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Reconfigurable Valley Topological Phononic Waveguide with Local C_{3v} Symmetry

C_{3v} 対称性の局所形成による再構成可能なバレートポロジカルフォノニック導波路

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1. Introduction

In recent years, as an analogy of topological insulators/superconductors, topological acoustics in which the concept of band topology is applied to acoustic dispersion have attracted attention. By applying the concept to phononic crystals, it is possible to make an acoustic waveguide robust against bending or a defect at the frequency of the edge state, in comparison with conventional phononic waveguides that have suffered from the backscattering at the corner/defect. In order to use topological acoustic waveguide in any device application, such as a switchable acoustic filter, waveguide structure is desired to be reconfigurable at will. However, only a few attempts have been made in this aspect until now [1][2].

In the present study, the finite element method (FEM) was used to design and simulate the phononic waveguides with topologically protected edge states. By making arrangement of the same metal cylinder variable, we propose a phononic structure that can control the position at which the topological edge state emerges along desired path.

2. Design of three rods valley topological acoustic waveguide[3]

The phononic structure in this study are based on a two-dimensional unit cell with three rods arranged in a hexagonal lattice (**Fig. 1(a)**). This structure has a C_{3v} symmetry which produces valley topological band structures [3-5]. In this structure, the rotation angle α is defined for relative positions of the three rods. We assume that the three rods are made of stainless steel and embedded in water.

K+ mode and K− mode appear at the K point in the phononic band diagram for the structure with α = −30° and 30°, respectively. These two modes and the direction of acoustic intensity are inverted in their mutual location at α = 0°. We have previously confirmed [3] that topological phase transitions of phonon bands occur in the reciprocal space and can be controlled simply by α .

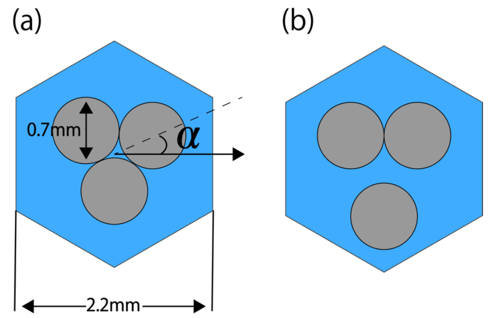

Fig. 1 Unit cell structure with **(a)** C_{3v} symmetry (α = 30°) **(b)** broken C_{3v} symmetry (α = 30°).

We constructed a topological acoustic waveguide with the supercell created by arranging unit cells composed of three rods with two different angles (α = −30° and 30°). The eigenmode analysis of this supercell revealed that the edge states appear at the K and K' points for the structure at around 400 kHz.

Based on the above analyses, we have fabricated a crank-shaped waveguide and measured the sound pressure. As a result, it showed high robustness near 400 kHz in analysis and experiment.

3. Reconfigurable valley topological waveguide

Figure 1(b) shows unit cell structure with broken C_{3v} symmetry (α = 30°), a newly proposed structure in the present work. **Figure 2(a)** shows the sound pressure distribution in the straight waveguide when C_{3v} symmetry is broken (C_{2v}) in all unit cell structures in which three stainless steel rods are placed in water. In this case, the sound wave incident from the left does not propagate. On the other hand, as shown in **Figure 2(b)**, the sound wave propagates along the interface when the C_{3v} symmetric structure is recovered only in the four layers near the interface. From this observation, it is suggested that a reconfigurable topological acoustic waveguide can be constructed by introducing a local structure of a topological interface into a phononic crystal with a local broken symmetry. We also examined a reconfigurable crank-shaped waveguide and simulated the acoustic wave propagation along the waveguide. A FEM calculation show high robustness for the acoustic wave of the frequency in the edge band.

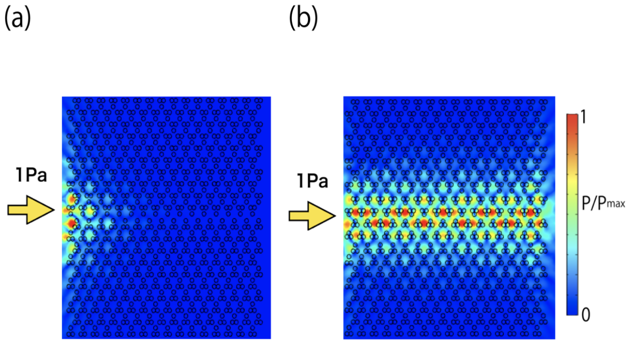

Fig 2. Sound-pressure distribution (absolute value) for 370kHz incident wave in phononic waveguides with **(a)** all deformed unit cell structures and **(b)** reconfigured topological waveguide.

In addition, by horizontally shifting one row of stainless rods below the straight waveguide where the local symmetry has been broken from C_{3v} at each unit cell, one row of structure with downward convex C_{3v} symmetry is formed leading to a new topological interface. Sound waves propagate along this new interface in the same way as in the original interface. This approach makes it possible to move the topological interface to an arbitrary position by simply shifting some arrays of rod.

4. Conclusion

In the present work, we demonstrated that the propagation of sound waves can be controlled by designing the positions of local C_{3v} symmetry of three rods unit cell structure. By introducing local C_{3v} symmetric structures in a periodic structure with a symmetry broken from the original C_{3v} symmetry, the topological edge state can emerge at the position of the unit cell with the C_{3v} symmetry. Furthermore, the positions/paths of the edge state can be moved by shifting layers of rods in the periodic structure. In the presentation we further demonstrate in detail that a topological acoustic waveguide can be constructed in a reconfigurable manner by the three-rods system. Our approach will open-up a practical way to realizing highly efficient reconfigurable acoustic waveguides.

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