^2} = 0$$

Modulated

$$\frac{\partial^2 T}{\partial x^2} - \frac{i\omega}{D_T}T = 0$$

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Temperature Distributions in Semiconductors

$$\frac{d^2T_s(x)}{dx^2}-\sigma^2T_s(x)=-\frac{1}{k}\left[\frac{\varepsilon-\varepsilon_g}{\varepsilon}\beta I_0\exp(-\beta x)-\frac{\varepsilon_g}{\tau}\delta n_p(x)\right]$$

a) $$-k\frac{\partial T(x)}{\partial x}\Big|_{x=0}=s_1 dn_p(0)\varepsilon_g$$

b) $$-k\frac{\partial T(x)}{\partial x}\Big|_{x=l}=-s_2 dn_p(l)\varepsilon_g$$

$$T_{therm}(x)=\frac{I_0}{k}\frac{\varepsilon-\varepsilon_g}{\varepsilon}\frac{\beta}{\beta^2-\sigma_i^2}\left[b\frac{e^{\sigma_i(x-l)}+e^{-\sigma_i(x-l)}-e^{-\beta l}\left(e^{\sigma_i x}+e^{-\sigma_i x}\right)}{e^{\sigma_i l}-e^{-\sigma_i l}}-e^{-\beta x}\right]$$

$$T_{br}(x)=\frac{\varepsilon_g B_1}{\tau k\sigma_i^2}\left\{\frac{B_2e^{\sigma_i x}+B_3e^{-\sigma_i x}}{e^{\sigma_i l}-e^{-\sigma_i l}}-\frac{1}{c^2-1}\left[\frac{\delta n_p(x)}{B_1}+\frac{b^2-c^2}{b^2-1}e^{-\beta x}\right]\right\}$$

$$T_{sr}(x)=\frac{2\varepsilon_g}{k\sigma}\frac{s_1\delta n_p(0)\cosh[\sigma(x-l)]+s_2\delta n_p(l)\cosh(\sigma x)}{e^{\sigma l}-e^{-\sigma l}}$$

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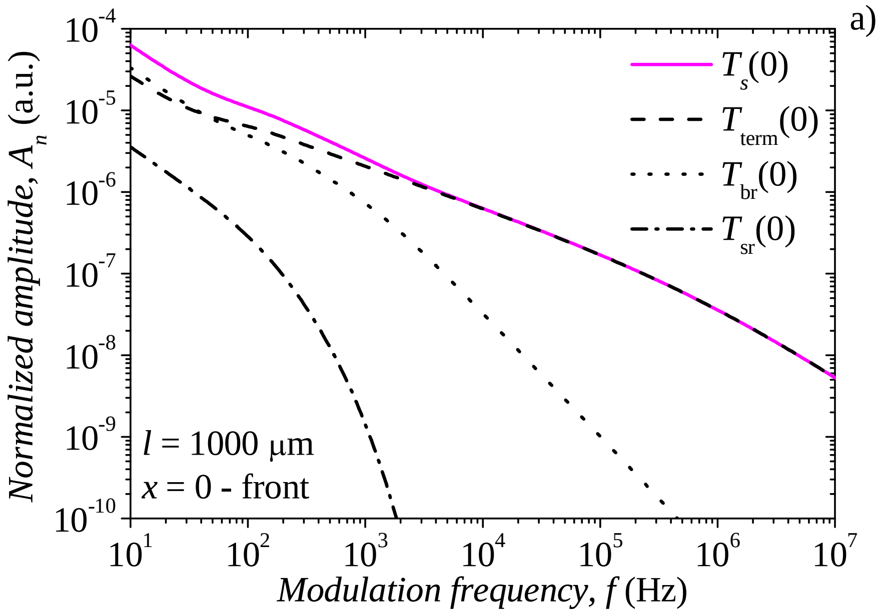
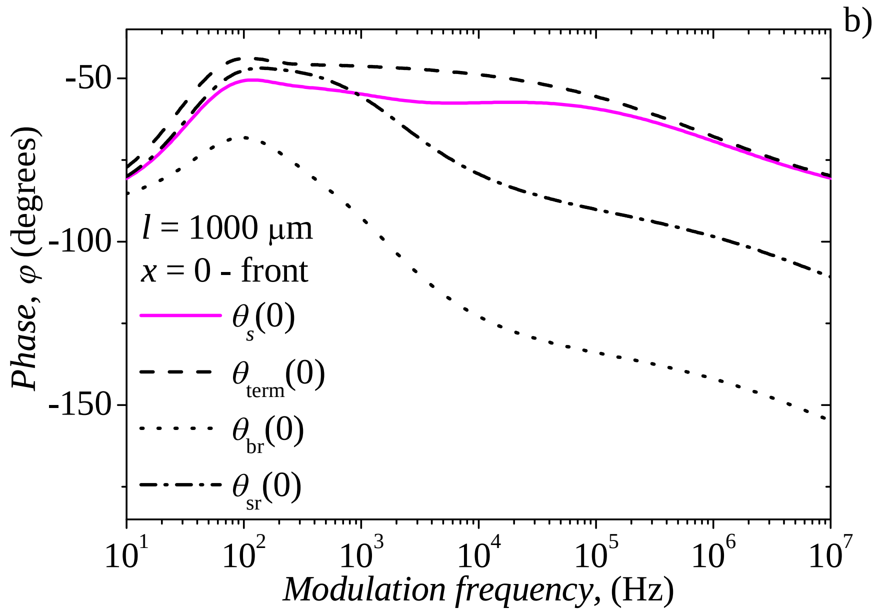
Temperature Distributions in Semiconductors – at front (0) and back (*l*)

