Ultrafast Optical Time-Domain Spectroscopy of Phonon Transduction in Traveling-Wave Optomechanical Devices

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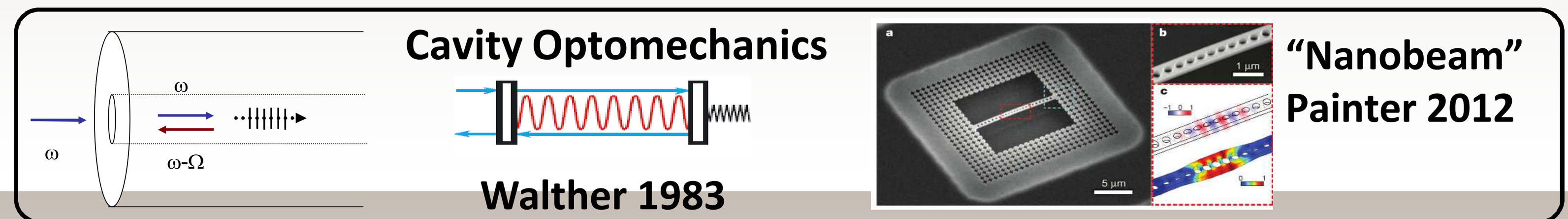
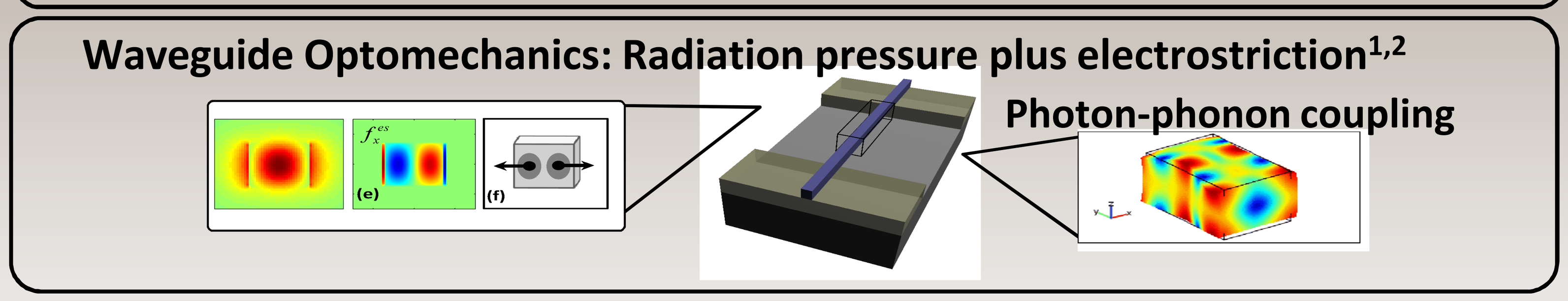
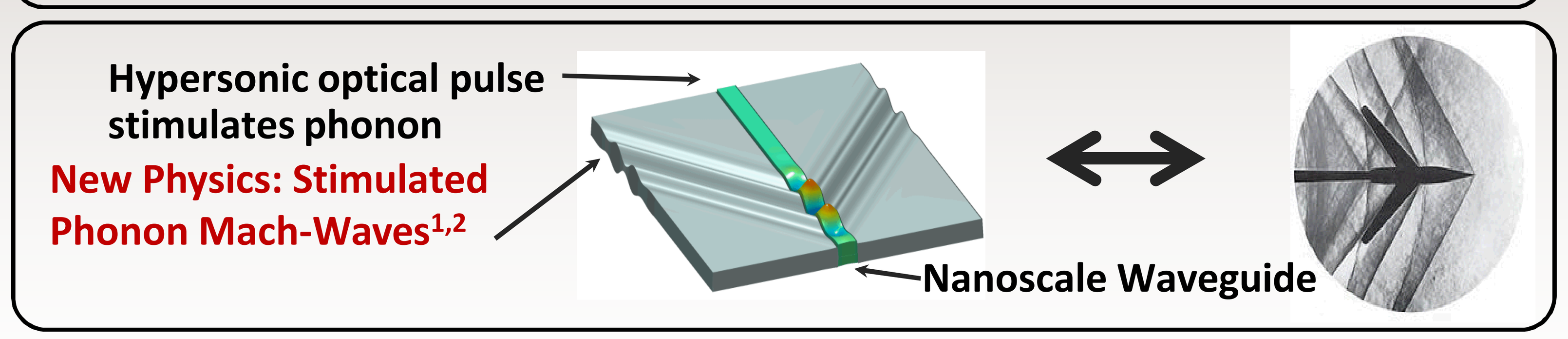
Introduction

