

# Acoustic Metamaterials Tunable Gradient Index Phononic Crystals For Acoustic Wave Manipulation

Metamaterials have attracted enormous interests from both physics and engineering communities in the past 20 years, owing to their powerful ability in manipulating electromagnetic waves. However, the functionalities of traditional metamaterials are fixed at the time of fabrication. To control the EM waves dynamically, active components are introduced to the meta-atoms, yielding active metamaterials. Recently, a special kind of active metamaterials, digital coding and programmable metamaterials, are proposed, which can achieve dynamically controllable functionalities using field programmable gate array (FPGA). Most importantly, the digital coding representations of metamaterials set up a bridge between the digital world and physical world, and allow metamaterials to process digital information directly, leading to information metamaterials. In this Element, we review the evolution of information metamaterials, mainly focusing on their basic concepts, design principles, fabrication techniques, experimental measurement and potential applications. Future developments of information metamaterials are also envisioned. This book opens a new avenue to an engendering field of applied physics, located at the OC crossingOCO of modern photonics, electromagnetics, acoustics and material science. It also highlights the concept of OC non-localityOCO, which proves to be not a special feature of quantum phenomena, but is shown to have an important counterpart in classical physics and its engineering applications too. Furthermore, it visualizes the physical results by means of simple analytical presentations, reduced sometimes to the elementary functions.

This book presents the emerging regime of zero refractive index photonics, involving metamaterials that exhibit effectively zero refractive index. Metamaterials are artificial structures whose optical properties can be tailored at will. With metamaterials, intriguing and spellbinding phenomena like negative refraction and electromagnetic cloaking could be realized, which otherwise seem unnatural or straight out of science fiction. Zero index metamaterials are also seen as a means of boosting nonlinear properties and are believed to have strong prospects for being useful in nonlinear optical applications. In summary, this book highlights almost everything currently available on zero index metamaterials and is useful for professionally interested and motivated readers.

Metamaterials—artificially structured materials with engineered electromagnetic properties—have enabled unprecedented flexibility in manipulating electromagnetic waves and producing new functionalities. This book details recent advances in the study of optical metamaterials, ranging from fundamental aspects to up-to-date implementations, in one unified treatment. Important recent developments and applications such as superlens and cloaking devices are also treated in detail and made understandable. The planned

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monograph can serve as a very timely book for both newcomers and advanced researchers in this extremely rapid evolving field.

Dielectric Metamaterials

Graded Elastic Metamaterials for Energy Harvesting

Devices and Applications

Resolution Below the Diffraction Limit

Physics and Engineering Explorations

Elastic Waves in Solids I

*Metamaterials: Theory, Design, and Applications goes beyond left-handed materials (LHM) or negative index materials (NIM) and focuses on recent research activity. Included here is an introduction to optical transformation theory, revealing invisible cloaks, EM concentrators, beam splitters, and new-type antennas, a presentation of general theory on artificial metamaterials composed of periodic structures, coverage of a new rapid design method for inhomogeneous metamaterials, which makes it easier to design a cloak, and new developments including but not limited to experimental verification of invisible cloaks, FDTD simulations of invisible cloaks, the microwave and RF applications of metamaterials, sub-wavelength imaging using anisotropic metamaterials, dynamical metamaterial systems, photonic metamaterials, and magnetic plasmon effects of metamaterials.*

*State-of-the-Art Materials Science in Belgium 2017MDPI*

*This research monograph provides a brief overview of the authors' research in the area of ordered granular media over the last decade. The exposition covers one-dimensional homogeneous and dimer chains in great detail incorporating novel analytical tools and experimental results supporting the analytical and numerical studies. The proposed analytical tools have since been successfully implemented in studying two-dimensional dimers, granular dimers on on-site perturbations, solitary waves in Toda lattices to name a few. The second part of the monograph dwells on weakly coupled homogeneous granular chains from analytical, numerical and experimental perspective exploring the interesting phenomenon of Landau–Zener tunneling in granular media. The final part of the monograph provides a brief introduction to locally resonant acoustic metamaterials incorporating internal rotators and the resulting energy channeling mechanism in unit-cells and in one- and two-dimensional lattices. The monograph provides a comprehensive overview of the research in this interesting domain. However, this exposition is not all exhaustive with regard to equally exciting research by other researchers across the globe, but we provide an exhaustive list of references for the interested readers to further explore in this direction.*

