Publ. Astron. Obs. Belgrade No. 89 (2010), 147-150 *Contributed Paper*

PHOTOTHERMAL DEPTH PROFILING OF OPTICAL GRADIENT MATERIALS BY NEURAL NETWORK

MARICA POPOVIĆ[1], DRAŠKO FURUNDŽIĆ[2]
and SLOBODANKA GALOVIĆ[1]
[1]*The "Vinca" Institute of Nuclear Sciences, Mike Petrovica Alasa 12-14, 11001 Belgrade, Serbia*
E-mail: maricap,bobagal@vinca.rs
[2] *Mihajlo Pupin Institute, Volgina 15, 11000 Belgrade, Serbia*
E-mail: fudra07@gmail.com

Abstract. The mathematical model which describes dependence of optically induced temperature variations on modulation frequencies of incident laser beam is derived. By analysis of the model it is shown that measured photothermal frequency response involves information about magnitude and shape of depth variations of the sample absorption coefficient. The neural network for photothermal optical depth profilometry is suggested and developed. The numerical simulations have been carried out for suitably chosen optically gradient samples. It has been demonstrated that the suggested algorithm has high accuracy and low noise sensitivity with a short reconstruction surface time. Also, the algorithm doesn't demand the special computer resources.

1. INTRODUCTION

Photothermal (PT) methods are based on direct or indirect recording of surface temperature variations that arise from the generation and transfer of heat produced as a consequence of the absorption of laser radiation of modulated intensity by a sample, see Terasina et al. The key to depth profiling by the PT effect is that the distance of propagation of the light induce thermal waves is controlled by varying the modulation frequency. But reconstruction of the optical depth structure from PT responses hasn't been easy at all, see Power 2002 and Harata and Sawada 1989. In recent years, PT techniques have found wide applications in the depth reconstruction of the thermal transport properties while the depth profiling of the optical absorption coefficient in a laser irradiated sample (via the depth profile of heat flux deposited in the sample by light absorption) has been less commonly studied inverse problem although there are many problems of practical interest in which the sample is thermally homogeneous, and yet the optical absorption varies continously with distance from the surface. The reasons seems that the solving of optical inverse problem is too complicated and time consuming to do with microcomputer, and calculated results of depth profiles are easily diverted at deep values and are too sensitive to the noises which are inevitably contained in the original data measured.

In this paper, the mathematical model which describes dependence of optically induced temperature variations on modulation frequencies of incident laser beam is derived. Here is observed connection between surface temperature variations and depth-dependent optical absorption coefficient. By analysis of the direct model, the neural network for PT optical depth profilometry is suggested and developed. Using this network, spatial profiles of optical absorption coefficient for several suitable chosen samples are determined and accuracy and noise sensitivity of the suggested algorithm are discussed.

2. SOLUTION OF THE DIRECT FT PROBLEM FOR OPTICAL INHOMOGENEOUS STRUCTURES

Optical and thermal properties are observed on the thermally homogeneous and optical transparent structure, and its optical absorption coefficient varies continuously with the depth from the initial value γ_0 on the surface to the value γ_1 on the depth d (presented in Fig. 1). The system is excited by plane electromagnetic waves, so a one-dimensional profile of temperature change in the material, along the depth axis z, is considered. Also, we assumed the constant efficiency with which the optical energy absorbed by the solid is converted to heat via nonradiative processes, $\eta(x) = \eta_0$.

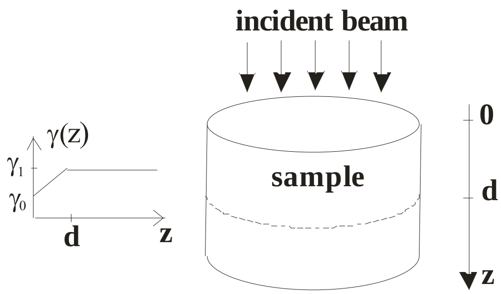

Figure 1: Schematic representation of the observed model.

It is derived expression for surface temperature variations when the optical absorption coefficient is varying randomly by PT system equation evalution, see Galovic et al.

$$\overline{\vartheta}(0,\omega) = \frac{z_{cs} I_0}{1+\overline{r}_a}\left(J_1(d) + J_2(\infty)\right)$$

where are $\overline{r}_a = \dfrac{z_{cs}}{z_{ca}}$, $J_i(z) = \int_0^z u_2(t) S_i(t)\,dt$, $i = 1,2$

Differencial signal is given by expression

$$D(0,\omega) = (J_1(d) + J_2(\infty))$$

When $\gamma(z)$ **is** $\gamma(z) = \begin{cases} az + \gamma_0, \, 0 \le z < d \\ \gamma_1, \, z \ge d \end{cases}$**,** differencial signal is

$$D(0,\omega) = \frac{\gamma_1}{y_4}\exp(-y_4) + 1 - \exp(-y_3) +$$

$$+\frac{\sqrt{\pi}\bar{\sigma}_s}{\sqrt{2a}} \cdot \left[\exp(-y_1) erf\sqrt{y_1} - \exp(y_2 - y_3) erf\sqrt{y_2 - y_3}\right]$$

$y_1 = \frac{(\gamma_0 + \bar{\sigma}_s)^2}{2a}$, $y_2 = \frac{(ad + \gamma_0 + \bar{\sigma}_s)^2}{2a}$, $y_3 = \frac{ad}{2}\left(d + \frac{2(\gamma_0 + \sigma_s)}{a}\right)$ and $y_4 = \gamma_1 + \bar{\sigma}_s$.

