

Free-bromine-induced anomalous bulk photovoltaic effect in chiral metal halides for self-driven circularly polarized light detection

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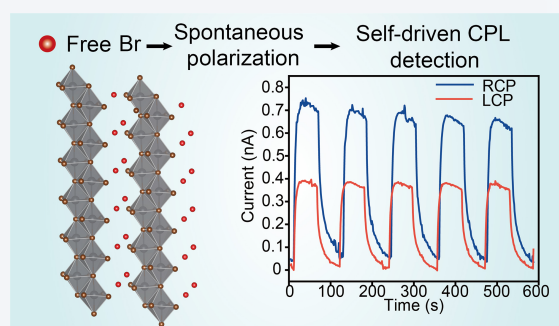
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ABSTRACT: Chiral polar metal halides can generate spontaneous polarization, endowing them with potential for self-driven circularly polarized light (CPL) detection. However, most chiral metal halides crystallize in non-polar space groups and cannot generate spontaneous polarization, making efficient self-driven CPL detection difficult. In this work, for the first time, we propose a strategy to induce spontaneous polarization into non-polar chiral halides by introducing free halogens into the halide lattice via a solvothermal method. We find that this strategy not only breaks the intrinsic symmetry of non-polar R/S -MPZPbBr₄ and transforms it into R/S -MPZPbBr₄·0.5Br₂ with the polar space group C_2 , but also induces larger octahedral distortion, which enhances the circular dichroism anisotropy factor (g_{CD}) by 8 times. Benefiting from spontaneous polarization and the enhanced g_{CD} , R/S -MPZPbBr₄·0.5Br₂ exhibits an anomalous photovoltaic effect of 3.8 V under zero bias and enables efficient self-driven CPL detection, with an anisotropic response factor (g_{res}) as high as 0.61. Our work opens a new pathway for designing chiral metal halides for self-driven CPL detection.

KEYWORDS: chiral metal halides, spontaneous polarization, bulk photovoltaic effect, circularly polarized light (CPL) detection



1 Introduction

Chiral metal halides possess unique circular dichroism (CD) and circularly polarized luminescence due to their non-centrosymmetric crystal structures, enabling them to directly generate differential optical responses to circularly polarized light (CPL). Unlike conventional polarization detection schemes that rely on external polarizers, the intrinsic chiroptical activity of chiral metal halides provides an ideal material platform for compact CPL detectors [1–4]. For example, Oh et al. significantly enhanced the chiroptical performance of two-dimensional lead-iodide chiral metal halides by introducing a dual-spacer cation strategy using non-chiral hexane-1,6-diammonium (HDA) and chiral 1-(chlorophenyl)ethylammonium (CIPEA), achieving a circular dichroism anisotropy factor (g_{CD}) as high as 0.018 [5]. Ishii et al.

synthesized a one-dimensional (1D) helical lead-iodide halide based on chiral naphthylethylamine (R/S -NEA)PbI₃. Owing to the asymmetric electronic transitions characteristic of the helical 1D structure, (R/S -NEA)PbI₃ achieves g_{CD} as high as 0.013 [6]. These studies demonstrate the unique structural advantages of chiral metal halides for CPL detection.

In self-driven CPL detection, the key to efficient separation of photogenerated carriers without an external electric field lies in the bulk photovoltaic effect (BPVE). The BPVE originates from the non-centrosymmetric structure of crystals and can generate photovoltages well exceeding the bandgap. For chiral polar halides, the synergy between non-centrosymmetry and spontaneous polarization can form a strong built-in electric field, significantly enhancing the BPVE [6–9]. For example, in 2024, Long et al. synthesized a chiral three-dimensional perovskite (R/S -PyEA)Pb₂Br₆ with space group $P2_1$, and combined it with a one-step capillary-bridge assembly technique to achieve full-Stokes polarization detection [10]. In 2025, Sun et al., for the first time, realized synergistic coupling of multiaxial ferroelectricity and broadband photopyroelectric effects in (BZA)₂(DMA)BiBr₆ through an organic mixed-cation alloying strategy, achieving a photocurrent enhancement ratio (~ 4800%) far exceeding that of known

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ferroelectric materials [11]. Furthermore, Luo et al. reported that para-site halogen substitution of the spacer cation ((4IBA)₂(EA)₂Pb₃Br₁₀) significantly enhanced P_s and promoted Br ion migration, thereby realizing an ultra-large anomalous photovoltaic output of 38.2 V [12]. The above studies show that polar chiral halides, which combine chirality and spontaneous polarization, exhibit unique advantages in self-driven CPL detection [13–17]. However, a large number of chiral metal halides crystallize in non-polar space groups (such as $P2_12_12_1$). They lack a spontaneous electric dipole moment and cannot form a strong built-in electric field to drive an efficient BPVE [18–21].

