

Acoustic Metamaterials And Phononic Crystals Preamble

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Crystals A Comprehensive Overview Acoustic metamaterials and phononic crystals represent a fascinating frontier in materials science offering unprecedented control over sound waves While often used interchangeably they possess subtle differences that impact their design and

a p p l i c a t i o n s T h i s a r t i c l e p r o v i d e s a c o m p r e

understanding with practical implications and future prospects I Fundamental Concepts What are

Acoustic Metamaterials and Phononic Crystals Both acoustic metamaterials and phononic crystals manipulate sound waves through their carefully engineered microstructure creating

effective material properties not found in nature Think of it like this a single brick is just a brick

but arranging bricks in a specific pattern can create an archway a structure with entirely new

properties Similarly these materials leverage microstructure to achieve desired acoustic behavior

Phononic Crystals PnCs These are periodic structures meaning their internal structure repeats

itself regularly in space Imagine a perfectly ordered array of air pockets within a solid material

The periodicity leads to the formation of band gaps frequency ranges where sound waves

prohibited from propagating through the material This is analogous to the

levels in electronic band theory The size and arrangement of the repeating units determine the

position and width of these band gaps They are inherently passive devices manipulating

propagation through their structure alone Acoustic Metamaterials AMs AMs are more broadly

defined They can be periodic like PnCs but they also encompass aperiodic structures and those

with resonating elements Instead of relying solely on periodicity they m

resonatorssmall structures designed to interact strongly with sound waves at specific

frequencies Think of tiny springs and masses embedded within the material These resonators

can effectively absorb deflect or focus sound waves even at wavelengths much larger than the

resonators size This is akin to using a small object to absorb a much larger wave AMs can be

passive like PnCs or active incorporating external energy sources to dynamically control their

acoustic properties 2 II Theoretical Underpinnings The behavior of both PnCs and AMs is

governed by wave equations often simplified using effective medium theory EMT for

homogenization and analysis EMT allows treating the complex microstructure as a homogeneous

material with effective material properties eg effective density and bulk modulus However EMT

breaks down near band edges and resonances requiring more sophisticated numerical methods

like finite element analysis FEA or finite difference time domain FDTD for precise modelling. These methods directly solve the wave equation within the complex geometry of the material. **Band Gaps in PnCs** The formation of band gaps in PnCs is attributed to Bragg scattering. When the wavelength of the sound wave is comparable to the lattice constant of the structure, waves scattering from different unit cells interfere destructively, leading to wave suppression within the band gap. This is analogous to X-ray diffraction in crystals. **Resonant Effects in AMs** The unique acoustic properties of AMs are often achieved through localized resonance effects. Resonators within the AM interact strongly with incident sound waves at their resonant frequencies, leading to significant absorption or scattering. The design of these resonators is crucial for achieving specific acoustic functionalities. **III Practical Applications** The ability to manipulate sound waves has opened doors to numerous applications. **Noise Control** AMs and PnCs are being developed for noise barriers, sound absorbers, and vibration dampeners in various settings, from construction to automotive industries. Their ability to control sound frequency bands makes them highly effective. **Acoustic Imaging and Sensing** PnCs can be designed to focus sound waves, enhancing the resolution of acoustic imaging systems. AMs can act as sensitive sensors, detecting minute changes in acoustic environments. **Acoustic Cloaking** By carefully designing AMs, it's possible to create devices that deflect sound waves around an object, making it invisible to sound. This has implications for stealth technologies and underwater acoustics. **Energy Harvesting** AMs can be designed to efficiently harvest acoustic energy from the environment, converting it into electrical energy. This holds potential for self-powered sensors and other applications. **Medical Ultrasound** PnCs and AMs can improve the focusing and delivery of ultrasound waves, enhancing medical imaging and therapeutic applications. **3 IV Challenges and Future Directions** While the field shows immense promise, several challenges remain. **Fabrication** Creating complex microstructures with high precision and reproducibility can be challenging and expensive. Advances in 3D printing and microfabrication techniques are crucial for overcoming this hurdle. **Scalability** Many AM and PnC designs are currently limited in size and scalability. Developing cost-effective methods for producing larger structures is essential for widespread adoption. **Modeling and Design** Predicting and optimizing the acoustic properties of complex AM and PnC structures requires sophisticated numerical simulations. Further developments in computational methods are needed. The future of acoustic metamaterials and phononic crystals lies in pushing the boundaries of material design, fabrication, and theoretical understanding. Research into novel materials, innovative fabrication, and advanced computational methods will unlock a wider range of applications and lead to even more impactful technological advancements. We can expect to see more sophisticated designs capable

