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Higher-order Band Control and Topological Elastic Waveguide Design using Resonant-type Phononic Crystals

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1. Introduction

Recently, phononic crystals have attracted attention as a method for controlling sound waves. Phononic crystal [1-5] is a periodic structure of different elastic materials, and its phonon dispersion has the bandgap that prohibits sound propagation in the crystal. Phononic crystal has been applied for designing acoustic lenses, waveguides, and modulators in wide frequency ranges. However, the conventional phononic crystal waveguides suffer from large transmission loss at curved portions in the waveguide paths. In this study, we focused on topological acoustic waveguides, which exhibit highly robust wave propagation against defects and corners. A topological acoustic waveguide [6] has the characteristics of a conductor at the boundary and an insulator in the interior, similar to a topological electrical insulator. This is due to the band topology invariance, a common feature in the wave mechanics. The unidirectional transmission of sound waves and high robustness against disturbance can be realized through chirality of the edge state which emerges at the boundary between bands with different band topologies. Although many phononic structures have been proposed in recent years, not many investigations on the control of the higher-order band gap have been reported. The boundary surface state can be changed by modulating the edge state through resonance structures [6]. As a result, it is possible to realize robust topological valley transport along a predetermined path with high controllability over the desired frequency band. In this study, we numerically designed a topological phononic structure with an internal resonance structure to control the higher-order band gap and to achieve efficient sound wave propagation.

2. Band Gap Control and Topological Acoustic Waveguides Design

Figure 1 shows that a crystal structure of hexagonal lattice of grooved elliptical columns of stainless steel in water with a period of 2.2 cm arranged with C_{3v} symmetry forms second-order bandgap in its dispersion within the ultrasonic range between 600 and 700 kHz. The optimum structure that maximizes the second-order bandgap was searched by changing structural parameters, *i.e., a*, *b*, *c*, and *d* in the inset of Fig. 1.

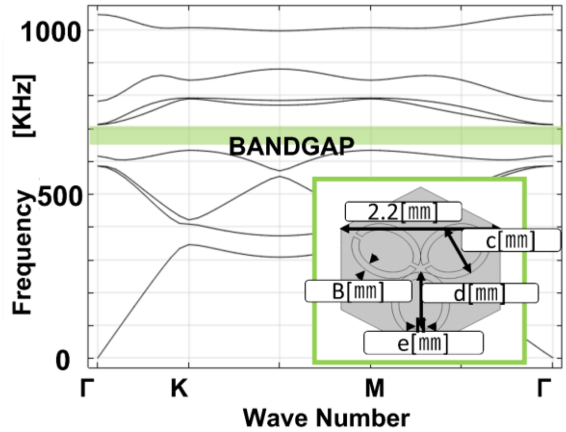

Fig. 1 Dispersion diagram of phononic structure with Y-shaped grooved ellipses.

Figure 2 shows the dependence of the bandgap on the groove width (*d*) of the hollow elliptical column. The optimum structure, which has larger band gap with different band topologies at the upper and lower edges of the band gap, was searched by changing *d* as well as other structural parameters. By constructing a supercell having interfaces between two oppositely oriented crystals of the optimized structure, we confirmed that a band topology transition occurs in the second-order bandgap and that edge modes appear within the gap.

Numerical simulations using the finite element method confirmed that in the Z-shaped waveguide formed with the topological interface, as illustrated in **Fig. 3** an incident acoustic wave propagated with very little loss (transmittance of approximately 90%) at the corners of the waveguide.

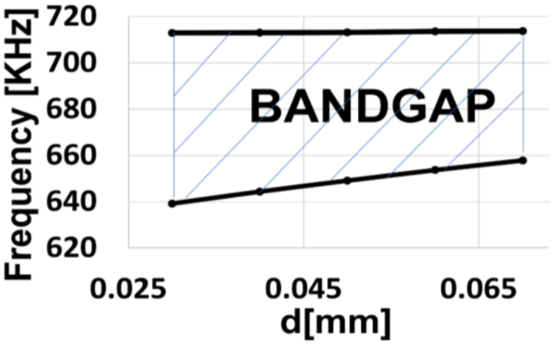

Fig. 2 Dependence of width of the second-order bandgap on a structural parameter, *d*.

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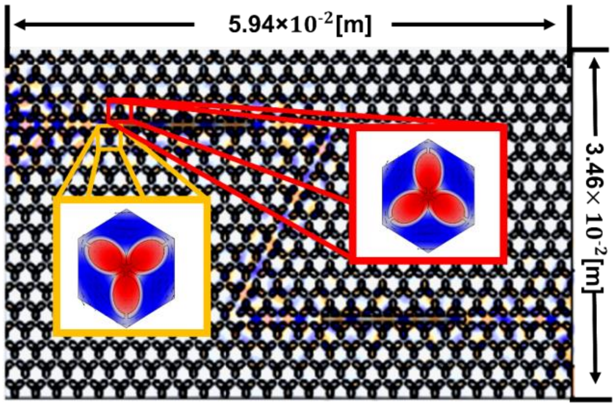

Fig. 3 Numerical simulation of edge mode propagation in Z-shaped waveguide with the interface between two oppositely oriented phononic structures.

3. Conclusion.

The present study showed that it is possible to control effectively the band gap using the resonant structure with Y-shaped grooved hollow ellipses built into a unit cell. The phononic structure was optimized by adjusting structural parameters in the resonant structure so that topological edge mode emerges within the second-order band gap. The waveguide formed with a topological interface can make acoustic wave propagate with little backscattering along the waveguide at a higher-order edge mode frequency. Currently we are designing a three-dimensional phononic structure toward an experimental demonstration. In the presentation, we will report details on the design of a phononic structure with elastic plates loaded with a pillar structure as a component resonating at desired frequencies.

Acknowledgement

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References

[1] Y. Pennec, J. O. Vasseur, B. Djafari-Rouhani, L. Dobrzynski, and P. A. Deymier, Surf. Sci. Rep. **65**, 229 (2010)

[2] Y. Pennec, B. Djafari-Rouhani, J. O. Vasseur, A. Khelif, and P. A. Deymier, Phys. Rev. E. **69**, 046608 (2004)

[3] P. A. Deymier, ‘‘Acoustic Metamaterial and Phononic Crystals‘‘, Springer Series in Solid-state Sciences **173**, 1(2013)

[4] D. Hatanaka and H. Yamaguchi, Phys. Rev. Appl. **13**, 024005 (2020)

[5] K. Okuno and K. Tsuruta, Jpn. J. Appl. Phys. **59**, SKKA05 (2020).

[6] Y.-F. Tang, B. Liang, J. Yang, J. Yang, and J.-C. Cheng, Appl. Phys. Express **12**, 094002 (2019).