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

Ultrahigh-speed magnophononic resonator devices

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Purpose and Background of the Research

●Outline of the Research

A phononic (acoustic) resonator, such as a bell or a tuning fork, is among the oldest devices which humans have applied to various technologies. It has recently changed its shape as a micro-scale device such as a bulk acoustic resonator, a quartz oscillator or a microwave filter, and is widely used in various systems such as a mobile terminal, an in-vehicle device, sensors and timing devices. With the development of beyond 5G or 6G communications, it will be important to develop multifunctional, integrated, and ultra-high frequency technologies. Especially in the high frequency range above 10 GHz, the effects of radiation loss and mutual interference of electromagnetic waves will degrade the system performance, and it will be difficult to entrust the technology solely based on existing semiconductor devices.

On the other hand, it is a well-known fact that magnetic materials, which have also been applied to technology for a long time, have recently been used as a microstructural spintronics device, and are now being put into practical use. In this study, we will explore the hybrid device technology of these phononic resonators and spintronic structures, and aim to establish a new ultrafast device technology utilizing various characteristic physical properties of ferromagnetic materials.

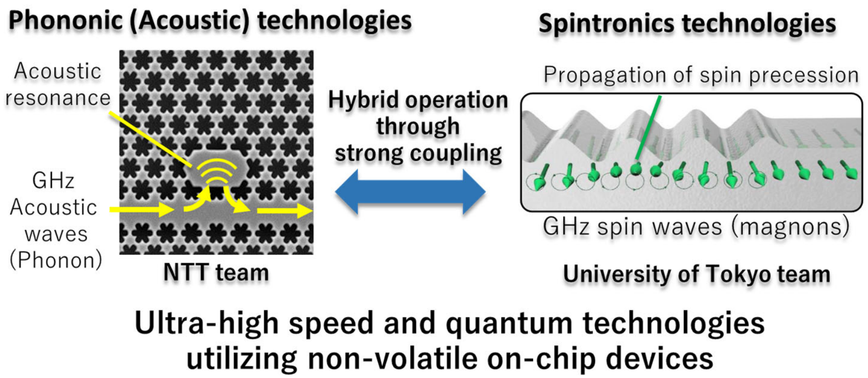

Figure 1. Schematic viewgraph showing the basic concepts in this project.

●Key Ideas

The unique features of this project are (1) the use of acoustic resonators made of phononic crystals and nitride semiconductor bulk acoustic resonators, which are advantageous for on-chip integration and high frequencies operation, and (2) the use of hybrid magno-phononic structures using low-loss spintronic materials such as synthetic antiferromagnetic and ferrimagnetic thin films that have the magnetic resonance in ultra-high frequency region. This project has academic and technological uniqueness aiming to realize ultrafast phononic devices with new functions by utilizing the interaction between phonons and magnons.

● Impacts

Phononic resonators are one of the key devices used in various information processing technologies such as mobile terminals and high performance sensors. If the characteristics can be "reconstructed" by the information stored in the magnetic domain, it will be possible to optimize the characteristics according to the situation and application. The range of its use is expected to expand greatly, such as variable filter/timing devices and acoustic waveguides that can reconfigure the propagation characteristics. In addition, by mediating the magnetoacoustic effect, it is possible to form phononic elements on platforms made of non-piezoelectric materials such as Si, allowing the fusion with existing Si integrated circuits. Compared to electrical signals, the radiation loss of the phonon flow is very small, and it could potentially lead to energy saving, miniaturization and speedup of various high-frequency devices.

Expected Research Achievements

●Magnon-phonon strong coupling

It is important to enlarge the magnon-phonon coupling in order to make the expected device functions appeared. The most important milestone is to obtain the coupling larger than the loss of magnetic resonance. To that end, magnetic materials with large magnetoelastic coupling and small magnetic relaxation are integrated in a phononic crystal resonator.

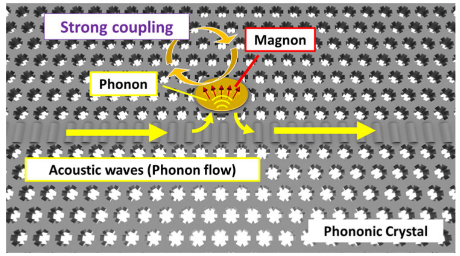

Figure 2. A magnophononic device based on a phononic crystal.

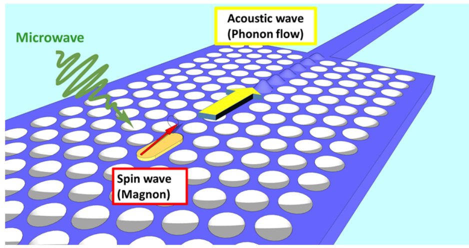

Figure 3. Magnon-induced phonon emission utilizing a phononic crystal resonator.

● Coupled operation

We optimize the magnetic material to realize strong coupling based on the studied magnetoelastic properties and establish the magnophononic control technology at the nanoscale. Eventually, we aim to generate phonon oscillations by magnons through the magnetoelastic effect and also to control the magnon state by phonons.

●Ultra-high frequency operation

We introduce new ultra-high-frequency magnetic materials with synthetic antiferromagnetism and ferrimagnetism, realizing integrated devices on a chip that combines phononic resonators and ferromagnetic materials. Various resonator structures, such as BAW and SAW as well as phononic crystals, and high-quality nitride semiconductors will be advantageous for high frequency operation.

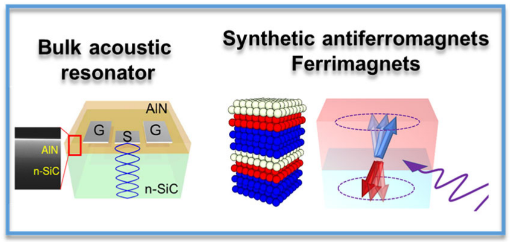

Figure 4. Basic device elements for ultra0high frequency operation.

In addition, the research will be conducted on fundamental technologies such as material growth and process technologies as well as the high-frequency characterization methods, for example, using optomechanical techniques.

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