3P1-10

Transmission and focusing of ultrasonic wave in silicone by two-dimensional phononic crystal

2次元フォノニック結晶によるシリコーン中の超音波伝送と集束

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1. Introduction

The phononic crystals, periodic constructures consisting of materials with different acoustic/elastic characteristics, have been attracting much attention [1] due to their unique properties leading to, *e.g.* efficient waveguides, acoustic lens by negative refraction, and so on [2-4]. In conventional research, however, phononic crystals using fluid such as water and air as ultrasonic propagation medium have been mainly designed and it has limited the design degree of freedom.

In the present work, we designed 2D phononic structures using PDMS, a kind of silicone, as a structural medium improving the usage environment and design degree of freedom. Using PDMS we fabricated a phononic acoustic waveguide that allow wave propagation only in the defective part by introducing a line defect inside.

In addition, we designed a gradient index (GRIN) acoustic lens [5-7] that enables focusing of incident sound by giving a refractive index distribution inside the 2D phononic crystal. The refractive index distribution was controlled by changing structural parameters of the crystal structure. In the previous research, a refractive index distribution were mainly realized by changing cylinder diameter. In this research, the refractive index is controled, in stead, by changing the crystal lattice length.

2. Design and analysis of Phononic waveguide

Eigenmode analyses on a 2D phononic crystal were carried out based on the two-dimensional (2D) finite element method (FEM). **Figure 1(a)** shows the band structure of the phononic crystal consisting of stainless cylinders in PDMS with the unit cell depicted in the inset (a1) of Fig. 1(a). The phononic band gap lies between 300 and 580 kHz. On the other hand, for the system of a supercell with a line defect, as depicted in the inset (a2), localized defect modes (red lines) appear within the band gap.

Figure 1(b) shows the results of numerical simulation of ultrasonic propagation at a frequency of 500 kHz in the phononic crystals with a line defect (waveguide). The figure shows that the incident wave entering the straight waveguide from the left is confined and propagates in the waveguide. Also from the figure, it is confirmed that the wave propagating through the waveguide is a mixed mode of the localized modes (m = 0 and 1) depicted in Fig. 1(a). This mixture may be due to that the incident wave frequency chosen (500 kHz) was rather close to the cross over point of these localized modes as shown in Fig. 1(a).

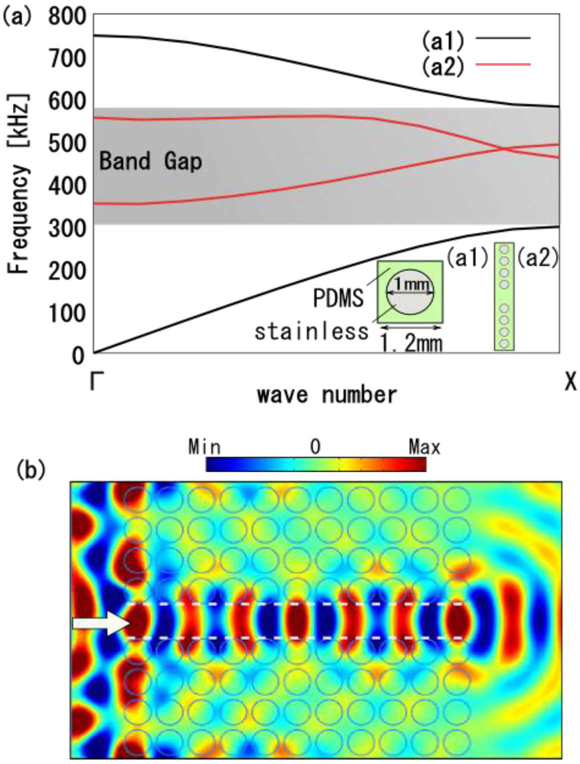

Fig. 1 (a) Band structure of phononic crystal. [Inset: (a1) Unit cell and (a2) supercell with a defect]. The gray area indicates band gap in the crystal without the defect. The horizontal axis corresponds to the wave number direction in the Brillouin zone. (b) Wave front of the ultrasonic wave propagating at 500 kHz in the phononic waveguide.

