Journal of Physics and Chemistry of Solids 116 (2018) 174–179

Contents lists available at ScienceDirect

Journal of Physics and Chemistry of Solids

journal homepage: www.elsevier.com/locate/jpcs

Opening complete band gaps in two dimensional locally resonant phononic crystals

Xiaoling Zhou [a,*], Longqi Wang [b]

[a] Shanghai Institute of Aerospace System Engineering, Shanghai 201109, China
[b] School of Civil & Environmental Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore

ARTICLE INFO

Keywords:
Complete band gap
Two dimensional LRPC
Tunable properties
Geometrical parameter

ABSTRACT

Locally resonant phononic crystals (LRPCs) which have low frequency band gaps attract a growing attention in both scientific and engineering field recently. Wide complete locally resonant band gaps are the goal for researchers. In this paper, complete band gaps are achieved by carefully designing the geometrical properties of the inclusions in two dimensional LRPCs. The band structures and mechanisms of different types of models are investigated by the finite element method. The translational vibration patterns in both the in-plane and out-of-plane directions contribute to the full band gaps. The frequency response of the finite periodic structures demonstrate the attenuation effects in the complete band gaps. Moreover, it is found that the complete band gaps can be further widened and lowered by increasing the height of the inclusions. The tunable properties by changing the geometrical parameters provide a good way to open wide locally resonant band gaps.

1. Introduction

Phononic crystal or acoustic band gap materials are materials with periodic arrangement [1–3]. The band gap properties which in certain frequency elastic wave cannot transmit through the periodic materials have potential applications in vibration and noise control. Thus, they attracted a growing interest in recent years, especially when the concept of locally resonant phononic crystal (LRPC) is proposed [4–8]. The wave length in the locally resonant band gap is two order smaller than the lattice size. This low frequency band gap property is of great importance in engineering applications.

Liu et al. [5] first reported the LRPC which consists of a hard core with rubber coating layer embedding into the matrix periodically. The three dimensional LRPC possessed a band gap with frequency as low as 400 Hz. And the lattice size is as small as 1.55 cm. Then Hirsekorn [9] and Wang [10] investigated two dimensional LRPC with three components and gave simplified models to predict the band gap boundaries. Zhou and Chen [11] utilized electric field and the initial stress to tune the locally resonant band gap frequencies. They mainly considered the two dimensional LRPCs with infinite size in the out-of-plane direction. Lamb waves in locally resonant phononic slabs are also studied because the thin plate structures are useful in engineering [12–15]. Hsu and Wu [12] reported flexural-dominated resonant band gaps which significantly depend on both the radius of the circular rubber filler and the plate thickness. Usually the two dimensional LRPCs have wide band gaps in the periodic directions and they can hardly have large full band gaps. Some researchers proposed PC with resonant stubs deposited on a plate [16–19]. Spring-mass resonators are attached on a thin plate [20] or between double plates [21] to obtain flexural wave band gaps. Wang et al. [22] studied the tuning properties and waveguide of multi-stub LRPC plate. Assouar et al. [23] used double-sided arrangement of pillars in the phononic crystal plates to lower and widen the locally resonant band gaps. Zhang et al. [24] showed low frequency locally resonant band gaps in the out of plane direction by cutting a spiral groove from the phononic crystal plates with periodic spiral resonators. The emphasis of these works is to get wide and low frequency band gaps, and most of the band gaps are in the out-of-plane direction. Another type of LRPC is slab with resonators obtained by etching holes in the structures [25]. Yu and Lesieutre [26] used 3D printing to fabricate an acoustic band gap structure consisting of a honeycomb matrix with spherical cores attached inside and they found that the materials can reduce the peak dynamic response. Very interesting, complete band gaps have been achieved in two dimensional phononic crystal slab due to the local rotational or translational resonance [27]. The geometry parameters can be design to tune the band gaps. Ma et al. [28] also reported to open a large full phononic band gap in thin plate with three layered spherical resonators. The vibration degree of freedoms which are translating and rotating motion patterns appeared in both the in-plane and out-of-plane

* Corresponding author.
E-mail address: zhouxiaoling87@163.com (X. Zhou).

https://doi.org/10.1016/j.jpcs.2018.01.025
Received 26 November 2017; Accepted 14 January 2018

0022-3697/© 2018 Elsevier Ltd. All rights reserved.

directions and contribute to large full band gaps. These works indicated that large complete band gaps can be achieved in two dimensional locally resonant phononic crystals by carefully designing the resonators.

In this paper, two dimensional locally resonant phononic crystals which are composed of thin plates and cylindrical resonators are investigated. By adjusting the geometrical property of the cylindrical resonators, complete band gaps are opened. The band structures, band gap mechanisms and transmission properties are revealed. Also, the tunable properties of the band gaps are discussed.

2. Models and method

The unit cell of the two dimensional locally resonant phononic crystal models are shown in Fig. 1. Three different types of LRPC models are investigated in this paper. As shown in Fig. 1(a–c), the embedded inclusions of the three models have different height and coating layers. As shown in Fig. 1(a), the model I is a typical two dimensional three components filled-in LRPC with the inclusion and the plate having the same height. The component materials are steel, rubber and aluminum, respectively. Model II in Fig. 1(b) is a kind of LRPC with a higher inclusion embedding in the thin plate. The materials of Model II are the same with Model I. For the Model III which shown in Fig. 1(c), the inclusion consists of a higher steel core with rubber-steel-rubber coating layers and then embedding into the thin aluminum plate. The unit cells arrange periodically in a square lattice manner and the Brillouin zone is illustrated in Fig. 1(d). The lattice size of the LRPC is $a = 0.04$ m and the radius of the inclusion is $r_1 = 0.018$ m. The coating layers have the same thickness of $\Delta t = 0.002$ m in the radial direction. For model I in Fig. 1(a), the inclusion and the plate have the same height of 0.002 m. In Fig. 1(b) and (c), the height of the inclusions is $h = 0.008$ m while the height of the plate is $e = 0.002$ m. The materials constants are given in Table 1.

