Photoacoustics 37 (2024) 100581

Contents lists available at ScienceDirect

Photoacoustics

journal homepage: www.elsevier.com/locate/pacs

Editorial

Special issue introduction: Ultrafast photoacoustics

Ultrafast Photoacoustics, more commonly known as picosecond laser ultrasonics (PLU), is a research domain involving the use of ultrashort light pulses to generate and detect acoustic waves at GHz-THz frequencies. Pioneering research in this field was conducted in the 1980s, which established the experimental and theoretical background for both the generation and detection of coherent picosecond acoustic pulses [I1, I2]. Fundamental applications include measuring phonon attenuation, evaluating phonon interactions with electrons and magnons in solids, including quantum-electronic structures, and studying picosecond acoustic solitons and shock fronts.

The practical applications of PLU are also diverse. Apart from measurements on homogenous materials such as metals, semiconductors and dielectrics in bulk or thin-film form, PLU has been applied to the imaging of inhomogeneous materials, including plant and animal cells, with nanometer spatial resolution in the direction of acoustic propagation. PLU has also been used to investigate the vibrational behaviour of nanostructures and nano-objects. It can monitor not only coherent longitudinal waves but also coherent shear waves, surface acoustic waves, and Lamb waves in plates. Experiments have been conducted in both solids and liquids.

This Special Issue on Ultrafast Photoacoustics compiles research from many different areas of photoacoustics involving ultrafast lasers in physical and applied acoustics, specifically within the field of PLU. To the best of our knowledge, this marks only the second instance of such a journal collection, which represents the state of the art in this field. The previous collection was published nearly 10 years ago in the journal Ultrasonics (Elsevier) [I3]. This new Special Issue, assembled in 2022–2023, provides a platform for recent achievements across all areas of PLU. Topics include ultrasonic generation and detection techniques, instrumentation, signal processing, inverse analysis, materials characterization, industrial and biomedical applications, simulation and theory, and the fundamental treatment of ultrafast acousto-optic and opto-acoustic phenomena.

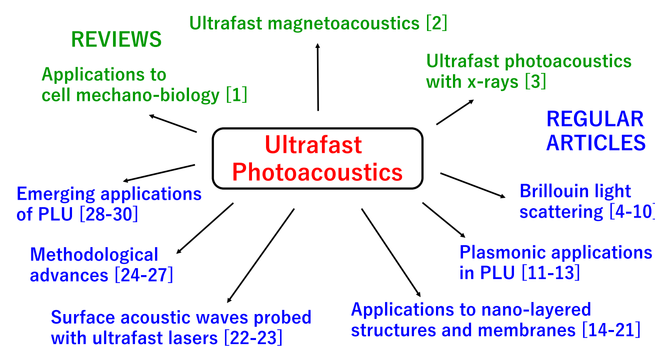

Fig. 1. Map of the articles in the Special Issue. PLU: Picosecond Laser Ultrasonics.

This Special Issue consists of 30 articles, including three reviews and 27 regular articles (see Fig. 1). The review articles (shown in green in the figure) offer up-to-date summaries of various topics in PLU, covering biomedical applications, ultrafast magnetoacoustics, and the use of ultrafast X-rays for detecting coherent acoustic pulses.

For the reader's convenience, the remaining 27 articles in this Special Issue (shown in blue in Fig. 1) are categorized into six groups with the following titles: Brillouin light scattering, Plasmonic applications in PLU, Applications to nano-layered structures and membranes, Surface acoustic waves probed with ultrafast lasers, Methodological advances, Emerging applications of PLU.

Vitalyi E. Gusev, Guest Editor

Bertrand Audoin, Guest Editor

Oliver B. Wright, Guest Editor

https://doi.org/10.1016/j.pacs.2023.100581

Available online 23 December 2023

1. Review articles

1.1. Applications to cell mechano-biology

Applications of picosecond acoustics in cell imaging and mechanobiology have advanced significantly in recent decades, with major findings discussed in the review article [1]. PLU provides an alternative modality for label-free and non-contact cell imaging, which relies on contrast derived from a cell's intrinsic mechanical properties. A unique feature of PLU is its ability to track the propagation of mechanical waves inside cells, particularly within the nucleus. The quantitative evaluation of the nucleus's mechanics in-situ offers new insights into probing its supramolecular organization and understanding changes in its response to biological cues. Other articles related to applications of PLU to cell mechanobiology can be found in Sections 2.3, 2.5 and 2.6 of this Special Issue.

