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Editorial: Developments in Acoustic, Phononic, and Mechanical Materials for Wave Control

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Editorial on the Research Topic

Developments in Acoustic, Phononic, and Mechanical Materials for Wave Control

Wave control at will is of particular interest to the scientific and engineering fields due to its importance in imaging, sensing, and communication. In the past two decades, designing novel structural and artificial composite materials with unprecedented functionalities for wave control has been a hot topic among the research community since the realization of the first acoustic metamaterials with negative effective elastic constant in 2000 (Liu et al., 2000). Acoustic metamaterials are structural materials consisting of deep subwavelength unit cells that achieves different effective dynamic properties based on resonances (Cummer et al., 2016). As an example, the negative effective mass density of the first acoustic metamaterial was realized by operating near the dipolar resonance of the unit cells (Mei et al., 2006). Meanwhile, acoustic metamaterials with negative effective bulk modulus can be achieved by operating near the monopolar resonance of the unit cells (Fang et al., 2006). When designing the structures of the unit cells to attain an overlap of the frequency bands associated with negative density and bulk modulus, the effective refractive index becomes negative (Lee et al., 2010). A metamaterial with negative refractive index can be used as a superlens for super-resolution imaging (i.e., imaging beyond the diffraction limit with deep subwavelength resolution) (Kaina et al., 2015). In addition to resonance-based metamaterials, sonic and phononic crystals with periodic structures were developed to induce frequency bandgaps through Bragg scattering for wave guiding and filtering (Martínez-Sala et al., 1995).

These novel concepts were later extended into mechanical structures and materials for the manipulations of elastic waves, stress, and deformations (Bertoldi et al., 2017). Auxetic metamaterials with negative Poisson's ratio were designed with inverted hexagon patterned structures (Lakes, 1987). Judicious designs of unit cell chirality in deformation have enabled the conversion between compression and twisting (Frenzel et al., 2017). Lattice defects were used to regulate the stress distribution in mechanical lattices (Paulose et al., 2015). The ancient techniques of origami and kirigami have also inspire many new designs of mechanical materials for deformation control to achieve deployable structures, flexible medical stents, and flexible electronic devices (Melancon et al., 2021). Spinning gyros were applied to induce topological effects for robust one-way propagation of elastic wave along the edge of mechanical crystals (Wang et al., 2015). Topological mechanisms were developed to control the propagation of domain walls (Kane and Lubensky, 2014). Nonlinearity of lattice structure was implemented for the realization of nonreciprocal mechanics (Coulais et al., 2017). More recently, these newly obtained mechanical properties have been integrated with the design of acoustic metamaterials to realize a self-adaptive soft acoustic invisibility cloak (Xue and Zhang, 2021). Zhang and Wang discussed the control of rolling elastic waves in anisotropic materials in the article "*Boundary Reflections of Rolling Waves in Cubic Anisotropic Material*" of this collection.

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While achieving unprecedented material properties is still an exciting direction to pursue, the focus of the research community has started shifting towards the practical applications of the novel functionalities. Acoustic superlens with negative refractive index has the potential to achieve super-resolution imaging, but the fact that the subwavelength images can only be formed near the lens limits its application in biological systems. On the contrary, ultrasound contrast agents including microbubbles and phase-transition nanodroplets provide more practical solutions. Ultrasound localization microscopy with micrometer scale resolution was developed using microbubbles flowing in blood for the visualization of the brain vasculature of a mouse (Errico et al., 2015). The use of phase-transition nanodroplets has the potential to further improve the imaging quality (Luke et al., 2016). However, the presence of the skull prevents the realization of high-quality ultrasound brain imaging for large mammals including humankinds due to the strong acoustic impedance mismatch and porosity of the cranial bone. A passive acoustic metamaterial was designed to match the acoustic impedance and reduce ultrasound reflection (Shen et al., 2014), but the ignorance of the porosity induced acoustic attenuation makes the metamaterial impractical in improving the transcranial ultrasound transmission. An active non-Hermitian complementary acoustic metamaterial was proposed to counteract the impedance mismatch and porosity induced loss simultaneously (Craig et al., 2019). In this collection, Craig et al. presented the effect of skull imperfections on the performance of transcranial ultrasound improvement by the use of the non-Hermitian complementary acoustic metamaterial in the article "*Non-Hermitian Complementary Acoustic Metamaterials for Imaging Through Skull with Imperfections*," showing a significant increase in transcranial ultrasound transmission when properly designed metamaterial is used even for skulls with imperfect geometry and uniformity.

Another major challenge of practical applications of metamaterials is from the nature of their resonance-based designs, limiting the operating frequency band for the control of waves, particularly for low frequency audible range. In the article "*Low-Frequency Broadband Acoustic Metasurface Absorbing Panel*" of this collection, Ji et al. coupled multiple types of resonators to extend the operation bandwidth for low-frequency acoustic absorption. Wang et al. designed a composite perforated partitioned sandwich panel for absorption of low-frequency sound waves underwater in the article "*A Composite Perforated Partitioned Sandwich Panel with Corrugation for Underwater Low-Frequency Sound Absorption*" of this collection. Besides acoustic absorption, the control of sound reflection requires prudent designs. In this collection, Qin et al. presented a metasurface consisting of differential phase shifters to achieve broadband control of sound reflection in the article "*Acoustic Wave Reflection Control Based on Broadband Differential Phase Shifters*."

In addition to the designs of metamaterials, phononic crystals are also commonly used for the control of wave propagation. Reyes et al. applied defects in phononic crystals to realize high quality factor cavity in the article "*Optimization of the Spatial Configuration of Local Defects in Phononic Crystals for High Q Cavity*" of this collection. Lucklum et al. discussed the use of phononic crystals as a new class of resonant sensors in the article "*Phononic Crystal Sensors: A New Class of Resonant Sensors – Chances and Challenges for the Determination of Liquid Properties*" of this collection.

The development of new materials for the control of acoustic and elastic waves will continue to be an active hot topic among the scientific and engineering research communities. We hope the readers will find this collection to be inspiring for their future research in structural materials and wave propagations.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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