

# **BOOK OF ABSTRACTS**

**3<sup>rd</sup> Conference on Photoacoustic and  
Photothermal Theory and Applications**

**13-16 September 2016, Warsaw (Poland)**

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## PREFACE

Intensive development of photoacoustic and photothermal techniques in the past decades has led them no longer being considered just as research topics, but as practical and unique measuring tools. The Conference on Photoacoustic and Photothermal Theory and Applications (CPPTA) has been planned to be a venue where scientists and engineers who deal with photoacoustic or photothermal techniques can share their experiences and ideas. Its scope covers virtually all the aspects of photoacoustic, photothermal and related research, including theory, instrumentation and a wide range of applications:

- theoretical considerations,
- light-matter interaction,
- instrumentation and methodology,
- lasers and other light sources,
- spectroscopy, applications in chemistry,
- sensors, actuators and industrial applications (including environmental sensors, generation of ultrasound, etc.),
- applications in medicine, biology and agriculture,
- imaging (including thermography, tomography, microscopy, depth profiling, etc.),
- ultrafast, micro/nanoscale and nonlinear phenomena,
- thermophysics (including characterization of materials),
- other aspects and applications of PA / PT techniques.

The first two CPPTA conferences were organized in 2013 and 2014 and showed relatively strong interest of many researchers from all over the world. Number of abstracts submitted for the 3rd CPPTA was very similar (about 50 works were accepted for oral and poster presentations). We hope that this number will increase in the future. We strongly encourage young researchers to participate in the CPPTA conferences. They will have the opportunity not only to present the results of their research, but most of all, to learn about the latest discoveries and trends, meet the world's experts in the fields of PA / PT, and listen to speeches, during which top international scientists will summarize their experiences and talk about new ideas and perspectives of further development in the PA and PT fields.

Finally, I greatly appreciate very warm reception and a lot of support and valuable advices that I received from the participants of the previous CPPTA conferences. It was a great reward for our efforts and strong motivation to our work on further improvements.

Tomasz Starecki

(Conference Chair)



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# KEYNOTE SPEECHES

## Photothermal and photoacoustic characterization of soft matter systems

C. Glorieux ✉

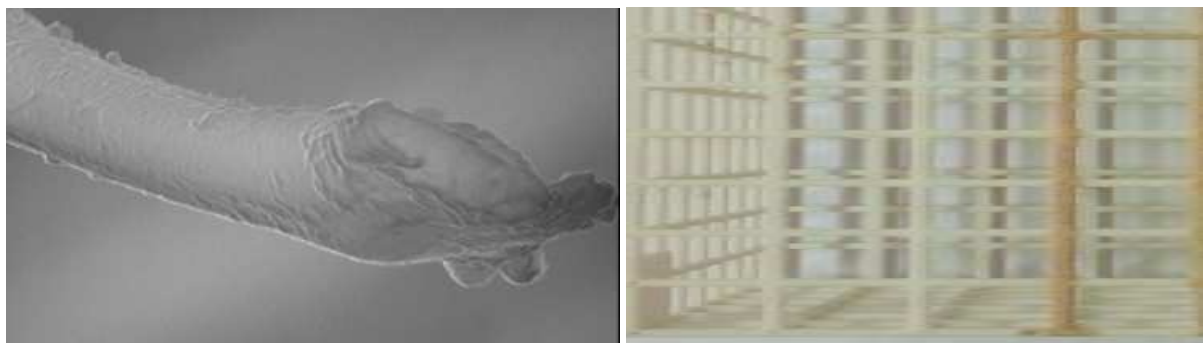
Soft Matter and Biophysics  
Department of Physics and Astronomy - KU Leuven  
Celestijnenlaan 200D, B3001 Heverlee, Belgium

✉ [christ.glorieux@kuleuven.be](mailto:christ.glorieux@kuleuven.be)

The physical behavior of soft matter is to a large extent linked to structural (dis)order and molecular mobility, and to temperature, pressure and composition driven transitions between different phases. By probing their macroscopic viscoelastic behavior, valuable information is obtained on intermolecular interactions. The temperature dependence of their enthalpy and specific heat capacity across phase transitions gives direct insight into their thermodynamic nature, while their thermal conductivity is very sensitive to their structure and changes therein. In view of that, characterizing the elastic and thermal properties is a commonly used approach to study soft matter systems.

Photoacoustic and photothermal (PAPT) techniques offer particular advantages for the study of thermoelastic behavior. Optical excitation is noncontact, and, combined with optical or other fast displacement, strain or temperature variation detection approaches, the flexibility of generating arbitrarily chosen spatiotemporal patterns in a very large range of scales, from sub-micron to mm and from femtosecond to minute scales offers a great window to study the dynamics of thermoelastic phenomena.

In this presentation, the unique features of PAPT methodology are illustrated on a series of soft matter systems, by a variety of excitation-detection combinations. An overview is given on experimental results obtained by the transient grating technique, the thermal lens technique and photopyroelectric spectroscopy, on the thermal and elastic behavior of glassformers, illustrating the wide frequency range that can be accessed: from mHz till beyond 100MHz. Applications on the thermal and/or elastic characterization of fibers in different structural configurations are discussed, illustrating the versatility of PAPT approaches in terms of sample geometry. Also applications on gels and nanofluids, investigated with a diverse set of PAPT methods, are presented.



**Fig. 1.** Left: Profile of the dragline silk of *N. clavipes* spider (diameter 3.1 $\mu$ m) under SEM imaging. Right: polyamide grid with a strut thickness of 1.1mm.

## Portable non-contact laser-ultrasound scanner for ultra-fast, high-resolution inspection of composites

I. Pelivanov <sup>✉</sup><sup>1,2</sup>, Ł. Ambroziński<sup>1,3</sup>, M. O'Donnell<sup>1</sup>

<sup>1</sup>Department of Bioengineering, University of Washington, Seattle, WA, USA

<sup>2</sup>Faculty of Physics, Moscow State University, Moscow, Russia

<sup>3</sup>AGH University of Science and Technology, Krakow, Poland

<sup>✉</sup>[ivanp3@uw.edu](mailto:ivanp3@uw.edu)

Composites are increasingly replacing metals for a number of applications where their strength and greatly reduced weight are extremely important. As composite structures become more routine, non-destructive tools are needed to monitor their structural integrity and material response to different damage mechanisms, such as mechanical impact and thermal insult.

Among NDE imaging methods, only ultrasound (US) and X-ray tomography can precisely determine defect location in 3D regardless of FRP composite type. However, X-ray scanners are very expensive and cumbersome. 3D X-ray imaging is also very time-consuming; moreover, the chamber limits the size of the sample and both sample surfaces must be accessed (i.e., through transmission measurement required), making this technology completely unsuitable for in-situ applications.

Conventional US pulse-echo techniques usually require couplants or full immersion of the component, thereby limiting their general use. In addition, the layered structure of most composite materials, and their relatively high US attenuation, makes it difficult to resolve a single composite layer.


Laser-ultrasound (LU) has many advantages over conventional US. First, laser-generated US transients are ultra-wideband and, therefore, provide at least 3 times better resolution compared with conventional transducers having the same characteristic frequency. Second, LU is fundamentally a non-contact approach that eliminates all coupling issues. The disadvantages of LU scanners are their low pulse repetition frequency (PRF), high cost of pump lasers, and some issues with stability and low sensitivity on receive. These limitations, however, have been recently overcome with a new kHz-rate fiber-optic pump-probe system [1] having a modified Sagnac interferometer on receive [2, 3].

This presentation summarizes our recent studies on advanced composite structure evaluation. We show that the LU scanner is very efficient for both large defect localization and material structure evaluation, enabling flaw detection with sub-ply resolution [1-3], visualization of pores [4] and wrinkles, evaluation of heat damage [5] and 3-D imaging of impact damage [6] with resolution rivaling 3-D X-ray tomograms but at high speed with single surface access.

- [1] Pelivanov, A. Shtokolov, C.-W. Wei, M. O'Donnell, *IEEE Tran. Ultrason. Ferroelect. Freq. Contr.* **62**, 1696 (2015)
- [2] Pelivanov, T. Buma, J. Xia, C.-W. Wei, M. O'Donnell, *J. Appl. Phys.* **115**, 113105-1 (2014)
- [3] Pelivanov, T. Buma, J. Xia, C.-W. Wei, M. O'Donnell, *Photoacoustics* **2**, 63 (2014)
- [4] Pelivanov, M. O'Donnell, *Composites Part A* **79**, 43 (2015)
- [5] Pelivanov, L. Ambroziński, M. O'Donnell, *Composites Part A* **84**, 417 (2016)
- [6] Pelivanov et al, *Photoacoustics* (submitted 03/2016)

## PLENARY / INVITED TALKS

## Quartz enhanced photoacoustic spectroscopy: Principles and recent advancements

V. Spagnolo <sup>1</sup>, P. Patimisco<sup>1,2</sup>, A. Sampaolo<sup>1,2</sup>, M. Giglio<sup>1</sup>,  
A. Geras<sup>4</sup>, T. Starecki<sup>4</sup>, L. Dong<sup>3</sup>, F. K. Tittel<sup>2</sup>

<sup>1</sup>Dipartimento Interateneo di Fisica, Università e Politecnico di Bari,  
CNR-IFN UOS BARI, Via Amendola 173, Bari, Italy

<sup>2</sup>Rice University, Department of Electrical and Computer Engineering,  
6100 Main Street, Houston, TX 77005, USA;

<sup>3</sup>State Key Laboratory of Quantum Optics and Quantum Optics Devices,  
Institute of Laser Spectroscopy, Shanxi University, Taiyuan 030006, China


<sup>4</sup>Institute of Electronic Systems, Warsaw University of Technology,  
Nowowiejska 15/19, 00-665 Warsaw, Poland

 [vincenzoluigi.spagnolo@poliba.it](mailto:vincenzoluigi.spagnolo@poliba.it)

The detection and measurement of trace gas concentrations is important for both the understanding and monitoring of a wide variety of applications, such as environmental monitoring, industrial process control analysis, combustion processes, detection of toxic and flammable gases, biomedical breath analysis applications. One of the most robust and sensitive trace-gas optical detection techniques is the quartz enhanced photo-acoustic spectroscopy (QEPAS), which is capable of extremely high detection sensitivities with a compact and relatively low-cost absorption detection module. We will present here our recent advancements of the QEPAS technique. First, will be described the physical principles on which the QEPAS technique [1] is based, followed by a detailed study of the experimental and theoretical analysis of the influence of quartz tuning fork (QTF) dimensions on the main physical parameters controlling the QTF performance. The relevant QEPAS parameters include the quality factor  $Q$ , the resonance frequency, the fork stiffness, the spring constant, and the electrical resistance [2]. Furthermore, an overview of our latest developments in QEPAS trace-gas sensor technology, such as the realization of mid-IR and THz QEPAS sensors employing custom QTFs [3, 4] will be presented. A novel micro-resonator configuration able to amplify the QEPAS signal-to-noise ratio by more than two orders of magnitude [5] and the first implementation on QTF overtone flexural modes for QEPAS sensing [4, 6] will also be reported.

- [1] P. Patimisco, G. Scamarcio, F. K. Tittel, V. Spagnolo, *Sens.* **14**, 6165 (2014)
- [2] P. Patimisco, A. Sampaolo, L. Dong, M. Giglio, G. Scamarcio, F. K. Tittel, V. Spagnolo, *Sens. Actuat. B* **227**, 539 (2016)
- [3] H. Wu, A. Sampaolo, L. Dong, P. Patimisco, X. Liu, H. Zheng, X. Yin, W. Ma, L. Zhang, W. Yin, V. Spagnolo, S. Jia, F. K. Tittel, *Appl. Phys. Lett.* **107**, 111104 (2015)
- [4] Sampaolo, P. Patimisco, M. Giglio, M. S. Vitiello, H. E. Beere, D.A. Ritchie, G. Scamarcio, F. K. Tittel, V. Spagnolo, *Sens.* **16**, 439 (2016)
- [5] H. Zheng, L. Dong, A. Sampaolo, H. Wu, P. Patimisco, X. Yin, W. Ma, L. Zhang, W. Yin, V. Spagnolo, S. Jia, F. K. Tittel, *Opt. Lett.* **41**, 978 (2016)
- [6] F. K. Tittel, A. Sampaolo, P. Patimisco, L. Dong, A. Geras, T. Starecki, V. Spagnolo, *Opt. Expr.* **24**, A682 (2016)

## Laser-based realization of 1D guided topographical wedge waves with unrivaled nonlinearity

P. Hess <sup>1</sup>, A. M. Lomonosov<sup>1-3</sup>, A. P. Mayer<sup>2</sup>

<sup>1</sup>Institute of Physical Chemistry, University of Heidelberg, D-69120 Heidelberg, Germany

<sup>2</sup>HS Offenburg, University of Applied Sciences, D-77723 Gengenbach, Germany

<sup>3</sup>General Physics Institute, Russian Academy of Sciences, 119991 Moscow, Russia

 [Peter.hess@urz.uni-heidelberg.de](mailto:Peter.hess@urz.uni-heidelberg.de)

Nonlinear wave phenomena such as shock formation, solitons or turbulence occur in various fields of science and technology. The build-up of steep wave fronts to shocks and the formation of sharp spikes may be regarded as cumulative nonlinear effects resulting from a resonant interaction of harmonics of the wave field, which is possible in the absence of dispersion. Apart from rare exceptions, the acoustic modes of conventional one-dimensional (1D) waveguides such as fibers and channel waveguides are normally dispersive, which inhibits the growth of higher harmonics. However, the fundamental modes of 1D wedge waves (WWs) are localized within a depth of approximately one wavelength at the apex of the wedge and the elastic strain energy remains concentrated there due to the nondispersive and nondiffractive nature. Fundamental WWs are subsonic, i.e. their phase velocity is below the phase velocities of surface and bulk waves and therefore they do not couple with these 2D and 3D elastic waves. For these reasons, strong nonlinear behavior can be expected during propagation of WW pulses with finite amplitude in nonlinear media.

To launch a transient WW pulse with sufficient magnitude, the absorption layer technique was employed, where a 1 ns pulse of a Nd:YAG laser operating at 1.064  $\mu\text{m}$  was focused into a small spot of a highly absorbing liquid layer deposited on one wedge face near the edge. The resulting local surface inclination, associated with the transient WW pulse, was detected by the probe-beam-deflection method at two different spots near the tip, using a 532 nm continuous-wave Nd:YAG laser. While in isotropic materials, well defined antisymmetric flexural (ASF) modes are excited, with a predominant particle motion normal to the mid-apex plane such a simple description cannot be applied to low symmetry anisotropic wedges without mid-apex mirror plane.

The rectangular silicon wedge studied had the wedge faces  $(-1-1-1)$   $90^\circ(-110)$ . The low symmetry removes the restrictions responsible for the nonexistence of second-order nonlinearity. This allowed for the first time the observation of a new type of efficient second-order nonlinearity with dominating frequency-up conversion. The acoustic pulses, showing steepening, narrowing, and spiking to shock-like profiles, were generated and detected by the laser-based pump-probe setup. The shock formation process is described theoretically by a nonlinear evolution equation, which also allows for prediction of the characteristic features of 1D shock waves differing from their bulk and surface wave analogs. This includes besides simulations of the nonlinear pulse profile, the explanation of the more efficient frequency-up than frequency-down conversion, and the resulting shorter shock formation distance as compared to surface and bulk waves. The conditions required to realize this type of strong nonlinearity can be easily fulfilled in anisotropic materials such as single-crystal silicon. Therefore, these observations open the door to the new field of dispersion-free 1D waveguides with unrivaled intrinsic nonlinear behavior.

[1] A. M. Lomonosov, P. D. Pupyrev, P. Hess, A. P. Mayer, *Phys. Rev. B* **92**, 014112 (2015)

## Photothermal spectroscopy: A physical method, a chemical technique

M. A. Proskurnin ✉

Chemistry Department, M.V. Lomonosov Moscow State University, Moscow, Russia

✉ [proskurnin@gmail.com](mailto:proskurnin@gmail.com)

The talk will survey the main trends of research in photothermal spectroscopy directly or indirectly related to analytical chemistry and applied chemical analysis. Particular attention will be given to the novel areas, coupling of photothermal spectroscopy to other techniques, and the advances over conventional methods. Measurement of biomedical and technological samples and disperse systems will be exemplified. Prospects for the practical photothermal analysis will be discussed.

