3Pb1-1

Design of Topological Phononic Structure and Application to Thin Plate Elastic wave

Motoki Kataoka‡, Yuito Ohashi, Masaaki Misawa, and Kenji Tsuruta*
(Grad. School Nat. Sci. Eng., Okayama Univ., Japan)

1.Introduction

As an analogy of topological insulators and superconductors, "topological acoustics", which applies the concept of band topology to acoustic dispersion, has attracted increasing attention in recent years. By applying this concept to phononic crystals, acoustic waveguides are expected to be much more robust against bending or defects at the edge-state frequencies than the conventional phononic waveguides that suffers from backscattering at corners/defects. In the present study, we design topological phononic crystals on thin plastic plates, aiming at the development of efficient elastic waveguides for next-generation information devices. We focus on a snowflake-like structure in the unit cell, which has been extensively adopted due to its controllability of the dispersion in recent years. Topological waveguides are designed from the phonon dispersion analyses by finding edge modes appearing at interfaces between crystals with different band topologies. The transmission efficiency of the waveguides is evaluated numerically along with its experimental validation. This study proves that the robust propagation of elastic waves in thin plates is realized by topological phononic structures, and it paves the way to the development of new high-efficiency acoustic devices.

2. Numerical Design of 3-dimensional Topological Waveguide with Snowflake Phononic Structure

In this study, valley-topological band structure of the phononic crystal in plastic thin plates [1-5] was designed by optimizing shape of the snowflake-like holes in a hexagonal unit-cell. It was confirmed that the phase transition of the phonon band topology occurred when the spatial symmetry of the unit cell was destroyed by changing the length of the six branches of the snowflake. **Figure 1** shows the designed waveguide with two oppositely oriented snowflake unit cells, band diagram of the supercell, and the edge mode appeared at the frequency depicted in the red curve in the band diagram. Based on the 3-dimensional analysis, we designed a Z-shaped topological waveguide by arranging two types of unit cells one above the other with adjusted lengths of six branches of snowflakes. The incident wave at 85 kHz propagates efficiently along the interface via the topologically protected mode.

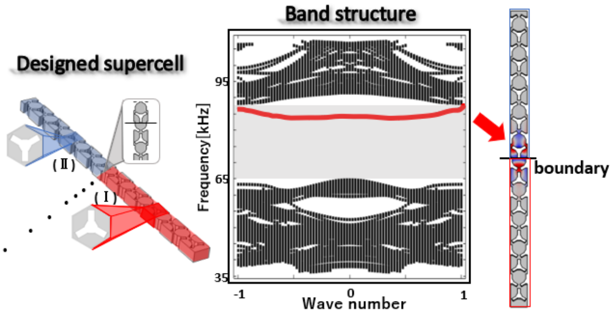

Fig. 1 Designed supercell, band structure, and out-of-plane displacement of the edge mode.

3.Experiments on Elastic-wave Propagation in Thin Plate Topological Waveguides

Next, we examined a Z-shaped waveguide based on the topological phononic crystals fabricated on a plastic (polypropylene) plate, as depicted in **Figure 2**. The fabrication has been done using a 3D printer that utilizes an optical stereolithography technology. The number of unit cells in the fabricated waveguide is 161 and the dimension of the waveguide is 14 cm (W) x 5.8cm (D) x 3.8mm (H). In addition, absorbers are attached to all the sides of the waveguide in order to remove excess propagation modes.

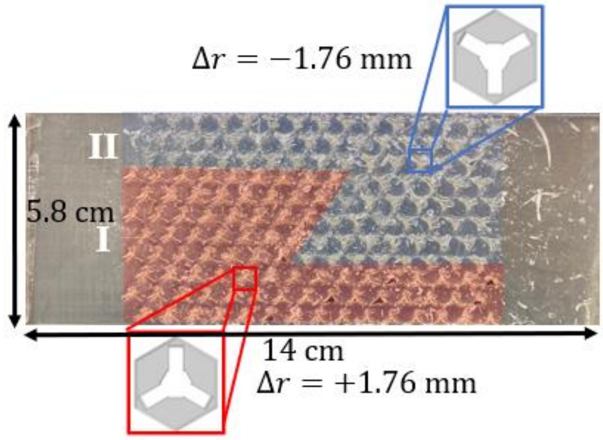

Fig. 2 Fabricated Z-shaped topological waveguide.

