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Hypersonic lamb waves in silicon membranes

Lamb waves are acoustic waves guided by the mechanically free opposite surfaces of an elastic plate. Various methods for the generation and for the detection of Lamb waves by lasers have been developed. Femtosecond lasers have been applied to generate and detect longitudinal resonance bulk acoustic modes in free-standing silicon nanomembranes to up to 500 GHz frequencies and down to 20 nm wavelengths [1]. Also Rayleigh waves with wavelengths down to 100 nm and frequencies up to 90 GHz [2] have been generated and detected in silicon by depositing on the substrate surface metallic gratings with nanometer-periodicity. As the dispersion relations of the propagating Lamb waves are emerging from the standing wave resonances (these correspond to the wavenumber of the lamb waves being zero), these experiments indicate that propagating Lamb waves in nanomembranes at similarly high frequencies could be all-optically monitored if the conditions for their effective generation and detection are achieved. Here we combine the application of the femtosecond pump-probe technique and a metallic gratings to achieve the generation and detection of the propagating Lamb waves at frequencies up to 230 GHz and wavelengths down to 100 nm in nanomembranes.

The pump-probe technique used is asynchronous optical sampling (ASOPS) [3]. For ASOPS two femtosecond Ti:sapphire oscillators are coupled. The repetition rates are 800 MHz and 800+x MHz due to the actively stabilized offset x in the repetition rates the time delay between the two laser pulses is monotonically changed. This allows measuring a time window of 1.25 ns in 0.2 ms. The membranes are obtained from a commercially available Si-on-insulator wafer, which is wet-etched from the backside with potassium hydroxide using a silicon-nitride etch mask, resulting in ~340 nm thick Si membranes. On top of the membrane, lithographically ~15nm thick gratings are produced, etched with reactive ion-etching and filled with aluminum by evaporation.

We expect that Lamb waves with hundreds of GHz frequencies and tens of nanometers wavelengths can find applications not only in the testing and evaluation of the nanomembranes, but also for probing the interaction of travelling acoustic waves with charge carriers and other type of excitations in solids in the nano-confined geometry.

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