Single-Phase Phononic Crystals with 4-Fold Rotational Symmetry

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Abstract

In this study, we investigate the mechanisms underlying bandgap (BG) formation in two-dimensional phononic crystals (PnCs) exhibiting 4-fold rotational symmetry. Our focus spans symmorphic symmetry groups, such as *p4* and *p4mm*, as well as the nonsymmorphic *p4gm* group. By introducing reproducible design families based on these symmetry groups, we enable systematic exploration of their acoustic properties.

Through detailed parametric analysis, we uncover the interplay between Bragg scattering and local resonance mechanisms, demonstrating their combined potential to yield exceptionally wide, complete omnidirectional BGs in single-phase PnCs. The study identifies nonlinear relationships between geometric parameters and BG size, revealing critical design principles for maximizing attenuation performance. Numerical simulations, complemented by experimental validation, confirm the emergence of strongly coupled BGs capable of attenuating both longitudinal (P-wave) and shear (S-wave) modes. Designs featuring large resonators interconnected by thin ligaments are particularly effective, achieving BGs up to 118% relative width with attenuation exceeding 80 dB within just three unit cell layers.

Our findings emphasize the crucial role of resonator-to-connector configurations, analogous to mass-spring systems, in facilitating the coupling of resonant and Bragg mechanisms. Remarkably, we demonstrate that simpler symmorphic symmetry designs can rival or exceed the BG performance of nonsymmorphic counterparts, challenging traditional design paradigms. These results not only deepen our understanding of BG formation in single-phase PnCs but also provide actionable insights for developing advanced vibration isolation and wave manipulation technologies.

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