Journal of Applied Physics

Editorial for the special collection on non-invasive and non-destructive methods and applications, I: Festschrift—A tribute to Andreas Mandelis

Cite as: J. Appl. Phys. **132**, 230401 (2022); https://doi.org/10.1063/5.0133988
Submitted: 07 November 2022 • Accepted: 30 November 2022 • Published Online: 20 December 2022

Vitalyi Gusev and Mladen Franko

AIP Publishing

Journal of Applied Physics · EDITORIAL · scitation.org/journal/jap

Editorial for the special collection on non-invasive and non-destructive methods and applications, I: Festschrift—A tribute to Andreas Mandelis

Cite as: J. Appl. Phys. **132**, 230401 (2022); doi: 10.1063/5.0133988
Submitted: 7 November 2022 · Accepted: 30 November 2022 ·
Published Online: 20 December 2022

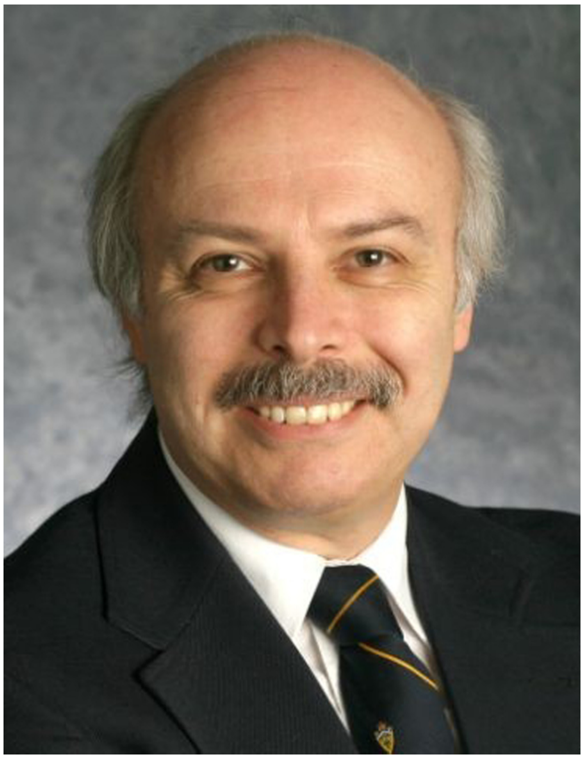
View Online · Export Citation · CrossMark

Vitalyi Gusev[1,a] and Mladen Franko[2]

AFFILIATIONS

[1]Laboratoire d'Acoustique (LAUM), Le Mans University, Le Mans 72085, France
[2]Laboratory for Environmental Research, University of Nova Gorica, Goriška SI-5000, Slovenia

Note: This paper is part of the Special Topic on Non-Invasive and Non-Destructive Methods and Applications Part I Festschrift.
[a]**Author to whom correspondence should be addressed:** vitali.goussev@univ-lemans.fr



It is our pleasure to introduce this Festschrift of the Journal of Applied Physics to honor Professor Andreas Mandelis on the occasion of his 70th birthday and to recognize his many outstanding contributions to the field of theoretical and experimental photothermal (PT), photoacoustic (PA), and photonic/optoelectronic diffusion-wave science and technology.

FROM BEGINNINGS TO CAREER PATHWAYS

Andreas was born in the island of Kerkyra (Corfu) Greece in 1952. He moved to the United States in 1970 where he received his B.S. in physics from Yale University in 1974. He then pursued graduate studies at Princeton University, where he received his Master's in Mechanical and Aerospace Engineering and his Ph.D. in Applied Physics and Materials Science in 1979 with Barrie S. H. Royce, one of the leading researchers who worked on the "renaissance" of the field of photoacoustic spectroscopy in condensed matter after a century since its inception in the 1880s. Photoacoustic spectroscopy and associated effects were rapidly propelled to popularity in the mid-1970s among US and international groups in both academia and industry, fuelled by the emergence of new pulsed and CW laser sources in ever-increasing wavelength ranges. At Princeton, Andreas completed a doctoral dissertation titled "Theory of the frequency and time domain photoacoustic spectroscopy of condensed phases." He was also inspired by his co-advisor, solid-state physicist Roman Smoluchowski, son of statistical physics pioneer Marian Smoluchowski, on the physics of defects in solids that led Andreas to a path of lifelong interest in non-destructive evaluation instrumentation, metrology, defect characterization, and imaging for applications to wide ranges of materials including biotissues. Following his graduation from Princeton he moved to Canada to take up a research position at Bell Northern Research Labs, Ottawa, in 1980–1981. He subsequently accepted a faculty appointment at the University of Toronto in 1981 where he is now a Professor at the Department of Mechanical and Industrial Engineering with concurrent appointments at Electrical and

