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Evaluation of Thermophysical Properties of Semiconductors by Photoacoustic Phase Neural Network

Katarina Lj Djordjevic[1], Slobodanka P Galović[1], Miroslava I Jordović-Pavlović[2], Dragan D Markushev[3], Dragana K Markushev[3], Mioljub V Nešić[1], Marica N Popović[3]

[1]University of Belgrade, „VINČA" Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, PO box 522, 11000 Belgrade, Serbia

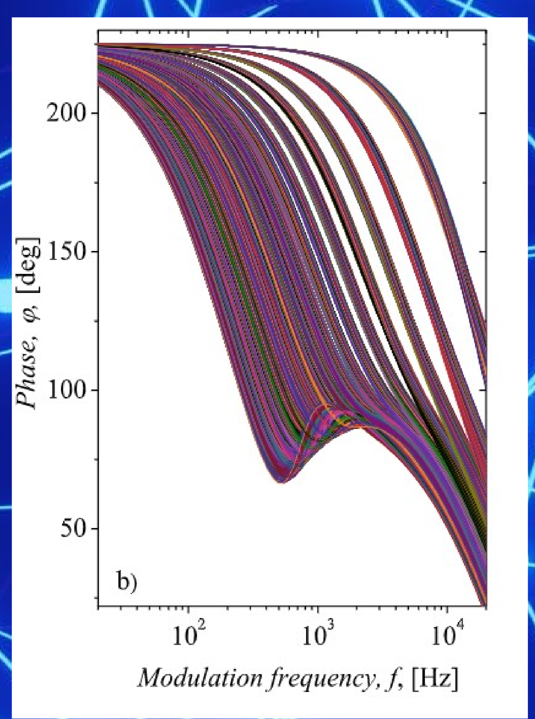
[2]College of Applied Sciences Užice, Trg svetog Save 34, Uzice, Serbia

[3]University of Belgrade, Institute of Physics Belgrade, National Institute of the Republic of Serbia, Pregrevica 118, 11080 Belgrade (Zemun), Serbia

Abstract

The idea of this paper is to develop a method for determination thermal diffusivity, linear expansion coefficient and thickness of a semiconductor sample from photoacoustic phase measurement by using neural network. The neural network has been trained on a large basis of photoacoustic phases obtained from a theoretical Si n-type model in the range of 20Hz to 20kHz. The advantages of using a phase neural network with high accuracy and precision in prediction depending on the number of epochs are presented, as well as analyzes of the application of random Gaussian noise to the network in order to better predict the experimental photoacoustic signal. An analysis of a theoretical photoacoustic model with a phase neural network is demonstrated.

For the analysis of parameter determination from phases, we trained phase neural networks on a large database obtained from theoretical model for a silicon sample in the expected range of parameter changes:



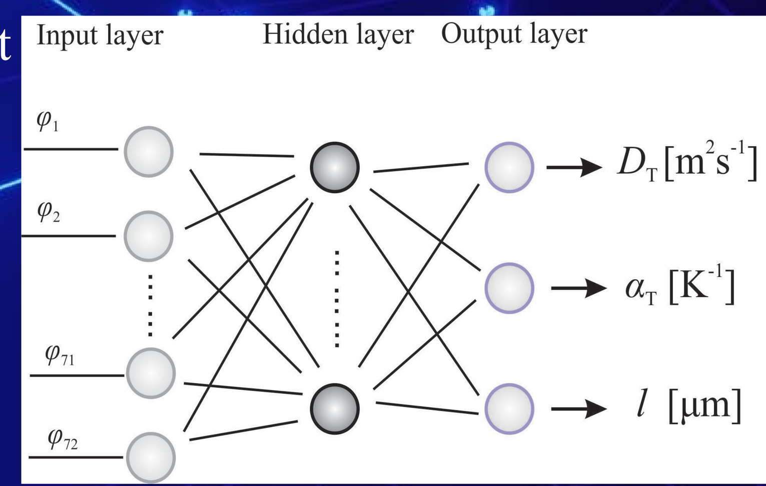
$D_T = (8.1-9.9)\cdot 10^{-5}\mathrm{m^2s^{-1}}$

$\alpha_T = (2.34-2.86)10^{-6}K^{-1}$

$l = (1-10)\cdot 10^{-4}\mathrm{m},$

Experimental signals for three silicon samples with a radius of RS=4mm and a thickness of 830μm, 417μm and 128μm were measured with an open photoacoustic cell.

