

# Fractional Quantum Multiferroics from Coupling of Fractional Quantum Ferroelectricity and Altermagnetism



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## Abstract

- The intrinsic competition between the mechanisms driving ferroelectricity and magnetism in single-phase materials severely limits their performance, typically resulting in weak magnetoelectric coupling at room temperature. Here, we propose a solution to this long-standing problem through the novel concept of fractional quantum multiferroics (FQMF), achieved by coupling fractional quantum ferroelectricity (FQFE) with altermagnetism (AM).
- Symmetry analysis shows that reversing the FQFE polarization necessarily inverts the AM spin splitting under parity–time or time-reversal operations.
- A minimal tight-binding model reproduces this effect, demonstrating electrically driven spin control without rotating the Néel vector.
- We identify a series of candidate materials holding FQMF. Notably, MnTe exhibits a high Néel temperature of 300 K, a large switchable spin splitting of 0.8 eV, and a tunneling magnetoresistance exceeding 300%.
- This work establishes FQMF as a distinct and promising route to achieving room-temperature strong magnetoelectric coupling.

## 1. Background

Magnetoelectric multiferroic are coveted for memory, sensor and spintronic functions. However, in single-phase systems, ferroelectricity and magnetism are intrinsically competitive: ferroelectricity typically relies on lattice distortions and requires polar point group symmetry, while magnetism often originates from partially filled  $d$  orbitals that inherently suppress such distortions. Fractional-quantum ferroelectricity (FQFE) removes this obstacle by allowing polarization to appear in non-polar point groups, thereby enabling the coexistence of robust magnetoelectric coupling and high Curie temperatures.