*In this book the authors present several examples of techniques used to overcome the Abby diffraction limit using flat and 3D diffractive optical elements, photonic crystal lenses, photonic jets, and surface plasmon diffractive optics. The structures discussed can be used in the microwave and THz range and also as scaled models for optical frequencies. Such nano-optical microlenses can be integrated, for example, into existing semiconductor heterostructure platforms for next-generation optoelectronic applications. Chapter 1 considers flat diffractive lenses and innovative 3D radiating structures including a conical millimeter-wave Fresnel zone plate (FZP) lens proposed for subwavelength focusing. In chapter 2 the subwavelength focusing properties of diffractive photonic crystal lenses are considered and it is shown that at least three different types of photonic crystal lens are possible. With the aim of achieving subwavelength focusing, in chapter 3 an alternative mechanism to produce photonic jets at Terahertz frequencies (terajets) using 3D dielectric particles of arbitrary size (cuboids) is considered. A scheme to create a 2D “teraknife” using dielectric rods is also discussed. In the final chapter the successful adaptation of free-space 3D binary phase-reversal conical FZPs for operation on surface plasmon-polariton (SPP) waves demonstrates that analogues of Fourier diffractive components can be developed for in-plane SPP 3D optics. Reviewing*

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*theory, modelling and experiment, this book will be a valuable resource for students and researchers working on nanophotonics and sub-wavelength focusing and imaging.*

*Trends and Applications*

*Acoustic Metamaterials*

*Plasmonics and Super-Resolution Imaging*

*Waves in Gradient Metamaterials*

*Zero Index Metamaterials*

This book delivers a comprehensive and up-to-date treatment of practical applications of metamaterials, structured media, and conventional porous materials. With increasing levels of urbanization, a growing demand for motorized transport, and inefficient urban planning, environmental noise exposure is rapidly becoming a pressing societal and health concern. Phononic and sonic crystals, acoustic metamaterials, and metasurfaces can revolutionize noise and vibration control and, in many cases, replace traditional porous materials for these applications. In this collection of contributed chapters, a group of international researchers reviews the essentials of acoustic wave propagation in metamaterials and porous absorbers with viscothermal losses, as well as the most recent advances in the design of acoustic metamaterial absorbers. The book features a detailed theoretical introduction describing commonly used modelling techniques such as plane wave expansion, multiple scattering theory, and the transfer matrix method. The following chapters give a detailed consideration of acoustic wave propagation in viscothermal fluids and porous media, and the extension of this theory to non-local models for fluid saturated metamaterials, along with a description of the relevant numerical methods. Finally, the book reviews a range of practical industrial applications, making it especially attractive as a white book targeted at the building, automotive, and aeronautic industries.

Recent technological advances in the development of fast digital signal processors have made the active control of sound a practical proposition. This book brings together results from research in the two disciplines of acoustics and signal processing and presents the fundamentals of noise control in a unified manner. Practical applications are presented wherever possible although the emphasis is on the algorithmic principles which form the foundation of practical systems. The volume is written in textbook style and aimed at both undergraduate and postgraduate students of acoustics and signal processing, professional acoustical and electrical engineers, and researchers in the field of active control." Key Features

- \* Presents the fundamental principles governing both the physical properties of sound fields and modern digital techniques for processing acoustic signals
- \* Describes the physical mechanisms and energy interchanges involved in active control of sound for one- and three-dimensional problems
- \* Presents the principles and practicalities of the design of single- and multi-channel controllers for both random and deterministic sound fields

Absorbers and diffusers are two of the main design tools for altering the acoustic conditions of rooms, semi-enclosed spaces and the outdoor environment. Their correct use is important for delivering high quality acoustics. Unique and authoritative, this book describes how to effectively measure, model, design and apply diffusers and absorbers. It is a resource for new and experienced acousticians, seeking an understanding of the evolution, characteristics and application of modern diffusers. Absorption is a more established technology and so the book blends traditional designs with modern developments. The book covers practical and theoretical aspects of absorbers and diffusers and is well illustrated with examples of installations and case studies. This new edition brings Acoustic Absorbers and Diffusers up-to-date with current research, practice and standards. New developments in measurement, materials, theory and practice since the first edition (published in 2004) are included. The sections on absorbers are extended to include more about noise control.