1.2. Ultrafast magnetoacoustics

The article [2] is one of the first reviews in the field of ultrafast magnetoacoustics, which exploits the ultrafast optical excitation of a magnetic material to generate and detect coherent phonons and magnons. Ultrafast magnetoacoustics can be considered a combination of two independent research fields involving ultrashort laser pulses: picosecond ultrasonics and femtosecond optomagnetism. This article reviews ultrafast magnetoacoustic experiments on nanostructures made from the alloy Galfenol (Fe,Ga). The authors focus on the crucial role of the magnon-phonon interaction in the coherent magnon response to ultrafast optical excitation. Strong effects are manifest, and are largely determined by the unique properties of Galfenol. In particular, the article highlights how to significantly influence the magnetic response in this material on optical excitation by controlling the spectrum of generated coherent phonons and their subsequent interaction with magnons. The following effects are covered: resonant phonon pumping of magnons, formation of magnon polarons, and the driving of magnetization waves by guided phonon wavepackets. Thanks to the ability of phonons and magnons to serve as information carriers for quantum communications and neuromorphic computing, the experimental results reviewed underscore the potential of ultrafast magnetoacoustics in applications to emerging areas of modern nanoelectronics.

1.3. Ultrafast photoacoustics with X-rays

The article [3] is the first review article to discuss PLU experiments using ultrashort hard X-ray probe pulses to monitor coherent picosecond acoustic phonons generated in laser-excited nanoscale structures from Bragg-peak shifts. This 'picosecond ultrasonics with X-ray' (PUX) method provides direct, layer-specific, and quantitative information on the picosecond strain response for structures down to a few nm in thickness, irrespective of the optical properties. The method encompasses ultrathin and opaque metal heterostructures, continuous and granular nanolayers, as well as negative thermal expansion materials, all of which pose challenges for measurement with established all-optical techniques. Modelling the transient strain using the elastic wave equation and connecting the driving photo-induced stress via the Grüneisen parameter to energy-density changes in the microscopic subsystems of the solid, i.e., electrons, phonons, and spins, provides an opportunity to reveal ultrafast energy flows between the different subsystems. A very recent article on this topic may be found in Section 2.6 of this Special Issue.

2. Regular articles

2.1. Brillouin light scattering

Brillouin light scattering was originally implemented in experiments where thermal phonons were probed by photons from a continuous laser, making use of analysis in the spectral domain [I4,I5]. In PLU experiments, however, it is the coherent phonons generated by pump optical pulses that are detected. By using ultrashort probe optical pulses together with the optical sampling technique, time-domain measurements of the Brillouin interaction become possible. Information is then extracted from the interactions that occur during the propagation of the optically generated coherent phonons in the structure under investigation.

An interesting intermediate situation is presented in the article [4], in which case a continuous laser is used to detect the interaction with coherent phonons optically generated by ultrashort pump optical pulses. The detected signals are then 3–4 orders of magnitude higher than those detected when there is no pump, i.e., when only spontaneous thermal phonons are detected. Remarkably, the authors demonstrate the detection of multiple resonance modes in a thin bilayer structure of gold and silicon. Whether or not the detection is resolved in the time domain, the measurement of the frequency shift associated with the Brillouin interaction only provides access to the sound velocity if the refractive index of the medium is known. When multiple measurements are performed for different optical-incidence angles, it is possible to extract both quantities simultaneously, i.e., sound velocity and refractive index. This experimental analysis has been automated by the authors of article [5], expanding the possible range of applications, for example, to 3D imaging of these parameters in biological cells. This angular scanning can be avoided if lateral access to the sample is possible: by exploiting the simple laws of refraction, article [6] shows that the dependence of the Brillouin frequency shift on the transparent medium's refractive index is eliminated if lateral optical-probe access is enabled. Under this condition, measurement of sound velocity, and its potential depth dependence, is possible independent of the refractive index of the medium.

Another interesting application of time-resolved Brillouin scattering is the reconstruction of transient strains propagating through an opaque or a transparent medium. Strain pulse restoration for an opaque medium is discussed in the article [7], in which case the Brillouin oscillations contributing to acoustic echoes are heavily damped. This work makes use of a classical theoretical formula describing the dependence of the complex echo signals detected by ultrafast optical interferometry on the coherent acoustic phonon field in the material. Strain pulse restoration is achieved by filtering in the frequency domain, and this is demonstrated by numerical simulations and by the analysis of experimental results for a chromium film. The method requires a knowledge of the acoustic, optical, and acousto-optical (photoelastic) parameters of the material. The tomographic reconstruction of the propagation of a transient strain pulse in a transparent medium is considered in the article [8]. The authors used a hemispherical glass sample, and recorded the waveforms resulting from the Brillouin interaction at various optical-incidence angles, θ, between the coherent phonon wave vector and the probe photon wave vector, spanning a wide angular range. An inverse problem based on a knowledge of a theoretical formula relating the change in reflectivity in a transparent medium to the strain distribution was formulated to derive the strain pulse shape. By applying this method at each time step, the authors generated a movie of the propagation of acoustic strain in glass with a spatial resolution of $\sim$120 nm and a temporal resolution of $\sim$1 ps. This time-resolved Brillouin tomography technique could be used to image the propagation of other transient fields involving ultrafast perturbations in the refractive index.