Recently, much attention is paid to the application of photothermal spectroscopy in microfluidic systems ( $\mu$ TAS). But, however widespread these areas are, the potentialities of photothermics in chemistry are wider. In this talk, some examples of relevant analytical applications based on well-known and novel photometric reactions will be given. Photothermics shows wide potentialities both for the determining the absorption-band parameters and for detecting laser-induced photochemical reactions; high precision of the measurements of absorption spectra is observed both in solutions and in cellular structures. Novel preconcentration techniques involving photothermics will be discussed


As a part of well-known paradigm that photothermal spectroscopy is ‘not just highly sensitive photometry’, new applications of photothermal spectroscopy are connected with recent developments in solid-state techniques. Novel sensible materials (specially designed polymer matrices or surface-enhanced glasses/films with grafted or absorbed reagents) can be used as transparent layers, films, or resins. These materials serve as transducers in novel gas/aerosol/solute optical sensors and in state-of-the-art separation/preconcentration analytical methods. Photothermal spectroscopy is used for a considerable increase in the sensitivity of photometric measurements of such materials. The examples that will be given include trace metal determination, classical and enzyme kinetic indicator systems, immunoassays, and nanoparticle-assisted sensible materials.

Another field is the analysis of heterogeneous materials, including those with dynamically appearing and changing heterogeneity. The examples will include the formation of nanoparticles, precipitation, protein crystallization, which can be monitored and analyzed using photothermal techniques. The examples will include the use of polymer and surfactant-based organized media for the photothermal detection and investigation of nanomaterials and some proteins and their supramolecular complexes with metal chelates, lipids, etc. Such intermediate (or *ex vivo*) platforms are known to be based on organized media of hydrophilic polymers—either micellar or structural. The polymer modification of the solution stabilizes and mildly fixes nanoparticles, micelles, or cells in place and provides the overall physicochemical properties closer to the intended real application of the test entity. As a result, they provide very sensitive measurement of test entities with photothermal spectroscopy in various environments. Moreover, due to its intrinsic sensitivity, versatility, and non-destructivity, photothermal spectroscopy is a valuable assessment/probing unit of such a test platform.

Finally, in many state-of-the-art chemistry applications, geological and soil science, and materials-research studies, the detailed information on thermophysical parameters is required along with the direct information of the chemical composition, so physicochemical methods that provide the overall, local, or mapped information on thermal conductivity/diffusivity/effusivity, heat capacity etc. are on demand. Photothermal spectroscopy now develops into such ‘thermal spectroscopy’ as a counterpart of optical spectroscopy, and some relevant examples of these studies will be given.

# THEORETICAL CONSIDERATIONS

## Propagation characteristics of laser-generated Rayleigh waves in composite plate with gradient changes of near-surface viscous properties

Y.-J. Guan<sup>1</sup>, H.-X. Sun <sup>1,2</sup>, S.-Q. Yuan<sup>1</sup>, S.-Y. Zhang<sup>2</sup>

<sup>1</sup>Research Center of Fluid Machinery Engineering and Technology, Faculty of Science, Jiangsu University, Zhenjiang 212013, China

<sup>2</sup>Lab of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing 210093, China

 [jsdxshx@ujs.edu.cn](mailto:jsdxshx@ujs.edu.cn)

Composites have been widely used in aircrafts, spacecrafts, and other engineering industries, and the viscoelastic effects of the composites and the attenuation effects induced by the viscoelasticity become more and more important [1, 2]. Practically, with the composites prolonged air exposure, the near-surface viscous properties of the composites have changed by the drying and hygral environment, which induces surface fatigue cracks and reduces the service time in the composites. It is very important to evaluate the near-surface viscous properties of the composites. Laser ultrasound technique has potential applications in nondestructive evaluation and characterizations of various structures [3-5]. Therefore, in order to evaluate the quality of the composites, it is necessary to study the propagation characteristics of the laser-generated Rayleigh waves in the composites.

In this paper, considering the gradient change of the near-surface viscous property, finite element models are established in frequency domain to numerically study laser-generated Rayleigh waves in a composite plate, and the propagation characteristics of the Rayleigh waves in the composite plate are studied in detail, and the influences of the changes of the viscous moduli and thickness of the near-surface layer on the attenuations of the Rayleigh waves in the composite plates are discussed. Furthermore, the effects of the changes of each viscous moduli ( $C''_{11}$ ,  $C''_{12}$ ,  $C''_{22}$ , and  $C''_{66}$ ) on the propagation characteristics of the Rayleigh waves are also investigated.

The results show that, with the change of the near-surface viscous moduli, the attenuation of the longitudinal wave (L) and Rayleigh wave (R) decrease, and the attenuation of R changes greater than that of L. With the increase of the viscous moduli and thickness of the near-surface layer, the attenuation of R decreases. Moreover, with the increases of  $C''_{12}$  in the near-surface layer, the attenuation of R increases. But with the increases of  $C''_{11}$ ,  $C''_{22}$ , and  $C''_{66}$ , the attenuation of R decreases. The study provides theoretical basis for evaluating the near-surface viscous properties of the composites by the laser ultrasound technique.

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## The two-stage process of dynamic thermoelasticity under pulsed laser loading

B. A. Zimin<sup>1</sup>, V. E. Sventitskaya <sup>2</sup>, Y. V. Sudenkov<sup>3</sup>

<sup>1</sup>Institute of Problems of Mechanical Engineering,  
V.O., Bolshoj pr., 61, St. Petersburg, 199178, Russia

<sup>2</sup>BSTU "VOENMEH" named after D. F. Ustinov,  
1<sup>st</sup> Krasnoarmeyskaya str., 1, St. Petersburg, 190005, Russia

<sup>3</sup>Saint-Petersburg State University,  
Universitetsky pr., 28, Peterhov, St. Petersburg, 198504, Russia

 [vsvent@yandex.ru](mailto:vsvent@yandex.ru)

Dynamic problem of thermoelasticity was first considered by Danilovskaya, who found an exact solution for thermal stresses during the pulsed flow of radiant energy. Temporal profiles of stress pulses (or a mass velocity of the particles) which described by these solution represent a bipolar compression-distention pulse with commensurate values of the amplitudes and the duration of the phases comparable with the duration of a radiation pulse.

Subsequent studies of the problem of dynamic thermoelasticity have not made any fundamental changes in the solution for thermoelastic stresses. It is noted in some experimental studies that the parameters of stress pulses in metals differ significantly from the above mentioned theoretical solutions. A fundamental difference in the ratio of the durations and magnitudes of the phases of compression and extension of the thermal stresses in metals and in dielectrics was shown by the authors.

An analysis of thermoelastic response of materials under the pulsed laser irradiation is based on two-step process. The first stage of the process is determined on time of the action of the radiation pulse  $t \leq \tau_u$ . The second stage takes into account the thermoelastic effect in time of heat transfer after the pulse action  $t \geq \tau_u$ . The assumption of additivity of displacements  $u = u_a + u_T$  can be applied to describe the two-step process of thermoelastic reaction of solids. Where  $u_a$  is the displacement which is corresponded to the decision and  $u_T$  is the displacement of the medium due to heat transfer activity ("the thermal piston"), that is corresponded to the second step of the process. The authors get the mass velocity of the particles from the Duhamel ratio for  $t \geq \tau_u$  (with taking into account that on the border  $z \cong 2\sqrt{\chi t}$  is no stresses  $\sigma = 0$ ):

$$\frac{\partial u_T}{\partial t} = c_0^2 \int \frac{\partial(\alpha_T T)}{\partial z} dt.$$

Then taking into account the heat extension equation we obtain:

$$\frac{\partial u_T}{\partial t} = C_1 \sqrt{\chi t},$$

where  $C_1$  is constant value.

Thus, the elastic pulse which excited by the "the thermal piston" will increase after the end of the radiation action proportionally to changing of depth of the thermal diffusion. The duration of actions of the «the thermal piston» depends on the temperature gradient. It should be noted that in the framework of continuum mechanics it is possible to explain the differences of thermoelastic responses as in dielectrics so in metals taking into account the two-stage process of dynamic thermoelasticity.

## Nonlinear photoacoustic response of the two layer solids

T. Kh. Salikhov <sup>✉1</sup>, Yu. P. Khodjaev<sup>1</sup>, D. M. Sharifov<sup>2</sup>

<sup>1</sup>Tajik National University, Dushanbe, Tajikistan

<sup>2</sup>L.N.Gumilyov Eurasian National University, Astana, Kazakhstan

✉ [t\\_salikhov@rambler.ru](mailto:t_salikhov@rambler.ru)

The linear theory of the generation of the photoacoustic(PA) signal of bilayer solids samples has been presented in [1]. Purpose of the this paper is the construction of the theory of nonlinear PA response by two layers solids. Take into account that the nonlinear PA - signal due the temperature dependence of thermal and optical parameters of the two layers samples and also thermal parameters of the buffer gas and the substrate. Consequently, as the original equations system is the following nonlinear heat conduction equations for all four (buffer gas, first and second sample and substrate layers) layers in PA - cell:

$$C_{pg}(T_g) \frac{\partial T_g}{\partial t} = \frac{\partial}{\partial x} (\kappa_g(T_g) \frac{\partial T_g}{\partial x}), \quad 0 \leq x \leq l_g, \quad (1)$$

$$C_{PS(1)} \frac{\partial T'_{S(1)}}{\partial t} = \frac{\partial}{\partial x} [k_{S(1)}(T) \frac{\partial T'_{S(1)}}{\partial x}] + 0.5I_0 A_{S(1)}(T)(1 + e^{i\omega t}) e^{\beta_1 x}, \quad -l_{S(1)} \leq x \leq 0, \quad (2)$$

$$C_{PS(2)} \frac{\partial T'_{S(2)}}{\partial t} = \frac{\partial}{\partial x} [k_{S(2)}(T) \frac{\partial T'_{S(2)}}{\partial x}] + 0.5I_0 A_{S(2)}(T)(1 - R_{S(1)}(T))(1 + e^{i\omega t}) e^{-\beta_1^{(0)} l_1} e^{\beta_1^{(0)}(x+l_1)}, \quad -(l_{S(1)} + l_{S(2)}) \leq x \leq -l_{S(1)}, \quad (3)$$

$$C_{pb}(T_b) \frac{\partial T_b}{\partial t} = \frac{\partial}{\partial x} (\kappa_b(T_b) \frac{\partial T_b}{\partial x}), \quad -(l_b + l_{S(1)} + l_{S(2)}) \leq x \leq -l_{S(1)} - l_{S(2)}, \quad (4)$$

where  $C_{pi}(T_i)$  - heat capacities in unit volume,  $\kappa_{pi}(T_i)$  - thermal conductivity,  $A_{S(i)}(T)$  - emissivity and  $R_{S(i)}(T)$  - reflection coefficient of the respective layers. Temperature dependence of the value  $C_{pi}(T)$ ,  $\kappa_i(T)$  and  $A_{S(i)}(T)$  present in form:  $(1 - R_{1S(1)}) = (1 - R_{1S(1)})^{(0)} (1 + \delta_{4(1)} T'_{S(1)}(0, t))$ ,  $C_{pi} = C_{pi}^{(0)} (1 + \delta_i T'_i)$ ,  $\kappa_i = \kappa_i^{(0)} (1 + \delta_{2i} T'_i)$ ,  $A_{S(i)}(T) = A_{S(i)}^{(0)} (1 + \delta_{3S(i)} T'_i)$ , where  $C_{pi}^{(0)} = C_{pi}(T_0)$ ,  $\kappa_i^{(0)} = \kappa(T_0)$ ,  $A^{(0)} = A(T_0)$  -initial value,  $\delta_i = (1/C_{pi}^{(0)}) (\partial C_{pi} / \partial T)$ ,  $\delta_{2i} = (1/\kappa_i^{(0)}) (\partial \kappa_i / \partial T)$ ,  $\delta_{3i} = (1/A^{(0)}) (\partial A / \partial T)$ ,  $\delta_{4i} = (1/(1 - R_{1S(1)})^{(0)}) (\partial (1 - R_{1S(1)}) / \partial T)$  are thermal coefficients of the this parameters. In (1) - (4) value  $\beta_i$  -absorption coefficients and are assumed as constant value.

In equations (1)-(4) a perturbation of temperature in all layers  $T'_i(t, x)$  are the sum of the locally equilibrium  $T_{0i}(x)$  and oscillatory parts  $\Phi_i(t, x)$ . Values  $\Phi_i(t, x)$  we will present as superposition of the linear  $\Phi_{Li}(x, t)$  and nonlinear  $\Phi_{Ni}(x, t)$  components, where  $\Phi_{1N}(t, x)$  and  $\Phi_{2N}(t, x)$  these same fluctuations on the principal and second harmonics. This allowed us to get a system of interrelated equations for  $T_{0i}(x)$ ,  $\Phi_{Li}(x, t)$ ,  $\Phi_{1N}(t, x)$  and  $\Phi_{2N}(t, x)$ . This system of equations together with boundary conditions allowed us to obtain the requiring expression for  $\Phi_{1N}(t, x)$  and  $\Phi_{2N}(t, x)$  and then the oscillatory of pressure in buffer gas layer on the fundamental  $\delta p_1(\omega)$  and second harmonics  $\delta p_2(2\omega)$ . The analysis of expressions  $\delta p_1(\omega)$  and  $\delta p_2(2\omega)$  for limiting cases has been done.

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## **Photothermal response of a double-layered semi-transparent sample including multiple optical reflexions**

M. N. Popović <sup>1</sup>, M. V. Nesić<sup>1,2</sup>, S. P. Galović<sup>1</sup>


<sup>1</sup> Vinca Institute of Nuclear Sciences, PO Box 522, 12-14, 11001 Belgrade, University of Belgrade

<sup>2</sup> School of Electrical Engineering, Bul. kralja Aleksandra 73, 11120 Belgrade, University of Belgrade

 [maricap@vinca.rs](mailto:maricap@vinca.rs)

In this work, surface temperature variations of an optically irradiated, double-layered sample are studied. One layer of the sample is assumed to be a surface absorber, while the exposed layer is regarded as a transparent volume absorber. The expressions for surface temperature variations of the exposed layer, due to the absorption of excitation EM radiation, are derived with regard to the effect of multiple reflexions in the exposed layer. The discussion is focused on the study of the influence of inner reflection coefficient at the hetero-surface of the two consisting layers on surface temperature variations. The differences in amplitude and phase characteristics, predicted by the classical model and the derived one, are discussed.

## **Pulsed excitation photoacoustic response of media with thermal memory**

S. P. Galović <sup>1</sup>, M. V. Nesić<sup>1,2</sup>, M. N. Popović<sup>1</sup>, D. Markushev<sup>3</sup>, S. Todosijević<sup>4</sup>, Z. Šoškić<sup>4</sup>

<sup>1</sup> Vinca Institute of Nuclear Sciences, PO Box 522, 12-14, 11001 Belgrade, University of Belgrade

<sup>2</sup> School of Electrical Engineering, Bul. kralja Aleksandra 73, 11120 Belgrade, University of Belgrade

<sup>3</sup> Institute of Physics Belgrade, Pregrevica 118, 11080 Zemun, University of Belgrade

<sup>4</sup> Faculty of Mechanical and Civil Engineering Kraljevo, Dositejeva 19, 36 000 Kraljevo, University of Kragujevac

 [bobagal@vinca.rs](mailto:bobagal@vinca.rs)

The time-dependent gas-microphone photoacoustic response of a hypothetical, disc-shaped sample with thermal memory is examined theoretically. Two types of irradiation geometry are considered: planar surface source and point-focused electromagnetic source. In both types, Green's functions are used to calculate the time profiles of photothermal and photoacoustic waves. The analytical formulas, derived for these waves, allow for easy numerical computations, and can be used for the interpretation of the experimental data.