Accordingly, controllably introducing spontaneous polarization into non-polar chiral halides while maintaining the chiral structure has become a research focus in the field of self-driven CPL detection [22–27]. In recent years, researchers have developed several ingenious strategies to break centrosymmetry or induce polarization. For example, Yang et al. applied a local strain gradient on the surfaces of centrosymmetric SrTiO₃, TiO₂, and silicon single crystals using an atomic force microscope tip. Through the flexoelectric effect, they induced local symmetry breaking and realized the flexo-photovoltaic effect in materials that originally did not exhibit the bulk photovoltaic effect [28]. Another promising strategy is intralayer sliding. Li et al. found that in a monolayer of two-dimensional GaSe with a mirror-symmetric structure, intralayer sliding of the Se sublayer breaks the local mirror symmetry, thereby generating out-of-plane and in-plane ferroelectricity that are intercorrelated, with the polarization strength increasing with the number of layers [29]. Although the above strategies based on mechanical strain gradients and intralayer sliding have successfully introduced polarization into materials lacking centrosymmetry, these methods typically require precise nanoscale external force application or rely on relative sliding between specific atomic layers, posing challenges for macroscopic controllable fabrication and device integration. Notably, current attempts to induce spontaneous polarization in non-polar chiral halides have mainly focused on external physical field modulation, whereas the strategy of introducing free halogens to break crystal symmetry and induce spontaneous polarization has remained completely unexplored to date [30–32].

In this work, we propose a new strategy based on free-halogen modulation, distinct from traditional polarization-induction approaches relying on external mechanical strain. Free bromine was introduced into the lattice of R/S -MPZPbBr₄ via a hydrobromic acid solvothermal method. This strategy shortens the distance between hydrogen-bond donors and acceptors through steric effects, thereby significantly enhancing the hydrogen-bonding interactions. Such enhanced hydrogen-bonding interactions not only break the intrinsic symmetry of the crystal, transforming its space group from non-polar $P2_12_12_1$ to polar C_2 , but also induce larger octahedral distortion, which enhances g_{CD} by 8 times. Benefiting from the synergy of spontaneous polarization and the enhanced g_{CD} , R/S -MPZPbBr₄·0.5Br₂ exhibits an anomalous BPVE and achieves high-performance self-driven CPL detection. This work opens a new pathway for realizing self-driven CPL detection in non-polar chiral systems.

2 Experimental section

2.1 Materials

R -(−)-2-methylpiperazine (C₅H₁₂N₂, 98%, R -MPZ), S -(+)-2-

methylpiperazine (C₅H₁₂N₂, 98%, S -MPZ), and lead(II) bromide (PbBr₂ analytical reagent (AR), 99%), were purchased from MACKLIN and hydrobromic acid (HBr, 40%) was purchased from Kelong Chemical Co. These materials were used without any purification or other treatment and without secondary purification processes.

2.2 Synthesis of R/S -MPZPbBr₄

R/S -MPZPbBr₄ crystals were prepared via the slow-evaporation crystallization method. 1 mmol (0.367 g) of PbBr₂ and 1 mmol (0.100 g) of R/S -MPZ were weighed and transferred into a 20 mL glass vial. Subsequently, 2 mL of HBr was added to the vial, which was then sealed and placed on a heating plate maintained at 60 °C. The mixture was stirred for 30 min until all solids were fully dissolved to yield a transparent precursor solution. Afterwards, the vial cap was removed to enable slow solvent evaporation under a constant temperature of 60 °C. White crystalline precipitates formed after several days. Once crystallization was complete, the resulting crystals were collected, washed three times with anhydrous ethanol, and dried at room temperature to afford the target product.

2.3 Synthesis of R/S -MPZPbBr₄·0.5Br₂

R/S -MPZPbBr₄·0.5Br₂ crystals were synthesized using the programmed cooling crystallization method. 1 mmol (0.367 g) of PbBr₂ and 1 mmol (0.100 g) of R/S -MPZ were weighed and loaded into a 20 mL glass vial. HBr (2 mL) was added to the vial, which was subsequently sealed and set on a heating plate. The mixture was heated to 150 °C under continuous stirring. Along with the temperature increase, the solution gradually turned from yellow to red, which signified full dissolution of the precursors and the occurrence of coordination reaction. The mixture was further stirred at 150 °C for 30 min to achieve complete dissolution of solids and generate a clear solution. Afterwards, the stir bar was taken out, and the solution was slowly cooled down to room temperature at a rate of 2 °C/h. Red crystals were precipitated during the crystallization process. Upon the completion of crystallization, the as-obtained crystals were harvested, washed three times with anhydrous ethanol, and dried at room temperature to afford the target product.

2.4 Characterizations

The crystal structure, morphology, and elemental distribution were characterized by X-ray diffraction (XRD, Bruker D8 Discover) and scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS, Zeiss Sigma 500). Photoluminescence (PL) and time-resolved PL decay were measured using a Horiba Jobin Yvon Fluorolog-3 spectrometer. Absorption spectra were recorded on a ultraviolet–visible–near-infrared (UV–Vis–NIR) spectrophotometer (PerkinElmer Lambda 750). CD spectra were collected on a Jasco J-715 spectropolarimeter, and each spectrum represents the average of 3–5 scans.

