Inversion Techniques Applied to Picosecond Acoustics

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Laser picosecond acoustics can be used to probe the interior of materials nondestructively [1]. In the conventional setup, pumped light pulses from an ultrashort pulsed laser generate longitudinal acoustic phonon pulses in opaque thin films in the frequency range from 10 to 1000 GHz. Delayed probe light pulses detect any phonon pulses that return to the surface. The detected phonon strain pulse shape depends on the phonon generation and propagation, related to ultrafast carrier diffusion, the electron-phonon interaction, and phonon scattering. The phonon strain pulse shape can be indirectly assessed by an analysis of the temporal variation of the changes in the probe light reflectivity or optical phase as a function of the delay time between the optical pump and the probe pulses.

Here we present a new method for visualizing plane picosecond acoustic waves traveling in a transparent medium using ultrashort optical pulses. The principle is as follows: longitudinal acoustic phonon pulses are optically generated in a thin opaque film coating a transparent medium. Phonon pulses transmitted to the transparent medium induce a weak modification of the refractive index distribution, through the photoelastic effect. As a consequence, the optical reflectivity of the sample is perturbed when probed by light pulses incident from the transparent medium side. A simple integral relationship is known to relate the change in the optical reflectivity to the perturbed refractive index field inside a sample [2, 3]. To visualize the spatial acoustic strain distribution, we solve the inverse problem of computing the strain field from the observed perturbation in the angular reflectivity spectrum using s-polarized probe light. We can then effectively animate the propagation of the acoustic strain wave by repeating the inversion process for a sequence of delay times between the optical pump and probe pulses.

A hemisphere of BK7 glass is coated with a thin Au film on the flat surface, and mounted on a rotation stage. Optical pump pulses (~ 500 fs in duration) from a Ti:Sapphire laser excite the phonon pulses. The reflectivity of the delayed probe light pulses (s-polarized) incident from the glass side is monitored as a function of the probe angle of incidence and the pump-probe delay time. The propagating acoustic strain distribution is then calculated from this angle scan data to ~ 50 to 100 nm spatial resolution. We discuss the effect of the angular resolution and the noise level of the measurement on the accuracy of the reconstruction process.

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