## Photothermal diagnostics of inhomogeneous media with thermal memory

M. V. Nesić <sup>1,2</sup>, M. N. Popović<sup>1</sup>, S. P. Galović<sup>1</sup>


<sup>1</sup>Vinca Institute of Nuclear Sciences, PO Box 522, 12-14, 11001 Belgrade, University of Belgrade  
<sup>2</sup>School of Electrical Engineering, Bul. kralja Aleksandra 73, 11120 Belgrade, University of Belgrade

 [mioljub.nesic@vinca.rs](mailto:mioljub.nesic@vinca.rs)

The results of inverse problem solution to photoacoustic diagnostics of inhomogeneous media with thermal memory are presented. Because of the ill-posed nature of the problem, Tikhonov's regularization algorithm has been used in coping with sound response measurement errors. The approximation of the algorithm originates from the discretization, which is necessary in numerical analysis. The results of numerical simulation are given and discussed.

# INSTRUMENTATION AND METHODOLOGY

## Characterization of quartz tuning fork parameters for photoacoustic spectroscopy

M. Helman , A. Dudkowiak

Faculty of Technical Physics, Poznan University of Technology, Piotrowo 3, 61-138 Poznan, Poland

 [marek.j.helman@doctorate.put.poznan.pl](mailto:marek.j.helman@doctorate.put.poznan.pl)

Setups for measuring the concentrations of gases are important from a practical point of view. These measurements can be performed using absorption spectroscopy techniques. One of most robust and sensitive trace-gas absorption spectroscopy methods is photoacoustic spectroscopy (PAS), which is capable of high detection sensitivities [1]. In recent years, quartz enhanced photoacoustic absorption spectroscopy (QEPAS) [2] is a rapidly developed method wherein quartz tuning fork (QTF) is used as sharply resonant acoustic transducer to detect weak photoacoustic excitations.

We described the study of important parameters of distributed feedback laser emitting light around 1580 nm, used for measuring concentrations of gases. During the tests the characteristics of the laser power as a function of current supply were measured at selected work temperatures. Then, changes in the wavelength of the laser radiation in response to the modulation of supply current were examined.

Within the work we designed and manufactured compact absorption detection module equipped with QTF. Studies on relevant parameters of QTF used to measure trace-gas concentrations were described. Characterization of the influence of pressure and humidity of gas mixture on QTF parameters such as resonant frequency, phase shift, and the Q-factor were performed. Subsequently the impact of the vertical position of the laser beam corresponding to the QTF was analyzed.

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## Comparison of the chosen nondestructive techniques for investigations of the recombination parameters of electronic materials

Ł. Chrobak, M. Maliński ✉

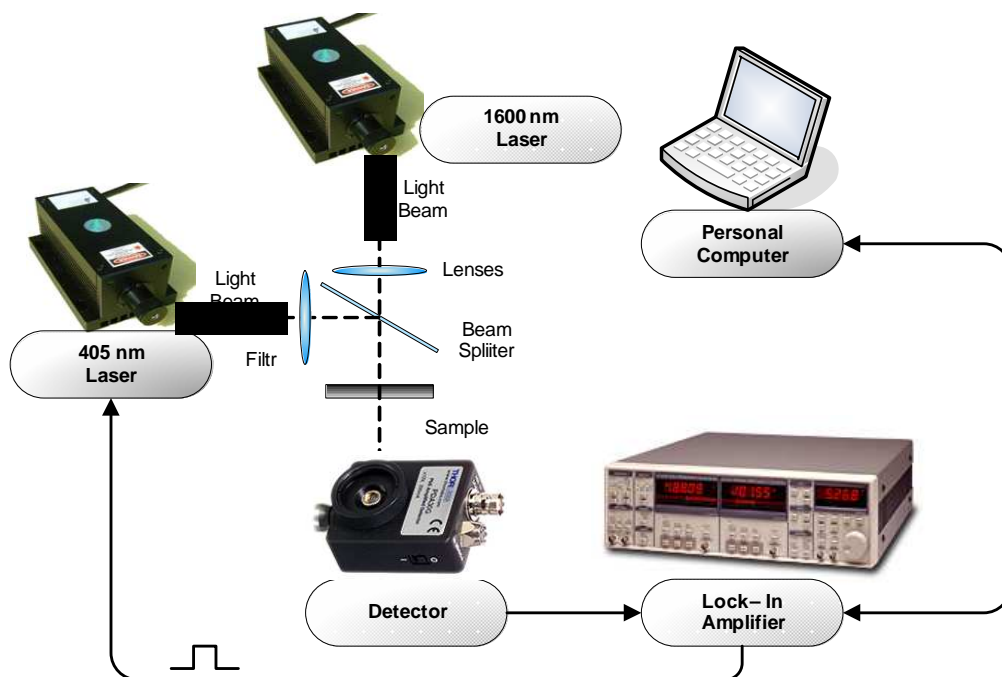
Faculty of Electronics and Computer Science  
 Technical University of Koszalin  
 Śniadeckich 2, 75-453 Koszalin, Poland

✉ [mirosław.malinski@tu.koszalin.pl](mailto:mirosław.malinski@tu.koszalin.pl)

This paper presents a comparison of a few nondestructive measuring techniques used for determination of the recombination parameters of semiconductor samples.

The following frequency domain methods were tested experimentally and analyzed theoretically: two photoacoustic methods (PA) i.e. mirror vs matt and transmission, a modulated free carrier absorption (MFCA) and a photothermal radiometry (PTR) method.

With these methods the optically excited minority carriers' lifetimes and velocities of the surface recombination of a series of silicon samples were determined and compared. The example experimental set-up built for the measurements of the frequency MFCA characteristics is presented in Fig.1.




**Fig.1.** Experimental MFCA set-up for the frequency characteristics measurements.

The experimental, computer controlled, set-ups built for PA and PTR frequency measurements are shown and discussed in the paper too. The construction details and the technical limitations of these methods and set-ups are also presented and discussed in detail.

The possibility of the application of these methods for the mapping of the spatial distributions of the recombination parameters of silicon wafers is also presented and discussed. It is illustrated with the MFCA maps of the lifetimes of carriers of silicon wafers. The experimental set-ups built and used for the mapping of the lifetime of carriers is shown and discussed too.

## Broadband acoustic focusing by temperature gradients in air

Y.-J. Guan<sup>1</sup>, H.-X. Sun <sup>1,2</sup>, S.-Q. Yuan<sup>1</sup>, S.-Y. Zhang<sup>2</sup>

<sup>1</sup>Research Center of Fluid Machinery Engineering and Technology, Faculty of Science,  
Jiangsu University, Zhenjiang 212013, China

<sup>2</sup>Lab of Modern Acoustics, Institute of Acoustics, Nanjing University, Nanjing 210093, China

 [jsdxshx@ujs.edu.cn](mailto:jsdxshx@ujs.edu.cn)

Recently, the research on the acoustic focusing lenses has attracted more and more attention owing to its broad application prospects in a variety of important fields. Based on the negative refraction mechanism, many kinds of the acoustic focusing lenses have been proposed, such as the sonic crystals [1, 2] and acoustic metamaterials [3-5]. Although many types of lenses in the above researches have realized the focusing effect with high efficiency, but the focusing frequency range is narrow, even a single frequency, which arises from the complexity of the refraction index gradient and the large acoustic impedance difference between the lens material and ambient medium. Therefore, it is important to realize the broadband acoustic focusing effect with the refraction index gradient in a single medium.

In this paper, we have proposed an acoustic focusing lens composed of several heat sources with different temperatures symmetrically placed on both sides in air. We have realized the broadband acoustic focusing effect in a single medium, and the focusing effect arises from the desired refractive index distributions induced by the temperature gradients in air. Moreover, we have also discussed the influences of the temperatures and positions of the heat sources on the focusing effect in details.

The results show that the acoustic focusing lens has a broader bandwidth ( $>4.0$  kHz), higher intensity amplification ( $>7.5$  times), and a simpler structure, and the focusing intensity amplifications and positions of the focus spot are closely related to the incident frequency, the temperatures and positions of the heat sources. Therefore, we can control the focusing effects by these parameters. These results are helpful to promoting the realization of broadband acoustic focusing effect in a single medium, which has potential applications in acoustic focusing devices.

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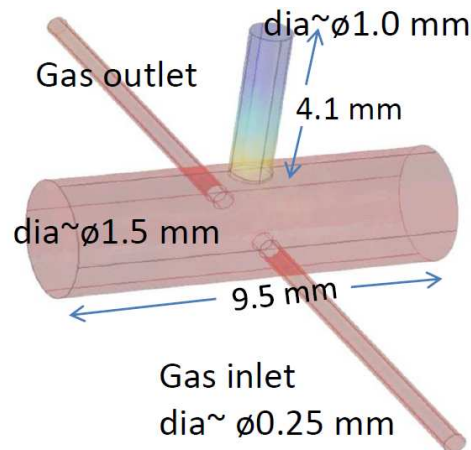
## Quartz enhanced photoacoustic spectroscopy with off-axis coupled micro-resonators

M. Lassen<sup>✉1</sup>, L. Lamard<sup>2</sup>, A. Peremans<sup>2</sup>, J. C. Petersen<sup>1</sup>

<sup>1</sup>Danish Fundamental Metrology, Matematiktorvet 307, DK-2800 Kgs. Lyngby, Denmark

<sup>2</sup>Laserspec BVBA, 15 rue Trieux Scieurs, B-5020 Malonne, Belgium

✉ [ml@dfm.dk](mailto:ml@dfm.dk)



Sensitive trace gas detection is very important and finds application within urban air quality and emission monitoring, industrial gas detection, food processing, security monitoring, breath analysis, to mention a few cases. Ideally sensors are expected to be cheap, portable, miniaturized, automated stand-alone devices, which are highly sensitive and species selective. For this innovative photoacoustic (PA) sensing is very promising technology [1,2]. A quartz-enhanced photoacoustic spectroscopy (QEPAS) sensor consisting of two acoustic coupled micro-resonators (mRs) with an off-axis 20 kHz quartz tuning fork (QTF) is presented [3]. The QEPAS system is pumped resonantly by a pulsed mid-infrared optical parametric oscillator (MIR OPO). The MIR pulsed OPO is based on a fanned-out periodically poled LiNBO<sub>3</sub> nonlinear crystal and provides a spectral bandwidth of less than 1 cm<sup>-1</sup>. The repetition rate can be changed continuously from 10 kHz to 80 kHz, with 10-20 ns pulse duration depending on the repetition rate. The continuous tuning ability of the MIR OPO repetition rate allows for synchronization with the acoustic resonance of the QEPAS cell. The complete acoustic coupled mR system is optimized based on finite element simulations and experimentally verified. The results demonstrate that the off-axis T-shaped configuration is only limited by the thermal noise of the QTF. Spectroscopic measurements have been conducted on methane in the 3.1-3.7  $\mu\text{m}$  wavelength region. We demonstrate that the compact QEPAS sensor with an instrument limited bandwidth of 1 cm<sup>-1</sup>, allows for differentiation of the individual gasses in a complex mixture and at the same time the QEPAS sensor exhibits gas concentration sensitivities at the ppb level [3].

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## Beam profile improvement of 808-nm high-power diode laser stacks for optoacoustic applications

M. Sánchez, S. Rodríguez, L. Leggio , S. Gawali, H. Lamela


Department of Electronics Technology, Universidad Carlos III de Madrid,  
Avenida de la Universidad, 30, 28911, Leganés (Spain)

 [lleggio@ing.uc3m.es](mailto:lleggio@ing.uc3m.es)

In the last two decades, great progresses have been made for a future implementation of optoacoustic (OA) imaging techniques in biomedical applications, but there are still some drawbacks to be solved. Typically, the laser sources used for generating OA signals are solid state lasers, such as Nd:YAG or Ti:Sapphire lasers, dye lasers or CO<sub>2</sub> lasers, but they provide the necessarily high energies (mJ) only with low repetition rates (Hz) that are not sufficient for functional imaging with high resolution. Alternatively, high power laser diodes have been introduced as laser sources for OAI, due to their high repetition rates (a few kHz), lower costs and sizes if compared to solid state lasers. Nevertheless, their drawbacks consist in a low energy per pulse ( $\mu$ J) and a relatively highly divergent beam that needs collimation optics. For this reason, the employment of diode laser bars and stacks significantly increases the energy per pulse up to a several mJ. The diode laser bars and stacks imply a big challenge if compared to single emitters for several reasons. Firstly, they need very demanding electronic requirements, as forward voltages and currents of several tens of volts and hundreds of amperes, respectively. Secondly, their highly divergent beam profiles require precise collimation by means of fast axis and slow axis collimations (FAC and SAC, respectively) that often are not enough to achieve proper performances (beam twistors or other optics are necessary).

In this work, we show 808-nm diode laser stacks driven with 17 volts and  $\sim$  200 amperes by a home-made current driver. Particular emphasis will be attributed to the optics employed to collimate and after focus the beam in a spot. For the moment we do not use FAC and SAC lenses due to their shortage in the market. To one of the two stacks we apply optical fibers as collimation lenses attached to the emitters and we compare the performances of beam profile with those of the other stack that uses conventional optics. The results demonstrate that the former stack better collimates the beam, allowing an easier focusing in a spot in a successive stage. We will apply the light beam to an ink inclusion hosted in a turbid phantom to generate high optoacoustic signals. The future aim is to focus the beam in an optical fiber ( $< 400 \mu\text{m}$ ) applicable to optoacoustic endoscopy.

## **Increasing bandwidth of photoacoustic techniques for thermoelastic characterization by calibration of microphone**

S. Todosijević <sup>1,2</sup>, Z. Šoškić<sup>2</sup>, S. Galović<sup>3</sup>

<sup>1</sup>School of Electrical Engineering, University of Belgrade,  
Bulevar Kralja Aleksandra 73 Belgrade, Serbia


<sup>2</sup>Faculty of Mechanical and Civil Engineering, University of Kragujevac,  
Dositejeva 19 Kraljevo, Serbia

<sup>3</sup>Vinča Institute of Nuclear Sciences, University of Belgrade, P. O. Box 522, 11001 Belgrade, Serbia

 [todosijevic.s@mfkv.kg.ac.rs](mailto:todosijevic.s@mfkv.kg.ac.rs)

Range of modulation frequencies used for thermoelastic characterization by photoacoustic techniques depends on bandwidth of microphones that are used for detection of photoacoustic response. Since the theoretical models consider transfer function of measurement system flat, their application for solution of inverse photoacoustic problem and material characterization are limited to frequency ranges where amplitude-frequency characteristic of microphones may be considered constant. This paper presents methodology for calibration of commercial microphones, which will result in calculation of dependencies of amplitude and phase delay of their response on input signal frequency. The measured dependencies may be further used to develop software that will use photoacoustic measurements in wider range of modulation frequencies, leading to increased accuracy of thermoelastic characterization by photoacoustic techniques.

## **Phase offset in multichannel photoacoustic detection**

P. Zbysiński<sup>1</sup>, T. Starecki <sup>2</sup>

<sup>1</sup>BTC Korporacja, Lwowska 5, 05-120 Legionowo, Poland

<sup>2</sup>Institute of Electronic Systems, Warsaw University of Technology,  
Nowowiejska 15/19, 00-665 Warsaw, Poland

 [t.starecki@ise.pw.edu.pl](mailto:t.starecki@ise.pw.edu.pl)

Multichannel photoacoustic detection is based on use of several microphones (or other pressure sensors). Use of multiple microphones increases the overall signal amplitude and allows for signal to noise ratio improvement by means of noise averaging. However in some cases spatial distribution of the pressure sensors may result in the noticeable phase offset of the signals, especially at higher frequencies of light beam modulation. The presentation shows examples of such situations and presents potential solutions to the problem.

## Ultracompact electronic system for photoacoustic measurements

T. Starecki ✉, A. Geras

Institute of Electronic Systems, Warsaw University of Technology,  
Nowowiejska 15/19, 00-665 Warsaw, Poland

✉ [t.starecki@ise.pw.edu.pl](mailto:t.starecki@ise.pw.edu.pl)

Electronic instrumentation used in photoacoustic setups is usually based on bulky, heavy, expensive and power-hungry components like lock-in amplifiers, arbitrary, function or sine generators, etc. The discussed solution presents an ultracompact system (73 x 39 mm) dedicated for photoacoustic measurements. The system allows for independent stimulation of two light sources and high speed, high resolution photoacoustic signal recording from two channels, which can work in fully independent two-channel mode or hardware implemented differential mode. The system is powered and controlled via a USB interface. Most of the system settings can be programmatically controlled.

