Giant photoelasticity of the superlattice polaritons for laser ultrasonics

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High-frequency coherent phonons in the GHz range have a potential for application in quantum technologies due to their nanometer wavelengths being comparable with the size of quantum nano-devices. Such phonons can be excited and detected optically with the all-optical laser ultrasonics. Single quanta of localized phonons are possible to excite and detect by suspended structures and non-suspended optomechanical resonators. While propagating phonons are prospective logistic elements of quantum networks, their detection sensitivity remains so far insufficient. Therefore, increasing strength of photon-photon coupling became of interest to the community [1,2]. In this work, we show that it is possible to reach quantum sensitivity of the detection with a standard pump-probe set-up by exploiting giant photoelasticity of exciton-polariton resonance in a short period GaAs/AlAs superlattice (SL) [3].

The examined SL structure contains 30 periods of GaAs and AlAs layers with 12 and 14.2nm thicknesses deposited on the GaAs substrate. The initial measurements of reflectivity spectrum R_0 (solid line in Fig.1a) show clear polariton resonance positioned at $\hbar\omega_0$ = 1.55eV where the dielectric permittivity function is steepest. For excitation and detection of the coherent phonon wave packet, we used a standard pump-probe experimental set-up with a mechanical delay line and a lock-in amplifier. A coherent acoustic phonon wave packet is generated by absorption of 200fs pump laser pulse by a metal transducer at the back of the sample. Strain pulse propagates into GaAs substrate and reaches the GaAs/AlAs SL at the front, where it gets detected (Fig.1b). In order to resolve the effect of SL polariton on the transient reflectivity signal $\Delta R(t)$, we have used probe laser pulse with a narrow spectrum of 1.4meV (dashed line in Fig.1a)- comparable with the width of the resonance. By sweeping the central wavelength of the probe in the vicinity of the resonance we obtained signals for several detuning values of probe photon energy. Transient reflectivity signals are presented in Fig.1c; they possess clear oscillatory behaviour called Time Domain Brillouin Scattering (TDBS). The amplitude of the TDBS signal depends strongly on the photon energy of the probe and it is presented in Fig.1d. For a qualitative description of obtained results, we have created a theoretical model which fits experimental data (blue line in Fig.1d). The most important experimental result is the observation of enhanced sensitivity of the TDBS signal at the polariton resonance, for probe photon energy $\hbar\omega = \hbar\omega_0$. For pump fluence $J \sim 0.1 \mathrm{mJ/cm}^2$, we obtain the TDBS signal with amplitude $\frac{\Delta R}{R} \sim 10^{-2}$, which is three orders of magnitude larger than for a similar phonon wave packet detected in a material without presence of polariton resonance [4].

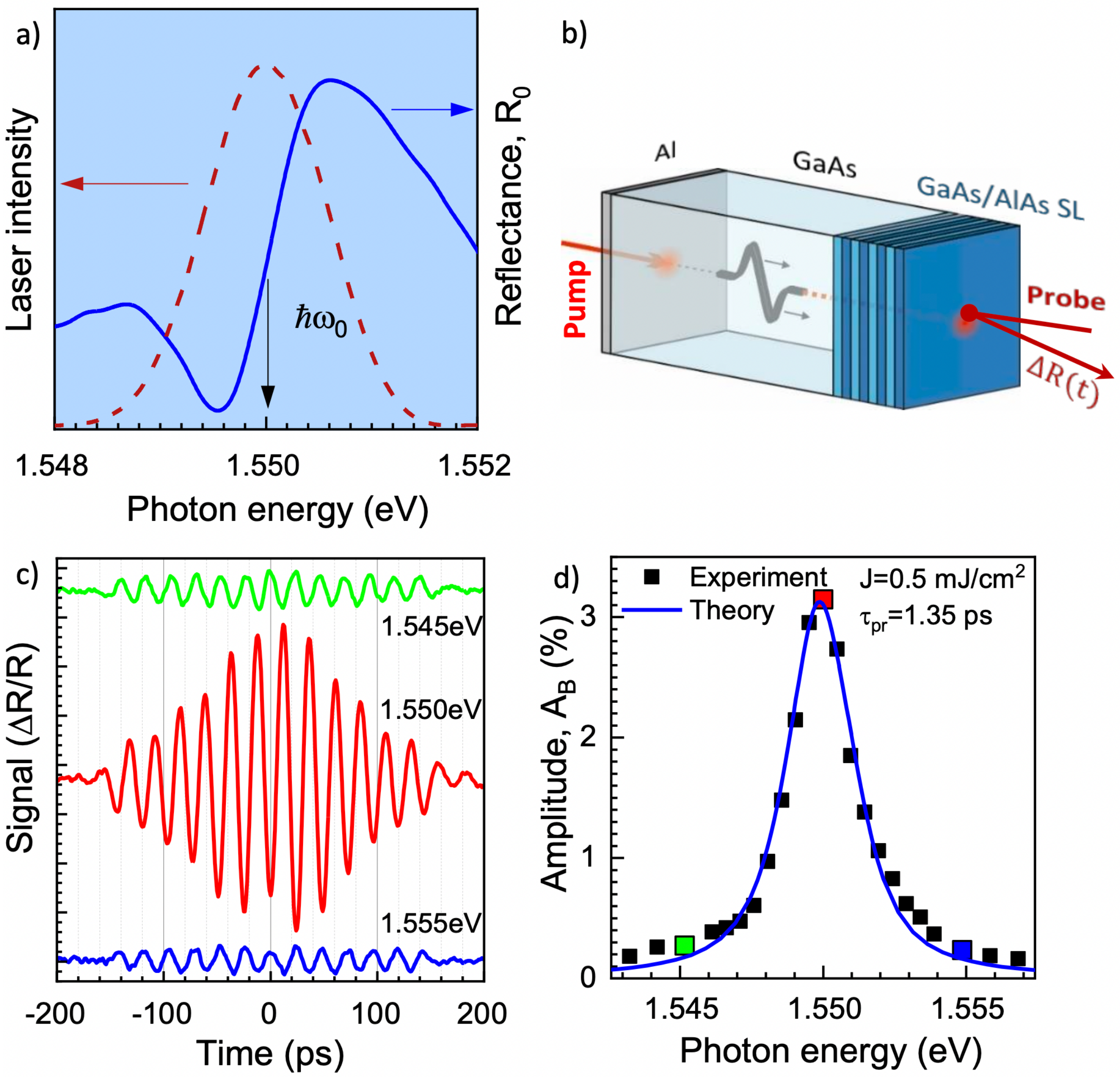

Fig. 1. a) Reflectivity spectrum in the vicinity of the polariton resonance (blue solid curve). The red dashed curve shows the spectrum of the probe beam. **b)** Schematics of excitation and detection of propagating coherent phonon wavepacket. **c)** TDBS signals measured in the vicinity of polariton resonance. **d)** TDBS amplitude dependence on probe beam energy.

Our experiments reveal giant photoelasticity of polaritons and extremely high sensitivity to propagating coherent phonons. The strong dispersion of the dielectric permittivity in the vicinity of the polariton resonance results in a strong ultrafast response of the optical properties to dynamical strain which accompanies the coherent phonons. This discovery opens new possibilities of ultrasensitive measurements of extremely low-density phonon fluxes. The presented technique can find its applications in the detection of phonons on the quantum level as well as phonon imaging exploited in laser ultrasonics.

References

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