Computer Engineering and at the Institute of Biomaterials and Biomedical Engineering. He has been the Canada Research Chair (Tier 1) in Diffusion-Wave and Photoacoustic Sciences and Technologies. He is the Director of the Center for Advanced Diffusion-Wave and Photoacoustic Technologies (CADIPT) and of the Institute for Advanced Non-Destructive and Non-Invasive Diagnostic Technologies (IANDIT)). He also founded or co-founded two Toronto companies: Quantum Dental Technologies (www.thecanarysystem.com) and Diffusion-Wave Diagnostic Technologies, Inc. (www.diffusewavetech.com).

SCIENTIFIC RESEARCH ACHIEVEMENTS AND PROFESSIONAL HIGHLIGHTS

Professor Mandelis's achievements have been recognized with numerous national and international prizes, awards, and fellowships. His own research career of 45+ years (and still going strong!) has resulted in many pioneering theoretical and experimental achievements that have led to over 650 publications cited over 12 400 times in the scientific literature. His papers have been downloaded more than 66 000 times (Research Gate). He is a Fellow of the American Physical Society (APS), the Society for Optical Engineering (SPIE), the American Association for the Advancement of Science (AAAS), and the American Society of Mechanical Engineers (ASME), among other societies, and a Distinguished Fellow of the International Engineering and Technology Institute (IETI). In 2006 he was elected Fellow in the Academy of Sciences of The Royal Society of Canada and in 2013 he was inducted as Fellow of the Canadian Academy of Engineering. He received the American Physical Society's (APS) 2012 Keithley Award in Instrumentation Science, the inaugural Ontario Discovery Award in Science and Engineering (the Ontario Premier's Innovation Award), the ASME 2009 Yeram Touloukian Award and Medal in Thermophysics, the Senior Prize of the International Photoacoustic and Photothermal Association (IPPA), the Canadian Association of Physicists (CAP) Medal for Outstanding Achievement in Industrial and Applied Physics, and the CAP-INO Medal for Outstanding Achievement in Applied Photonics. In 2014 he was elected Killam laureate, recipient of the Killam Prize in Engineering, one of Canada's highest academic prizes awarded annually by the Governor General of Canada. In 2017 he was the recipient of the inaugural Canadian NDT Research Award, Canadian Institute for Non-Destructive Evaluation (CINDE) and in 2020 he received the Ultrasonics Career Prize of the Proteomass Scientific Society of Portugal. He was Editor-in-Chief of the Springer *International Journal of Thermophysics* (2014–2019) and Topical Editor of the Optical Society of America's (OSA) journal *Optics Letters* (2012–2018). Currently he is an Associate Editor of the American Institute of Physics (AIP) journals *Review of Scientific Instruments*, *Journal of Applied Physics*, a member of the editorial board of the SPIE *Journal of Biomedical Optics* and a scientific advisory board member of *Quantitative InfraRed Thermography* (QIRT) (Taylor & Francis). He is also Contributing Editor of the AIP flagship magazine *Physics Today*. He has been Editor-in-Chief of the book series "Progress in Photothermal and Photoacoustic Science and Technology," published by the SPIE. He has also been on the editorial or advisory boards of *Applied Physics Letters*, *NDT&E International*, *Journal of Analytical Sciences* (J. Chem. Soc. Japan), and a guest editor of a number of special issues in the area of PA/PT and, generally, diffusion-wave phenomena. He has trained 211 undergraduate BASc thesis students, 39 PDFs and Research Associates, 73 MASc and Ph.D. students, 11 knowledge transfer users, and 38 visiting scientists and students, many of whom have kept collaborating with him and his group through the years, producing impactful joint research while pursuing careers of their own.