A significant advantage of harnessing the time-resolved Brillouin interaction lies in its role in the analysis of transient acoustic wavefronts as they evolve during propagation. This approach is limited by the optical absorption of the probe beam or by ultrasonic attenuation, with the latter resulting from either acoustic absorption or diffraction. When propagation occurs in a stratified medium, the Brillouin signature of each layer appears successively on the temporal trace of the reflectivity change, provided that the acoustic reflection coefficients between layers are not too large. Time-resolved Brillouin scattering thus allows the analysis of stratified media with a thickness resolution on the order of a few nanometers. In situations where one or more interfaces are inclined, complex scenarios may arise in which the wave vectors of phonons and probe photons are no longer aligned. A theory has been developed in the article [9] to describe these interactions, by taking into account these misalignments, the Gaussian form of the optical and acoustic beams, and their pulsed nature. An application is presented in the article [10], in which beam deflection is produced by an inclined interface resulting from the non-uniform variation in the thickness of a sample subjected to an intense and non-hydrostatic pressure field. Through an analysis supported by theory, it was possible to determine the local inclination of the interface from a single point measurement. This opens up a wide range of possibilities for monitoring and imaging local structural changes in samples

2.2. Plasmonic applications in PLU

Three articles report on new findings in the application of surface plasmon polariton (SPP) resonances to achieve enhanced detection sensitivity in PLU experiments. In these experiments, a prism (used in the Kretschmann configuration) was used to couple the probe light to a SPP resonance and thus enable PLU detection in nanometer-thick metallic films.

In the article [11], it is revealed that when approaching the SPP resonance condition, the phase of the acoustically-induced oscillatory signal shifts because the spatial region for the most efficient detection of acoustic waves is displaced from the prism/metal interface to the metal/air interface. In the article [12], the application of asynchronous optical sampling under the SPP resonance condition enabled detection of higher-order vibrational modes of a metal film and the attenuation therein up to sub-THz frequencies. This revealed the importance of the contribution of the acoustically-induced film thickness variations to the detection process. The article [13] reports on novel PLU experiments on metallic gratings, consisting of a short-period grating modulated by a longer-period grating. This leads to two sidebands in the spatial frequency domain, and to three SPP resonances at different optical wavelengths for the same optical incidence angle, producing diffraction efficiency increases for specific diffraction orders. The experiments revealed that probing optical reflectivity changes close to SPP resonances leads to enhancements in the detection of surface and longitudinal bulk acoustic waves by factors of about 20 and 40, respectively, compared with reflectivity changes observed when probing at off-resonance wavelengths. Measuring the optically diffracted probe light was found to lead to an enhancement factor approaching 100 for the detection of longitudinal bulk acoustic waves.

2.3. Applications to nano-layered structures and membranes

Eight articles report on advances in one of the classical areas of PLU, namely the evaluation of the elasticity of single- and multi-layer nanostructures. This progress is made possible by applying ultrafast photoacoustic techniques to emerging materials and structures. The development of accurate and reliable protocols for structures of practical interest in micro- and nano-device fabrication is also influential in facilitating these advances. The structures considered in this Section are not limited to inorganic materials, but also relate to organic materials such as those in biology.

In the article [14], mesoporous TiO_2 resonators for coherent acoustic phonons up to 90 GHz with quality factors up to 7 are demonstrated by means of ultrafast transient pump-probe reflectometry and interferometry. The experimental results and theoretical modelling suggest a pathway for engineering more complex structures for nanoacoustic sensing and reconfigurable optoacoustic nanodevices based on cost-effective fabrication methods, such as sol-gel techniques.

The article [15] is devoted to the proposal and experimental testing of a metrological protocol for the accurate measurement over a large temperature range of the elastic and thermoelastic properties of industrial thin-film resins deposited on industrial-size wafers. This protocol combines A) colored picosecond acoustics (CPA), for monitoring the propagation of picosecond coherent phonon pulses in thin films to measure the product of sound velocity and the refractive index, and the acoustic propagation time across the film, with B) spectroscopic ellipsometry (SE), for measurement of the thin-film thickness and refractive index. The refractive index from SE is used to extract the sound velocity and thickness from CPA. The extracted thickness is in excellent agreement with the thickness measured from SE, confirming the consistency of the developed metrology.