$$T_s(0) = T_{therm}(0) + T_{br}(0) + T_{sr}(0)$$





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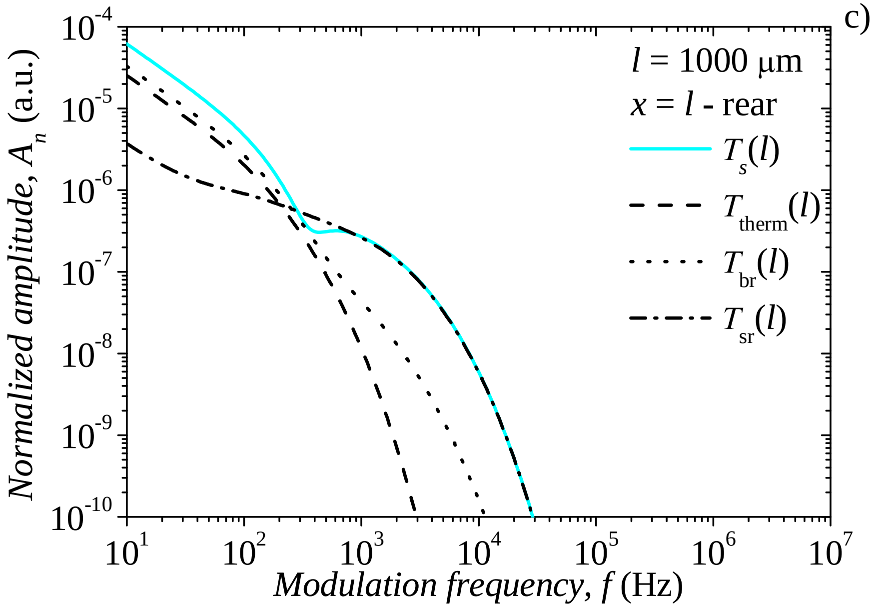
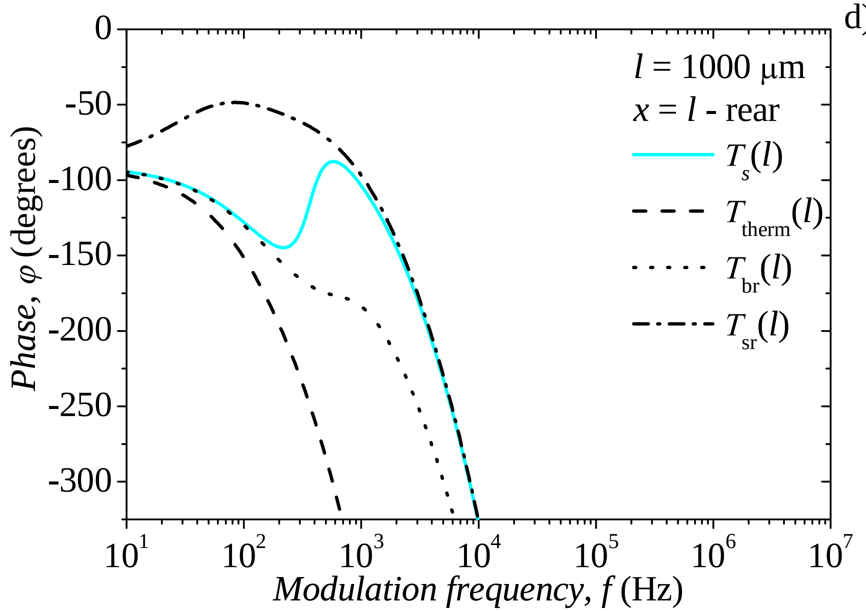
Temperature Distributions in Semiconductors – at front (0) and back (l)