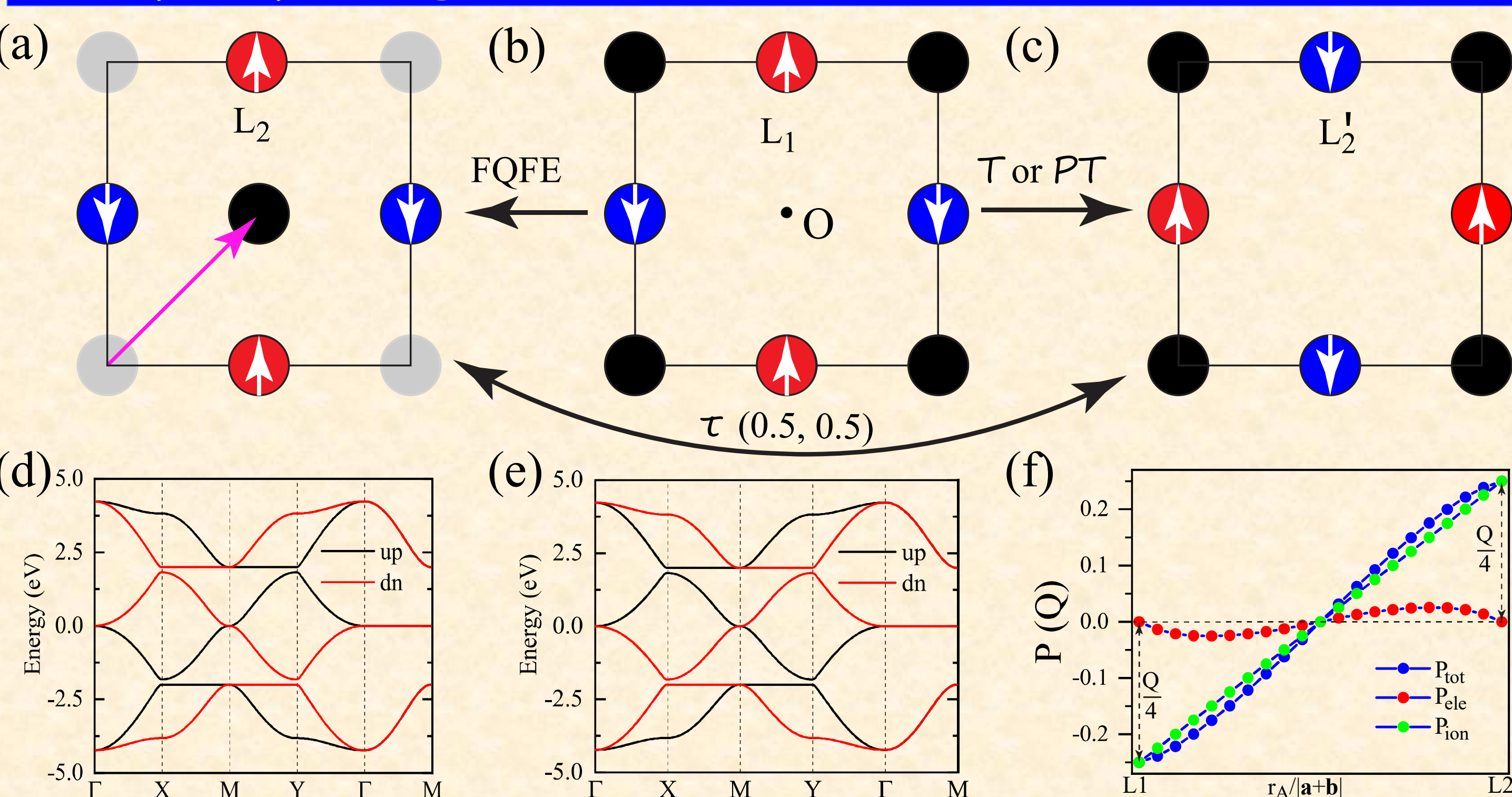
## 2. Symmetry Analysis

FQFE: [crystal structure:  $L_1 \rightarrow L_2$ ]; [electric structure:  $\varepsilon_n^1(k, s) \rightarrow \varepsilon_n^2(k, s)$ ]

IF  $PTL_1 = L_2$ :  $\varepsilon_n^2(k, s) = PT\varepsilon_n^1(k, s) = P\varepsilon_n^1(-k, -s) = \varepsilon_n^1(k, -s)$

