Physica B 404 (2009) 3795–3798

Contents lists available at ScienceDirect

Physica B

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

Phononic band structure in a two-dimensional hybrid triangular graphite lattice

Ruiju Wei, Bin Wu *, Cunfu He, Huanyu Zhao

College of Mechanical Engineering & Applied Electronics Technology, Beijing University of Technology, Beijing 100124, PR China

ARTICLE INFO

Article history:
Received 1 May 2009
Received in revised form
22 June 2009
Accepted 25 June 2009

PACS:
43.20.+g
43.35.+d
43.50.+y

Keywords:
Phononic crystal
Band gap
Plane wave expansion method

ABSTRACT

The propagation of acoustic wave in a two-dimensional phononic crystal of a hybrid triangular graphite array is investigated by the plane wave expansion (PWE) method. Our numerical results show that the location and width of the band gaps can be tuned by altering the radii of scatters at different positions.

1. Introduction

Phononic crystals (PCs) have received an increasing amount of attention during the recent years. Phononic crystals are periodic elastic/acoustic composites which exhibit a range in frequency where elastic/acoustic wave propagation is strictly forbidden (phononic band gaps; PBGs) [1–4]. Absolute band gaps confer to these artificial materials' potential applications such as sound insulators, acoustic/elastic filters, acoustic waveguide, acoustic–optical devices and improvements in the design of transducers [5–8]. In recent years, great progresses have been made in understanding the mechanism of wave propagation in PCs, e.g. of the band gap formation [1,6], localized defect mode [7,8], acoustic wave tunneling [9], negative refraction [10], high acoustic source directivity [11], collimation phenomena [12].

Since the superior features of PCs result from the PBG, it is essential to design crystal structures with a band gap as large as possible. It is well known that the degeneracy of photonic/phononic bands at high-symmetry points in the Brillouin zone is one of the bottlenecks to create the band gap [13–17]. It was found that several approaches are useful to break the degeneracy of bands, e.g. by introducing anisotropy in the material [13] or reducing the symmetry of the structure or scatters [14–17]. For example, Caballero et al. [15] placed a smaller rod at the center of a unit cell and in this way the band gaps enlarged. Martinez et al. [16] considered a hybrid triangular graphite lattice and found a number of photonic band gaps existed by varying the radii of scatters of two sub-lattices within reasonable fabrication tolerances. Wang et al. [17] pointed out that the absolute photonic band gap could be enlarged by rotating non-circular air rods in dielectric background. Motivated by these works, in this paper, we consider a hybrid triangular graphite lattice by reducing the symmetry, as depicted in Fig. 1. This geometry includes graphite and triangular structure in particular. We apply the plane wave expansion (PWE) method to investigate band structures of two-dimensional (2D) PCs composed of stainless steel rods embedded in air.

2. Model and calculation method

2.1. The model

In this paper, the 2D periodic structure, that we consider is a hybrid triangular graphite lattice by placing two additional rods averagely at the diagonal of triangular lattices, as depicted in Fig. 1, where the orange dots (positions A) denote triangular lattice sites with lattice constant $a = 10\,\mathrm{cm}$, while the blue dots (positions B) denote graphite structure in which the distance between the centers of nearest-neighbor cylinders is $a/\sqrt{3}$. In

* Corresponding author. Tel.: +86 10 67392067; fax: +86 10 67391617.
E-mail address: wb@bjut.edu.cn (B. Wu).

0921-4526/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.physb.2009.06.145

order to calculate, simply we set Cartesian coordinates as Fig. 1. The dashed lines represent the primitive unit cell of 2D array. Because of adding two additional 'atoms' in the unit cell, the symmetry of the structure is reduced. Let R be the radius of the cylinders of the triangular sub-lattice and R_b be the radius of the cylinders of the graphite sub-lattice. Corresponding to the close-packed condition, the radii of the rods should satisfy: $R/a \leq 0.5$, $R_b/a \leq 1/2\sqrt{3}$, and $R/a + R_b/a \leq 1/\sqrt{3}$. Obviously when R_b is equal to R or zero, the ordinary triangular lattice is obtained (different lattice constant), and when R is equal to zero, we get a usual graphite lattice. Different configurations for the hybrid structure is obtained for different values of R and R_b. Accordingly, the primitive basis vectors of the hybrid triangular graphite lattice may be chosen as

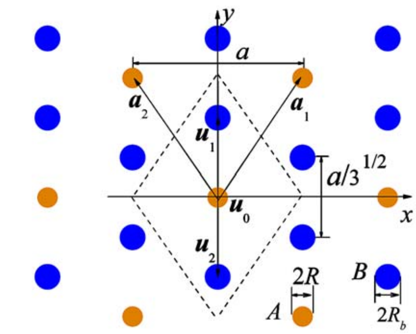

Fig. 1. Sketch of the 2D PCs with hybrid triangular graphite lattice, where the orange dots (positions A) denote a triangular lattice with lattice constant $a = 10$ cm, while the blue dots (positions B) denote a graphite structure with the distance between the centers of nearest-neighbor cylinders being $a/\sqrt{3}$. The related radius of the scatters are R and R_b, respectively. The dashed lines represent the primitive unit cell of 2D array.