In the article [16], the acoustic vibrational modes of a sub-100-nm-thick gold nanoplate (Au NPL) deposited on a glass surface were examined using ultrafast pump-probe transient absorption microscopy in reflection mode. Resonant frequencies were detected up to the seventh overtone, corresponding in continuum mechanics to the free vibrations of the nanoplate. The observed faster decay of the overtones compared to the fundamental vibrational mode suggests the necessity for more intricate theoretical modelling and additional critical experiments. Understanding the energy dissipation paths of these modes in nano-optomechanical devices is fundamentally important for applications, and merits further investigation.

The GHz viscoelasticity of biological cell membranes was probed in the article [17] by measuring the lifetime of coherent acoustic vibrations of a structure composed of Au NPLs or Au NPLs in contact with bio-membranes, surrounded by liquids. The vibrational dynamics was evaluated by ultrafast pump-probe transient absorption microscopy. By comparing the vibration dynamics of Au NPL-based structures with and without cell membranes, the contribution from the cell membrane to the damping was determined by use of a theoretical model of the viscoelasticity. It was demonstrated that membrane viscoelasticity can distinguish between a cancerous cell line and a normal cell line.

In the article [18], ultrafast photoacoustics was applied to examine THz vibrational modes of bi-layer and tri-layer semiconducting transition metal dichalcogenide MoS_2, epitaxially grown on a sapphire substrate, including modes not detectable by Raman spectroscopy. The vibrations of these few-layer structures were monitored by near-UV pump-probe transient transmission measurements. The experimental results allowed estimates of the van der Waals coupling constants between the layers and the substrate, and between the neighbour and the next-nearest neighbour layers, as well as the intralayer stiffnesses and the dependence of these constants on the number of layers. This information is of crucial importance for the engineering of multilayered devices from single-layer materials.

Van der Waals bonding of single- or bi-layer two-dimensional (2D) opaque materials to transparent substrates can be analyzed and characterized through the evaluation of picosecond coherent acoustic pulse generation by ultrashort laser pulses, as described in the article [19]. The asymmetric bipolar profiles of the detected $\sim$5 ps duration strain pulses generated in such 2D materials contain information on the ultrafast dynamics of the van der Vaals bonds between the 2D material and the substrate, associated with photo-induced heat and charge carrier transfer. The charge and heat transfer times, revealed through fitting the experimental results to a theoretical model, should be beneficial for the design of devices based on 2D materials.

Article [20] concerns a theoretical and numerical study of photoacoustic transduction using single- or multi-wall carbon nanotubes in water. Depending on the pulse duration and characteristic size of the nanotubes, the acoustic wave in water can arise either from heat diffusion from the nanotube to the water or from the ultrafast expansion of the nanotubes. This research provides opportunities to explore high-frequency acoustic damping in water and gain insights into thermal conductance in nano-systems immersed in liquids.

In the article [21], ultrafast photoacoustics was applied in a tomographical context to investigate nanoscale multilayered structures along the depth direction with lateral inhomogeneities, i.e., in directions normal to the layering direction. A structure composed of graphitized layers buried in diamond, formed by ion implantation followed by annealing, was studied. This involved combining the analysis of optically-detected acoustic motion of the sample in the time-domain (echo arrivals and Brillouin oscillations) with that in the frequency domain (resonant hypersonic spectroscopy). At the same time, two different types of acoustic response were optically induced: the dominant channel for the optoacoustic conversion of light absorption occurred either in the graphitized layer or in the metallic film deposited on the diamond. It was found that the totality of accumulated signals was sufficient to reveal the depth profile of the structure, which consists of both transparent and opaque layers. This was achieved by fitting the signals to a model describing the acousto-optical response at each point on the sample. The combined use of local depth profiling and lateral mapping via experiments at different points of the sample can thereby serve as a tool for hypersound tomography.

2.4. Surface acoustic waves probed with ultrafast lasers

Two articles [22,23] describe new achievements in the application of ultrafast photoacoustics to the 2D imaging of the propagation of surface acoustic waves. Article [22] reports on a detailed study of the propagation of point-excited GHz surface acoustic waves on a microscopic 2D phononic crystal. Constant-frequency images are extracted in the region around the phononic band gap. Mode conversion and refraction at the interface between a square-shaped phononic crystal and the surrounding non-structured substrate are studied in relation to analytical models of the dispersion relation, revealing intriguing wavefronts. This time-domain imaging technique was extended in the article [23] to a wideband investigation of the GHz eigenstates of a phononic crystal cavity. Using omnidirectionally excited phonon wave vectors, the 2D acoustic field inside and outside a hexagonal cavity in a honeycomb-lattice phononic crystal formed in a microscopic crystalline silicon slab was probed, thereby revealing the confinement and mode volumes of phonon eigenstates lying both inside and outside the phononic-crystal band gap. A novel numerical approach to extract the cavity Q factor by means of toneburst acoustic excitation and analysis of the acoustic Poynting vector distribution allowed a quantitative measure of the spatial acoustic energy storage characteristics of the cavity. The experimental and analytical techniques developed in the articles [22,23] open the way for a more detailed understanding of the acoustic properties of phononic crystals, phononic metamaterials, and their derived surface wave devices.

