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Reconfigurable Waveguide Design in Valley-Topological Phononic Crystal

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1. Introduction

The reconfigurability of valley phononic waveguide, as well as its robustness against defects and bends, is one of the keys to controlling energy transmittance in highly integrated switchable acoustic devices. In 2018, Z. Zhang *et al.* [1] proposed a reconfigurable structure for topologically protected sound propagation by rotating three-legged unit cells without altering the lattice structure. In the later year, A. Darabi et al. [2] proposed another type of reconfigurability in topological elastic-wave insulator and demonstrated it experimentally. In the present study, we focus on continuous translation of circular rod arrays for local symmetry inversion in a phononic crystal to propose a reconfigurable waveguide interface, as graphically illustrated in **Fig.1(a)** and **1(b)**. The two-dimensional valley phononic waveguide based on the two differently oriented C_{3v} symmetric geometries has exhibited highly robust immunity as well as high energy transmittance of acoustic wave via the topologically protected valley edge state [3]. The proposed structural change leaves a dimer array at the interface region, which may induce localized mode leading to less energy transfer in the reconfigurable waveguide. We show, however, that despite the presence of the localized mode the reconfigurable straight waveguide interface can accommodate wave transmission with the robustness as high as that in the valley topological phononic waveguide without the dimers. In addition, the continuous translation of rod to break the local symmetry can also be applied for switching on and off the band-gap opening. These analyses are performed based on finite-element calculations and simulations by using a general purpose software package (COMSOL Multiphysics).

2. Continuous Translation for Local C_{3v} Symmetry Inversion

We arrange a supercell in which each hexagonal unit cell is composed of three circular rods made of stainless-steel based on differently oriented C_{3v} symmetric structures. We have set the lattice constant a = 2.2 [mm] and the diameter of each circular rod d = 0.7 [mm], respectively. The speed of sound and mass density of water and stainless-steel rods are 1490[m/s], 1000[kg/m^3]; 5780[m/s], 7800[kg/m^3], respectively. Here, the width and height of the rectangular super cell are defined as a and $\frac{30a}{\sqrt{3}}$, respectively. The two pseudo-spin modes appear near the K point in the supercell's Brillouin Zone [**Fig. 1(c)**]. Both the upper and lower bulk bands are identical, and the edge states appear around 310-430 kHz. On the other- hand, when we construct a uniform C_{3v} symmetric structure of rectangular array of the unit cell with the orientation $\alpha = 30°$, no edge mode appears in the frequency range. By using continuous translation, *i.e.* shifting one rod from all layers below an interface, one can construct $\alpha = -30°$ oriented rod array in the lower layer.

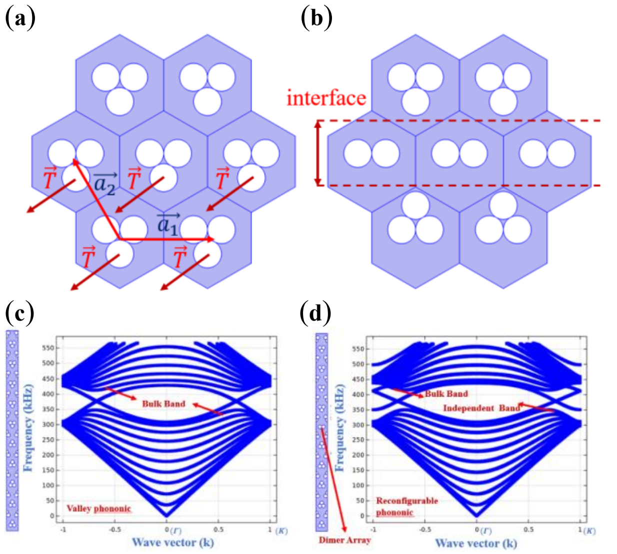

Fig.1 (a)Schematic of uniform structure of a rod array in a valley-topological phononic crystal, (b) reconfigurable structure constructed by continuous translation of a rod array in the structure illustrated in (a), (c) band diagram for supercell structures of valley phononic crystal, and (d) that of reconfigurable phononic crystal.