LIFELONG QUEST FOR ENERGY CONVERSION PHYSICS AND APPLIED METROLOGIES

The *Journal of Applied Physics* and the authors of the preface are thankful to all the participating authors in this Special Collection. The large number of contributions reflects the high esteem to which the international PT, PA, and diffusion-wave communities have held Andreas's seminal works over half a century of research that encompass an unusually wide range of scientific and engineering disciplines. In exemplary ways, Andreas's research career aligns with, and fulfils, the great promise of the PA renaissance of the 1970s to become the foundation for an ever growing range of multi-sectorial, multi-disciplinary scientific and technological innovations and applications that are still evolving five decades hence. Andreas understood early on that the winning advantage of PA and related phenomena lies in the *inherent dynamic energy conversion mechanisms* involved (optical-to-acoustic, -thermal, and/or -electronic/photonic) which, when transcribed into inspection methodologies, diagnostic and instrumentation systems, impart very wide signal dynamic ranges significantly superior to other measurement techniques that are not subject to similar processes, thereby positioning photoacoustics, photothermics, and general diffusion waves to become outstanding diagnostic modalities for *very sensitive* detection of phenomena such as nascent flaws and defects in solids and manufactured materials, early lesion appearance and demineralizations in hard biotissues, the early onset of tumors in soft tissues and abnormal concentrations of blood constituents, or the occurrence of (opto)electronic defects and trap states in semiconductor electronics and their effects on the functionality of semiconductor devices such as photovoltaic solar cells operating under non-equilibrium conditions.

FESTSCHRIFT COLLECTION OF ARTICLES

We are pleased to present a Collection of invited and contributed Festscrift papers in the *Journal of Applied Physics* special issue "Non-Invasive and Non-Destructive Methods and Applications—Part I" as an excellent reflection of progress and developments in PA, PT, and diffusion-wave physics that encompass Andreas's published work on conceptualization and development of optical-to-thermal, thermoelastic, ultrasonic, and photonic energy dynamic conversion physics and kinetic processes, resulting in high-dynamic-range, high-sensitivity, and high-specificity analytical instrumentation and measurement methodologies, systems, devices, and multi-disciplinary applications. Specifically, he has several inventions, 43 patents and patents pending in the areas of PT tomographic imaging, signal processing and measurement, hydrogen sensors, non-invasive biosensors, dental diagnostics, several semiconductor non-destructive and non-contacting technologies, and laser biophotoacoustic and biothermophotonic imaging. His multi-decade multi-faceted research has led to

21 advanced non-destructive/non-invasive diagnostic, inspection and monitoring modalities, techniques and technologies (CV at https://cadipt.mie.utoronto.ca/personnel/mandelis-andreas/), many of which are now in academic, industrial and biomedical/dental clinical use around the world. Presented below are the major research topics in this Collection, which loosely include 11 disciplinary categories directly or indirectly impacted by Andreas and his team's research.

(1) *Novel photothermal and photoacoustic analytical methodologies and spectroscopy:* An opening review by Fomina and Proskurnin describes up-to-date progress in photothermal radiometry (PTR), a key non-destructive and spectroscopic modality with applications to materials and chemical research.[1] In new developments in PT measurements of multi-layers, Balderas-López addresses signal normalization issues to facilitate quantitative measurements of thermophysical properties[2] and Chirtoc and Horny derive a general expression ("master equation") to account for thermal impedance across multi-layers.[3] A timely review by Kitamori's group[4] presents recent growth in PT spectroscopy for the sensitive detection of non-fluorescent or nonlabeled molecules in micro/nanofluidic channels. Developments in another, more traditional, area of laser and broadband infrared spectroscopy are contributed by Zhang *et al.*,[5] who describe a new portable spectroscopic instrument for the identification of trace gases polluting the environment, such as CH_4 and C_2H_2, and by Xia *et al.*,[6] who review three laser absorption spectroscopy techniques (typically a popular PA application), namely, wavelength modulation spectroscopy (WMS), cavity ringdown spectroscopy (CRDS), and frequency comb spectroscopy (FCS).

