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Perfect-bandgap acoustic metamaterial rod based on a single material

単一材料でできた完全バンドギャップをもつ音響メタマテリアル棒

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1. Introduction

Solid geometries guide multiple acoustic waves whose polarizations are different owing to the presence of compressional and shear stresses. In the case of a rod, elastic wave polarizations can take four different forms, i.e. compressional, two-directional bending, and torsional modes at low frequencies. Supressing such elastic modes is an industrially important issuse. Acoustic metamaterials are prime examples of human-made solid media designed to this end. In spite of recent remarkable progress of this field, there is still a need for metamaterial rods or beams for damping, i.e. metarods or metabeams. Geometries with perfect bandgaps in a particular frequency range where no acoustic modes can propagate are suitable for strong dampers. Moreover, single-material structures are desirable for easy manufacturing. But, to our knowledge, perfect bandgap metarods have been achieved only by combining several materials, [1-3] although some single-material phononic-crystal rods or beams with perfect bandgaps have been reported [4,5]. Recently, we designed a single-material perfect acoustic bandgap metabeam for the kHz range, and experimentally demonstrated it [6]. In this study, we design and experimentally demonstrate a single-material perfect acoustic bandgap metarod [7].

2. Design and Simulation

The metarod, made of acrylic, is shown in **Fig. 1**. The structure is assembled by bonding an outer tube (diameter 50 mm and wall thickness 2 mm) and inner structures consisting of two Y-shaped supports, a thin rod, an inner cylinder, and a thick rod, to make 10 unit cells (each unit cell of length 60 mm). A detailed description is reported in [7].

The numerically derived dispersion relation calculated by commercial finite-element-method software, COMSOL Multiphysics, is shown in **Fig. 2**, showing the existence of a perfect bandgap for all three mode types (the two bending modes are degenerate because of the symmetry of the rod). Strikingly, in spite of the rods being able to guide

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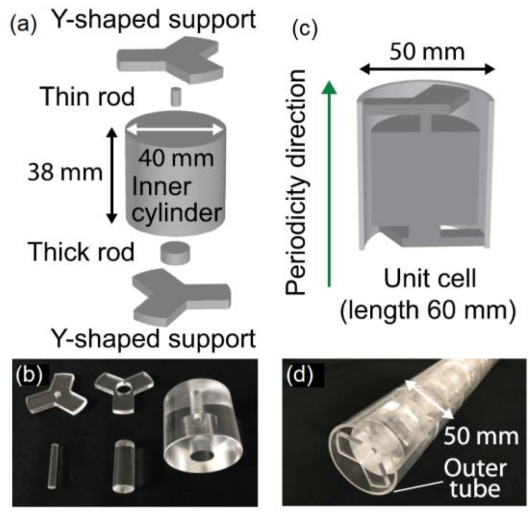

Fig. 1. Acrylic metarod design. (a),(b) The internal components of the metarod. (c) Cross section of unit cell. (d) Photograph of the assembled metarod.

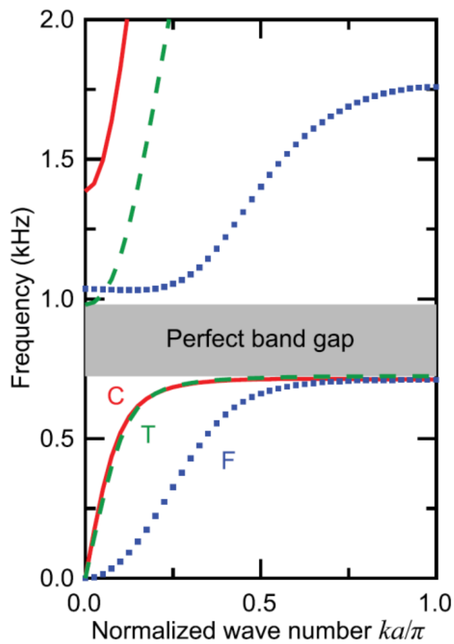

Fig. 2. Acoustic dispersion relation for axial propagation in the metarod. k and a are the axial wavevector and unit-cell length, respectively. The solid red, dotted blue, and dashed green curves correspond to compressional (C), flexural (F), and torsional (T) eigenmodes, respectively, Branches of the two degenerate flexural eigenmodes overlap.

different acoustic polarizations, this structure damps out all three axially propagating acoustic modes in the bandgap region.