- Optomechanics, the study of the interaction of electromagnetic radiation and mechanical waves, enables the exploration of novel fundamental light-matter interactions and the development of new classes of information processing.



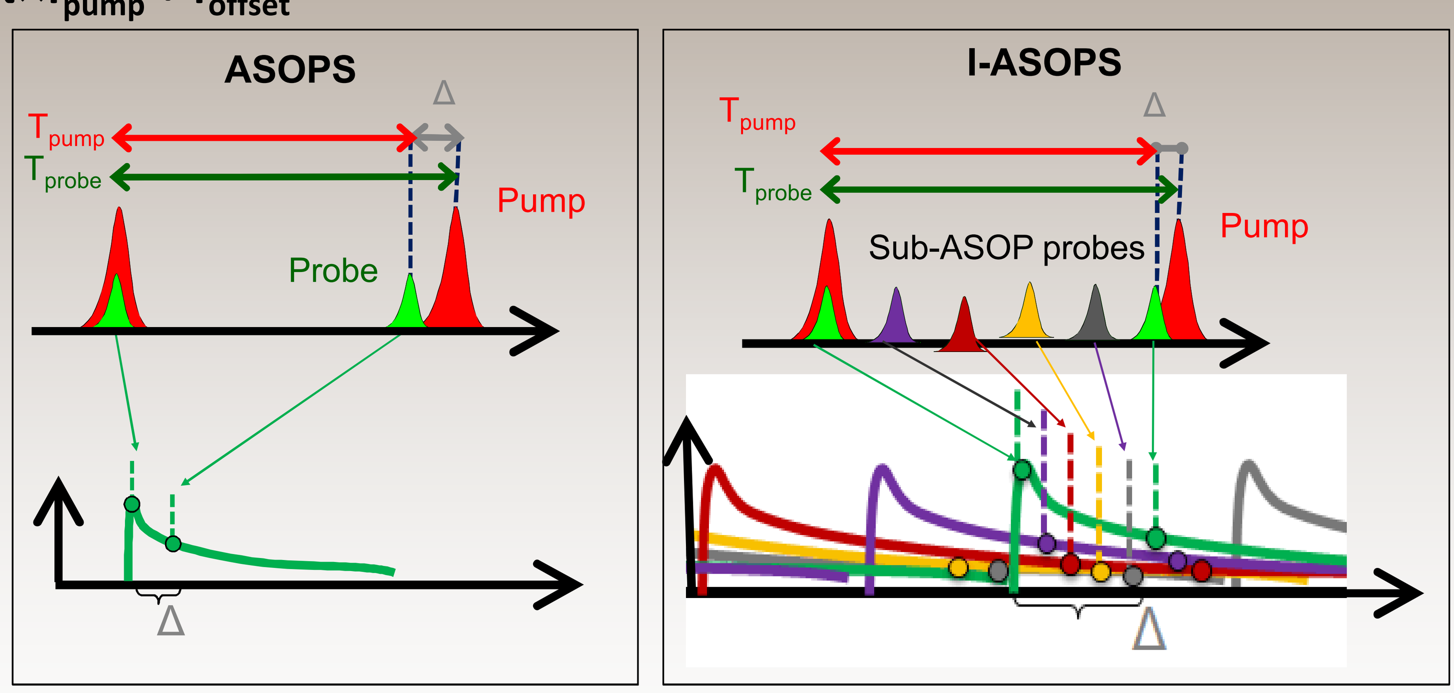




- Non-resonant structures present a unique problem: long-lived transients over a wide range of frequencies.