of manipulating not just the amplitude but also the polarization and phase of sound waves potentially leading to unprecedented control over acoustic fields

V ExpertLevel FAQs

1 What is the key difference between a local resonance metamaterial and a phononic crystal Local resonance metamaterials achieve their resonance of embedded subwavelength inclusions independent of the periodicity of the structure Bragg scattering in phononic crystals relies on the periodic arrangement of unit cells creating band gaps through destructive interference of waves scattered from different unit cells

2 How can we overcome the limitations of effective medium theory in designing complex acoustic metamaterials Effective medium theory often fails to accurately capture the behavior of complex structures with sharp resonances or near band edges Fullwave numerical simulations such as finite element analysis or finite difference time domain are required for accurate modelling and design optimization

3 What are the current limitations in manufacturing largescale acoustic metamaterials Current manufacturing techniques often struggle with the high precision and complexity needed for largescale fabrication of acoustic metamaterials Costeffective scalable manufacturing methods such as advanced 3D printing and rolltoroll processing are crucial for realizing largescale applications

4 How can we design acoustic metamaterials for broadband sound absorption Broadband sound absorption can be achieved through various methods including combining multiple resonators with different resonant frequencies using graded structures with varying impedance or utilizing porous materials with inherent broadband absorption properties

5 What are the potential applications of topological acoustic metamaterials Topological acoustic metamaterials leverage topological protection to create robust waveguides and devices that are insensitive to structural imperfections This is achieved by creating robust acoustic circuits and waveguides for applications like energy harvesting and acoustic sensing in harsh environments

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Introduction to Photonic and Phononic Crystals and Metamaterials

Theory and Design of Acoustic Metamaterials

Dynamic Equivalent Modeling of Acoustic Metamaterials

Electromagnetic Nanomaterials

Acoustic and Mechanical Metamaterials for Various Applications

Phononic Crystals

An Introduction to Waves in Mechanical Periodic Structures and Metamaterials

Acoustic Metamaterials

Handbook of Micromechanics and Nanomechanics

Acoustic Metamaterials

Programmable Elastic Metamaterials for Wave Control and Device Applications

Phononic Crystals

Integrated Green Energy Solutions, Volume 1

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

Discoveries in Phononic Crystals and Acoustic Metamaterials

Active Plasmonics and

Acoustic Metamaterials Phononic Metamaterials Based on Complex Geometries Fundamentals and Applications of Acoustic Metamaterials Pierre A. Deymier Pierre A. Deymier Arthur R. McGurn Perngjin Frank Pai Nansha Gao Inamuddin Fuyin Ma Abdelkrim Khelif Arnab Banerjee Sz-Chin Steven Lin Shaofan Li Richard Craster Hui Chen Vincent Laude Milind Shrinivas Dangate Saeid Hedayatrasa Pai Wang Muralidhar Sai Ambati Sisi Sophie Ni Vicente Romero-Garcia

