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Control and Optical Visualization of Ultrasonic Propagation in Phononic Crystal

フォノニック結晶における超音波伝搬制御と光学的可視化

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1. Introduction

The phononic crystals, periodic constructures consisting of materials with different acoustic/elatic characteristics, have attracted much attention [1] due to their unique properties leading to efficient waveguides and acoustic lens by negative refraction [2-6]. In spite of such promises, no comprehensive study by direct observation of wavefronts inside the structure has been reported.

In the present work, phononic-crystal based structures in water with the bandgap around 200-300 kHz are designed by numerical calculations. We fabricate the designed structures and conduct an ultrasonic exmperiments. Here, we adopt an optical measurement of the wavefront in order to evaluate transmission properties of the structure without interfering the acoustic field [7-8].

2. Mode analysis of Phononic Crystal

Eigenmode analyses on a 2D phononic crystal were carried out based on two-dimensional (2D) finite element method (FEM). **Fig. 1(a)** shows the band structure of the phononic crystal consisting of copper cylinders in water with the unit cell depicted in the inset (a1). The phononic band gap lies between 150 and 210 kHz. On the other hand, for the system of a super cell with line defect, as depicted in the inset (a2), a localized defect mode (red line) appears within the band gap.

Fig. 1(b) shows the band structure of another phononic structure. **Fig. 1(c)** illustrates the equivalent frequency surface at 200 kHz in the k space. An incident wave in water with the wave number on the blue circular arc refracts to the wave in the phononic crystal with the wave vector on the red circular arc, resulting in a negative refraction at the interfaces between water and the crystal.

3. Fresnel Method for Optical Visualization

Ultrasonic propagation was visualized using Fresnel diffraction method. The illuminating light generated from the xenon flash lamp (the flashing time: 180 ns) is diffracted by the density variation

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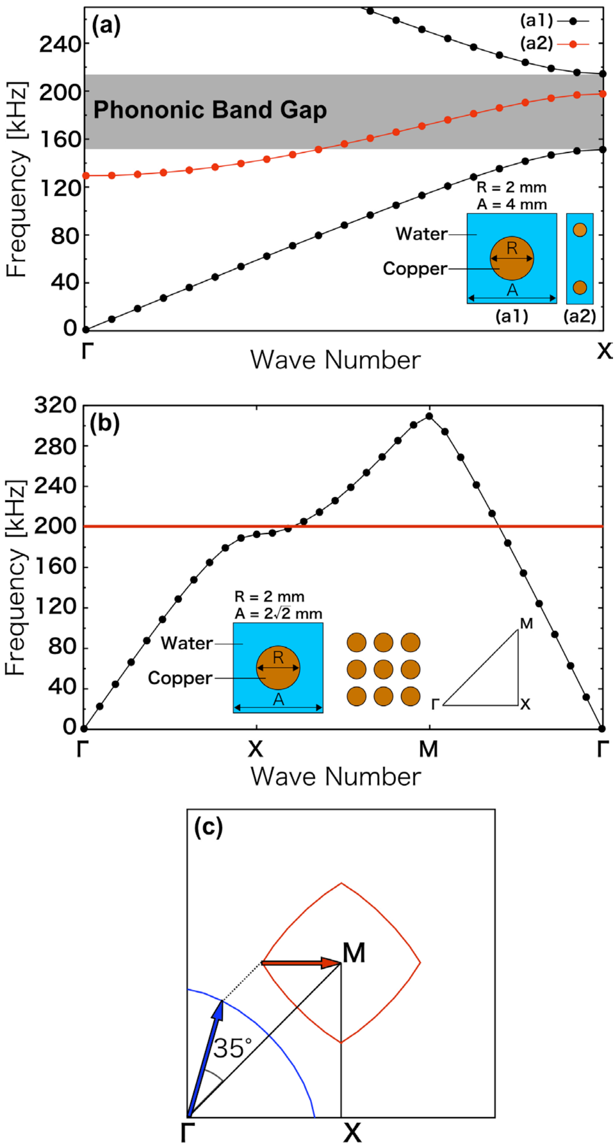

Fig. 1 (a) Band structure of phononic crystal. [Inset: (a1) Unit cell and (a2) supercell with defect]. The gray region shows band gap for the crystal without the defect. Fig. 1 (b) is the first band structure within the brillouin zone. Fig. 1 (c) illustrates the equivalent frequency surfaces in k space for the bands of water (blue circular arc) and of phononic crystal (red circular arc) at 200 kHz. Blue (red) arrow is the directions of group velocity in water (the crystal).

in water caused by ultrasonic generated from the transducer. The wavefront can be confirmed as light and darkness by capturing the diffracted light with a CMOS camera. The wavefront is visualized as a still image by synchronizing the transducer with the xenon flash lamp.