$$T_s(l) = T_{therm}(l) + T_{br}(l) + T_{sr}(l)$$





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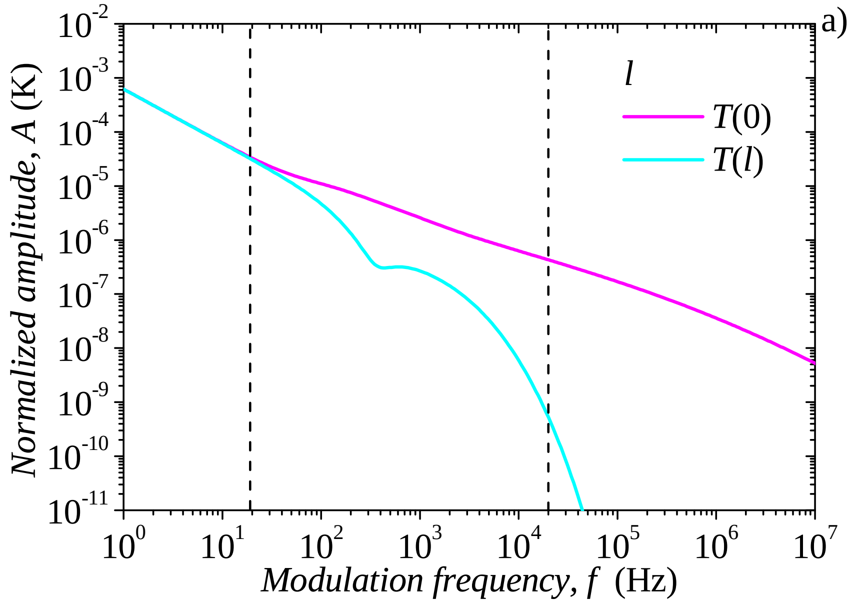
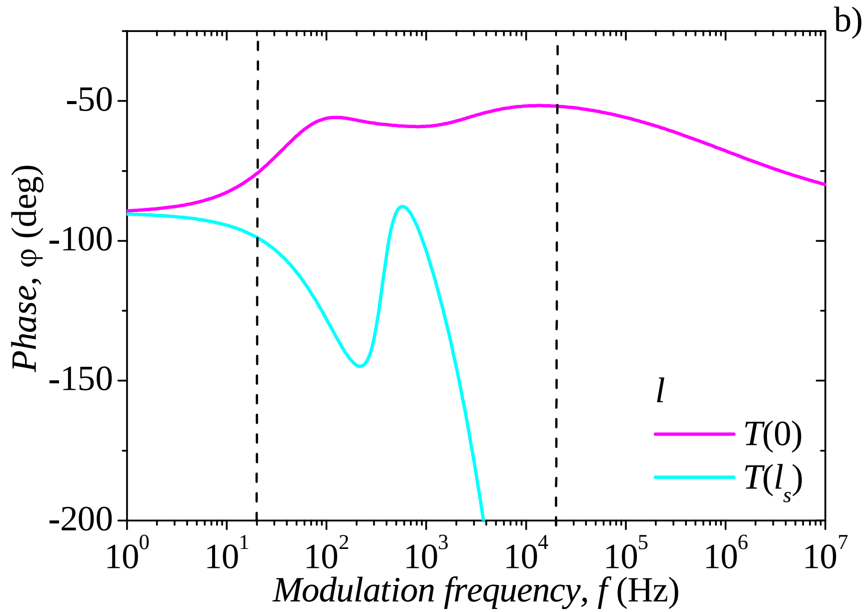
Temperature Distributions in Semiconductors – at front (0) and back (*l*)