(2) *Photothermal and photoacoustic systems for environmental, biological and dental diagnostics, materials and thin film studies:* Thin films have been studied using PA detection for a long time since the modern renaissance of photoacoustics in the 1970s. An article by Rodriguez-Garcia's group[7] presents a new methodology using a differential PA system to determine the effective water vapor diffusion coefficient and the effective permeability coefficient in thin films such as a piece of paper and standard polystyrene. The Canary Dental Caries Detection System is a PT device developed by Andreas's group that now has been used to monitor cracks in teeth and the structural integrity of teeth over time in clinical dental applications by dentist Stephen H. Abrams and researcher Konesh S. Sivagurunathan.[8] The studies of Khosroshahi *et al.*[9] of the interaction of a pulsed Nd:YAG laser with bovine serum albumin solution (i.e., S0) and S0 containing gold nanourchin (i.e., S1) used combined PA and PT probe beam deflection techniques for high specificity. The changes in absorbance and chemical bonds were studied by UV–Vis and near-FTIR spectroscopy. A biological application of PA microscopy and thermal imaging of six different creole corn varieties is reported by Cruz-Orea and his group[10] leading to non-destructive characterization of these non-homogeneous materials.

(3) *Laser photoacoustics and ultrasonics:* Biomedical PA has been an area of very rapid growth over the past 20–25 years. Jun Xia's group has been developing a large number of imaging applications of biotissues combining PA imaging with high-resolution ultrasound and shear wave elastography to improve measurements of optical absorption, acoustic reflection, and stiffness volumetrically.[11] Using a non-destructive laser ultrasonic technique with an optical microphone detection module and a finite element simulation based on a thermo-mechanical coupling model, Song *et al.*[12] were able to detect artificial subsurface defects in carbon fiber-reinforced polymer (CFRP) composites. In a similar type of application, Glazov and Muratikov[13] demonstrated that the strong stress dependence of laser ultrasonic signals can be used to estimate mechanical stresses in solid materials.

(4) *Non-destructive evaluation and imaging:* PA and PT techniques (notably infrared thermography) are routinely used for non-destructive diagnostics and materials inspection. Glorieux presents[14] a comprehensive Perspectives article on the high potential of PA and PT methods for substantial advances in diverse scientific disciplines: biomedical diagnostics, cell and tissue mechanobiology, thin film and interface characterization, characterization of the microstructure of solids, and the physics of relaxation in glass-forming liquids. Sfarra and co-workers[15] introduce a thermographic data analysis method named "TriMap thermography" with convolutional autoencoder to reduce noise and enhance the quality of thermograms. Li *et al.*[16] describe a non-destructive PTR method using thermal diffusivity ratio and degradation layer thickness measurements to quantitatively evaluate the aging degrees of silicone rubber composite insulators being serviced in high-voltage power transmission systems in the field.

(5) *Thermal-wave radar and linear-frequency modulation (LFM) imaging*: Thermal wave radar (TWR) and the related photoacoustic radar are highly efficient and rapid non-destructive PT inspection techniques pioneered by Andreas's group in the 1980s as frequency modulated (FM) time delay photoacoustic and photothermal wave spectroscopies. More recently, LFM imaging extension modalities were independently developed by the Mandelis and Mulaveesala groups in 2005–2009. TWR waveforms are used to increase image quality through signal-to-noise ratio (SNR) improvements over conventional lock-in thermography, thereby enhancing target detection probability. Luo *et al.*[17] present an orthogonal phase-coded linear frequency modulated (OPCLFM) excitation waveform, which further improves significantly the SNR and depth resolvability of TWR compared to the LFM waveform.

(6) *Non-invasive biosensors*: Since the early 2000s, PT biosensor developments have been increasingly reported due to the high dynamic range of devices based on optical-to-thermal energy conversion. Nelson G. C. Astrath and co-workers[18] applied spectroscopic and PT methods to investigate a commercially available green fluorescent graphene quantum dot (GQD) as a potential antimicrobial agent and to determine its theranostic properties. Their results demonstrated the potential of this GQD as a photodynamic and photothermal agent.