# SPECTROSCOPY, APPLICATIONS IN CHEMISTRY

## Investigation of thermal decomposition and stability mechanisms of nitro rich high energy materials using UV-Vis laser based pulsed photoacoustic pyrolysis technique

A.K. Chaudhary ✉, K. S. Rao


Advanced Centre of Research in High Energy Materials (ACRHEM), University of Hyderabad,  
Hyderabad-500 046, India

✉ [anilphys@yahoo.com](mailto:anilphys@yahoo.com)

The paper reports the systematic study of thermal decomposition<sup>1</sup> and stability mechanisms of some newly synthesized nitro rich 1,2,4 triazoles high energy materials named as 1-(4-methyl-3,5-dinitrophenyl)-1H-1,2,4-triazole (P-Me-DNPT), 1-(4-methoxy-3,5-dinitrophenyl)-1H-1,2,4-triazole (P-OMe-DNPT) and 2,6-dinitro-4-(1H-1,2,4-triazole-1-yl) aniline (P-NH<sub>2</sub>-DNPT)<sup>2</sup> compounds. The thermal stability and decomposition mechanisms of these compounds are evaluated along with their finger print spectra between 30 and 350 °C using 266 nm and 532 nm laser based pulsed Photoacoustic pyrolysis technique<sup>3,4</sup>. We made an attempt to identify the role of NO<sub>2</sub> and NO gases in the process of thermal decomposition<sup>5</sup>. Thermo gravimetric-differential thermal analysis (TG-DTA) data of these compounds are combined with PA results to understand the role of multi-steps decomposition mechanisms of 1,2,4-triazoles. Thermal “Q” values and data acquisition time also provide valuable information about the life time stability of HEMs molecules as propellants for rocket fuel.

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## QEPAS sensor for ultra-high sensitivity detection of leaks in mechatronic components

A. Sampaolo <sup>1,2</sup>, P. Patimisco<sup>1,2</sup>, M. Giglio<sup>1</sup>, P.P. Calabrese<sup>1</sup>, L. Chieco<sup>3</sup>, G. Scamarcio<sup>1</sup>,  
F. K. Tittel<sup>2</sup>, V. Spagnolo<sup>1</sup>

<sup>1</sup>Dipartimento Interateneo di Fisica, Università e Politecnico di Bari,  
CNR-IFN UOS BARI, Via Amendola 173, Bari, Italy

<sup>2</sup>Rice University, Department of Electrical and Computer Engineering,  
6100 Main Street, Houston, TX 77005, USA;

<sup>3</sup>MASMEC S.p.A., Via dei Gigli, 21, Modugno BA

 [angelo.sampaolo@uniba.it](mailto:angelo.sampaolo@uniba.it)


The safety of car engines represents one of the main issues and important valuation parameter for automobile customers. High standard of reliability requires accurate performance evaluation methods for any single mechatronic part. Differential pressure measurements are typically employed by the automotive industry for the testing of vacuum seals in mechanical components. The limitation of this approach is the low sensitivity and the fluctuations of repeated measurements.

We will report here a new way to identify leaks based on the detection of specific gas species via quartz-enhanced photoacoustic (QEPAS) spectroscopic technique [1]. A QEPAS sensor was integrated into a vacuum-seal test station for diesel engine injectors. The test station consisted of a piston making seal with a high-vacuum valve connected to the QEPAS sensor. We selected sulfur hexafluoride (SF<sub>6</sub>) [2], as the target gas and employed a 1% SF<sub>6</sub> in N<sub>2</sub> mixture as a test gas carrier. An external-cavity quantum cascade laser emitting at 10.56 μm, coupled to a 300-μm bore diameter hollow core waveguide was used as the laser source [3, 4]. We characterized and calibrated the SF<sub>6</sub> sensor employing certified leak standards. A minimum detection sensitivity of 2.75 ppb for a 1 second of integration time was achieved, which corresponds to a detectable leak flow of 3x10<sup>-5</sup> sccm/min. A minimum detectable leak flow of < 3x10<sup>-7</sup> sccm/min could be achieved by using pure SF<sub>6</sub> as gas carrier. We tested our sensor with five high vacuum valves and each was characterized for defects of different sizes. The smallest defect (the insertion of a metallic wire of 20-μm diameter) produced a leak flow of 0.04 sccm/min, orders of magnitude higher than the minimum detectable flow [1].

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**SENSORS, ACTUATORS  
AND INDUSTRIAL APPLICATIONS**

## Photonic crystal as a temperature IR sensor

M. Torres-Cisneros <sup>1</sup>, R. Guzmán-Cabrera<sup>1</sup>, D. May-Arrijo<sup>2</sup>, I. Hernandez-Romano<sup>3</sup>,  
H. Plascencia-Mora<sup>1</sup>, Patrick LiKamWa<sup>4</sup>, E. Aguilera-Gómez<sup>1</sup>, T. Cordova-Fraga<sup>5</sup>

<sup>1</sup>NanoBioPhotonics Group, School of Engineering, University of Guanajuato,  
Salamanca, Gto 36885, Mexico

<sup>2</sup>Unidad Aguascalientes, CIO, Aguascalientes, Ags, Mexico

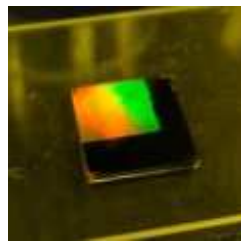
<sup>3</sup>CONACYT Research Fellow-Electronics Department, Sede Palo Blanco, University of Guanajuato,  
Salamanca, Gto 36885, Mexico

<sup>4</sup>Multiple Quantum Wells, CREOL, Central Florida University, Orlando FL, EUA

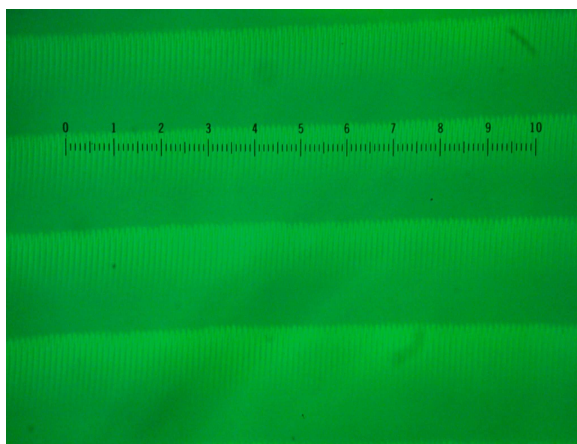
<sup>5</sup>DCI, Campus Leon, University of Guanajuato

 [torres.cisneros@ugto.mx](mailto:torres.cisneros@ugto.mx)

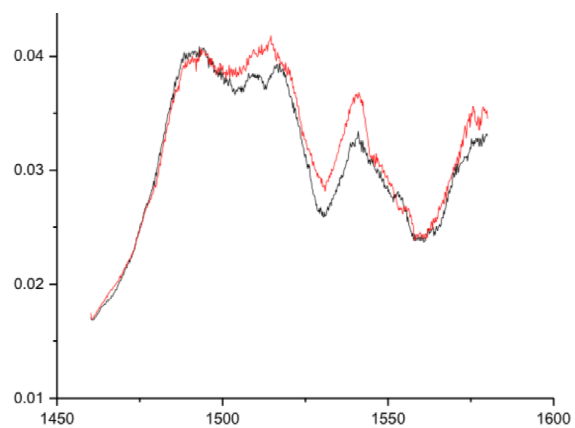
Photonic crystals can be seen as periodic materials where the spectra transmission can be modified by changing the difference of the materials refractive index or its geometry. Particularly 1D photonic crystal can be built on a sensitive temperature substrate and with this goal, we can use specific materials for the PC and/or the waveguides. In this work we report a IR temperature sensor by using a one dimensional photonic crystal fabricated on the top of previously fabricated waveguides. The waveguides were built over a 2 microns thick SU8 layer, the dimensions of the waveguide are 0.2 microns high and 18 microns width. The waveguides path is modulated by recording the photonic crystal by using the 1805 photoresist. Fig. 1(a) displays a panoramic view of the sample where we can appreciate waveguides with no PC recorded for reference. Fig.1(b) shows the PC modulated waveguide and Fig 1(c) presents the transmission spectra of the waveguides where we can appreciate the temperature dependence.



(a)



(b)




(c)

Fig. 1. a) Photonic Crystal and waveguides build on substrate. b) close view of the periodic pattern over the waveguides. c) temperature dependence transmission spectra of the PC in 1450-1600 nm window.

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## Thermal effects and latent energy in metals at the different speeds of deformation

B. A. Zimin<sup>1</sup>, V. E. Sventitskaya <sup>2</sup>, I. V. Smirnov<sup>3</sup>, Y. V. Sudenkov<sup>3</sup>

<sup>1</sup>Institute of Problems of Mechanical Engineering,  
V.O., Bolshoj pr., 61, St. Petersburg, 199178, Russia

<sup>2</sup>BSTU “VOENMEH” named after D. F. Ustinov,  
1<sup>st</sup> Krasnoarmeyskaya str., 1, St. Petersburg, 190005, Russia

<sup>3</sup>Saint-Petersburg State University,  
Universitetsky pr., 28, Peterhov, St. Petersburg, 198504, Russia

[vsvent@yandex.ru](mailto:vsvent@yandex.ru)

Theory of plastic deformation of metals is the subject of intense research in the last decade due to the numerous requests of technical sciences. Deformation and fracture of metals is accompanied by the conversion of mechanical work into other forms of energy - thermal, electromagnetic, acoustic. Infrared radiation (which is produced by processes of deformation and fracture of materials) allowed to get the methods for speed rating of the neck development during the deformation of polypropylene and to describe the process of heat generation in the tip of moving crack.

The authors presented the results of experimental studies of dissipation processes during the deformation of metal samples (Cu, aluminum alloy D16AM, titanium BT1 and steel 12X18H10T) at different speeds of deformations. Infrared radiation is controlled by the thermal imaging camera ThermoCAM SC 300. Mechanical tests were conducted at the room temperature by the universal machine SHIMADZU AG-X at three different speeds of the active capture (5 mm / min, 10 mm / min and 20 mm / min).

As the result of each experiment the authors received the loading diagram and the intensity of heat release thermogram. The presented results allowed to determine some integral energy parameters: the specific work expended on the sample deformation and the heat energy released during the loading as well as the Taylor – Quinney coefficient.

The research results show that the Taylor - Quinney coefficient increases due to growing of speed of deformation for the tested materials, with almost no dependence of the diagram from the deformation speed. So the speed of deformation firstly affects the thermodynamics of the process of plastic deformation. Thus, there is the relative decreasing of the latent energy with increasing of speed of deformation. Note that, it is important to take into account the viscosity in the laws of connection between stresses and strains in metals.

## Laser thermal wave diagnostics of heat transport in soldered contacts of semiconductor devices

A.L. Glazov<sup>1</sup>, K.L. Muratikov <sup>1</sup>

<sup>1</sup>Ioffe Physical-Technical Institute of RAS, Department of Solid State Electronics,  
Polytechnicheskaya 26, 194021, St.Petersburg, Russia.

 [klm.holo@mail.ioffe.ru](mailto:klm.holo@mail.ioffe.ru)

The operation of modern microelectronic, solar cells, high-power semiconductor devices is accompanied by the evolution of a significant amount of heat. The density of heat evolution in working regions of some elements becomes so high that thermal effects frequently play the role of factors limiting further progress in improvement of the main performance characteristics of devices. In this context, investigation of heat transfer processes is among the topical tasks of the physics and technology of high various microelectronic and semiconductor devices.

The aim of the present investigation was to assess the quality of dynamic heat-exchange properties of bonded interfaces between separate units of multielement high-power switches using the laser thermowave photodeflection (PD) method. According to this, thermal waves are locally excited by pumping laser radiation that is strongly absorbed by the probed object material. This radiation is modulated at a preset frequency and focused onto the edge surface of an object (semiconductor structure). The laser-induced thermal waves are detected by monitoring the deviation of a probing laser beam, which is induced by a thermal lens formed in air near the object surface during the excitation of thermal waves. This approach was successfully used by us to monitor nonstationary thermal processes in semiconductors and ceramics [1–4].

Devices in several groups were soldered by a tin–lead alloy (POS 63) or WS483 at a temperatures recommended by manufactures. Prior to soldering, ohmic contacts were formed on the semiconductor plates by the chemical deposition of metals onto the surface of structures followed by fusion of the metal in vacuum under elevated temperature. The technology of forming metal contacts on ground and polished semiconductor structures was the same in all groups of samples. In one group, 7 to 8  $\mu\text{m}$  thick aluminum layers were deposited additionally by evaporation onto clean polished semiconductor surfaces, after which the elements were stacked and fused together in vacuum at a pressure of about  $10^2$  kPa and a temperature of about 700 C. The diffusion welding of polished diode plates was performed via thin (30  $\mu\text{m}$ ) aluminum foil in vacuum at a pressure of about  $10^5$  kPa and a temperature of about 500 C.

The obtained results show that laser thermowave PD methods can provide qualitative and quantitative assessment of the dynamic heat exchange properties of soldered and bonded interfaces in multielement semiconductor devices fabricated using various assembly technologies. The obtained results also demonstrated that for characterization of nonstationary heat flows through contacts of semiconductor structures at micrometer scale it is necessary to take into account not only thermal resistance (Kapitza resistance) but also the thermal capacitance of a contact.

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## SLS one of the modern technology of laser surface treatment

M. Musztyfaga-Staszuk ✉

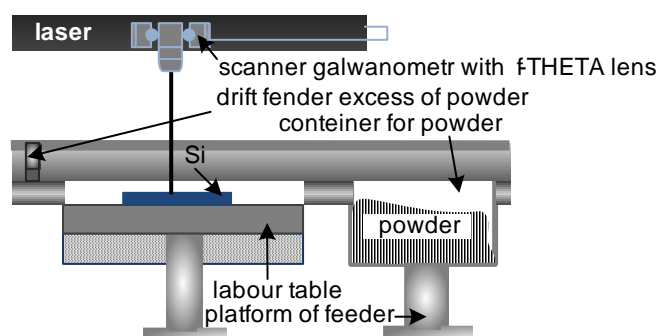
Silesian University of Technology, Faculty of Mechanical Engineering,  
Welding Department, Konarskiego 18A, 44-100 Gliwice, Poland

✉ [malgorzata.musztyfaga@polsl.pl](mailto:malgorzata.musztyfaga@polsl.pl)

One of the methods to acquire solar energy are photovoltaic cells. One of the stages of their fabrication is the production of front electrode. The application of an unconventional method of selective laser sintering using CO<sub>2</sub> laser (Fig. 1) for the fabrication of front electrode of silicon photovoltaic cell was a real challenge. The most notable research results yielded by the manager's investigation studies are indicative of what further investigation studies should be focused on. The main objective of the paper is to work out guidelines apply to laser micromachining of the front electrode of the photovoltaic cell concern the selection of parameters such as the laser beam and laser beam feed rate, which give possibility to assure of its a proper quality and suitable utilize properties (including as well electrical properties).

The results of the author's research have yielded the answers to the following research questions:

- 1) What is the optimal granularity of the applied silver powder and optimal composition of silver paste for the acquisition of front electrode of solar silicon cell using the method of selective laser sintering?
- 2) Do the electrical properties of the electrode closely depend on the share of particular components of pastes or powders they are made from?
- 3) What is the impact of the condition of silicon substrate surface (its morphology and anti-reflexive layer) as well as the thickness of the deposited metallic coating on the resistance value of Si-Ag interface?
- 4) Does the laser micromachining of silicon elements of photovoltaic cells from monocrystalline silicon, including the selective laser sintering of front electrode to its surface, using CO<sub>2</sub> laser have influence on the quality improvement of the cell through minimizing the resistance of front electrode interface with the substrate?