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This volume, available for the first time in paperback, is a standard work on the physical aspects of acoustics. Starting from first principles, the authors have successfully produced a unified and thorough treatment of the subjects of generation, propagation, absorption, reflection, and scattering of compressional waves in fluids, progressing to such topics as moving sound sources, turbulence, and wave-induced vibration of structures. Material is included on viscous and thermal effects, on the acoustics of moving media, on plasma acoustics, on nonlinear effects, and on the interaction between light and sound. Problems, with answers in many cases, are given at the end of each chapter. They contain extensions to further applications, thus enhancing the reference value of the book. Many of the examples worked out in the text and in the problem solutions were not previously published. Anyone familiar with calculus and vector analysis should be able to understand the mathematical techniques used here.

**Acoustics of Ducts and Mufflers With Application to Exhaust and Ventilation System Design**  
**Propagation of Sound in Porous Media**

**Functional Metamaterials and Metadevices**

**Modelling Sound Absorbing Materials**

**Acoustic Waves in Periodic Structures, Metamaterials, and Porous Media**  
**Theory, Design and Application**

Hyperbolic metamaterials were originally introduced to overcome the diffraction limit of optical imaging. Soon thereafter it was realized that hyperbolic metamaterials demonstrate a number of novel phenomena resulting from the broadband singular behavior of their density of photonic states. These novel phenomena and applications include super resolution imaging, new stealth technologies, enhanced quantum-electrodynamic effects, thermal hyperconductivity, superconductivity, and interesting gravitation theory analogs. Here I review typical material systems, which exhibit hyperbolic behavior and outline important new applications of hyperbolic metamaterials, such as imaging experiments with plasmonic hyperbolic metamaterials and novel VCSEL geometries, in which the Bragg mirrors may be engineered in such a way that they exhibit hyperbolic properties in the long wavelength infrared range, so that they may be used to efficiently remove excess heat from the laser cavity. I will also discuss potential applications of self-assembled photonic hypercrystals. This system bypasses 3D nanofabrication issues, which typically limit hyperbolic metamaterial applications. Photonic hypercrystals combine the most interesting features of hyperbolic metamaterials and photonic crystals.

This book provides an in-depth analysis as well as an overview of phononic crystals. This book discusses numerous techniques for the analysis of phononic crystals and covers, among other material, sonic and ultrasonic structures, hypersonic planar structures and their characterization, and novel applications of phononic crystals. This is an ideal book for those working with micro and nanotechnology, MEMS (microelectromechanical systems), and acoustic devices. This book also: Presents an introduction to the fundamentals and properties of phononic crystals Covers simulation techniques for the analysis of phononic crystals Discusses sonic and ultrasonic, hypersonic and planar, and three-dimensional phononic crystal structures Illustrates how phononic crystal structures are being deployed in communication systems and sensing systems

This book presents a complete framework for energy harvesting technologies based on graded elastic metamaterials. First, it provides a comprehensive survey of state-of-the-art research on metamaterials for energy harvesting and then explores the theoretical wave mechanics framework, going from inhomogeneous

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media to graded elastic metamaterials. The framework can be used to thoroughly analyse wave propagation phenomena in beams, plates, and half-spaces and to investigate the effect of local resonance on creating bandgaps or wave mode conversions. All these concepts converge together with piezoelectric materials in the study and design of piezo-augmented arrays of resonators. The energy harvesting performances of the graded metamaterials are then compared to conventional solutions, in order to quantify their advantages for applications. Plasmonics is an emerging field mainly developed within the past two decades. Due to its unique capabilities to manipulate light at deep subwavelength scales, plasmonics has been commonly treated as the most important part of nanophotonics. Plasmonic-assisted optical microscopy techniques, especially super-resolution microscopy, have shown tremendous potential and attracted much attention. This book aims to collect cutting-edge studies in various optical imaging technologies with advanced performances that are enabled or enhanced by plasmonics. The basic working principles, development details, and potential future direction and perspectives are discussed. Edited by Zhaowei Liu, a prominent researcher in the field of super-resolution microscopy, this book will be an excellent reference for anyone in the field of nanophotonics, plasmonics, and optical microscopy.