3 Results and discussion

1D R/S -MPZPbBr₄ with the space group $P2_12_12_1$ was synthesized by an evaporation-crystallization method [33]. Subsequently, free bromine was introduced via a solvothermal method, followed by cooling crystallization to obtain 1D R/S -MPZPbBr₄·0.5Br₂ with the space group C_2 . Powder X-ray diffraction (PXRD) patterns confirm

the successful synthesis of the target phase, and no impurity peaks are observed (Fig. 1(b)), and Figs. S1 and S2 in the Electronic Supplementary Material (ESM)), and scanning electron microscopy with EDS further confirms the introduction of free Br and its uniform elemental distribution (Fig. 1(c)), and Figs. S3 and S4 in the ESM). X-ray photoelectron spectroscopy (XPS) verify that the free bromine incorporated into the crystal lattice exists in the form of free bromine (Fig. S5 in the ESM). Notably, starting from $R\text{-MPZPbBr}_4$ that crystallizes in the non-polar space group $P2_12_12_1$, the crystals were immersed in HBr solution. The solution was heated to 150 °C to completely dissolve $R\text{-MPZPbBr}_4$, forming a clear solution. Subsequently, the solution was slowly cooled at a rate of 5 °C/h, and red crystals gradually precipitated. The obtained crystals were washed and dried to afford the target product $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$. During this process, free Br successfully enters the crystal lattice, breaks the symmetry of the original crystal, and transforms the space group from non-polar $P2_12_12_1$ to polar C_2 , thereby introducing spontaneous polarization into the material, activating the bulk photovoltaic effect, and achieving a functional conversion from luminescence to photodetection. Conversely, $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ was dissolved in HBr and then subjected to solvent evaporation at 60 °C. As the solvent slowly evaporated, white crystals gradually precipitated from the system. After washing and drying, the initial $R\text{-MPZPbBr}_4$ was recovered (Fig. 1(d)).

To further elucidate the origin of the space-group change induced by the introduction of free Br, the crystal structures of the two materials were analyzed in depth. After free Br introduction, the interchain distance would be expected to increase owing to

steric effects, but the opposite trend is observed. The interchain distance of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ is 10.62 Å, significantly smaller than that of $R\text{-MPZPbBr}_4$ (10.69 Å, Fig. 2(a)). This change is attributed to the fact that free Br alters the electron density around bromine atoms and the hydrogen-bond acceptor sites of the organic cations, thereby strengthening the hydrogen bonds between the organic cations and the inorganic framework and shortening the interchain distance. Moreover, the introduction of free Br brings additional Br⁻ ions, forming more Br...Br halogen bonds that provide extra attractive forces, leading to tighter stacking of adjacent chains. Hirshfeld surface analysis and the corresponding interaction force diagram of free Br (Fig. 2(b)) and Figs. S6–S9 in the ESM) show that in $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ the interactions of free Br with neighboring atoms include Br...Br and Br...H, with Br...Br accounting for 80.2% and Br...H for 19.8%, indicating that the reduction in interchain distance results from the synergistic effect of both factors.

Further structural analysis reveals that the average lengths of C–H...Br and N–H...Br hydrogen bonds in $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ are significantly shortened, which is attributed to the steric effect of free Br that compresses the distance between hydrogen-bond donors and acceptors (Figs. 2(c) and 2(d)). Shorter hydrogen bonds generally correspond to stronger interactions, and such stronger interactions predispose the octahedra to larger geometric distortions, thereby increasing the degree of octahedral distortion. Quantitative analysis of the octahedral distortion based on structure refinement confirms this: the distortion index and bond-angle variance of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ are 0.0335 and 15.6, respectively, higher than those of $R\text{-MPZPbBr}_4$ (0.0319 and 12.8) (Fig. 2(e)). The

