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Solution-Processed Chiral Perovskites for Biomedical Applications

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Editorial
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Editorial

Chirality (conformational arrangements) is a geometric property describing objects that are non-superimposable on their mirror images, a phenomenon known as broken mirror symmetry. In molecular science, this results in two distinct mirror-image forms called enantiomers, often labelled as *R/S or L/D*, which are right-handed and left-handed versions of the same molecule. The functional significance of chirality arises from how these specific "handednesses" interact at chiral interfaces or with chiral light, enabling highly precise molecular analysis and offering great potential for biomedical applications [1].

Keywords

Chiral Perovskites; Semiconductors; Nanomaterials

Abbreviations

CD: Circular Dichroism; CPL: Circularly Polarized Luminescence; NLO: Nonlinear Optical; CISS: Chiral-Induced Spin Selectivity.

Introduction

Chirality is a ubiquitous property of nature and is essential to organic systems such as DNA, RNA, proteins, and saccharides. Notably, these biological systems are homochiral, meaning they exist in only one enantiomeric form, a property critical to sustaining life. Naturally, often only one enantiomer (configuration) is biologically active or beneficial, while its mirror image can be inert or even harmful. A stark example is found in Parkinson's disease treatment: *L*-dopamine provides therapeutic relief, whereas its counterpart, *D*-dopamine, can lead to toxic side effects like mitochondrial dysfunction and weight loss. This underscores the urgent need to develop synthetic chiral materials. Consequently, there is a strong drive to engineer inorganic chiral nanostructures. These nanomaterials offer significant advantages, including a high surface-to-volume ratio for enhanced interactions, superior structural stability, tunable optical, electrical, and magnetic properties, resilience in harsh environmental conditions, and straightforward synthesis [2].

Recent advances have led to asymmetric, engineered perovskites by incorporating chiral molecular organics into their frameworks, expanding their potential beyond displays into medicine. This engineered asymmetry directly yields unique chiroptical and electronic phenomena: circular dichroism (CD), circularly polarized luminescence (CPL), nonlinear optical (NLO) responses, and the chiral-induced spin selectivity (CISS) effect. Given the fundamental role of chiroptical effects in biological processes, the ability to modulate a perovskite's key features via chiral ligand integration becomes a powerful tool, thus facilitating their customization for a spectrum of cutting-edge applications. Despite the established role of perovskite-based materials technologies in bioimaging and detection [3,4], the landscape of chiral perovskites and their considerable potential for advanced biology remains markedly underexplored.

Various methodologies enable the integration of chirality into perovskite architectures. These include:

- a chiral ligand-induced strategy, where chiral organic

molecules are incorporated as A-site cations a comparatively straightforward approach [5]

- inducing chiral distortion on perovskite surfaces using adsorbed chiral molecules [6]
- achieving enantiomer enrichment via chiral dislocations prompted by organic molecules Zhong WH, et al. [7] and
- a final mechanism involving chirality transfer through electronic interactions between achiral inorganic frameworks and chiral ligands. These techniques collectively provide a toolkit for imparting chiroptical activity.

Several distinct synthetic strategies have been developed to impart chirality into perovskite architectures. The first is the **chiral ligand-induced strategy**, which involves introducing suitable chiral organic molecules as the A-site cation; this method is regarded as relatively straightforward. A second approach induces **chiral distortion** of the perovskite surfaces through interaction with adsorbed chiral molecules. A third technique achieves **enantiomer enrichment** via chiral dislocations prompted by organic molecules. Finally, a fourth mechanism operates through **chirality transfer**, mediated by electronic interactions between inherently achiral inorganic frameworks and chiral ligand molecules [8]. These methods provide a versatile platform for engineering chiroptical properties.

This curated collection consolidates the fundamentals and recent advancements in chiral perovskite architectures, providing a foundational understanding for emerging technological platforms. This pioneering study, conducted by Zhao, et al. [9], investigated the development of bifunctional, water-stable chiral perovskite nanomaterials, Bio-(S/R-PEA)$_2$CsPb$_2$Br$_7$, for advanced biological applications. Synthesized via an improved ligand-assisted method and stabilized with mPEG-NH$_2$, these materials uniquely integrate chirality to biological specificity. Their dual functionality was demonstrated in two distinct realms: first, as highly sensitive fluorescent probes for aqueous H_2S detection, exhibiting rapid, visually detectable fluorescence quenching and a low detection limit. Second, leveraging their inherent positive surface charge, they served as potent antimicrobial agents, achieving exceptional inhibition rates over 97% against E. coli by disrupting bacterial membrane permeability. This work represents a significant breakthrough, marking the first application of organic-inorganic hybrid perovskites as versatile bifunctional tools that combine superior optical properties with inherent biocatalytic activity for imaging and antibacterial applications [10].

Similarly, Huang, et al. [5] used a low-temperature crystallization method to successfully synthesize a pair of enantiomeric single-crystalline perovskites, R- and S-(BrBA)$_2$PbBr$_4$. These two-dimensional chiral materials display notable structural distortion in their inorganic frameworks, driven by the integrated chiral organic cations. This structural feature provides a significant circular dichroism response and a photocurrent anisotropy factor of 0.14 at 405 nm. Along with a wide optical bandgap and a device design with vertical electrodes, these properties enable highly sensitive detection of circularly polarised ultraviolet light with minimal dark current. Additionally, the semiconductor demonstrates exceptional performance in X-ray detection, achieving a sensitivity of 531.33 $\mu CGy^{-1}cm^{-2}$ and an impressively low detection limit of below 100 $nGys^{-1}$, greatly surpassing the sensitivity required for medical imaging. Practical X-ray imaging tests confirm its strong potential for direct application in radiographic procedures.

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