Scanning phononic lattices with surface acoustic waves

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Abstract

We examine the transmission and reflection of surface acoustic waves from a two-dimensional hexagonal lattice. Highly anisotropic signals are observed by continuously scanning the wavevector angle. Preliminary models of wave propagation through this phononic lattice predict the acoustic dispersion and a complete band gap; however, the experimental results indicate that more realistic modeling of surface acoustic waves in elastically modulated media is required. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Ultrasound imaging; Photonic materials; Surface acoustic waves

Photonic lattices have received a great deal of attention over the last few years [1,2]. The existence of frequency gaps for electromagnetic waves in these periodic structures has potential for modifying the radiative strength of optical transitions and for manipulating microwaves and light beams. Analogous to photonic structures are phononic lattices, which support vibrational waves in elastic media [3–5]. This paper describes experiments performed on a two-dimensional hexagonal lattice using recently developed ultrasonic-scanning methods.

The sample examined here consists of a hexagonal array of aluminum posts surrounded by Aremco Crystalbond\textsuperscript{TM} 509, a polymer with a 40° C melting point. As shown in Fig. 1a, the sample was constructed by milling sets of parallel lines in an aluminum block, leaving hexagonal-shaped posts sticking up from an aluminum base. The sample was then electropolished, which rounded the sharp edges of the hexagonal pillars and left nearly circular columns. Filling the space between the posts with Crystalbond and polishing the surface flat gave a hexagonal array of high-density inserts in a low-density background.

The experiment performed on this sample is conceptually simple. A cylindrically-focused ultrasonic immersion transducer produces a line of constant phase on the sample surface. This line generates a surface wave that propagates along the surface and is detected by a second transducer whose focal line is a distance d from the source region. By rotating the sample about an axis normal to the excitation surface, acoustic propagation along all directions in the surface can be studied. Since cylindrically focused transducers are used in these
Fig. 1. (a) Sketch depicting the sample construction. The hexagonal lattice has a nearest-neighbor distance $a = 1.17$ mm and a filling fraction of 15%. The straight lines in the figure indicate the cuts made in an aluminum block to form the lattice. (b) Sketch of Kushwaha and Halevi’s model system.

experiments, rotating the sample scans the direction of the wavevector $k$ relative to the lattice.

What do we expect to see from these experiments? Kushwaha and Halevi have derived dispersion relations for acoustic propagation in similar systems [4]. Their hexagonal system, shown in Fig. 1b, consists of infinite circular cylinders imbedded in an isotropic background. Propagation is assumed to be in the plane perpendicular to the cylinder axes (the $x$–$y$ plane in Fig. 1b), and the waves are assumed to be polarized perpendicular to this plane (along the $z$-axis in the figure). Although their calculation assumes bulk propagation through an infinite sample, we have used it as a preliminary model of our surface-wave experiment.

Constant-frequency curves obtained from their equations are shown in Fig. 2a. For low frequencies, where the wavelength of the surface waves are longer than the distance between the posts, the acoustic waves should propagate as in a homogeneous medium. As the wavelength of the surface waves approach the lattice spacing, dispersive effects become more important, until (for frequencies above 1.0 MHz) acoustic stop bands appear. The locations of the stop bands between the first three Brillouin zones in this lattice are shown as the shaded regions in Fig. 2b. The calculations predict forbidden frequencies between about 1.1 and 1.3 MHz for all wavevector directions. Therefore, the system is said to have a complete band gap.

Fig. 2. (a) Constant-frequency curves for this lattice. (b) Locations of the stop bands between the first three Brillouin zones. Note the complete band gap between the first and second zones.
What is actually seen in the experiment? Fig. 3a shows an angle-time image showing signals transmitted across 10 mm of the sample. Although a short excitation pulse (about 0.5 μs width with 5 MHz central frequency) was used, the transmitted wave has considerable amplitude more than 15 μs after the pulse is first detected. A Fourier transform of the image is displayed as Fig. 3b, showing that the energy in the transmitted wave is rather strongly attenuated above about 1.3 MHz. The features centered at about 1.22 MHz has a similar structure to the edges of the lowest stop band predicted in Fig. 2. However, the intensity remains large through the band gap region, contrary to expectations. Obviously, a more sophisticated model, which explicitly incorporates surface waves and the effects of fluid loading, is required to explain this interesting data.

A related experiment measures the frequency dependence of reflections from the periodic structure. A single transducer is focused onto the lattice, and the signal reflected back into that transducer is recorded and analyzed. A Fourier transform of this signal, shown in Fig. 4, shows a multitude of bright features extending past 6 MHz. The reflections between 1.0 and 1.3 MHz agree with the expected locations of the lowest band gaps, providing graphic evidence for Bragg scattering from the lattice. The higher frequency reflections, however, are not explained with the present simple model.

In conclusion, our experiments have introduced an interesting acoustically modulated material and a powerful technique for examining its spectroscopic behavior. The theoretical challenge of properly modeling surface waves on these fluid-loaded periodic materials remains.

This work was supported in part by the Department of Energy grant DEFG02-96ER45439.
in the Fredrick Seitz Materials Research Laboratory.

References


