# PROPAGATION OF ACOUSTIC WAVES IN A PHOTONIC CRYSTAL PLATE WAVEGUIDES

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## ABSTRACT

We have studied propagation of acoustic waves in a photonic crystal plate and related waveguides. A two dimensional photonic crystal plate consisting of circular steel cylinders which form a square lattice in an epoxy matrix was studied. The Bloch theorem was employed to deal with the periodic condition. The dispersion curves and displacement fields were calculated to identify the band gaps and eigen modes. Our results shows that eigen modes of acoustic wave inside the wave guides and the modes are affected by the geometry arrangement of wave guides. Inside the photonic crystal plate waveguides, wave propagation is well confined within the structure. We have analyzed the bulk acoustic waves in the unbounded photonic crystals with a free surface. We found that many applications of photonic crystals were designed accordingly, such as elastic wave filters, couplers and wave guides. We also found that as a result of the waveguiding, the photonic plate with a polyline defect that forms a sharply bent waveguide and it was applied to use for frequency selection of Lamb waves. The obtained results were compared with previously obtained results of theoretical and experimental works and were found in good agreement.

**Key words :** Acoustic waves, Epoxy matrix, Block Theorem, Eigen modes, Wave guides.

## INTRODUCTION

Jia-Hong Sun and Tsung-Tsong Wu[1] analyzed propagation of acoustic waves in a photonic crystal plate and related waveguides. The Bloch theorem was employed to deal with the periodic condition and the fraction free condition was set on the top and bottom boundaries of the plates. A photonic crystal wave guide is an important elementary component to build up acoustic wave in the surface acoustic wave guides is another considerable issue[2-3]. The plate is constructed by periodic arranged elastic materials with two free surfaces. The finite difference time domain method had been developed to analyze the bolk acoustic waves in finite photonic crystals. This method has the flexibility to construct a variety of two dimensional and three dimensional periodic structures and the phenomenon of acoustic waves propagating inside the structures can be investigated.

## METHOD

In this method a variety of two dimensional and three dimensional periodic structures and the phenomena of acoustic waves propagating inside the structure was investigated. We consider a photonic crystal made of the aforementioned subwavelength cylinders. The building block is a square column of width d, consisting of a collection of dielectric cylindrs at the subwavelength scale. The schematics of the photonic crystal and the building block in the unit cell are shown in Fig. 1.

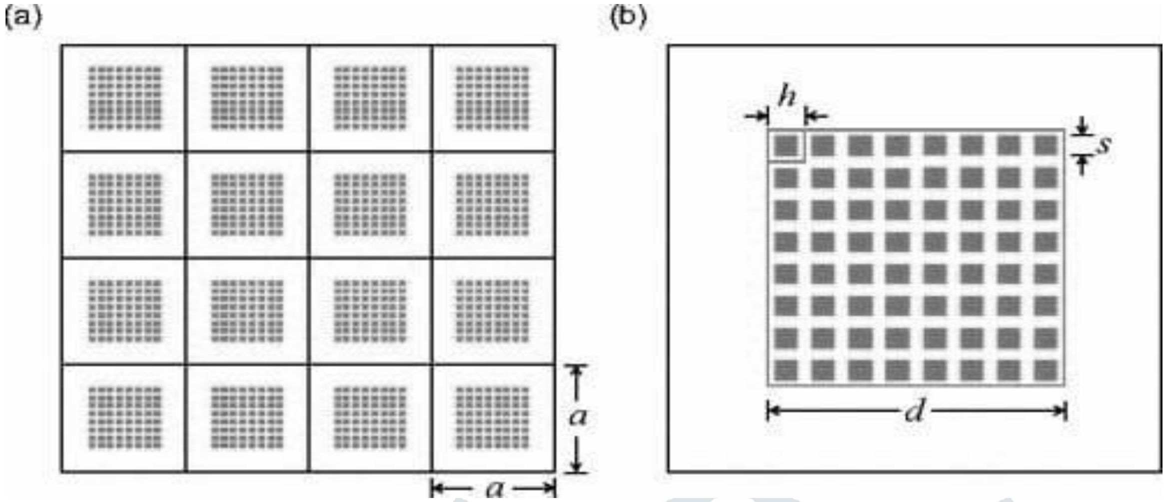


Fig.-1 : Schematics of (a) the photonic crystal made of collection of subwavelength cylinders and (b) the building block in the unit cell.

