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Suppressing Diffraction of Surface Acoustic Waves Using Phononic Lens

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1. Introduction

Phononic crystal (PnC) is an acoustic metamaterial, which consists of periodically arranged elastic materials in the background media. While acoustic waves propagating in PnC, there are some special phenomena. The band gap can block waves with the certain frequency range, and anisotropic propagation makes the phase and group velocity in different directions. In recent years, there were several applications of PnCs. Based on the band gaps, PnC were used as the gratings in surface acoustic wave (SAW) device, such as SAW resonator, filters and sensor[1-3]. Further, a hybrid design of inter-digital transducer (IDT) and PnC SAW device was designed to reduce the acoustic loss of surface waves and enhance its efficiency[3].

In this paper, we analyzed 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 group and phase velocity. Then negative refraction were observed at some frequency. The diffraction of surface waves can be suppressed at the chosen frequency. Thus energy leakage in SAW devices can be improved.

2. Anisotropic propagation in tungsten/lithium niobate PnCs

The tungsten / lithiun niobate PnCs were used in this paper. The lattice constant *a* of PnC is 4 µm, radius *r* and thickness *h* of tungsten film are 0.4*a* and 400 nm. We set the X-coordinate of material at the ΓM direction in k-space.

Fig. 1 shows the band structure of PnC in the first Brillouin zone. There are partial band gaps in the ΓY direction. The partial band gap of Rayleigh waves starts from 370 MHz at point Y and ends at 460 MHz at point M_2. For Love waves, the range is 385-430 MHz.

For suppressing the diffraction, the waves toward ΓM direction were studied. We calculated the directions of group velocities from EFC at frequencies within 370-460 MHz. The refraction angle reach the minimum (-24°) near M_1 point at 445 MHz (while incidence angle of waves is 7.75° in pure material). The refraction at the interface of pure $LiNbO_3$ and PnC was shown **Fig. 2**, and 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.

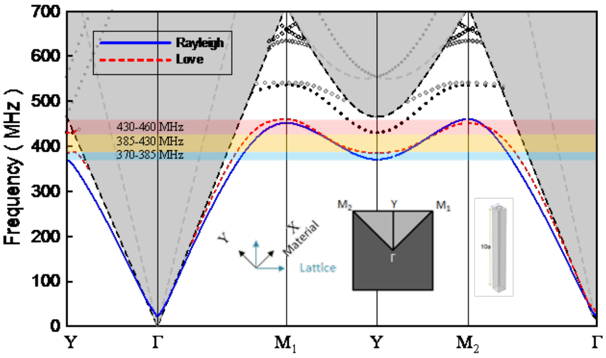

Fig. 1 Dispersion curve of $W/LiNbO_3$ PnC
(a=4 µm, h = 400 nm, r = 0.4a)

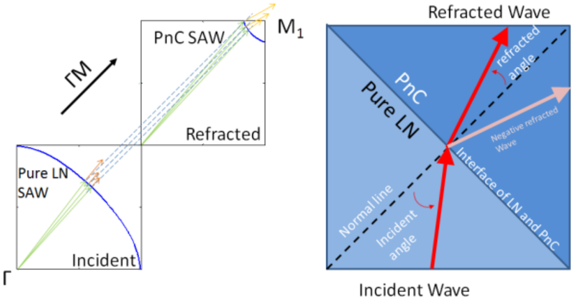

Fig. 2 Incident waves and refracted waves

Table. 1 Refraction angles of phase and group velocities @445MHz toward ΓM_1 direction

Pure Material (incident)		PnC (refracted)	
θ_{phase}	θ_{group}	θ_{phase}	θ_{group}
7.75°	4.15°	5.30°	-24.0°
5.00°	3.00°	3.50°	-16.5°
3.00°	1.90°	2.05°	-8.5°

3. Lower diffraction in phononic lens

To apply PnC as a lens in front of the source, the transmission and thickness of lens were analyzed. Due to the reflection at the interface and resonance within the PnC lens, the transmission become lower in some lenses of certain lengths. Therefore, we chose layers with higher transmission