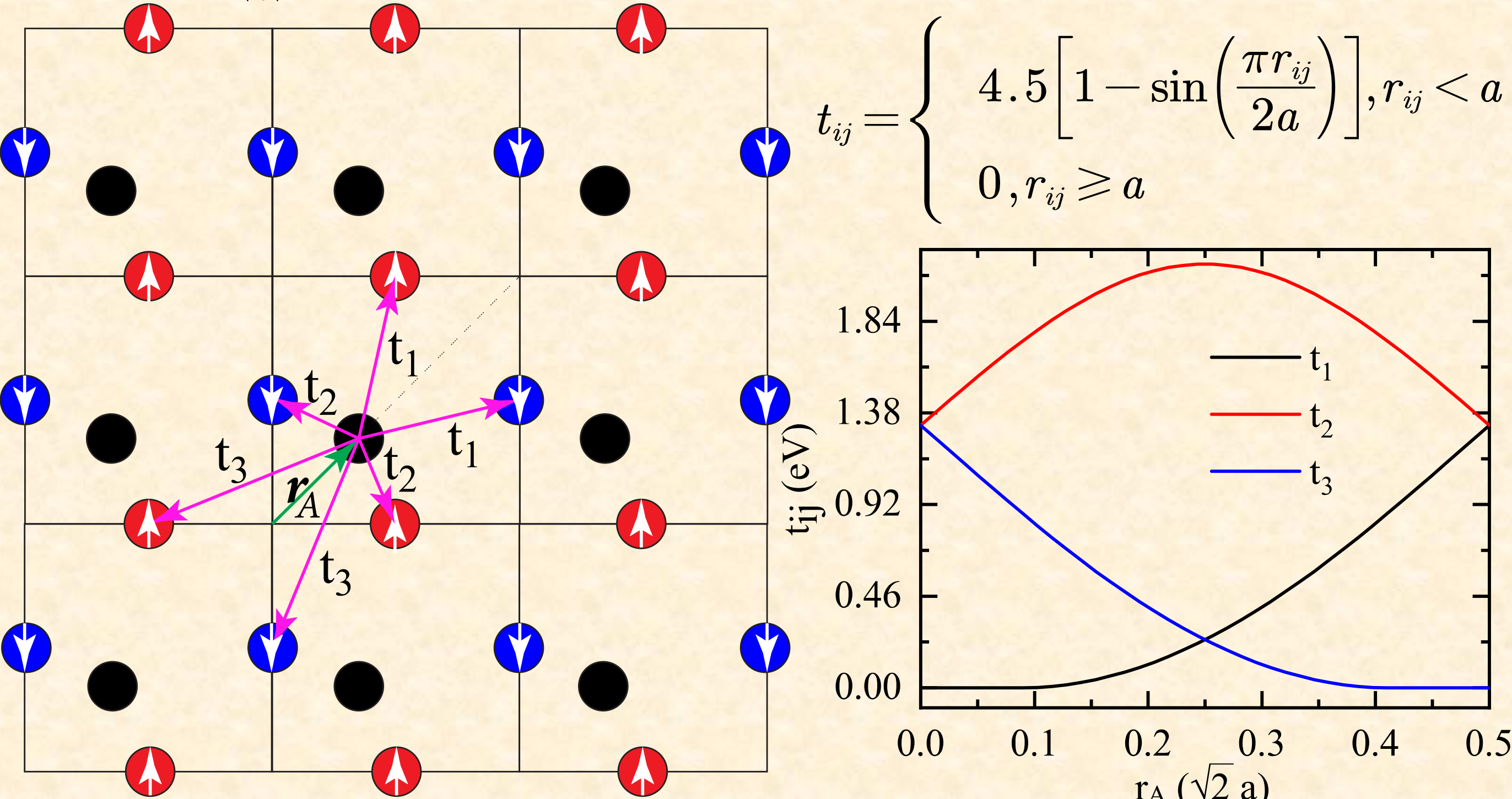
IF  $TL_1 = L_2$ :  $\varepsilon_n^2(k, s) = T\varepsilon_n^1(k, s) = \varepsilon_n^1(-k, -s) = \varepsilon_n^1(k, -s)$

