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Study of Surface Acoustic Waves in $SiO_2/LiNbO_3$ Layered-Structure Phononic Crystals

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1. Background and Objective

Phononic crystal (PnC) is an acoustic metamaterial which is composed of periodic media or periodic geometric structures. PnCs perform several important properties, including anisotropic propagation and acoustic band gaps. These phenomena were observed for bulk acoustic wave, surface acoustic wave (SAW), and Lamb waves, in various PnC structures, respectively. Applications of PnC, such as filters, reflective gratings, waveguides, and resonant cavities, were designed and were potential to be used in acoustic-electronic components. Among these components, SAW devices are widely used and suitable to combine with PnCs which were applied as reflective gratings by using the band gap property.

Currently, PnCs for SAW usually consist of cylindrical holes with high aspect ratio in the matrix. For a feasible fabrication, usually no other materials were inserted in the holes. Further, etching holes in the piezoelectric material is difficult, and limits the choice of substrate materials. In this paper, SiO_2/128° Y-X $LiNbO_3$ layered-structure PnCs for SAW were investigated. The PnCs consisting of periodic holes in the SiO_2 layer make the fabrication more feasible and the single crystal piezoelectric substrate promise to raise the performance of the SAW devices. The dispersion of SAWs in the layered-structure PnC was analyzed numerically. Various geometric designs were calculated and the band gaps were figured out. Thus the layered-structure PnC can be designed as reflective gratings, which can improve the performance and reduce the size of SAW devices simultaneously.

2. Band Gap of Surface Acoustic Waves in $SiO_2/LiNbO_3$ Layered-Structure PnC

The layered-structure PnC was designed on a SiO_2 layer over a 128° Y-cut $LiNbO_3$ substrate. Cylindrical holes through the SiO_2 layer were arranged periodically to form a square lattice as shown in **Fig. 1(a)**. Finite element method was used to analyze the dispersion of SAWs in the layered-structure PnC firstly. A unit cell was defined as shown in **Fig. 1(b)**. The ΓX-direction of PnC align with the X-direction of the $LiNbO_3$ substrate. Periodic boundary condition (PBC) based on Bloch theorem was set on the side surfaces to satisfy the condition that wave propagating in an infinite periodic PnC. The bottom surface was fixed because SAW decays rapidly along the depth. Then the modes of acoustic waves in PnC were determined by calculating the eigenfrequencies of the unit cell. Redundant modes resulted from the fixed BC was removed by applying a post-processing program. Then the ranges of band gaps were identified.

The layered-structure PnC has a partial band gap for SAW propagating along the ΓX-direction. The typical PnC in the study has the lattice constant a of 20 μm and the hole radius r of 6 μm. By changing geometric dimensions of the layered PnC, the band gaps varied correspondingly. **Fig. 2(a)** shows the band gap ranges of surface waves for different thickness h of the SiO_2 layer. The width of gaps becomes narrower and the range shifts higher while thickness is thinner. The band gap distribution for SAW in the layered-structure PnC of various radii in the 20 μm thickness SiO_2 layer was shown in **Fig. 2(b)**. The PnC with smaller hole radius perform a smaller band gap. These results show that PnCs defined in a layered structure still have band gaps for SAW. Thus reflective grating can be designed accordingly.

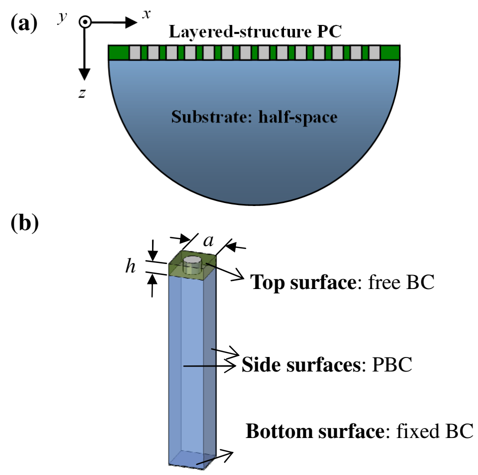

Fig. 1 (a) The schemas of a layered-structure phononic crystal. (b) The unit cell adopted in FE to analyze band of SAW.

