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Elastic wave guiding through micro-architected materials

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ABSTRACT

Architected materials present an unprecedented design space to control material functionality across length and time scales. Among the range of functionalities studied, the control of elastic wave propagation (or “wave guiding”) through these materials is particularly exciting, albeit challenging. A powerful measure of a propagating wave is dispersion, i.e., the relationship between its frequency and wavenumber. In architected materials, dispersion is affected either by the architecture (structural), or the constituent material (constitutive law). In a broad sense, using architecture as a control variable for wave guiding involves understanding, measuring and controlling these dispersion relations. Recent advances in scalable computational frameworks have found conventional experimental capabilities wanting on the following fronts: (1) fabricating materials with large number of unit cells (scale separation), (2) exciting and measuring elastic waves with high spatial and temporal resolution (to sample enough points on the dispersion surface), and (3) de-coupling structural/architectural and material effects on dispersion.

We overcome these limitations through a multi-step experimental paradigm involving the fabrication of micro-architected materials on a silicon wafer, and characterizing their dynamic behavior using a home-built photo-acoustic pump-probe experiment. We will begin our discussion with an overview of “conventional” experiments on truss-based architected meta-structures, driven by existing numerical models. Motivated by the inadequacies of these experiments in the context of recent scalable computations, we will delve into a discussion of our new experiment. Samples were fabricated using cleanroom micro-fabrication techniques using commercially-procured Silicon-On-Insulator (SOI) wafers – our final samples are free-standing micro-architected “thick” films with over 500’000 unit cells within a 100 mm diameter wafer. We will then bring these samples to the lab, to characterize wave propagation using a pulsed-laser source to excite the acoustic wave, and a home-built heterodyne interferometer to measure particle velocities with tens of nanosecond temporal and sub-nanometer spatial resolution. Data from periodically-architected samples show excellent agreement with finite element simulations, and demonstrate the ability of our experiment to probe at least up to the second modes. We will end our discussion with experimental realizations of computationally-designed spatially-graded architectures for wave guiding, and the potential of this experiment to feed computational design codes with large, automated and high-throughput data sets — invaluable for rigorous data-driven computational design of elastic wave guides.

ABOUT THE SPEAKER

Vignesh is an assistant professor in the Department of Mechanics at the Ecole Polytechnique in Palaiseau, France. He received his undergraduate degree from the National Institute of Technology in Trichy, before moving to the Johns Hopkins University for his masters and PhD under the mentorship of Prof. K.T. Ramesh. At Hopkins, he studied plastic deformation and failure of magnesium under high-strain-rate dynamic loading. He then moved to the ETH in Zurich, Switzerland for a post-doctoral stint with Prof. Dennis Kochmann, where he currently serves as a visiting scientist. In Zurich, Vignesh explores problems on electro-mechanical coupling in ferroelectric materials and elastic wave guiding in architected metamaterials. He is now developing an experimental program in France to study the dynamic behavior of materials, with a recent fascination for impact-induced phase transformations.

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