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

Multicaloritronics

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Project Information	Project Number : 22H04965 Project Period (FY) : 2022-2026 Keywords : Ferroelectrics, Spin caloritronics, Thermoelectrics, Heat transport

Purpose and Background of the Research

●Outline of the Research

The physics of transport phenomena has been developed by introducing new degrees of freedom and transport carriers that drive "flows" of electricity, heat, and spin or magnetism. For example, in the field of spintronics, the interaction between charge and spin currents has been the main subject of research. The scope of spintronics was explosively expanded by introducing a magnon and temperature gradient as a new transport carrier and driving force, respectively, and new phenomena, principles, and functionalities were discovered one after another. The fusion of spintronics and heat transport/thermoelectric properties gave birth to a field called spin caloritronics, which has grown into an interdisciplinary field rapidly.

In this project, we will develop a new science of transport phenomena in ferroelectrics, which have not been used in spin caloritronics. We introduce ferrons, which are collective motions of spontaneous electric polarization in ferroelectrics, as energy carriers and electric field gradients as driving forces, and elucidate their transport phenomena. This will create "**multicaloritronics**," a cross-disciplinary field of spin caloritronics and ferroelectric physics (Fig. 1). As the history of spin caloritronics shows, the introduction of new transport carriers and driving forces leads to the discovery and elucidation of new phenomena and creation of new functionalities. If ferrons can interact with charge, heat, and spin currents, it is expected to lead to the discovery of many transport phenomena corresponding to each off-diagonal component in the extended transport matrix, and to the creation of innovative energy conversion and control technologies (Fig. 2).

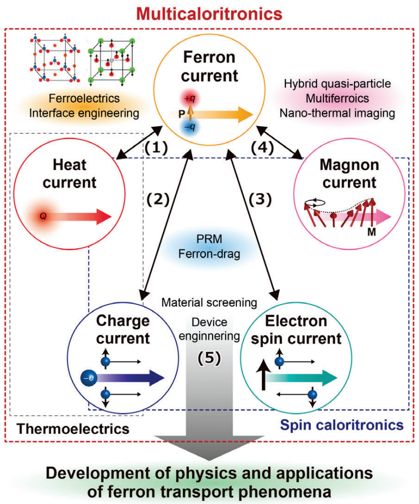

Figure 1. The concept of this project.

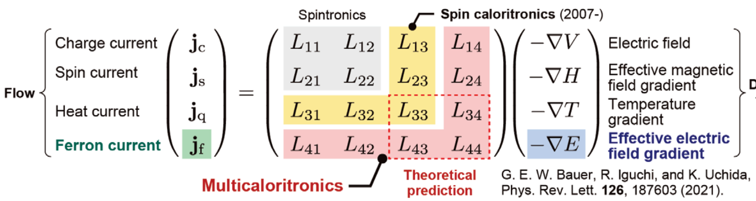

Figure 2. Transport phenomena in multicaloritronics.

Expected Research Achievements

By elucidating the nature of ferron-induced transport phenomena and demonstrating their functionalities, we will lay the foundation for the science and technology based on multicaloritronics. In this project, the following five tasks will be addressed:

(1) Experimental observation of ferron heat transport and thermoelectric conversion in ferroelectric capacitor structures
(2) Clarification of ferron/charge current interaction in ferroelectric/metallic hybrids
(3) Elucidation of ferron/spin current interaction in ferroelectric/ferromagnetic hybrids
(4) Elucidation of ferron/magnon interactions and hybrid ferron quasiparticles
(5) Exploration of new materials and optimization of device structures for high performance ferron transport and conversion phenomena.

We have theoretically shown that (A) ferrons contribute to thermal conduction in ferroelectrics and (B) thermoelectric conversion phenomena occur in ferroelectrics due to ferron transport. These have not been demonstrated yet (Fig. 3) [1-3]. The start-up task of this project is to experimentally observe (A) and (B), for which the basic theory has already been established (task (1)). Subsequently, the target will be extended to hybrid structures of ferroelectrics, metals, and ferromagnets, and fundamental principles and techniques will be established not only for transport properties induced by ferrons themselves but also for interaction between ferrons and electron-spins/magnons (tasks (2)-(4)). By means of our thermal measurement technologies, we will not only explore the principles and functionalities but also optimize materials/devices to improve the performance in ferron-induced phenomena (Fig. 4, task (5)). Through these studies, we will contribute to the establishment of a global research network beyond the framework of spin caloritronics.

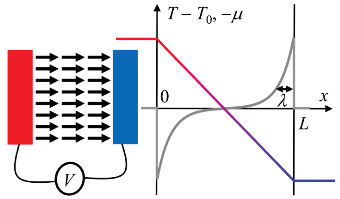

Figure 3. Schematic of the thermoelectric effect in a ferroelectric capacitor [1].

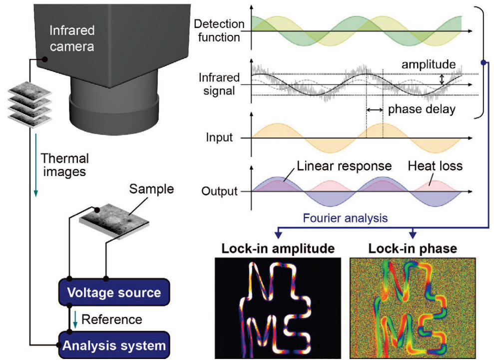

Figure 4. Lock-in thermography method.

Research team:

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Reference

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