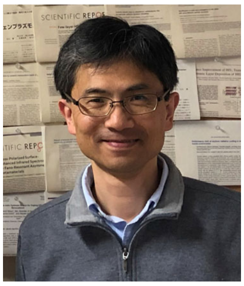
【Grant-in-Aid for Scientific Research (S)】

Broad Section D



Title of Project : Development of Ultrasonic Topological Phononics for Multifunctional Elastic Wave Devices

TSURUTA Kenji
(Okayama University, Academic Field of Natural Science and Technology, Professor)

Research Project Number : 21H05020 Researcher Number : 00304329
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Keyword : topological phononics, phononic crystal, topology optimization, surface acoustic wave imaging, spin-mechanics

【Purpose and Background of the Research】

After the Nobel Prize in Physics in 2016, topological insulators and superconductors focusing on geometrical phase (topology) of wave function of electron have been an active research field. The topology is an invariant in wave phenomena which has not received much attention until recently. The edge modes appeared in interfaces and surfaces are protected by the topology from disturbance due to the presence of impurities and structural disorder. Recently, topological phononics which applies the same theoretical framework to the propagation mode of elastic wave attracts attention as well.

In this study, we aim to predict/design the topologically protected edge mode based on computational algorithms and visualize it via time-resolved measurements as well as mapping techniques to mechanical systems. Extra low-loss transmission of the elastic wave through the edge mode will be thereby verified in the GHz ultrasonics regime. In addition, novel functions such as spin-mechanical coupling and nonlinear amplification will be developed in the regime. The final goal of the present study is to realize a novel super-multiplexed elastic wave device which requires and intervenes no electrical current and voltage over the whole operations inside the device.

【Research Methods】

In this study, we [1] design optimum phononic structures based on computational methodologies, [2] perform time-resolved measurement of the edge-mode propagation in membranes as well as mapping of the designed systems into mechanical analogues, and [3] fabricate and examine the topological phononic structures at μm scale for edge mode propagation in the GHz regime, in order to develop non-reciprocal and/or spin mechanical devices. These will be done through an intimate collaborative research between the representative group (Okayama Univ.) and the partner groups (Waseda Univ., Hokkaido Univ., NTT) (Fig. 1).

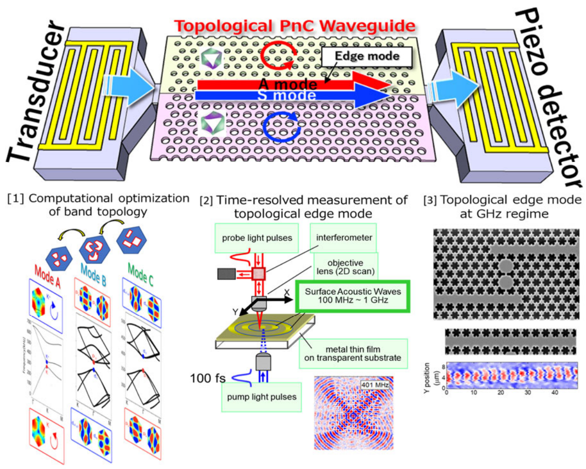

Fig.1 Multimode topological phononic device to be designed in the present study (top) and each technological elemental for [1] designing, [2] visualizing, and [3] implementing, and functionalizing the device at GHz regime.

【Expected Research Achievements and Scientific Significance】

The rectification and/or non-reciprocity where elastic waves propagate unidirectionally, as well as their signal amplification and modulation can be a fundamental element in the next-generation processing devices, which is an information carrier alternative or complementary to electron and photon. For example, the wavelength of phonon is five orders of magnitude shorter than that of electromagnetic wave (photon) at the same frequency, adding a new axis in the design space of integrated circuits. However, previous attempts have been hampered by extremely low transmission efficiency, and it is thus far from the application to the information processing device at present. The present study targets to resolve this issue by utilizing topologically protected edge mode in elastic wave devices, paving a way to realizing ultra-low power consumption devices.

【Publications Relevant to the Project】

· K. Okuno and K. Tsuruta, "Topologically robust sound wave transport in two-dimensional phononic crystal with a circular rod arrangement in water", Jpn. J. Appl. Phys. **59**, SKKA05(8pages) (2020).
· D. Hatanaka and H. Yamaguchi, "Real-space characterization of cavity-coupled waveguide systems in hypersonic phononic crystals", Phys. Rev. Appl. **13**, 024005 (9pages) (2020).
· P. H. Otsuka, S. Mezil, O. Matsuda, M. Tomoda, A. A. Maznev, T. Gan, N. Fang, N. Boechler, V.E. Gusev, O. B. Wright, "Time-domain imaging of gigahertz surface waves on an acoustic metamaterial", New J. Phys. **20**, 013026 (12pages) (2018).

【Homepage Address and Other Contact Information】

http://www.cc.okayama-u.ac.jp/~eng_mdd/
tsuruta@okayama-u.ac.jp