reversing the FQFE polarization necessarily inverts the AM spin splitting



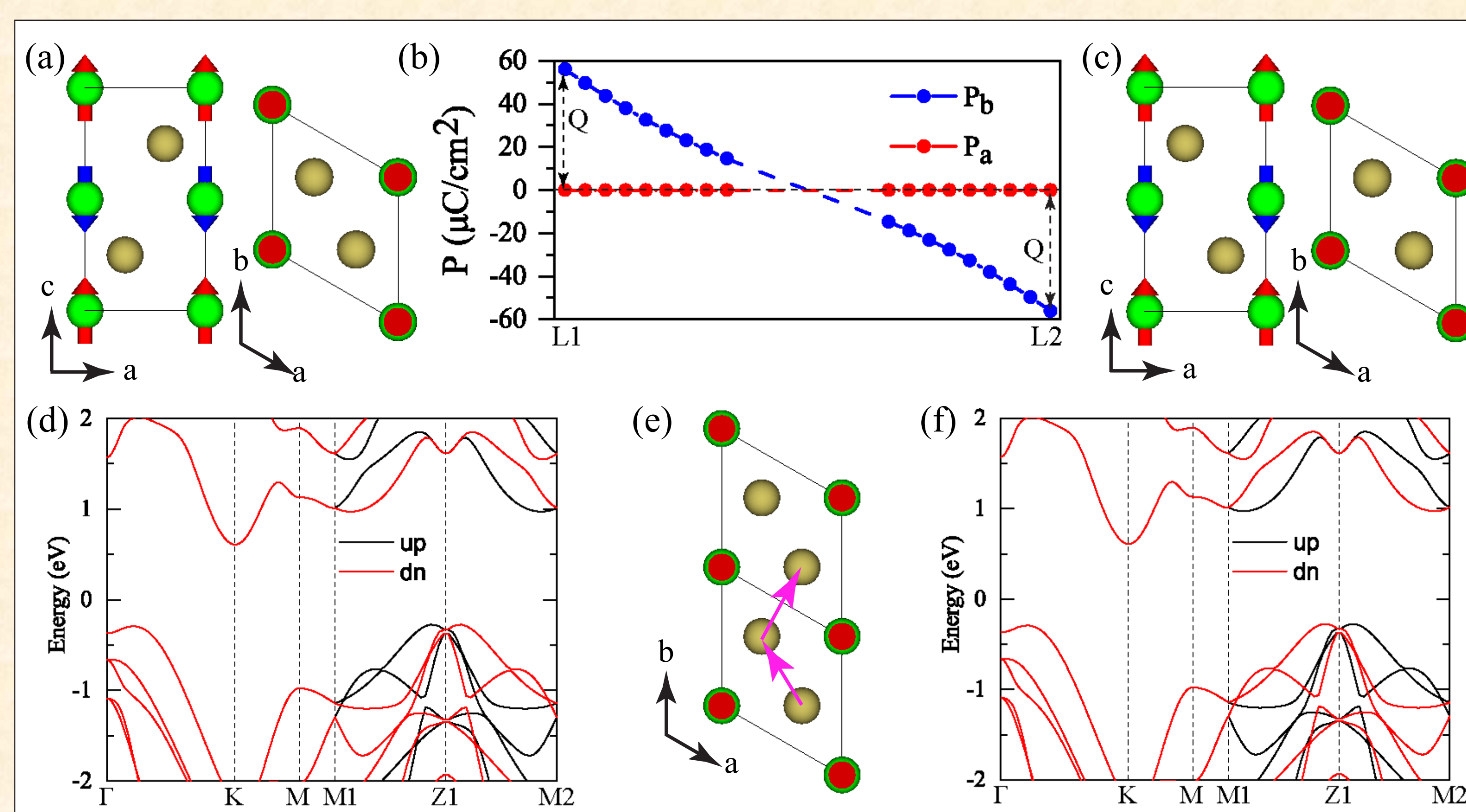
## 3. Tight-Binding Model Calculation

$$H = - \sum_{\langle ij \rangle, s} t_{ij}(\mathbf{r}_A) c_{i,s}^\dagger c_{j,s} - J \sum_{i,s,s'} M_i c_{i,s}^\dagger \sigma_{ss'}^z c_{i,s'} - \mu \sum_{i,s} c_{i,s}^\dagger c_{i,s}$$