In this configuration, the subwavelength cylinders are responsible for the existence of resonant cavitylike modes in a nonpolaritonic structure. Basic features of resonant cavitylike modes are either manifest or implied in the dispersion characteristics. For propagation of waves parallel to the lattice plane, the time-harmonic magnetic mode (with time dependence $e^{-i\omega t}$) is described by

$$-\nabla.\left(\frac{1}{\varepsilon}\nabla H\right) = \left(\frac{\omega}{c}\right)^2 H \qquad (1)$$

It is sufficient to solve the underlying problem (periodic structure of infinite extent) in one unit along with the Bloch condition.

$$H(r + a_i)=e^{ik.ai}H(r) \qquad (2)$$

applying at the unit-cell boundary, where k is the Bloch wave vector and $a_i$(i=1, 2) is the lattice translation vector.

For a photonic crystal with complex geometry, the dispersion relations can be efficiently solved by the inverse iteration method. In this approach, the eigensystem. Eq. (1), is solved by making good use of the Hermitian property of the differential operator, The important step is the calculation of the Rayleigh quotient

$$R_Q = \frac{< x, Ax >}{< x, x >} \qquad (3)$$

where A is the matrix constructed by discretization of the differential operator, x is the vector consisting of all discrete values of H (over the unit cell), and the inner product {...} is taken over the unit cell. An initial guess of x, usually prescribed as a random distribution, is used to give a first value of $R_Q$ which in turn is utilized to refine the vector x through solving a matrix inversion

$$(A - \mu I)x_n = x_o \qquad (4)$$

where $x_o$ and $x_n$ are referred to as old and new values of x, respectively, and $\mu$ is a parameter. This procedure is repeated until the Rayleigh quotient $R_Q$
converges within a certain accuracy; the quotient $R_Q$ and the vector x are then given as the solution pair of the eigenvalue and eigenfunction.

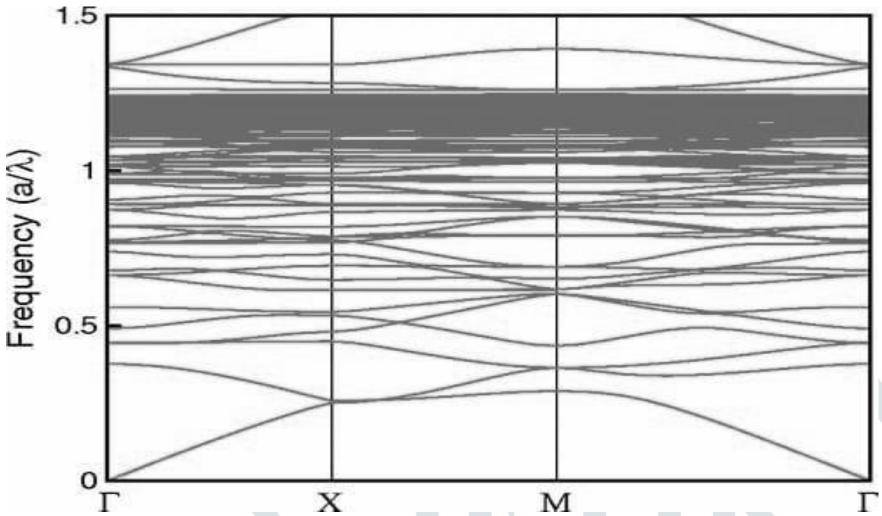


Fig.-2 : Dispersion diagram for the photonic crystal made of collections of subwavelength cylinders, where $\varepsilon_1$ – 200+5i, $\varepsilon$ = 1, d/a = 0.8, h/a=0.05, and s/h=0.8.