Theoretical Acoustics

Finite Element Investigation of Tunable and Non-reciprocal Elastic Wave Metamaterials

Design Optimisation and Validation of Phononic Crystal Plates for Manipulation of Elastodynamic Guided Waves

Acoustic Absorbers and Diffusers

Engineering Vibration

Interface Transmission Tutorial Book Series

**Fundamentals and Applications of Nanophotonics** includes a comprehensive discussion of the field of nanophotonics, including key enabling technologies that have the potential to drive economic growth and impact numerous application domains such as ICT, the environment, healthcare, military, transport, manufacturing, and energy. This book gives readers the theoretical underpinnings needed to understand the latest advances in the field. After an introduction to the area, chapters two and three cover the essential topics of electrodynamics, quantum mechanics, and computation as they relate to nanophotonics. Subsequent chapters explore materials for nanophotonics, including nanoparticles, photonic crystals, nanosilicon, nanocarbon, III-V, and II-VI semiconductors. In addition, fabrication and characterization techniques are addressed, along with the importance of plasmonics, and the applications of nanophotonics in devices such as lasers, LEDs, and photodetectors. Covers electrodynamics, quantum mechanics and computation as these relate to nanophotonics Reviews materials, fabrication and characterization techniques for nanophotonics Describes applications of the technology such as lasers, LEDs and photodetectors

This book presents the most recent theoretical developments and numerical/experimental validations of new metamaterials and phononic crystals for the broadband absorption of elastic waves and vibrations in structures. These nine chapters explore many aspects of phononic crystals and acoustic/elastic

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metamaterials, including sound attenuation/absorption, extraordinary transmission, wave broadband mitigation, wave steering, cloaking via the transformation method, optimization of phononic crystals, and active acoustic metamaterials.

This book is a printed edition of the Special Issue "State-of-the-Art Materials Science in Belgium 2017" that was published in Materials

Elastic waves possess some remarkable properties and have become ever more important to applications in fields such as telecommunications (signal processing), medicine (echography), and metallurgy (non-destructive testing).

These volumes serve as a bridge between basic books on wave phenomena and more technically oriented books on specific applications of wave phenomena.

The first volume studies the different mechanisms of propagation in isotropic and anisotropic media. The second volume describes the generation and applications of free and guided waves.

Hyperbolic Metamaterials

Theory and Applications of Electromagnetic Metamaterials

Topics On The Nonlinear Dynamics And Acoustics Of Ordered Granular Media

Active Control of Sound

Information Metamaterials

From Fundamentals to Industrial Applications

This book is a printed edition of the Special Issue "Metasurfaces: Physics and Applications" that was published in Applied Sciences

This comprehensive book presents all aspects of acoustic metamaterials and phononic crystals. The emphasis is on acoustic wave propagation phenomena at interfaces such as refraction, especially unusual refractive properties and negative refraction. A thorough discussion of the mechanisms leading to such refractive phenomena includes local resonances in metamaterials and scattering in phononic crystals.

This text presents material common to a first course in vibration and the integration of computational software packages into the development of the text material (specifically makes use of MATLAB, MathCAD, and Mathematica). This allows solution of difficult problems, provides training in the use of codes commonly used in industry, encourages students to experiment with equations of vibration by allowing easy what if solutions. This also allows students to make precision response plots, computation of frequencies, damping ratios, and mode shapes. This encourages students to learn vibration in an interactive way, to solidify the design components of vibration and to integrate nonlinear vibration problems earlier in the text. The text explicitly addresses design by grouping design related topics into a single chapter and using optimization, and it connects the computation of natural frequencies and mode shapes to the standard eigenvalue problem, providing efficient and expert computation of the modal properties of a system. In addition, the text covers modal testing methods, which are typically not discussed in competing texts. software to include Mathematica and MathCAD as well as MATLAB in each chapter, updated Engineering Vibration Toolbox and web site; integration of the numerical simulation and computing into each topic by chapter; nonlinear considerations added at the end of each early chapter through simulation; additional problems and examples; and, updated solutions manual available on CD for use in teaching. It uses windows to remind the reader of relevant facts outside the flow of the text development. It introduces modal analysis (both theoretical and experimental). It introduces dynamic finite element analysis.

