CEMS Topical Meeting Online

Interplay between Chirality and Magnetism

Timetable

and

Abstracts

Timetable

Time	Speaker	Title of the Talk
13:00	Daigo Miyajima (RIKEN CEMS)	Opening
13:10	Hiroshi Yamamoto (IMS)	Chirality-Induced Spin Selectivity in an Organic Superconductor
13:55	Kouta Kondou (RIKEN CEMS)	Observation of Chirality Induced Magnetoresistance Due toThermally Driven Spin Polarization
14:40	Tetsuaki Itou (Tokyo University of Science)	Current-Induced Magnetization in Elemental Tellurium
15:25	Closing	
15:40	Kouji Taniguchi (Tohoku University)	Optical responses coupled with spins in the chirality-introduced layered organic-inorganic hybrid perovskites
16:25	Masayuki Suda (Kyoto University)	Novel Hybrid Chiral Mateirlas for Spin-polarized Charge Transport and Spin-dependent Electrocatalytic Applications
17:10	Closing	

Chirality-Induced Spin Selectivity in an Organic Superconductor

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Chirality-Induced Spin Selectivity (CISS) effect is attracting recent attention as a new source of spin polarized current. Through this effect, chiral molecules can sometimes generate electrical currents whose spins are highly oriented depending on the molecular handedness and the current direction. It also provides unique methods for enantio-separation, enantio-selective electrochemical reactions, and an efficient water oxidation. The mechanism of CISS effect is, however, yet to be clarified, as the effect is much larger than expected one estimated by normal theoretical investigation based on a small spin-orbit coupling for light elements. In a hypothetical consideration, it is proposed that an enhancement of spin polarization is based on anti-parallel spin polarizations at two opposite ends of a chiral molecule created in a non-equilibrium condition.

In our experiment, we have tried to confirm this hypothesis by using an organic chiral superconductor, which has chiral crystal structure with coherent electrons, under electrical excitation. By measuring spin-dependent voltage drop created at nickel electrodes attached to the chiral superconductor, we have successfully confirmed an enhanced spin accumulation exceeding the expectation from Edelstein effect. Moreover, formation of a pair of antiparallel spin accumulations at two opposite ends of the superconducting crystal was confirmed, which further supports the above hypothesis.

Observation of chirality induced magnetoresistance due to thermally driven spin polarization

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Molecular chirality is an essential parameter for inducing spin functionalities in organic materials. Indeed, the spin polarization of electrons passing through chiral molecules has been investigated intensively since 20 years ago [1]. This feature is called the chiral induced spin selectivity (CISS) effect, which has been confirmed using various experimental techniques [2]. Such a chiral molecule-induced phenomenon should lead to the driving principle of nanoscale spin manipulation in the wide range of fields such as spintronics, quantum computing, and biochemistry.

Recently, several experimental studies have reported that a chiral molecule could behave like a magnet [3-6]. In contrast to the previously reported CISS effect, no bias charge current flows through the molecule implying that the magnetization, i.e., spontaneous spin polarization, might emerge in the chiral molecules. Thus, here we experimentally demonstrate the CISS-related spontaneous spin polarization by means of magnetoresistance measurements. Figure shows the schematic illustration of chiral molecule induced current-in-plane magnetoresistance (CIP-MR) [7]. By using the chiral molecule/ferromagnet bilayer, we observed the chirality dependent CIP-MR, which does not require the bias charge current in the chiral molecule. Moreover, the temperature dependence of the CIP-MR suggests thermally driven spontaneous spin-polarization in the chiral molecules is the key for the observed MR.