Acoustic Metamaterials and Phononic Crystals Acoustic Metamaterials and Phononic Crystals Introduction to Photonic and Phononic Crystals and Metamaterials Theory and Design of Acoustic Metamaterials Dynamic Equivalent Modeling of Acoustic Metamaterials Electromagnetic Nanomaterials Acoustic and Mechanical Metamaterials for Various Applications Phononic Crystals An Introduction to Waves in Mechanical Periodic Structures and Metamaterials Acoustic Metamaterials Handbook of Micromechanics and Nanomechanics Acoustic Metamaterials Programmable Elastic Metamaterials for Wave Control and Device Applications Phononic Crystals Integrated Green Energy Solutions, Volume 1 Design Optimisation and Validation of Phononic Crystal Plates for Manipulation of Elastodynamic Guided Waves Discoveries in Phononic Crystals and Acoustic Metamaterials Active Plasmonics and Acoustic Metamaterials Phononic Metamaterials Based on Complex Geometries Fundamentals and Applications of Acoustic Metamaterials *Pierre A. Deymier Pierre A. Deymier Arthur R. McGurn Perngjin Frank Pai Nansha Gao Inamuddin Fuyin Ma Abdelkrim Khelif Arnab Banerjee Sz-Chin Steven Lin Shaofan Li Richard Craster Hui Chen Vincent Laude Milind Shrinivas Dangate Saeid Hedayatrasa Pai Wang Muralidhar Sai Ambati Sisi Sophie Ni Vicente Romero-Garcia*

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

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introduction to photonic and phononic crystals and metamaterials by arthur r mcgurn presents a study of the fundamental properties of optical and acoustic materials which have been of recent

interest in nanoscience and device technology the level of the presentations is appropriate for advanced undergraduates beginning graduate students and researchers not directly involved in the field references are given to guide the reader to more advanced study in these fields discussions of the physics of photonic and phononic crystals focus on the transmission properties of optical and acoustic radiation arising from their diffractive interaction in these engineered materials the frequency transmission and non transmission bands of radiation are explained in terms of the symmetry properties of the photonic and phononic artificial crystal structures basic applications of these properties to a variety of their technological applications are examined the physics of metamaterials is discussed along with their relationships to the ideas of resonance properties of negative index of refraction perfect lens and unusual optical effects the new optics of metamaterial media makes available are examined related effects in acoustics are also covered basic principles of surface acoustic and electromagnetic waves are explained these form an introduction to the fundamental ideas of the recently developing fields of plasmonics and surface acoustics

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 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 derives physical models from basic principles studies the effect of equivalent models on the dynamic characteristics of phononic crystals and acoustic metamaterials and analyzes the physical mechanisms behind vibration and noise reduction it first summarizes the research status of vibration and noise reduction and research progress in phononic crystals and acoustic metamaterials based on this one dimensional periodic beam two dimensional thin plate with circular hole and corresponding gradient structures are introduced and their dynamic characteristics are discussed in detail therefore different equivalent methods for different models are proposed through theoretical analysis modal analysis and transmission rate analysis finally a helmholtz type acoustic metamaterial i.e. a multi layer slotted tube acoustic metamaterial is studied aiming at the low frequency band gap of this model a theoretical model for solving the inverse problem of acousto electric analogue equivalent is proposed and the effect of structural parameters on the low frequency band gap is studied using this equivalent model this book closely revolves around how to conduct equivalent research on artificially fabricated periodic

structures the methods and conclusions presented in this book provide a new theoretical basis for the application of artificial woven periodic structures in the field of low frequency vibration reduction and noise reduction and are also an innovation in the discipline of vibration and noise control this book is suitable for undergraduate students graduate students and teachers in vibration and noise majors in universities and can also provide references for engineering and technical personnel in related fields

electromagnetic metamaterials the book presents an overview of metamaterials current state of development in several domains of application such as electromagnetics electrical engineering classical optics microwave and antenna engineering solid state physics materials sciences and optoelectronics metamaterials have become a hot topic in the scientific community in recent years due to their remarkable electromagnetic properties metamaterials have the ability to alter electromagnetic and acoustic waves in ways that bulk materials cannot electromagnetic metamaterials properties and applications discusses a wide range of components to make metamaterial engineered devices it gives an overview of metamaterials current stage of development in a variety of fields such as remote aerospace applications medical appliances sensor detectors and monitoring devices of infrastructure crowd handling smart solar panels radomes high gain antennas lens high frequency communication on the battlefield ultrasonic detectors and structures to shield from earthquakes audience researchers and engineers in electromagnetic and electrical engineering classical optics microwave and antenna engineering solid state physics materials sciences and optoelectronics

