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Ultrafast optical time-domain spectroscopy of opto-mechanical interactions

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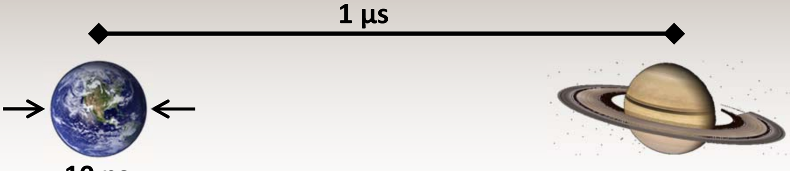
Observation of coherent opto-mechanical interactions can require straddling the optical and mechanical domains, which occur on different time scales.

The time domain captures both magnitude and phase information which can be used to separate competing nonlinear effects that occur on different time scales. Many opto-mechanical phenomena require few picosecond resolution sampling to faithfully observe. However, high-Q acoustic resonances may live for many nanoseconds. Acoustic transduction may involve microsecond delays. Electronics lack the timing resolution and speed to observe ns—µs length phenomena with few ps precision.

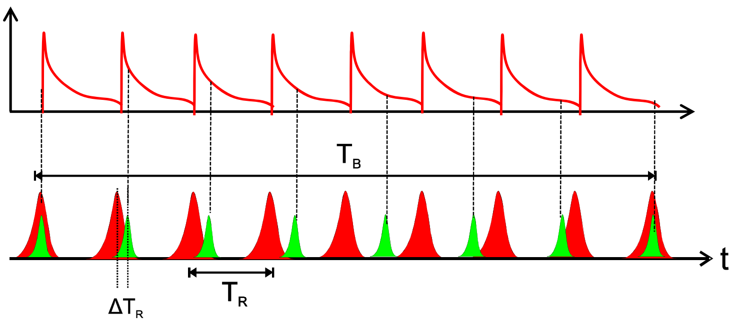


The ratio of the average distance from Earth to Saturn over the diameter of Earth is precisely 100,000—or 1 µs over 10 ps.

Asynchronous optical sampling enables the terahertz oscilloscope with mechanically impossible speed.

Traditional pump probe experiments use a moving delay mirror to vary the time between a pump and probe pulse as the sample response is recorded. Scanning 100 ns at 1 kHz would require moving a mirror 15 m at 108,000 kph.

However, a pair of ultrafast lasers with slightly detuned repetition rates, f_{rep}, can act like a sampling oscilloscope. The pulsing period, T_{rep}, sets the length of the time window, while the difference in repetition rates (beat frequency) f_B, sets the scan rate. The number of samples per time window is determined by the beat and repetition frequencies, $N_s = f_{rep}/f_B$. The sampling rate, $f_s = N_s \cdot f_{rep}$.



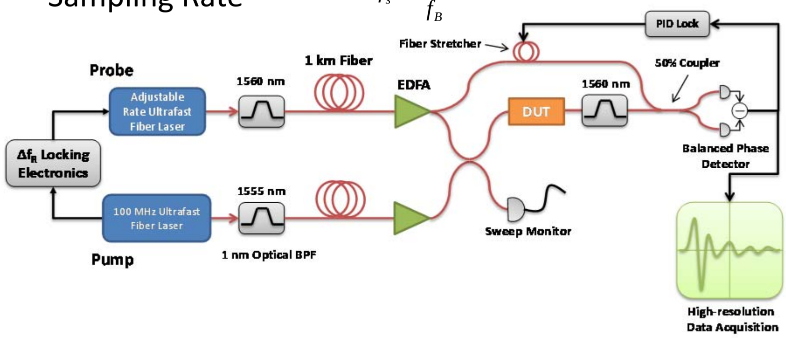
Beat Period ☞ $$T_B = \frac{1}{f_1} - \frac{1}{f_2} = \frac{1}{\Delta f}$$

Sampling Rate ☞ $$f_s = \frac{f_{rep}^2}{f_B}$$

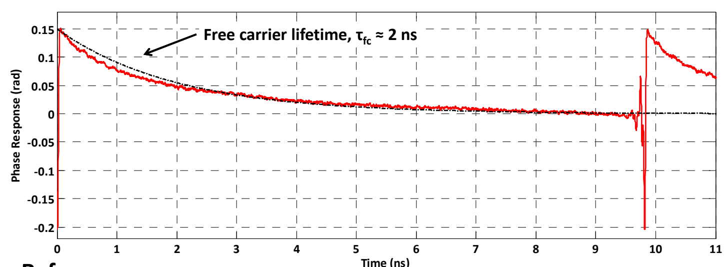
Picosecond pulses are generated from ultrafast fiber lasers via filtering and stretching. A fiber inter-ferometer detects the SBS induced phase shift.

The offset (beat) frequency between lasers is locked by detecting a microwave harmonic from the master laser and generating an offset frequency with a Direct Digital Synthesizer (DDS) to lock the slave laser to.

Picosecond pulses are generated from fs pulses via spectral filtering and stretching in 1—2 km of fiber. After amplification, the pump and probe are coupled into the device. The probe is spectrally isolated and interfered with the probe reference in a stabilized, balanced fiber interferometer. A digital acquisition board acquires the optically sampled response of the nonlinear medium.



Preliminary results demonstrate precise measurement of free carrier lifetime from two-photon absorption.



To observe SBS nonlinear effects, acquisition board sensitivity will be improved. Furthermore, separate waveguides for pump and probe (acoustic transduction) will eliminate free carrier background.

Key References:

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2. A. Bartels et al., “Ultrafast time-domain spectroscopy based on high-speed asychronous optical sampling,” Rev. Sci. Instrum., Vol. 78, pp. 35107 (2007).
3. F. Hudert et al., “Confined longitudinal acoustic phonon modes in free-standing Si membranes coherently excited by femtosecond laser pulses,” Vol. 79, pp. 201307 (2009).

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