$$T_s(x) = T_{\text{therm}}(x) + T_{\text{br}}(x) + T_{\text{sr}}(x)$$





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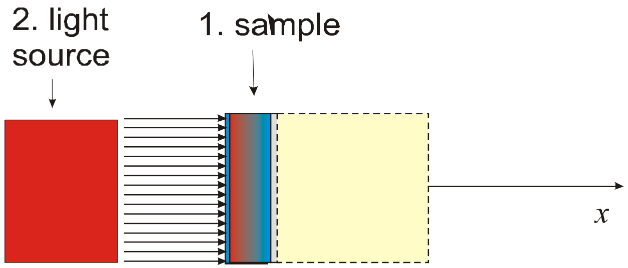
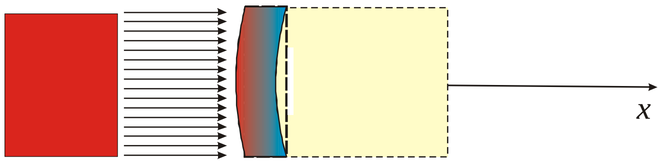
Photoacoustic Signal Generation in Semiconductors



$$\delta p_{\mathrm{TD}}(f) = \frac{\gamma_{\mathrm{g}} p_0 \sqrt{D_g}}{l_c T_0 \sqrt{2\pi f}} T_s(l)$$



$$\delta p_{\mathrm{TE}}(f) = 3\pi \cdot \alpha \frac{\gamma_{\mathrm{g}} p_0}{V_0} \frac{R_s^4}{l^3} \int_0^l \left(x - \frac{l}{2} \right) \cdot T_s(x) \mathrm{d}x$$

$$\delta p_{\mathrm{PE}}(f) = 3\pi \cdot d_n \frac{\gamma_{\mathrm{g}} p_0}{V_0} \frac{R_s^4}{l^3} \int_0^l \left(x - \frac{l}{2} \right) \cdot n(x) \mathrm{d}x$$

$$\delta p(f) = \delta p_{\mathrm{TD}}(f) + \delta p_{\mathrm{TE}}(f) + \delta p_{\mathrm{PE}}(f)$$