Measurement Solution: Interleaved Asynchronous Optical Sampling (I-ASOPS)

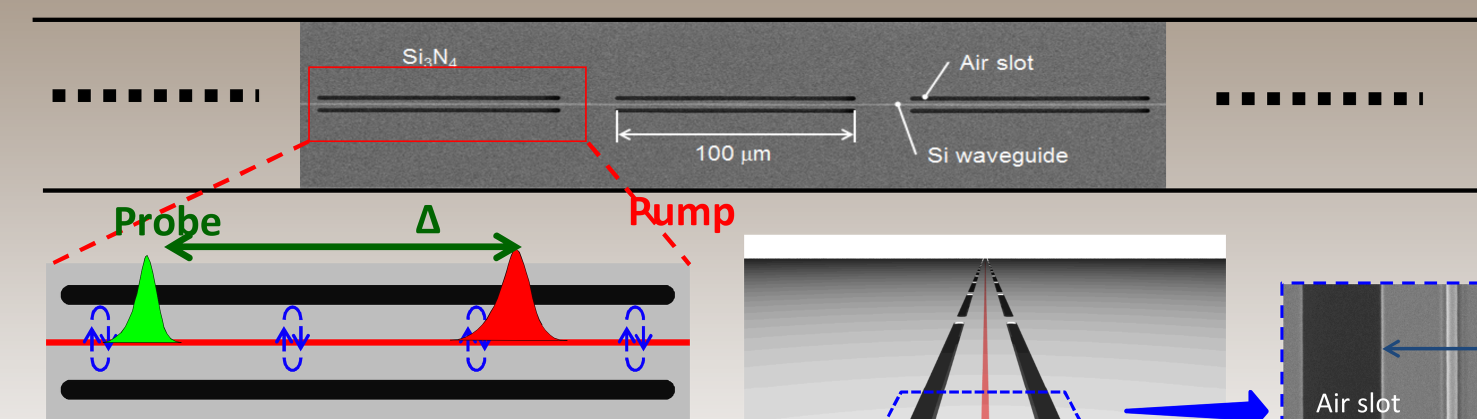
- Novel measurement tool has enabled the observation of optomechanical phenomena not detectable using CW laser (frequency domain) techniques.
- By offset frequency-locking a pump and probe lasers, the delay between the pulses is swept over the full period of the pump using ASOPS[3].
- In I-ASOPS, multiple probe pulses are launched for each pump pulse ➔ $f_{probe} = N \times f_{pump} + f_{offset}$



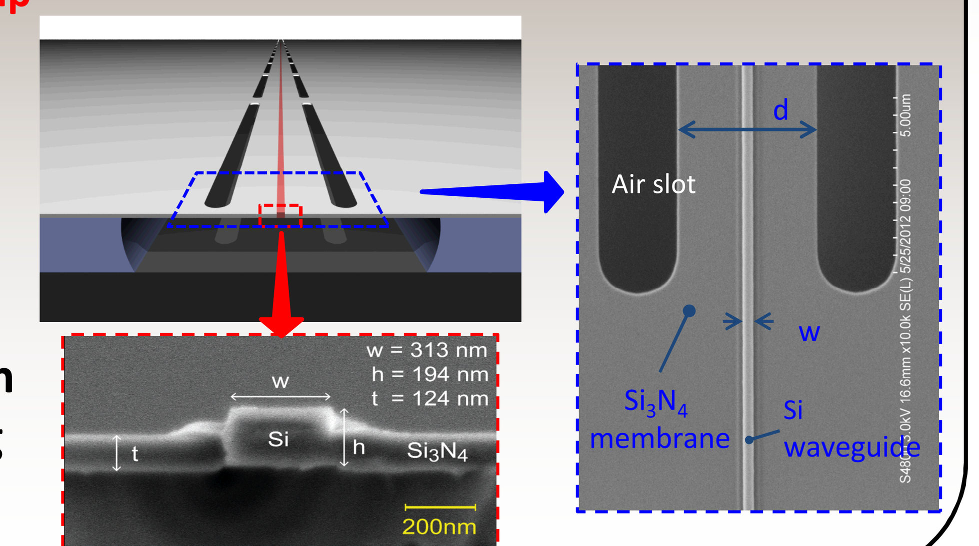
- I-ASOPS can be considered as N simultaneous ASOPS, each at a different phase relative to the pump pulse train.
- Temporal resolution increases by a factor of N, i.e. $\Delta' = \Delta/N$
- Avoids artifacts from parametric pumping.

