TEMPERATURE DISTRIBUTION AND IT'S INFLUENCE ON PIEZO-PAS CHARACTERISTICS THEORETICAL APPROACH

M.Maliński
Faculty of Electronics, Technical University of Koszalin
17 Partyzantów St Koszalin, Poland.

The General Temperature Distribution Equation **T(x,β,l,α,f,R)** describes the spatial distribution of the periodical contribution of the temperature alongside the thickness of one layer sample placed on a thermally thick backing material thermally conducting or insulating.

Descriptions: **x**- coordinate, **β**- optical absorption coefficient, l- thickness of the sample , **α**- thermal diffusivity, **f**- frequency of modulation , **R**- thermal reflection coefficient sample-backing.

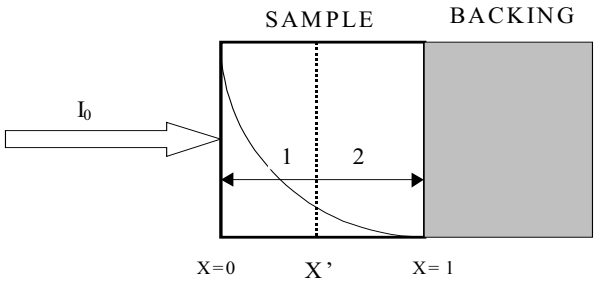


Fig.1. The schematic diagram of the theoretical situation considered.

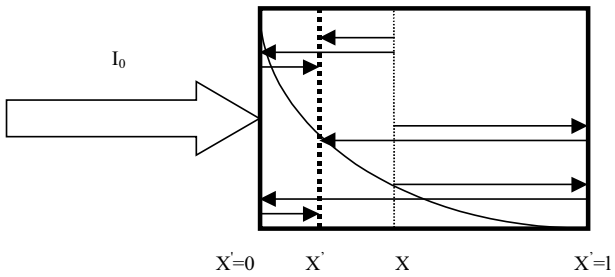


Fig.2. Schematic presentation of the four thermal wave contributions to the temperature T(x')- at the point x'. X-notes the place of the original generation of the temperature. An assumption x>x'.

$$T(x',t) = T(x') \cdot \exp(i \cdot \omega \cdot t)$$

Insulating Backing Material.

$$T(x') = \frac{\beta \cdot I_0}{2 \cdot \lambda \cdot \sigma \cdot (1 - \exp(-2 \cdot \sigma \cdot l))} \cdot \left[M(x') + N(x')\right]$$

$$M(x') = \frac{\left[\exp(\sigma \cdot x') + \exp(-\sigma \cdot x')\right] \cdot \left[\exp((-\sigma - \beta) \cdot x') - \exp((-\sigma - \beta) \cdot l)\right]}{\beta + \sigma}$$

$$+ \frac{\exp(-2 \cdot \sigma \cdot l) \cdot \left[\exp(\sigma \cdot x') + \exp(-\sigma \cdot x')\right] \cdot \left[\exp((\sigma - \beta) \cdot x') - \exp((\sigma - \beta) \cdot l)\right]}{\beta - \sigma}$$

$$N(x') = \frac{\left[\exp(-\sigma \cdot x') + \exp(-2 \cdot \sigma \cdot l + \sigma \cdot x')\right] \cdot \left[1 - \exp((-\sigma - \beta) \cdot x')\right]}{\beta + \sigma}$$

$$+ \frac{\left[\exp(-\sigma \cdot x') + \exp(-2 \cdot \sigma \cdot l + \sigma \cdot x')\right] \cdot \left[1 - \exp((\sigma - \beta) \cdot x')\right]}{\beta - \sigma}$$

All Backing Materials.

$$T(x') = \frac{\beta \cdot I_0}{2 \cdot \lambda \cdot \sigma \cdot (1 - R \cdot \exp(-2 \cdot \sigma \cdot l))} \cdot \left[M(x') + N(x')\right]$$

$$M(x') = \frac{\left[\exp(\sigma \cdot x') + \exp(-\sigma \cdot x')\right] \cdot \left[\exp((-\sigma - \beta) \cdot x') - \exp((-\sigma - \beta) \cdot l)\right]}{\beta + \sigma}$$

$$+ \frac{R \cdot \exp(-2 \cdot \sigma \cdot l) \cdot \left[\exp(\sigma \cdot x') + \exp(-\sigma \cdot x')\right] \cdot \left[\exp((\sigma - \beta) \cdot x') - \exp((\sigma - \beta) \cdot l)\right]}{\beta - \sigma}$$

$$N(x') = \frac{\left[\exp(-\sigma \cdot x') + R \cdot \exp(-2 \cdot \sigma \cdot l + \sigma \cdot x')\right] \cdot \left[1 - \exp((-\sigma - \beta) \cdot x')\right]}{\beta + \sigma}$$

$$+ \frac{\left[\exp(-\sigma \cdot x') + R \cdot \exp(-2 \cdot \sigma \cdot l + \sigma \cdot x')\right] \cdot \left[1 - \exp((\sigma - \beta) \cdot x')\right]}{\beta - \sigma}$$

