Introduction to the special issue on non-reciprocal and topological wave phenomena in acoustics

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I. INTRODUCTION

For nearly two decades the field of acoustic metamaterials has seen an explosion of research activity focused on exploring the possibilities for controlling acoustic and elastic wave propagation through the design of materials across multiple length scales. Acoustic metamaterial research has previously focused on determining sub-wavelength structures that produce effective material behavior that can be characterized as negative dynamic density and bulk modulus or a high degree of material property anisotropy. Those studies were conducted primarily with the objective of creating novel devices like acoustic cloaks, lenses, or perfectly absorbing surfaces (Cummer *et al.*, 2016; Haberman and Norris, 2016). At its core, metamaterials research focuses on challenging the assumptions of the limits of material response to propagating acoustic and elastic disturbances and, in so doing, can provide new insight to longstanding problems or suggest entirely new areas of research activity in acoustics. The content of this Special Issue is focused primarily on the simple challenge of understanding, modeling, and measuring media that essentially allows one to hear but not be heard, i.e., non-reciprocal acoustic media. The principle of acoustic reciprocity is a fundamental principle of nature that is not broken easily (Lord Rayleigh, 1873). One must therefore consider media that violate the underlying assumptions of acoustic reciprocity such as linearity and microscopic reversibility (Fleury *et al.*, 2015). While not solely concerned with non-reciprocal wave phenomena, the emerging field of topological acoustics and mechanics highlights analogues in classical wave systems with quantum mechanical behavior (Huber, 2016) and has also seen significant progress in the last 2–3 years. Research in this area focuses primarily on understanding periodic media that support wave motion confined to its boundaries (edges, interfaces, and corners). These boundary waves have topological origin and differ fundamentally from classical surface and interface waves such as Rayleigh, Stoneley, or Scholte waves (Khanikaev *et al.*, 2016; Chen *et al.*, 2018). Specifically, research on topological acoustics probes how one may generate behavior like non-reciprocal edge modes which are the analogue to the quantum Hall effect. Likewise, symmetry-protected wave modes at the interface of two media that minimally interact with scatterers and/or permit the creation of waveguides with sharp angles to guide energy around objects in analogy with the quantum spin Hall effect (QSHE) or the quantum valley Hall effect (QVHE) are also of interest.

The manuscripts in this issue provide a glimpse into these emerging areas of study. The issue begins with contributions concerning topological effects in lattice materials, primarily on acoustical analogues of the QVHE and QSHE. Deng *et al.* (2019) provide an analysis of acoustic analogues of QVHE and QSHE and Chen *et al.* (2019a) then investigate pseudospins and associated edge states of flexural modes in a plate with snowflake-like lattice structures. Jiang *et al.* (2019) then provide an analysis of the acoustic analogue of topological valley edge states using resonators at lattice nodes. The contribution by Long and Ren (2019) demonstrates the analogue of Thouless pumping in a one-dimensional acoustic system with spatially modulated geometric parameters and Hasan *et al.* (2019) present a general method of analysis for topological wave phenomena in acoustic and elastic systems. The last two contributions on topological wave phenomena in acoustics investigate the ability to tune topologically protected modes. Chen *et al.* (2019b) study the effect of lattice node geometry on the appearance of Dirac cones and spin states at interfaces while Darabi and Leamy (2019) describe the ability to tune topological insulator behavior in elastic plates by varying parameters of a two-dimensional elastic lattice. The remaining articles in the issue focus on the analysis and demonstration of classical wave motion that breaks reciprocity or demonstrates intriguing unidirectional behavior. Goldsberry *et al.* (2019) develop a finite element model of slow nonlinear deformation to modulate the effective properties of a structured elastic waveguide in time and space in order to break reciprocity for small amplitude signal waves. Attarzadeh *et al.* (2019) take a different route to breaking reciprocity in

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a one-dimensional system by introducing an angular momentum bias associated with gyroscopic elements and Wiederhold *et al.* (2019) consider the use of flow to introduce a momentum bias and thus beak reciprocity and suggest an associated acoustic device. Wapenaar and Reinicke (2019) present a unified wave equation for non-reciprocal materials and employ it to extend well-known approaches to seismic imaging in the presence of non-reciprocal effects. Zangeneh-Nejad and Fleury (2019) then introduce a model and experimental demonstration of a linear four-port acoustic device, termed a rat-race coupler, which displays novel excitation and isolation behavior through destructive interference. The effects of nonlinearity are then considered by Mojahed *et al.* (2019) where it is shown that non-reciprocal energy transport associated with either energy localization or breather arrest depends on the position of excitation in a lattice (Mojahed *et al.*, 2019). The two contributions that follow investigate non-Hermitian systems in the context of extreme wave control. Wu *et al.* (2019) present an active system to control the magnitude and direction and wave propagation through the use of paired loss and gain elements attached to an elastic beam and Thevamaran *et al.* (2019) model and measure non-Hermitian systems consisting of spatially distributed linear and nonlinear losses in fork-shaped resonant elements to produce asymmetric acoustic reflectance and transmittance. Last but not least, Norris and Packo (2019) provide a detailed analysis of flexural wave scattering from pairs of closely-spaced scatterers to obtain almost total absorption for incidence on one side, with almost total reflection if incident from the other side.

On a final note, as Guest Editors, we would like to thank the editorial staff for their assistance in putting the special issue together in accordance with the standards of the Journal. We would also like to thank the Editor in Chief, James Lynch, for his encouragement and advice. Most importantly, we would like to extend a special thanks to all of the contributors and reviewers who provided high quality manuscripts that clearly display the expanding breadth of ongoing research in these fields. We hope that this collection stimulates further research in these areas of study and we look forward to future contributions to the Journal.

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