Device Concept[1,2]: Traveling-Wave Photon-Phonon Device

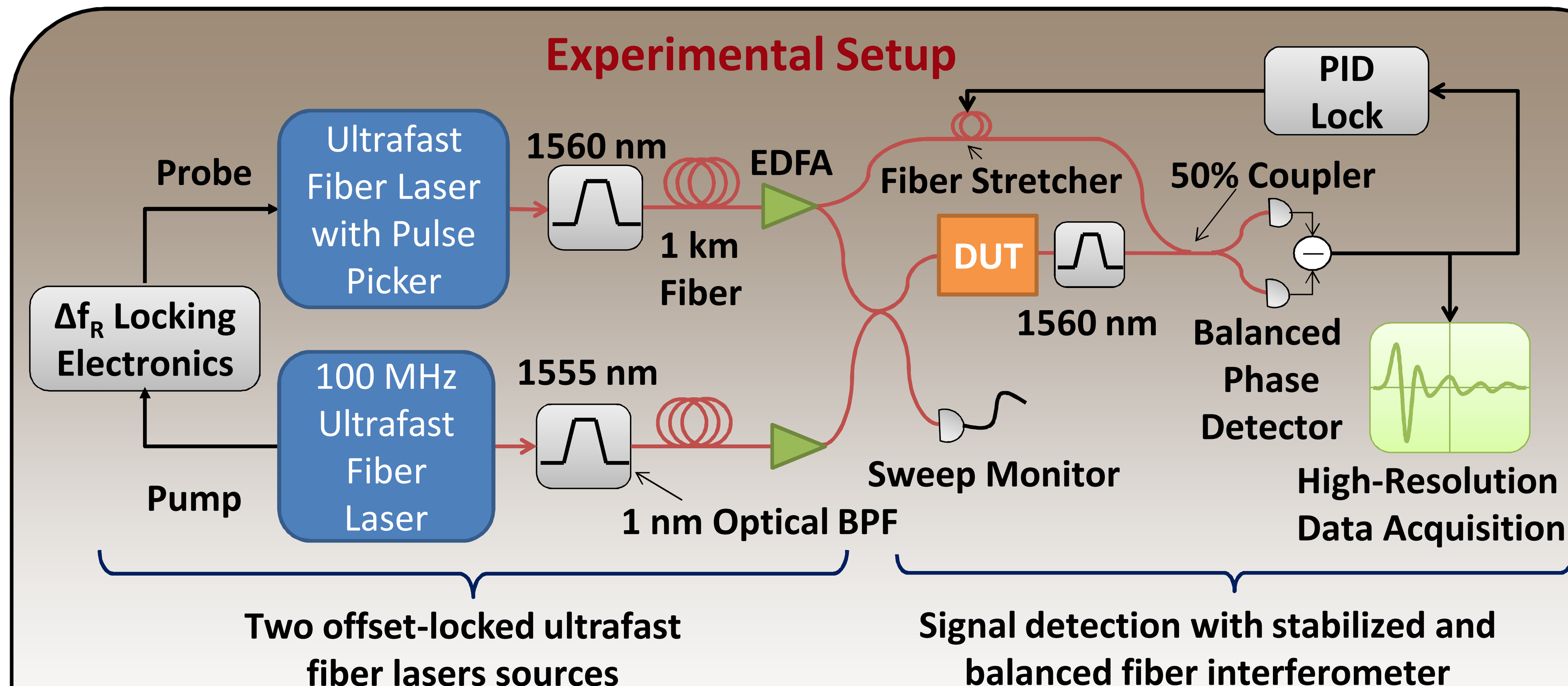
- Non-resonant waveguide devices allow high-frequency, broadband transduction for RF signal processing.