(7) *Photopyroelectric effects, sensors and applications*: Photopyroelectric spectroscopy (PPES) and its theoretical underpinnings were pioneered by Andreas in the mid-1980s who gave the name to the technique, with the first spectroscopic application reported in parallel by his group and by the

late Hans Coufal. Due to its experimental simplicity and high sensitivity, PPES in the 2020s has become the preferred PT method for measuring thermophysical and optical properties of thin materials and phase transitions in solids and liquids. In a comprehensive Tutorial, Dadarlat *et al.*[19] present an overview of the development of the PPE technique from its beginning in 1984 to the present day. Furthermore, the article reviews the use of PPES to study physical and chemical processes such as molecular associations, food adulteration, spectroscopic, and calorimetric applications.

(8) *Thermophysical property measurements using thermal waves*: Besides the development and thermophysical applications of PPE detection within the traditional field of thermal waves, Wang and co-workers[20] review several other popular PT modalities widely used for measuring a material's thermophysical properties and interface thermal conductance/resistance.

(9) *Photocarrier-density waves, photovoltaic solar cell and nanoscale semiconductor metrologies*: A major area of diffusion-wave physics and applications, photocarrier radiometry (PCR) and combined photothermal-photocarrier-photoluminescence diagnostics and imaging, pioneered by Andreas's group, is a growing non-destructive field for micro-/nano-electronics and optoelectronics. Lofty and co-workers[21] present the theory of a one-dimensional elastic–electronic deformation problem under the influence of a magnetic field. As a guide to further experimental work, they use a hyperbolic two-temperature model that introduces thermal load, mechanical force, and photocarrier recombination conditions at the free surface of a semiconductor. Markushev *et al.*[22] demonstrated enhancement of the thermoelastic component of the PA signal of silicon membranes coated with a thin TiO_2 film. They found several orders of magnitude enhancement that increases in thinner membranes due to higher ratios between the film and membrane thicknesses. Lei *et al.*[23] increased the sensitivity of PCR measurements of front- and rear-surface recombination velocities in Si wafers by simultaneous parameter extraction using a highly accurate differential PCR modality. In a related Tutorial, Sun *et al.*[24] discuss lock-in carrieography (LIC), a semiconductor dynamic photoluminescence imaging modality also pioneered by the Mandelis group, juxtaposing homodyne (HoLIC) and high-frequency heterodyne (HeLIC) modes, in applications to quantitative imaging of optoelectronic material and solar cell properties and photocarrier transport parameters. In a complementary solar-cell study, Baesso and co-workers[25] present the current state-of-the-art of application of PA and PT methods used to characterize solar cell materials and devices, including a discussion on application of PA and PT measurements for maximizing energy-conversion and quantum efficiency of several types of solar cells. Alvarado-Gil and co-workers[26] present a critical analysis of experimental results and the application of theoretical models aimed to study the effects of percolation phenomena on the thermal and electrical properties of two-phase materials such as composites made of high conductivity particles in a polymeric matrix. They discuss the development of new materials with enhanced thermal conductivity and amplified thermal percolative effects.

(10) *Waveform engineering in dynamic PT and thermographic imaging methods*: State-of-the-art infrared thermography method development is an area of significant growth. A novel laser spot thermography technique used to scan over the surface of a sample is described by Puthiyaveettil *et al.*:[27] A three-dimensional numerical model is developed using a commercial finite element software package and the method is applied to an oxide layer (50 μm thickness) at 600 °C acting as a thin resistive layer at the top surface on a mild steel sample. They concluded that because the thermal and optical properties of this oxide layer are different from those of the base metal, this leads to a drastic variation in the thermal profile after the oxidation temperature. Ziegler and co-workers[28] address a different aspect of dynamic thermography: super-resolution reconstruction of images beyond the physics-imposed limit by the diffusion properties of thermal-wave propagation. Salazar and Mendioroz address the issue of depth sensitivity in PT defect detection methods,[29] thereby establishing detectability limits: for good thermal conductors, submicron delaminations can be sized down to 10 mm, whereas for thermal insulators, they can be sized down to less than 0.5 mm. This method enables the assessment of resolution of otherwise blurred internal defects/inhomogeneities. Super-resolution in thermal imaging can also be achieved using scanning thermal microscopy, here reviewed in a Perspectives paper by Bodzenta and Kaźmierczak-Bałata and applied to thermal transport in nanoscale devices and structures.[30]

