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Article / Book Information

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Title(English)	Theory of Generation and Conversion of Phonon Angular Momentum
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（博士課程）
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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

Phononics has obtained renewed interest in recent years since the discovery of the phonon Hall effect and the topological nature of phonon systems. Inspired by the discovery of the phonon Hall effect, the angular momentum of phonon has been formulated. The phonon angular momentum is microscopic local rotations of atoms around their equilibrium positions in a lattice. Nevertheless, it usually cancels between phonon modes, and the total phonon angular momentum is zero. In this thesis, we focus on how to generate this phonon angular momentum and to convert it to other degrees of freedom.

In this thesis, we first theoretically propose a phonon thermal Edelstein effect and conversion of the phonon angular momentum to a rigid-body rotation and a magnetization. In non-magnetic crystals without inversion symmetry, the phonon angular momentum of each phonon mode is an odd function of wave vector, and the total phonon angular momentum in equilibrium vanish. When the temperature gradient is applied, the phonon distribution deviates from equilibrium, and then the total phonon angular momentum becomes nonzero. This mechanism is analogous to the Edelstein effect in electronic systems. We estimate the phonon angular momentum generated by the temperature gradient, such as wurtzite GaN, Te, and Se by using the first-principle calculation. Since the phonon angular momentum cannot be directly observed, we propose conversion of the phonon angular momentum to a rigid-body rotation of the crystal and to a magnetization. When the crystal can rotate freely, the phonon angular momentum by the temperature gradient is converted to a rigid-body rotation of the crystal due to the conservation of the angular momentum. This rigid-body rotation is sufficiently fast for experimental measurement when the size of the sample is of the order of micrometer. On the other hand, because the nuclei have effective charges, the phonon angular momentum induces a magnetization.

Next we propose another mechanism for generation of the phonon angular momentum; phonon magnetoelectric effect. In magnetic crystals without the inversion and time-reversal symmetries, the phonon angular momentum consists of two terms: an equilibrium term and a term proportional to a temperature gradient. For the phonon thermal Edelstein effect in magnetic crystals, the response tensor is determined by a magnetic point group. On the other hand, when both symmetries are broken and their product is conserved, the phonon angular momentum of each phonon mode becomes zero at all wave vector, and the total phonon angular momentum becomes zero. In this case, the phonon thermal Edelstein effect does not occur, in order to generate the phonon angular momentum, we propose another mechanism, where the phonon angular momentum is generated by the electric field. This mechanism is analogous to the magnetoelectric effect in multiferroic materials. The response tensor for the magnetoelectric effect of phonons is determined by the magnetic point group of the system. We also show that the phonon angular momentum is generated by the electric field using our toy model. In the magnetoelectric effect of phonons, the modulation of the phonon angular momentum of each phonon mode due to the lattice deformation is important.

Lastly, we show a microscopic mechanism of generating spin magnetization by phonon angular momentum. In previous works in spintronics, it has been shown that the magnetization and the spin current are generated by a mechanical rotation via the spin-rotation coupling, which couples the electron spin and the mechanical rotation. However, it is not understood how the phonon angular momentum which is the microscopic local rotation of atoms couple to electron spins. We discuss the microscopic mechanism for the coupling between the electron spin and the microscopic local rotation of atoms using a toy model. Since the phonon frequency is typically much smaller than that of the electron motion, we calculate the spin expectation values in the two-dimensional honeycomb lattice with the Rashba spin-orbit interaction and the microscopic local rotation of atoms in sublattices A and B by using the second order adiabatic approximation. We show the time average of the spin expectation values along the microscopic local rotational axis over one cycle is proportional to the angular velocity of rotational motion of atoms. Therefore, we expect that the spin magnetization is induced by the microscopic local rotation in systems with the spin-orbit interaction.