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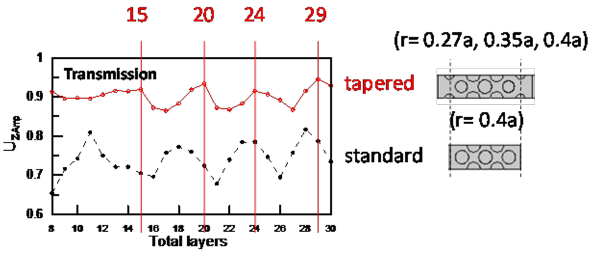

Fig. 3 Transmission of SAW passing PnC lenses with different layers. The inset shows the standard PnC lens and the lens with tapered PnC.

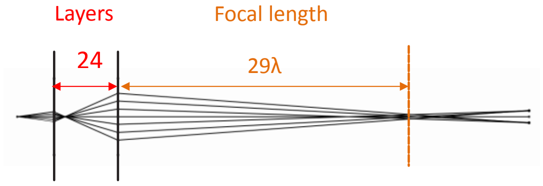

Fig. 4 Trajectory of SAW passing PnC lens.

and use tapered structure at the interfaces of PnC lens to raise the transmission. The transmission of PnC with different layers was shown in **Fig. 3**.

As shown in the **Fig. 4**, we calculate the rays of the incident and refracted Rayleigh waves through a PnC lens in the ΓM_1 direction. SAW crossing the lens were deflected and focused at the outside region. The PnC lens with more layers makes the focal point farther. As a result, the diffraction of SAW was depressed.

The 3D simulation of SAW passing through a PnC lens was shown in **Fig. 5**. The surface waves were excited by a point source. **Fig.5 (a)** showed the amplitude filed of SAW in the pure $LiNbO_3$ substrate and **Fig.5 (b)** is the case with a PnC lens. As shown in **Fig.5 (c)**, the SAW through the PnC lens has higher amplitude. Thus the PnC lens suppress the diffraction.

4. Conclusion

The band structure of tungsten / lithiun niobate PnCs was analyzed. The anisotropic propagation was applied to suppress diffraction of surface waves in ΓM_1 direction. In the transmission rate analysis, we used tapered PnC to make transmission rate over 85%. The rays were calculated to predict the focal length and position of focal points.

In 3D simulation, we shows the SAW was converged. Compare to the case without PnC, PnC structure makes the distribution of amplitude flater and more stable. The side diffraction was suppressed. The result can be used to make low-diffraction SAW devices.

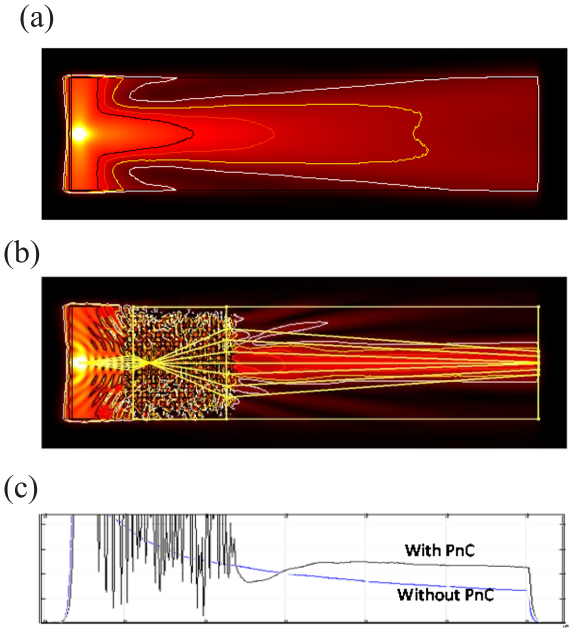

Fig. 5 The SAW amplitude fields excited by a point source: (a) without PnC lens; (b)with a PnC lens. (c) Amplitude distribution of cases (a) and (b).

Acknowledgment

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