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Editorial: Advances in phononic and acoustic metamaterials

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Editorial on the Research Topic
Advances in phononic and acoustic metamaterials

The quasi-particle linked to mechanical vibration, namely the phonon, is responsible for everyday sound and heat transmission in air, water and other media. Hence, investigating and controlling the phononic properties of materials provides new opportunities and powerful tools to tailor acoustic wave propagation and heat transport [1,2]. During the past few decades, there has been considerable interest in studying theoretically and experimentally the acoustic, elastodynamic and thermal properties of artificial media made of small inclusions. These metamaterials are engineered to exhibit exotic properties beyond what naturally occurs in materials, including negative bulk-modulus [3], zero/negative density and infinite thermal conductivity [4]. Many tantalizing concepts and counterintuitive effects have been realized with these well-designed artificial structures, including diodes [5], cloaking [6], superlens [7], negative refraction [8], and topological transport [9,10].

Phononic and acoustic metamaterials have shown a great potential in improving our daily lives, such as isolating and absorbing environmental noise, constructing thermally insulated buildings, creating one-way secret communications, and so on. Meanwhile, theoreticians in phononics and acoustics have explored different paths, such as how broken symmetries, exceptional points and topological boundaries tend to change the laws of sound and heat propagation for instance. In this Research Topic, we gather some of the newest cutting-edge designs and theories in the phononic and acoustic metamaterials domain, for waves ranging from infrasound, sound, ultrasound, hypersound but also heat transport, and mechanical metamaterials.

The advance of quantum technology enables us to study nonequilibrium heat transport in circuit quantum electrodynamics platforms. Wang F.-Y. et al. analyze the influence of resonator-resonator coupling on steady-state heat transport by including the two-mode qubit-resonator model, which is considered as one representative case of the qubit-resonator coupling systems. The eigen-mode picture of coupled resonators is unraveled, which shows great contribution to steady-state transport behaviors, e.g., negative differential thermal conductance, thermal rectification, and heat current enhancement. These results may provide some physical insight for the smart energy manipulation in photon (phonon)-based hybrid quantum systems.

It is expected that an isotropic artificial structure with temperature-dependent constitutive materials may bring omnidirectional nonlinearity enhancement, which means that the equivalent nonlinear coefficient is larger than arbitrary constituents. Wang and Dai investigate the macroscopic nonlinear effect of composite metamaterials. They introduce a new control degree of freedom, namely geometrical configuration, into designing nonlinear thermal metamaterials. Configuration-induced directional nonlinearity enhancement is achieved by elaborately constructing anisotropy in shape of composite. Rigorous analytical methods and robust numerical simulations based on the effective medium theory predict this fascinating and useful effect, promising a refined control in heat diffusion.

The multi-physical effect of thermoelectric meta-devices is very interesting but not well explored. Zhang Q. et al. proposes a novel thermal meta-device that could simultaneously achieve thermal shielding and electricity generation. The meta-device has a tilted layered structure composed thermoelectric materials. Upon an incident heat flux induced by 80 K temperature difference, the meta-device generates a maximum output voltage of 20.4 mV, while its interior experiences no temperature gradient. The electricity generation is brought by the Seebeck effect of the Bi_2Te_3 layers. The thermal shielding effect is designed based on the transformation theory. The work may inspire future designs of thermoelectric devices with thermal management functionalities.

Scattering cancellation is shown to be an effective way to design invisibility devices for acoustic waves and electromagnetic waves. Kan W. et al. propose such a device to cancel the scattered wave using two layers of periodical subwavelength structures by coating the scattering object with the designed composite material. Such scattering cancellation effect could be demonstrated for a fiber optical nanoprobe *via* fabricating the coating layers by simply etching cylinders or doping elements in silicon/SOI wafer. It is shown that the 632.8 nm TE polarized light travels through the coated fiber optical nanoprobe with the wavefront undisturbed, and serve as evidence of the effectiveness of the designed invisibility coating.

Acoustic metamaterial and metasurface with exotic physical properties have attracted broad attention in the past decade. However, their performance is usually hampered to manufacturing inaccuracies, limiting their application in water. Li Z. et al. propose a simple strategy of embedding air bubbles of different sizes inside a polymer to freely manipulate the transmitted underwater acoustic wavefields. The bubble-arrayed acoustic metasurface covering the phase shift of 2π consists of multiple air bubbles with different diameters. The authors demonstrate various novel effects of the transmitted wavefield manipulation: the abnormal refraction, Bezier beams, and the acoustic bottle beam. It provides a distinguished method to simplify the configurations with a relatively high transmission ratio, which will be used for designing waterborne metasurfaces to flexibly manipulate the transmitted wavefronts and inspire lots of applications for underwater explorations.

Manipulating the acoustic waves beyond the diffraction limit offers an alternative application potential in high-resolution imaging and medical ultrasound diagnosis and treatment. Li H.-H. et al. present a two-dimensional circular meta-lens with a sub-wavelength acoustic Helmholtz resonator array to implement the super-diffraction focusing. The unit structure of the designed acoustic meta-lens is a hybrid structure composed of a series of Helmholtz resonators and Fabry–Perot resonance straight tubes. The series connection of Helmholtz resonators yields a large-span phase shift, while the Fabry–Perot resonance maintains impedance matching to enhance sound transmission. The proposed method can possibly promote the application and development of the medical ultrasound imaging and therapy.

These papers have shown a variety of possibilities with phononic metamaterials in both physical mechanisms and functional devices. It is expected that phononic metamaterials will greatly change the way about how to illustrate the classical acoustic/thermal theories and how to design novel phononic apparatus in the near future.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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