Ultra-thin longitudinal-shear-coupled meta-barrier for low-frequency underwater sound insulation

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Résumé

Underwater noise pollution from anthropogenic activities, such as offshore oil and gas exploration, poses significant threats to marine life. A common mitigation strategy involves enclosing primary noise sources within physical barriers to reduce noise levels in surrounding environments.

Underwater noise-mitigating barriers typically achieve sound reduction through two primary mechanisms: (i) sound absorption using locally resonant systems (e.g., foam and bubble elements, modified Helmholtz resonators) or (ii) sound reflection using structures such as air bubble curtains and double cylindrical casings. While effective, these approaches have limitations: optimal performance is usually restricted to specific frequency ranges, and transmission loss can drop to zero at other frequencies. Locally resonant systems, in particular, can achieve substantial attenuation but are generally narrowband and struggle with low-frequency noise. Addressing significant low-frequency noise attenuation remains a challenge, especially for thin structures with small thickness-to-wavelength ratios that can operate over broad frequency ranges.

In this work, we present a novel design for thin metamaterial-based underwater barriers that attenuate acoustic waves through anisotropic effective material properties. Using a topology optimization approach, we design a unit cell for a metabarrier that maximizes coupling between normal stresses and shear strains (and vice versa). The resulting metabarriers achieve remarkable performance:

A subwavelength thickness ratio (_˜1/70) at low frequencies below 1 kHz.

High sound transmission loss values at higher frequencies (above 2 kHz), depending on the number of unit cells used in the thickness direction.

Additionally, we evaluate the impact of increased hydrostatic pressure on the submerged structures and propose modifications to enhance their viability for real-world applications.

Our results not only introduce a new metamaterial-based solution for underwater noise mitigation, but also highlight the potential of leveraging anisotropy to develop advanced acoustic insulation technologies, paving the way for innovative applications in underwater environments

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