**Fig. 1.** The EOSINT M 250 Xtended device equipped with laser CO<sub>2</sub>

## Quality and economics efficiency of thermal cutting high yield strength steel

A. Rzeźnikiewicz ✉

Silesian University of Technology, Welding Department, Gliwice, Poland

✉ [agnieszka.rzeznikiewicz@polsl.pl](mailto:agnieszka.rzeznikiewicz@polsl.pl)

Cutting is a technological operation which starts the production process. Metal cutting today is characterised by higher quality demands and increasing cost pressures. The edges of cut parts should not require any further processing and are expected to exhibit maximum dimensional accuracy. As a result, the ability of traditional cutting techniques to meet these demands is being increasingly questioned. The objective of the research was to quantify the influence of oxyfuel flame cutting, plasma arc cutting and laser cutting processes on the edge quality, hardness and width of the heat affected zone of the high yield strength steel. 15 mm plates were oxyfuel flame cut using Eckert Szafir BL-2 with optimum industrial quality parameter settings. 15 mm plates were plasma cut using High Tolerance Plasma Arc Cutting with optimum industrial quality parameter settings and 15 mm plates were laser cut using TRUMPF TruLaser 3030.

To evaluate quality of thermal cut edges the following geometrical quality factors was measured: perpendicularity or angularity tolerance, mean high of the profile as per EN ISO 9013 (Thermal cutting - Classification of thermal cuts - Geometrical product specification and quality tolerance'). Mean height of the profile Rz5 of the thermal cut high yield strength steel 15 mm thick was also determined by three- and two-dimensional surface topography measured using the confocal laser scanning microscope. It was also measured the width of the heat effected zone and the hardness. It was shown that, the quality of the thermal cutting, in addition to the geometrical characteristics of the surface, also provides the width of the heat affected zone and its properties.

The technical aspect has a significant impact on the choice of cutting technology but it is also very important to know the economic aspect of cutting technology. Knowledge of competitive cutting methods and a comprehensive analysis of the technical aspects as well as economic aspects of cutting technology allows to avoid wrong decisions. In this economic analysis was calculated the direct costs (electric energy, gases, depreciation and consumables), without the labour cost of the thermal cutting methods.

## Laser absorption characteristics in diode laser surface transformation hardening of ductile cast iron

D. Janicki ✉

The Silesian University of Technology, Faculty of Mechanical Engineering, Welding Department,  
Gliwice, Poland

✉ [damian.janicki@polsl.pl](mailto:damian.janicki@polsl.pl)

The paper presents an approach to the estimation of the absorption of diode laser beam during laser surface transformation hardening of ductile cast iron. The temperature rise distribution in and around laser beam on the surface of the workpiece as well as with respect to depth was determined. The effect of surface roughness, laser power and traverse speed on the absorptivity values was established. The experiments were conducted using a continuous wave high power direct diode laser with a rectangular laser beam spot and the uniform distribution of laser power (top-hat beam profile). The rectangular laser beam spot of size 1.8x6.8 mm, at focal length 82 mm, was focused on the top surface of the workpiece. The short axis of the beam was set parallel to the traverse direction. Argon was used as the shielding gas. The surface of the workpieces was ground unidirectionally. The roughness parameter  $R_a$  perpendicular to the grinding direction varied from 0.05 to 0.2  $\mu\text{m}$ .

In an effort to estimate the absorptivity values at different processing conditions the experimental results have been coupled with numerical simulations. The experimental approach included temperature measurements on and under the surface of the workpiece during hardening process at different laser power levels (400 W to 1000 W) and traverse speeds, ranging from 1.66 mm/s to 16.66 mm/s. The surface temperature of the workpiece was measured with an Infrared (IR) camera FLIR A600-Series. The temperature distribution under the surface of the workpiece was measured by means of thermocouples. Six K-type thermocouples were placed at different distances from the surface of the workpiece (in the range from 1.5 mm to 0.1 mm) along the hardening direction (in the center of the hardening zone). The sampling frequency for all thermocouples was 200 Hz. A comparison between the IR results with the thermocouple measurements was made.


The thermal modeling of the hardening process was performed using ANSYS software. A three dimensional numerical model was developed taking into account the temperature dependence of the physical properties of the used ductile cast iron and the surface heat loss through convection and radiation. The laser beam was considered as a moving rectangular heat source with a uniform distribution of laser power. The thermal model was validated by the experimental data recorded by the IR camera and thermocouples.

Additionally, the influence of surface roughness of the workpiece on the reflectivity of the used ductile cast iron at room temperature was determined using a setup comprising an Ocean Optics PC2000-ISA-PC Plug in Fiber Optics Spectrometer, ISP-REF Integrating Sphere and WS-1 diffuse reflectance standard.

The absorptivity of the diode laser beam by ductile cast iron varied from 45% to about 75% depending upon the processing conditions.

APPLICATIONS IN MEDICINE, BIOLOGY  
AND AGRICULTURE

## Photoacoustic approach to characterizing semisolid phantoms

B. Reyes-Ramírez <sup>1</sup>, G. Gutiérrez-Juárez<sup>1</sup>, L. Polo-Parada<sup>2</sup>, C. García-Segundo<sup>3</sup>,  
G. Martínez-Ponce<sup>4</sup>

<sup>1</sup>Departamento de Ingeniería Física, División de Ciencias e Ingenierías, Universidad de Guanajuato, Loma del Bosque 103, Lomas del Campestre, C. P. 37150, León, Guanajuato, México

<sup>2</sup>Department of Medical Pharmacology and Physiology, Dalton Cardiovascular Research Center, University of Missouri-Columbia, Columbia, MO, USA

<sup>3</sup>Imagenología Biomédica: Física y Computacional, Centro de Ciencias Aplicada y Desarrollo Tecnológico, Universidad Nacional Autónoma de México, Circuito Exterior S/N, Cd. Universitaria, A. P. 70-186, Coyoacán, C. P. 04510, México D.F.

<sup>4</sup>Laboratorio de Holografía, Centro de Investigaciones en Óptica A. C. A. P. 1-948, 37000 León Guanajuato, México

 [bartolome.r@fisica.ugto.mx](mailto:bartolome.r@fisica.ugto.mx)

Over the last decade, research and development of medical ultrasound transducers with working frequencies higher than 20 MHz has offered new challenges in photoacoustics. Among them, the elaboration of biological tissue phantoms made up of materials that look like real tissue, which are used to calibrate, assess and quantify the performance of ultrasound scanners. In order to characterize these media, some physical properties have to be measured, such as the sound speed, acoustic impedance and scattering, as well as optical absorption, scattering and attenuation of the light propagating beam through the phantom. In this study, the thermoelastic model of the photoacoustic effect with one degree of freedom in the spatial coordinates for a plane sample is analyzed with the aim of assessing the ultrasound speed in solid and semisolid samples typically used in biological phantoms. The proposed model considers a sample with thickness  $L$ , and Beer's absorption law for a medium immersed in a not absorbent fluid with different acoustical impedance. It is shown that the photoacoustic signal, in the transmission mode of detection, is composed mainly by pairs of pulses, with time interval between both pulses equal to  $\tau = 2L / c_s$ , where  $c_s$  is the sound speed in the sample. In order to validate these results as a method to measure the sound speed in the elaborated phantoms, we performed a series of experiments using 12 mm thick solutions with different concentrations of copper nitrate. The photoacoustic pressure was induced by nanosecond laser pulses and detected with homemade capacitive sensors made of 28  $\mu\text{m}$  thick Polyvinylidene Fluoride films operating in the piezoelectric mode. These results are compared to measurements obtained using traditional photoacoustic configuration which was independent of the proposed model.

## Elastic evaluation of poly (lactic acid) electrospun membranes by pulsed photoacoustic technique

M. Navarrete <sup>1,3</sup>, R. Vera-Graziano<sup>2,3</sup>, A. Maciel-Cerda<sup>2,3</sup>, F. M. Sánchez Arévalo<sup>2,3</sup>, O. Zurita<sup>1,3</sup>

<sup>1</sup> Instituto de Ingeniería, Universidad Nacional Autónoma de México, Ciudad de México, México

<sup>2</sup> Instituto de Investigación en Materiales, Universidad Nacional Autónoma de México, Ciudad de México, México

<sup>3</sup> Av. Universidad 3000, Col. Universidad Nacional Autónoma de México, Ciudad de México, 04510, México

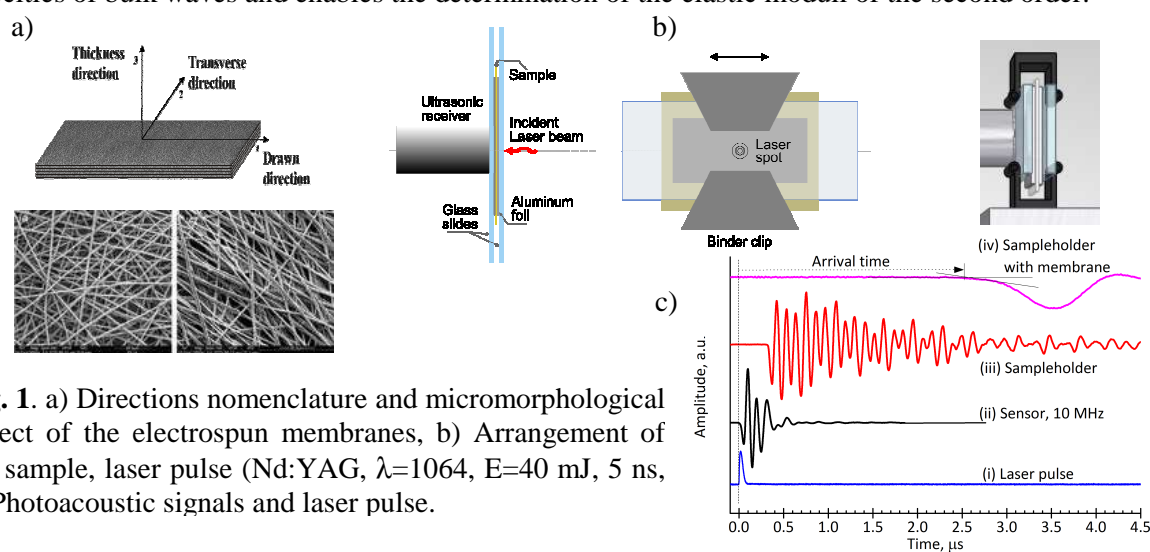
 [mnm@pumas.iingen.unam.mx](mailto:mnm@pumas.iingen.unam.mx)

Tissue engineering commonly uses electrospun nanofibers to build surfaces capable of promoting cell regeneration and human organ reconstruction [1]. This electrospun nonwoven mats are designed commonly to mimic extracellular matrix [2]. While the tensile properties of electrospun membranes have commonly been reported in the literature, assessment of the properties in the other directions have been mostly unexplored. Only a few theoretical attempts to determine the modulus in the thickness direction using a multiscale modeling strategy have been made [3]. Knowing all elastic properties can allow engineers design properly these scaffolds for specific applications, such as implants, replacement tissue or organ substitutes. The aim of this work is to determine the mechanical properties of poly (lactic acid) membranes with inclusion of hydroxyapatite nanoparticles. The elastic moduli in two directions using pulsed photoacoustic technique are determined. As well, we make comparisons between different morphologies: electrospun membranes and thin films. Besides, in the conventional tensile test machine are realized assays according to an ASTM D1708 standard. The membrane samples are prepared in two different geometry:

a. To determine the longitudinal and shear waves in drawn direction: the sample is rolled in a cylindrical shape, and wrapped in Mylar foil, and then it is placed within a glass tube to attach it. A short metal rod (with the same diameter of the rolled membrane) on each side of the cylindrical sample is attaching to ensure the transmission of the acoustic waves.

b. To determine the longitudinal and shear velocity in transverse direction: the sample is kept between two layers of aluminium foil with a glass slide as support.

The measurement of propagation time of these waves over a known distance renders the propagation velocities of bulk waves and enables the determination of the elastic moduli of the second order.



**Fig. 1.** a) Directions nomenclature and micromorphological aspect of the electrospun membranes, b) Arrangement of the sample, laser pulse (Nd:YAG,  $\lambda=1064$ ,  $E=40$  mJ, 5 ns, c) Photoacoustic signals and laser pulse.

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## Identification of porosity in bone through sound

R. Guzmán-Cabrera<sup>1</sup>, M. Torres-Cisneros<sup>1</sup>, T. Cordova<sup>2</sup>, I. Delgadillo<sup>2</sup>, N. Padilla-Raygoza<sup>3</sup>  
J. C. Martínez<sup>4</sup>

<sup>1</sup> División de Ingenierías, Universidad de Guanajuato campus Irapuato-Salamanca, Carretera Salamanca-Valle de Santiago, 36885 Salamanca, GTO, México Loma del Bosque 103 Col. Lomas del Campestre, 37150. León, GTO, México

<sup>2</sup> División de Ciencias e Ingenierías, Universidad de Guanajuato campus León.

<sup>3</sup> Departamento de Enfermería y Obstetricia, División de Ciencias de la Salud e Ingenierías, Universidad de Guanajuato, Campus Celaya-Salvatierra, Celaya, Guanajuato, México

<sup>4</sup> Unidad Profesional Interdisciplinaria de Ingeniería, Campus Guanajuato, IPN. Av. Mineral de Valenciana No. 200 Col. Industrial Puerto Interior. C.P. 36275. Silao, GTO, México

✉ [guzmanc@ugto.mx](mailto:guzmanc@ugto.mx)

Reflection occurs when an ultrasound wave reaches an interface between two media with different acoustic impedances. The amplitude of the portion reflected depends on the impedance of the material, density and velocity of propagation of both. This is trivial interfaces and soft tissues in high hard tissue such as bone. This paper puts forward a methodology based on sound propagation in human tissue in order to help early detection of diseases such as osteoporosis occurs. The characterization of bones at different frequencies depending on their porosity is presented. The ultimate goal is used by these data for the application and early detection of osteoporosis.

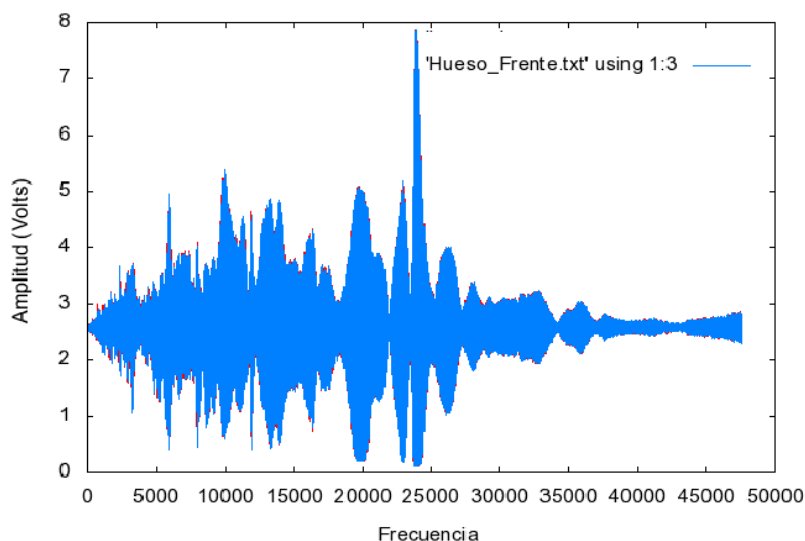



Fig. 1. Resonance frequency around 240000Hz, with sensors in front of the bone

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## Evaluation of serum ferritin in hemodialysis patients by Raman spectroscopy and XRF: preliminary results

J. M. Ruvalcaba<sup>1</sup>, T. Cordova<sup>1</sup>, M. G. De la Rosa<sup>1</sup>, J. J. Bernal<sup>1</sup>, B. O. Murillo<sup>2</sup>, J. C. Martínez<sup>3</sup>,  
J. Ruiz-Pinales<sup>4</sup>, R. Guzmán-Cabrera <sup>4</sup>

<sup>1</sup>División de Ciencias e Ingenierías, Universidad de Guanajuato campus León.  
Loma del Bosque 103 Col. Lomas del Campestre, 37150. León, GTO, Mexico

<sup>2</sup>Unidad de Investigación Clínica, UMAE No. 1, IMSS.