- Transversely-oriented phonon resonator
  - ➢ Allows engineering of the phonon resonance frequency by changing the membrane width.



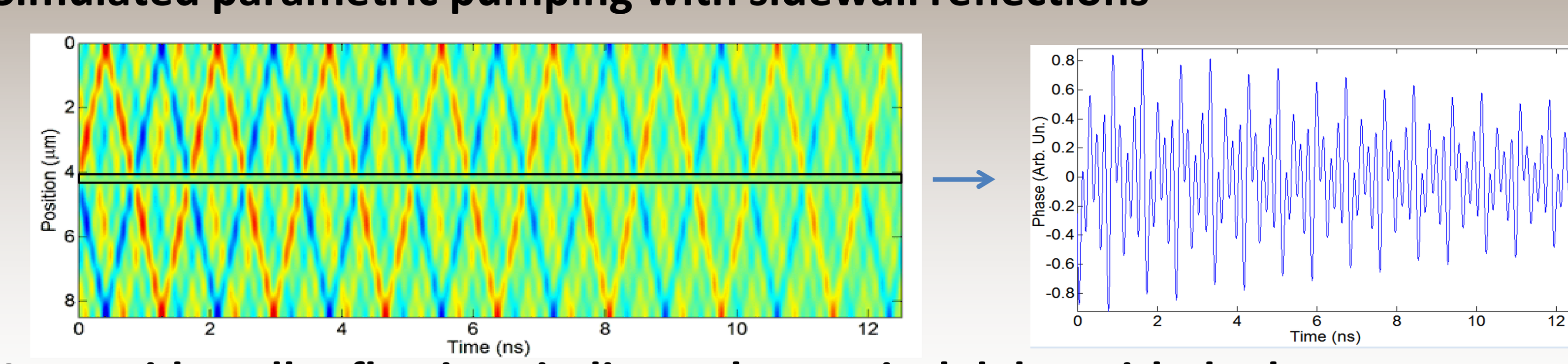
Experimental Setup



- Two picosecond-fiber laser sources (pump and probe) locked with an 80MHz repetition rate and a 1kHz offset allow for 80,000 samples of 12.5ns.
- Shot noise-limited detection permits micro-rad phase sensitivity.

Impulse Response of Membrane Structure

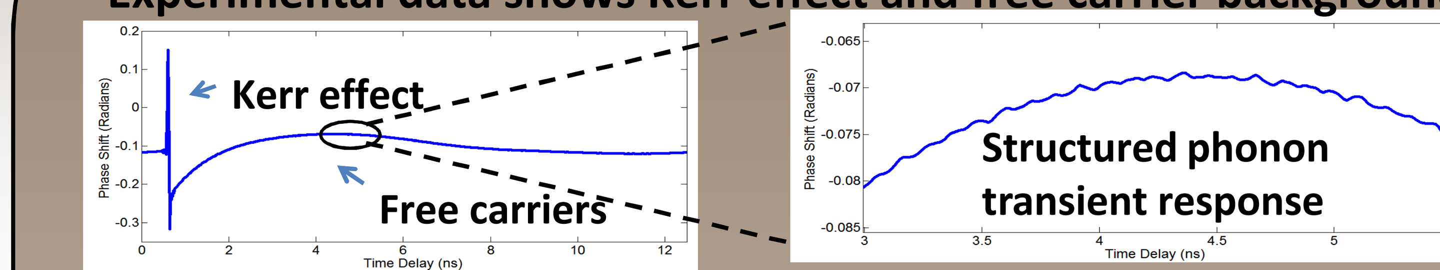
- The pump pulse generates a phonon pulse via optical transduction, which imparts a phase shift on the signal
- Simulated parametric pumping with sidewall reflections