Figure 2 shows the dispersion diagram for a photonic crystal made of collection of subwavelength cylinders, where $\varepsilon_1$ = 200+5i, $\varepsilon$ =1, d/a = 0.8, h/a = 0.05, and s/h = 0.8, A large number of frequency branches appear for TE polarization. As the frequency gets closer to a/λ≈ 1.24, more branches are observed. These collective modes have similar features to those of resonant cavity modes that occur in polaritonic structures. They are dispersion-less in nature; that is, their frequencies are insensitive to the change of wave vector. As a result, the corresponding frequency branches tend to be flattened. In a polaritonic structure, the dispersion-less nature comes from the strong coupling of photons with phonons in the polar material. As the underlying photonic crystal is made of a dielectric material there is no such coupling behaviour.

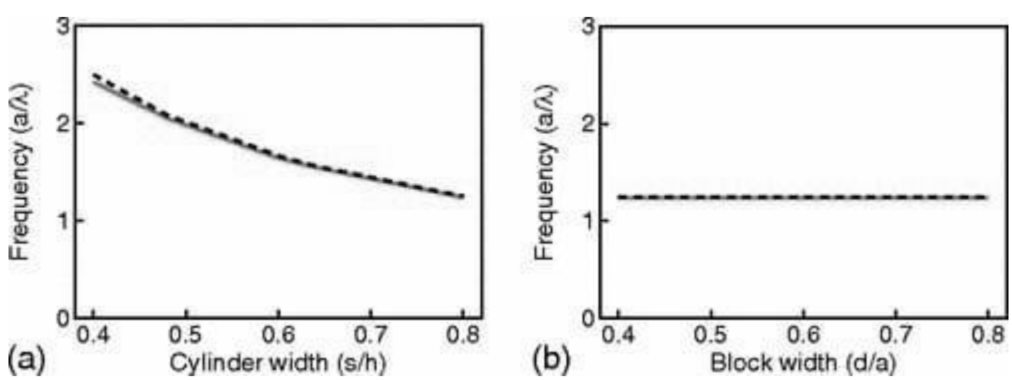


Fig.-3 : Variations in the asymptotic frequency for resonant cavitylike modes with respect to (a) cylinder width s, where h/a=0.05 and d/a=0.8, (b) block width d, where h/a=0.05 and s/h=0.8. The dashed line denotes the frequency

$\varepsilon_{mT}$.

The effective permeability $\mu_{eff}$ reaches very large values when the frequency approaches $\omega_{mT} = \pi c\sqrt{2} / s \sqrt{\varepsilon_1} = 1.25(2\pi c/a)$ from below. In this situation, the subwavelength cylinders serve as a device for trapping electromagnetic fields and the building block acts like a high-index cavity. In a polaritonic structure, the asymptotic frequency of resonant cavity modes depends on the subwavelength cylinders. Figure 3 shows the variations in the asymptotic frequency with respect to the cylinder width and block width. It is shown in Fig. 3(a) that the asymptotic frequency decreases as the cylinder width increases. In particular, this frequency is inversely proportional to the cylinder width and very close to $\omega_{mT}$ (denoted by the dashed line). On the other hand, the asymptotic frequency remains unchanged as the block width alters, as shown in Fig. 3(b).

## RESULTS AND CONCLUSION

We analyze the bulk acoustic waves in the unbounded photonic crystals[4] and the surface acoustic wave in the photonic crystals with a free space[5-8]. The results show that energy in the desired frequency range can be drawn out from a broadband signal based on the proposed design. The results could be further applied to innovative design of acoustic wave devices.

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