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Design and measurement of topological elastic waveguide based on phononic crystal
フォノニック結晶を用いたトポロジカル弾性波導波路の設計・計測

Motoki Kataoka[1†], Masaaki Misawa[1], Kenji Tsuruta[1] ([1]Okayama Univ.)
片岡 源樹[1†]，三澤 賢明[1]，鶴田 健二[1]（[1]岡山大院 自然）

1. Introduction

Acoustic waveguides based on phononic crystals have been attracting attension as a useful means to design their operating frequencies using the band-enginiering scheme similar to electronic-strcuture design in semiconductors. However, many of acoustic waveguide using phononic crystals have been hampered to be used widely by unavoidable transmission loss due to the scattering of sound waves at defects and bending in the waveguide. Here, we adopt the concept of a topological insulator for phononic band design. A topological insulator is an object that is an insulator inside the object but exhibits metallic properties at the boundary. Topological insulator undergoes a topology transition in the electronic energy band via continuous change of structure/phases. Such a topological phase transition can also occur in the phonon band in periodic structures. As a result, the topologically protected edge state that appears at the interface enables sound wave control with high robustness against defects and bending in the waveguide. In this study, we discuss the relationship between robustness and edge mode characteristics from the results of propagation efficiency in topological acoustic waveguides using finite-element numerical simulations and an experimental measurement for a prototype phononic structure.

2. Two-dimensional topological phononic crystal with snowflake structure

In this study, we design a valley-type band structure for two-dimensional unit cell [1-5] with a snowflake-type structure made of silicon in a hexagonal lattice. It is confirmed that the topological phase transition of the phonon band occurs when the spatial symmetry of the unit cell is destroyed by changing the length of the six branches of the snowflake. **Figure 1** shows the eigenmode and band diagram of phononic dispersion in the snowflake structure. Two types of unit cells with adjusted lengths of six branches of snowflakes are arranged one above the other to design a Z-shaped topological acoustic waveguide. An incident wave of 33 kHz, the edge frequency predicted by the super-cell analyses, propagates efficiently along the interface, as shown in **Figure 2**. Transmission efficiency is nearly 98% even with the existence of the bents, indicating high robustness of the waveguide due to the topologically protected mode.

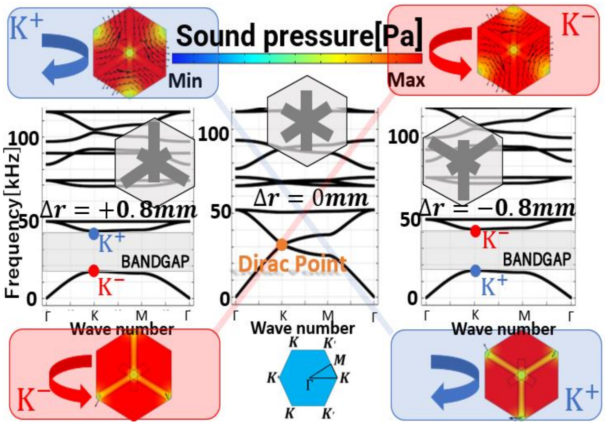

Fig. 1. Unit cell and band structures of a phononic crystal in air (2D).

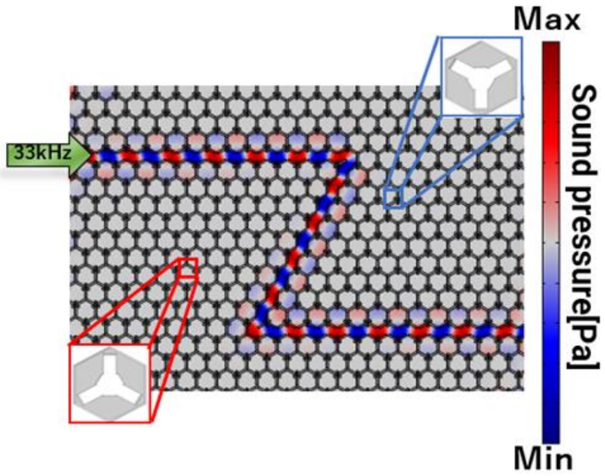

Fig. 2. Sound-pressure distribution (absolute value) in Z-shaped topological waveguide (2D).

3. Membrane-type topological phononic crystal with snowflake-shaped holes

Next, we design a topological phononic crystal in a plastic membrane for elastic wave control, that is useful in engineering a possible on-chip structure. This requires a three-dimensional structural design and the band structure in such a system may become complicated due to the mixture of longitudinal and transverse modes. Here we design a new valley-type 3D topological phononic structure by optimizing shape of the snowflake type unit cell again. Also, the material is changed to polypropylene considering prototype fabrications using a 3D printer. **Figure 3** shows the eigenmodes and band diagrams of the optimized unit-cell structures. It is confirmed that this structure also has an edge state, and a topological phase transition undertakes similarly to the previous result for the two-dimensional system. When an incident wave at 87 kHz is emitted to a Z-shaped topological elastic waveguide, the edge state at the boundary is excited and highly efficient elastic-wave propagation is thus achieved, as shown in **Figure 4**.

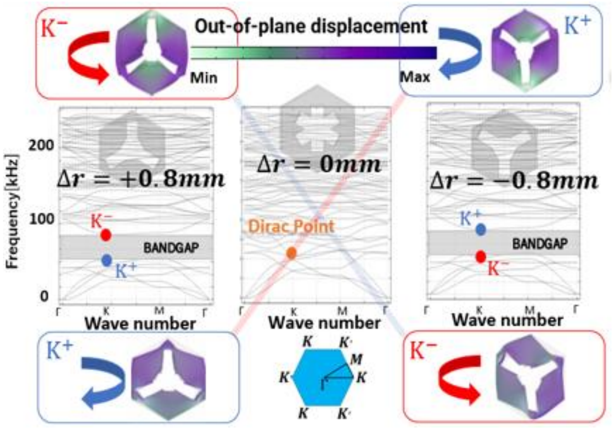

Fig. 3. Unit cell and band structures of an elastic-membrane phononic crystal (3D).

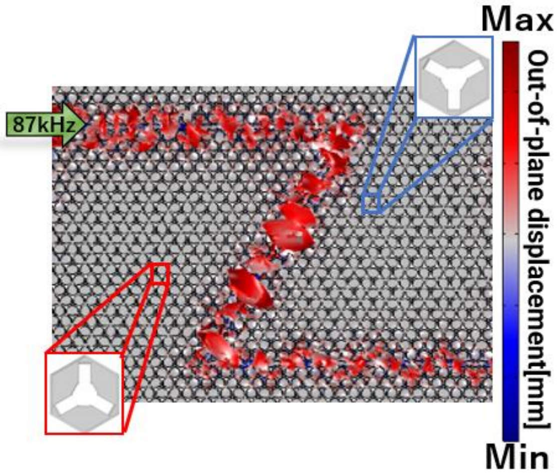

Fig 4. Sound-pressure distribution (out-of-plane displacement) in Z-shaped.

4. Conclusion

In this study, we performed topological elastic wave control using membrane-type phononic crystals extended from the design of a two-dimensional phononic structure in air. It was shown that a topological phase transition occurs in each phononic crystal, and a topological edge state appears at the boundary between two types of unit cells. Furthermore, robustness of the waveguide was confirmed by observing the topologically protected edge state excited by incident waves. Fabrication and measurement of transmission properties for a prototype structure designed based on the present analyses will be reported in the presentation.

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