There is a separate chapter on design and special sections to emphasize design in vibration.

This book has grown out of the research activities of the author in the fields of sound

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propagation in porous media and modelling of acoustic materials. It is assumed that the reader has a background of advanced calculus, including an introduction to differential equations, complex variables and matrix algebra. A prior exposure to theory of elasticity would be advantageous. Chapters 1-3 deal with sound propagation of plane waves in solids and fluids, and the topics of acoustic impedance and reflection coefficient are given a large emphasis. The topic of flow resistivity is presented in Chapter 2. Chapter 4 deals with sound propagation in porous materials having cylindrical pores. The topics of effective density, and of tortuosity, are presented. The thermal exchanges between the frame and the fluid, and the behaviour of the bulk modulus of the fluid, are described in this simple context. Chapter 5 is concerned with sound propagation in other porous materials, and the recent notions of characteristic dimensions, which describe thermal exchanges and the viscous forces at high frequencies, are introduced. In Chapter 6, the case of porous media having an elastic frame is considered in the context of Biot theory, where new topics described in Chapter 5 have been included.

Negative Refraction, Imaging, Lensing and Cloaking

Acoustic Metamaterials and Phononic Crystals

Theory and Design of Acoustic Metamaterials

Diffractive Optics and Nanophotonics

An Introduction to Metamaterials and Waves in Composites

Metasurfaces: Physics and Applications

This dissertation studies elastic wave propagation in metamaterials subjected to an externally-applied static or spatiotemporally-varying pre-strain. Elastic metamaterials are media with subwavelength structure that behave as effective materials displaying atypical effective dynamic properties that are used to directly control the propagation of macroscopic waves. One major design limitation of most metamaterial structures is that the dynamic response cannot be altered once the microstructure is manufactured. However, the ability to modify, or tune, wave propagation in the metamaterial with an external pre-strain that induces geometric nonlinearity is highly desirable for numerous applications. Acoustic and elastic metamaterials with time- and space-dependent effective material properties have also recently received significant attention as a means to induce non-reciprocal wave propagation.

However, the modulation of effective material properties in space and time using mechanical deformation has been unexplored. Tunable elastic metamaterials that exhibit large effective material property changes under a varying external pre-strain are therefore strong candidates for a non-reciprocal medium. The complex geometry present in unit cells that exhibit large geometric nonlinearity necessitates the development of a numerical technique. In this dissertation, a finite element approach is derived and implemented to study elastic wave propagation in a static pre-strained metamaterial, then generalized to include the effects of a spatiotemporally-varying pre-strain. A honeycomb structure composed of a doubly-periodic array of curved beams, known as a negative stiffness honeycomb (NSH), is analyzed as a tunable and non-reciprocal elastic metamaterial. It is shown that NSH exhibits significant tunability and a high degree of anisotropic wave behavior when a static pre-strain is imposed. This behavior can be used to guide wave energy in different directions depending on static pre-strain levels. In addition, it is shown that partial band gaps exist where only longitudinal waves propagate. The NSH therefore behaves as a meta-fluid, or pentamode metamaterial, which may be of use for applications of transformation elastodynamics such as cloaking and gradient index lens devices. A negative stiffness chain, a quasi-one-dimensional

representation of NSH, is also shown as a case example of a non-reciprocal medium. It is shown in this work that this structure displays a high degree of non-reciprocity for a small amount of modulation pre-strain. The utility of the finite element approach is further demonstrated by investigating the effects of chiral geometric asymmetry to enhance the non-reciprocal behavior of elastic wave propagation in NSH

