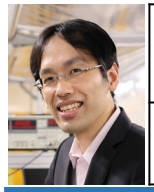
【Grant-in-Aid for Scientific Research (S)】

A Study of Chiral Molecular Spintronics



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Project Information	Project Number : 25H00414　　Project Period (FY) : 2025-2029 Keywords : Spintronics, Chiral molecules, Magnetoresistance, Biomolecules

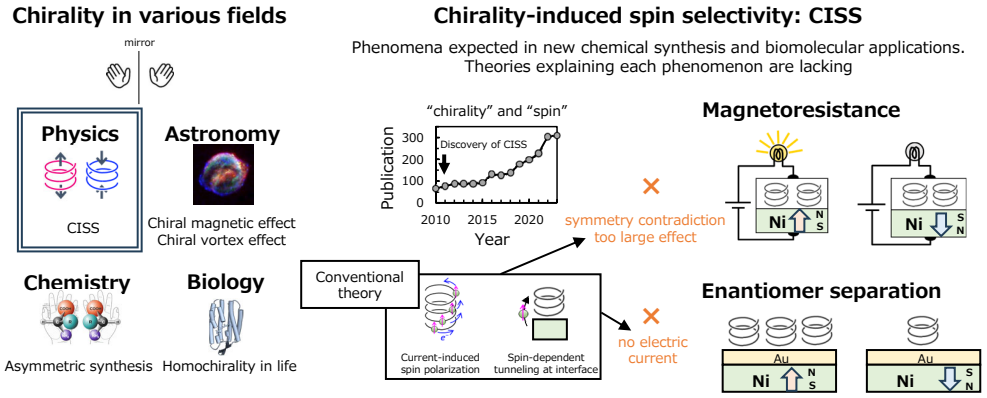
Purpose and Background of the Research

●Outline of the Research

This study applies nano-spintronics technology to a phenomenon known as chirality-induced spin selectivity (CISS), aiming to physically elucidate the phenomenon and utilize it in applications.

●Background of the Research

Chirality refers to a property where an object, like the right and left hands, cannot be superimposed on its mirror image. This property is considered important in various fields such as physics, chemistry, biology, and astronomy. In physics, it is known that chirality is associated with electric currents, producing orbital angular momentum. Moreover, when the interaction between spin and orbit is added, a phenomenon is predicted where the spin becomes polarized by the electric current. This related phenomenon is called CISS, and has been researched for about the last ten years. Meanwhile, a consensus on their fundamental causes has not yet been reached.



Question : **Can CISS-related phenomena be physically understood and applied ?**

Figure 1. Chirality-induced spin selectivity and question in this study

Recently, it was demonstrated that the CISS phenomenon can be observed without using an electric current, through an effective magnetic field (Figure 2.). Furthermore, the origin of this new CISS phenomenon was shown to be spin polarization within chiral molecules induced by heat (Figure 3.). These results suggest that the CISS observed without using electric currents represents the essence of CISS phenomena.

●Purpose of the Research

In this study, we will use sample fabrication and measurement techniques of nano-spintronics to understand the mechanisms of CISS-related phenomena, including magnetoresistance effects, and to develop new theory. The study will also establish methods to enhance the CISS effect. Furthermore, by focusing on the homochirality characteristics of biomolecules, this research aims to apply these findings to biomolecules and beyond.

This study is expected not only to bring new developments in spintronics research but also to re-evaluate the importance of spin science in physics, chemistry, biology, and medicine, fostering new interdisciplinary research.

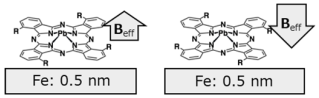


Figure 2. Effective field
Appl. Phys. Express **13**, 113001 (2020)

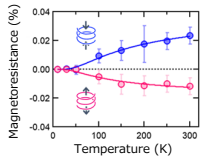


Figure 3. Thermally driven spin polarization
J. Am. Chem. Soc. **144**, 7302 (2022)

Expected Research Achievements

●(I) Construction of Theoretical Framework for CISS through the Thermally Driven Spin Polarization

Our preliminary research suggests that the spin polarization of chiral molecules is closely related to heat, which may serve as a universal origin for the CISS phenomenon. Therefore, this project will utilize first-principles calculations to theoretically derive spin polarization induced by thermal excitation, taking lattice vibrations into account.

●(II) Establishment of Methods to Enhance CISS

By optimizing the arrangement of molecules, we aim to enhance the effects of CISS. We will also develop new materials to replace nickel (Ni), which has been commonly used in traditional CISS research.

●(III) Application of CISS to the Dynamics of Homochiral Biomolecules

We will focus on rhodopsin, a protein that reacts to light energy and possesses various functions. The goal is to electrically investigate how rhodopsin achieves its multifunctionality and how its structure changes, utilizing the effects of CISS.

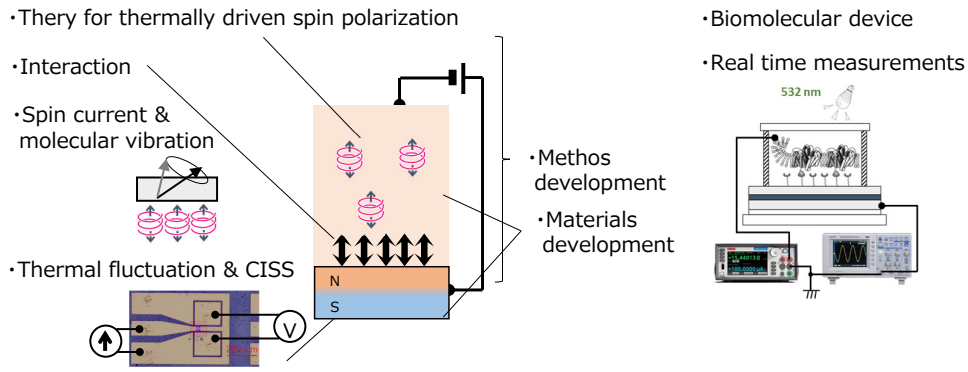


Figure 4. Implementation Overview

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