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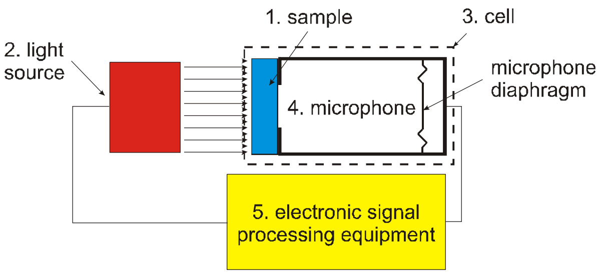
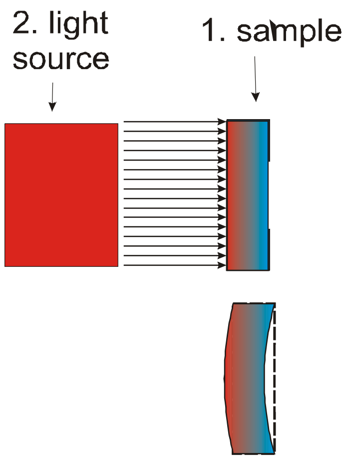
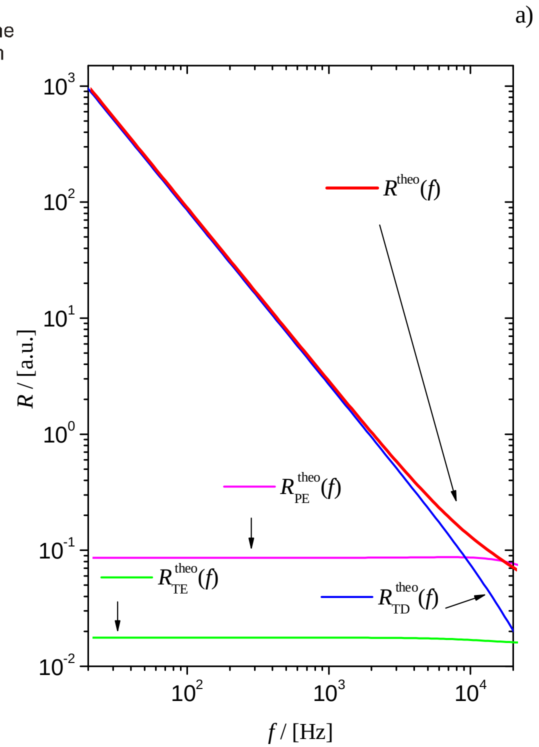
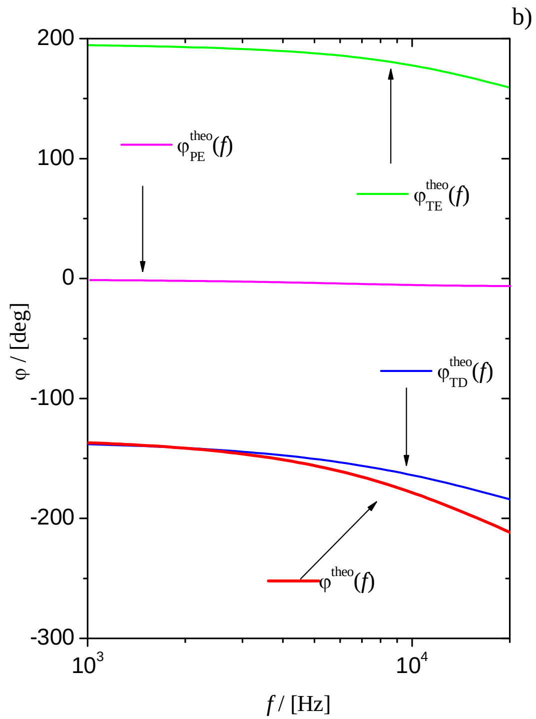