Blvd A. López Mateos 1813, Obregon. C.P. 37340. León, GTO, México

<sup>3</sup>Unidad Profesional Interdisciplinaria de Ingeniería, Campus Guanajuato, IPN. Av. Mineral de  
Valenciana No. 200 Col. Industrial Puerto Interior. C.P. 36275. Silao, GTO, México

<sup>4</sup>División de Ingenierías, Universidad de Guanajuato campus Irapuato-Salamanca, Carretera  
Salamanca-Valle de Santiago, 36885 Salamanca, GTO, México

 [guzmanc@ugto.mx](mailto:guzmanc@ugto.mx)

Iron metabolism in the human body is utmost important because it is involved in the formation of hemoglobin and oxygen transport, essential life processes. To quantify iron levels with better accuracy greater sensitivity tests are used, such as serum ferritin. One difficulty in measuring serum ferritin are cost/time studies, as testing by enzyme-linked immunosorbent assay (ELISA). In this paper the use of Raman spectroscopy is proposed to detect differences in serum ferritin concentrations in subjects with high levels (>500 ng/ml), such as patients undergoing hemodialysis for kidney failure, anemic patients with low levels (<30 ng/ml) and a control group with levels between 30 and 500 ng/ml. Showing results by principal component analysis (PCA) and linear component analysis (LDA). Furthermore, the study is complemented by analyzing the amount of iron in different groups by X-Ray Fluorescence (XRF) to correlate with serum ferritin. Suggesting that Raman spectroscopy is a powerful tool for clinical diagnosis.

Table 1. Normal ranges in serum ferritin and iron storage.

	Men	Average	Women	Average
Ferritin (µg/L)	36-224	103	2-83	35.6
Iron (mg)	140-1390	690	0-340	210

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# IMAGING

## Thermographic reconstruction by Fourier synthetic aperture focusing technique (F-SAFT) from virtual acoustic waves

P. Burgholzer <sup>1</sup>, M. Thor<sup>2</sup>, J. Gruber<sup>2</sup>, G. Mayr<sup>2</sup>

<sup>1</sup> Christian Doppler Laboratory for Photoacoustic Imaging and Laser Ultrasonics, Research Center for Non Destructive Testing GmbH (RECENDT), Linz, Austria

<sup>2</sup>School of Engineering, University of Applied Sciences Upper Austria, Wels, Austria

 [peter.burgholzer@recendt.at](mailto:peter.burgholzer@recendt.at)

Heat diffusion and damped acoustic waves show a lot of similarities. Both can be modelled mathematically by second order linear partial differential equations in space and time. Linearity assures that all solutions of both equations can be represented as a superposition of wave trains having a certain wave-vector  $k$  or frequency  $\omega$  using a Fourier transformation in space or time, respectively. These wave trains show either an exponential decay of the amplitude in time with a real wave-vector and a complex frequency (Fourier  $k$ - $t$ -space) or an amplitude decay in space with a real frequency and a complex wave-vector (Fourier  $x$ - $\omega$ -space). Both can describe the same physical solution but depending on the experimental set-up one description can be more advantageous. For photoacoustic or photothermal reconstruction the signals are measured usually at the sample surface as a function of time and therefore Fourier  $x$ - $\omega$ -space using a complex wave-vector  $K(\omega)$  as a function of the real frequency  $\omega$  is adequate. For damped acoustic waves as well as for thermal waves the imaginary part of the complex wave-vector gives the attenuation exponent. Thermal waves are highly damped as the imaginary part is equal to the real part. Their amplitude is decreased by more than a factor of 500 within a propagation distance of one wavelength [1].

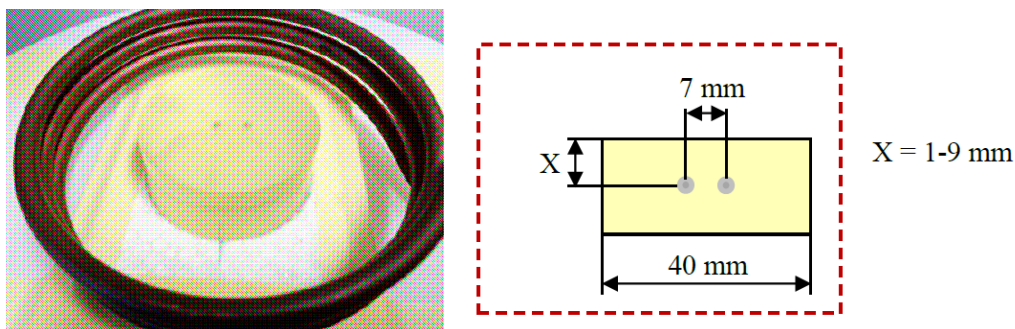



Fig. 1. Steel balls embedded in epoxy (depth  $X = 1-9$  mm) and heated by surrounding induction coil.

La Riviere et al. introduced a local transformation from the acoustic wave without damping to the actual measured signal including damping. The inverse transformation is ill-posed and was regularized to reconstruct acoustical images [2]. We used the same transformation to get a virtual acoustic wave from the measured temperature signal. From that virtual acoustical signal the original temperature distribution just after the excitation pulse was reconstructed by a Fourier synthetic aperture focusing technique (FSAFT) [3]. We demonstrated the 2D- and 3D- reconstruction capability of this method by simulations and experimentally. Two small steel balls (diameter 2 mm, distance 7 mm) were embedded in epoxy (depth varying between 1-9 mm) and heated by a short electro-magnetic pulse. The temperature was measured at the surface (Fig. 1) by an infrared camera. From the reconstructed signals the two balls could be resolved individually up to a depth of 8 mm.

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## Visualization of the Au<sup>2+</sup> ions implanted regions in silicon with the MFCA, optical and PA methods

M. Maliński <sup>1</sup>, Ł. Chrobak<sup>1</sup>, W. Madej<sup>1</sup>, N. Kukharchyk<sup>2</sup>

<sup>1</sup>Faculty of Electronics and Computer Science TU of Koszalin  
2 Śniadeckich St., 75-453 Koszalin, Poland

<sup>2</sup>Angewandte Festkörperphysic, Ruhr Universität Bochum Universitätsstrasse 150,  
Bochum D-44780, Germany

 [mirosław.malinski@tu.koszalin.pl](mailto:mirosław.malinski@tu.koszalin.pl)

Investigated silicon samples were implanted with the Au<sup>2+</sup> ions of the energy 100 keV and the dose of implantation 10<sup>14</sup>/cm<sup>2</sup>. The area of the implanted region was 2mm·2mm. Size of the Si substrate samples was 5mm·5mm. Optical microscope images of Au<sup>2+</sup> implanted regions indicated that the optical reflection coefficient of the implanted region was about 15% -20% bigger than that of the substrate. Next the X-Y maps of the amplitude distributions of the MFCA (modulated free carrier absorption) signal of the silicon Au<sup>2+</sup> implanted samples were measured (see Fig.1.). They were measured with the experimental set-up built for the MFCA mapping and frequency characteristics. The maps showed that for 405 nm laser illumination the MFCA amplitude signal in the implanted region was about 100 times smaller than that for the substrate what was the result of a strong decrease of the lifetime of carriers. Its value also depended on the wavelength of the illuminating light.

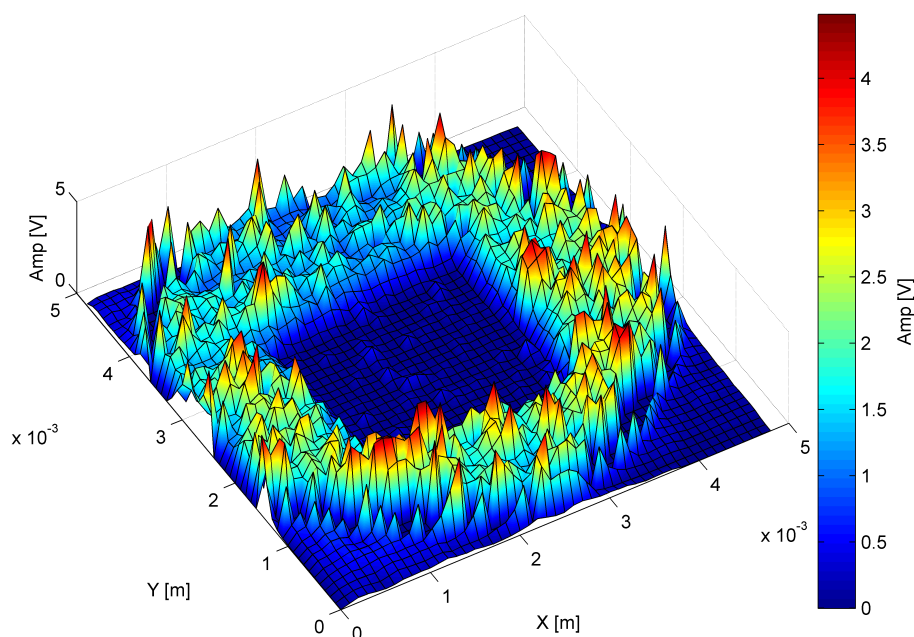



Fig.1. Amplitude distribution map of the MFCA signal of the silicon Au<sup>2+</sup> implanted sample

The measurements of the cross sections of the amplitude MFCA signals for three wavelengths of the laser illuminating light (405 nm, 520 nm, 660 nm) enabled determination of a several time increase of the optical absorption coefficient of the implanted regions, respective to the substrate. The thickness of the implantation depth computed in the SRIM program was 1000 Å. The maps of the amplitude of the PA signal were measured too. Unfortunately the PA measurements did not show the implanted regions. Theoretical considerations, performed in a 2 layer PA model, showed that this is the result of a too small depth of the Au<sup>2+</sup> implanted region. As a result one can conclude that the MFCA method turned out to be the best method for the visualization of implanted regions in silicon samples.

## Quantitative thermal wave imaging of GaAs and CdMgSe samples using lock-in infrared thermography

M. Pawlak <sup>1</sup>, M. Streza<sup>2</sup>, K. Strzałkowi<sup>1</sup>, M. Chirtoc<sup>3</sup>

<sup>1</sup>Institute of Physics, Nicolaus Copernicus University, Grudziadzka, 87-100 Torun, Poland

<sup>2</sup>National Institute for R&D of Isotopic and Molecular Technologies, 67-103 Donath Street, 400293 Cluj Napoca, Romania

<sup>3</sup>Multiscale Thermophysics Lab. GRESPI, Université de Reims Champagne Ardenne URCA, Moulin de la Housse BP 1039, 51687 Reims, France

 [mpawlak@fizyka.umk.pl](mailto:mpawlak@fizyka.umk.pl)

In this work we report results on the quantitative thermal wave imaging of GaAs and CdMgSe samples, using lock in infrared thermography (LIRT). It was shown that the photothermal radiometry (PTR) or modulated infrared radiometry (MIRR) signals yield information not only on the thermal parameters and the electronic transport properties, but also about the infrared absorption coefficient [1,2]. In the present experiment it is the effective infrared absorption coefficient within the wavelength band of the IR camera  $1.5\ \mu\text{m} - 5.1\ \mu\text{m}$ . Fig. 1 presents the two experimental configurations used for the investigations.

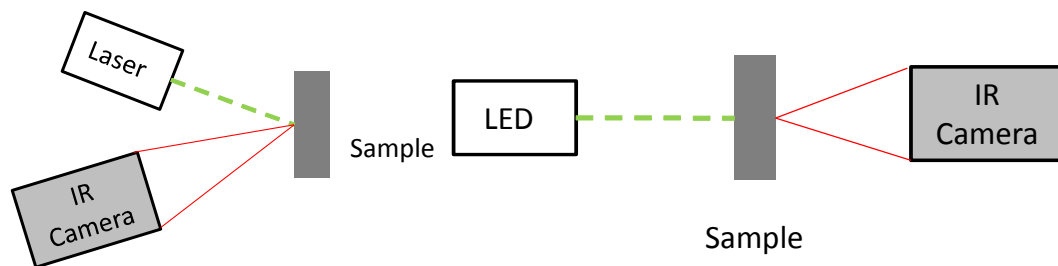


Fig.1. Experimental configurations : (a) in thermal wave reflection, (b) in thermal wave transmission.

The CdMgSe crystal was analyzed by using a Nd:YAG laser in thermal wave reflection mode, whereas the n-GaAs wafer was examined in thermal wave transmission mode, by using a high-power modulated LED panel light source. The infrared images are analyzed using the one dimensional thermal wave field expressions [1,3] in order to obtain the thermal diffusivity and the effective infrared absorption coefficient.

The obtained results are in good agreement with those obtained using the photothermal radiometry and the Hall measurements.

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## Low frequency laser ultrasound imaging of Vickers indentations in metals

A.L. Glazov<sup>1,2</sup>, N.F. Morozov<sup>2,3</sup>, K.L. Muratkov <sup>1,2</sup>

<sup>1</sup>Ioffe Physical-Technical Institute of RAS, Department of Solid State Electronics,  
Polytechnicheskaya 26, 194021, St.Petersburg, Russia.

<sup>2</sup>Institute of Problems of Mechanical Engineering, Russian Academy of Sciences,  
St. Petersburg, 199178 Russia

<sup>3</sup>St. Petersburg State University, St. Petersburg, 199034 Russia

 [klm.holo@mail.ioffe.ru](mailto:klm.holo@mail.ioffe.ru)

Laser ultrasound (LU) and photoacoustic (PA) methods of the investigation of solids have been successfully used for diagnostics of local elastic, thermoelastic, and thermal properties of bulk materials and thin-film coatings. The possibility of providing high spatial resolution allows by applying LU and PA methods for investigation of these properties in the vicinity of surface defects of various types. In particular, investigations of LU and PA effects near Vickers indenter marks in ceramics showed the dependence of LU and PA signals on internal stresses at tips of near-surface cracks. The strong dependence of the LU and PA signals on the external mechanical stresses in these regions has been also demonstrated.

The aim of the present investigation was to study peculiarities of LU and PA signals behavior inside Vickers indented regions in metals. For this purpose, we have studied the character of LU signal intensity distribution in Vickers-indented areas of several metals such as industrial steel, nanocopper and nanonickel. Choice of so different materials was driven by a desire to find out the general features specific to indented metals. All specimens were Vickers indented with a load in the range of 10 N up to 98 N. Laser thermoelastically generated acoustic waves in the samples were excited by modulated radiation of an argon laser at the frequency of about 140 kHz and focused on the sample surface into a 2- $\mu\text{m}$ -radius spot. The LU response signal was detected by using a piezoelectric transducer mounted on the rear side of the sample. The images were obtained by scanning LU microscopy at a 2.5 or 5- $\mu\text{m}$  step in both coordinates. Some preliminary results in this field have been presented by us in publications [1,2].

To detect the influence of external stress on the behavior of LU signals inside Vickers indented areas three images were obtained for each indentation. The first image corresponds to initial state of a sample, the second one to its state under a given external stress and the third one to a final state of unloaded sample. It was found that in a certain range within the external load deformation inside indented area had substantially elastic nature. However, for all investigated metals in these cases an essential modification of LU images under external loading was detected which disappeared under unloading.

It was found that these reversible LU signal changes due to external stresses can reach several tens of percent. These changes of LU signals greatly exceeded the possible contribution from the known acoustoelastic effects. A theoretical model qualitatively explaining the observed results was developed. It takes into account the dependence of the elastic moduli of metals on temperature and stresses amplification due to the presence of near-surface stress concentrators inside Vickers indentations.

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## Thermographic assessment of the HAZ properties and structure of thermomechanically treated steel

J. Górka ✉, D. Janicki, M. Fidali, W. Jamrozik

Silesian University of Technology

✉ [jacek.gorka@polsl.pl](mailto:jacek.gorka@polsl.pl)

In this paper an influence of simulated thermal cycle on properties and HAZ structure of 10 mm thick S700 MC steel plates. The introduction of thermomechanically processed steels with high yield and relatively low carbon equivalent, will significantly reduce the time of welding works by reducing the preheating temperature, or even complete removal of this processing step, furthermore reduction of cross-sectional areas of structural elements, making welded structures with the same capacity will be more slender and lighter. The simulation of thermal cycles was carried out on a specially built test stand equipped with resistive heating source, infrared camera VarioCam Head HR with 50 mm lens and a computer with software IRBIS 3 plus. Simulation was prepared for simple thermal cycle. Simulation studies of thermal cycles consisted of resistive heating of samples prepared for the impact test. Single thermal cycles were simulated at temperatures ranging from 400 to 1200 °C. For each temperature three repeats were carried out. Sample distance from the camera lens was 460 mm, and the video ran track at a height of 1550 mm. The simulation was carried out in air at the temperature of 237 °C and humidity of 23,7 %. During the course of the study, the temperature was acquired as a function of time and the following parameters were established:

- $T_{max}$  - specimen max. temperature,
- $t_n$  - specimen heating time from 50 °C up to  $T_{max}$ ,
- $t_8$  - time for decreasing temperature below 800 °C,
- $t_5$  - time for decreasing temperature below 500 °C,
- $t_{8/5}$  - specimen cooling time (temperatures range 800-500 °C).