To elucidate the band gap properties of the three types of LRPCs, the band structures and the frequency response are simulated by the finite element method (FEM). For the structures, the elastic wave motion equation is as follows,

$$\nabla[[\lambda(\mathbf{r}) + 2G(\mathbf{r})](\nabla\cdot\mathbf{u})] - \nabla\times[G(\mathbf{r})\nabla\times\mathbf{u}] = \rho\ddot{\mathbf{u}} \tag{1}$$

where λ and G are the Lame constants of the materials, and ρ is the density. $\mathbf{r}$ is the coordinate vector. $\mathbf{u}$ and $\ddot{\mathbf{u}}$ are the displacement vector and its second order derivative of time, respectively. For the LRPCs, the displacement field satisfy the Bloch theory which is described as,

Table 1
Material constants of the three components.

	Density (kg/m^3)	Lame constants (GPa)	
	ρ	λ	G
Aluminum	2600	40.4	26.9
Rubber	1300	60.5e-5	4e-5
Steel	7780	121.4	81

$$\mathbf{u}(\mathbf{r}) = \overline{\mathbf{u}}(\mathbf{r})\cdot e^{i(\mathbf{k}\cdot\mathbf{r}-\omega t)} \tag{2}$$

where t is the time and $\mathbf{k}$ is the wave vector. ω refers to the angular frequency. For the LRPC models, the displacement amplitudes have the form of,

$$\overline{\mathbf{u}}(\mathbf{r}) = \overline{\mathbf{u}}(\mathbf{r} + n_1\mathbf{a}_1 + n_2\mathbf{a}_2) \tag{3}$$

where n_1 and n_2 refer to integers; $\mathbf{a}_1$ and $\mathbf{a}_2$ represent the lattice vectors.

For the LRPC models, the linear triangular elements are utilized to simulate the band gap properties by the finite element method (FEM). Elastic wave in three directions are taken into account in the simulations.

3. Results and discussions

3.1. Band structures and mechanisms

The band structures and band gap mechanisms of the three types of models shown in Fig. 1(a–c) are discussed in this section. The band structures of the two dimensional LRPCs are shown in Figs. 2, 4 and 6. The band gap boundaries are identified in the band structures and the corresponding displacements are given in Figs. 3, 5 and 7. Combined with the band structures and the displacement fields, the band gaps in the in-plane and out-of-plane directions can be revealed.

As shown in Fig. 2, it can be found that there are no obvious complete band gaps in the band structure of Model I. The band gap from 90 Hz (see Point 1) to 201 Hz (see Point 4) is for the flexural wave in the out-of-plane direction. One can see from Fig. 3 that the steel core moves as a whole

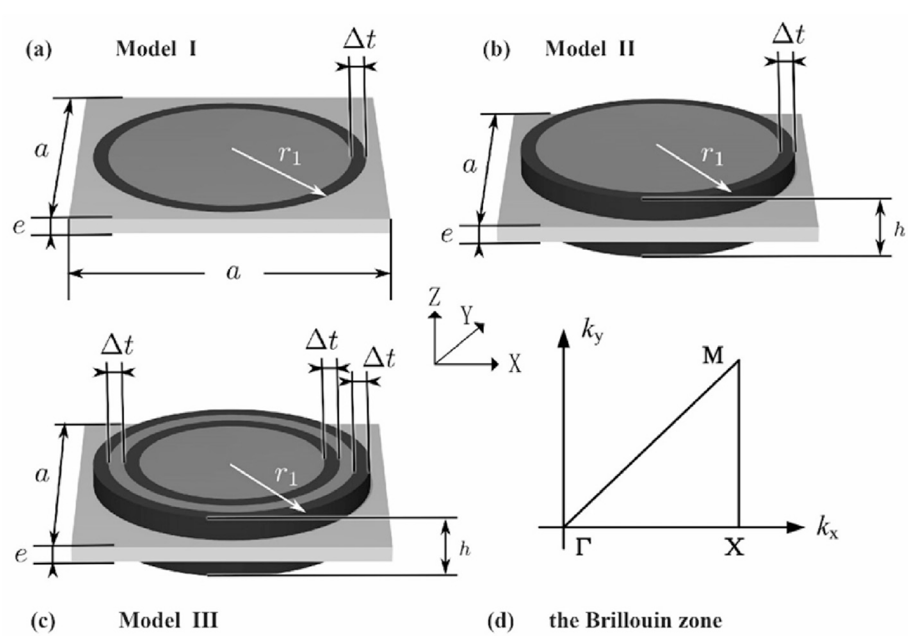

Fig. 1. The unit cells of the two dimensional LRPCs with (a) Model I, (b) Model II and (c) Model III. (d) The irreducible first Brillouin zone of the square lattices.

Download English Version:

https://daneshyari.com/en/article/7920460

Download Persian Version:

https://daneshyari.com/article/7920460

Daneshyari.com