This equation can be treated as a general temperature distribution equation. It comprises several specific cases known in literature as special cases of the presented equation.

Specific temperature values on the front & rear surface.

a)T(x=0,l,β,R)- temperature front equation Bennett & Patty
b)T(x=l,l,β,R)- temperature rear equation
c)T(x=0,l=∞,β)-temperature front model of Ouzafe
d)T(x=0,l,β=∞) and T(x=l,l,β=∞)- temperature front & rear of the opaque samples respectively-model of Leite et al.

Specific temperature distributions.

Temp. distribution in an opaque half infinite sample ***T(x, β=∞, l=∞).***

$$T^*(X') = \frac{I_0}{\lambda \cdot \sigma} \cdot \exp(-\sigma \cdot X')$$

Temp. distribution in a half infinite sample ***T(x, β ,l=∞)***

$$T^*(X') = \frac{\beta \cdot I_0}{\lambda \cdot \sigma} \cdot \left[\frac{\exp(-\sigma \cdot X') + \exp(-\beta \cdot X')}{\beta + \sigma} + \frac{\exp(-\sigma \cdot X') - \exp(-\beta \cdot X')}{\beta - \sigma} \right]$$

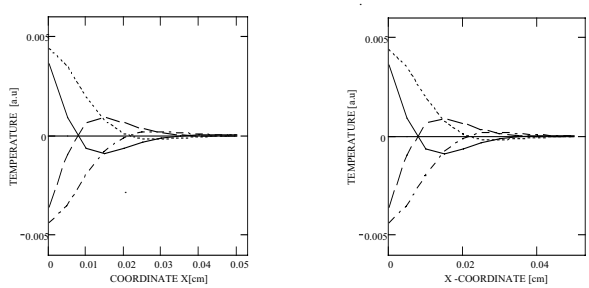
Temp. distribution in an opaque sample. ***T(x,β=∞, l).***

$$T^*(X') = \frac{I_0}{\lambda \cdot \sigma} \cdot \left[\frac{\exp(\sigma \cdot (l - X')) + \exp(-\sigma \cdot (l - X'))}{\exp(\sigma \cdot l) - \exp(-\sigma \cdot l)} \right]$$

Temp. distribution in a finite transparent sample, ***T(x, l, β≈0).***

$$T^*(x) = \frac{I_0}{\lambda \cdot \sigma^2}$$

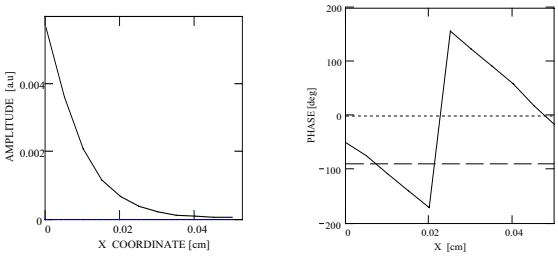
Practical temp. distributions (Case of GaAs)



R=1 R= -1

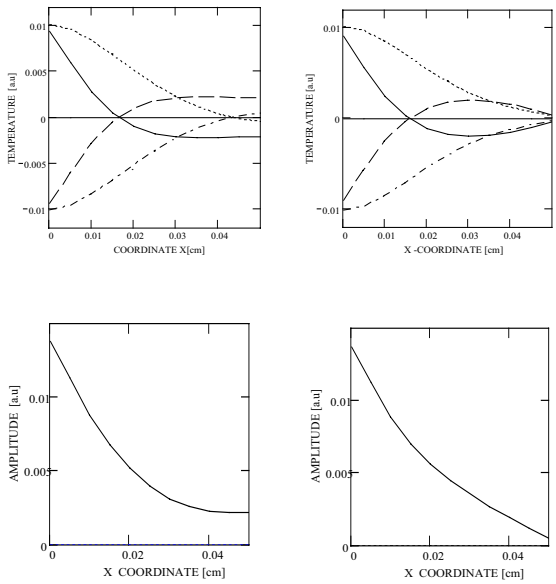
Parameters: α=0.1cm^2/sec,f=400 Hz, l=0.053 cm, β=1000 cm^{-1}

Description : solid line t=0, dotted t=T/4
Dash t=2T/4,dashdot t=3T/4
Amplitude and phase distributions at 400 Hz.