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

metamaterials are artificial engineered materials designed to manipulate wave propagation in ways not possible with conventional materials an introduction to waves in mechanical periodic structures and metamaterials presents a systematic and rigorous treatment of wave propagation

in periodic structures with a particular focus on mechanical and acoustic metamaterials this book bridges fundamental concepts and advanced topics offering a unified framework to analyze discrete and continuous periodic systems key topics include comprehensive mathematical formulation of wave propagation in 1d and 2d periodic structures in depth discussion on spectral element formulation transfer matrix method and bandgap formation coverage of advanced concepts such as energy transportation meta damping non reciprocity active control and nonlinear metamaterials unique focus on damping evaluation in metamaterials critical for shock resistance and transient dynamic applications this book serves as an accessible yet rigorous resource for senior undergraduate and graduate students in structural engineering mechanical engineering applied physics and materials science as well as for researchers seeking to deepen their understanding of wave mechanics in metamaterials

acoustic metamaterials are of growing interest due to their ability to manipulate the propagation of acoustic waves in an extraordinary manner to benefit various applications such as communications biosensing and medical diagnosis and therapy among various construction methods of acoustic metamaterials artificially engineered elastic periodic structures known as phononic crystals pcs are the strongest candidates since they exhibit complete phononic band gaps and negative refractions due to the periodicity of the structure in this book a new class of acoustic metamaterials gradient index phononic crystal grin pc is introduced to overcome the limitations of regular pcs and further enrich the control over acoustic waves grin pcs with different gradient profiles are designed to guide acoustic waves in extraordinary manners that are not shown in nature or regular pcs a practical method for tuning the phononic band gaps of a pc is investigated the concepts presented in this book serve as important foundations for the future development of acoustic devices

this book presents the latest developments and applications of micromechanics and nanomechanics it particularly focuses on some recent applications and impact areas of micromechanics and nanomechanics that have not been discussed in traditional micromechanics and nanomechanics books on metamaterials micromechanics of ferroelectric piezoelectric

the revised edition of this book offers an expanded review of acoustic metamaterials novel materials which can manipulate sound waves surface rayleigh waves and water waves in surprising ways which include collimation focusing negative refraction passive and active 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 updated chapters cover filtering effects extraordinary transmission sub wavelength imaging via tomography or time reversal techniques cloaking via transformation acoustics elastodynamics and acoustic scattering cancellation for this revised edition six new chapters have been introduced to reflect recent developments in experimental acoustics and metasurfaces including acoustic impedance gratings and mirror symmetric metamaterials phononic subsurfaces time modulated and topological crystals the latter two are illustrated by simple python program examples the broad scope gives the reader an overview of the state of the art in acoustic metamaterials research and an indication of future directions and applications it will serve as a solid introduction to the field for advanced students and researchers in physics applied mathematics and mechanical engineering and a valuable reference for those working in metamaterials and related areas

emerging from electromagnetic waves and fast extending to acoustic and elastic waves metamaterials that exhibit extraordinary wave control abilities have been gaining soaring attention over the past two decades elastic metamaterials with engineered microstructures have provided a variety of appealing solutions for controlling elastic waves and vibrations by tailoring their internal microstructures at a subwavelength scale elastic metamaterials fruitfully distinct themselves from traditional materials or phononic crystals by their striking functions in wave trajectory manipulation cloaking nonreciprocal and topological wave control as well as low frequency wave vibration mitigation and absorption

the book provides a comprehensive presentation of the topic of phononic and sonic crystals including acoustic and elastic wave propagation in homogeneous and periodic media bloch waves and band structures surface phononic crystals and phononic crystal slabs evanescent bloch waves and complex band structures local resonance dispersion and negative refraction and phononic band gap guidance the book is accompanied with a comprehensive set of finite element model fem scripts for solving basic phononic crystal problems as supplementary material the scripts should allow the reader to generate band structures for 2d and 3d phononic crystals to compute bloch waves waveguide and cavity modes and more