$$a_1 = a(1, \sqrt{3})/2, \ \ a_2 = a(-1, \sqrt{3})/2 \tag{1}$$

The primitive vectors of the reciprocal lattice are given by

$$b_1 = 2\pi(1, 1/\sqrt{3})/a, \ \ b_2 = 2\pi(1, 1/\sqrt{3})/a \tag{2}$$

The three infinite cylinders of the primitive unit cell are located at positions

$$u_1 = -u_2 = (0, a/\sqrt{3}), \ \ u_0 = (0, 0) \tag{3}$$

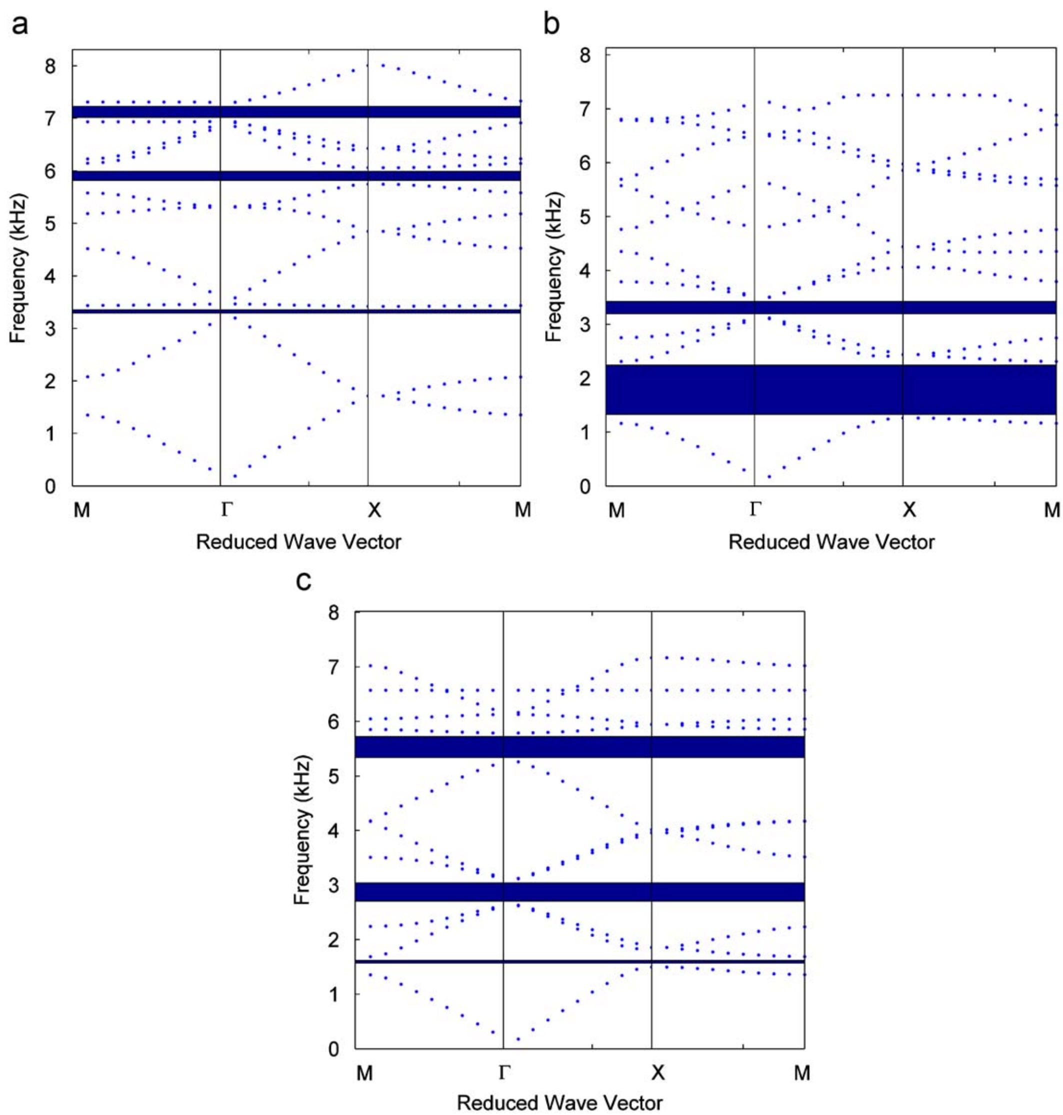

Fig. 2. Acoustic band structure of two-dimensional phononic crystals of steel rods arrayed in air. (a) Ordinary triangular lattice at filling fraction $f = 0.46$; The lattice constant is $a = 10$ cm. (b) Hybrid triangular graphite lattice for a fixed $R_b/a = 0.25$ and $R/a = 0.05$, i.e. filling fraction $f = 0.46$; (c) $R_b/a = 0.25$ and $R/a = 0.2$. The absolute band gaps are indicated by the shaded area.