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3D HIERARCHICAL LATTICE FERROELECTRIC METAMATERIALS: THERMO-ELECTRO-MECHANICAL PROPERTIES

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ABSTRACT

Hierarchical cellular materials are ubiquitous in nature and lead many extraordinary mechanical properties, such as ultralight, ultrastiff, and high toughness. In this study, we introduce three families of 3D hierarchical lattice metamaterials, i.e., cubic, octahedron, and hybrid families, made out of ferroelectric materials. Multiscale asymptotic homogenization (MAH) is introduced for predicting the effective thermo-electro-mechanical properties of hierarchical ferroelectric metamaterials. The effect of hierarchy order, lattice topology (including aspect ratio) and relative density on piezoelectric and pyroelectric figures of merit, which assess the multifunctional performance of ferroelectric metamaterials when used as sensors and energy harvesters, is explored. Although 1st-order lattice ferroelectric metamaterials remarkably improve the piezoelectric and pyroelectric figures of merit compared to fully-solid ferroelectric materials, increasing hierarchy order can further improve these figures of merit. Hybrid hierarchical lattice ferroelectric metamaterials show improved piezoelectric and pyroelectric properties that are not achievable by their fractal-like counterparts. For example, compared to the 1st-order BCC ferroelectric metamaterials with an FOM_{33} of more than 50 times higher than bulk ferroelectric materials, FOM_{33} of the 2nd-order octet-truss/BCC hierarchical metamaterials can be improved by 50.7%; this improvement is 43.8% and 43.2% for 2nd-order BCC and 2nd-order octet-truss self-similar hierarchical metamaterials, respectively. Finally, scaling relationships for predicting the thermo-electro-mechanical properties of lattice hierarchical ferroelectric metamaterials, covering the whole range of relative densities, are proposed. The study highlights the potential applications of bioinspired hierarchical structures, with integrated mechanical, piezoelectric, and pyroelectric properties, as hydrophone, pressure and temperature sensors, and energy harvesters.