Coherent Excitation of Multiple Nano-opto-mechanical Modes in Silicon with Ultrafast Time-domain Spectroscopy

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SF2M.6 (Fri. 11:45 AM – 12:00 PM)

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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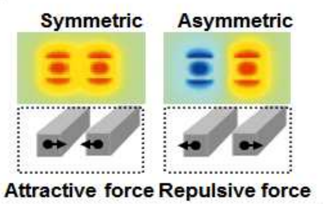
Overview

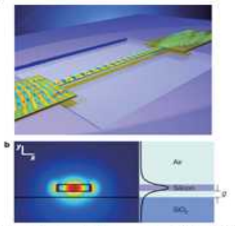
- Motivation: Non-resonate waveguide device concept
- Prior characterization with CW optical beams
- Investigation of pulsed opto-mechanical transduction with Asynchronous Optical Sampling (ASOPS)
- Conclusion

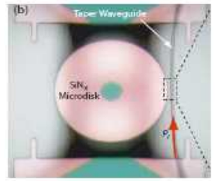
Motivation

- Optomechanics has been studied extensively with cavity-coupled resonant opto-mechanical devices

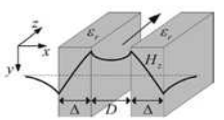


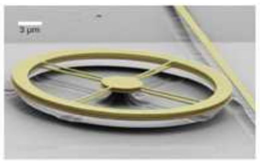
Povinelli, et. al. Opt. Lett. 30,3042 (2005).


Mo Li *et al.* Nature 1, 480–484 (2008).

Optical microdisk

Eichenfield, M. *et al.* Nat. Photon. 1, 416–422 (2007).

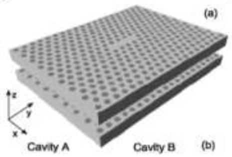
T. Carmon, H. Rokhsari, L. Yang, T. Kippenberg, and K. Vahala, Phys. Rev. Lett. 94, 223902 (2005).


A. Mizrahi & L. Schächter Opt. Lett. 32, (2007), p.692-694


G. S. Wiederhecker, L. Chen *et al* Nature 462 2009, p.633

Dual microring geometry:


Rakich, Popovic *et al.* Nat. Photon. 1, 685-669 (2007).



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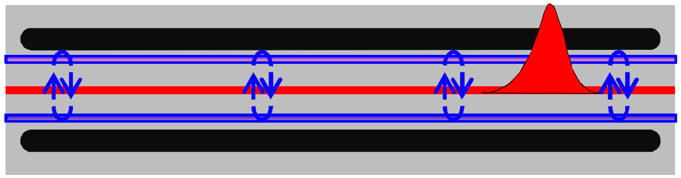
→optical forces & radiation pressure, →quantum ground state cooling,
→ phonon laser,
→ optically induced transparency
→ sensitive motion sensors, etc, . . .

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



→non-resonant for optical mode allows broadband transduction

→Previously experimentally and theoretically studied device with CW laser sources.

→In this work, we us pulsed ps-laser sources to study pulsed opto-mechanical transduction to evaluate potential use in information processing applications with phonon pulses.