Dielectric Metamaterials: Fundamentals, Designs and Applications links fundamental Mie scattering theory with the latest dielectric metamaterial research, providing a valuable reference for new and experienced researchers in the field. The book begins with a historical, evolving overview of Mie scattering theory. Next, the authors describe how to apply Mie theory to analytically solve the scattering of electromagnetic waves by subwavelength particles. Later chapters focus on Mie resonator-based metamaterials, starting with microwaves where particles are much smaller than the free space wavelengths. In addition, several chapters focus on wave-front engineering using dielectric metasurfaces and the nonlinear optical effects, spontaneous emission manipulation, active devices, and 3D effective media using dielectric metamaterials. Highlights a crucial link in fundamental Mie scattering theory with the latest dielectric metamaterial research spanning materials, design and applications Includes coverage of wave-front engineering and 3D metamaterials Provides computational codes for calculating and simulating Mie resonances

To meet the demands of students, scientists and engineers for a systematic reference source, this book introduces, comprehensively and in a single voice, research and development progress in emerging metamaterials and derived functional metadevices. Coverage includes electromagnetic, optical, acoustic, thermal, and mechanical metamaterials and related metadevices. Metamaterials are artificially engineered composites with designed properties beyond those attainable in nature and with applications in all aspects of materials science. From spatially tailored dielectrics to tunable, dynamic materials properties and unique nonlinear behavior, metamaterial systems have demonstrated tremendous flexibility and functionality in electromagnetic, optical, acoustic, thermal, and mechanical engineering. Furthermore, the field of metamaterials has been extended from the mere pursuit of various exotic properties towards the realization of practical devices, leading to the concepts of dynamically-reconfigurable metadevices and functional metasurfaces. The book explores the fundamental physics, design, and engineering aspects, as well as the full array of state-of-the-art applications to electronics, telecommunications, antennas, and energy harvesting. Future challenges and potential in regard to design, modeling and fabrication are also addressed. An analysis of the major topics in sound suppression and noise control for the analysis and design of acoustical mufflers, air conditioning and ventilation duct work. Both fundamentals and the latest technology are discussed, with an emphasis on applications.

Theory, Design, and Applications

Fundamentals and Applications of Nanophotonics

Generalized Continuum Mechanics and Engineering Applications

Mathematical Theory of Optics

Fundamentals and Applications

Artificial Crystals for Sonic, Acoustic, and Elastic Waves

Metamaterials have become one of the most important emerging technologies in

the scientific community due to its unusual electromagnetic properties. Consequently, during the last years, a huge deal of efforts has been concentrated in order to design functional components and devices based on metamaterials for many potential applications. The main objective of this book is to present in-depth analysis of the theory, properties, and realizations of novel devices that could be integrated within modern and future communication systems. The book contains 11 chapters written by acknowledged experts, researchers, academics, and microwave engineers, providing comprehensive information and covering a wide range of topics on several aspects of microwaves and optics, including polarization conversion, asymmetric transmission, transmission lines, filters, plasmonic lenses, tunable metamaterials, light manipulation, absorbers, and antennas, among others. This book is suitable for scholars from large scientific domain and therefore given to engineers, scientists, graduates, and other interested professionals as a reference on these artificial materials of tomorrow.

Phononics: Interface Transmission Tutorial Book Series provides an investigation of modern systems that includes a discrete matrix description. Classical continuous systems relying on the use of differential equations are recalled, showing that they generally have a specific limit on their corresponding modern matrix formulation. A detailed description of the mathematical languages that enables readers to find the composite system linear transmission properties is provided in the appendix. The physical model is described with exacting detail, and the bibliography is built to cite—in chronological order—all the scientists that have contributed over many years. Each volume is written with the aim of providing an up-to-date and concise summary of the present knowledge of interface transmission science, thus fostering the exchange of ideas among scientists interested in different aspects of interface transmission. The book serves as an introduction to advanced graduate students, researchers, and scientists with little study on the subject, and is also useful to help keep specialists informed on general progress in the field. Offers a unique approach on phononics from the interfacial transmission point-of-view Teaches the modern physics of interface transmission, in particular, phononics through composite systems Authored and edited by world-leading experts on interface transmission The new concept of metamaterial is increasingly attracting the interest of physicists and mechanical engineers. Such materials are obtained by suitably assembling multiple individual elements but usually arranged in (quasi-)periodic substructures in order to show exotic global mechanical properties. Indeed, the particular shape, geometry, size, orientation and arrangement of their constituting elements can affect, the propagation of waves of light or sound in a manner not observed in natural materials, creating material properties which may give rise to unexpected engineering applications. Particularly promising in the design and description of metamaterials are those micro-structures which present high contrasts in their mechanical properties: these micro-structures, once

