

## Architectural Design Strategies in Ceramic–Polymer Hybrid Piezoelectric Composites for Enhanced Energy Harvesting Performance

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**Abstract.** Ceramic–polymer piezoelectric composites integrate the high piezoelectric activity of ferroelectric ceramics with the mechanical flexibility and durability of polymers, forming a key platform for next-generation energy harvesting. This review critically examines recent progress in hybrid composites for mechanical-to-electrical energy conversion, emphasizing architectural design strategies that govern structure–property–performance relationships. Particular focus is placed on connectivity patterns (0–3, 1–3, and 3–3) and advanced engineering approaches—including aligned ceramic networks, porous scaffolds, core–shell structures, gradient configurations, and interfacial functionalization—which enhance stress transfer, electromechanical coupling, and power density while reducing brittleness and dielectric loss. Lead-based (e.g., PZT) and lead-free systems (e.g., BTO, KNN), combined with flexible matrices such as PVDF and its copolymers, are assessed for applications in low-frequency vibrations, wearable electronics, structural health monitoring, and self-powered sensors. Scalable fabrication methods (freeze casting, electrospinning, 3D printing) and multiphysics modelling are evaluated alongside major challenges: polarization stability, fatigue resistance, interfacial debonding, and long-term reliability. The review provides a unified framework for architectural optimization and strategic directions toward efficient, robust, and sustainable energy harvesters.

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