3Pa1-5
Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 325-326
8-10 November, 2011

Imaging Lamb waves in a phononic crystal waveguide
フォノニック結晶平板上におけるラム波伝播イメージング

R. Chinbe[1†], S. H. Kim[2], P. H. Otsuka [1], M. Tomoda[1], O. Matsuda[1], I. A. Veres[3], Y. Tanaka[1], H. S. Jeon[2], and O. B. Wright[1] ([1]Hokkaido Univ.; [2]Seoul National Univ.; [3]Recendt, Research Center for Non Destructive Testing, Austria)
珍部 涼太 [1†], キム シーハン [2], オオツカ ポール [1], 友田 基信 [1], 松田 理 [1], ヴェレス イストバン [3], 田中 之博 [1], ジェオン ヘオンス [2], ライト オリバー[1] ([1] 北大, [2] ソウル大, [3] オーストリア非破壊検査研究センター)

1. Introduction

Phononic crystals (PCs) have been the subject of much recent research because of their flexibility to control acoustic wave propagation [1]. An important property of PCs is the existence of phononic band gaps (PBGs) that block acoustic waves of specific frequencies from travelling. Applications of PCs in high-frequency signal processing, such as filtering, have been proposed. Confining, or guiding, mechanical energy in PCs with two-dimensional periodicity is possible because of omnidirectional PBGs [2], i.e., complete phononic band gaps (CPBGs). It has been demonstrated that honeycomb lattices exhibit a relatively wide CPBG when in slab form [3].

In this paper we present results for real-time imaging [4] of optically-generated Lamb waves at frequencies up to ~1 GHz in PC slab structures based on honeycomb lattices. We also carry out numerical simulations with a finite element time domain method. Simulations and experimental results are compared.

2. Sample

The sample was based on a microscopic honeycomb lattice of circular holes patterned on a (111) silicon-on-insulator wafer by dry etching. The insulating silicon oxide was then removed by etching to leave a free-standing crystalline Si slab of thickness 6.5 μm. Finally, a Pt dot of thickness 20 nm and diameter 2 μm was deposited outside the structure using a focused ion beam for the excitation of the Lamb waves.

A typical sample design is shown in Fig. 1; a Y-shaped region with no holes forms a PC waveguide. The center-to-center spacing of the holes (formed through the whole slab thickness) is a = 6.6 μm, whereas the diameter is $2r$ = 5.8 μm (r/a=0.44). The waveguide width is $3a$ = 19.8 μm.

---

chinbe@eng.hokudai.ac.jp

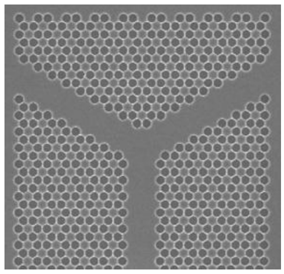

Fig. 1 Scanning electron microscope image of the PC waveguide. The hole diameter is 5.8 μm, the hole spacing is 6.6 μm, and the slab thickness is 6.5 μm. The first complete phononic band gap lies between 230 and 320 MHz. The angle between the branches of the guide is 120°.

The expected first CPBG lies between 230 and 320 MHz for this phononic slab, as verified by simulations based on the orthogonal plane wave method.

3. Experiment and simulation

1. Pump-probe measurement

We use optical pulses of duration ~200 fs, wavelength 830 nm and repetition rate 80.4 MHz from a Ti:sapphire femtosecond laser. The 415 nm pump beam derived from this laser is used to generate Lamb waves at a point source by thermoelastic expansion. An 830 nm beam, after being delayed relative to pump beam, is used to probe the sample. The beams are focused to spots ~1 μm in diameter. The probe spot is scanned across the sample relative to the pump to obtain images at various delay times over an area ~200×200 μm^2. Animations of the out-of-plane velocity of the surface motion at acoustic frequencies up to ~1 GHz are recorded. Constant frequency images are obtained by Fourier transforming in the time domain. Figures 2 (b) and (d) correspond to such experimental images at ~322 MHz and ~80 MHz, respectively. The waves

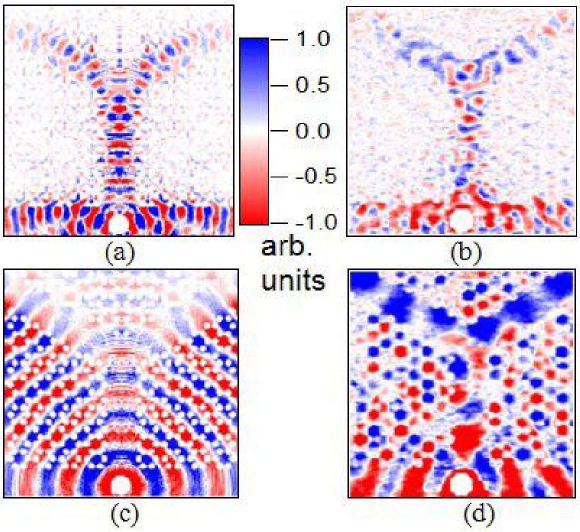

Fig. 2 Experimental (b), (d) and simulated (a), (c) images of the out-of-plane velocity of the surface motion of a sample consisting of a Y-shaped waveguide in a honeycomb-lattice phononic crystal slab in (111) silicon. (a) and (b) correspond to 322 MHz (inside the complete phononic crystal bandgap), whereas (c) and (d) correspond to 80 MHz. The white circles show the source positions.

are generated at the entrance to the waveguide, as shown by the white circles in Fig. 2.

2. Numerical simulation of Lamb wave propagation

Commercial finite-element software (PZFlex, Weidlinger A., Inc.) was used to model the PC waveguide structure over a region of $0.174\times0.179\times0.176$ μm^3 using $\sim10^8$ elements. Thermoelastic generation is replaced by an impulsive in-plane dipolar force. Figure 2 (a) and (c) show the results of the simulation corresponding to the experimental results shown in the same figure.

4. Discussion

The 322 MHz waves lie in the CPBG of the waveguide. Therefore the waves in the waveguide are strongly confined as they propagate along the waveguide. In contrast the waves at 80 MHz are not guided and pass through the honeycomb lattice. These trends are clear in both experiment and simulation. At 322 MHz the waves can be seen to split into the two branches. However, some differences between experiment and simulation are evident at both frequencies. One possible reason is that the source in experiment is slightly offset from the symmetry position, whereas in the simulation the source is placed symmetrically.

5. Conclusion

In conclusion we have visualized Lamb waves in Y-shaped PC waveguide using an ultrafast optical method. Both experimental and simulated images were obtained, and compared. This work should lead to new diagnostic techniques for the propagation of surface acoustic waves in phononic structures, including surface acoustic wave devices.

References

1. M. Sigalas, E. N. Economou, Solid State Commun. **86**, 141 (1993).
2. F. L. Hasio, A. Khelif, H. Moubchir, A. Choujaa, C. C. Chen, and V. Laude, Phys. Rev. E **76**, 056601 (2007).
3. S. Mohammadi, A. A. Eftekhar, A. Khelif, W. D. Hunt, and A. Adibi, App. Phys. Lett. **92**, 221905 (2008).
4. T. Tachizaki, T. Muroya, O. Matsuda, Y. Sugawara, D. H. Hurley, and O. B. Wright, Rev. Sci. Instrum. **77**, 043713 (2006).