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Gigahertz optomechanical photon-phonon transduction between nanolines

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1. Introduction

Surface acoustic waves (SAWs) have been of great interest for the last 50 years, ever since the invention of interdigital transducers (IDTs) [1] and the application of lasers for SAW generation [2]. SAWs in the ultrasonic range have been widely used in communication and signal-processing technologies, materials characterization, photonic modulation, optomechanics and sensing.

One major problem with IDTs is the need for a piezoelectric substrate for their operation. Gigahertz SAWs can be excited by laser-induced thermoelastic stress localized within the SAW penetration depth, i.e. the acoustic wavelength, provided that the laser intensity temporal spectrum contains these frequencies and the spatial spectrum of the sample surface features contains the required SAW acoustic wavenumbers [3]. The intensity envelope of ultrafast laser pulses (of sub-ps and fs duration) do contain these required frequencies. Reaching the required wave numbers often involves laser-induced grating patterns on the sample surface [4,5] or deposited metal gratings [6,7], down to sub-100-nm spatial periods [7-9]. However, gratings require several spatial periods, thus imposing a limit on miniaturization.

Here we present experimental results for a miniaturized geometry for both optoacoustic excitation and detection of GHz SAWs, by means of a single nanowire SAW emitter and a single nanoline SAW receiver, localizing the transduction regions to ~70 nm in width [10].

2. Sample and experiments

Our emitter consists of a gold nanowire of thickness 50 nm, width 65 nm and length 5 μm on a glass substrate, whereas our receiver consists of a line of nanorods each of thickness 50 nm, width 65 nm and length 210 nm, separated by 100 nm gaps (Fig. 1 (a)), forming a nanoline of length 5 μm. This line is arranged to be at a distance of 5 μm from the nanowire.

We apply 200 fs duration laser pulses at 410 nm wavelength for the generation of the coherent surface acoustic waves on the (left-hand) nanowire over a laser line source ~70 × 3 μm^2 set parallel to the nanowire, and at 820 nm wavelength for the detection on the (right-hand) nanoline over a spot of diameter ~3 μm. The dimensions of the nanorods are chosen to increase the sensitivity of the detection process through their deformation by ensuring their longitudinal plasmon resonance is in the vicinity of the probe light wavelength [11-14], and the probe light is chosen to be polarized along the nanorods for optimum optical detection sensitivity. Figure 1(b) (top) shows the detected optical reflectivity change at the detector nanoline, with a SAW arrival corresponding to a time equal to that of the SAW propagation from the nanowire. Figure 1(b) (bottom) shows the modulus of the temporal Fourier transform vs frequency. This indicates that SAW pulses centred at ~8 GHz are detected. Numerical modelling of the vibrations of the gold nanorods used for detection on the glass substrate reveals that the maxima in the detected frequency spectrum (Fig. 1(b), bottom) are in the vicinity of vibrational resonances of nanorod, as shown in Figure 2. Consequently, in the experiments the acousto-optic nanoline detector

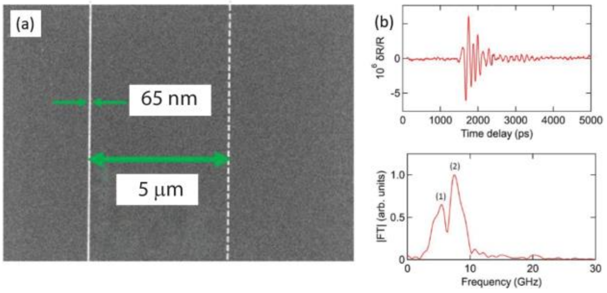

Fig. 1 (a) SEM image of the gold nanolines deposited on a glass substrate for optical generation (left) and optical detection (right) of coherent surface acoustic waves propagating to the right along the surface. (b) Transient reflectivity normalized variation ΔR/R detected at a 5 μm distance between the generator nanowire and the detector nanoline (top) and its temporal Fourier spectrum (|FT|) (bottom), showing two main resonances.

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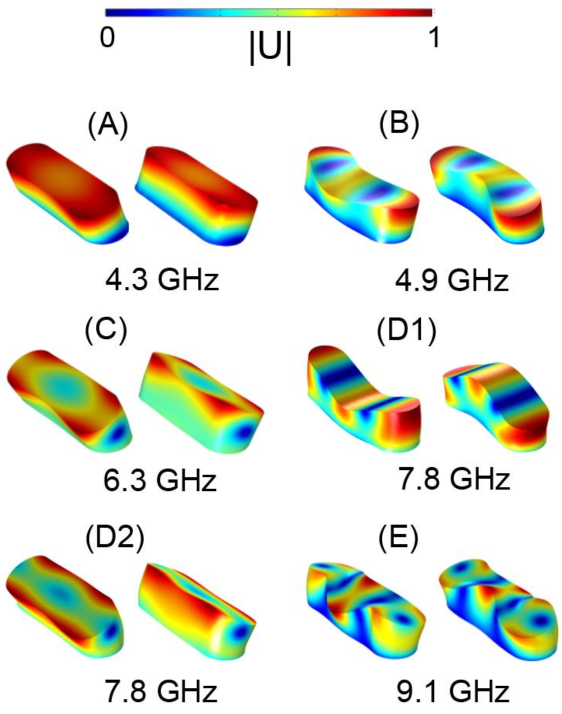

Fig. 2 Predicted three-dimensional views of the motion of a nanorod at the principal resonance frequencies obtained with COMSOL Multiphysics finite-element software. The colour scale represents the modulus of the displacement.

effectively operates in vibrational resonance mode.

3. Conclusions

In conclusion, we have demonstrated that through the optimization of gold detector nanolines along with the wavelength and polarization of the probe light, experiments with nanolocalized nanoline-to-nanoline transduction of pulsed SAWs in the GHz range are feasible. This research therefore provides promising avenues for future development of wideband frequency localized opto-acoustic transducers for SAWs up to 1 THz, with applications to the sensing of chemical compounds, adsorbed gases or biological species.

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