2-5-18. Inorganic Chiral Materials

Overview

Research on inorganic chiral materials traces back to 1811, when Arago discovered the optical rotation of quartz. The field subsequently expanded to include metal complexes, inorganic crystals, and related systems. In the 21st century, the scope of inorganic chirality has broadened to encompass metallic nanoclusters, semiconductor quantum dots, chiral magnets, photonic crystals, metamaterials, and perovskite materials. Recent advances have focused on the development of novel crystal structures and optoelectronic, photonic, and spin-related functionalities, yielding a rapidly emerging interdisciplinary area at the interface of photochemistry and materials science. These achievements have paved the way for applications in optical devices and spintronics, positioning inorganic chiral materials as pivotal for next-generation technological innovations.

Current Status and Frontiers

In recent years, the development of inorganic chiral materials has undergone a remarkable transformation, driven by nanostructure control via surface modification, self-assembly, and integration with organic chiral molecules. Early research focused on optically active crystals such as quartz and elemental tellurium, as well as chiral-ligand-based metal complexes (including chiral lanthanide complexes). Since the 2000s, advances in nanomaterials have led to extensive synthesis and applications of chiral metal and semiconductor nanostructures. Synthetic strategies employing chiral auxiliaries, ligand exchange, and self-assembled templating have produced a diverse array of chiral nanoparticles, including those based on gold, silver, palladium, and metal oxides. At the nanoscale, controlled anisotropy and morphology enable the emergence of strong circular dichroism (CD) and circularly polarized luminescence, propelling research toward bio-sensing and advanced optical devices. Of particular interest is the recent elucidation of chirality-induced spin selectivity (CISS) effects and spin-polarized states in inorganic chiral crystals with broken special inversion symmetry (e.g., $CrNb_3S_6$). These findings have accelerated the integration of chiral materials into spintronics and quantum information science.

The lead halide perovskites, focused on next-generation solar cell materials, has further expanded the landscape of chiral materials. Notably, two-dimensional (2D) hybrid perovskites incorporating chiral molecules into the organic layers can induce both chirality and polarity at the layer scale. Taniguchi and Miyasaka demonstrated bulk photovoltaic effects (BPVE) in such materials. The observed BPVE, fundamentally different from conventional photovoltaic effects, arises from the spatial asymmetry and chiral structure within the perovskite layers, leading to dramatic enhancement of photovoltage performance. Additional studies on similar hybrid systems have identified spin-split states due to broken inversion symmetry, resulting in new spin-photonic functionalities such as the circular photogalvanic effect.

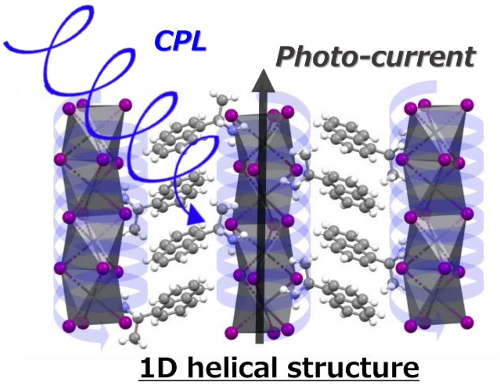

Figure 1. CPL detection of 1D helical perovskite.

Ishii and co-workers have recently developed one-dimensional (1D) helical lead halide perovskite crystals. Incorporation of chiral organic cations induces a helical structure within the inorganic framework, resulting in extraordinary circular dichroism surpassing that of previously reported organic and 2D chiral perovskites. Thin-film devices employing these 1D crystals as photoactive layers achieve selective detection of right- and left-circularly polarized light, with record-high polarization extinction ratio ratios (up to 25.4) in circularly polarized photodetectors. This outstanding performance originates from a unique spin-split band structure arising from the synergy between the helical lattice and strong spin-orbit coupling of Pb and I ions. Intriguingly, spin polarization and bulk photovoltaic effects as high as 15 V are observed in systems with additional polarity. Such low-dimensional chiral perovskites have garnered international attention as promising materials for chiral photonics and advanced spintronic technology.

References

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Future Perspectives and Directions

Future research on inorganic chiral materials is expected to benefit from advances in nanoscale structural control and hybridization with organic frameworks, enabling the integrated manipulation of light, charge, and spin in multifunctional materials. In particular, the continued evolution and practical realization of low-dimensional chiral perovskites and helical crystals will accelerate the deployment of high-performance circularly polarized light detection, photovoltaic generation, and spintronic devices. The scope of applications is expected to extend to quantum information processing, light energy conversion, and beyond. (Author: Ayumi Ishii)