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

Exploration of Novel Materials’ Properties Based on Multiferroic Conversion

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Project Information	Project Number : 25H00392　　Project Period (FY) : 2025-2029 Keywords : Ferroic order, Multiferroics, Symmetry breaking, Domain, Nonreciprocal response

Purpose and Background of the Research

●Outline of the Research

This research project explores novel materials’ properties resulting from the conversion of ferroic states by combining multiple ferroic states classified according to the breaking of various symmetries, such as time reversal, space inversion, rotation, and mirror symmetries. We term such conversion "**multiferroic conversion**“. Through approaches such as materials design and development based on the multiferroic conversion and experimental demonstrations of the conversion by external perturbations, we establish the concept of multiferroic conversion which ties seemingly unrelated ordered states, and manifests new materials’ properties by freely converting the ferroic state.

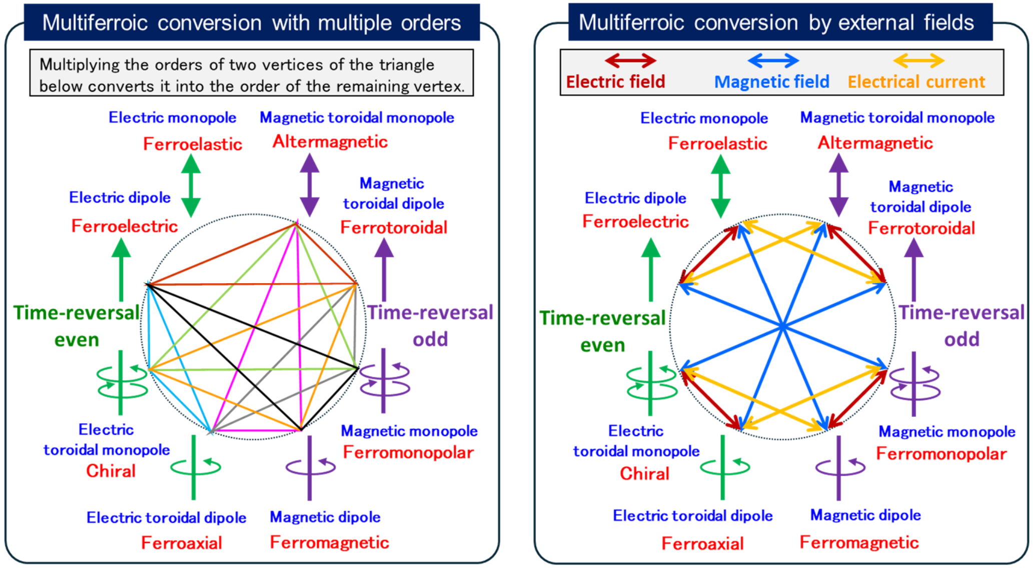

Figure 1. Multiferroic conversion of various ferroic orders and their order parameters with multiple orders (left) and by external perturbations (right).

●Background of the Research

Materials that exhibit multiple ferroic orders are called multiferroics. Among them, those showing the coexistence and/or combination of magnetic order breaking time-reversal symmetry and ferroelectric order breaking space-reversal symmetry have been extensively studied over the past twenty years. Recently, studies on ferroic materials expand toward new classes of ferroic states with various symmetry breakings such as “ferrotoroidal order" breaking both time reversal and space inversion and "ferroaxial order" breaking some mirror symmetry.

●Concept and Purpose of the Research

Recently, our group demonstrated that the application of an electric field to ferroaxial materials manifests optical phenomena specific to chiral materials, such as optical rotation and magnetic chiral dichroism (see Figure 2). This phenomenon can be viewed as a symmetry conversion from the ferroaxial state to the chiral state by an applied electric field. This research project extends this idea to a broader range of ferroic states, which we term “multiferroic conversion”, as summarized in Figure 1. We explore experimental demonstrations of new materials’ properties based on the multiferroic conversion.

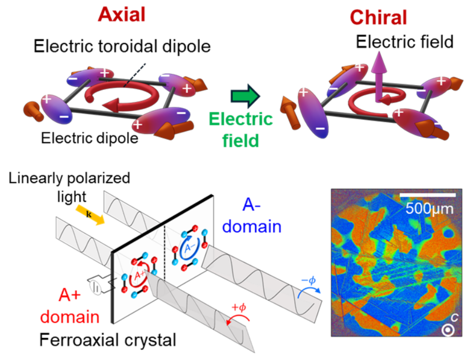

Figure 2. Chiral order and optical rotation induced by an electric field to ferroaxial order.

Expected Research Achievements

We establish the concept of multiferroic conversion that connects different ordered states by designing and synthesizing materials and developing observation methods for a wide variety of materials, including magnetic materials, metals, semiconductors, and dielectrics. To achieve novel materials’ properties and functionalities resulting from this conversion, we will proceed with the following approaches.

●Multiferroic conversion with multiple orders

By combining multiple ferroic orders, we demonstrate multiferroic conversion to a different ferroic order for a variety of orders (see the left panel in Figure 1). An example of this type conversion is shown in Figure 3.

●Multiferroic conversion by external fields

We demonstrate the multiferroic conversion induced by external perturbations such as electric fields, magnetic fields, and electrical currents, as shown in the right panel of Figure 1. An example of this type conversion is shown in Figure 4.

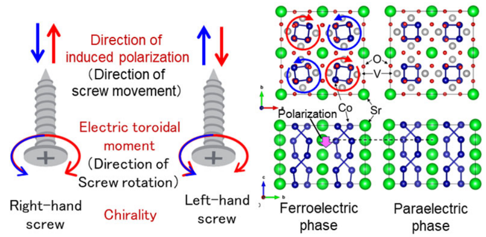

Figure 3. (left) Conversion from ferroaxial order times chiral order to ferroelectric order. (right) An example of materials.

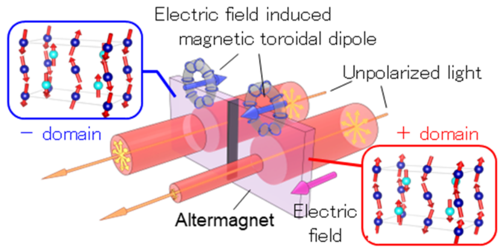

Figure 4. Electric-field-induced directional dichroism expected to emerge in a time-reversed odd altermagnet.

●Improvement of multiferroic properties

Improvement of known multiferroic properties (e.g., enhancement of the effect, room-temperature operation, etc.) will be pursued through approaches such as consideration of electronic transitions and materials development.

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