Traveling-Wave Phonon-Photon Device Concept

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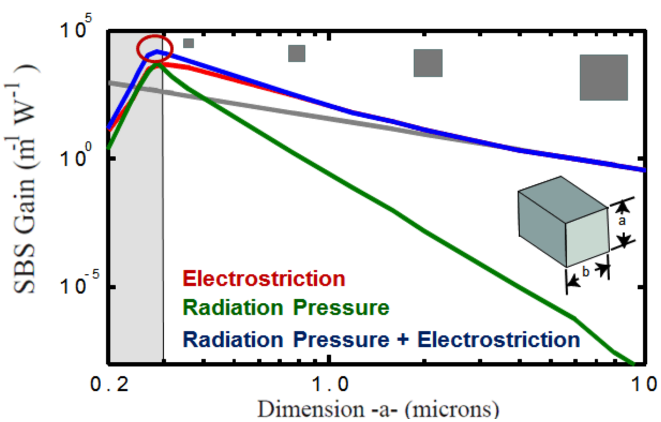
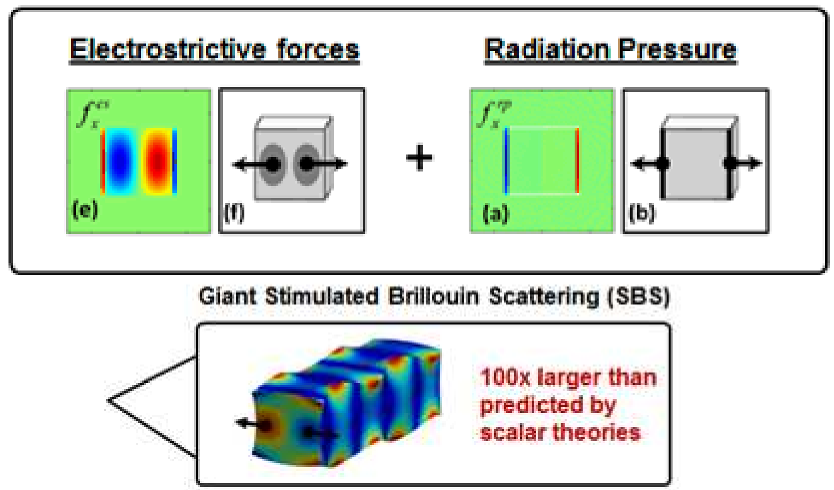
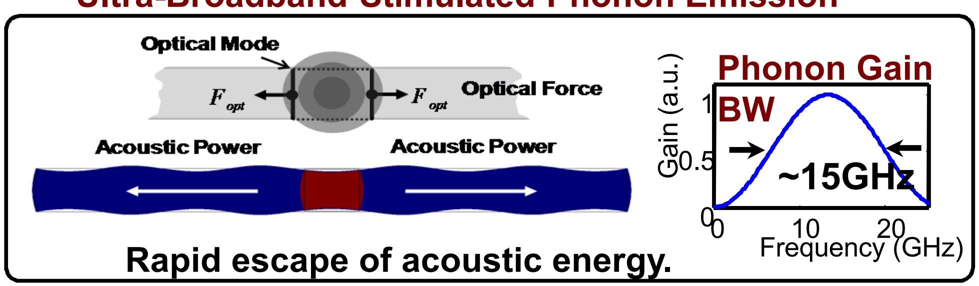
- Practical non-resonant devices require high optomechanical transduction to be viable.
- Previously shown dramatic **enhancement of optomechanical transduction** do to coherent combination of radiation pressure and electrostrication in nanoscale waveguides





- Additionally we have shown **ultra-broadband transduction bandwidth** with transversely oriented phonon modes

Ultra-Broadband Stimulated Phonon Emission



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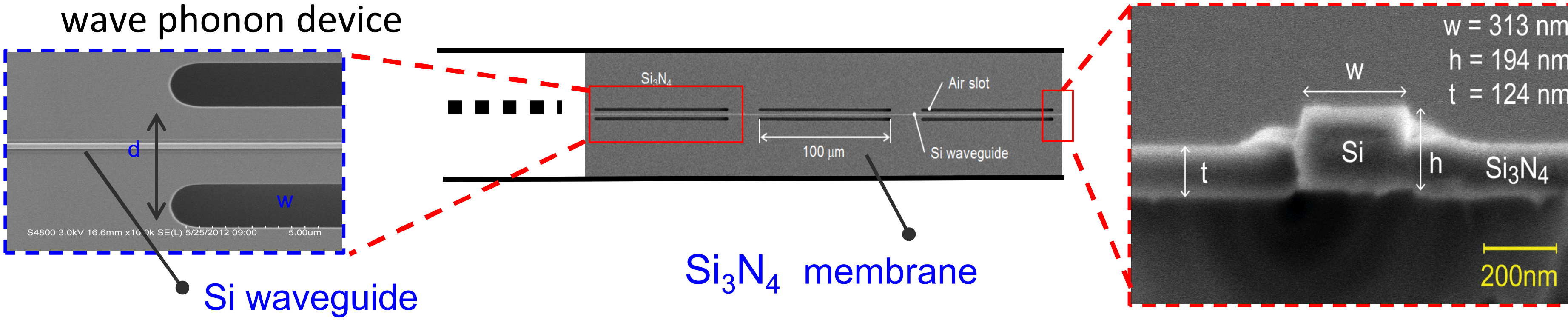
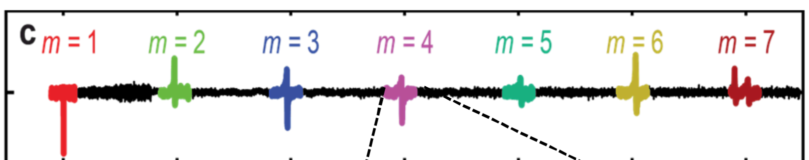
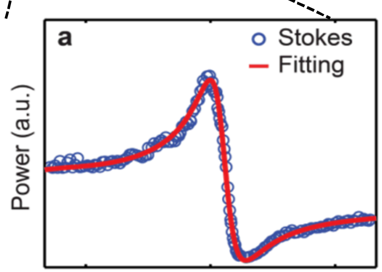
Previous Device Design and Characterization with CW laser sources in frequency domain