---

*Corresponding author:tsuruta@okayama-u.ac.jp

An elastic (Lamb) wave was excited at the left end of the waveguide by a piezoelectric transducer attached to one side of the plate with an electrical signal from a function generator amplified by an amplifier. Also, in order to measure wave propagation accurately, reflective tape is attached to the measurement points. The wave propagation along the Z-shaped interface was confirmed and visualized by measuring an out-of-plane displacement with a laser Doppler vibrometer. **Figure 3** shows spacial distribution of the displacement (normalized by its maximum value) in the waveguide for the incident wave at the frequency of 84.2 kHz, which was predicted to be an edge mode by the supercell analysis. The figure clearly indicates that the wave excited at the input port was propagating to the output port with little attenuation/loss. Similar result was obtained by reversing the arrangement of topological phononic crystals where another type of edge mode has been predicted to be excited at the interface.

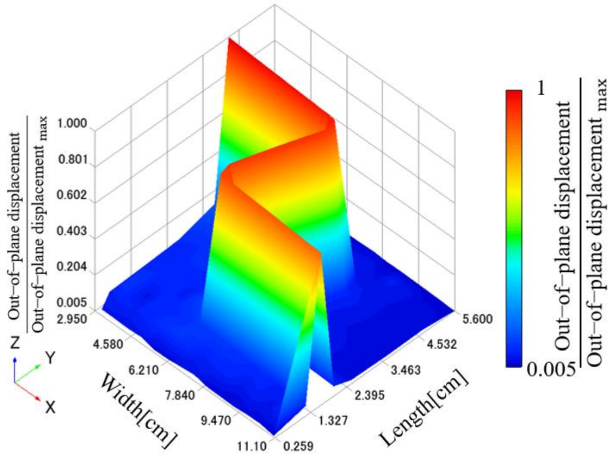

Fig. 3 Spacial distribution of (normalized) out-of-plane displacement obtained with laser Doppler measurement.

4.Conclusion

In this study, we designed and fabricated a three-dimensional phononic structure and an efficient elastic-wave propagation via the topologically protected edge mode was confirmed experimentally by using a laser Doppler measurement. It was shown that a topological phase transition occurs in each phononic crystal with snowflake unit cell by changing structural unit, and a topological edge state appears at the boundary between the two types of unit cells. The robustness of the waveguide designed based on the band-structure analyses was confirmed numerically and experimentally by observing wave transmission via the topologically protected edge states excited at frequency predicted from the band structure. Detailed analyses will be reported in the presentation.

Acknowledgement

This work was supported in part by the JSPS KAKENHI Grant Numbers 21H05020 and 21K18877.

References

1. K. Okuno and K. Tsuruta, Jpn. J. Appl. Phys. **59**, SKKA05 (2020).
2. A. Khelif, A. Choujaa, S. Benchabane, B. Djafari-Rouhani, and V. Laude, Appl. Phys. Lett. **84**, 4400 (2004).
3. Y. Pennec, B. Djafari-Rouhani, J. O. Vasseur, A. Khelif, and P. A. Deymier,Phys. Rev. E. **69**, 046608 (2004).
4. J.-H. Sun and T. -T. Wu, , Phys. Rev. B. **71**, 174303 (2005).
5. X. Li and Z. Liu, , Phys. Lett. A. **338**, 413 (2005).
6. D. Hatanaka and H. Yamaguchi, Phys. Rev. Appl. **13**,024005,(2020)