Acoustic Waves Coupled to Quantum Dots in Nanomechanical Structures.

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An experimental study of coupling between high frequency acoustic waves (13 GHz) and optical properties of individual quantum dots (QD) embedded in nanomechanical structures will be presented. The structures tested are based on self-assembled InAs QDs in ultrathin suspended films of single crystal GaAs. The elastic excitations are generated by ultrashort ($\tau < 100$ fs) laser pulses while phonon-induced perturbations in the electronic spectrum of the QD are detected by monitoring non-resonantly excited photoluminescence.
In an effort to enhance the interaction with the QDs we use near-longitudinal phonons (as opposed to flexural elastic waves[1,2] or surface acoustic waves[3]) to modify the QD excitation spectrum. The flexibility in implementing optoacoustic excitations allows us to generate both, broadband bulk acoustic phonons and resonant elastic waves defined by the geometry of a nanostructure. The results of our pump-probe experiments (Fig. 1) together with theoretical analysis indicate that super high frequency range (SHF, 3-30 GHz) symmetric Lamb waves (S1) optically generated in suspended ultrathin films can be a potent vehicle for delivering elastic excitations to QDs, with the coupling strength enhanced by the very slow group velocity (~700 m/s) of S1 waves.
In order to detect the shifts in QD energy levels induced by the phonons we populate the excited states of the dot with a separate, low power laser beam and detect sound-induced deviations in the wavelength of the photons emitted during radiative recombination. The asymmetric broadening that appear on high resolution optical spectra in the presence of the direct acoustic excitation (Fig. 2) is attributed the effect of broadband bulk acoustic waves. The sidebands observed on PL spectrum when the resonant modes of the nanomechanical structure dominate the elastic excitations (Fig. 2) are consistent with the effect of narrow band S1 Lamb waves propagating in a GaAs ultrathin plate.
The ability of phonons to alter the QD electronic states could be used in quantum information systems (e.g. for the QD spin manipulation). In a reverse approach, the QD-based method of detecting compressional sound waves in nanostructures (featuring nm-scale spatial resolution and very low readout power) can be enabling for SHF applications in nanomechanics.

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[1] S. G. Carter et al., Appl. Phys. Lett. 111, 183101 (2017)
[2] M. Munsch et al., Nature Comm. 8:76 (2017)
[3] M. Metcalfe et al., Phys. Rev. Let. 105, 037401 (2010)

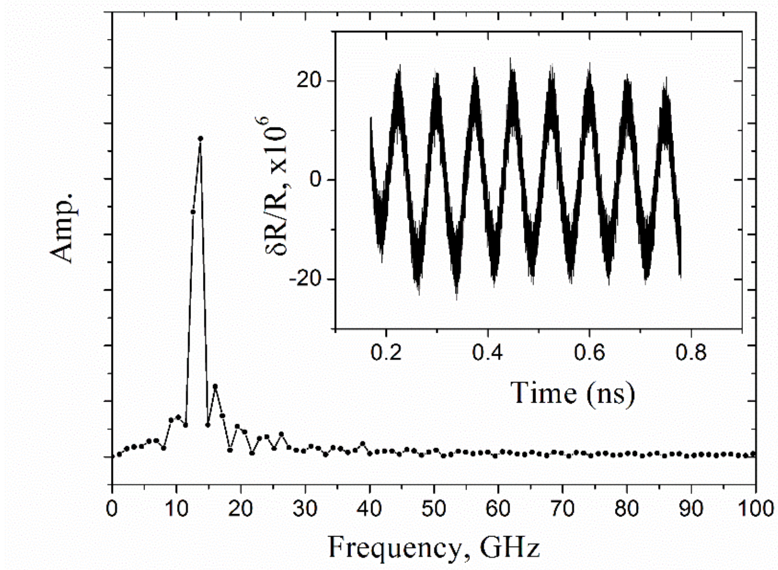

Figure 1: The Pump-Probe experiment: The reflectivity of the ultrathin (190nm) suspended GaAs plate exhibits pronounced oscillations (inset), centered at ~13 GHz and attributed to acoustic S1 Lamb waves excited by ultrashort Ti:Sapphire laser pulses.

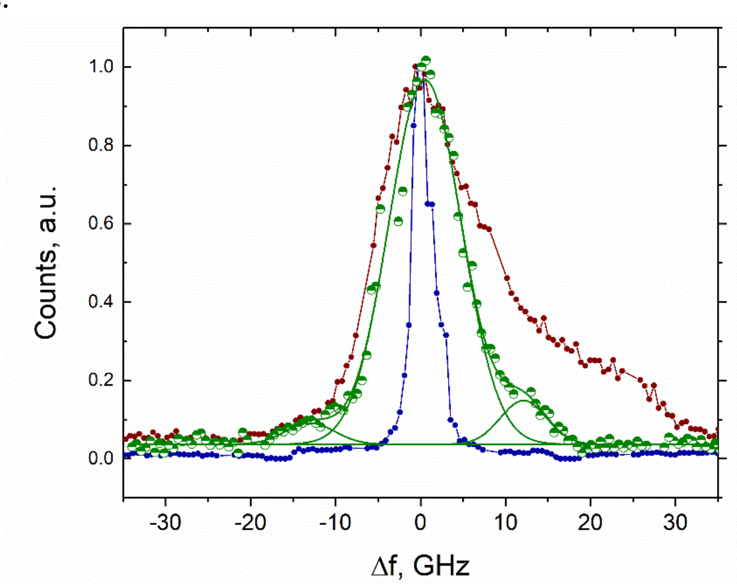

Figure 2: The PhotoLuminescence (PL) spectrum of an Individual QD: The asymmetric broadening (red solid dots) is attributed, at least partially to the shock front generated by Ti:Sapphire laser pulses. The frequency offset of the sidebands observed on PL spectrum when the effect of the shock front is mitigated (half-filled green circles) match the frequency of the symmetric S1 Lamb waves (Fig. 1). The undisturbed PL line shape in the absence of acoustic excitation is shown by solid blue circles. The PL spectra are normalized and shifted for clarity.

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