Si sample, thin plate





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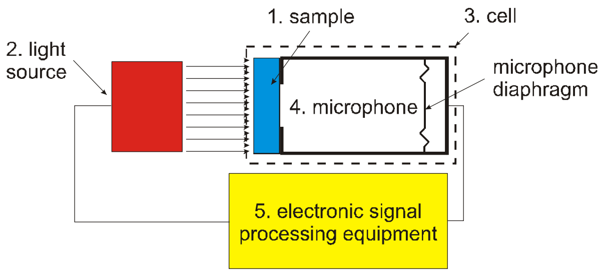
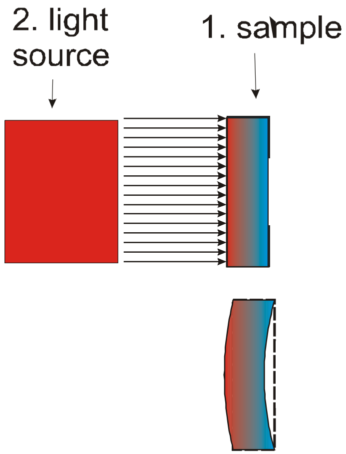
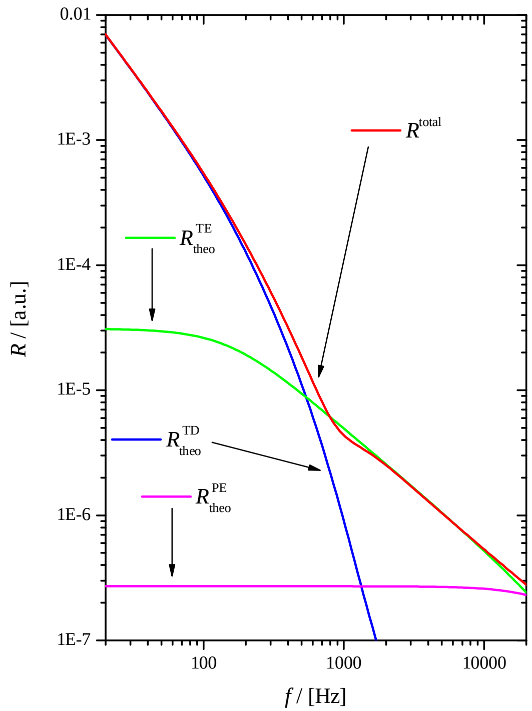
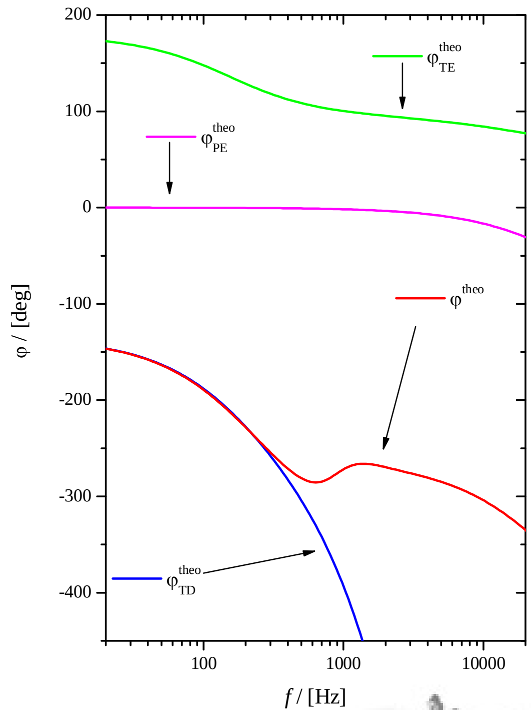




Si sample, thick plate





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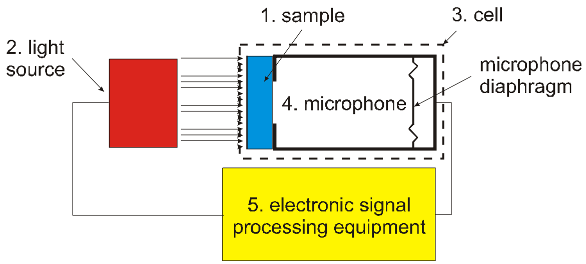
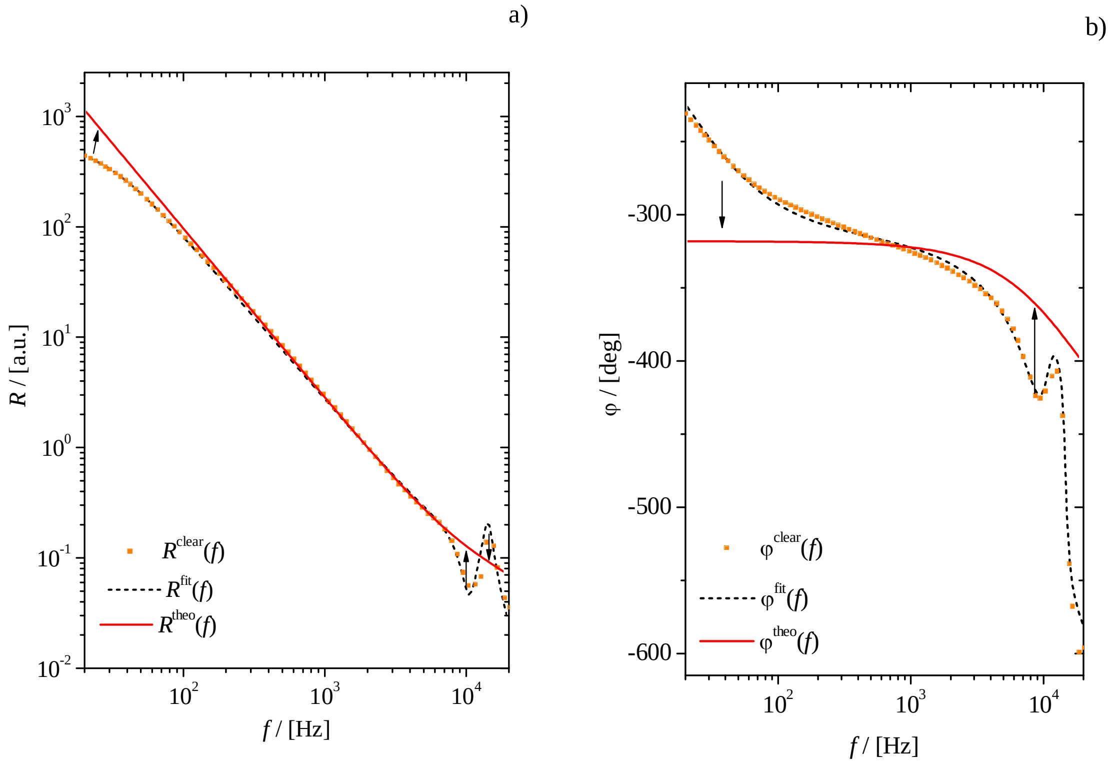
Open photoacoustic cell technique: Measurement procedure