The reconfigured supercell band diagram depicted in **Fig. 1(d)** shows that the upper band is regarded as a bulk band, whereas the lower band corresponds to an independent (localized) mode attributed to the presence of dimer array at the interface. This can impact not only on the wave transmission due to the localization of the mode but also on the band topology.

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3. Reconfigurable Valley-Topological Waveguide

Based on the band-structure design described above, we first constructed a valley topological waveguide with rectangular arrays of differently oriented ($\alpha = 30°$ and $\alpha = -30°$) C_{3v} symmetric unit cells made of stainless-steel rods immersed in water. **Fig. 2(a)** depicts the waveguide structure along with the pressure field distribution in the case that an incident acoustic wave at 400 kHz was input from the left port region (designated as "input") and the transmittance was measured at the region "output". The figure clearly shows that highly efficient wave transmission was realized at the frequency that was aimed from the band-structure design in the previous section.

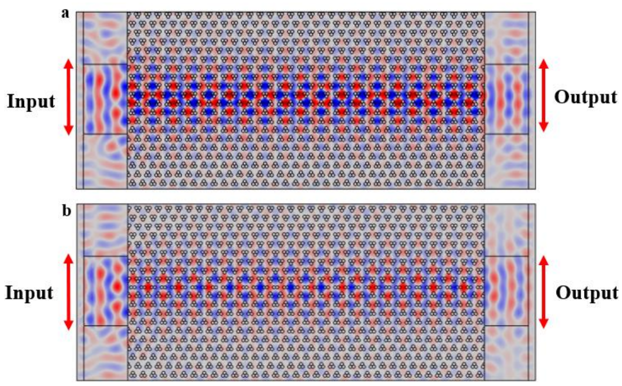

Fig. 2 (a) Pressure field in valley phononic waveguide at 400 kHz and (b) in the reconfigurable phononic waveguide.

To show that a topological waveguide can be constructed by the continuous translation of rod arrays proposed in the previous section, we first prepared a rectangular array of unit cells with a uniform C_{3v} symmetric structure with single orientation $\alpha = 30°$. We shifted one rod from each unit cell in all the layers below an interface by using the translation vector $\vec{T} = \left(-\frac{a}{2}, -\frac{\sqrt{3}}{2}a + \sqrt{3}d\right)$. The rod array with orientation $\alpha = -30°$ was thereby created in the lower half layer. The uniform phononic structure was shown to be reconfigured to a waveguide with an interface between upward and downward convex with C_{3v} symmetric structure ($\alpha = 30°$ in upper layer and $\alpha = -30°$ in lower layer, respectively) as depicted in **Fig. 2(b)**. It should be noted here that the continuous translation of rod leaves a dimer array with C_{2v} local symmetry in the waveguide.

4. Results and Discussion

The wave-transmission phenomena in a topological phononic structure are closely connected with band gap topology via protected edge state appear around the gap frequency range 350-430 kHz, as shown in Fig. 1(c). Fig. 2(a) shows that the incident wave can transmit efficiently via the edge state at 400 kHz. Fig. 2(b) shows, on the other hand, slightly degraded pressure field in the waveguide path. Nevertheless, transmittance for incident wave around the same frequency range is nearly the same as in the case of Fig. 2(a). It reveals that even there is the localized mode present in the path of reconfigured waveguide interface, the acoustic wave can still propagate robustly as comparable with an ideal valley phononic waveguide. This indicates that acoustic energy transport can be controlled by designing the robust reconfigurable waveguide interface with continuous translation of rods via the topologically protected edge state. This approach demonstrates a new practical way to controlling energy transmission toward robust switchable as well as reconfigurable device based on continuous translation of the unit cell structure for local C_{3v} symmetry inversion in the valley-topological phononic crystals.

Acknowledgement

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