Mechanics of Materials 93 (2016) 168–183

Contents lists available at ScienceDirect

Mechanics of Materials

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

Dispersion relations of elastic waves in one-dimensional piezoelectric phononic crystal with mechanically and dielectrically imperfect interfaces

Xiao Guo[a], Peijun Wei[a,b,*], Li Li[a]

[a] Department of applied mechanics, University of Science and Technology Beijing, Beijing 100083, China
[b] State Key Laboratory of Nonlinear Mechanics (LNM), Chinese Academy of Science, Beijing, Beijing 100080, China

ARTICLE INFO

Article history:
Received 3 June 2015
Revised 21 September 2015
Available online 14 November 2015

Keywords:
Dispersion relations
Piezoelectricity
Phononic crystal
Imperfect interface
Bloch wave
Transfer matrix

ABSTRACT

The effects of mechanically and dielectrically imperfect interfaces on dispersion relations of elastic waves in a one-dimensional piezoelectric phononic crystal are studied in this paper. Six kinds of imperfect interfaces between two different piezoelectric materials constituting the phononic crystal are considered. These imperfect interfaces include: the mechanically compliant dielectrically weakly conducting interface, the mechanically compliant dielectrically highly conducting interface, the grounded metallized interface, the low dielectric interface, the tangent fixed interface and the tangent slippery interface. Based on transfer matrices of piezoelectric slabs and imperfect interfaces, the total transfer matrix of a typical single cell in the periodical structure is obtained. Furthermore, the Bloch theorem is used to obtain the dispersive equations of in-plane and anti-plane Bloch waves. The dispersive equations are solved numerically and the numerical results are shown graphically. In the case of normal propagation of elastic waves within piezoelectric slabs, the analytical expressions of the dispersion equations are derived and compared with other literatures. The influences of mechanically and dielectrically imperfect interfaces on the dispersive relations are discussed based on the numerical results.

1. Introduction

As a kind of artificial periodic composite materials or structures, phononic crystal can give rise to complete acoustic band gaps within which elastic waves propagation are forbidden while in other frequency ranges elastic waves can propagate without exhaustion. Therefore, phononic crystal can be used to control the propagation of elastic waves and thus attracted attentions of many researcher, such as, Sigalas and Economou (1992), Kushwaha et al. (1993), Kafesaki et al. (1995), Suzuki and Yu (1998), and Liu et al. (2000). In recent years, piezoelectric materials were introduced into the manufacture of phononic crystal due to its unique electromechanical coupling effect. Alvarez-Mesquida et al (2001) studied the shear horizontal wave propagation processes in a layered piezoelectric composite based on a recursive system of equations involving the piezoelectric impedance. Qian (2004a, 2004b) studied the propagation behavior of horizontally polarized shear waves (SH-waves) in a periodic piezoelectric-polymeric layered structure. The dispersive equation and the phase velocity of SH-waves were obtained. Further, the influence of initial stress on the stop band and the dispersion relation of the SH-waves was discussed in detail. Monsivais et al. (2005) studied surface and shear horizontal waves in finite and infinite piezoelectric composite media, considering the transmission, dispersion relation, angular dispersion relation, and eigenmodes of vibration of the

* Corresponding author at: Department of applied mechanics, University of Science and Technology Beijing, Beijing 100083, China. Tel./fax: +86 10 82388981.
E-mail address: weipj@ustb.edu.cn (P. Wei).

http://dx.doi.org/10.1016/j.mechmat.2015.11.004

composites. Chen and Wang (2007) studied the band gaps of both in-plane and anti-plane elastic waves propagating along an arbitrary direction in one-dimensional disordered phononic crystals. The localization of wave propagation due to random disorder was discussed by introducing the concept of the localization factor. It is found that phononic quasi-crystals involve more bands with localization of wave motion compared with the periodic structure. The localization factor may act as an accurate and efficient parameter to characterize band structures of both ordered and disordered (including quasi-periodic) phononic crystals. Pang et al. (2008, 2014) studied the wave propagation in layered periodic composites consisting of piezoelectric and piezomagnetic phases and derived the dispersion relations of Lamb waves and SH waves. Wang et al. (2008, 2010) investigated the elastic wave propagation in two-dimensional and three-dimensional phononic crystals with piezoelectric and piezomagnetic inclusions taking the magneto-electro-elastic coupling or initial stress into account.