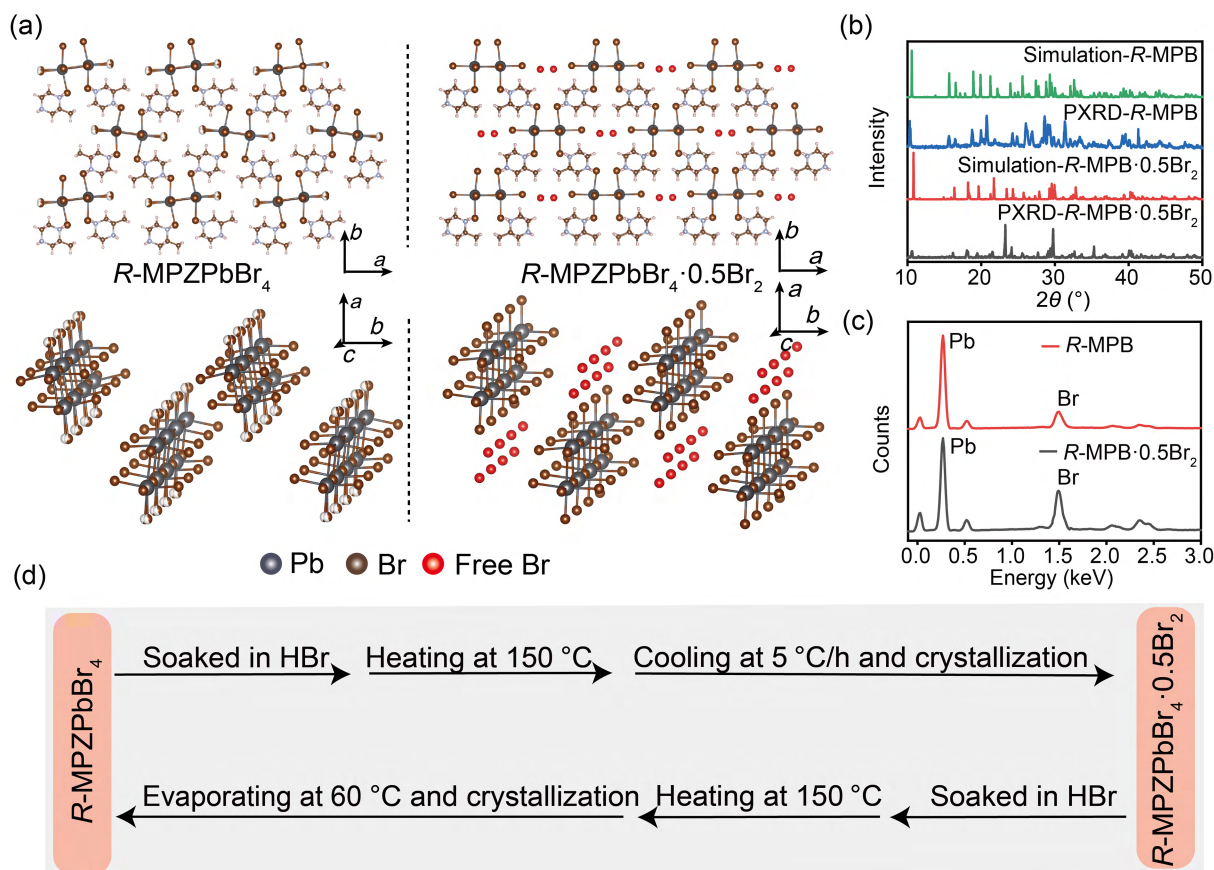


Figure 1 (a) Crystal structures, (b) PXRD patterns, (c) EDS, and (d) schematic diagram and experimental methods for the interconversion between self-driven CPL detection materials and CPL materials of $R\text{-MPZPbBr}_4$ and $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$.

larger octahedral distortion leads to a greater breaking of symmetry, which in turn triggers the space-group transition from $P2_12_12_1$ to C_2 .

Larger structural distortion implies more pronounced symmetry breaking, which induces a larger electric dipole moment and ultimately generates a stronger CD response. Figures 3(a)–3(c) clearly verify this trend that R -MPZPbBr₄ exhibits a single CD peak at 385 nm, whereas after the introduction of bromine, R -MPZPbBr₄·0.5Br₂ shows two peaks at 480 and 583 nm. The CD

spectra of both materials are in good agreement with their corresponding absorption spectra. In terms of g_{CD} , the maximum value of R -MPZPbBr₄·0.5Br₂ reaches 5.2×10^{-2} , which is approximately 8 times higher than that of R -MPZPbBr₄ (6×10^{-3}), fully demonstrating the advantage of distortion-enhanced chiroptical responses. However, PL results show that R -MPZPbBr₄ exhibits bright yellow emission at 591 nm, whereas R -MPZPbBr₄·0.5Br₂ shows almost no PL signal. This luminescence