- Previously designed and characterized traveling-wave phonon device

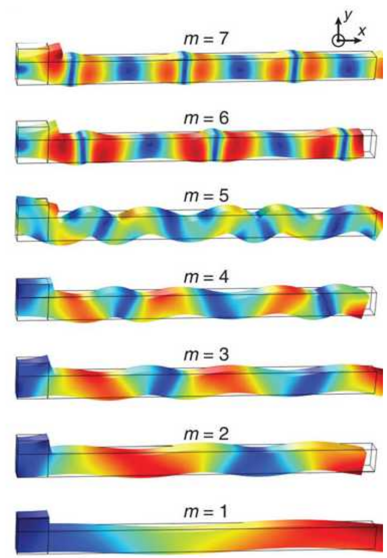


- Optomechanical transduction was characterized with a dual color CW heterodyne setup → mechanical modes linewidths were measured by scanning frequency





Heedeuk. Shin *et al.* "Tailorable stimulated Brillouin scattering in nanoscale silicon waveguides" *Nat. Comm.* 6 June 2013.



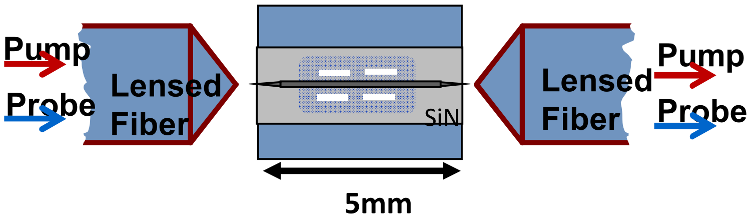
→ Structure supports multiple modes

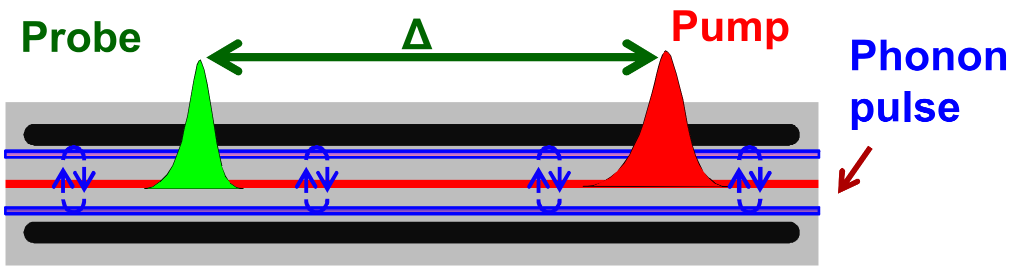
→ Interrogation in frequency domain leads to mixing with intrinsic nonlinearities and limited phase information