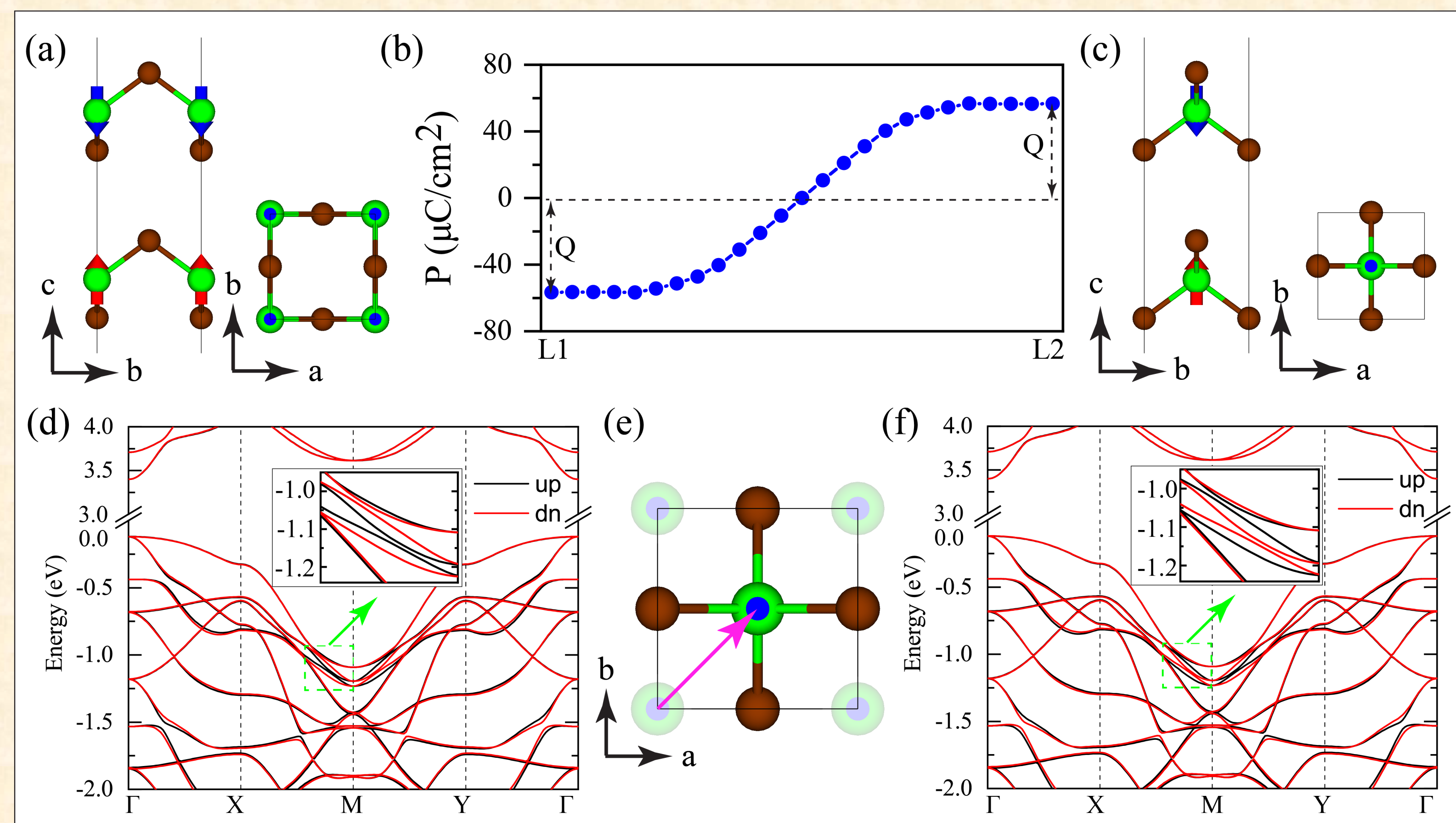


With polarization reversal, hopping-parameter exchange, thus spin-splitting inversion.