(11) *PT-mediated diffusion-wave physics and applications*: Thermal lensing is a very sensitive PT method. Its sensitivity is now enhanced (doubled) through a mode-mismatched configuration probing thermal lens introduced by Shen and co-workers.[31] They were able to measure the linear absorption (attenuation) coefficient of de-ionized water at 532.3 nm down to two significant figures compared to earlier one-significant-figure measurements. Terazima introduced a sensitive PT transient grating method to measure thermal energy occlusion with high temporal resolution based on changes in the refractive index of a material. He describes[32] the dynamics of reaction schemes of proteins that cannot be detected by optical spectroscopy ("spectrally silent dynamics"), such as enthalpy changes, conformational changes, and changes in intermolecular interactions. The Tutorial by Burgholzer *et al.*[33] reviews the impact of heat diffusion on the spatial resolution limit of PT imaging. Describing diffusion as a random walk, they offer the insight that such stochastic processes involve not only a Gaussian spread of the mean values in space, with the variance proportional to the diffusion time, but also temporal and spatial fluctuations around these mean values. The paper sets the limits of spatial and depth resolution in diffusion-wave fields that can be overcome by including additional information such as sparsity or positivity.

EPILOGUE: COMMUNITY SERVICE AND CELEBRATION

Perhaps Andreas's most important contribution to the worldwide Photoacoustic and Photothermal community has been his decades-long tireless devotion to the development, encouragement, and rewarding of the highest quality human capital representing the field through the founding in 2001 of the International Photoacoustic and Photothermal Association (IPPA) along with theoretical photoacoustics pioneer Gerald (Gerry) Diebold of Brown University. The IPPA is an international prize-awarding scientific society aimed at recognizing outstanding research by top senior scientists and engineers and by the brightest young minds in the Field through the research community's direct involvement in nominations and selections, resulting in a monetary award and a certificate with citation of major achievements. Ever since, the IPPA awards form a very special ceremonial part and plenary session during the biennial international conferences on photoacoustic and photothermal phenomena (ICPPP), the most recent one having been presented during the ICPPP21 in Bled, Slovenia, June 2022.

During the same conference, to celebrate Andreas's 70th birthday, several happenings were organized on June 22, Andreas's actual birthday, at the initiative of Mladen Franko, the ICPPP21 Chair and his colleague members of the Organizing Committee from the University of Nova Gorica and the University of Ljubljana. The celebrations started with a huge birthday bash and party during lunch where all conference participants had the opportunity to sample excellent Bled cream cake and wish "happy birthday" to Andreas. The celebrations culminated with a Special Plenary Session with an introduction by Roberto LiVoti of the University of Rome "La Sapienza" who reviewed the highlights of Andreas' multifaceted impact in the PA/PT scientific community and beyond. The ceremony concluded a plenary talk and public forum discussion on "Modalities of Photothermal Coherence Tomography," an imaging methodology pioneered by Andreas's group. Last but not least, Andreas's anniversary did not go unnoticed during the Conference dinner on June 23, which was spiced up by traditional Slovenian folk dances. Of course, Andreas was invited to join young folk dancers for the Slovenian Hat Dance. And he performed outstandingly, as he did in science and academia throughout his career.

REFERENCES

[1] P. S. Fomina and M. A. Proskurnin, "Photothermal radiometry methods in materials science and applied chemical research," J. Appl. Phys. **132**, 040701 (2022).

[2] J. A. Balderas-López, "Generalized expression for the self-normalized signal in photothermal experiments for multilayered materials in the frequency domain," J. Appl. Phys. **132**, 055104 (2022).