2.5. Methodological advances

Several methodological advancements in this Special Issue aim to simplify experimental setups and/or accelerate acquisition times for imaging. Conventional systems for ultrafast optical sampling consist mainly of two types. One uses a mechanical delay line to introduce a time delay between the pump and probe pulses, whereas the other uses two lasers with slightly different repetition frequencies for asynchronous stroboscopic detection. Article [24] examines the performance of a system in which the two pulse trains required for asynchronous detection are derived from a single laser by introducing a birefringent crystal into the laser cavity. This simplifies the setup, makes it more compact, and ensures excellent performance. A veritable paradigm shift is proposed in the article [25]. While optical sampling has traditionally been achieved by a controlled delay between the pump and probe pulses, the authors suggest keeping the pump-probe delay fixed while significantly stretching the spectral width of the probe pulses. Time is then encoded through the optical wavelength, which is spatially shifted within each probe pulse. This approach demonstrates a performance comparable to conventional systems, as illustrated by applications in 3D biological cell imaging.

It is common in PLU to only monitor the transient reflectivity change of the sample caused by the local refractive index perturbations induced by the acoustic strain. However, for certain materials, particularly those of industrial interest such as copper, the piezo-optic conversion coefficients (i.e., photoelastic constants) at the probe wavelengths used tend to be small, resulting in low-sensitivity detection. In such cases, interferometric detection of optical phase changes allows for the measurement of the acoustic displacement of the sample interfaces rather than the strain. Article [26] investigates the performance of a simple and compact interferometric technique in which reference and signal light pulses are separated and then recombined by passing through a birefringent crystal. To reduce imaging times, particularly for biological applications, article [27] presents a system for acquiring sample reflectivity changes using multiple parallel pathways. The measurement is carried out using a multicore optical fiber, which affords a system spatial resolution comparable to that of conventional systems but reduces image acquisition time by at least a factor of 3.

2.6. Emerging applications of PLU

This final section sheds light on emerging applications of the PLU technique. These applications involve the optical determination of the bandgap deformation potential in semiconducting materials, the monitoring of strain pulses emitted by metallic opto-acoustic transducers, and the probing of changes in the supramolecular organization of cell nuclei induced by chemical and physical DNA damaging agents.

In the article [28], the authors report on a novel ultrafast photoacoustic method to extract the acoustic deformation potential of a semiconductor, a constant that plays a major role in quantifying the interactions of acoustic waves with charge carriers. The method is based on the joint analysis of time-domain Brillouin oscillations monitored with and without a metal transducer, when the photon energy of the ultrafast pump laser pulses is located near the semiconductor band gap. Applying this method to GaAs allowed the determination of the bandgap deformation potential constant, yielding results in good agreement with values reported in the literature.

In the article [29], picosecond ultrasonics with X-rays (PUX) is used to validate the concept of manipulating the shape and sign of picosecond acoustic pulses through an external magnetic field in metallic transducers with giant forced magnetostriction. The experimental metallic heterostructure, used to demonstrate a functional optoacoustic transducer, comprises a dysprosium (Dy) optoacoustic transducer and a niobium (Nb) detection layer, separated by a propagation layer. The Dy layer undergoes a field-dependent first-order ferromagnetic–antiferromagnetic phase transition, providing, upon laser excitation, an additional large contractive stress compared to its zero-field response. The zero-field response of normal metallic optoacoustic transducers can thus be overcome in the case of rare-earth metal transducers by an additional B-field-dependent stress of an opposite polarity released upon laser-induced demagnetization. This enables the tuning of picosecond strain pulses as a function of the B-field.

In the article [30], it is shown that PLU allows the tracking of coherent acoustic phonons during propagation in a biological cell intra-nucleus nanostructure. The complex stiffness moduli of a nucleus and its thickness were measured for cells exposed to increasing doses of chemical and physical DNA damaging agents. The intrinsic physical properties, experimentally accessible with PLU, are shown to be sensitive to the compaction or decompaction of the chromatin network induced by the cell response to DNA damage. These structural changes are believed to either enable the operation of repair and signaling proteins or block the path for damaging species. PLU thus offers bright prospects for the development of innovative therapies. It could also be used to probe in situ the structural changes that hinder genome access, or to measure the impact on the chromatin scaffold of drugs that, on the contrary, promote this access.