→ **Dynamic range limited by Kerr background**

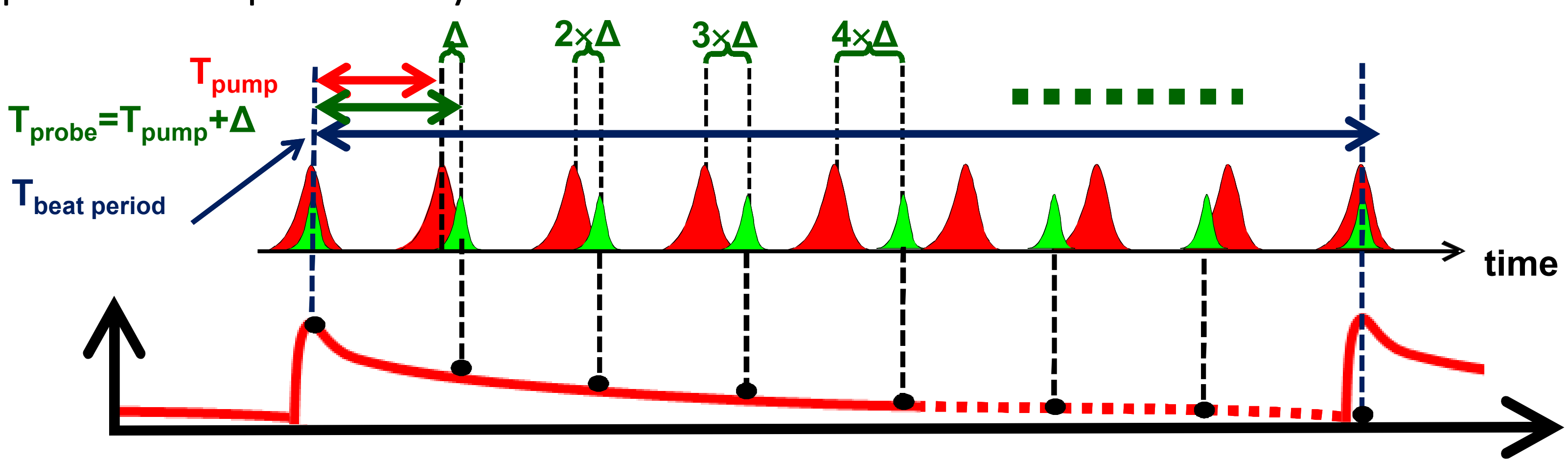
Pulsed Optomechanical Transduction with Asynchronous Optical Sampling (ASOPS)

- Transduction of laser pulses to phonon modes assess the viability of pulsed phonon devices





- In ASOPS, the repetition rate of pulsed pump (f_{pump}) and probe (f_{probe}) lasers are detuned by an offset frequency (f_{offset}) such that the time delay between consecutive pulses is ramped linearly