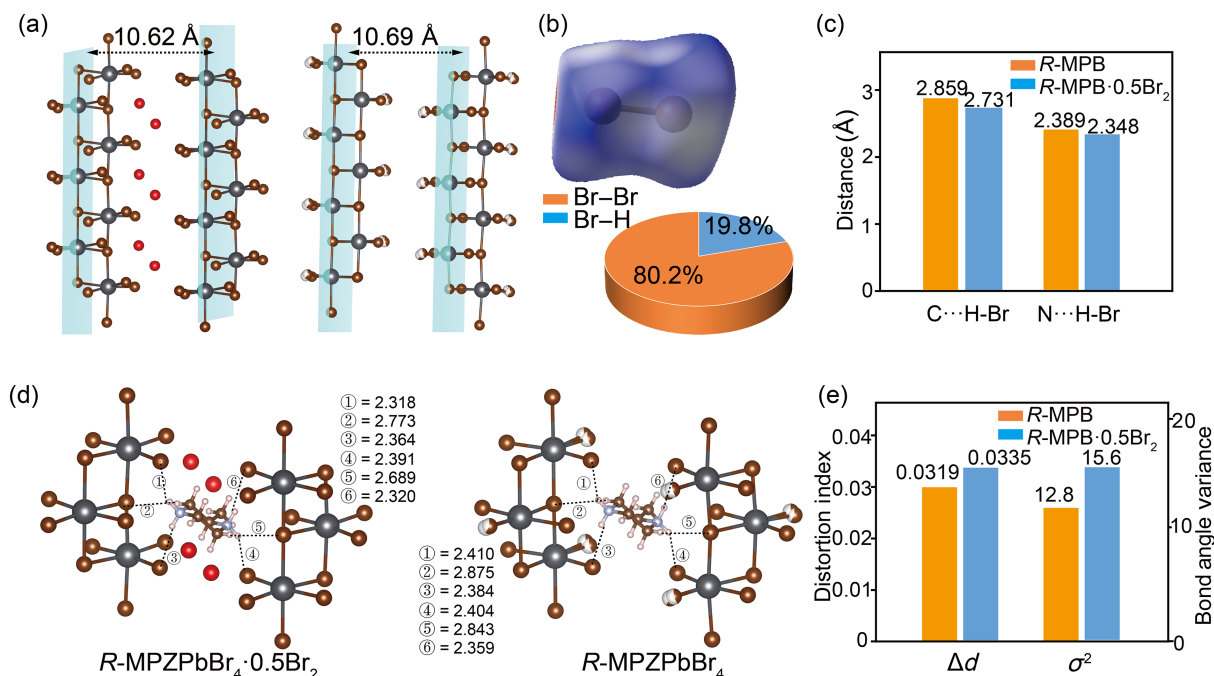


Figure 2 (a) Interchain spacing of R -MPZPbBr₄ and R -MPZPbBr₄·0.5Br₂. (b) Hirshfeld surface and pie diagram of interaction forces of R -MPZPbBr₄·0.5Br₂. (c) Average hydrogen bond length. (d) Hydrogen bond parameters and (e) octahedral distortion and bond angle variance of R -MPZPbBr₄ and R -MPZPbBr₄·0.5Br₂.

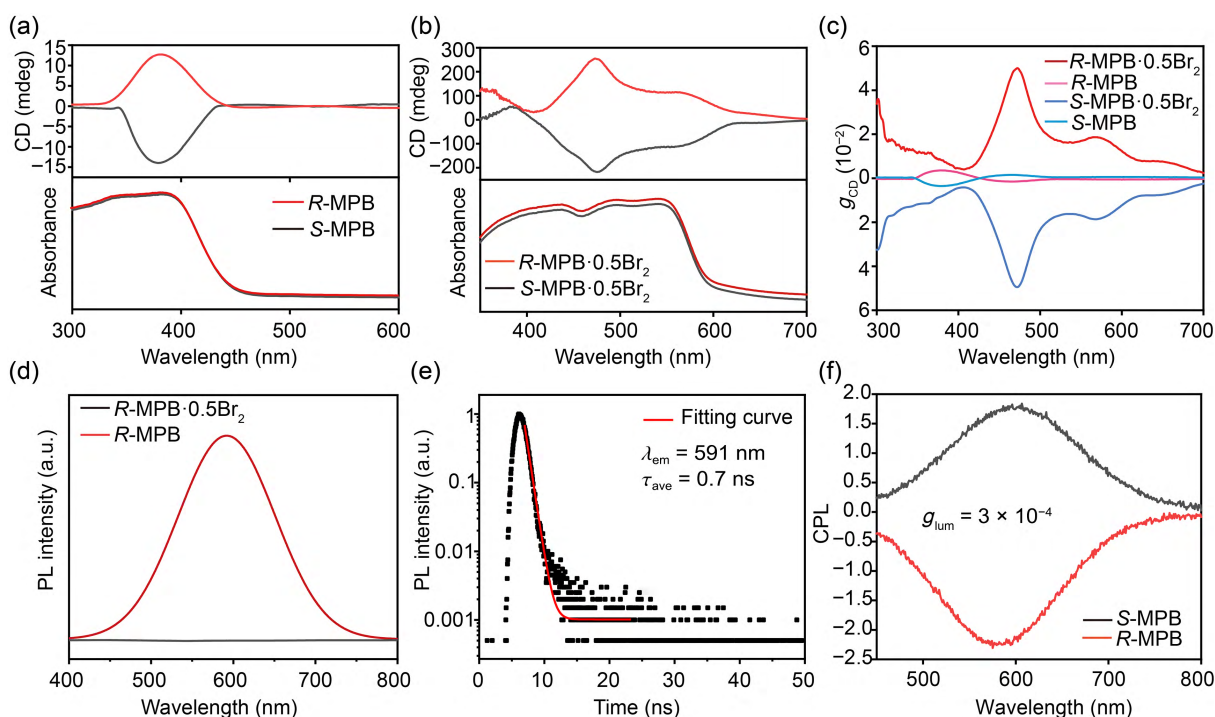


Figure 3 UV-Vis absorption spectra, CD spectra of (a) R/S -MPZPbBr₄ and (b) R/S -MPZPbBr₄·0.5Br₂. (c) The calculated g_{CD} of R/S -MPZPbBr₄ and R/S -MPZPbBr₄·0.5Br₂. (d) PL spectra of R -MPZPbBr₄ and R -MPZPbBr₄·0.5Br₂. (e) Luminescence lifetime of R -MPZPbBr₄. (f) CPL of R/S -MPZPbBr₄.

quenching can be attributed to the fact that free Br fills the halogen vacancies in the original lattice, altering the band filling state, leading to an imbalance in carrier concentration and consequently exacerbating the non-radiative Auger recombination process. Notably, $R\text{-MPZPbBr}_4$ has a luminescence lifetime of 14.8 ns (Fig. 3(e)) and exhibits standard circularly polarized luminescence emission (Fig. 3(f)) with an anisotropy factor g_{lum} of 3×10^{-4} , demonstrating its great potential as a high-quality circularly polarized luminescent material.

Although $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ cannot serve as a circularly polarized luminescence material, the low symmetry conferred by its space group endows it with great potential in the field of self-driven CPL detection. Specifically, the angles between the three crystallographic axes (a , b , c) of $R\text{-MPZPbBr}_4$ are all 90° , whereas

the b -axis of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ forms an angle of 105° with the other two axes. This difference manifests itself when the crystal is rotated about the a -axis. $R\text{-MPZPbBr}_4$ can easily achieve structural coincidence through translation, while $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ cannot overlap (Fig. 4(a)). The same phenomenon is observed upon rotation about the c -axis (Fig. S10 in the ESM). The equatorial projections of the point groups of the two crystals (Fig. 4(b)) further confirm this.