3. Conclusions

In conclusion, this Special Issue on Ultrafast Photoacoustics not only reveals the current state of the art but, more importantly, provides insights into the potential directions for future research in picosecond laser ultrasonics, nanoacoustics, ultrafast acoustics and photoacoustics. Commercial applications of picosecond laser ultrasonics to date have been mainly concentrated in the semiconductor processing industry, but this collection should hopefully stimulate diverse further applications with strong societal impact. Moreover, it should serve as a valuable resource for researchers already well-versed in the field as well as acting as a catalyst for attracting new scientists to the realm of picosecond laser ultrasonics.

We extend our sincere gratitude to Dr. Ivan Pelivanov (Section Editor) for initiating this Special Issue and to Dr. Alexander Oraevsky (Editor-in-Chief) for his unwavering support.

References

[I1] C. Thomsen, J. Strait, Z. Vardeny, H.J. Maris, J. Tauc, J.J. Hauser, Coherent phonon generation and detection by picosecond light pulses, Phys. Rev. Lett. 53 (1984) 989–992.
[I2] C. Thomsen, H.T. Grahn, H.J. Maris, J. Tauc, Surface generation and detection of phonons by picosecond light pulses, Phys. Rev. B 34 (1986) 4129–4138.
[I3] Special Section: Ultrafast Acoustics, Ultrasonics Volume 56 (2015) 1–171. https://www.sciencedirect.com/journal/ultrasonics/vol/56/suppl/C.
[I4] L. Brillouin, Diffusion de la lumière et des rayons X par un corps transparent homogène, Ann. De. Phys. 9 (17) (1922) 88–122.
[I5] J.G. Dil, Brillouin scattering in condensed matter, Rep. Progr. Phys. 45 (1982) 285.
[1] B. Audoin, Principles and advances in ultrafast photoacoustics; applications to imaging cell mechanics and to probing cell nanostructure, Photoacoustics 31 (2023) 100496.
[2] A.V. Scherbakov, T.L. Linnik, S.M. Kukhtaruk, D.R. Yakovlev, A. Nadzeyka, A. W. Rushforth, A.V. Akimov, M. Bayer, Ultrafast magnetoacoustics in Galfenol nanostructures, Photoacoustics 34 (2023) 100565.
[3] M. Mattern, A. von Reppert, S.P. Zeuschner, M. Herzog, J.E. Pudell, M. Bargheer, Concepts and use cases for picosecond ultrasonics with x-rays, Photoacoustics 31 (2023) 100503.
[4] R. Białek, T. Vasileiadis, M. Pochylski, B. Graczykowski, Fano meets Stokes: four-order-of-magnitude enhancement of asymmetric Brillouin light scattering spectra, Photoacoustics 30 (2023) 100478.
[5] M. Tomoda, A. Kubota, O. Matsuda, Y. Sugawara, O.B. Wright, Time-domain Brillouin imaging of sound velocity and refractive index using automated angle scanning, Photoacoustics 31 (2023) 100486.
[6] M. Tomoda, A. Toda, O. Matsuda, V.E. Gusev, O.B. Wright, Sound velocity mapping from GHz Brillouin oscillations in transparent materials by optical incidence from the side of the sample, Photoacoustics 30 (2023) 100459.
[7] T. Tachizaki, J.J. Baumberg, O. Matsuda, M. Tomoda, H. Ogi, O.B. Wright, Spectral analysis of amplitude and phase echoes in picosecond ultrasonics for strain pulse shape determination, Photoacoustics 34 (2023) 100566.
[8] M. Tomoda, H. Matsuo, O. Matsuda, R. Li Voti, O.B. Wright, Tomographic reconstruction of picosecond acoustic strain pulses using automated angle-scan probing with visible light, Photoacoustics 34 (2023) 100567.
[9] V.E. Gusev, T. Thréard, D.H. Hurley, S. Raetz, Time-domain Brillouin scattering theory for probe light and acoustic beams propagating at an angle and acousto-optic interaction at material interfaces, Photoacoustics 33 (2023) 100563.
[10] S. Sandeep, S. Raetz, N. Chigarev, N. Pajusco, T. Thréard, M. Edely, A. Bulou, A. Zerr, V.E. Gusev, Time-domain Brillouin scattering for evaluation of materials interface inclination: Application to photoacoustic imaging of crystal destruction upon non-hydrostatic compression, Photoacoustics 33 (2023) 100547.
[11] T.S. Lee, C.K. Sun, Effect of surface plasmon on optical detection of picosecond ultrasonic pulses generated in aluminum nanofilms, Photoacoustics 31 (2023) 100509.
