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Time-resolved imaging of negative refraction of surface acoustic waves in two-dimensional phononic crystals
二次元フォノニック結晶による表面弾性波の負屈折の時間分解イメージング

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1. Introduction

Phononic crystals (PCs) are artificial periodic structures that can control the acoustic properties of media. When the acoustic wavelength is comparable with the period of the phononic crystal, they show various exotic behaviors such as phononic band gaps[1], the negative refraction[2-4], or super-lensing[2,4], etc.

Negative refraction has attracted attention because of its potential for controlling acoustic waves. Sukhovich et al[2]. have demonstrated negative refraction experimentally in a phononic crystal made of a periodic array of stainless rods in a liquid[2]. The period is of mm order, and negative refraction is observed for acoustic waves in MHz frequency region. Negative refraction in the GHz frequency region would be, however, highly interesting to study, because of various potential applications in GHz acousto-electronic devices. It is also important to clarify the dispersion relation of PCs which show negative refraction. One of the possible required conditions for negative refraction is that the group velocity of the phononic crystal should be in the opposite direction (at least for a single component of the velocity vector) to the phase velocity. When the phononic crystal satisfies this condition, negative refraction should be observed at interfaces between the phononic crystal and a non-PC medium.

2. Methods

We study the negative refraction of surface acoustic waves in the GHz frequency region. Our method consists of the following three parts: theoretical investigation by simulations, sample fabrication, and experimental time-resolved imaging of the acoustic wave propagation on the structure.

(1) Theoretical investigation by simulations: We attempt to reproduce the negative refraction by conduct simulations using a commercial finite element software, PZ-Flex. The proposed PC structure is a periodic triangular array of air holes on a Si substrate. With these simulations we can optimize various parameters of the PC structure for negative refraction, such as the period, diameter, and depth of holes, as well as the boundary shape of the PC region.

(2) Sample fabrication: We make PC samples by boring holes on a Si substrate with a focused ion beam (FIB) processing unit. The structure of the samples is determined by reference to the results of the above simulations. The silicon substrate is chosen because of its well-established process technology.

(3) Time-resolved imaging of the acoustic wave propagation on the PC structures: We use a time-resolved two-dimensional surface acoustic wave imaging system[5] based on the optical pump-probe technique to obtain two-dimensional snapshot images of the out-of-plane surface displacement velocity with ps temporal resolution, μm horizontal spatial resolution, and pm vertical spatial resolution. With this technique we can image the acoustic waves over a typical area ~200 μm × 200 μm for frequencies up to ~1 GHz. Constant frequency images are obtained by a Fourier transform in the time domain[5,6].

In this paper, we mainly concentrate on the simulations.

3. Simulation and Results

The sample studied in the simulation consists of a right-triangle-shaped PC region embedded in the non-PC region both made of Si. The PC contains a triangular lattice of air holes whose diameter is 0.5 μm and depth is 5 μm. The period, d, is 2.65 μm. The surface acoustic waves, with maximum frequency 2 GHz, are excited on this sample using a line-shaped source located outside of the PC region.

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The generated line-shaped wave front goes into the PC region with zero incident angle. We expect negative refraction when the wave exits the PC. The situation is schematically shown in **Fig. 1**. **Figure 2** shows a typical simulation result at 1686 MHz. It is obtained by temporal Fourier analysis. Negative refraction can be clearly seen.

We fabricated the PC structure based on the simulation specifications, and are now conducting time-resolved imaging experiments on this sample.

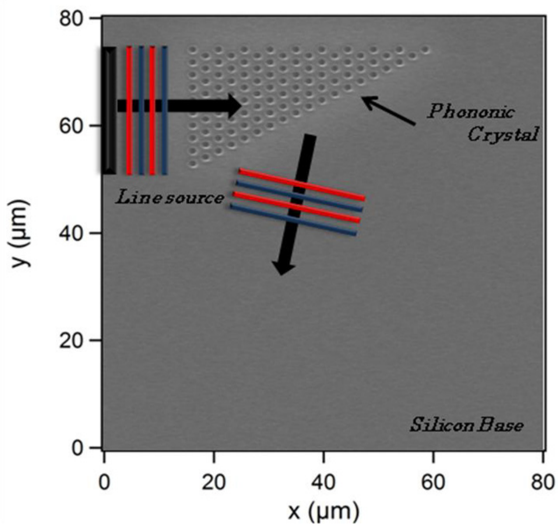

Fig. 1: The sample structure used in the simulation. The incident and negatively refracted acoustic waves are schematically shown.

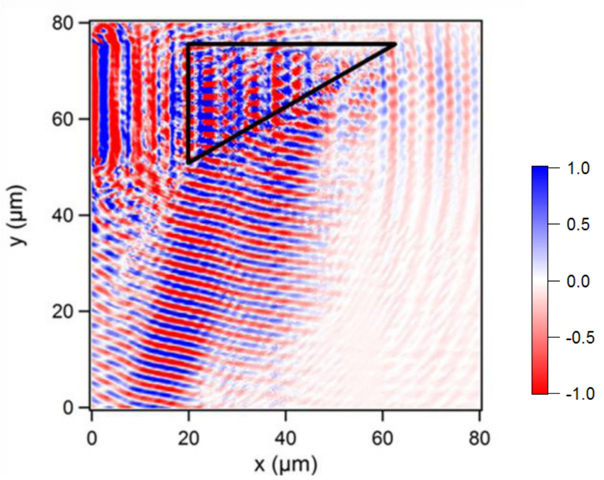

Fig. 2 Result of the simulation of the vertical component of the surface velocity at 1686 MHz. Negative refraction below the PC region is clearly observed.

References

1. S. Mohammadi, A. A. Eftekhar, A. Khelif, W. D. Hunt, and A. Adibi, Appl. Phys. Lett. **92,** 221905 (2008).
2. A. Sukhovich, Li Jing, and John H. Page, Phys. Rev. B **77**, 014301 (2008).
3. B. Bonello, L. Belliard, J. O. Vasseur, B. Perrin, and O. Boyko, Phys. Rev. B **82**, 104109 (2010).
4. K. Imamura and S. Tamura, Phys. Rev. B **70,** 174308 (2004).
5. T. Tachizaki, T. Muroya, O. Matsuda, Y. Sugawara, D. H. Hurley, and O. B. Wright, Rev. Sci. Instrum. **77,** 043713 (2006).
6. D. M. Profunser, E. Muramoto, O. Matsuda, and O. B. Wright, Phys. Rev. B **80,** 014301 (2009).
7. D. M. Profunser, O. B. Wright, and O. Matsuda, Phys. Rev. Lett. **97,** 055502 (2006).