It is well known that the presence of an inversion center forces the positive and negative charge centers to coincide, thereby canceling the macroscopic dipole moment. To further verify the cancellation process of the dipole moment, the polarization intensities of the four octahedra in $R\text{-MPZPbBr}_4$ and $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ were calculated by categorizing them into two

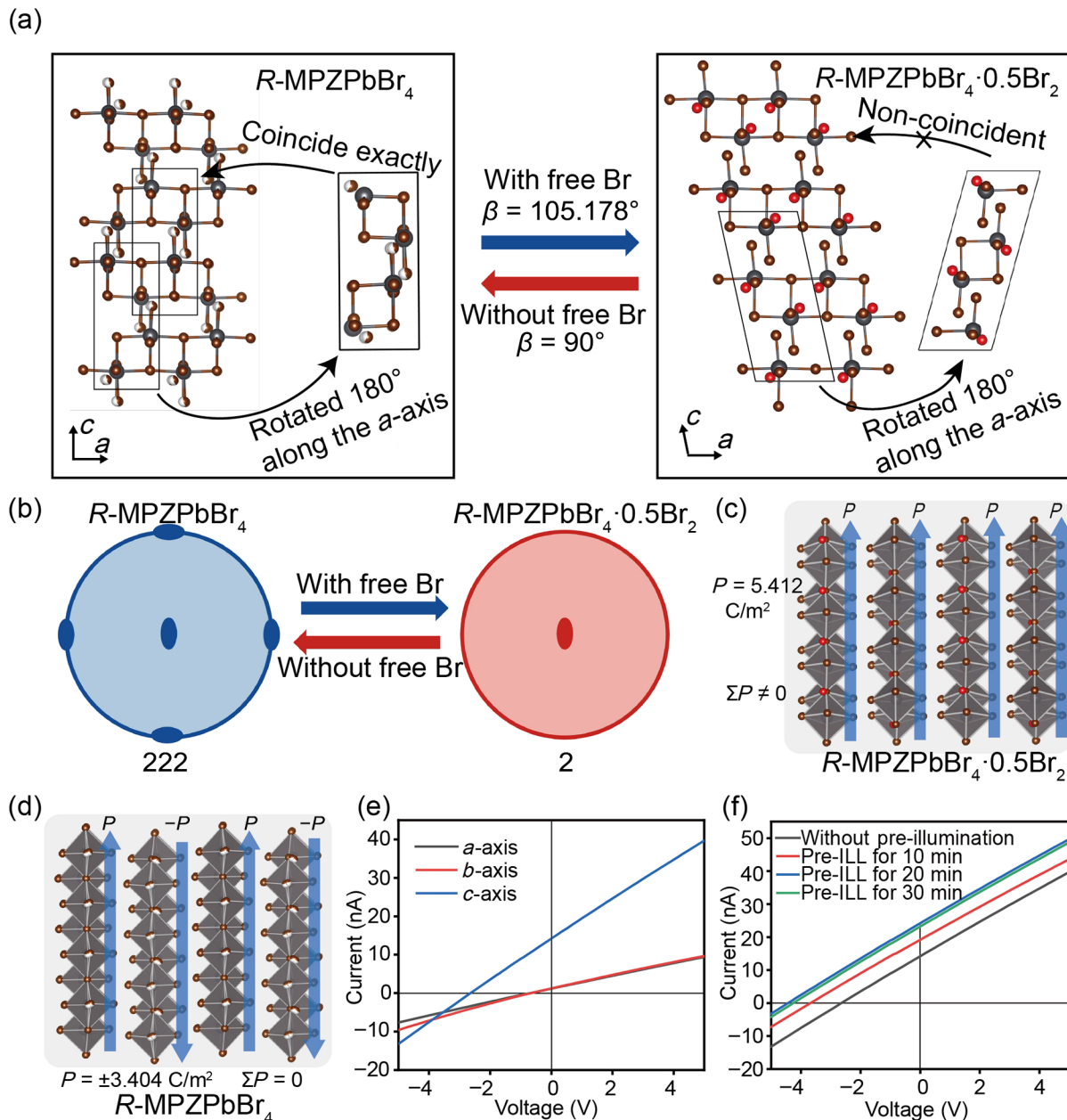


Figure 4 (a) Rotation symmetry along the a -axis. (b) Equatorial plane projection of point groups and spatial symmetry operations of space groups of $R\text{-MPZPbBr}_4$ and $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$. (c) Polarization intensities of different chains of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ and (d) $R\text{-MPZPbBr}_4$. (e) I - V curves along various axes of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$. (f) I - V curves for various pre-illumination durations of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$.