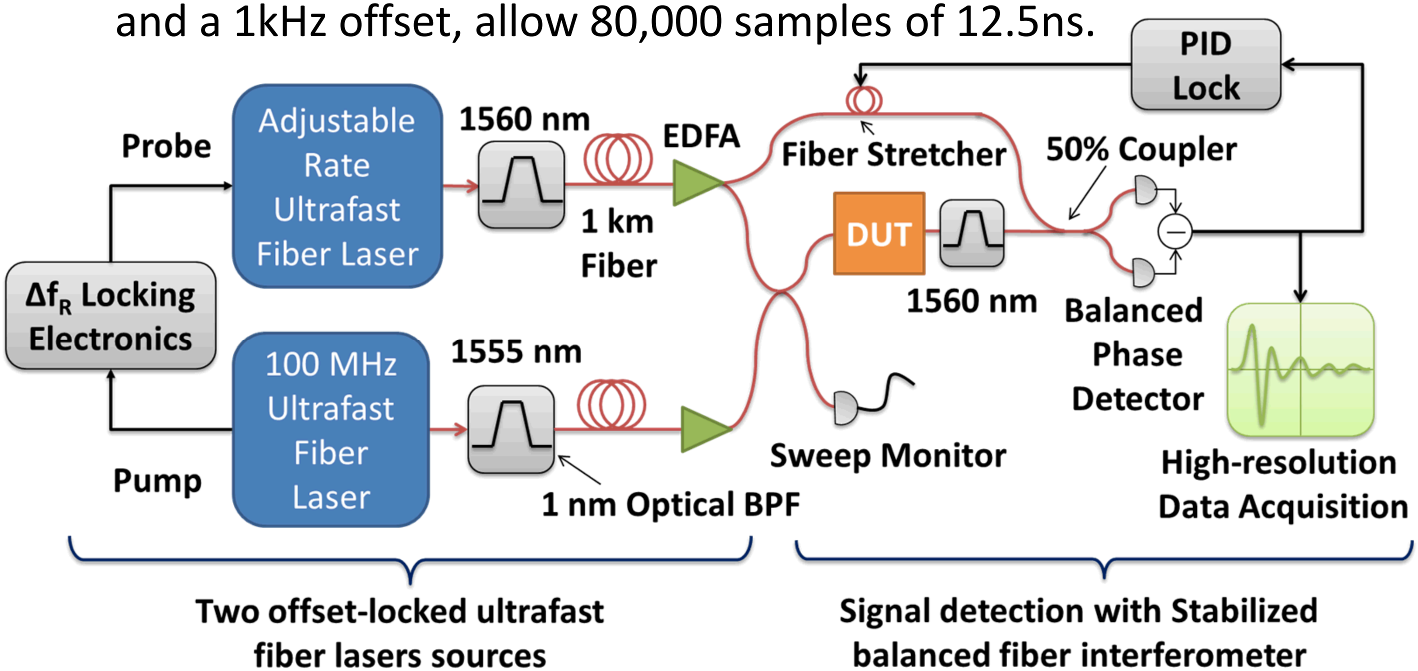


Waveform periodic with T_{beat} and with $N_{sample} = T_{pump}/\Delta$

- 100 MHz laser sources with 10kHz f_{offset} → $f_{optical}$ =1 THz without the need for mechanical delay lines.

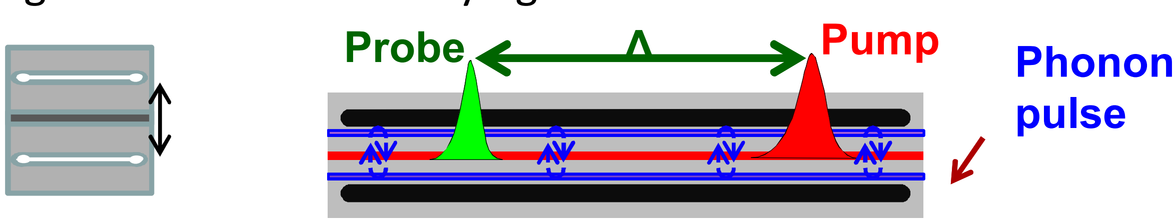
Experimental Setup

- Two ps-fiber laser sources (pump and probe) locked with an 80MHz repetition rate and a 1kHz offset, allow 80,000 samples of 12.5ns.



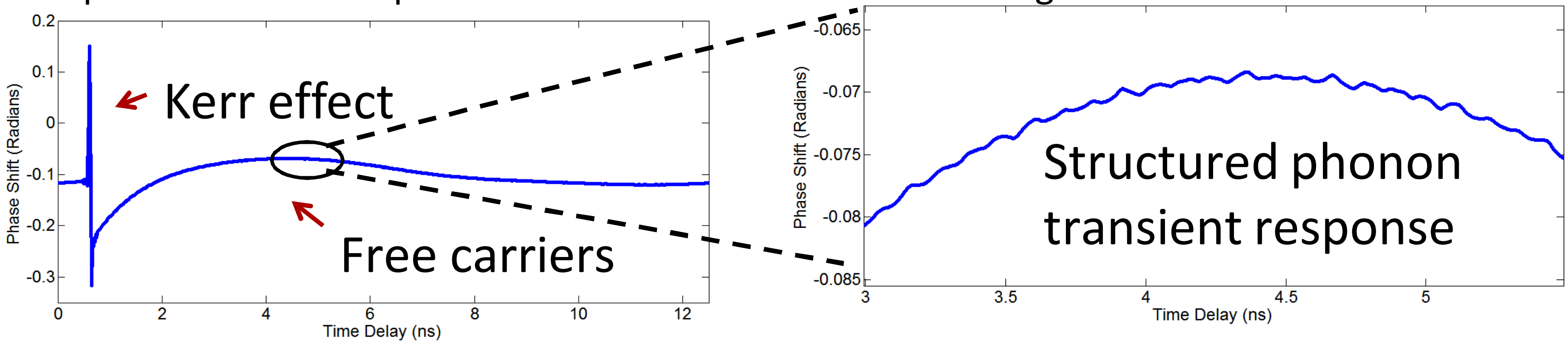
→ Sampling card and laser systems tightly synchronized enabling long-term averaging

