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Low-frequency noise suppression using adaptive metamaterials

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ABSTRACT

Designing lightweight and compact materials for broadband low-frequency sound insulation and absorption presents strong challenges nowadays. In this work, adaptive metamaterials with the piezoelectric-structural-acoustic coupling are proposed for the low-frequency noise suppression. The adaptive metamaterial for sound insulation is designed by attaching thin plate (epoxy resin) with tunable local resonators, which consists of the hybrid shunted piezoelectric stacks and mass blocks. An analytical model is established to evaluate the soundproof property of the adaptive metamaterial. The piezoelectric stack with the shunting circuits could behave like an elastic spring with the frequency-dependent stiffness. Therefore, the circuit parameters can be optimized so that the frequency dependent stiffness of the stack follows the high transmission-loss trajectory, giving rise to the giant sound reflection. Results show that the sound transmission loss of the metamaterial can reach 30 dB over both broadband frequencies and incident angles. The adaptive metamaterial for sound absorption is composed of an aluminum membrane enclosing an air cavity. The membrane is covered with piezoelectric films, and constrained by a ground spring that is realized by a piezoelectric stack with shunting circuits. The developed analytic model discovers that the piezoelectric film functions for nearly total acoustic absorption at narrow-band frequencies, while the piezoelectric stack can broaden this high-absorption bandwidth according to the adaptive mechanism. Results show that the sub-wavelength metamaterial can achieve high sound absorption with 0.7 relative bandwidth at extremely low frequencies. The proposed adaptive metamaterials may find potential applications in broadband and low-frequency noise insulation and absorption.

Key words: *adaptive metamaterials; acoustic metamaterials; piezoelectric materials; broadband sound insulation; broadband sound absorption*