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Energy Trapping of Quartz Resonators with Pillar Phononic Crystals

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1. Introduction

AT-cut quartz resonators utilizing the thickness shear mode (TSM) are used widely as frequency reference in an electronic system. However, the supporting condition of a quartz plate affects tremendously the TSM characteristics. For example, the unwanted flexure and loss would be induced by the anchors, which attach the quartz plate to the substrate. In particular, the trend in miniaturization makes the problem more serious. To improve the attachment effects, a quartz plate with beveled edge was proposed [1-3].

Phononic crystals [4-5] are artificial structures with periodic variation of elastic property. Analogous to photonic crystals, phononic crystals with band gaps forbid acoustic waves within the frequency ranges of band gaps to propagate through the structure and reflects completely the acoustic waves. In 2015, the air-hole phononic crystals were utilized for trapping acoustic energy of the AT-cut quartz resonators for the first time [6]. Although the anchor loss is reduced significantly, the air-hole phononic crystals lower the impact strength of the AT-cut quartz resonators.

In this paper, the pillar phononic crystals are utilized for trapping acoustic energy and reducing anchor loss of AT-cut quartz resonators but keeping impact strength. A 3D model of quartz resonators is developed by using the finite element software, COMSOL. Finite element analyses of the AT-cut quartz resonators with phononic crystals and the lossy epoxy attachments, as shown in Fig. 1, are presented herein. The resonance response of an AT-cut quartz resonator with no phononic crystal is first calculated. A square-lattice phononic crystal plate, made of an AT-cut quartz plate with wolfram pillars, is analyzed and designed to have a complete band gap covering the quartz resonator's resonance frequency. Finally, the mode shape and impedance of the quartz resonators with three rows of wolfram-pillar phononic crystals are simulated to evaluate the isolation performance of the phononic crystals.

2. Resonanace analysis of quartz resonator with no phononic crystal

The AT-cut quartz resonator with no phononic crystal was characterized by calculating its eigenfrequency and frequency response. The material constants of quartz crystal used in the simulation are from Ref. [7]. The material constants of the epoxy attachments are listed in Table I. The electrode is Au film whose constants can be found in COMSOL material library. Besides, the loss constants of quartz crystal, Au film, and epoxy are 10^{-6}, 10^{-5}, and 10^{-4}, respectively. The resonance frequency of the TSM mode is around 16.42 MHz when the quartz plate is 0.1 mm in thickness. In Fig. 2, the total displacement field of the TSM resonance shows the flexure component in TSM appears stronger when the epoxy attachments are introduced, which indicates the boundary of the quartz plate seriously affects the resonance characteristics. Moreover, the frequency response shows that the AT-cut quartz resonator with no phononic crystal has an impedance of 75.78 Ω.

3. Bandgap analysis of wolfram-pillar phononic crystals

The band structure of a square-lattice phononic crystal plate, made of an AT-cut quartz plate with wolfram pillars, was calculated by the finite element method. As shown in Fig. 3, the height H, lattice constant a, and radius r of the unit cell are 16, 111, and 49.95 μm, respectively. The frequency band structure of Lamb waves in the phononic crystal plate depicts the square-lattice phononic crystal plate gives rise to a complete band gap from 16.37 to 16.51 MHz, which covers the quartz resonator's resonance frequency.

4. Resonanace analysis of quartz resonator with wolfram-pillar phononic crystals

The AT-cut quartz resonators with phononic crystals were analyzed to evaluate the isolation performance of the phononic crystals. The mode shape of the AT-cut quartz resonator with 3 rows of the designed wolfram-pillar phononic crystals are shown in Fig. 4. The AT-cut quartz resonator with the phononic crystals has a more centralized diaplacement field distribution than the one without phononic crystals, indicating that the phononic crystals indeed contribute to a confinement of

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acoustic energy in the AT-cut quartz resonator. Besides, from the frequency response shown in Fig. 6, the AT-cut quartz resonator with the phononic crystals has a lower impedance of 8.51 Ω than the one with no phononic crystal. Note that the 3 rows of the designed wolfram-pillar phononic crystals are enough to significantly reducing anchor loss of AT-cut quartz resonators.

5. Conclusions

The square-lattice wolfram-pillar phononic crystals were utilized for trapping acoustic energy and reducing anchor loss of AT-cut quartz resonators. Finite element analyses of the AT-cut quartz resonators with the phononic crystals and two lossy epoxy attachments were implemented for evaluating the isolation performance of the phononic crystals herein. Results show the quartz resonator with the wolfram-pillar phononic crystals exhibits a good energy confinement inside electrode area and a small impedance. Although the air-hole phononic crystals have a better energy trapping performance [6], the AT-cut quartz resonator with wolfram-pillar phononic crystals has more robust impact strength. Therefore, the square-lattice wolfram-pillar phononic crystal is valid for reducing anchor loss of an AT-cut quartz resonator.

Acknowledgment

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Table I Material constants of epoxy in simulation.

Young’s modulus (GPa)	3.9379
Poisson ratio	0.3769
Density (kg/m^3)	1157.8
Loss	10^{-4}

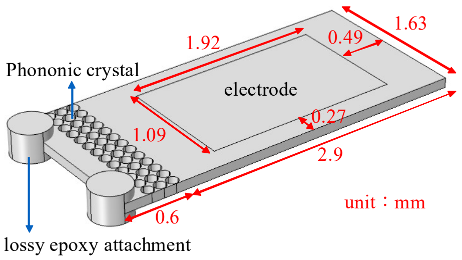

Fig. 1 Illustration of an AT-cut quartz resonator with phononic crystals and two lossy epoxy attachments.

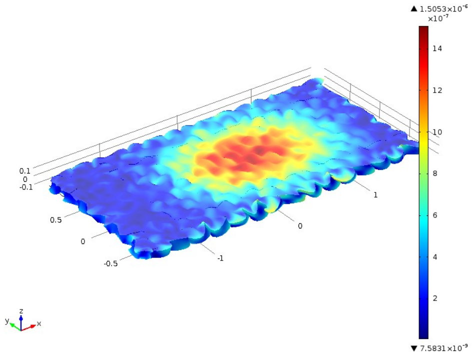

Fig. 2 TSM mode shape of the AT-cut quartz resonator with no phononic crystal.

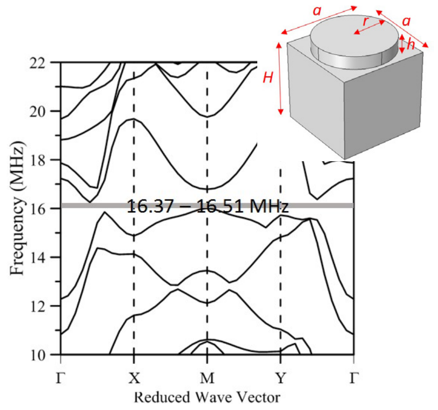

Fig. 3 Band structure of a square-lattice wolfram-pillar phononic crystal plate.

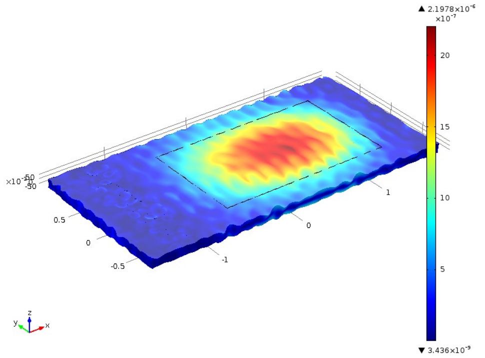

Fig. 4 TSM mode shape of the AT-cut quartz resonator with square-lattice wolfram-pillar phononic crystals.