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FDTD Simulations of Acoustic Waves in Two-Dimensional Phononic Crystals using Parallel Computer

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The finite-difference time-domain (FDTD) method has been applied to the calculation of the phonon band structure of two-dimensional (2D) phononic crystals, consisting of metal cylinders placed periodically in liquid. By comparing several combinations of materials for metal cylinder and liquid, we analyze the dependence of the band structures on sound speed and density of liquid media. Moreover, the negative refraction of the acoustic waves is observed at the interfaces between phononic crystal slab and the liquid. We find that an acoustic " lens effect " with the slab appears due to the negative refractions. The relationship between the focal intensity in the lens effect and the band structure is discussed.

1 INTRODUCTION

In periodic, dielectric structures, so called photonic crystals, there are complete band gaps (photonic band gap) of electromagnetic waves. The analogy between photons and phonons has suggested a new class of materials, called phononic crystal or sonic crystal: It consits of periodic elastic composites of two or more materials [1]. It has attracted a great deal of interest in the study of the propagation of waves because of their novel physical properties.

Possible features of the photonic metamaterial, which has negative permittivity and permeability simultaneously, has been predicted in 1968 [2]. A negative refractive index is one of these features. Conventional optical lenses have positive refractive index, so it needs curved surfaces to get an image focused, whereas a negative refraction allows flat slab to focus electromagnetic waves [3]. Recently [4], this material, known also as a left-handed material, has been designed theoretically and experimentally [5]. The negative refraction behavior can also be achieved without negative permittivity/permeability or backward wave effect [6]. It is due to the negative photonic effective mass. In this case, the photonic crystal has an effective refractive index attributed to the photonic band structure. Such a photonic crystal behaves like a right-handed but unconventional medium.

Recently, analogous phenomena for acoustic and elastic wave propagation in phononic crystals have been predicted [1]. In Ref. [1], a negative refraction and an imaging effect of acoustic waves were achieved in the phononic crystal consisting of square arrays of rigid or liquid cylinders embedded in air background. Also, an acoustic negative refraction was observed experimentally in steel cylinders placed in air background [7,8]. Computer simulation [9] also supports that the phononic crystal, consisting of a hexagonal array of steel cylinders in air back ground, exhibits the acoustic lens effect. This effect is expected to lead to novel mechanisms for acoustic devices, acoustic sensors, and acoustic energy carriers to piezoelectric generator, for example.

In the present study, we calculate the dispersion relations of phonons and equivalent frequency surface (EFS) of 2D phononic crystals, which consist of metal cylinders embedded in liquid base, using the finite-difference time-domain (FDTD) method. We demonstrate existence of the negative refraction of acoustic waves at the interface of the liquid and the phononic crystal slab. Frequency range for the negative refrac-

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