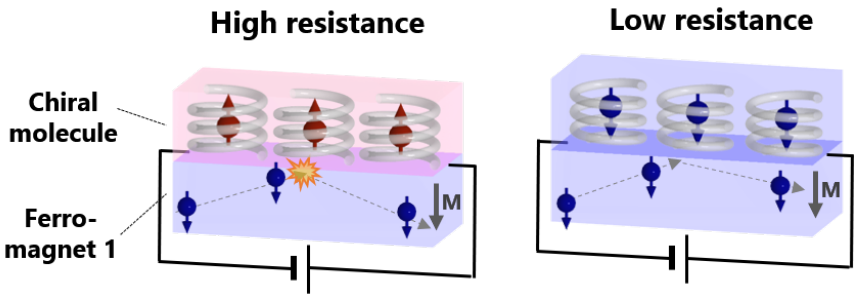

Figure Schematic illustration of chiral-molecule induced current-in-plane magnetoresistance in chiral molecule/ferromagnet bilayer. Springs beside each chiral molecule denote the helicity.

[1] K. Ray, S. P. Ananthavel, D. H. Waldeck, and R. Naaman, Science **283**, 814 (1999).
[2] R. Naaman, Y. Paltiel, and D. H. Waldeck, Nature Reviews Chemistry **3**, 250 (2019).
[3] O. Ben Dor *et al.,* Nat Communications **8**, 14567 (2017).
[4] H. Alpern *et al*., Nano Letter **19**, 5167 (2019).
[5] S. Miwa, K. Kondou *et al*., Applied Physics Express **13,** 113001 (2020).
[6] N. Goren, S. Yochelis, G. Jung, G. Y. Paltiel, Applied Physics Letters, **118** (17) (2021).
[7] K. Kondou *et al.* arXiv:2112.08607

Current-induced magnetization in elemental tellurium

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I will present our demonstration of current-induced bulk magnetization in trigonal tellurium [1]. From the viewpoint of symmetry, the current-induced bulk magnetization effect can be observed in a system belonging to "gyrotropic" point groups, which include chiral (enantiomorphic) point groups, as shown in Fig. 1 [2]. Meeting this condition, trigonal tellurium consists of helical right-handed or left-handed chains of tellurium atoms in a hexagonal arrangement and belongs to the chiral point group D_3.

We measured the ^{125}Te NMR spectra of single crystals of p-type tellurium under an applied pulsed electric current parallel to the *c* axis. We observed the current-induced shift of a ^{125}Te-NMR spectrum depending on the strength and the polarity of an applied electric current. We also observed that the current-induced NMR shift is reversed by a chirality reversal of the tellurium crystal structure. These results clearly indicate that an applied current induces bulk electronic magnetization.

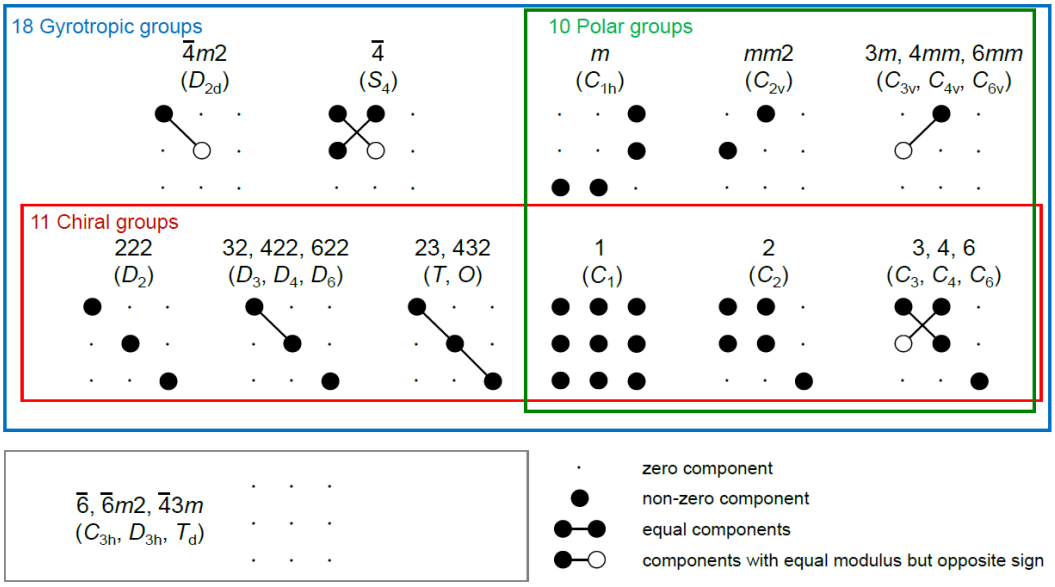

Fig 1. Possible second-rank axial tensor forms of the linear current-induced magnetization effect for 21 noncentrosymmetric crystal point groups [2].