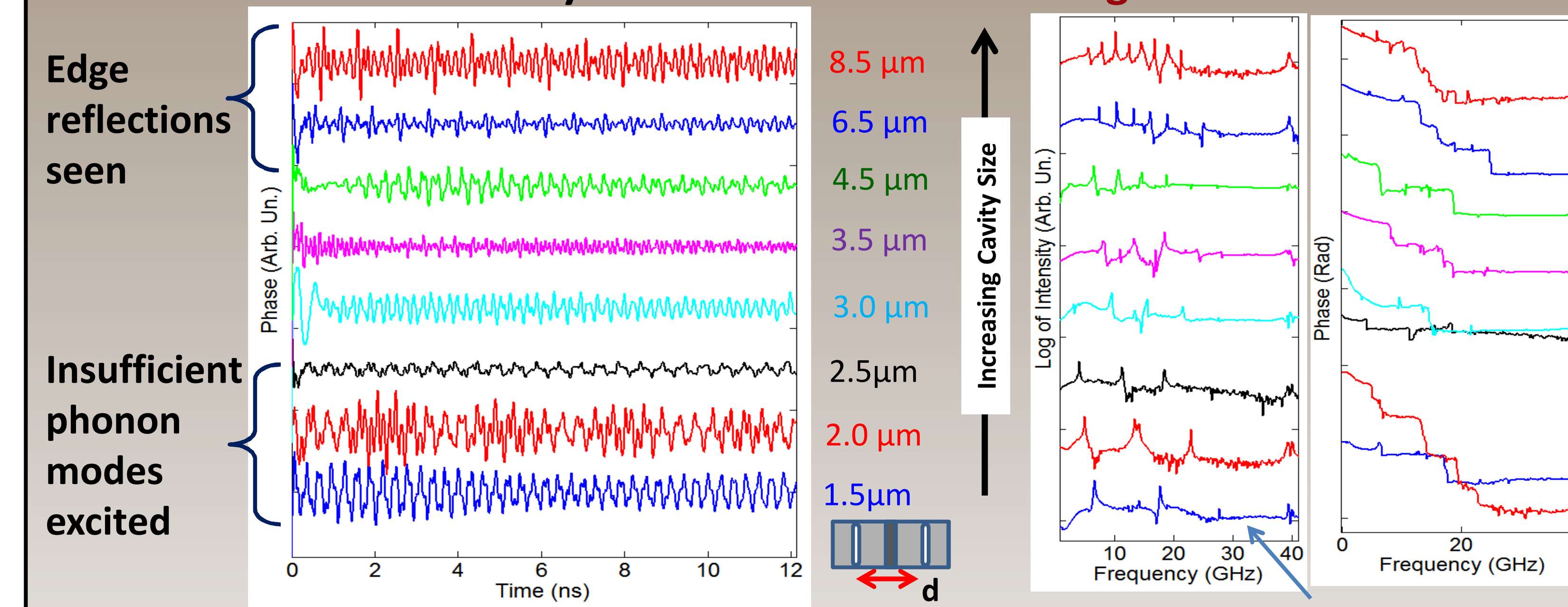
- Large sidewall reflections indicate that optical delay with dual waveguide devices are feasible.

Time Domain Measurements

- Experimental data shows Kerr effect and free carrier background



- Time-domain filtering enables isolation of phonon transient s: reflections are observed for sufficiently wide membranes ➔ Background-free detection!