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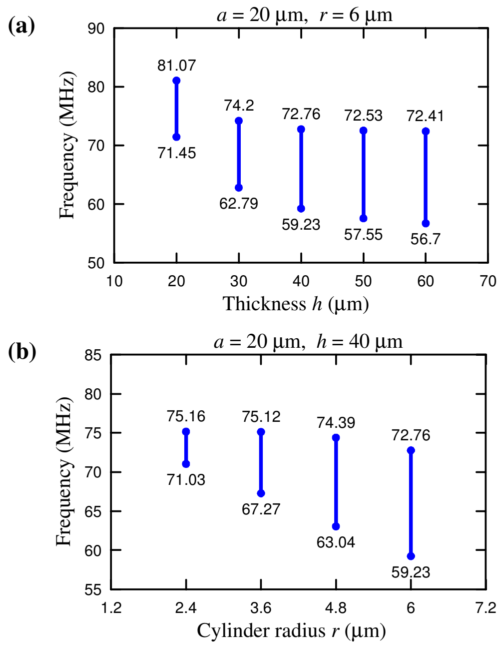

Fig. 2 The band gap ranges of layered-structure PnCs. (a) Varied layer thickness *h*. (b) Varied cylinder radius *r*.

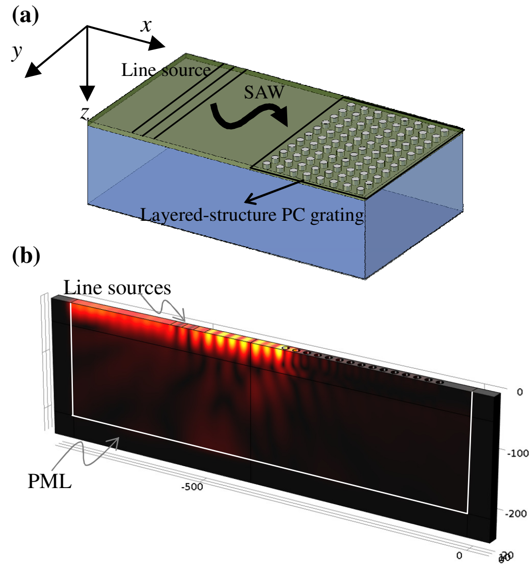

Fig. 3 (a) The PnC reflective grating for SAW. (b) The displacement field (amplitude of component *Uz*) of 66 MHz SAW propagating toward the PnC grating.

3. Design of Phononic Reflective Grating

Based on the band gap property, PnC in $SiO_2/LiNbO_3$ layered structure can be design as gratings to reflect SAW as shown in **Fig. 3(a)**. A PnC grating with a = 20 µm, r = 6 µm and h = 40 µm was demonstrated. The band gap of SAW was 59.23-72.76 MHz as shown in Fig. 2 and thus an operating frequency was chosen as 66 MHz. The frequency response was calculated by finite element method. Perfectly matched layer (PML) was set around the grating to simulate a half space as shown in **Fig. 3(b)**. Line sources on the surface generate SAW toward PnC grating on the +*x* direction. The displacement field in Fig. 3(b) shows that SAW does not penetrate the 10-layer PnC. The reflected wave superposed on the incident wave result in a standing wave pattern obviously. Thus the layered-structure PnC can reflect SAW efficient and can be used as a grating in SAW devices.

4. Results

In this paper, layered-structure PnCs in a SiO_2/128° Y-X $LiNbO_3$ were investigated. The dispersion and band gap of SAW were analyzed numerically. The variation of band gaps caused by geometric change was also calculated. Based on the band gap property, a PnC reflective grating was achievable in the layer-structure SAW devices.

Acknowledgment

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