3P1-8

Structural Design of Topological Surface Acoustic Waveguides with Pillar-shaped Phononic Crystals

Yuito Ohashi[1†], Yusuke Hata[1], Masaaki Misawa[2] and Kenji Tsuruta[1*]
([1]Okayama Univ; [2]Fukuoaka Inst. Technol;)

1. Introduction

Recent years have seen technological innovation toward Beyond 5G/6G. One of the challenges in the target is to increase the peripheral components which can stably operate in the high frequency ranges. In particular, various attempts have been made to improve the efficiency and multifunctionality of communication devices using surface acoustic waves (SAW) operating in the GHz band. Among them, topological phononic crystals,[1],[2],[3],[4],[5] which have the characteristics of a conductor on the boundary surface and an insulator inside, have attracted much attention recently for their ability to efficiently manipulate SAW. We have been recently attempting to design highly efficient elastic waveguides using topological phononic crystals,[6],[7],[8],[9] and are currently focusing on pillar-type phononic crystals. It has been recently reported that the fabrication of nanoscale pillar structures on semiconductor substrates enables the design of topological SAW waveguides in the MHz band.[10] In the present study we aim to design topological SAW devices that operate at higher frequencies and in multiple frequency bands, while using the same design scheme as we have developed. As a preparatory step toward the GHz band design, we first explored the structure of millimeter-scale topological phononic crystals for the purpose of controlling surface acoustic waves in the kHz band.

2. Band Gap Control and Topological Acoustic Waveguides Design

A phononic crystal consisting of two pillars with a cylinder on the upper edge on a polypropylene substrate as the unit cell of a period of 8.4 mm was numerically designed using the finite element method. Figure 1 shows the phonon dispersion for two pillars with the same shape (left) and two pillars with different shapes(right). By breaking the symmetry, a band gap emerges between in the two bulk bands, blocking sound waves in the respective frequency region, as shown in Fig.2. When the symmetry of the pillars is broken and crystals of different orientations are combined to form a boundary plane, a localized band with edge state characters appears in the gap, as depicted in Fig 3.

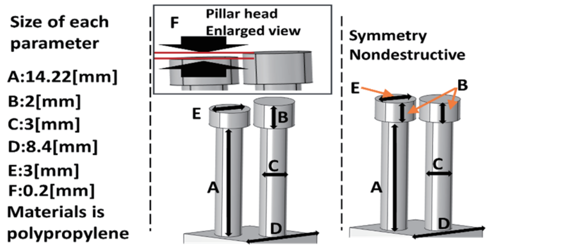

Fig. 1 Structural parameters of phononic crystals with symmetric (right) and asymmetric (middle) pillar structures (middle) pillars arrays in the unit cell.

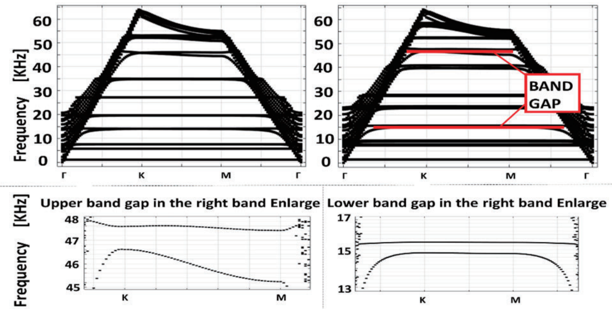

Fig.2 Band diagram symmetry (left) and asymmetry (right) of topological phononic crystals and band gap expansion

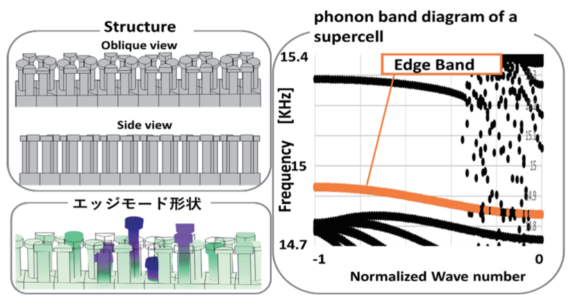

Fig. 3 Supercell structure (top left), edge mode displacement shapes (bottom left), and phonon band diagram of a supercell (right).

By numerical simulation based on the finite element method, we demonstrate a surface wave propagation in a linear waveguide with the boundary surface discussed above. Figure 4 shows a preliminary result of the edge-mode propagation along the boundary. Here a surface acoustic wave was injected at the left edge of the waveguide by exciting a vibrational mode with displacements along the x- and z-directions. The present simulation confirmed that the incident surface acoustic waves propagate in the linear waveguide through the topological edge state as shown in Fig. 4. In the presentation, we will discuss more details of these results.

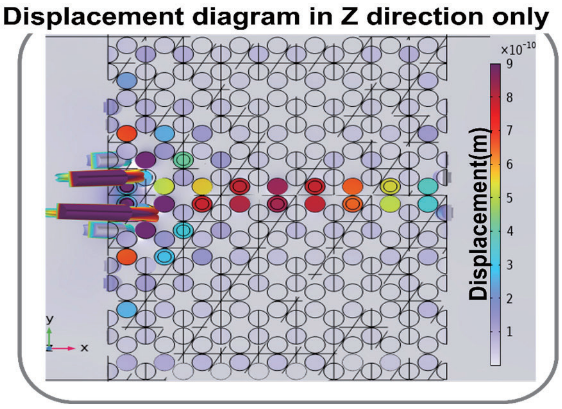

Fig. 4 Numerical simulation of edge mode propagation in a waveguide with an interface between two opposing pillar phononic structures. (Displacement in z-direction only)

3. Conclusion

In conclusion, we have shown that surface acoustic waves can be controlled in a single material by using a columnar resonance structure. By tuning the structural parameters of the unit cell, topological edge modes appear near the third-order band gap. In the waveguide formed at the topological interface, we were able to confirm the surface acoustic wave along the waveguide at the edge mode frequency. Actual fabrication of a phononic structure using a 3D printer as well as an experimental verifications of the edge propagations will further be conducted.

Acknowledgement

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

References

[1] P. Wang, L. Lu, and K. Bertoldi, Phys. Rev. Lett. **115**,104302 (2015).
[2] L. Yao *et al*., Appl. Acoust. **177**, 107931 (2021).
[3] T. Liu and F. Semperlotti, Phys. Rev. B. **100**, 214110 (2019).
[4] K. Okuno and K. Tsuruta, Jpn. J. Appl. Phys. **59**, SKKA05 (2020).
[5] O. Zhang *et al*., Nat. Electron. **5**,157-163(2022).
[6] Y. Ohashi, M. Kataoka, H. Takeshita, M. Misawa and K. Tsuruta, Proc. 43rd Symp. Ultrasonic Electronics, 2022, 3Pb1-3.
[7] M. Kataoka, Y. Ohashi, M, Misawa, K. Tsuruta, Proc. 43rd Symp. Ultrasonic Electronics, 2022, 3Pb1-1.
[8] M. Kataoka, M. Misawa, and K. Tsuruta, Symmetry **14**, 2133(2022).
[9] Md. S. Ali and K. Tsuruta, Jpn. J. Appl. Phys. **62**, SJ1002(2023)
[10] Z.-D. Zhang et al., Phys. Rev. Appl. **16**, 044008(2021).