Specimens were tested on impact, strength test and also hardness. Metallographical tests were also performed. Results of researches gave the possibility to show the influence of welding thermal cycle on HAZ structure and properties of S700MC steel. It was also possible to indicate an optimal linear energy range for high quality welding.

The study revealed that there is a possibility to use a dedicated system to simulate simple thermal cycles of S700 MC steel in specific ranges of the cooling time  $t_{8/5}$ . Analysis of the results of the study showed that the welding thermal cycle strongly influences the structural changes and phase in the HAZ zone of S700 MC steel. Areas of HAZ heated to high temperatures, above 1000°C, show a sudden drop of toughness to unacceptable levels of impact strength (27 J/cm<sup>2</sup>). This sharp decrease in toughness is associated with uncontrolled separation processes of MX phases and dissolution of carbides, niobium and vanadium carbonitrides in austenite during heating. It was noticed that the chemical composition of steel and especially titanium and aluminum content is sufficient to bind in the HAZ free nitrogen and reduce the aging process. The control of the amount of heat introduced into the joint area during welding will reduce the adverse separation processes in the weld and HAZ which will ensure adequate toughness of the connection. Precise knowledge of the phenomena occurring in the HAZ during the thermal cycle can impact the ability to control properties and structure of the welded joint.

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## **Quantitative photoacoustic imaging in the acoustic regime using single plane illumination microscopy**

K. Sadiq ✉, A. Beigl, P. Elbau, O. Scherzer

Johann Radon Institute for Computational and Applied Mathematics (RICAM),  
Altenberger Strasse 69, 4040, Linz, Austria

✉ [kamran.sadiq@oeaw.ac.at](mailto:kamran.sadiq@oeaw.ac.at)

We study the photoacoustic tomography model taking into consideration that the material has variable density and bulk modulus is spatially varying. We propose an approach to simultaneously reconstruct absorption density, bulk modulus and material density from photoacoustic measurements using photoacoustic sectional imaging. We use SPIM (single plane illumination microscopy) to estimate these parameters. Mathematically, we use asymptotic expansion techniques for the Born approximation, which was used in [A. Kirsch and O. Scherzer (2012)] before for simultaneous estimation of the sound speed and absorption density.

ULTRAFAST, MICRO / NANOSCALE  
AND NONLINEAR PHENOMENA

## Photopyroelectric characterization of magnetic nanofluids: influence of type and size of nanoparticles on the thermal parameters

D. Dadarlat ✉, I. Craciunescu, R. Turcu, C. Tripon

National R&D Institute for Isotopic and Molecular Technologies, Cluj-Napoca, Romania

✉ [ddadarlat@gmail.com](mailto:ddadarlat@gmail.com)

During last years the photopyroelectric (PPE) technique, proved to be very suitable when characterizing liquid samples. This is due to the fact that the thermal contact between a solid and a liquid (sensor/sample) is perfect and consequently, accurate results are expected [1]. We count as a recent application of the PPE calorimetry the thermal characterization of the magnetic nanofluids [2]. The PPE technique, in various detection configurations, has been used in order to find the influence of the carrier liquid, type of surfactant and concentration of nanoparticles, on the thermal parameters of the nanofluid [2, 3]. In this paper we will investigate the influence of type and size of nanoparticles on the thermal parameters. Two types of carrier liquids (transformer oil and polypropylene glycol) have been combined with two types of magnetic nanoparticles ( $\text{Fe}_3\text{O}_4$  and  $\text{MnFe}_2\text{O}_4$ ). The resulting magnetic nanofluids were investigated by using the two well-known PPE detection configurations: (i) the back (BPPE) detection, combined with the thermal-wave-resonator-cavity (TWRC) scanning procedure was used for thermal diffusivity measurements; (ii) the front (FPPE) configuration, together with the frequency scanning technique was used for thermal effusivity investigations. In both detection configurations the information was contained in the phase of the PPE signal. The size of nanoparticles was 10 nm, 35 nm and 50 nm for  $\text{Fe}_3\text{O}_4$  and 10 nm, 20 nm and 80 nm for  $\text{MnFe}_2\text{O}_4$ .

As a general result, the presence of the nanoparticles decreases the value of the thermal parameters of pure carrier liquids and both thermal diffusivity and effusivity decrease with increasing nanoparticles size, independently on the carrier liquid. As an order of magnitude, the influence of the nanoparticles size is more pronounced for the thermal effusivity (relative change 24%) compared with thermal diffusivity (relative change 7%).

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## **The revival of a laser-driven opto-hydroacoustics: breakdown bulk acoustic source vs surface explosion source**

S. V. Egerev ✉

Andreyev Acoustics Institute  
4 Shvernika street, 117036, Moscow, Russia

✉ [segerev@gmail.com](mailto:segerev@gmail.com)

Laser-driven remote optoacoustic sources proved to be prospective for the marine research. It is well-known, that the region of interaction of laser radiation with the sea medium can play the role of a source of underwater sound. By the end of the Eighties, research centers in the USSR, the USA, and in China had sufficient success in full-scale applications of opto-hydroacoustic technology. The diagnostics of surface waves, the bathymetry, the analysis of bottom reverberation, and the diagnostics of the fine surface structure of the sea medium have passed the feasibility resesarch stages.

The core problem here is the conversion efficiency of optical energy to acoustical energy. Depending on the conditions of sound excitation in water, the value of the conversion efficiency varies from  $10^{-11}$  to 0.1. Acceptable are optoacoustic conversion mechanisms providing efficiency not less than 0.01. Accordingly, were chosen (a) combined subsurface acoustic source, where the major contribution to sound excitation is made by rapid heating and explosion while the contribution of thermal expansion remains considerable and (b) nonlinear bulk underwater source, driven by laser breakdown in the sea medium. The last mentioned source provides the record-breaking efficiency of photoacoustic conversion (up to 10%). It can be evaluated that the underwater breakdown acoustic source corresponding to laser energy value 30 J is similar to the blast of 0.2 g trotyl. So, about 0.5 J of acoustic energy can be delivered remotely to the underwater environment which was enough to solve a row of sea monitoring tasks [1].

However, despite the high efficiency of conversion, a nonlinear volume source did not find wide application in marine technologies because of the technical difficulties in its implementation. The problem was that there was no appropriate laser hardware in the beginning of the Nineties. At that times, the research was conducted with the use of powerful ship-based or airborne CO<sub>2</sub> lasers. These were heavy devices, very inconvenient and expensive in maintenance. These devices excite surface nonlinear combined source which attain value even greater than that in the previous case (1 MPa m and over at the maximum). However, on the whole, the conversion efficiency is smaller because of the pronounced directivity of the radiation pattern along the normal to the surface, and it reaches only a value of  $10^{-2}$ . Finally, the R&D efforts were interrupted for more than two decades while pending more convenient hardware.

The new terawatt femtosecond lasers seem to provide this new opportunity of exciting bulk breakdown sources [2,3]. They appear to deliver about 0.3 J of acoustic power to the underwater environment in a very convenient mode however in a very broad spectral range (up to 6 MHz). The repetition rate is about 10 Hz which is convenient for signal processing.

Now, it is good time to thoroughly compare energy, spectral and directivity characteristics of the breakdown bulk acoustic source and these of surface explosion source. The communication is devoted to the comparison of these two phenomena.

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## Thermo-optical sound excitation by Bessel-Gaussian light beam in a dense layer of carbon nanotubes

G. S. Mityurich <sup>1</sup>, J. Berdowski<sup>2</sup>, M. Aleksiejuk<sup>3</sup>, E. V. Chernenok<sup>1</sup>, A. N. Serdyukov<sup>1</sup>

<sup>1</sup>Gomel State University, 246019, Gomel, Belarus

<sup>2</sup>Institute of Physics, Jan Dlugosz University, 02-106, Czestochowa, Poland

<sup>3</sup>Institute of Fundamental Technological Research, 42-200, Warszawa, Poland

 [george\\_mityurich@mail.ru](mailto:george_mityurich@mail.ru)

In last years many researchers are actively studying the properties of carbon nanotubes (CNTs) and also their use as nanoagents based on methods of laser photoacoustics [1-3]. Applying of various polarization modes of Bessel-Gaussian light beams is perspective method for thermo-optic excitation of sound in these structures. An important feature of the Bessel-Gaussian light beams is a diffraction-free in a certain region of space, the occurrence of radial energy flow, which compensate changes in the transversality beam with shielding its central area, and the ability of high energy concentration near the beam axis [4]. This allows for possibility of controlling with amplitude-phase characteristics occurring photoacoustic signal.

Authors of paper [5] developed the device of controlled thermo-optical generation of acoustic waves. The appliance allows implement the controlled thermo-optical generation of acoustic waves in the automatic mode. Also this device significantly improves the performance and functionality for non-destructive optical-acoustic control materials and products, inspection and medical diagnosis.

In this paper solved the problem of determining the amplitude of photodeflections response in three layer structure which comprise a dense layer of carbon nanotubes irradiated with TE- polarizing mode of Bessel-Gaussian light beam. In the case of transversal geometry of the interaction by the Green's function we obtained expression for amplitude of the photodeflection signal that is occurring in a layer of chiral nanotubes and also zigzag and armchair types of nanotubes.

It is established that the amplitude value of the photodeflection response depends on dissipative, geometric and thermal parameters of nanotubes, also on parameters of the chirality of the nanotube, energy and the polarization properties of Bessel-Gaussian light beam.

Graphic analysis showed that the value of photodeflection signal is strongly oscillating function of the by radial coordinate for different periods of time exposure of nanostructures and for different geometrical parameters of CNTs. This phenomenon is due to the influence of the Bessel functions on the spatial distribution of temperature field which is arise due to the absorption of polarization mode Bessel-Gaussian light beam in the samples. The value of the resulting response is also very much dependent on the angle of taper Bessel-Gauss light beam, which which makes it possible to control the amplitude of photodeflection signal by selecting the required polarization modes quasi-diffraction-free radiation.

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# THERMOPHYSICS

## Combined photothermal techniques for thermal characterization of liquid thermoelectrics

D. Dadarlat <sup>1</sup>, M. Depriester<sup>2,3</sup>, K. Touati<sup>2,3</sup>, A. Hadj Sahraoui<sup>2,3</sup>

<sup>1</sup>National R&D Institute for Isotopic and Molecular Technologies, Cluj-Napoca, Romania

<sup>2</sup>Univ Lille Nord de France, 59044 Lille, France

<sup>3</sup>ULCO, UDSMM (EAC CNRS 4476), MREI-1, 59140 Dunkerque, France

 [ddadarlat@gmail.com](mailto:ddadarlat@gmail.com)

Among the PT methods, the contact ones, namely the photopyroelectric (PPE) and the photothermoelectric (PTE) techniques, proved to be suitable especially when characterizing liquid samples. This is due to the fact that the thermal contact between a solid and a liquid (sensor/sample) is perfect and consequently, accurate results are expected [1, 2].

On the other side, it is well-known that the thermoelectric effect occurs in liquid electrolytes due to the presence of several ion species. Recently, a growing interest is dedicated to the liquid thermoelectrics, especially due to the fact that Seebeck coefficients up to 7 mV/K have been reported [3]. In order to obtain the figure of merit of a thermoelectric material, electrical (to measure the electrical conductivity and the Seebeck coefficient) and thermal (to obtain the thermal conductivity) investigations are requested.

In this paper, two alternative optothermal methods are proposed for thermal characterization of liquid thermoelectrics (LTE). The first method is a combined photopyroelectric-photothermoelectric (PPE-PTE) technique, coupled with the thickness scanning (TWRC) procedure. Both pyroelectric and Seebeck effects are used for this purpose. The PPE-TWRC technique, in back detection configuration leads to the direct measurement of the LTE's thermal diffusivity. Simultaneously, the PTE-TWRC method, in front detection configuration, is used for the measurement of LTE's thermal effusivity. The second alternative is also a combined PPE-PTE technique, but coupled with both thickness and chopping frequency (FS) scanning procedures. The PPE-TWRC technique, in back detection configuration is used to the direct measurement of the LTE's thermal diffusivity. Based on the results obtained for thermal diffusivity, two PPE-FS scans, performed at two different thicknesses are used for the precise determination of absolute LTE's thicknesses. Simultaneously, PTE-FS scans, performed at the same thicknesses, lead to the value of LTE's thermal effusivity. The results, obtained for the measured thermal diffusivity and effusivity and calculated thermal conductivity on a well-known LTE (octanol + different TDAN concentration), are in good agreement with previously reported data [4].

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## Investigation of thermal properties of high density polyethylene/aluminum nanocomposites by the photothermal infrared radiometry

H. D. Koca<sup>1,2</sup>, T. Evgin<sup>1,3</sup>, N. Horny<sup>4</sup>, M. Chirtoc<sup>4</sup>, A. Turgut<sup>✉3</sup>, I. H. Tavman<sup>3</sup>

<sup>1</sup>Dokuz Eylul University, The Graduate School of Natural and Applied Sciences, Mechanical Engineering Department, Tinaztepe Campus, 35397, Buca, Izmir, Turkey

<sup>2</sup>Gediz University, Engineering and Architecture Faculty, Mechanical Engineering Department, Seyrek Campus, 35665 Menemen, Izmir, Turkey

<sup>3</sup>Dokuz Eylul University, Engineering Faculty, Mechanical Engineering Department, Tinaztepe Campus, 35397, Buca, Izmir, Turkey

<sup>4</sup>Multiscale Thermophysics Lab. GRESPI, Université de Reims Champagne Ardenne URCA, Moulin de la Housse, BP 1039, 51687 Reims, France

✉ [alpaslan.turgut@deu.edu.tr](mailto:alpaslan.turgut@deu.edu.tr)

Metal filled polymer nanocomposites have increasing interest for many engineering fields such as electrical heating, heat dissipation, converting mechanical signals to electrical signals and discharging static electricity [1] due to the fact that their electrical and thermal conductivity behave similar to that of a metal, whereas the processing methods and mechanical properties are typical for polymer [2]. Among the various metal particles, Al is commonly used as a filler material because of its high mechanical, electrical and thermal properties, low cost, density and easy processing [3]. Many studies can be found on the morphology, mechanical, thermal and electrical properties of polymer composites reinforced with Al micro particles. Although it is known that the Al microparticles advance the mechanical and thermal properties of polymer composites, nanoscale Al particles have not yet been studied enough to make definitive conclusions. Therefore, this study aims to investigate the thermal conductivity of HDPE/Al nanocomposites by using photothermal infrared radiometry (PTR).

HDPE/Al nanocomposites prepared using melt mixing method up to 30 vol. of filler content, following by compression molding. The thermal diffusivity of HDPE/Al nanocomposites was investigated at room temperature with frequency dependent PTR in the thermal reflection and transmission configurations [4]. Thermal waves were generated using a diode-pumped solid state (DPSS) laser having 245 mW of power which was intensity modulated with an acousto-optical modulator (AOM) in the frequency range  $f = 0.1$  Hz to 100 kHz. The frequency ranges were selected to allow data analysis according to one-dimensional heat transport model. The IR radiation from the sample surface was registered by IR HgCdTe detector.

Measurements of density, specific heat and thermal diffusivity (by modulated photothermal radiometry, PTR) were performed and effective thermal conductivity  $k_e$  of nanocomposites were calculated from the  $k = C\alpha$ . As seen in Fig. 1,  $k$  values increases linearly by increasing the volume fraction of Al. The highest  $k$  enhancement almost by factor 3.1 has achieved at 30 vol.% of filler content. The obtained results were compared with the others given in the literature.

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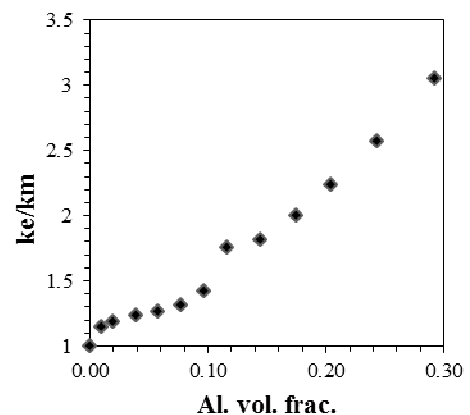



Fig.1. Relative thermal conductivity of nanocomposites as a function of volume fraction of Al.

