Modeling of Phononic Crystals Based on Piezoelectric Materials : Effective Properties and Tunability

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Phononic Crystals (PCs) (i.e. periodic arrangements of several materials) have received a great deal of interest for the last two decades because of the unusual properties that they can exhibit. Classically, depending on material properties and geometrical arrangement, PCs can produce band gaps, i.e. frequency ranges where the propagation of waves is forbidden (i.e. waves are evanescent). These Bragg band gaps offer several potential applications such as sonic insulators or filters, from the kHz to the GHz range depending upon the spatial periodicity.
In this paper, the general case of PCs made of piezoelectric materials is presented. Classically, the dispersion curve presents the variations of the frequencies as a function of the wavenumber, for a given propagation direction in the piezoelectric periodic structure.

First, in the large wavelength limit, a "material" approach is used in the case of piezoelectric composites with 13 connectivity. Slowness surfaces of bulk waves are computed using Finite Element method. These numerical results are fitted using relations deduced from Christoffel's equation for wave propagation in piezoelectric media which takes into account the symmetry class of the composite. It allows to deduce precise effective elastic, dielectric and piezoelectric parameters while taking into account the actual geometry of the composite.

Second, at higher frequency, the use of piezoelectric materials in the PCs confers tunability to the band gaps. Two devices have been studied: (1) stack of piezoelectric rods or plates, poled along their thickness, (2) a piezoelectric plate, poled along its thickness, covered by a periodic array of electrodes on its two faces. These devices exhibit Bragg gaps that depend on the electrical boundary conditions chosen on periodically placed electrodes. In both cases, an analytical model is developed that is compared to finite element results, validating the model. Depending on the electrical boundary condition, tunability is clearly demonstrated, i.e. an increase or a decrease of the width and the position of the stop bands. Moreover, an optimization is performed to maximize the width of the electrical Bragg band gap with respect to the orientation of the material. For both devices under study, ultrasonic experiments are presented, showing a good agreement with the theoretical predictions. Finally, potential applications of tunable RF using surface acoustic waves are discussed.