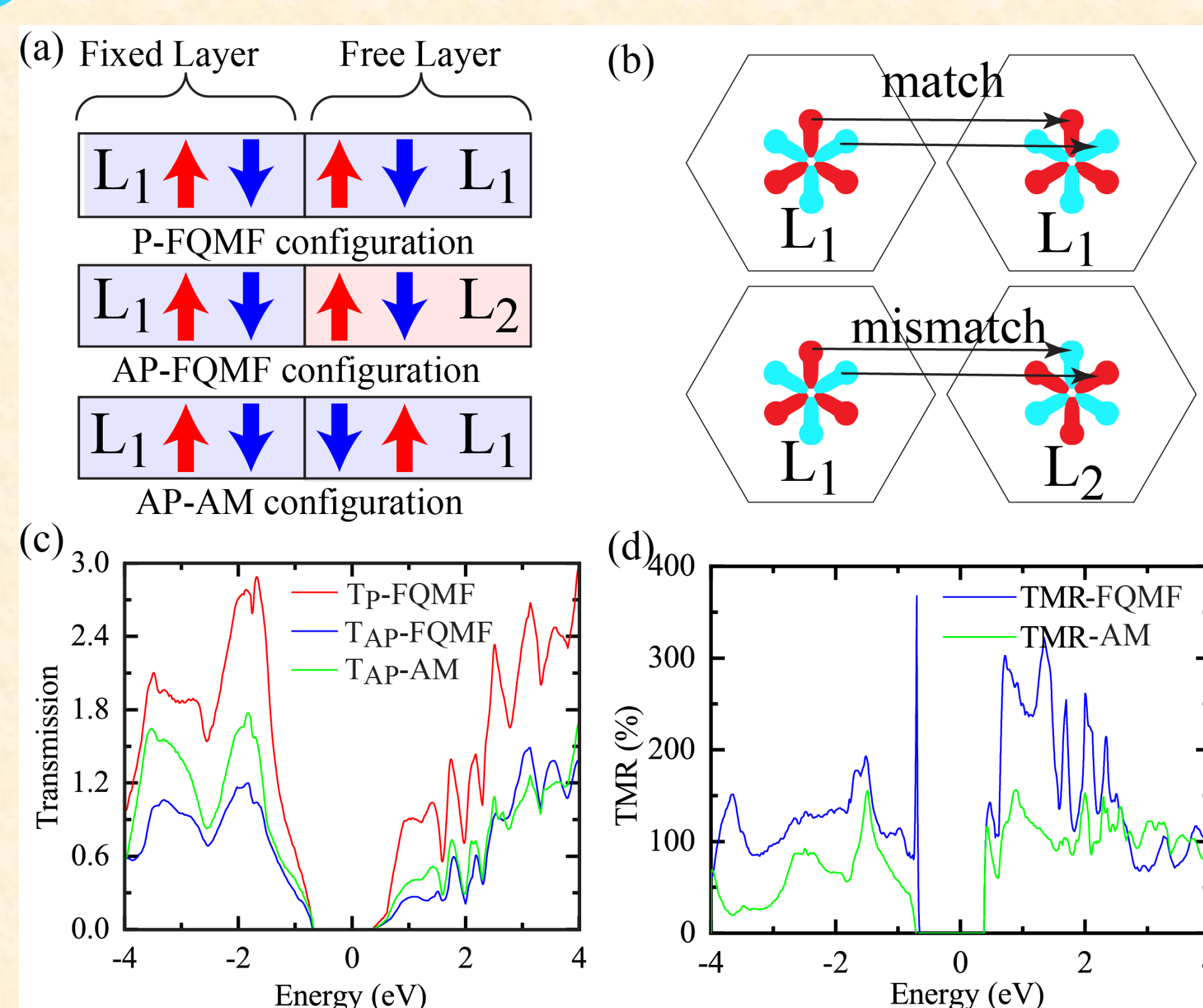
## 4. Real system—Bulk MnTe



## 5. Real system—bilayer MnBr₂



## 6. TMR in MnTe/MnTe FQMF tunnel junction



$$\begin{cases} \frac{T_P - T_{AP}}{T_{AP}} \times 100\%, & T_{AP} > 0.01 \\ 0, & T_{AP} \leq 0.01 \end{cases}$$

- The decrease in transmittance arises from two sources:
- spin mismatch in momentum space (characteristic of AM tunnel junctions).
- Periodic disruption of the atomic structure (characteristic of FE tunnel junctions).

M. Q. Dong, B. Liu, Z. H. Dai, Z. X. Guo\*, H. Xiang, and X. G. Gong\*, Phys. Rev. Lett. 136, 136702 (2026). Editors' Suggestion