

Ph.D. DISSERTATION DEFENSE

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Degree:	Doctor of Philosophy
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Title:	Dynamics of Nonlocal Elastic Metamaterials
Chairperson:	Dr. Christopher Sugino (Department of Mechanical Engineering)
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ABSTRACT

Elastic metamaterials enable unprecedented control over wave propagation by tailoring structural architecture rather than material composition. While conventional designs rely primarily on nearest-neighbor coupling, such local interactions limit the achievable dispersion characteristics, bandwidth, and the realization of nonreciprocal behavior. This dissertation details a comprehensive framework for the inverse design, implementation, and application of one-dimensional nonlocal elastic metamaterials capable of realizing prescribed, multi-band dispersion relations and unconventional wave phenomena.

First, a generalized inverse-design methodology is developed for one-dimensional lattices with arbitrary degrees of freedom and long-range stiffness, damping, and inertial interactions. The governing equations are formulated using Bloch theory, leading to a quadratic eigenvalue problem. The inverse problem is posed as a constrained optimization that incorporates physical realizability while employing L1-regularization to promote sparse interaction networks. The framework accommodates passive, active, and dissipative components and is validated through recovery of known lattice dispersions and multiple case studies targeting exotic dispersion features.

Second, practical mechanical realizations of nonlocal behavior are achieved using locally coupled architectures with auxiliary degrees of freedom. A translation-permutation symmetric metamaterial is designed and experimentally demonstrated to exhibit roton-like minima, maxon peaks, and high modal-density regions associated with zero-group-velocity modes. The results establish a planar, manufacturable platform for implementing complex nonlocal dispersion without direct long-range connections.

Third, programmable and strongly nonreciprocal wave propagation is realized through electromechanical hybridization in piezoelectric waveguides using nonlocal, non-conservative electrical networks. Two mechanisms of nonreciprocal hybridization are identified, including destructive-interference-based attenuation that enables strong directionality in short structures. Finally, building on this capability, a design methodology is presented to create multi-port, linear, time-invariant elastic circulators for the directional routing of elastic waves.