[1] T. Furukawa, Y. Shimokawa, K. Kobayashi, and T. Itou, *Nat. Commun.* **8**, 954 (2017).

[2] T. Furukawa, Y. Watanabe, N. Ogasawara, K. Kobayashi, and T. Itou, *Phys. Rev. Research* **3**, 023111 (2021).

Optical responses coupled with spins in the chirality-introduced layered organic-inorganic hybrid perovskites

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Organic-inorganic hybrid perovskite (OIHP)-type lead halides are recently attracting worldwide interest as a photoelectric conversion material, such as a light absorber in the solar cell [1]. Herein, we report the zero-bias photocurrent generating phenomena, such as bulk photogalvanic effect (BPVE) [2] and circular photogalvanic effect (CPGE) [3], and the nonreciprocal directional dichroism induced by the optical magneto-electric effect (OME-effect) [4] in the noncentrosymmetric 2D-OIHP metal halides, which are designed by incorporating organic chiral molecular cations between the inorganic layers of metal halides. In particular, the CPGE originates from spin-polarized electronic band structures in noncentrosymmetric systems with strong spin-orbit coupling (SOC) and is expected as a fascinating opto-electronic effect, which might generate spin-polarized current only by light irradiation without application of a bias voltage even in nonmagnetic systems. In our study, we have observed light-helicity-dependent steady photocurrents induced by the CPGE and the chirality dependent CPGE in the chiral 2D-OIHP lead iodides. These results indicate the formation of chirality dependent radial spin texture in the ***k***-space of chiral 2D-OIHPs with strong SOC. In addition, we have also developed noncentrosymmetric ferromagnets in 2D-OIHPs based on the materials design concept introducing chiral molecules into the inorganic layers. In the developed noncentrosymmetric ferromagnetic copper chlorides, nonreciprocal directional dichroism has been induced by the OME-effect. As demonstrated in our studies, OIHP-type compounds should be promising platforms for opto-spintronics and magneto-optics applications in the future.

[1] A. Kojima, K. Teshima, Y. Shirai, T. Miyasaka, *J. Am. Chem. Soc.,* ***2009***,*131*, 6050-6051.
[2] P.-J. Huang, K. Taniguchi, H. Miyasaka, *J. Am. Chem. Soc.,* ***2019***,*141*, 14520-14523.
[3] P.-J. Huang, K. Taniguchi *et al*., *Adv. Mater.,* ***2021***, *33*, 2008611 (1)-(9).
[4] K. Taniguchi *et al*., *Angew. Chem. Int. Ed..,* ***2021***, *60*, 14350-14354.

Novel Hybrid Chiral Materials for Spin-polarized Charge Transport and Spin-dependent Electrocatalytic Applications

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Abstract:

The chiral-induced spin selectivity (CISS) effect enables the application of chiral organic materials for spintronics and spin-dependent electrochemical applications. It has been demonstrated on various chiral monolayers, in which their conversion efficiency is limited. On the other hand, relatively high spin polarization (SP) rates are observed on bulk chiral materials; however, their poor electronic conductivities limit their application. In this study, the design of organic-inorganic hybrid materials with a high SP rate and high conductivity is reported. Molecular chirality was introduced to the inorganic nanomaterials such as metal nanoparitcles and transition metal dichalcogenides through the chemical reactions. This design approach activated multiple tunneling channels in the chiral layers, which resulted in a SP rate as high as 75%. The synergistic effect has been demonstrated as an interplay of the high SP rate and the high conductivity or high catalytic activity on the performance of spin-dependent electrocatalysis. This novel approach employed in this work paves way for the development of other novel chiral systems for spintronics and spin-dependent electrochemical applications.