integrated green energy solutions this first volume in a two volume set presents the state of the art for the concepts practical applications and future of renewable energy and how to move closer to true sustainability renewable energy supplies are of ever increasing environmental and economic importance in every country worldwide a wide range of renewable energy

technologies has been established commercially and recognized as an important set of growth industries for most governments world agencies including the united nations have extensive programs to encourage these emerging technologies this book will bridge the gap between descriptive reviews and specialized engineering technologies it centers on demonstrating how fundamental physical processes govern renewable energy resources and their applications although the applications are updated continually the fundamental principles remain the same and this book will provide a useful platform for those advancing the subject and its industries integrated resilient energy solutions is a two volume set covering subjects of proven technical and economic importance worldwide energy supply from renewables is an essential component of every nation s strategy especially when there is responsibility for the environment and sustainability these two volumes will consider the timeless renewable energy technologies principles yet demonstrate modern applications and case studies whether for the veteran engineer student or other professional these two volumes are a must have for any library

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 p 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 pla and addresses the critical role of considering stiffness in designing porous phps the multi objective topology optimization method is then expanded for designing 2d poro 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

phononic crystals and acoustic metamaterials are heterogeneous materials that enable manipulation of elastic waves an important characteristic of these heterogeneous systems is their ability to tailor the propagation of elastic waves due to the existence of band gaps frequency ranges of strong wave attenuation in this thesis i report discoveries of three new

types of band gaps i band gaps induced by geometric frustration in periodic acoustic channel networks ii band gap induced by high connectivity in periodic beam lattices and iii topological band gaps in gyroscopic phononic crystals that protects one way edge waves the investigations presented here shed new light on the rich dynamic properties of phononic crystals and acoustic metamaterials opening avenues for new strategies to control mechanical waves in elastic systems

facing the growing challenges of energy environment security and disease treatment the demand for novel materials are growing while the material centric approach have resulted in development of new materials for advanced applications we introduce a geometric approach as a complementary point of view for further innovation in this ever expanding and growing field inspired by the ubiquitous fractals like geometry of in natures the scale transformation i e dilation or contraction is included in the framework since fractal geometries shows structures at all scales usually discrete and finite in physical world we developed our framework using metamaterials since it enable us to design atoms or molecules and their relative arrangement with greater freedom i e not limited by the chemical bond or ionic bond in classical materials system we studied metamaterials using prefractals from both exact self similar fractal and random fractal samples for exact self similar fractals we choose h tree based prefractals and hilbert curve prefractals bounded system given their unique geometric properties and wide applications guided by the framework we investigated several key parameters e g level of iteration geometric anisotropy impedance contrast arrangement of subunit resolution that would dictate the dispersion behavior of the system it was found that for exact self similar prefractals multiple spectrum bandgaps i e broadband response can be achieved with increased level of iterations where translation symmetry is imposed through boundary condition furthermore the transition from scale dependence and independent described by the general framework has been observed for all the samples we studied furthermore for single prefractal resonator subwavelength 1.75λ behavior has been observed and explained using a simple analytical model for metamaterials based on fractional brownian motion the hurst constant is found to be a good indicator of phononic behavior of the system besides other parameters studied our findings does not only expand the repertoire for novel materials by introducing the ubiquitous yet unconventional geometry to metamaterials but also have interdisciplinary applications in biology seismology arts hence shine lights on our understanding of nature

in the last few decades metamaterials have revolutionized the ways in which waves are controlled and applied in physics and practical situations the extraordinary properties of

metamaterials such as their locally resonant structure with deep subwavelength band gaps and their ranges of frequency where propagation is impossible have opened the way to a host of applications that were previously unavailable acoustic metamaterials have been able to replace traditional treatments in several sectors due to their better performance in targeted and tunable frequency ranges with strongly reduced dimensions this is a training book composed of nine chapters written by experts in the field giving a broad overview of acoustic metamaterials and their uses the book is divided into three parts covering the state of the art the fundamentals and the real life applications of acoustic metamaterials

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