Ultrahigh-Sensitive Polariton Probing of Picosecond Strain Pulses in a GaAs/GaAlAs Superlattice

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Photoinduced ultrafast processes on the nanoscale are usually associated with the generation of stress. Some exemplary processes are the structural phase transitions of crystalline lattices or the ultrafast lattice and electron gas heating in metallic nanolayers. The stress is generated locally and results in the injection of the ultrashort strain pulse into the adjacent crystalline lattice. The strain pulse, which equals a coherent wavepacket of acoustic phonons, is an indicator of the photoinduced process, but can also serve as a nanoscopy tool for studying delicate objects, e.g. living cells [1]. Thus, the sensitivity of strain pulse detection becomes a crucial factor. In this work, we achieve ultrahigh detection sensitivity by optical probing of the strain pulse in the spectral vicinity of the polariton resonance in a semiconductor superlattice (SL) [2, 3]. Due to strong permittivity dispersion and large deformation potential, polaritons exhibit giant photoelasticity and strengthen the photon-phonon coupling. This allows us to detect strain pulses with an amplitude of only $\eta_0 \sim 10^{-9}$, which corresponds to an atomic lattice displacement on the scale of $\sim 10^{-16}$ m.

In the experiment, we generate and detect bipolar strain pulses in the pump-probe scheme using a femtosecond laser source, as illustrated in the left inset of Figure 1. The stress is generated by optically induced heating of a 100-nm Al layer by the pump pulse with fluence w, resulting in an ultrafast thermal expansion of the film. The strain pulse $\eta(z, t)$ is injected into the GaAs substrate and propagates with the longitudinal sound velocity of $v \approx 4800$ m/s. It is probed in the SL composed of 30 GaAs/$Ga_{0.67}Al_{0.33}As$ quantum wells. The measured transient reflectivity $\Delta R/R(t)$ shown in Figure 1, exhibits oscillatory behaviour known as time-domain Brillouin scattering (TDBS). The oscillations occur in the time frame of -150 ps $\leq t \leq$ 150 ps and indicate the propagation of coherent acoustic phonons through the SL towards the free surface and after reflection at $t = 0$ ps back towards the substrate. The fast Fourier transform spectrum of the TDBS signal shown in the right inset contains a single line at the Brillouin frequency of $f_B = 42$ GHz. It agrees with the TDBS selection rule $q = 2k_1$ defined by the conservation of the wave vector k_1 of light scattered at the propagating strain pulse with wave vector q. The ultimate sensitivity allows us to confidently measure TDBS signals for extremely low pump fluences corresponding to heating of the Al film of an order of 0.1 K.

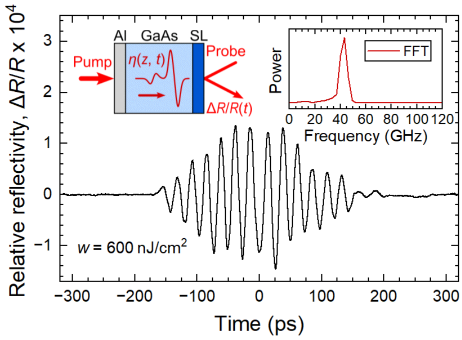

Figure 1: TDBS signal measured at a pump fluence of 600 nJ/cm^2. Left inset: Experimental pump-probe scheme for the optical excitation and detection of strain pulses $\eta(z, t)$. Right insert: Fast Fourier transform of the TDBS signal.

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