- The pump pulse generates a phonon-pulse via optical transduction which imparts a phase shift on the signal pulse that is measured in an interferometer having shot-noise-limited detection of a few μ-rad phase.
- “Slot” waveguide devices with varying widths were measured

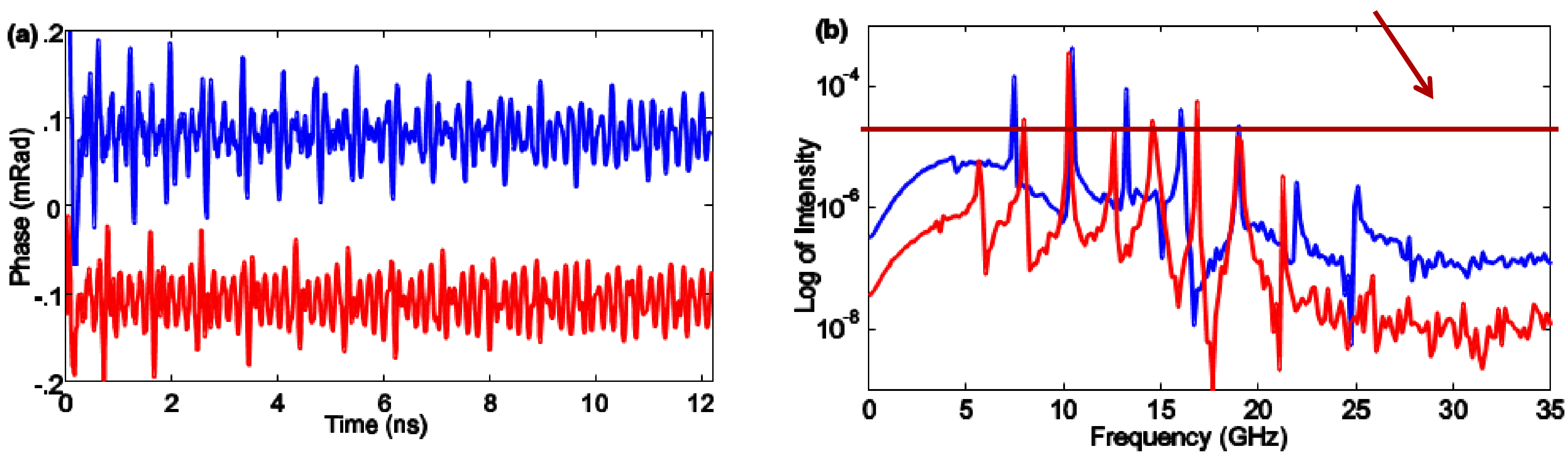


Time-domain signals allow separation of nonlinearities