3. Design and analysis of GRIN lens

Next, we designed the GRIN lens based on the phononic structure. **Figure 2(a)** shows a band

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diagram of unit cells having different filling factor (ff) of metal cylinder in a unit cell. As the ff increases, the propagation frequency band gets higher. The refractive index is obtained from the slope of the band diagram calculated for each unit cell. In this work, the index distribution is realized by changing the ff of each layer of the phononic crystal. The ff of middle layer is the lowest, and increase symmetrically in the upper and lower layers. A smooth index distribution is thus obtained in the lens. Here we designed a 19-layer, 12-rows GRIN lens.

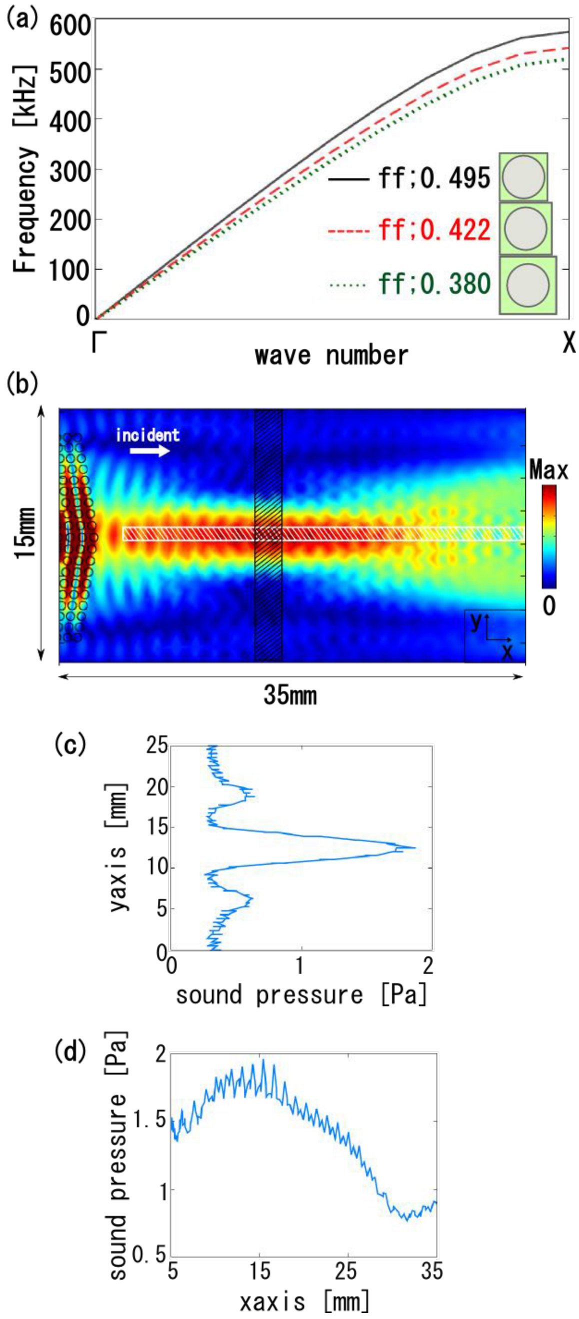

Fig. 2 (a) Band diagram of unit cells with different filling factors (ff). (b) Ultrasonic propagation at 470 kHz in the GRIN lens. (c), (d) The average pressure intensity distribution in the black hatched ((c)) and in the white hatched area ((d)) in Fig. 2 (b), respectively.

Figure 2(b) shows the results of numerical simulation of ultrasonic propagation at a frequency of 470 kHz in the GRIN lens. It can be seen that incident ultrasonic waves refracted by the GRIN lens are focused and the sound pressure is amplified near the focal point.

Figures 2(c) and 2(d) show the average pressure distributions in the black hatched area and in the white hatched area in Fig. 2(b) respectively. Figure 2(c) indicates that the incident wave is focused at a focal point with the aberration on the order of the wavelength along the direction normal to the incident direction (*y* axis), whereas the focal point is rather blurred along *x* axis as shown in Fig. 2(d) From these results, approximately twice the sound pressure intensity increase was obtained in the designed lens.

4. Conclusion

Using PDMS as the structural medium of phononic crystal, we designed a phononic acoustic waveguide operating at 470kHz. We also designed a GRIN lens by changing the lattice length of each layer of the phononic crystal. The GRIN lens we designed exhibited that the incident ultrasonic waves were focused to the extent of wavelength, leading to an efficient intensification of the sound pressure around the focal point.

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