Wave guiding in spatially graded on-chip metamaterials

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Abstract

We present a new paradigm for microscale wave guidance in metamaterials containing hundreds of thousands of spatially graded unit cells, enabled by recent advances in computational ray tracing and wafer-scale fabrication. Periodic and spatially graded metamaterials have emerged as powerful tools for controlling or suppressing elastic waves by careful engineering of the unit cell to optimize the elastic dispersion relations. However, scalability limits in fabrication have so far unfortunately restricted their realization to small structures, which severely hampers the exploitation of the theoretically available design space. Here, we discuss recent progress on three fronts – a micro-fabrication route for wafer-scale 2D metamaterials, an experimental characterization framework based on interferometry, and optimization of spatially graded structures by computational ray tracing – which jointly enable what was not possible before: the careful design of spatially graded metamaterials with hundreds of thousands to millions of unit cells for the successful guidance of waves along arbitrary paths. We restrict our attention to 2D beam-based metamaterials excited in out-of-plane bending, for which ray tracing allows us to spatially vary a predefined unit cell such as to purposefully adjust the local dispersion relations. The generated computational designs are fabricated from silicon-on-insulator wafers using a process involving photoresist deposition, patterning by exposure to ultraviolet light through a mask, followed by deep reactive ion etching and removal of the buried oxide layer, thereby generating free-standing unit cells in the device layer. The thus-fabricated samples are excited mechanically in out-of-plane bending mode by pulsed-laser excitation, and the resulting out-of-plane displacements are captured by interferometry. We demonstrate that this approach successfully admits the design and fabrication of metamaterials that steer elastic waves along complex paths in 2D. Moreover, we show that the wave guidance capability of those spatially-graded metamaterials is surprisingly broadband, enabling the successful wave guidance across broad frequency ranges.

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