[3] M. Chirtoc and N. Horny, "Toolbox for modeling frequency-domain photothermal experiments on multilayers," J. Appl. Phys. **131**, 214502 (2022).

[4] H. Shimizu, C. Chen, Y. Tsuyama, T. Tsukahara, and T. Kitamori, "Photothermal spectroscopy and micro/nanofluidics," J. Appl. Phys. **132**, 060902 (2022).

[5] X. Zhang, L. Liu, L. Zhang, X. Yin, H. Huan, L. Zhang, and X. Shao, "A compact portable photoacoustic spectroscopy sensor for multiple trace gas detection," J. Appl. Phys. **131**, 174501 (2022).

[6] J. Xia, F. Zhu, J. Bounds, E. Aluauee, A. Kolomenskii, Q. Dong, J. He, C. Meadows, S. Zhang, and H. Schuessler, "Spectroscopic trace gas detection in air-based gas mixtures: Some methods and applications for breath analysis and environmental monitoring," J. Appl. Phys. **131**, 220901 (2022).

[7] P. E. Martinez-Munoz, H. D. Martinez-Hernandez, C. F. Rojas-Beltran, J. L. Perez-Ospina, and M. E. Rodriguez-Garcia, "Development of a differential photoacoustic system for the determination of the effective water diffusion and water vapor permeability coefficients in thin films," J. Appl. Phys. **132**, 115111 (2022).

[8] S. H. Abrams and K. S. Sivagurunathan, "Detecting cracks in teeth and monitoring structural integrity over time with non-invasive PTR-LUM technology a solution for a major clinical challenge," J. Appl. Phys. **131**, 164501 (2022).

[9] M. E. Khosroshahi, Y. Patel, V. Woll-Morison, and R. Chabok, "Study of pulsed laser-induced heating in bio-plasmonic solution using combined photoacoustic and probe beam deflection technique: Thermoacoustic effects," J. Appl. Phys. **131**, 094701 (2022).

[10] A. Dominguez-Pacheco, C. Hernandez-Aguilar, and A. Cruz-Orea, "Obtaining thermal images of creole corn by means of photoacoustic microscopy," J. Appl. Phys. **131**, 215104 (2022).

[11] E. Zheng, H. Zhang, W. Hu, M. M. Doyley, and J. Xia, "Volumetric tri-modal imaging with combined photoacoustic, ultrasound, and shear wave elastography," J. Appl. Phys. **132**, 034902 (2022).

[12] P. Song, J. Liu, Z. Li, S. Wu, X. Sun, H. Yue, and M. Pawlak, "All-optical laser ultrasonic technique for imaging of subsurface defects in carbon fiber reinforced polymer (CFRP) using an optical microphone," J. Appl. Phys. **131**, 165106 (2022).

[13] A. L. Glazov and K. L. Muratikov, "Laser ultrasound imaging of mechanical stresses near holes and indented areas: Experimental results and theoretical model," J. Appl. Phys. **131**, 245104 (2022).

[14] C. Glorieux, "Perspective on non-invasive and non-destructive photoacoustic and photothermal applications," J. Appl. Phys. **131**, 170903 (2022).

[15] Y. Liu, M. Zheng, K. Liu, Y. Yao, and S. Sfarra, "Trimap thermography with convolutional autoencoder for enhanced defect detection of polymer composites," J. Appl. Phys. **131**, 144901 (2022).

[16] B. Li, H. Jiang, and B. Zhao, "Non-destructive aging evaluation of 500-kV field-serviced silicone rubber composite insulators with photothermal radiometry," J. Appl. Phys. **131**, 075108 (2022).

[17] Z.-T. Luo, P. Shen, H. Luo, S. Wang, X.-K. Wu, and H. Zhang, "Advanced orthogonal frequency and phase modulated waveform for contrast-enhanced photothermal wave radar thermography," J. Appl. Phys. **131**, 224903 (2022).

[18] A. T. S. Catanio, E. V. Bergmann, N. M. Kimura, T. Petrucci, C. F. Freitas, L. S. Herculano, L. C. Malacarne, and N. G. C. Astrath, "Spectroscopic and photothermal characterization of graphene quantum dots for antimicrobial applications," J. Appl. Phys. **131**, 155102 (2022).

