

## Progress in engineering high strain lead-free piezoelectric ceramics

REVIEW ARTICLE

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**Abstract** Environmental concerns are strongly driving the need to replace the lead-based piezoelectric materials currently employed as multilayer actuators. The current review describes both compositional and structural engineering approaches to achieve enhanced piezoelectric properties in lead-free materials. The review of the compositional engineering approach focuses on compositional tuning of the properties and phase behavior in three promising families of lead-free perovskite ferroelectrics: the titanate, alkaline niobate and bismuth perovskites and their solid solutions. The 'structural engineering' approaches focus instead on optimization of microstructural features including grain size, grain orientation or texture, ferroelectric domain size and electrical bias field as potential paths to induce large piezoelectric properties in lead-free piezoceramics. It is suggested that a combination of both compositional and novel structural engineering approaches will be required in order to realize viable lead-free alternatives to current lead-based materials for piezoelectric actuator applications.

**PACS** [89.20.Kk Engineering](#)  
[07.07.Tw Servo and control equipment; robots](#)  
[77.65.Ly Strain-induced piezoelectric fields](#)  
[81.40.Ef Cold working, work hardening; annealing, post-deformation annealing, quenching, tempering recovery, and crystallization](#)  
[85.50.-n Dielectric, ferroelectric, and piezoelectric devices](#)  
[77.80.Dj Domain structure; hysteresis](#)

**Subjects** [Electronics and devices](#)  
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