## Heading towards the thermal characterization of organic semiconductors layers

D. Trefon-Radziejewska <sup>1</sup>, J. Juszczyk<sup>1</sup>, A. Fleming<sup>2,3</sup>, N. Horny<sup>3</sup>, J. S. Antoniow<sup>3</sup>,  
M. Chirtoc<sup>3</sup>, A. Kaźmierczak-Bařata<sup>1</sup>, J. Bodzenta<sup>1</sup>

<sup>1</sup> Institute of Physics Center for Science and Education, Konarskiego 22B, 44-100 Gliwice, Poland

<sup>2</sup> Dept. Aerospace and Mech. Eng., Utah State University,

4130 Old Main Hill, Logan, UT 84322, USA

<sup>3</sup> Multiscale Thermophysics Lab., GRESPI, Universtit  de Reims Champagne Ardenne URCA,

Moulin de la Housse BP 1039, 51687 Reims, France

 [dominika.trefon@polsl.pl](mailto:dominika.trefon@polsl.pl)

Thermal characterization of organic semiconductors layers has become ever more important since they could be used in sensing and photovoltaic devices. Gas sensors or solar cells working at elevated temperatures can change their electrical characteristics and operating conditions. Study on thermal behavior of organic semiconductors offers useful information for engineers designing electronic systems especially with reduced devices' dimensions.

In this work, the metal phthalocyanines (MePc) - a promising class of organic semiconductor materials were thermally investigated using photothermal radiometry (PTR) and scanning thermal microscopy (SThM). Copper phthalocyanines (CuPc) and lead phthalocyanin (PbPc) with different thicknesses were deposited on Si (1 1 1) wafer and on glass substrates by physical vapour deposition in a high vacuum.

PTR method working in front-detection and frequency-domain regime was proposed for determination of the thermal diffusivity of MePc layers. PTR method imposes certain conditions on the preparation of samples in order to obtain thermal diffusivity from measurements. Therefore, half of the surface of the each organic layer was covered with a thin aluminum layer. It was necessary to improve absorption of the visible light in CuPc and PbPc as samples were optically excited by green laser beam (532 nm). Samples were scanned from 1 Hz up to 100 kHz. The analysis of measured PTR signal was based on a 1D model of heat transport in a layered structure.

To complement thermal investigations of MePc layers effective local thermal conductivity was obtained by the SThM quantitative measurements using Wollaston probe. Values of thermal conductivity were lower than 1 W/m·K for all samples.

## Determination of the elastic properties of electrospun membranes by surface acoustic waves technique

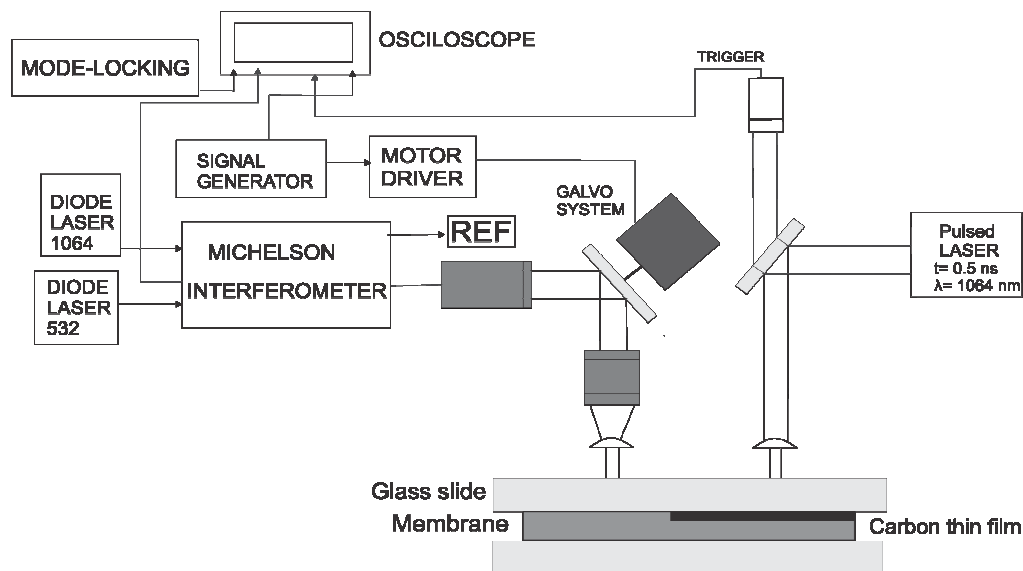
O. Zurita, M. Navarrete ✉

Instituto de Ingeniería, Universidad Nacional Autónoma de México,  
Av. Universidad 3000, Ciudad de México, 04510 México

✉ [mnmm@pumas.iingen.unam.mx](mailto:mnmm@pumas.iingen.unam.mx)

Scaffolds and porous materials made by electrospinning are commonly used in tissue engineering [1]. The mechanical properties of electrospun polymer are known through tensile tests or other methods (bending tests, nano-indentation), the tensile test is the most common, and it is applied to the membranes and to a single fiber [2]. A problem arises with these techniques: the load transfer is different due to the morphology of the material doing that the elastic properties have a dispersion of two to three orders of magnitude in their determination [3]. In order to improve the energy transfer we use a surface acoustic wave (Rayleigh wave). This type of wave propagates with lower attenuation [4]. Accordingly, we propose is developed a method to determine the effective elastic moduli of membranes by laser ultrasonics and the measurement of surface acoustic waves (SAW) by means an optical fiber interferometer.

For generate the surface acoustic waves we used a laser pulsed (Nd: YAG,  $\lambda=1064$  nm,  $E= 40$  mJ,  $\phi =5$  mm, 5-7 ns wide). The pulse laser is focusing with a cylindrical lens forming a line with 10 mm length and 15  $\mu$ m width onto a carbon layer attached to the sample [5]. Besides the membrane is stabilize between two glass slides, see figure 1. The waves are detected downstream with a stabilized Michelson interferometer optical fiber, and with determining the density we known the elastic constants ( $E$ ,  $G$ ,  $\nu$ ). The material we chose for electrospun samples is Poly (methyl methacrylate). The results are analyzed, compared with the values reported in the literature and with asymptotic homogenization method.



**Fig. 1.** Experimental set-up

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## Photoacoustic study of elastic bending and expanding in silicon membranes

D. M. Todorovic <sup>1</sup>, M. D. Rabasovic<sup>2</sup>, D. D. Markushev<sup>2</sup>, V. Jovic<sup>3</sup>, K. T. Radulovic<sup>3</sup>

<sup>1</sup> Institute for Multidisciplinary Research, University of Belgrade, Belgrade, Serbia

<sup>2</sup> Institute of Physics, University of Belgrade, Belgrade-Zemun, Serbia

<sup>3</sup> Institute for Chemistry, Technology and Metallurgy, Belgrade, Serbia

 [dmtodor@imsi.bg.ac.rs](mailto:dmtodor@imsi.bg.ac.rs)

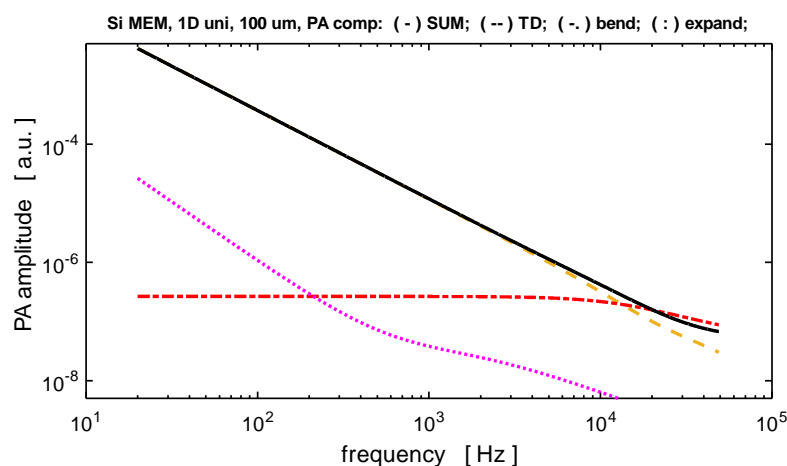
Theoretical model of the photoacoustic (PA) signal for optically excited Si membranes, which includes plasmaelastic (PE), thermoelastic (TE) and thermodiffusion (TD) mechanisms, is given in order to study the elastic bending and expanding. The Si samples (Si chip with square membrane) were modeled as thin elastic plate (the square plate simply supported on edges). The quasistatic and dynamic elastic displacements were taken in consideration.

The generation of periodic excess carriers in Si samples will produce heat due to carrier thermalization and recombination processes. The generated heat can produce an elastic deformation in the sample – the (TE) deformation. Also, the photogenerated carriers can produce directly a local strain that then generates elastic waves in a semiconductor – the PE deformation (the so-called electronic deformation). For these two components of elastic deformation it is possible to consider two types of elastic displacements: 1) elastic expansion and 2) elastic bending. The elastic expansion effect depends on the mean sample temperature or excess carrier density. Elastic bending is essentially due to the temperature or carrier density gradient inside the sample and is normal to the incident surface of the sample.

Relations for the PA amplitude and phase of elastic bending and expanding of the optically excited mechanical structure were derived. Possibility to obtain some elastic vibrations parameters (elastic expanding and bending) by the PA method were analyzed (Fig. 1).


The experimental amplitude and phase PA signal of the Si samples (Si chip with square membrane) were analyzed vs the modulation frequency of the optical excitation ( $f = 20 - 20000$  Hz). The influence of the thickness of optically excited Si square membrane to the experimental PA signal was analyzed.

This study is important to develop the experimental non-contact and non-destructive PA method, which enable to investigate the optical, thermal and elastic characteristics of micromechanical structures.



**Fig. 1.** PA amplitude components of the Si square membrane (thickness 100  $\mu\text{m}$ ):  
 ( -- ) thermodiffusion (TD); ( - . ) elastic bending (TE+PE); ( . - ) elastic expanding (TE+PE);  
 ( - ) sum of components (SUM).

## Piezoelectric photothermal spectroscopy of AlGaAs/GaAs heterostructures

J. Zakrzewski <sup>1</sup>, M. Maliński<sup>2</sup>, M. Pawlak<sup>1</sup>, Ł. Chrobak<sup>2</sup>

<sup>1</sup>Institute of Physics, Nicolaus Copernicus University,  
Grudziądzka 5/7, 87-100 Toruń, Poland

<sup>2</sup>Faculty of Electronics and Computer Science, Technical University of Koszalin,  
Śniadeckich 2, 75-453, Koszalin, Poland

 [jzakrzew@fizyka.umk.pl](mailto:jzakrzew@fizyka.umk.pl)

Piezoelectric photothermal spectroscopy (PPS) was used to characterize AlGaAs/GaAs heterostructures. PPS has been found to be very attractive method for monitoring of nonradiative states generated by optical absorption in semiconductors. In PPS, the stress and strain of a sample due to the absorption of electromagnetic radiation are detected by a piezoelectric transducer. The new procedure of measurements is applied. It involves the detection of the PPS signal in front and rear configurations and measurements with illumination of different surfaces of the samples. These configurations are associated with the geometry of sample and detector position. At rear mode, the sample is irradiated from one side and the detector is located on the other (non-illuminated), at front mode detector is located at the illuminated surface. Four pairs of amplitude and phase spectra are obtained for each sample. Due the theoretical models the waveform is different for each of configuration. The two layer model proposed by Fernelius [1] and interference model of Malinski [2] were chosen to analyze the phase and amplitude of PPS spectra. For each type of configuration, the theoretical models were fitted to experimental data in order to obtain the thermal and optical parameters of investigated material.

The PPS method turned out to be especially useful for determination of the values of the energy gaps of thin layers on the substrate and the spectrum of surface states of such a structure.

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## Thermal properties of chalcogenide thin films by photopyroelectric technique

M. Vanessa<sup>1</sup>, T.K. Das Roy<sup>1</sup>, S. Shaji ✉<sup>1,2</sup>

<sup>1</sup> Universidad Autónoma de Nuevo León, Facultad de Ingeniería Mecánica y Eléctrica, San Nicolás de los Garza, Nuevo León, México, 66455

<sup>2</sup> Universidad Autónoma de Nuevo León - Centro de Innovación, Investigación y Desarrollo de Ingeniería y Tecnología (CIIDIT), Apodaca, Nuevo León, México, 66600

✉ [sshajis@yahoo.com](mailto:sshajis@yahoo.com)

In this work, we measured thermal properties of chalcogenide thin films prepared by chemical bath deposition. Thermal parameters of SnS and Sb<sub>2</sub>S<sub>3</sub> thin films were measured by a photopyroelectric technique. The photopyroelectric method consists of detection of induced temperature variations of samples caused by a periodically modulated light source using a pyroelectric transducer. The light source used was a laser with wavelength of 532 nm and the pyroelectric transducer used was a polyvinylidene fluoride (PVDF) film with thickness 28 μm. The modulation frequency and laser power were the parameters varied in these measurements. This technique enables the study of dynamic thermal parameters such as thermal conductivity (k), thermal diffusivity (α), and thermal effusivity (e) of these thin films.

## Photothermal deflection investigation of effect of gallium doping and thermal annealing on the optical properties of tin sulfide films

M. Ben Mbarek ✉<sup>1</sup>, M. Reghima<sup>2</sup> N. Yacoubi<sup>1</sup>, N.Turki-Kamoun<sup>2</sup>

<sup>1</sup>Unité de recherche Photothermie, Bruit dans les composants et modélisation, Institut Préparatoire aux Etudes d'Ingénieurs de Nabeul (IPEIN), 8000 Mrezka, Nabeul, Tunisia

<sup>2</sup>Laboratoire de physique de la matière condensée, Faculté des sciences de Tunis El Manar, Tunisie 2092, Tunisia

✉ [bmmarwa90@yahoo.com](mailto:bmmarwa90@yahoo.com)

In this work we investigate the effect of gallium doping and thermal annealing on the optical properties of tin sulphide thin films using photothermal deflection spectroscopy (PDS). SnS thin films doped with gallium at different concentrations (0%, 4%, 6%, 8%, and 10%) were grown by chemical bath deposition technique (CBD). The optimum of thin film crystal structure was obtained with a gallium concentration of 4%. This layer was then annealed in nitrogen gas for 30 min at annealing temperatures ranging from 200°C to 600°C.

The optical properties (optical absorption spectrum and gap energy) were measured by drawing the amplitude and phase variation versus wavelength in experimental way and versus absorption coefficient in theoretical. By comparing point by point the normalized experimental and corresponding theoretical amplitude variation one, can deduce the optical absorption spectrum. Using the Tauc law for energies we can deduce the gap energy.

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## Investigation of thermal properties of cement sorel by photothermal deflection technique

R. Zgueb✉, N. Yacoubi

Unité de recherche Photothermie, Bruit dans les composants et modélisation,  
Institut Préparatoire aux Etudes d'Ingénieurs de Nabeul (IPEIN), 8000 Mrezka, Nabeul, Tunisia

✉ [rim\\_zgueb@hotmail.fr](mailto:rim_zgueb@hotmail.fr)

Photothermal deflection PTD is a non destructive Technique. PTD is based on the photothermal phenomenon, in which a modulated incident light on the specimen is transformed into heat and detected as a tension by using a position photodetector linked to a lock in amplifier. The signal depends directly on the thermal properties (Thermal conductivity, thermal diffusivity) of the specimen [1]. In this work we investigated the thermal property of cement Sorel (CS). Nowadays, the development of composite construction materials with low thermal properties will be an interesting alternative that would solve energy concerns. In this context, we investigate the effect of replacing Sorel cement with polymer PVAc [2]. The thermal properties are measured using the Photothermal Deflection Technique (PTD) by comparing the experimental curves of normalized amplitude and phase of photothermal signal versus square root modulation frequency to the corresponding theoretical ones. The experimental investigation revealed that the addition of the PVAc reduces the Thermal conductivity and thermal diffusivity of the cement and yield a lightweight. The thermal insulating effect of PVAc is attractive and indicates a high and promising potential for development.

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