The base of training and test of neural networks consists of 5491 phases of photoacoustic signals, from which 110 were extracted for the I test.
The same database was used to form neural networks with a certain % of noise, where random Gaussian noise with a different level (1-5)% was placed on each phase.



The networks had 72 neurons in the input layer, the number of neurons in the hidden layer was 50, and the number of output neurons was the same, 3, and represents the semiconductor parameters D_T, α_T and l.

Table1. Performance and number of training epochs of networks on signals with a certain % noise level.

Noise	performance	epoch
0	0.0000017246	1000
1%	0.0158	44
2%	0.037952	9
3%	0.052391	8
4%	0.072174	6
5%	0.070721	5

By increasing the percentage of noise, the network trains for a shorter time (reduces the number of epochs), which leads to faster termination of training.

Table 2. The % relative errors, max and averaged parameter prediction (D_T, α_T and l) for phasic neural networks with specified % noise level .

ITest	max % error			average % error		
	D_T	α_T	l	D_T	α_T	l
0	0.0273	0.0542	0.0488	0.0040	0.0137	0.0041
1%	4.9486	4.0797	2.6102	0.6748	0.7016	0.3984
2%	10.7968	7.8927	6.0712	2.0360	2.3332	1.0478
3%	11.8123	7.9326	5.3684	2.7558	2.8824	1.2435
4%	10.3026	7.8952	7.6432	3.0014	2.9103	2.5467
5%	10.8236	8.5714	7.6446	3.4590	3.1694	1.8964

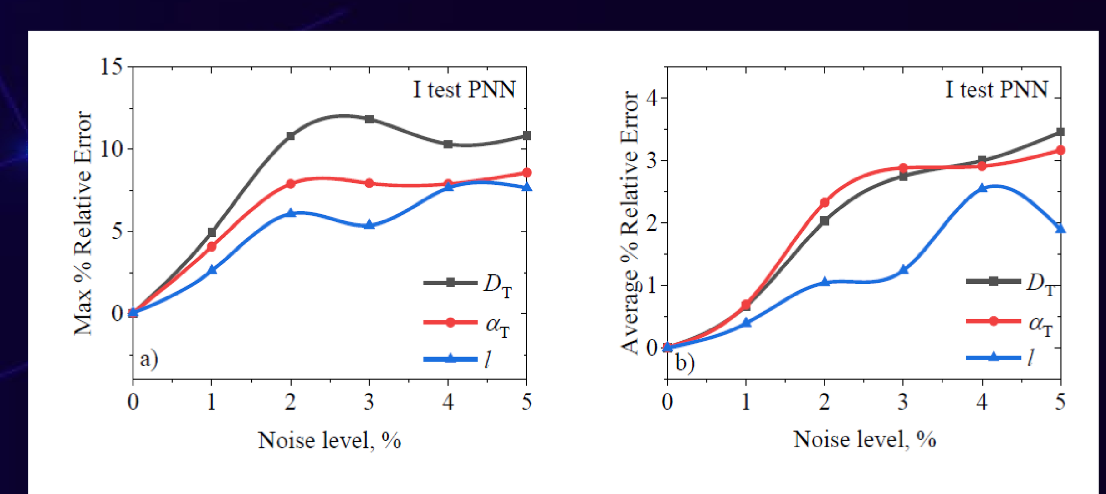


Fig 1. Max and average % parameter prediction error for thermal diffusivity D_T, expansion α_T and thickness l from 110 phases of photoacoustic signals (I test) taken from the data-base before training with different % noise level.

Test I: The network with the lowest noise level (0) has the lowest error and that the errors tend to increase with the increase of the noise level.

Table 3. The % relative errors, max and averaged parameter prediction (D_T, α_T and l) for phasic neural networks with specified % noise level.

IITest	max % error			average % error		
	D_T	α_T	l	D_T	α_T	l
0	31.6433	15.3729	16.3180	2.3443	1.3165	1.1680
1%	6.4489	2.6458	5.2358	1.0022	0.7648	0.5999
2%	14.2476	4.7840	13.8016	1.7041	1.6064	1.2381
3%	6.7114	6.9429	5.4485	1.8062	2.3598	1.0484
4%	7.0108	7.8894	4.3250	2.2337	2.4526	2.0073
5%	8.3557	8.6263	6.7657	2.6509	2.6872	1.3180