homogenized, may produce generalized continuum media, for example, second gradient or micromorphic. Many scientific challenges related to the application of generalized continuum theories to the characterization and conception of high-performance metamaterials can be identified. In this book we identify and discuss four main potential fields of applications of generalized continuum theories, namely, mechanical behavior of fibrous composite reinforcements, wave propagation in metamaterials, mechanical behavior of concrete and mechanically driven remodeling of bone in presence of bio-resorbable materials. For each field, we underline how the use of a generalized continuum theory can be of help for describing how the presence of microstructure can affect the global mechanical behavior of the considered metamaterials. Covers four main fields of the application of continuum theories Learn how to apply generalised continuum theory to describe the effects of microstructure on the mechanical behavior of materials Decipher the material properties which aid your engineering applications

About the book: This book is the first comprehensive review on acoustic metamaterials; novel materials which can manipulate sound waves in surprising ways, which include collimation, focusing, cloaking, sonic screening and extraordinary transmission. It covers both experimental and theoretical aspects of acoustic and elastic waves propagating in structured composites, with a focus on effective properties associated with negative refraction, lensing and cloaking. Most related books in the field address electromagnetic metamaterials and focus on numerical methods, and little (or no) experimental section. Each chapter will be authored by an acknowledged expert, amongst the topics covered will be experimental results on non-destructive imaging, cloaking by surface water waves, flexural waves in thin plates. Applications in medical ultrasound imaging and modeling of metamaterials will be emphasized too. The book can serve as a reference for researchers who wish to build a solid foundation of wave propagation in this class of novel materials.

Optical Metamaterials

Free and Guided Propagation

The Journal of the Acoustical Society of America

Gradient-Index Optics

Phononics

State-of-the-Art Materials Science in Belgium 2017

***This book provides a comprehensive and thorough treatment on fundamentals and applications of light propagation through inhomogeneous media. The authors present a description of the phenomena, components and technology used in GRIN Optics, and analyze various applications.***

***Phononic crystals are artificial periodic structures that can alter efficiently the flow of sound, acoustic waves, or elastic waves. They were introduced about twenty years ago and have gained***

**increasing interest since then, both because of their amazing physical properties and because of their potential applications. The topic of phononic crystals stands as the cross-road of physics (condensed matter physics, wave propagation in inhomogeneous and periodic media) and engineering (acoustics, ultrasonics, mechanical engineering, electrical engineering). Phononic crystals cover a wide range of scales, from meter-size periodic structures for sound in air to nanometer-size structures for information processing or thermal phonon control in integrated circuits. Phononic crystals have a definite relation with the topic of photonic crystals in optics. The marriage of phononic and photonic crystals also provides a promising structural basis for enhanced sound and light interaction. As the topic is getting popular, it is nowadays presented and discussed at various international conferences. After the first ten years during which the topic has remained mainly theoretical with a few proof-of-concept demonstrations in the literature, the evolution has been towards applications, instrumentation, and novel designs. The physical explanations for various effects are now well understood and efficient numerical methods and analysis tools have been developed. The book contains a comprehensive set of finite element model (FEM) scripts for solving basic phononic crystal problems. The scripts are short, easy to read, and efficient, allowing the reader to generate for him(her)self band structures for 2D and 3D phononic crystals, to compute Bloch waves, waveguide and cavity modes, and more. In active noise control an artificially-generated secondary acoustic field is used to interfere destructively with the unwanted sound field. This book deals with the control engineering of generating this secondary field. This technique has uses in suppressing machinery noise in particular.**