- Experimental data captures Kerr effect and free carrier background



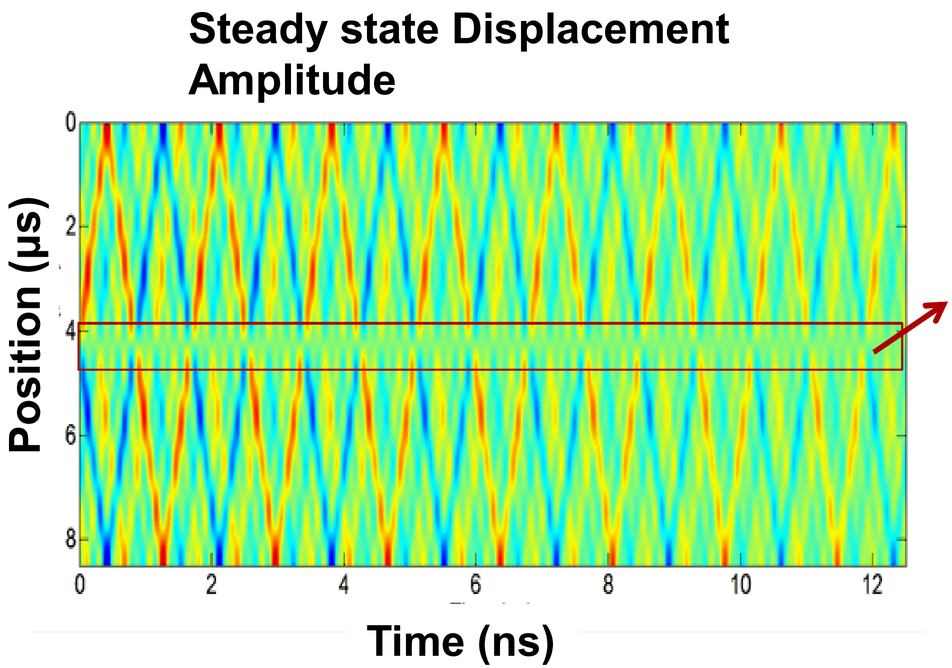
- Convergence after 100,000 averages
- In prior work, Kerr and free carrier response dramtically limited dynamic range

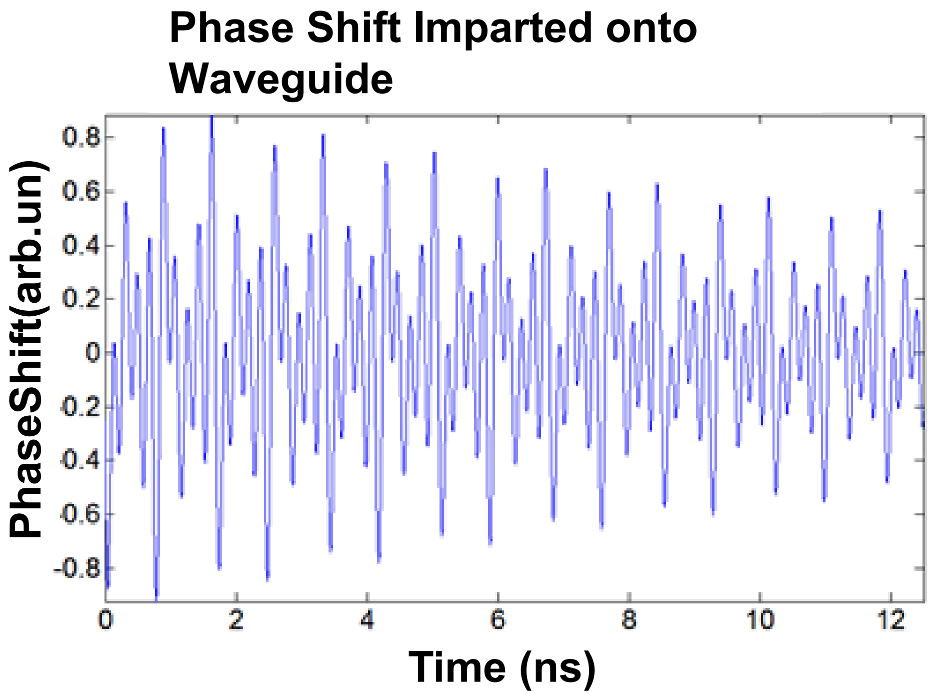


- Here we can use signal processing to separate fast phonon oscillation from slow transients and the instantaneous Kerr effect