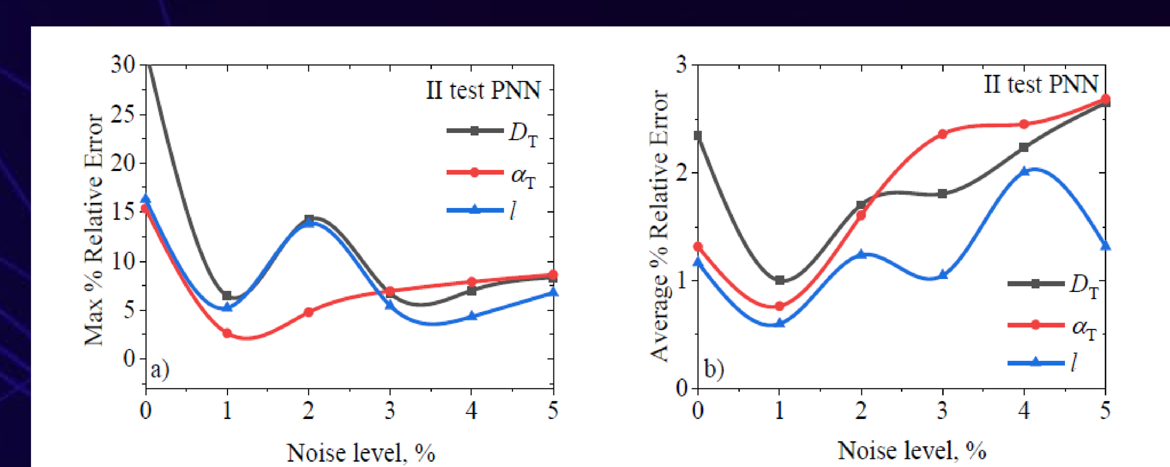


Fig 2. Max and average % parameter prediction error for thermal diffusivity D_T, expansion α_T and thickness l from 24 random phases of photoacoustic signals (II test)

Test II is a test on phases randomly selected from the range of the parameter. The network without added noise has the largest error on the phases of samples of small thicknesses. By adding noise (1%) thin sample errors are reduced to the optimal level for this test and then (>1%) tend to increase.

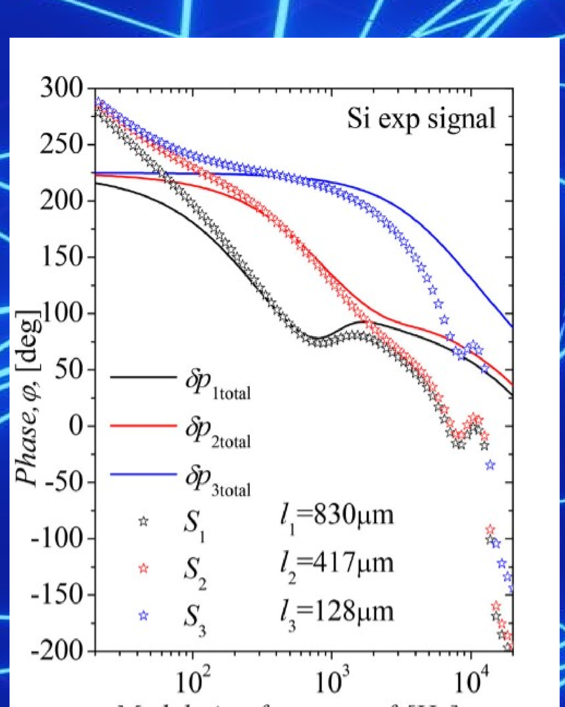


Table 4. Prediction of three parameters by phase neural networks (with certain % noise level) and relative % prediction error of three samples