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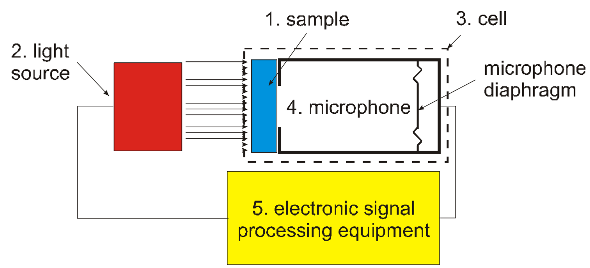
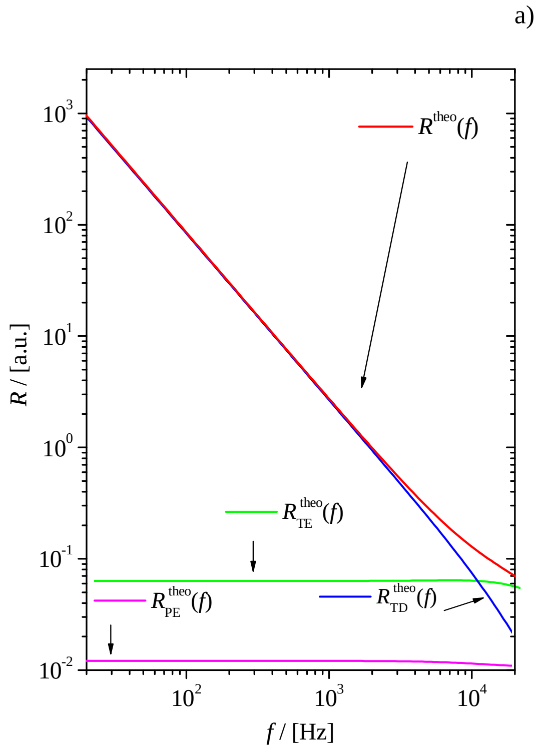
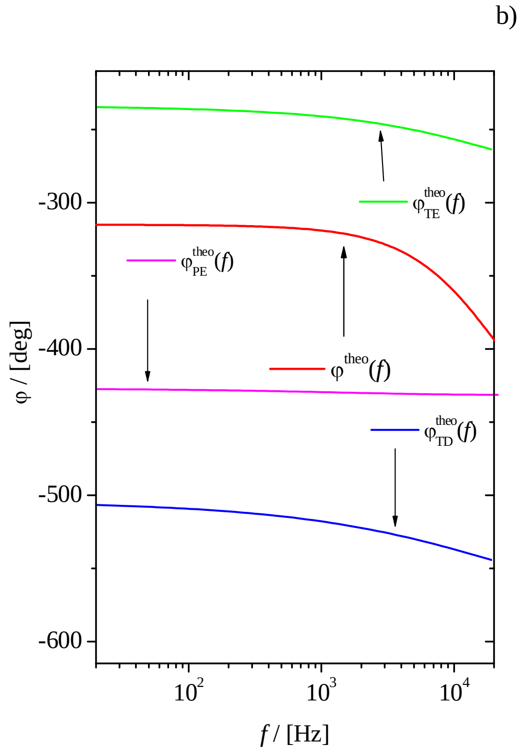
Open photoacoustic cell technique: Measurement procedure – macro and microstructures







