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Valley vortex edge modes in a phononic crystal at ultrahigh frequencies

Paul Otsuka[1†], Katsuya Nishimata[1], Motonobu Tomoda[1], Daiki Hatanaka[2], Hiroshi Yamaguchi[2], Kenji Tsuruta[3], Osamu Matsuda[1*], ([1]Grad. School Eng., Hokkaido Univ.; [2]NTT Basic Laboratories; [3]Dept. Electr. Electron. Eng., Okayama Univ.)

1. Introduction

Waveguide modes formed by defects in phononic crystals have been well studied experimentally and numerically. While they have been shown to be effective in guiding acoustic waves, transmission efficiency is limited by scattering at corners and discontinuities.[1,2)]

By appropriate choice of unit cell, phononic crystals can form topological insulators, which support robust one-way propagation along interfaces that are highly resistant to imperfections and bending of the interface.[3,4,5)] Such materials undergo a topological transition in their wavefunction upon some continuous change in their structure, resulting in protected edge states at interfaces between different topological phases, while being insulators in their bulk.

A topological phase transition can be produced by the breaking of some symmetry, such as time-reversal symmetry or inversion symmetry, in order to open a band gap at the Dirac points. In analogy with the Quantum Valley Hall effect, a phase transition in acoustic materials can be produced by breaking mirror symmetry, leading to chiral valley vortex states in the unit cell.[3,6)] Here we investigate the mode patterns in a topological phononic crystal at frequencies up to 500 MHz by performing numerical simulations and optical measurements of phonon propagation, particularly the guiding of bounded edge states. We analyze the mode patterns and investigate the **k**-space behavior by Fourier analysis.

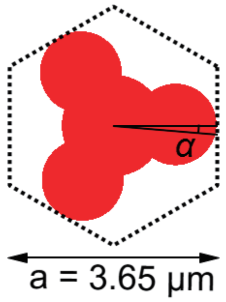

Fig. 1 Topological phononic crystal structure consisting of a hexagonal array of lobed holes with 3-fold symmetry.

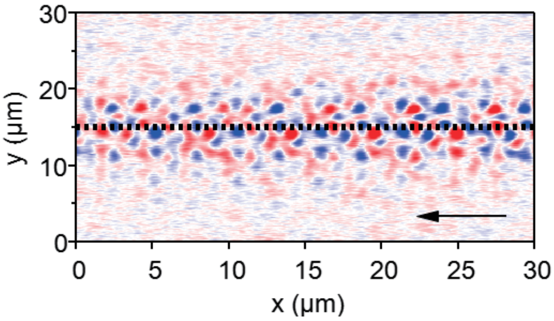

Fig. 2 Snapshot of the experimental field pattern of propagation along an interface (represented by the dashed line) at a frequency of 493 MHz. The top (+5°) and bottom (−5°) regions differ by an in-plane rotation of the unit cell. The arrow shows the direction of propagation.

2. Sample

We investigate a sample consisting of a hexagonal array of voids in a GaAs slab of 1μm thickness and unit cell spacing of 3.65 μm. The unit cell, shown in **Fig 1**, is a 3-fold symmetric structure with a central hole of radius 0.90 μm and surrounding lobes each with a radius of 0.72 μm. Mirror symmetry is broken by either a +5° (anitclockwise) or −5° (clockwise) rotation of the lobes in each unit cell. An interface between different topological phases is formed by rotating the individual unit cell orientations in different regions by ±5° with respect to each other. We investigated various arrangements with different boundary geometries.

3. Experiment

Surface acoustic waves of fixed frequency are generated in the samples via one of a set of electrically excited interdigital transducers (IDTs) on different sides of the PC. The accessible frequency range of the transducers is between 465 MHz and 505 MHz. The excited plane waves propagate from the IDT to the PC, where, depending on the conditions at the PC boundary, guided modes may be

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E-mail: [†]paul@eng.hokudai.ac.jp,
[*]omatsuda@eng.hokudai.ac.jp

excited at an internal interface.

The resulting surface motion is probed with periodic pulses from a mode-locked laser focused through a microscope objective to a spot of ~1 μm diameter.[7)] The surface displacements are detected from the reflected beam by an interferometer together with a lock-in amplifier, which is synchronized with the laser and electrical excitation by a heterodyne set-up. From the lock-in output we can extract the amplitude and phase of the surface motion. A tilting mirror system in the probe beam path before the objective lens allows two-dimensional images to be obtained by scanning the probe spot over the surface. The imaging results show the mode patterns at the interface boundaries. **Fig 2** shows an example of a field pattern of a propagating mode in the structure at 493 MHz, with excitation from the right-hand side. This frequency lies in the phononic crystal band gap. The image shows a complex field pattern confined to the vicinity of the interface.

4. Simulation

We performed numerical time-domain simulations to investigate the patterns of the propagating modes at the interface boundaries. A three-dimensional model of an array of unit cells was arranged with an interface bounded by regions of unit cells of +5° on one side and −5° on the other. Excitation was by a short implosive pulse, producing a broadband frequency distribution centered on ~490 MHz. The results are found to be consistent with the experimental result.

5. Conclusion

We performed numerical and experimental imaging measurements of valley vortex edge modes in a micron-scale topological phononic crystal at ultrahigh frequencies. The results demonstrate robust propagation in different waveguide configurations and help to elucidate the dynamics of the propagating modes. The results should help guide the development of topological phononic crystal designs for high frequency applications.

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