PNN	Sample no.1 (830μm)			Sample no.2 (417μm)			Sample no.3 (128μm)		
parameters	D_T^{ANN}	α_T^{ANN}	l^{ANN}	D_T^{ANN}	α_T^{ANN}	l^{ANN}	D_T^{ANN}	α_T^{ANN}	l^{ANN}
unit	$10^{-5}\mathrm{m^2s^{-1}}$	$10^{-6}\mathrm{K^{-1}}$	$10^2\mu m$	$10^{-5}\mathrm{m^2s^{-1}}$	$10^{-6}\mathrm{K^{-1}}$	$10^2\mu m$	$10^{-5}\mathrm{m^2s^{-1}}$	$10^{-6}\mathrm{K^{-1}}$	$10^2\mu m$
0%	9.0011	2.6003	8.2997	8.9958	2.6020	4.1689	11.7889	2.2092	1.4795
Rel % error	0.0127	0.0135	0.0030	0.0464	0.0785	0.0265	30.9883	15.0313	15.5833
1%	9.0131	2.5980	8.3060	9.0610	2.5849	4.1845	9.8674	2.5442	1.3610
Rel % error	0.1457	0.0777	0.0761	0.6780	0.5819	0.3777	9.6194	2.1460	6.3307
2%	9.0009	2.5875	8.2861	9.0930	2.6061	4.1931	10.2581	2.5214	1.4117
Rel % error	0.0099	0.4800	0.1666	1.0341	0.2357	0.5538	13.9786	3.0199	10.2928
3%RGN	9.0196	2.5876	8.3133	9.0642	2.6045	4.1918	9.0941	2.6609	1.3422
Rel % error	0.2183	0.4766	0.0394	0.7130	0.1749	0.5226	1.0450	2.3427	4.8579
4%	8.9949	2.58092	8.1578	8.9099	2.6194	3.9900	8.8366	2.6089	1.2998
Rel % error	0.0569	0.7338	1.7136	1.0010	0.7477	4.3163	1.8158	0.3425	1.5488
5%	9.0141	2.5802	8.3038	8.9779	2.5904	4.1616	8.8399	2.6157	1.2026
Rel % error	0.1566	0.7605	0.0460	0.2459	0.3692	0.2023	1.7782	0.6030	6.0439

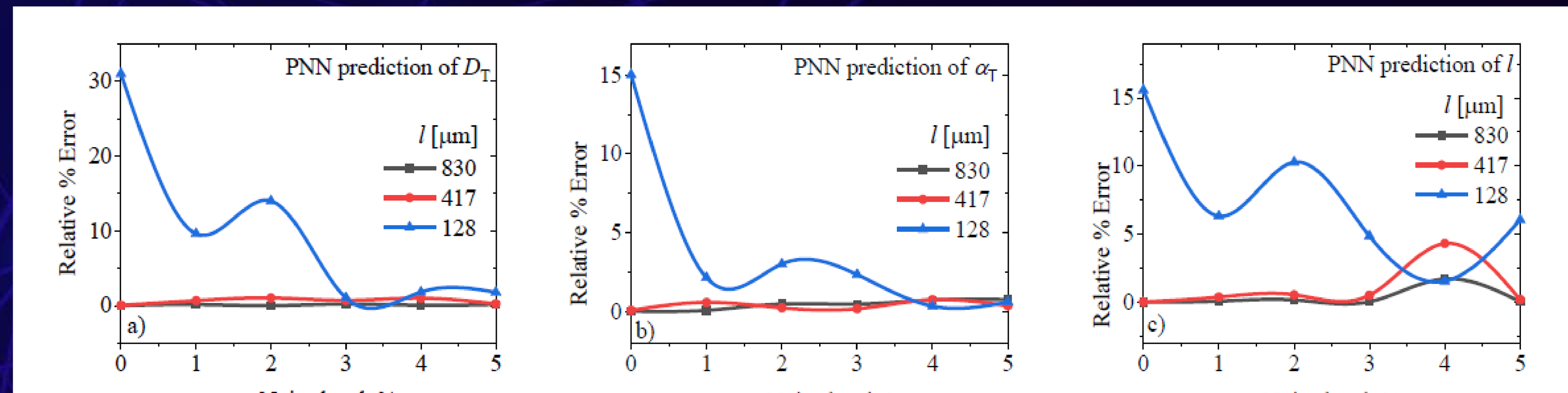


Fig 3. Relative errors %, predictions of three parameters: a) thermal diffusivity D_T^{ANN}, b) linear expansion α_T^{ANN} and c) sample thickness l^{ANN}, for three different thicknesses 830 , 417 and 128 μm.

Test on experimental stages of photoacoustic signals. Prediction errors on samples with thicknesses of 830 and 417 mm are <1% and are independent of the level of added noise
The phase network without added noise shows a large error (15-30)% of the parameter prediction. By adding noise, the prediction error drops to optimal (<2.5%) for networks (3.4)% noise.

Conclusion

This analysis shows that plasma thick samples can be characterized by a phasic neural network. For plasma thin samples, phase network prediction errors are large and can be improved by adding Gaussian noise. The networks are trained faster and the prediction errors show that the optimal noise is (3.4)% corresponding to the uncertainty of the experimental phase measurement

Acknowledgments

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[2] K. Lj. Djordjevic, D. D. Markushev, Ž. M. Ćojbašić, S. P. Galović, Inverse problem solving in semiconductor photoacoustics by neural networks, Inverse Problems in Science and Engineering (2020) 29(2):1-15, DOI 10.1080/17415977.2020.1787405