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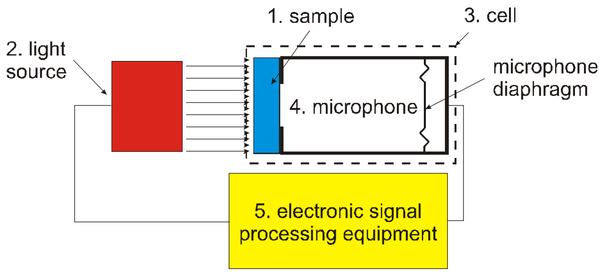
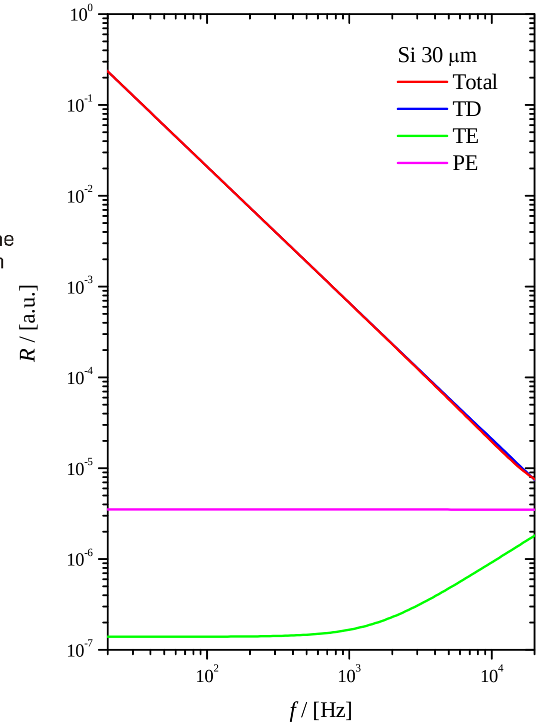
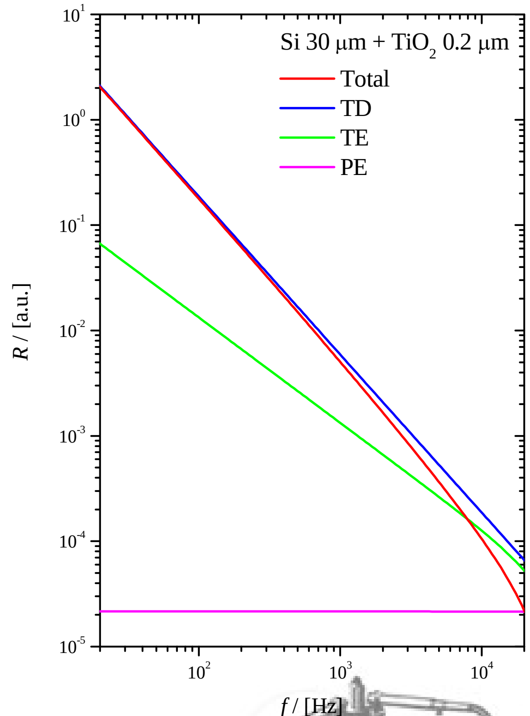
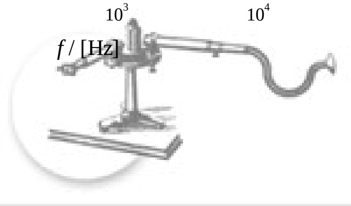
Open photoacoustic cell technique: Measurement procedure – micro- and nano-structures

Si 30 mm one-layer system   Si +TiO_2 two-layer system









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