[19] D. Dadarlat, C. Tripon, I. R. White, and D. Korte, "Photopyroelectric spectroscopy and calorimetry," J. Appl. Phys. **132**, 191101 (2022).

[20] J. Liu, M. Han, R. Wang, S. Xu, and X. Wang, "Photothermal phenomenon: Extended ideas for thermophysical properties characterization," J. Appl. Phys. **131**, 065107 (2022).

[21] A. M. Saeed, K. Lotfy, A. El-Bary, and M. H. Ahmed, "Functionally graded (FG) magneto-photo-thermoelastic semiconductor material with hyperbolic two-temperature theory," J. Appl. Phys. **131**, 045101 (2022).

[22] D. K. Markushev, D. D. Markushev, S. M. Aleksić, D. S. Pantić, S. P. Galović, D. V. Lukić, and J. Ordonez-Miranda, "Enhancement of the thermoelastic component of the photoacoustic signal of silicon membranes coated with a thin TiO_2 film," J. Appl. Phys. **131**, 085105 (2022).

[23] X. Lei, B. Li, Q. Sun, J. Wang, and Y. Wang, "Accurate characterization of surface recombination velocities of silicon wafers with differential nonlinear photocarrier radiometry," J. Appl. Phys. **131**, 125703 (2022).

[24] Q. Sun, B. Zhao, and J. Wang, "Lock-in carrierography of semiconductors and optoelectronics," J. Appl. Phys. **131**, 151101 (2022).

[25] A. C. Bento, N. Cella, S. M. Lima, L. A. O. Nunes, L. H. C. Andrade, J. R. Silva, V. S. Zanuto, N. G. C. Astrath, T. Catunda, A. N. Medina, J. H. Rohling, R. F. Muniz, J. W. Berrar, L. C. Malacarne, W. R. Weinand, F. Sato, M. P. Belancon, G. J. Schiavon, J. Shen, L. C. M. Miranda, H. Vargas, and M. L. Baesso, "Photoacoustic and photothermal and the photovoltaic efficiency of solar cells: A tutorial," J. Appl. Phys. **131**, 141101 (2022).

[26]I. Y. Forero-Sandoval, A. P. Franco-Bacca, F. Cervantes-Álvarez, C. L. Gómez-Heredia, J. A. Ramírez-Rincón, J. Ordonez-Miranda, and J. J. Alvarado-Gil, "Electrical and thermal percolation in two-phase materials: A perspective," J. Appl. Phys. **131**, 230901 (2022).
[27]N. Puthiyaveettil, P. Rajagopal, and K. Balasubramaniam, "Laser spot thermography for defect detection on mild steel at higher temperatures (30–600 °C)," J. Appl. Phys. **132**, 045106 (2022).
[28]J. Lecompagnon, S. Ahmadi, P. Hirsch, C. Rupprecht, and M. Ziegler, "Thermographic detection of internal defects using 2D photothermal super resolution reconstruction with sequential laser heating," J. Appl. Phys. **131**, 185107 (2022).
[29]A. Salazar and A. Mendioroz, "Sizing the depth and width of ideal delaminations using modulated photothermal radiometry," J. Appl. Phys. **131**, 085106 (2022).
[30]J. Bodzenta and A. Kaźmierczak-Bałata, "Scanning thermal microscopy and its applications for quantitative thermal measurements," J. Appl. Phys. **132**, 140902 (2022).
[31]E. Dy, C. Gu, J. Shen, W. Qu, Z. Xie, X. Wang, M. L. Baesso, and N. C. Astrath, "Sensitivity enhancement of thermal lens spectrometry," J. Appl. Phys. **131**, 063102 (2022).
[32]M. Terazima, "Revealing protein reactions using transient grating method: Photo-induced heating, volume change, and diffusion change," J. Appl. Phys. **131**, 140902 (2022).
[33]P. Burgholzer, G. Mayr, G. Thummerer, and M. Haltmeier, "Heat diffusion blurs photothermal images with increasing depth," J. Appl. Phys. **131**, 211101 (2022).