Simulation of System

- Simulated parametric pumping with side-wall reflections

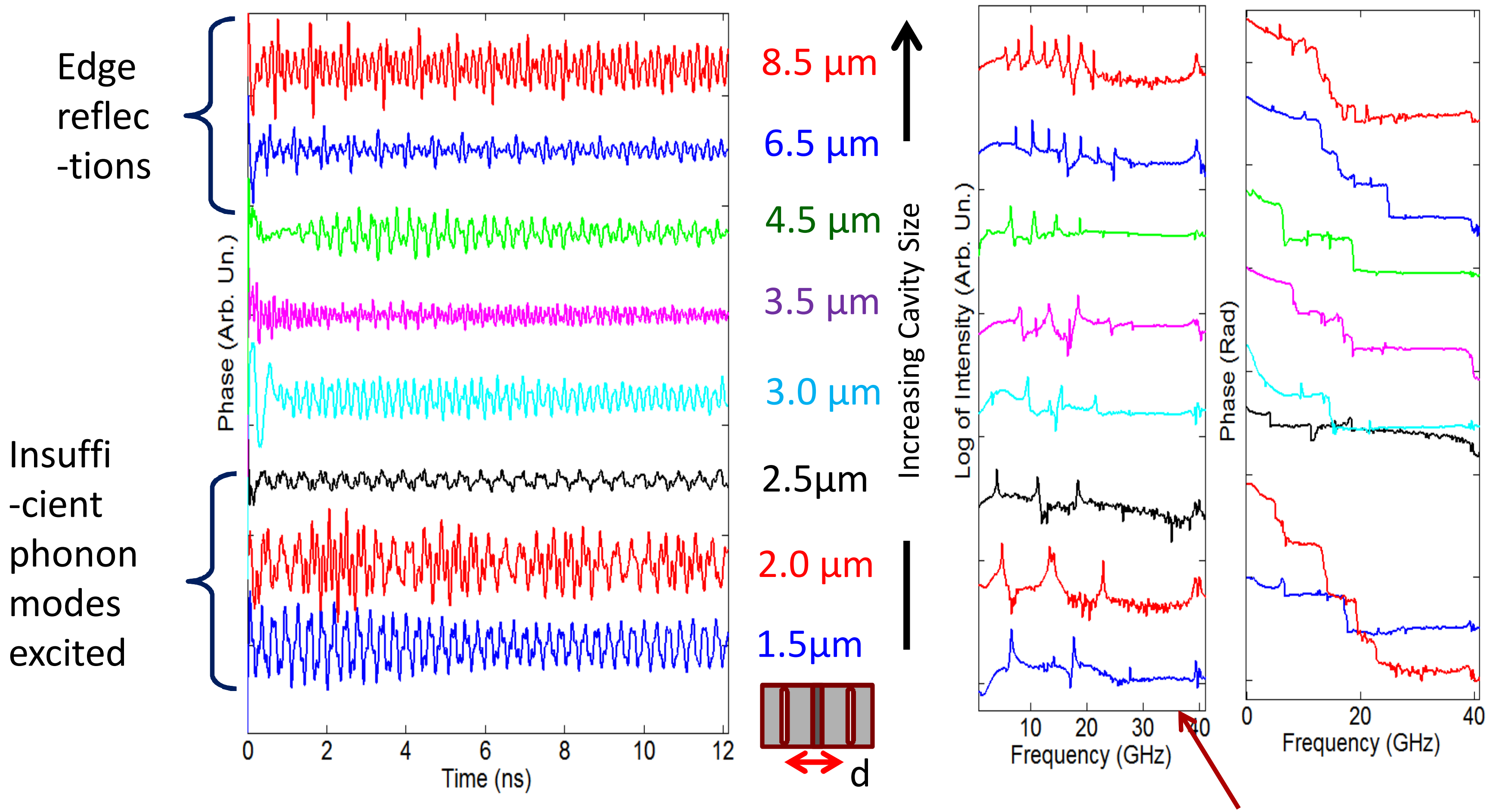




- Parametric pumping do to limited measurement window
- Large side-wall reflections indicate that optical delay with dual waveguide devices are feasible.

Measurement of impulsive phonon response vs device width

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



Frequency limitation from ps optical pulse duration

Summary and Conclusion

- Developed an ASOPS system enabling rapid time domain acquisition over long durations (ns-µs) with high (ps) temporal resolution and µ-radian sensitivity.
- Measured pulsed optical-phonon transduction in a traveling wave devices, and have ample sensitivity to measured the influence of phonon reflection from sidewalls.
- The number of modes excited and the degree of broadening due to phonon dispersion is sufficient for wide devices to allow for pulsed transduction.