Instantenous temperature & temperature amplitude distributions at 77 Hz.

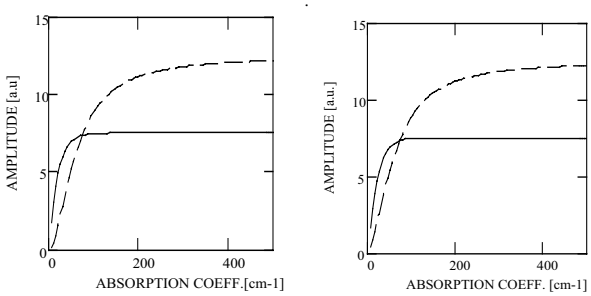
R=1 *R= -1*



The origin of the piezo detected spectra. Modified Jackson & Amer Equation.

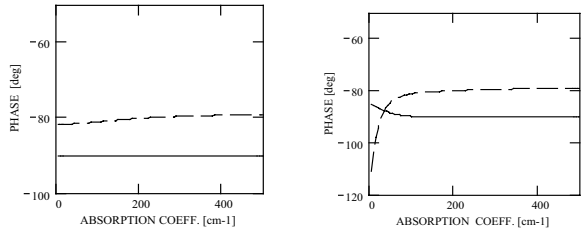
$$S = \left(\frac{1}{l}\cdot\int_0^l T(x)\cdot dx - \frac{1}{2\cdot r^2}\cdot\int_0^l\left(\frac{l}{2}-x\right)\cdot T(x)\cdot dx\right)\cdot(-1)$$

S = PISTON (solid line) - DRUM (dash line)



R=1 R= -1

Amplitudes of piston and drum vs optical absorption coefficient for different backing materials.

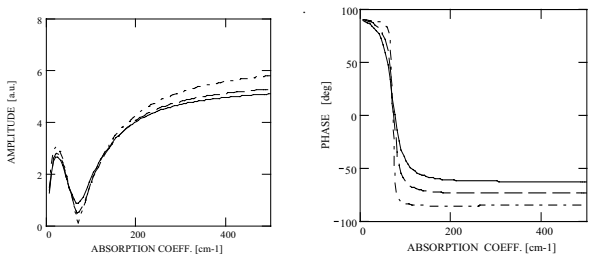


R=1 R= -1

Phase spectra of piston and drum vs optical absorption coeff.

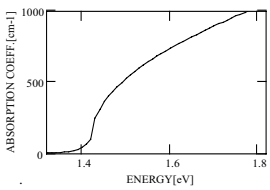
FULL DRUM EFFECT (amplitude & phase)

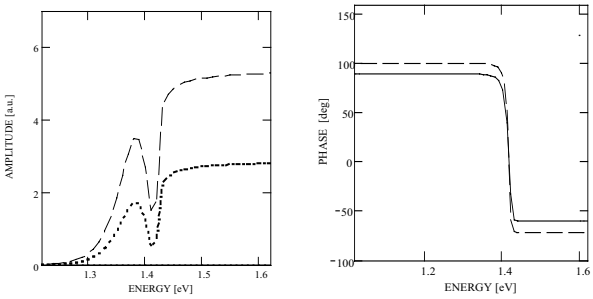
The piezo-detected PA spectra both amplitude ad phase can be computed in the domain of the optical absorption coefficient as shown below.



ENERGETIC AMP. & PHASE SPECTRA OF GaAs

The piezo detected PA amplitude and phase spectra can be also computed in the domain of the energy of the absorbed photons. It can be performed only when the dependance of the optical absorption coefficient versus the photon energy is assumed.(see the figure below)





Description: dash line f=400 Hz, dotted 800 Hz.

The figures above show the computed piezo PA spectra of GaAs both amplitude and phase. The results of computations agree very well with the spectra observed experimentally.

The amplitude spectra sxhibit characteristic hump at about 1.385 eV whose origin was discussed in the literature of the subject. In the model presented in this paper the hump is the result of pure mechanical vibrational modes of the sample and not of the electron levels below the energy gap of GaAs.