Fabrication and characterization of Si-based micro-architected metamaterials for elastic wave guiding

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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 available, the control of elastic wave propagation (or "wave guiding") through an architected material is particularly exciting and challenging. An important measure of wave guiding is "dispersion", i.e., the relationship between frequency and wavenumber of waves propagating in the material. In architected materials, dispersion could be affected either by the architecture (structural), or the constituent material (constitutive law). Despite a significant body of literature on this problem, fundamental experimental studies are complex due to limitations in (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) separating the structural and material effects on wave dispersion. We overcome these limitations through the fabrication of micro-architected materials on a silicon wafer, and characterizing their dispersion behavior using a home-built photo-acoustic pump-probe experiment. We will first discuss our sample fabrication technique from commercially-procured 100 mm Silicon-On-Insulator (SOI) wafers, to free-standing micro-architected "thick" films with over 500'000 unit cells. The choice of silicon ensures linear elastic material behavior. We will then bring these samples to the lab, to characterize dispersion; the experiment involves a pulsed laser source to excite the acoustic wave, and a home-built heterodyne interferometer to measure particle velocities on the sample surface with tens of nanosecond temporal resolution. The resulting data set is used to generate the full spatio-temporal evolution of elastic waves, which we analyze in Fourier space to compute dispersion. Data from periodically-architected samples show excellent agreement with finite element simulations, and demonstrate the ability of the experiment to probe up to the second dispersion mode. We will end the discussion with experimental realizations of computationally-designed spatially-graded architectures for wave focusing, and the potential of this experiment to generate large, automated and high-throughput data sets - invaluable for rigorous data-driven computational design of elastic wave guides.

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