3. Experiment

We measured the acoustic propagation characteristics for all three modes by means of the constructed 10-unit-cell metarod, of length 60 cm, connected on either side to an extra portion of bare tube of length 4 mm beyond the unit cells. The sample is excited by a sinusoidally driven piezoelectric disk bonded to an acrylic bar fixed on one end of metarod. Three-axis accelerometers are used at two points at both ends of the metarod in conjunction with lock-in detection in order to obtain a measure of the acoustic wave damping.

The experimental output/input amplitude ratio data sets for all three modes are shown on a logarithmic scale in **Fig. 3** together with the bandgaps found by simulation. All modes show marked damping in the bandgap regions. It is difficult to precisely determine the perfect bandgap experimentally, but the intensity ratio for all modes takes a value less than 0.25 (-6 dB) between 800 and 980 Hz, which is in reasonable correspondence with the simulated perfect-bandgap region.

4. Conclusions

We have demonstrated both experimentally and by simulation that a metarod consisting of acrylic building blocks in the form of a periodic triple-mode resonator array displays a perfect acoustic bandgap near 1 kHz. Larger stop bands should be accessible by the use of graded metarods, yielding more applications for practical use. Also, lower or higher frequencies may be conveniently accessed by the use of softer materials or harder materials, which should open the way to myriad outlets of this research not only in the damping of vibrations in industrial situations, but also in vehicles, ships, and aircraft. Moreover, scaling up to larger sizes should have important applications to the vibration isolation of buildings and in earthquake mitigation.

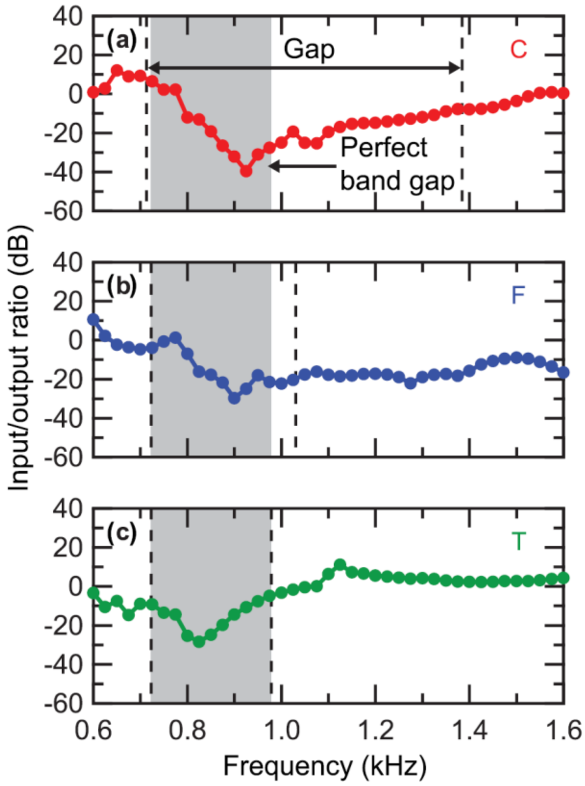

Fig. 3. Experimentally observed output/input acoustic amplitude ratio for each acoustic mode. (a)-(c) correspond to the compressional, flexural, and torsional modes, respectively. The vertical dashed lines indicate the band edges for each mode expected from the simulations, whereas the gray shaded region in each case corresponds to the perfect bandgap expected from the simulations.

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