3. NEURAL NETWORKS

By the analysis of the direct model for optical gradient structures it is shown that the three-layer perceptron arhitecture of neural network can be used. Neural network is designed to have three input neurons, each for modulation frequency, magnitude and phase of PT response respectivelly, fifteen neurons in the hidden layer and only one output neuron. Applied learning algorithm is back propagation. Back propagation is an iterative learning procedure that adjust weights to minimize the mean square error between the actual output and the desired output. This algorithm requires a continous differentiable nonlinear activation function, in our case that is tangent hyperbolic, see Furundzic et al. 1998.

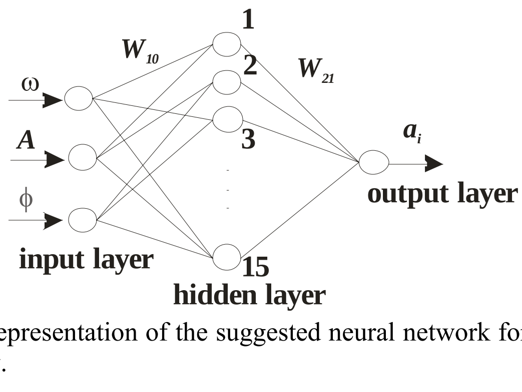

Figure 2: Schematic representation of the suggested neural network for photothermal optical depth profilometry.

The network has been trained on 20% of the total data set from different frequency ranges. It is achieved identification or determination of parameters of the model (weight matrix). Verification accomplished model is achieved on the rest 80% values of input data set, and the error on this test sample is negligible (0.2%). On the Fig. 3 is shown five values of reconstructed optical profile.

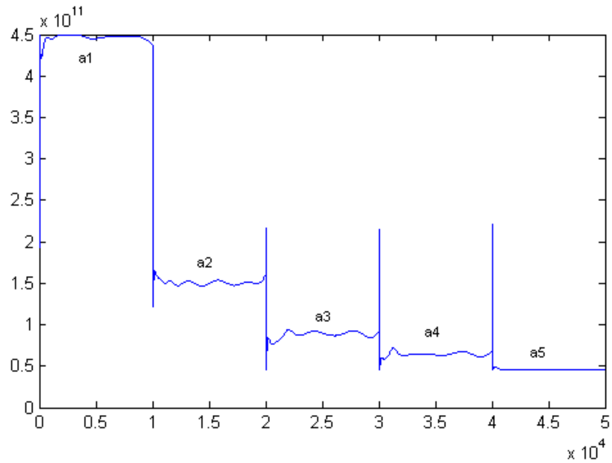

Figure 3: Reconstruction results of the optical depth profile by neural network.

Practical importance of this model is in it's ability of generalization solving on hole range values of optical absorption coefficient. Described neural network is accomplished in softwear package MATLAB and computing are preferred on standard notebook. Reconstruction of all five profiles after training neural network has been continuance for less than fifteen minutes.

4. CONCLUSION

In this paper has been shown that neural networks have excellent characteristics for optical profile reconstruction from measured PT response and significant advantages compared to the classic approach in the obtained computer resorces and processing data time. For this purpose has been used well determinated artificial sample whose optical absorption coeficient varies linearly to a depth d, in which reaches its constant valy. The developed neural network can be easily extended and trained to perform optical profile reconstruction due to general solutions direct PT problem for optical inhomogenous environment, which is derived in the second section of this paper.

References

Galovic, S., Soskic, Z., Popovic, M. *Reconstruction of the optical depth structure from photothermal response*, to be published.

Furundzic, D., Bekic, A. J., Djordjevic, M.: 1998, J. Systems Architectures, Elsevier.

Harata, A. and Sawada, T.: 1989, *J. Appl. Phys.*, vol. 65, pp. 959-963.

Power, J. F.: 2002, *Rev. Sci. Inst.*, vol. 73(12), pp. 4057-4141.

Terasina, M., Hirota, N., Braslavsky, S. E., Mandelis, A., Bialkowski, S. E., Diebold, G. J., Miller, R. S. D., Fpurnier, D., Palmer, R.A. and Tam, A.: 2004, *Pure Appl. Chem.*, vol. 76(6), pp. 1083-1118.