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Imaging surface acoustic waves on a metamaterial based on silica microspheres

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1. Introduction

Acoustic metamaterials, such as those consisting of periodic arrays of elastic membranes [1], double C resonators [2] and Helmholtz resonators [3], have received growing interest because of their potential to exhibit negative physical parameters, leading to the possibility of effects such as superlensing and cloaking. Whereas phononic-crystal related effects arise when the acoustic wavelength is similar to the size of the unit cell, in metamaterials the wavelength is considerably larger than the lattice constant. Generic metamaterial studies of acoustic propagation in periodic materials consisting of arrays of mm-sized spheres, in particular, have been successful in revealing acoustic-metamaterial band gaps for samples in which the lattice constant is two orders of magnitude smaller than the wavelength [4]. However, there have been few corresponding studies of similar materials consisting of microspheres. On the microscopic scale interesting effects such as adhesion become significant.

Previously the contact resonances of a 2D metamaterial array of microspheres on a substrate was probed through the interaction with surface acoustic waves (SAWs) using a laser-induced transient grating technique to measure dispersion [5]. Meanwhile, SAW imaging has been shown to be effective in investigating scattering and dispersion in phononic crystals in 2D **k**-space [6]. In this paper we apply real-time imaging of SAWs to a metamaterial based on silica microspheres.

2. Sample

Our sample consists of a hexagonally-packed monolayer of microscopic silica spheres deposited on a substrate consisting of a fused silica slab with a 0.20 μm aluminium film coating for coupling with laser pulses, as described previously [5]. The spheres have a diameter of 1.08 μm, and the silica slab is 1.5 mm thick. Different types of resonances, including rocking, lateral and axial resonances, have been observed in such microsphere structures [7,8,9], and similar effects are expected for the present sample. The sample structure is illustrated in **Fig. 1**, with an optical image of the surface shown in the inset.

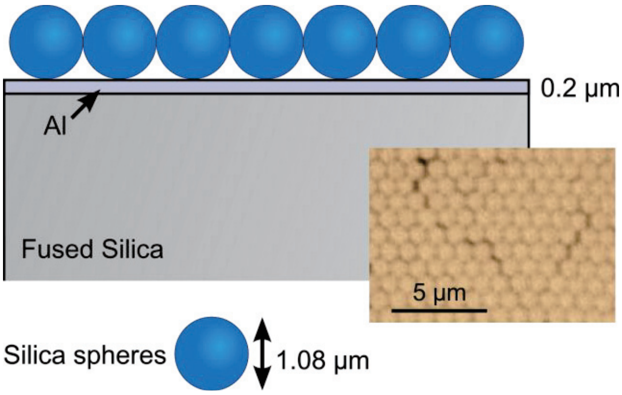

Fig. 1 Cross-sectional diagram of the metamaterial sample structure. Inset: Optical image of the sample surface

3. Experiment

Acoustic waves are excited and detected using an optical pump-probe set-up with a Ti:sapphire femtosecond laser [10]. The probe pulses, of wavelength 830 nm, repetition rate 80.4 MHz and duration ~200 fs, detect the out-of-plane surface velocity of the propagating waves. The pump beam is derived from the same laser and has a wavelength of 415 nm, exciting SAWs at a point by thermoelastic expansion. The 830 nm probe beam has a variable delay relative to the pump beam. The beams are focused to spots of about 1 μm in diameter. While keeping the pump fixed, the probe spot is scanned across the sample to generate images over areas up to ~200×200 μm² at

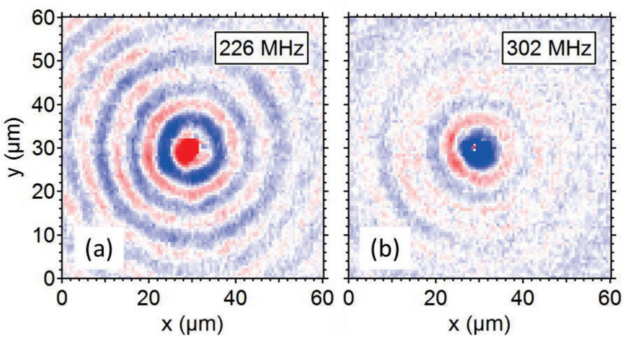

Fig. 2 Experimental images of acoustic surface waves on the microsphere metamaterial at (a) 226 MHz and (b) 302 MHz, probed from the back side.

various delay times, allowing animations of the surface motion to be obtained at acoustic frequencies up to ~1 GHz.

Experiments were performed firstly with the pump and probe focused on the top surface, through the spheres, and alternatively from the bottom surface, through the transparent substrate. The experimental images show surface waves propagating along the sample surface. Fourier analysis enables the propagation to be visualized at fixed frequencies and the dispersion relation to be obtained. Such images show that propagation depends on the acoustic frequency. Near the microsphere resonance frequencies we expect to see metamaterial band baps. **Figure 2** shows the acoustic field in the metamaterial at (a) 226 MHz and (b) 302 MHz. The acoustic field amplitude at 226 MHz is clearly greater than that at 302 MHz, suggesting a band gap and therefore a resonance around 302 MHz.

4. Conclusion

Surface acoustic wave propagation on an acoustic metamaterial consisting of an array of microscopic silica spheres on a substate was dynamically imaged in two dimensions at frequencies up to 1 GHz by an ultrafast optical technique. The acoustic dispersion relations obtained by spatial and temporal Fourier transforms reveal gaps. This study demonstrates the feasibility of studying metamaterials by surface acoustic wave imaging on the microscale. The results should prove useful for studying the adhesion and contact mechanics of microparticles.

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