Ultrafast Phononics in Membranes and Nanostructures

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The dynamics of acoustic phonons can be traced with high sensitivity in femtosecond pump-probe experiments. We investigate coherent acoustic phonons in different single-layer and double membrane systems as well as the acoustic dynamics of single nanostructures. We apply the method of high-speed asynchronous optical sampling which is based on two asynchronously locked femtosecond laser oscillators with approximately 1 GHz repetition rate. This method allows us to detect reflectivity changes below 10^{-7} within a few minutes of measurement times over 1 ns time delay with 50 fs resolution. [1,2] A model system for confined acoustic phonons are free-standing Si membranes.[3-5] A superposition of coherent confined longitudinal acoustic modes of odd order is observed after impulsive optical excitation.[4] The lifetime of these modes exceeds 5 ns at room temperature. This allows us to resonantly drive these modes by adjusting the repetition rate of the pump laser (1 GHz) to a sub-harmonic of the fundamental acoustic mode (19 GHz). By tuning the repetition rate we can map out the resonance excitation profile of the confined modes and accurately determine the Q factor.[5] This method is promising for the investigation of coherent excitation and selective amplification of acoustic modes of single nanostructures. In a double layer membrane system of aluminum and silicon we demonstrate the generation of an acoustic frequency comb combined of 24 modes of even and odd order spanning a frequency range from 12 GHz to 300 GHz.[6] The lifetime of each mode can be accurately determined giving a quantitative measure of frequency dependent damping times over the full frequency range in a single measurement.

The dynamics of single nanostructures is investigated for a silicon nitride doubly clamed beam.[7] Beams with two different clamping conditions are investigated. By calculating the strain integral on the surface of the resonators, we are able to reproduce the effect of the detection mechanism and identify all the measured modes. We show that our spectroscopy technique combined with our modelling tools allow the investigation of several different modes in the super high frequency range (3-30 GHz) and above, bringing more information about the vibration modes of nanomechanical resonators.

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