adjacent but distinct 1D chains (see the calculation details in Tables S6 and S7 in the ESM). The calculation results show that the polarization intensity of each chain in $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ is -5.412 C/m^2 , with $\Sigma p \neq 0$, thus exhibiting a macroscopic spontaneous polarization phenomenon (Fig. 4(c)). In contrast, the polarization intensities of adjacent chains in $R\text{-MPZPbBr}_4$ are $\pm 3.404 \text{ C/m}^2$, so the polarization intensities of adjacent chains cancel each other out, resulting in no macroscopic spontaneous polarization (Fig. 4(d)). The photocurrent measurement results strongly support this conclusion. In the I - V curve of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ along the b -axis, the open-circuit voltage is 2.5 V, significantly higher than the 0.8 V along the a - and c -axes (Fig. 4(e)). In contrast, for $R\text{-MPZPbBr}_4$, the open-circuit voltages and photocurrents along the three crystallographic axes show no significant differences, indicating the absence of spontaneous polarization (Fig. S11 in the ESM). Further pre-illumination experiments also corroborate this point. After pre-illuminating $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ for different durations and then testing the I - V curves, it was found that after 30 min of pre-illumination, the open-circuit voltage increased to 4.2 V, much higher than the 2.5 V under direct illumination (Fig. 4(f)). This is because spontaneous polarization is not an instantaneous process but evolves over time; sufficient pre-illumination allows the internal polarization of the material to be fully established, resulting in a higher open-circuit

voltage. Conversely, $R\text{-MPZPbBr}_4$ is almost unaffected by pre-illumination, further confirming that it does not possess spontaneous polarization (Fig. S12 in the ESM).

Unlike $R\text{-MPZPbBr}_4$, $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ crystallizes in the polar non-centrosymmetric space group C_2 , exhibiting significant spontaneous polarization. This enables directional separation of photogenerated carriers and the generation of BPVE without any external bias, making it highly suitable for self-driven CPL detection. In contrast, although $R\text{-MPZPbBr}_4$ also adopts a non-centrosymmetric structure (space group $P2_12_12_1$), it lacks spontaneous polarization, resulting in negligible distinguishable open-circuit voltage and thus ineffective self-driven CPL detection (Figs. S13 and S14 in the ESM). Based on these differences, we systematically evaluated the self-driven CPL detection performance of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$. As shown in Fig. 5(a), by setting the quarter-wave plate at 45° or 315° relative to the incident linearly polarized light, pure right-circularly polarized (RCP) or left-circularly polarized (LCP) light ($\lambda = 405 \text{ nm}$) is delivered to the device. Figures 5(b)–5(d) present the I - T , V - T , and I - T responses under various light power densities (20.5 – 102 mW/cm^2). Both the photocurrent and photovoltage increase monotonically with increasing power density, exhibiting stable, reproducible, gain-free optoelectronic responses. Notably, at a power density of 102 mW/cm^2 , the device shows an open-circuit voltage as high as

