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Study of Phononic Lens for SAW Devices

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1. Introduction

Phononic crystal (PnC) consisting of periodic elastic materials in the background media attracted many interests in the past two decads. Acoustic waves propagating in PnC have some special phenomena. Band gaps appear and block waves within a certain frequency range; anisotropic propagation makes the phase and energy velocity in different directions. Several applications of PnCs were proposed. Based on the band gaps, PnC were used as the gratings in surface acoustic wave (SAW) device, such as SAW resonator, filters and sensor [1-2]. Further, PnCs with anisotropic propagation were used as a lens to bend the propagating waves and to focus waves at a certain area. Negative refraction of waves in PnC were also reported [3-4].

In this paper, we reported our work after Reference 3. The band structure of a square lattce PnC made of circular tungsten films on a lithium niobate substrate. Equal frequency contours (EFC) were calculated to show the nonparallel direction of energy and phase velocity. Then negative refraction were observed at some frequency. The diffraction of surface waves can be suppressed at the chosen frequency. Thus improved performance of a two-port SAW device with a PnC lens were observed.

2. Rayleigh waves in tungsten/lithium niobate PnCs

In this study, the 128°Y-cut lithium niobate ($LiNbO_3$) was chosen as the matrix material and a square lattice PnC was formed by circular tungsten (W) films covering on the substrate. The lattice constant *a* was chosen as 10 μm, radius *r* and thickness *h* of tungsten film were 0.3*a* and 700 nm for the feasibility of fabrication. We set the *x*-coordinate of material at the ΓM direction in k-space (as shown in **Fig. 1**) to enhance the anisotropic property.

Figure 2 shows the band structure of PnC in the first Brillouin zone. Partial band gaps for SAW appear at ΓM_1 direction, and the frequency range is 216.5 to 234.7 MHz. According to our previous study, waves propagating toward around the ΓM direction were studied to suppress natural diffraction. Equal frequency contours (EFCs) were determined by cutting three-dimensional band structures at a chosen frequency. Then the energy-velocity directions of Rayleigh waves were calculated from EFC and also the refraction angles at the interface of pure $LiNbO_3$ and PnC.

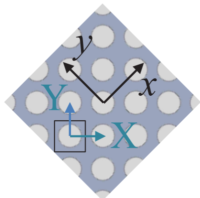

Fig. 1 Schema of the W/$LiNbO_3$ PnC and the unit cell. X-Y present the coordinate of PnC lattice and *x*-*y* the $LinNbO_3$.

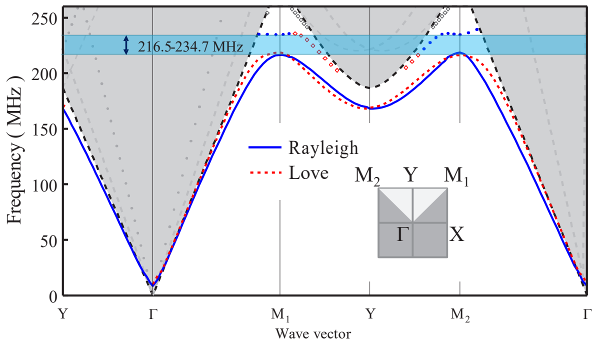

Fig. 2 Dispersion curves of W/$LiNbO_3$ PnC (a=10 μm, h = 700 nm, r = 0.3a)

Table. 1 Refraction angles of phase and energy velocities @210 MHz toward ΓM_1 direction

Pure Material (incident)		PnC (refracted)	
θ_{phase}	θ_{energy}	θ_{phase}	θ_{energy}
3.0°	1.9°	2.6°	-7.0°
5.8°	3.4°	4.9°	-9.0°

The refraction angle of energy velocity reaches -9° near M_1 point at 210 MHz while incidence angle is 3.4° in pure material. Some typical data were listed in **Table 1**. The result showed that Rayleigh at ΓM_1 direction has stronger self-collimation effect in both pure material and PnC structures.

3. Lowering diffraction by phononic lens

The negative refraction of energy velocities in the interface allowed a PnC lens, a simple

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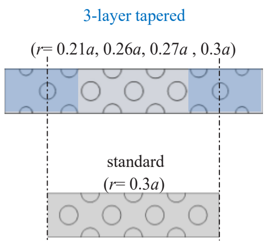

Fig. 3 The schematics of standard PnC and three-layer tapered PnC.

rectangular region of PnC, to lower diffraction of SAW. The energy velocity performed negative refraction while entered and leaved a PnC lens and thus the energy was focused. We learned that multi-reflection of SAW inside the PnC induced considerable loss. Thus tapered PnC region was attached at the boundaries of PnC lens were used to reduce mismatch of acoustic impedance and discontinuity. As shown in **Fig. 3**, a three-layer tapered PnC was defined by adding three-row tungsten film with smaller radii (0.21a, 0.26a and 0.27a). The tapered structure raised the transmission effectively from 92% to 99%.

Then SAW launched by an IDT was considered. **Fig. 4(a)** is the displacement amplitude in pure $LiNbO_3$ and **Fig. 4(b)** is the result of wave passing the PnC lens. By comparing the figures, the PnC lens did help keep the energy in the central line. Further, two-port SAW devices without and with a PnC lens were calculated as shown in **Fig. 5(a)** and **Fig. 5(b)**. **Fig. 5(c)** showed that the transmission coefficient S_{21} was raised in the device with a PnC lens.

4. Conclusion

In this study, the tungsten/lithium niobate PnCs was studied to be used in SAW device to suppress the diffraction and raise the performance. The PnC was used to be an acoustic lens to suppress diffraction of surface waves at 210 MHz along the ΓM direction. By using three-layer tapered PnCs, and the transmission through the PnC lens was raise to 99%. In 3D simulation, the surface waves was excited by an IDT. Applying the PnC lens made the distribution of amplitude field more stable and the two-port SAW device had a higher transmission coefficient with the PnC lens inside.

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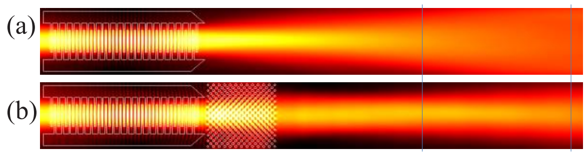

Fig. 4 The SAW amplitude fields excited by IDT: (a) without a PnC lens; (b) with a 25-layers PnC lens.

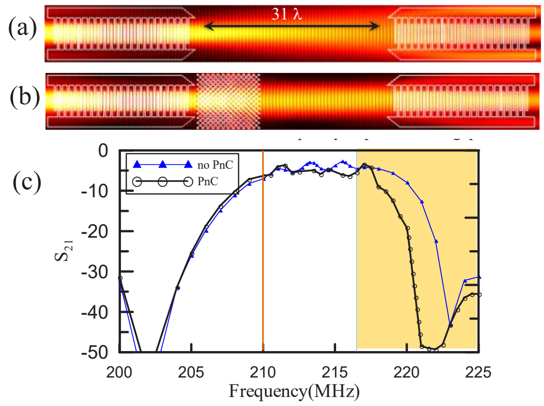

Fig. 5 The SAW amplitude fields in a two-port SAW device: (a) without a PnC lens; (b) with a PnC lens. (c) The transmission coefficient S_{21} of devices in (a) and (b).

References
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