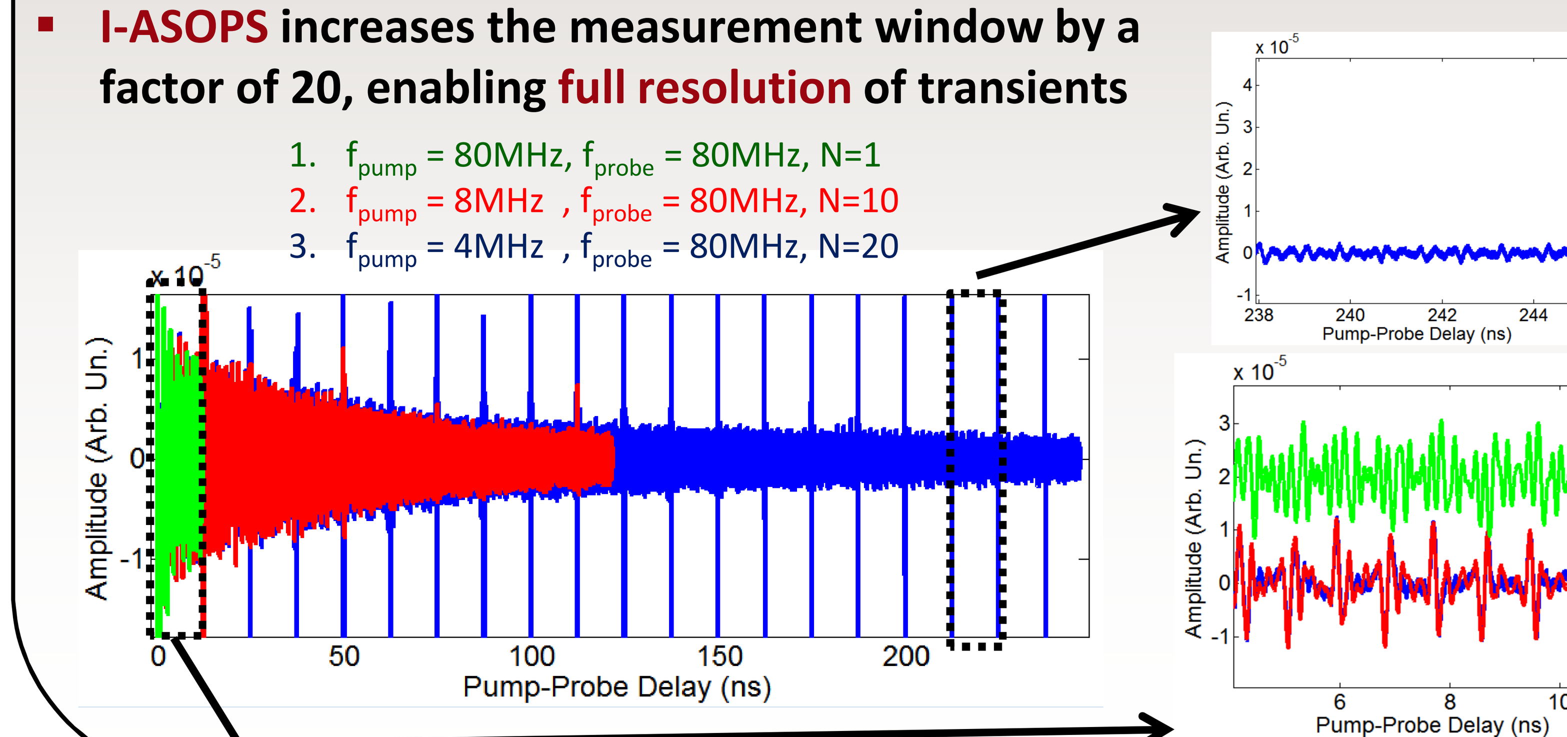


- Frequency domain (magnitude and phase) data shows phonon spectrum.

Frequency limited by picosecond optical pulse duration

- I-ASOPS increases the measurement window by a factor of 20, enabling full resolution of transients

1. f_{pump} = 80MHz, f_{probe} = 80MHz, N=1
2. f_{pump} = 8MHz, f_{probe} = 80MHz, N=10
3. f_{pump} = 4MHz, f_{probe} = 80MHz, N=20



Conclusions

- I-ASOPS enables rapid time domain acquisition over nano- to picosecond durations with picosecond temporal resolution and micro-radian sensitivity.
  - ➢ Background-free characterization for large dynamic range
  - ➢ Combination of long measurement time with high resolution
  - ➢ Direct measurement of optical delay
  - ➢ The system is available to Sandia collaborators for precision pump-probe experiments.

Possible applications include: 1.) Electronic and/or phononic transport in carbon nanotubes or semiconductor devices. 2.) Characterization of photonic devices. 3) Ultrafast pump-probe measurement, etc.

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2. H. Shin, "Tailorable Stimulated Brillouin Scattering in Nanoscale Silicon Waveguides," Nature Communications, Vol 4, No. 1944 (2013)
3. A. Bartels et al., "Ultrafast time-domain spectroscopy based on high-speed asychronous optical sampling," Rev. Sci. Instrum., Vol. 78, pp. 35107 (2007).