Elastic Energy Transport Leveraging through Tunable Topological Structures

D. E. Quadrelli, E. Riva, G. Cazzulani* and F. Braghin

Department of Mechanical Engineering (DMecc)
Politecnico di Milano
Via La Masa 1, 20156 Milan, Italy
Email: gabriele.cazzulani@polimi.it – Web page: https://www.mecc.polimi.it/

ABSTRACT

The exploitation of non-trivial topological properties of band structures in Phononic Crystals has recently proved to be a proficient way to obtain robust waveguides showing immunity to backscattering at defects and capability to overcome sharp bends without reflections [1-4]. This allows to reach an ideal unitary transmissivity for mechanical signals sent along the guide. According to the bulk-edge correspondence principle, these peculiar gapless states are obtained at the interface between two periodic lattices showing distinct topological features. Starting from this theoretical framework, this manuscript shows how it is possible to design an elastic waveguide that exploits the promising features of topological protection and at the same time achieves reconfigurability in the path followed by the carried signal and tunability in the working frequencies.

In particular, by break of the spatial inversion symmetry in the Kagome geometry, it is possible to obtain two different unit cells whose band structures show distinct topological characteristics in the context of the Quantum Valley Hall Effect [5]. An interface created between two regions made up by such cells is capable to support topologically protected edge waves. The integration in the structure of piezoelectic smart devices with negative capacitance shunting circuits allows then to locally alter the stiffness properties of each unit cell [6-7], making it possible to switch one into the other. This allows to move the interface between the two adjacent regions which constitutes the waveguide.

The robustness of the performances of the device is investigated introducing a random bias in the parameters of each cell of the hosting structure, mimicking imprecise tuning of the electrical components and production defects. The energy transport along the guide when such uncertainties are introduced is compared with the one in the nominal case showing the threshold of disorder the device is immune to.

Finally, exploiting the properties of unidirectional propagation of the topological modes and the tunability of the shape of the interface, this manuscript proposes the design of a mechanism to switch between different edge channels, to convey elastic energy to distinct points of the structure at need, creating a quantum-point like device [8].

REFERENCES

[1] S. D. Huber, Nat. Phys. 12, 621 (2016)

[2] D. Torrent, D. Mayou, and J. Sánchez-Dehesa, Phys. Rev. B 87, 115143 (2013)

[3] J. Vila, R. K. Pal, and M. Ruzzene, Phys. Rev. B 96, 134307 (2017)

[4] T.-W. Liu and F. Semperlotti, Phys. Rev. Appl. 9, 014001 (2018)

[5] H. Chen, H. Nassar, A. N. Norris, G. Hu, and G. Huang, Phys. Rev. B 98, 094302 (2018)

[6] N. W. Hagood and A. von Flotow, J. Sound Vib. 146, 243 (1991).

[7] R. Zhu, Y. Chen, M. Barnhart, G. Hu, C. Sun, and G. Huang, Appl. Phys. Lett. 108, 011905 (2016).

[8] L. Zhang, F. Cheng, F. Zhai, and K. Chang, Phys. Rev. B 83, 081402 (2011)