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# Tunable Acoustic Topological Insulator

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**Abstract:** Inspired by the quantum spin Hall effect (QSHE), we propose and numerically verify at tunable topological insulator by employing asymmetry and nonlinearity, to exhibit topologically protected edge states (TPES). These properties may open new research directions in realizing the quantized anomalous Hall effects and topological insulators.

## Introduction

In recent years, topological insulators exhibiting TPES have been developed and used to control mechanical waves in the form of static[1] and dynamical[2] edge states. These mechanical structures benefit from robustness against defects and are immune to back-scattering. These topological insulators are divided into two groups, i) active devices by realizing chiral edge states analogous to quantum Hal effect (QHE)[3], and ii) passive devices by realizing helical edge states analogous to quantum spin Hall effect (QSHE)[4]. In this work, we propose a passive tunable nonlinear mechanical topological insulator which employs a zone folding technique to realize QSHE. The operating band of the proposed structure depends on the input energy, which guaranties a tunable device without changing the geometry of the structure.

## System description and results

Figure 1(a) depicts the proposed structure composed of six masses in a hexagonal unit cell connected using linear springs (shown in blue and green). To break the inversion symmetry in this system, masses 2, 4, and 6 are connected to internal resonators using nonlinear springs. Figure 2(b-c) display the dispersion relationship for the proposed unit cell by employing a zone folding technique. As shown, by inputting energy into the system, a topological bandgap is created at the location of the Dirac cone. The width of this band is a function of input energy-i.e., larger input energy provides a bigger topological bandgap. This enables the device to have a tunable operating band, where the propagating waves are topologically protected against back-scattering. The Chern number associated to each band (the ones bounding the topological bandgap) is computed numerically by integrating the Burry curvature over the first irreducible Brillouin zone, and shown in these figures.

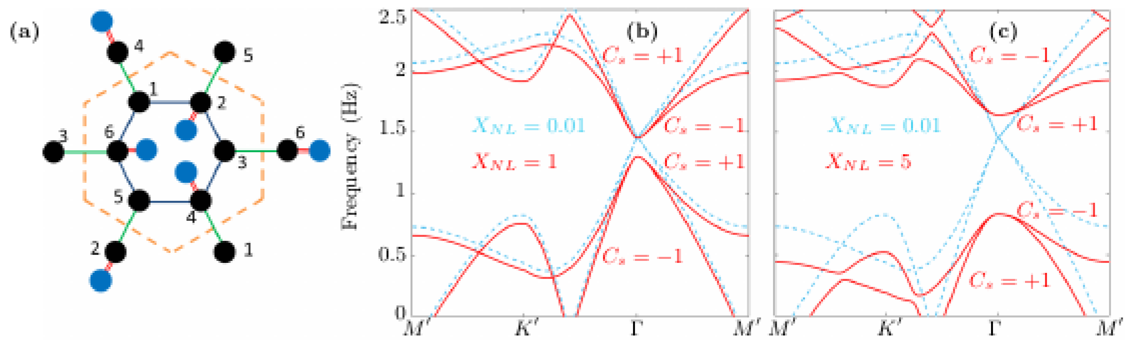


**Figure 1 (a)** A hexagon shaped unit cell (marked with orange dashed-lines) composed of six masses (m=1.2 kg) connected using linear springs (k_L=1 N/m), three resonators (m=0.6 kg) coupled with masses 2,4, and 6 by employing purely cubic springs (k_NL=1 N/m^3), **(b-c)** Numerically computed dispersion relationship along the edges of the first Brillouin zone with corresponding spin Chern numbers, when the displacement of the nonlinear springs is extremely small (plotted in blue), and when displacement of the nonlinear springs is sufficiently large (plotted in red).

A unique advantage of topological edge states is their immunity to back-scattering at sharp edges. Figure 2(a) depicts a structure composed of the hexagonal unit cell in Fig. 1(a) repeated in the lattice vector directions. In this structure, masses 2, 4, and 6 in each unit cells are connected to internal resonators by purely cubic springs. As marked in this figure, a harmonic force excitation on the right corner of the structure generates waves into the system. Figure 2(b) provides the displacement field of the proposed plate at the frequency 1.5 Hz whereby a single one-way edge mode propagates in a counter clock-wise manner without backscattering from the sharp edges of the structure. Propagation of the sending wave in the clock-wise direction along the edges is forbidden by applying proper boundary conditions to the cells near the source.

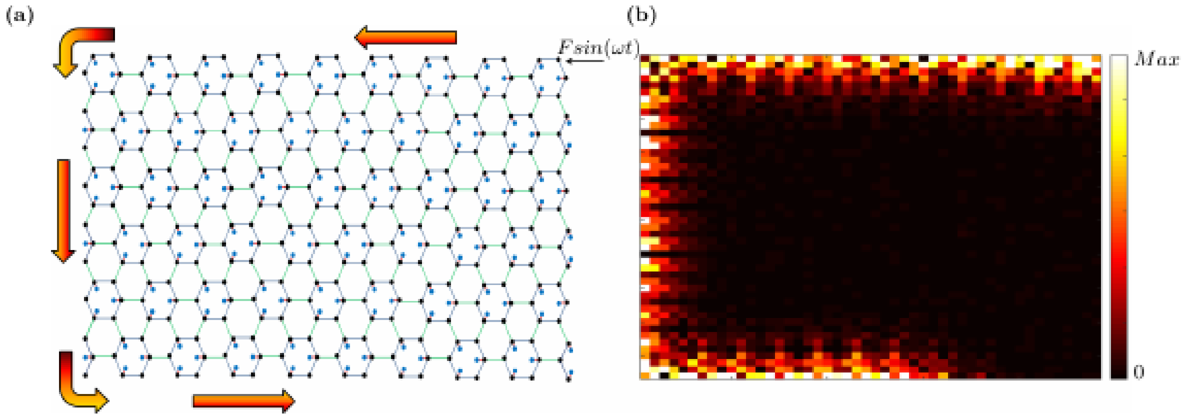


**Figure 2 (a)** Schematic of a phononic structure composed of hexagonal unit cells with nonlinear springs repeated in the lattice directions. A harmonic excitation of F*sin(omega t) excites the system on the upper right corner. **(b)** Numerically computed displacement field of a topological edge state excited by a source with frequency f = 1.4 Hz, located at the upper right corner of the system, documenting wave propagation along free edges without back-scattering.

## Conclusions

The proposed topological insulator utilizes nonlinearity and asymmetry to provide a self-tunable structure. The provided results show the potential of the structure to guide propagating waves along edges without back-scattering from sharp edges. This self-tunability may dramatically enrich the design and use of acoustic topological insulators in sensors, filters, waveguides, and other devices.

## References

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