Designing elastic metasurfaces for Scholte-Stoneley wave control at solid-fluid Interfaces

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Abstract

Scholte-Stoneley waves (SSWs) are interface waves propagating along solid-fluid boundaries, with significant potential for diverse engineering applications, such as microfluidics and lab-on-chip devices. However, achieving effective control over their propagation remains challenging. In this study, we propose a novel approach to manipulate SSWs using elastic metasurfaces, consisting of a periodic array of subwavelength mechanical resonators placed at the solid-fluid interface.
The solid and fluid media are chosen such that the velocity of the solid exceeds that of the fluid, cS> cF, ensuring that the standard SSW speed is close to the velocity of the fluid. The resonator is modeled as an equivalent boundary condition exerting a uniform vertical force on the solid medium, allowing for the derivation of analytical dispersion relations valid in the long-wavelength regime. Inspection of the dispersion curve reveals a strong interaction between the fundamental SSW mode and the collective resonances of the mechanical resonators. Unlike the typical behavior observed in surface Rayleigh waves interacting with elastic metasurfaces, this hybridization does not induce a frequency bandgap. Instead, the velocity and the degree of localization of the fundamental SSW mode can be finely tuned through careful design of the elastic metasurfaces.

To validate these theoretical predictions, we employ numerical finite element (FE) simulations and conduct eigenfrequency analyses. Subsequently, harmonic analyses are performed to delve deeper into the underlying physics of the problem. In particular, graded metasurface configurations are designed, featuring mass-spring resonators with spatially varying resonant frequencies along the metasurface array. This design approach enables two key phenomena: (i) rainbow effect, realized by gradually decreasing the metasurface resonance frequency along the array, and (ii) controlled conversion of SSWs into leaky fluid modes, achieved through a smooth increase in the resonance frequency along the array (1).

REFERENCES

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