[12] F. Noll, N. Krauß, V. Gusev, T. Dekorsy, M. Hettich, Surface plasmon-based detection for picosecond ultrasonics in planar gold-dielectric layer geometries, Photoacoustics 30 (2023) 100464.
[13] T.J. van den Hooven, P.C. Planken, Surface-plasmon-enhanced strain-wave-induced optical diffraction changes from a segmented grating, Photoacoustics 31 (2023) 100497.
[14] E.R. Cardozo de Oliveira, C. Xiang, M. Esmann, N. Lopez Abdala, M.C. Fuertes, A. Bruchhausen, H. Pastoriza, B. Perrin, G.J.A.A. Soler-Illia, N.D. Lanzillotti-Kimura, Probing gigahertz coherent acoustic phonons in TiO2 mesoporous thin films, Photoacoustics 30 (2023) 100472.
[15] A. Devos, F. Chevreux, C. Licitra, A. Chargui, L.L. Chapelon, Elastic and thermo-elastic characterizations of thin resin films using colored picosecond acoustics and spectroscopic ellipsometry, Photoacoustics 31 (2023) 100498.
[16] C. Wright, G.V. Hartland, Mode specific dynamics for the acoustic vibrations of a gold nanoplate, Photoacoustics 30 (2023) 100476.
[17] K. Yu, Y. Jiang, Y. Chen, X. Hu, J. Chang, G.V. Hartland, G.P. Wang, Compressible viscoelasticity of cell membranes determined by gigahertz-frequency acoustic vibrations, Photoacoustics 31 (2023) 100494.
[18] P.J. Wang, P.C. Tsai, Z.S. Yang, S.Y. Lin, C.K. Sun, Revealing the interlayer van der Waals coupling of bi-layer and tri-layer MoS2 using terahertz coherent phonon spectroscopy, Photoacoustics 28 (2022) 100412.
[19] P.J. Wang, C.J. Chang, S.Y. Lin, J.K. Sheu, C.K. Sun, Temporally probing the thermal phonon and charge transfer induced out-of-plane acoustical displacement of monolayer and bi-layer MoS2/GaN heterojunction, Photoacoustics 30 (2023) 100477.
[20] M. Diego, M. Gandolfi, A. Casto, F. Maria Bellussi, F. Vialla, A. Crut, S. Roddaro, M. Fasano, F. Vallée, N. Del Fatti, P. Maioli, F. Banfi, Ultrafast nano generation of acoustic waves, in water via a single carbon nanotube, Photoacoustics 28 (2022) 100407.
[21] A.Y. Klokov, N.Y. Frolov, A.I. Sharkov, S.I. Chentsov, R.A. Khmelnitsky, V. A. Dravin, Hypersound tomography of graphitized layers buried into diamond matrix, Photoacoustics 32 (2023) 100528.
[22] O. Matsuda, H. Koga, H. Nishita, M. Tomoda, P.H. Otsuka, O.B. Wright, Refraction, beam splitting and dispersion of GHz surface acoustic waves by a phononic crystal, Photoacoustics 30 (2023) 100471.
[23] P.H. Otsuka, R. Chinbe, M. Tomoda, O. Matsuda, Y. Tanaka, D.M. Profunser, S. Kim, H. Jeon, I.A. Veres, A.A. Maznev, O.B. Wright, Imaging phonon eigenstates and elucidating the energy storage characteristics of a honeycomb-lattice phononic crystal cavity, Photoacoustics 31 (2023) 100481.
[24] J. Pupeikis, W. Hu, B. Willenberg, M. Mehendale, G.A. Antonelli, C.R. Phillips, U. Keller, Efficient pump-probe sampling with a single-cavity dual-comb laser: Application in ultrafast photoacoustics, Photoacoustics 29 (2023) 100439.
[25] A. Ishijima, S. Okabe, I. Sakuma, K. Nakagawa, Dispersive coherent Brillouin scattering spectroscopy, Photoacoustics 29 (2023) 100447.
[26] M. Robin, R. Guis, M.U. Arabul, Z. Zhou, N. Pandey, G.J. Verbiest, Experimental and numerical study of Conoscopic Interferometry sensitivity for optimal acoustic pulse detection in ultrafast acoustics, Photoacoustics 30 (2023) 100470.
[27] R. Fuentes-Domínguez, M. Yao, W. Hardiman, S. La Cavera III, K. Setchfield, F. Pérez-Cota, R.J. Smith, M. Clark, Parallel imaging with phonon microscopy using a multi-core fibre bundle detection, Photoacoustics 31 (2023) 100493.
[28] L. Zhang, Y. Cai, L. Li, W. Feng, R.T. Wen, S. Shin, L. Guo, Metal transducer-assisted acoustic deformation potential characterization via coherent acoustic phonon dynamics, Photoacoustics 30 (2023) 100489.
[29] M. Mattern, J.E. Pudell, K. Dumesnil, A. von Reppert, M. Bargheer, Towards shaping picosecond strain pulses via magnetostrictive transducers, Photoacoustics 30 (2023) 100463.
[30] L. Liu, M. Simon, G. Muggiolu, F. Vilotte, M. Antoine, J. Caron, G. Kantor, P. Barberet, H. Seznec, B. Audoin, Changes in intra-nuclear mechanics in response to DNA damaging agents revealed by time-domain Brillouin micro-spectroscopy, Photoacoustics 27 (2022) 100385.