4. Result

Fig. 2 shows the results of numerical simulation and experimental visualization of ultrasonic propagation at a frequency of 200 kHz in the different phononic crystals. The incident wave entering the straight waveguide from the left is confined and propagates in the waveguide [Figs.2 (a, b)]. In the case of the bending waveguide [Figs.2 (c, d)], the wave entering the waveguide from the left is scattered upward at the corner and propagates along the waveguide. We thus succeeded in directly observing the ultrasonic wave confined and propagating in only the waveguides. In Figs. 2 (e, f), negative refraction at the interfaces between water and the phononic crystal is also observed successfully at 200 kHz. The incident angle of the normal to the phononic crystal surface are 35º. The red lines show the pathway of the ultrasonic propagation through the phononic crystal.

4. Conclusion

We numerically designed a phononic crystal having a defect mode and causing a negative refraction at an ultrasonic frequency of 200 kHz. By optical visualization technique based on the Fresnel method, we experimentally evaluated ultrasonic propagation characteristics in the phononic crystal. As a result, we succeeded in directly observing that the ultrasonic waves confined and propagated efficiently in the waveguides, and that the negative refraction occurred at the interfaces.

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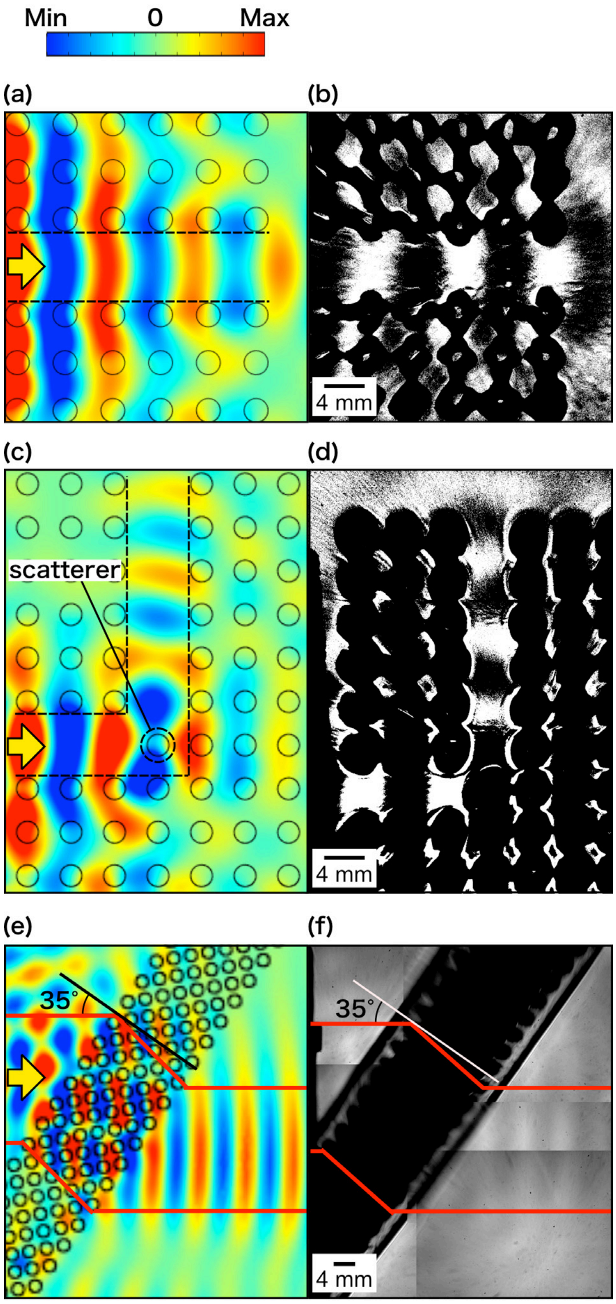

Fig. 2 Numerically simulated (a, c, e) and experimentally visualized (b, d, f) ultrasonic propagation at 200 kHz in phononic crystal. (a, b) and (c, d) are straight and bending waveguides, and (e, f) shows a negative refraction of ultrasonic in a phononic crystal, respectively.

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