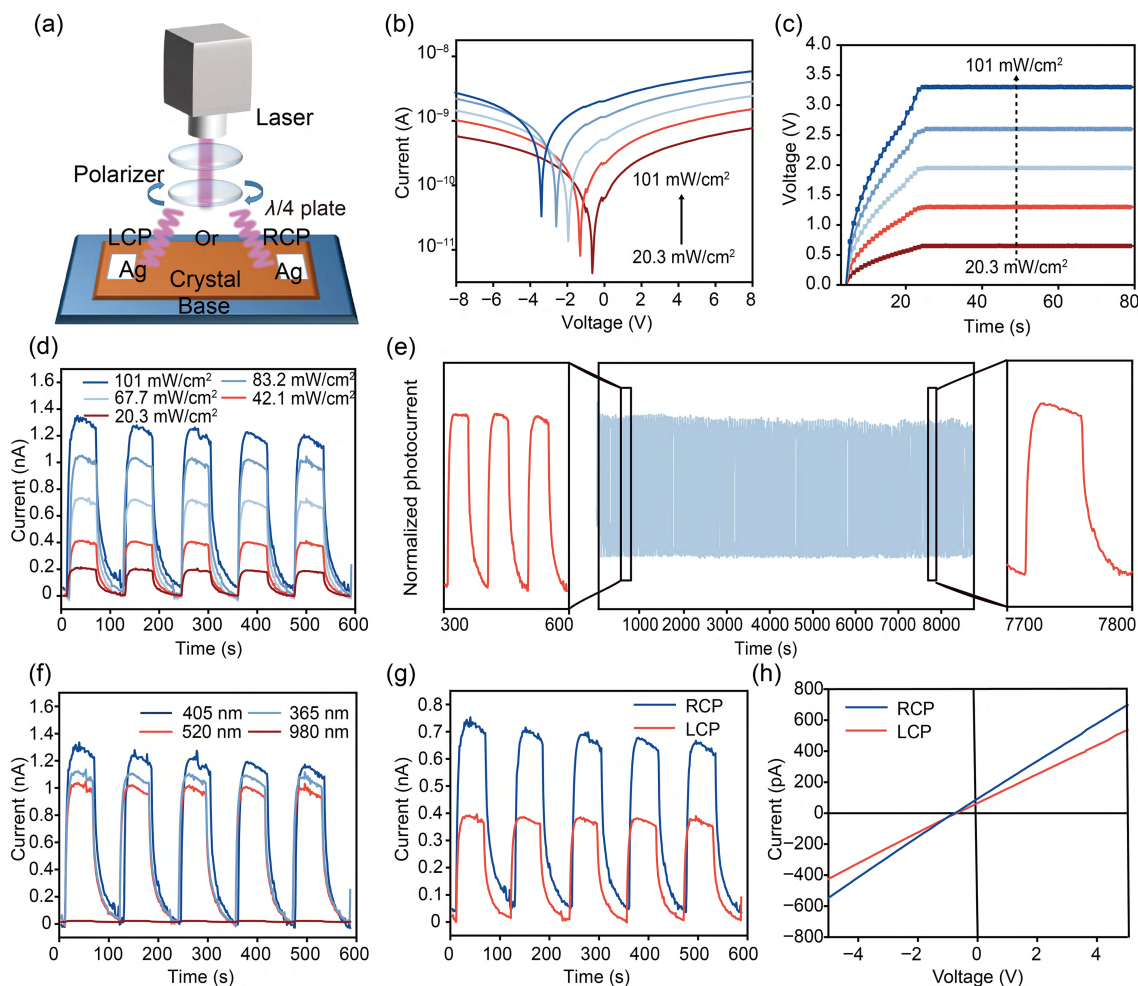


Figure 5 (a) Schematic of RCP and LCP light detection using chiral photodetector. (b) I - V curves, (c) V - T curves, and (d) I - T curves of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ under 405 nm light illumination with varying power. (e) Real-time reproducibility of the I - T curves at 0 V bias. (f) I - T curves of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ with varying excitation wavelengths light illumination. (g) I - T and (h) I - V curves of $R\text{-MPZPbBr}_4 \cdot 0.5\text{Br}_2$ under RCP and LCP of 405 nm light illumination.

3.8 V, surpassing the thermodynamic limit dictated by the bandgap (Fig. S15 in the ESM). This can be classified as an anomalous BPVE, originating from the spontaneous-polarization-induced nonlinear optical process rather than the built-in electric field of a conventional p–n junction. Figure 5(e) shows the real-time I – T curve under continuous 405 nm illumination for 8000 s (80 on–off cycles). No measurable degradation in the photocurrent on–off ratio or baseline is observed throughout the measurement, indicating excellent cycling stability and resistance to photofatigue of R -MPZPbBr₄0.5Br₂. To examine the wavelength dependence, the same device was tested under 365, 405, 520, and 980 nm excitation (Fig. 5(f)). Significant and comparable photocurrents are generated under 365, 405, and 520 nm illumination, demonstrating broadband self-driven detection capability from the ultraviolet to the visible region. The photocurrent under 980 nm excitation is markedly weaker, consistent with the material's absorption edge (Figs. 3(a) and 3(b)), further indicating that the photocurrent response originates primarily from intrinsic interband transitions. Under zero bias, R -MPZPbBr₄0.5Br₂ was illuminated with RCP and LCP light (405 nm, 102 mW/cm²) (Figs. 5(g) and 5(h)). RCP light consistently generates a higher photocurrent than LCP light. The calculated g_{res} reaches as high as +0.61, significantly outperforming most reported self-driven CPL detectors based on chiral halides. This high value directly benefits from the large $g_{\text{CD}} = 5.2 \times 10^{-2}$ of the material. S -MPZPbBr₄0.5Br₂ exhibits the opposite result: RCP consistently excites a higher photocurrent than LCP, with a g_{res} value of –0.55 (Fig. S16 in the ESM). Overall, R -MPZPbBr₄0.5Br₂ enables high-resolution, broadband, and stable CPL detection without any external bias.

4 Conclusion

In summary, through a free-bromine modulation strategy, we successfully converted the non-polar halide R/S -MPZPbBr₄ into a high-performance self-driven CPL detection material, R/S -MPZPbBr₄0.5Br₂. First, we revealed that free Br introduction significantly breaks the symmetry of R -MPZPbBr₄ and enhances the hydrogen-bonding interactions, endowing R -MPZPbBr₄0.5Br₂ with a higher g_{CD} (5.2×10^{-2}). Notably, the symmetry breaking further induces the generation of spontaneous polarization in R -MPZPbBr₄0.5Br₂. Driven by the polarization field, R -MPZPbBr₄0.5Br₂ exhibits an anomalous photovoltaic effect under zero bias, with an open-circuit voltage as high as 3.8 V. Thus, R -MPZPbBr₄0.5Br₂ demonstrates a high g_{res} (+0.61) in self-driven CPL detection. This work opens a new pathway for designing chiral metal halide materials for self-driven CPL detection.

Electronic Supplementary Material: Supplementary material (theoretical calculations and comparative plots of XRD, SEM, XPS, and I – V measurements for the two materials, providing full supporting evidence for the findings reported in the manuscript) is available in the online version of this article at <https://doi.org/10.26599/NR.2026.94908958>.

Data availability

All data needed to support the conclusions in the paper are presented in the manuscript and the Electronic Supplementary Material. Additional data related to this paper may be requested from the corresponding author upon request.

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Declaration of competing interest

All the contributing authors report no conflict of interests in this work.

Author contribution statement

Q. H. D.: Data curation, formal analysis, investigation, validation, writing – original draft. Z. Y. and Y. L. B.: Investigation. L. Y. W.: Methodology, writing – review & editing. B. S. Z.: Writing – review & editing. R. S. Z.: Funding acquisition, project administration, supervision, writing – review & editing. All the authors have approved the final manuscript.

Use of AI statement

None.

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