Vitalyi E. Gusev received his PhD degree in physics and mathematics (laser physics) in 1982 from the M. V. Lomonosov Moscow State University, Soviet Union. He received Habilitations in Moscow State University in mathematics and physics (acoustics) in 1992 and in Le Mans University, France, in 1997. He is currently a Professor at Le Mans University. Since 1980, his research interests were in the development of the theoretical foundations of nonlinear acoustic, optoacoustic, photothermal and thermoacoustic phenomena. His most recent research has focused on applications of picosecond laser ultrasonics for imaging, on nonlinear laser ultrasonics, acoustics of granular media and nondestructive testing and evaluation of nanomaterials and nanostructures. Vitalyi E. Gusev is the author of more than 350 publications in international journals and a book "Laser Optoacoustics" published in Russia (1991) and in the USA (1993). He was awarded the Lenin Comsomol Prize in Science and Technology, Physics (Nonlinear Acoustics) in 1987: highest award for the young researchers in the former Soviet Union. He became a Senior Prize Winner of the International Photoacoustic and Photothermal Association (2003) and a Senior Member of the Institute of French Universities (2006). In 2007, he was awarded the French Medal of the French Acoustical Society and, in 2010, the Gay-Lussac Humboldt Research Award. In 2013 and 2016, he became a Fellow of the Acoustical Society of America and of the American Physical Society, respectively.

Bertrand Audoin is Professor at Université de Bordeaux, France. He was involved in laser ultrasonics and its applications to the non-destructive evaluation of anisotropic materials. The research he led also focused on picosecond ultrasonics. He and coworkers have studied acoustic diffraction in sub-micron sized solid samples which made use of the absorption by a single particle as an opto-acoustic source. B. Audoin's current research focuses on picosecond bio-phononics: he achieved the first applications of picosecond ultrasonics to biological media, a field totally unexplored at the time. His group has in particular developed opto-acoustic microscopy of single cells, an imaging modality whereby mechanical properties provide the contrast mechanism.

Oliver B. Wright received his B.A. in physics at University College, Oxford and his Ph.D. in low-temperature solid-state physics at the Cavendish Laboratory, Cambridge. He continued this research at CRTBT, C.N.R.S. in Grenoble, France. After that he joined Schlumberger to work on optical sensors in Montrouge, Paris. Subsequently he moved to Nippon Steel Corporation, working as a Senior Researcher at their Electronics Research Laboratories, Sagamihara, Japan, mainly in the field of non-destructive characterization of materials using laser acoustic techniques and electromagnetic acoustic transducers. He then he worked on related topics at C.N.R. Istituto di Acustica in Rome and at C.N.R.S. in Besançon, France. From 1996 he has been a professor at Hokkaido University in Sapporo, Japan, in 2002, he became a Guest Professor at Osaka University. He specializes in laser

picosecond ultrasonics, surface acoustic wave imaging and acoustic metamaterials. In 2013 he founded the company Plum Science Co., Ltd. that makes novel waveguide-based desk lights and stand lights, on sale in many countries. He is a Fellow of the Institute of Physics, London.

Vitalyi E. Gusev*
Laboratoire d'Acoustique de l'Université du Mans (LAUM), UMR 6613, Institut d'Acoustique – Graduate School (IA-GS), CNRS, Le Mans Université, France

Bertrand Audoin
University of Bordeaux, CNRS, UMR 5295, I2M, F-33400 Talence, France

Oliver B. Wright
Graduate School of Engineering, Osaka University, Yamadaoka 2-1, Suita, Osaka 565-0871, Japan
Hokkaido University, Sapporo 060–0808, Japan

* Corresponding author.
E-mail address: Vitali.Goussev@univ-lemans.fr (V.E. Gusev).