However, the investigations above mentioned are based on the perfect interface, namely, all mechanical and dielectric quantities, for example, the displacement components, the traction components, the electric potential and the electrical displacement components, are assumed to be continuous across the interface. In actual situation, the appearances of imperfect interfaces due to the accumulative interfacial damages, local debonding or manufacturing defection is always inevitable. The influences of imperfect interfaces on the dispersive relations and the band gaps of the phononic crystal are therefore interesting. Fan et al. (2006) investigated certain waves which created the fluctuation perpendicular to the incident plane and propagated near an imperfectly bonded interface between two half-spaces of different piezoelectric materials. The existence of these waves relies on the imperfection of the interface bonding. Huang et al (2009) studied the interfacial SH waves propagating along the imperfectly bonded interface of a magnetoelectric composite consisting of piezoelectric (PE) and piezomagnetic (PM) phases. It was shown that the interfacial imperfection strongly affects the velocity of interfacial shear waves and the interfacial shear waves do not exist for the perfect interface. Zheng and Wei (2009) investigated the dispersive relations and the band gaps of elastic waves in 1-D phononic crystals. In their study, the imperfect interface with the traction components jumps or the displacement components jumps was considered. Pang and Liu (2011) investigated the reflection and transmission of plane waves at an interface between piezoelectric (PE) and piezomagnetic (PM) media. The mechanical imperfection of bonding behavior at the interface was described as the linear spring model. But dielectrically imperfect interfaces were not considered. Lan and Wei (2012, 2014) studied the influence of the imperfect interface on the dispersive characteristics and the band gaps of SH waves propagating through laminated piezoelectric phononic crystal. The imperfect interface is modeled as a thin membrane with elasticity and inertial even but without thickness or a thin interlayer with gradient variation of material parameters. However, the imperfect interface involved in their investigations is merely mechanically imperfect. The interface with dielectrically imperfect is not considered. In fact, the dielectric quantities may also be discontinuous across the interface. Sun et al (2011) studied the propagation of SH wave in a cylindrically multiferroic composite consisting of a piezoelectric layer and a piezomagnetic central cylinder in which the interface was damaged mechanically, magnetically or electrically. Piliposyan (2012) investigated the existence and propagation of a surface SH wave at the interface of two magneto-electro-elastic half-spaces. Four sets of boundary conditions, namely, full contact, partial contact with magnetically closed boundaries, partial contact with electrically closed boundaries and no electromagnetic contact, were considered. Alshits and Shuvalov (1993, 1995) once studied the reflection problem of transverse elastic waves from a periodic structure of piezomagnetic layers with thin superconducting interlayers and also from a periodic structure of piezoelectric layers with metallized interface. It was shown that the reflection coefficient can jump abruptly from zero to values close to unity when the phase state of the superconducting interlayers changes, which could be caused by a temperature change or an electric current. Wang and Sudak (2007) studied the influence of the mechanically compliant and dielectrically weakly (or highly) conducting interface when presented the analytical solution of a piezoelectric screw dislocation located within one of two joined piezoelectric half-planes. For the mechanically compliant interface, displacements are discontinuous across the interface. Similarly, the electric potential is discontinuous for the dielectrically weakly conducting interface and the normal component of electric displacement is discontinuous for the dielectrically highly conducting interface.

In this paper, the one-dimensional phononic crystal composed of two different piezoelectric materials with the mechanically and dielectrically imperfect interfaces are both considered. First, the transfer matrices of piezoelectric slabs and imperfect interfaces are derived from the motion equation of piezoelectric solids and mechanically and dielectrically interface conditions. Then, the total transfer matrix of one typical single cell of the periodical structure is obtained by the combination of the transfer matrices of piezoelectric slabs and that of imperfect interfaces. Finally, the Bloch theorem is used to obtain the dispersive equations of Bloch waves. Six kinds of imperfect interfaces between two different piezoelectric slabs are considered. These imperfect interfaces include: the mechanically compliant dielectrically weakly conducting interface, the mechanically compliant dielectrically highly conducting interface, the grounded metallized interface, the low dielectric interface, the tangent fixed interface and the tangent slippery interface. The dispersion equations of in-plane Bloch wave and anti-plane Bloch wave are both solved to obtain the dispersive curves and the numerical results are shown graphically. Based on these numerical results, influences of mechanically and dielectrically imperfect interfaces on the dispersive curves are discussed. Moreover, the analytical expressions of the dispersion equation are derived for the normal propagation situation of elastic waves within piezoelectric slabs and are compared with other literatures.