„The comparison of sensivities of different photoacoustic approaches in the field of determination of the thermal diffusivity"

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In this paper the analysis of the sensitivity of different frequency domain photoacoustic approaches on the changes of the thermal diffusivity of the measured material is shown and discussed. For the analysis of accuracies and sensivities the least square fitting method was applied.
From the point of view of determination of the thermal diffusivity from the frequency domain amplitude and phase characteristics the range of frequencies applied is one of the most important factors that determines the accuracy of its determination.
The optimal range of the frequancies applied is determined by the thermal diffusivity of a measured material and its thickness and is determined by the characteristic frequency $f_0=\alpha/(2\pi d^2)$.
The sensitivity of a given approach was estimated from the minimum of the Sum of Square Errors defined below:

$$SSE = \sqrt{\frac{\sum_{n=1}^{N}\left[PAS(f_n, f0\cdot(1+p)) - PAS(f_n, f0)\right]^2}{N-1}}$$

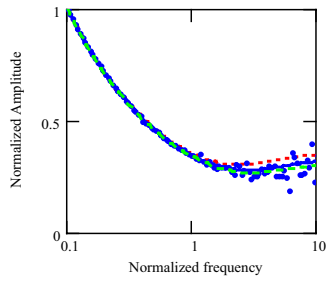
where p is the percentage change of f_0 and it is represented by solid lines on the figures. SSE values were compared with the values of the SSEN parameter defined below (dotted line on the figures).

$$SSEN = \sqrt{\frac{\sum_{n=1}^{N}\left[PAS(f_n, f0\cdot(1+p)) - PASN(f_n, f0)\right]^2}{N-1}}$$

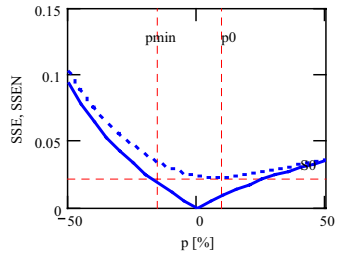
SSEN is the sum of square errors between the theoretical value calculated for fo with the Noise. For amplitude characteristics the normal distribution type Noise in the range ±2% of the amplitude at the frequency f=fo was taken.
For phase characteristics the normal distribution type Noise in the range ±2deg was taken.
The minimum value of SSEN gives the average, expected value of f0. The value of SSE equal to the value of SSEN in the point of minimum gives the accuracy of determination of the f0 (f0∈[pmin,pmax]).

Investigated cases

1. Front amplitude method: f range 0.1f0÷10f0.



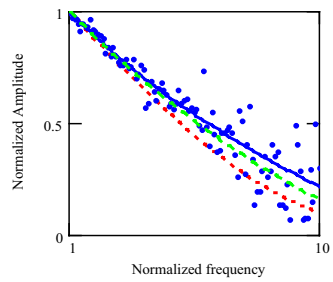
a)



b)

Fig. 1 a) Amplitude of PA signal vs. the frequency of modulation b) SSE and SSEN vs p- the percentage change of f0

2. Amplitude rear method: f range f0÷10f0.



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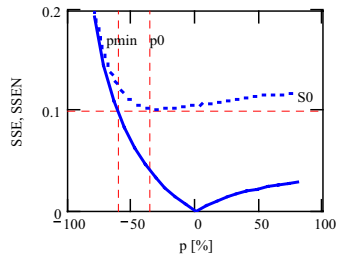
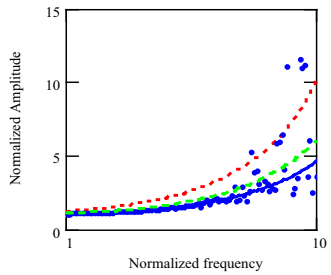


b)

Fig. 2 a) Amplitude of PA signal vs. the frequency of modulation b)SSE and SSEN vs p- the percentage change of f0

3. Amplitude Ratio Sf/Sr method: f range f0÷10f0.

Sf is the amplitude of the PA signal measured in the front configuration regime. Sr is the amplitude of the PA signal measured in the rear configuration regime.



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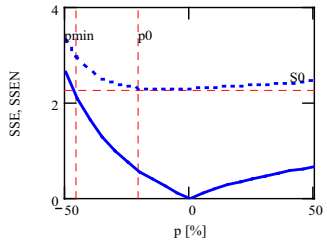
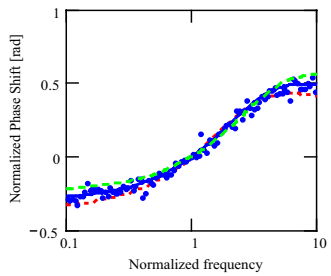


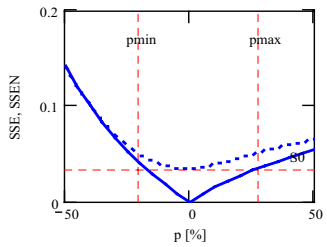
b)

Fig. 3 a) Amplitude ratio of Sf and Sr PA signals vs. the frequency of modulation b) SSE and SSEN vs p- the percentage change of f0

4. Phase front method: f range 0.1f0÷10f0



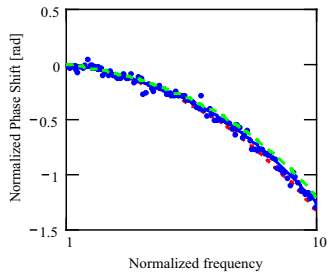
a)



b)

Fig. 4 a) Phase of PA signal vs. the frequency of modulation b) SSE and SSEN vs p- the percentage change of f0

5. Phase rear method: f range f0÷10f0



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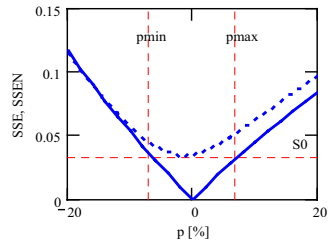
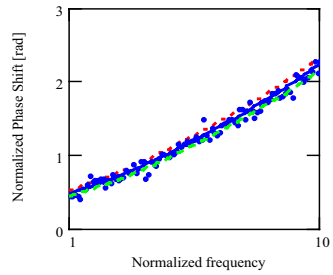


b)

Fig. 5 a) Phase of PA signal vs. the frequency of modulation b) SSE and SSEN vs p- the percentage change of f0

6. Phase Lag method: f range f0÷10f0



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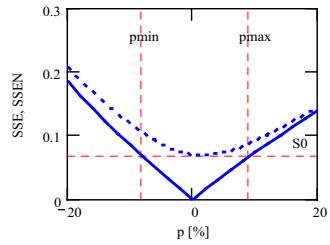

b)

Fig. 6 a) Phase Lag of PA signal vs. the frequency of modulation b) SSE and SSEN vs p- the percentage change of f0

Summary

The table below shows the comparison of percentage errors of determination of thermal diffusivities obtained by different photoacoustic measurement methods.

	pmin	p0	pmax
Phase Rear	-7%	0%	+7%
Phase Lag	-8%	0%	+9%
Phase Front	-28%	0%	+20%
Amplitude Front	-15%	+10%	+30%
Amplitute Rear	-60%	-35%	Not defined
Amplitude Ratio Sf/Sr	-45%	-20%	Not defined

It comes out from the comparision that the most accurate results can be obtained by the phase methods (p0=0%). Amplitude methods give systematic errors in the range from +10% to –35%.

Literature

[1] Z.Suszyński M.Maliński L.Bychto ‘ Thermal Measurement Method of Electronic Materials’. IEEE Transactions on Components, Packaging and Manufacturing Technology’ Part A Vol 21, No.3 September 1998.