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An AT-cut Quartz Phononic Lamb Wave Filter

Jia-Hong Sun[1†], Tsung-Tsong Wu[2], and Chia-Hao Hung[2] ([1]Dept. of Mechanical Eng, Chang Gung Univ., Taiwan; [2]Inst. of Applied Mechanics, National Taiwan Univ., Taiwan)

1. Background and Objective

Phononic crystals (PCs) are artificial composites made of two or more periodically arranged elastic materials or geometric boudaris. PCs have attracted a lot of attention in the last decade. Som special acoustic phenomena, such as band gaps, waveguiding, negative refraction and localized resonances, were observed for bulk waves, surface waves, and Lamb waves. Among these properties, band gaps play an important role on the potential frequency control. Based on the band gap property, Lamb wave resonant cavities constructed by PCs were investigated numerically. A two-port ZnO/silicon Lamb wave resonator with PC gratings was designed, fabricated, and characterized. Further, a narrow band ladder-type filter was realized by utilitizing dual Lamb wave resonators on the silicon-base PC plate. In this paper, a further study of phononic Lamb wave filters on a piezoelectric plate, an AT-cut quartz plate, were presented. The acoustic waves insede AT-cut quartz PC plate were analyzed numerically and a ladder-type filter were designed accordingly.

2. Phononic plate on AT-cut Quartz

A PC is defined on the AT-cut quartz plate firstly for the constructing the Lamb filter on it. Cylindrical holes were arranged periodically to form a square lattice as shown in Fig. 1(a). The thickness h of the quartz plate is 80 μm and the lattice constant a is 100 μm. Using finite element method, the band structure of acoustic wave in the PC plate can be calculated. By varying the radius r of the hole, the acoustic bands shift and may open a band gap. Fig. 1(b) shows the acoustic dispersion when the radius was chosen as 45 μm and a partial band gap along the ΓX-direction at 17.07-18.50 MHz was observed.

With the band gap frequency range, Lamb wave could not propagate through the PC structure and will be reflected efficiently. Then the PC could be used as reflective grating to construct a resonant cavity for Lamb wave. Fig. 2 shows the schema of a resonant cavity base on a phononic plate where ΔL represents the cavity length. By changing ΔL, the resonat frequency of Lamb waves inside the cavity will be manipulated. The supercell technique can be used to analyze the resonant modes. In this AT-cut quartz PC plate, a resonant cavity with ΔL=1971 μm allows a lowest antisymmetric (A_0) mode at 17.86 MHz.

3. Design of Phononic Lamb Wave Filter

The resonant frequency was controlled by tuning the cavity lengths, and then a dual cavities structure as shown in Fig. 3(a) could be design and a ladder-type filter can be designed by turning cavity length ΔL_1 and ΔL_2.

The fundamental ladder-type filter includes two Lamb wave resonators, a series resonator and a shunt resonator, as shown in Fig. 3(b), and the series resonant frequency of the series resonator (f_s^{series}) should be the same as the parallel resonant frequency of the shunt resonator (f_p^{shunt}). At the series resonant frequency of the shunt resonator, f_s^{shunt}, the signal from the transmitted port can pass through the shunt resonator to ground. At the parallel frequency of the shunt resonator, fpshunt, the shunt resonator is open; so the signal passes through the series resonator to the received port. Furthermore, in a series resonator, the signal passes at the resonant frequency (f_s^{series}) and stops at the parallel resonant frequency (f_p^{series}). Thus combining two resonators can result in a bandpass filter.

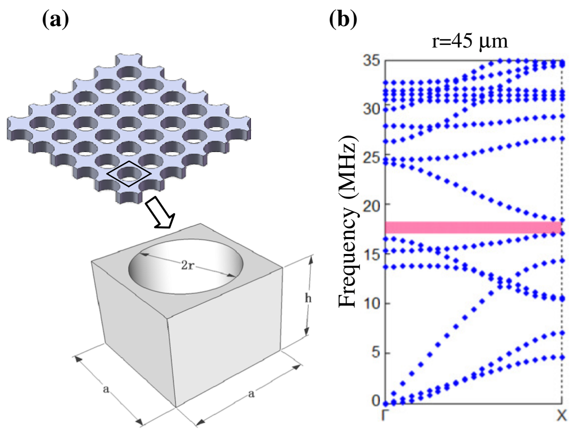

Fig. 1 (a) The schemas of a phononic plate and the unit cell. (b) The band diagram along the ΓX direction shows a band gap at 17.07-18.50 MHz.

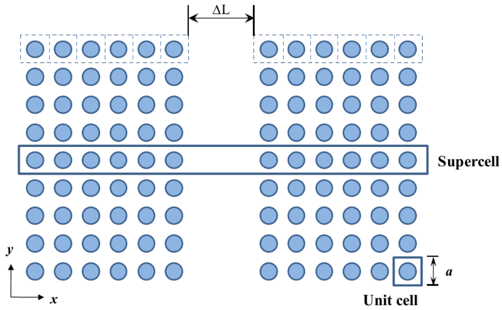

Fig. 2 The resonant cavity base on a phononic plate. The supercell is defined to analyze the cavity. ΔL represents the cavity length

4. Result

A bandpass filter consisting of two Lamb wave resonators with PC gratings was theoretically design and analyzed. The results showed that the Lamb wave filter utilizing PC-based reflective gratings is feasible and the performance is comparable to other filter topologies.

References

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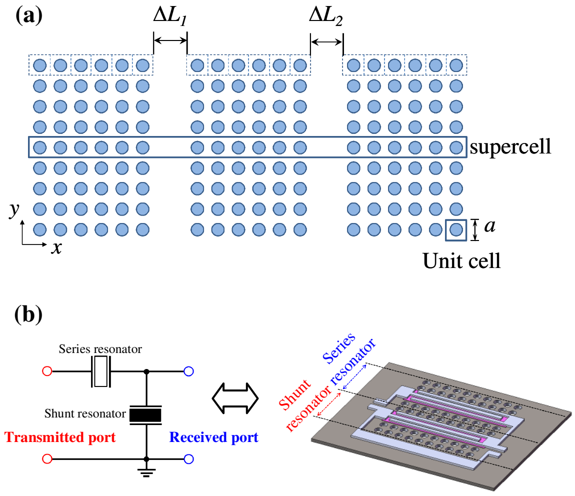

Fig. 3 The dual resonant cavities based on a phononic plate. The supercell was defined to analyze the cavities. (b) The circuit diagram and the schema of 1-stage ladder filter.