**Leading experts explore the exotic properties and exciting applications of electromagnetic metamaterials. Metamaterials: Physics and Engineering Explorations gives readers a clearly written, richly illustrated introduction to the most recent research developments in the area of electromagnetic metamaterials. It explores the fundamental physics, the designs, and the engineering aspects, and points to a myriad of exciting potential applications. The editors, acknowledged leaders in the field of metamaterials, have invited a group of leading researchers to present both their own findings and the full array of state-of-the-art applications for antennas, waveguides, devices, and components. Following a brief overview of the history of artificial materials, the publication divides its coverage into two major classes of metamaterials. The first half of the publication examines effective media with single (SNG) and double negative (DNG) properties; the second half examines**

**electromagnetic band gap(EBG) structures. The book further divides each of these classes into their three-dimensional (3D volumetric) and two-dimensional(2D planar or surface) realizations. Examples of each type of metamaterial are presented, and their known and anticipated properties are reviewed. Collectively, Metamaterials: Physics and Engineering Explorations presents a review of recent research advances associated with a highly diverse set of electromagnetic metamaterials. Its multifaceted approach offers readers a combination of theoretical, numerical, and experimental perspectives for a better understanding of their behaviors and their potential applications in components, devices, and systems. Extensive reference lists provide opportunities to explore individual topics and classes of metamaterials in greater depth. With full-color illustrations throughout to clarify concepts and help visualize actual results, this book provides a dynamic, user-friendly resource for students, engineers, physicists, and other researchers in the areas of electromagnetic materials, microwaves, millimeter waves, and optics. It equips newcomers with a basic understanding of metamaterials and their potential applications. Advanced researchers will benefit from thought-provoking perspectives that will deepen their knowledge and lead them to new areas of investigation.**

**Fundamentals, Designs and Applications**  
**Metamaterials**  
**Active Noise Control**  
**Phononic Crystals**

Requiring no advanced knowledge of wave propagation, *An Introduction to Metamaterials and Waves in Composites* focuses on theoretical aspects of metamaterials, periodic composites, and layered composites. The book gives novices a platform from which they can start exploring the subject in more detail. After introducing concepts related to elasticity, acoustics, and electrodynamics in media, the text presents plane wave solutions to the equations that describe elastic, acoustic, and electromagnetic waves. It examines the plane wave expansion of sources as well as scattering from curved interfaces, specifically spheres and cylinders. The author then covers electrodynamic, acoustic, and elastodynamic metamaterials. He also describes examples of transformations, aspects of acoustic cloaking, and applications of pentamode materials to acoustic cloaking. With a focus on periodic composites, the text uses the Bloch-Floquet theorem to find the effective behavior of composites in the quasistatic limit, presents the quasistatic equations of elastodynamic and electromagnetic waves, and investigates Brillouin zones and band gaps in periodic structures. The final chapter discusses wave propagation in

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*smoothly varying layered media, anisotropic density of a periodic layered medium, and quasistatic homogenization of laminates. This book provides a launch pad for research into elastic and acoustic metamaterials. Many of the ideas presented have yet to be realized experimentally—the book encourages readers to explore these ideas and bring them to technological maturity.*

*This thesis proposes novel designs of phononic crystal plates (PhPs) allowing ultra-wide controllability frequency ranges of guided waves at low frequencies, with promising structural and tunability characteristics. It reports on topology optimization of bi-material-layered (1D) PhPs allowing maximized relative bandgap width (RBW) at target filling fractions and demonstrates multiscale functionality of gradient PhPs. It also introduces a multi-objective topology optimization method for 2D porous PhPs allowing both maximized RBW and in-plane stiffness and addresses the critical role of considering stiffness in designing porous PhPs. The multi-objective topology optimization method is then expanded for designing 2D porous PhPs with deformation induced tunability. A variety of innovative designs are introduced which their maximized broadband RBW is enhanced by, is degraded by or is insensitive to external finite deformation. Not only does this book address the challenges of new topology optimization methods for computational design of phononic crystals; yet, it demonstrated the suitability and applicability of the topological designs by experimental validation. Furthermore, it offers a comprehensive review of the existing optimization-based approaches for the design of finite non-periodic acoustic metamaterial structures, acoustic metamaterial lattice structures and acoustic metamaterials under perfect periodicity.*