Parallel detection in picosecond ultrasonics with both commercial and custom array detection

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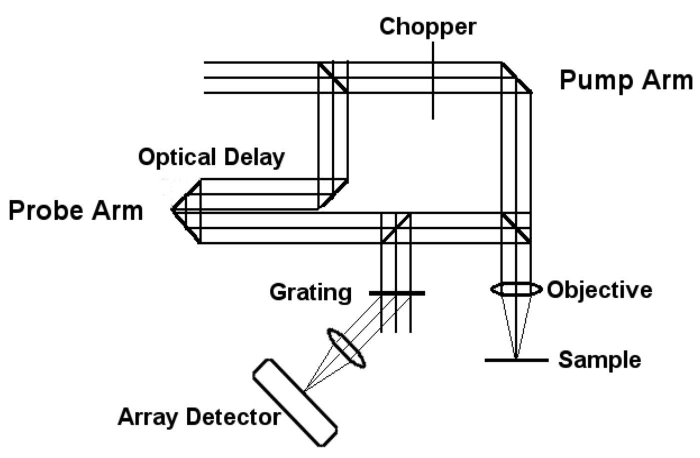
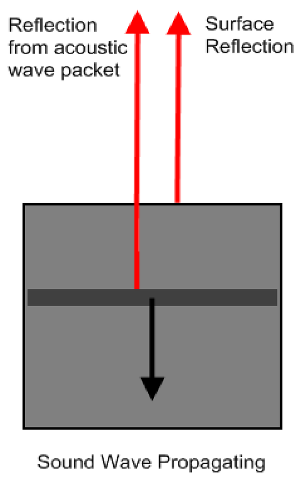
Introduction



Picosecond ultrasonics is a well established technique for material studies. These experiments are usually based on the pump probe technique, where one beam generates the acoustic wave and another delayed beam interacts with the acoustic wave packet in the sample.

•The relative time between the pump and probe pulses are controlled by an optical delay line. The high frequency signals are mixed down to an intermediate frequency by the use of a modulator (mechanical chopper or acousto-optical modulator).
•Typically a photodiode and lock-in amplifier are used as the detector.
•These are very sensitive and produce excellent measurements.
•However, overall picosecond ultrasonic measurements tend to be somewhat slow, making imaging applications impractical.
•We aim to address this issue by measuring many channels of data at once.



Samples: Gallium Arsenide (111)

•Produces large signals.

•Can generate Brillouin Oscillations at our wavelength of 800nm due to GaAs being semi-transparent.

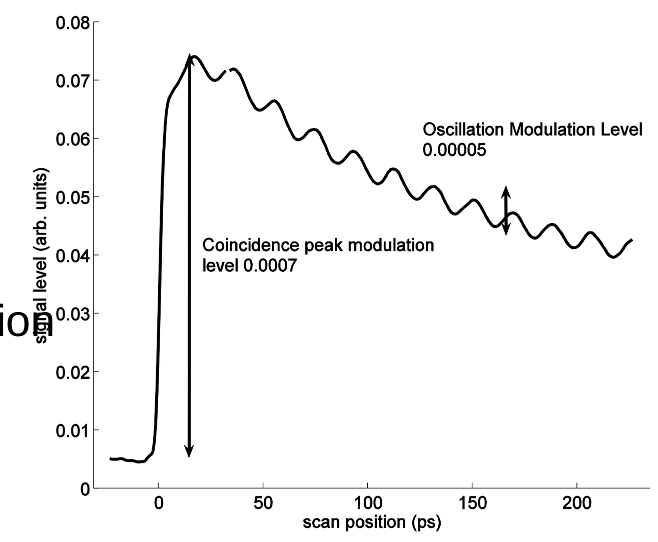
•Oscillations due to interference between reflections from the surface and reflection from acoustic wave packet.

A typical signal from a single channel experiment is shown. There are three distinct features

1. A large step change in the signal at t=0 (co-incidence peak)

2. A slow decay term due to the thermal relaxation of the sample

3. A decaying oscillation which is the signal of interest



Moving To Parallel Detection

•We need another method to demodulate signal as multiple lock-ins are impractical.

•The detectors need to capture many photons to reach the required SNR.

•The chosen Method must work well with squarewave modulation.

•We would like to recover both the amplitude and the phase of the signal.

Our Approach

•Use integrating camera with large well capacity to capture many photons.
•Phase stepping algorithm (equations shown) can be used to obtain the amplitude and phase of the signal and if carefully chosen will work well with square wave modulation.

α= angle
$\Delta\alpha$ = change in α between steps
S1 = real part of signal
S2 = imaginary part of signal
N = number of steps
m=current step
I = measured intensity

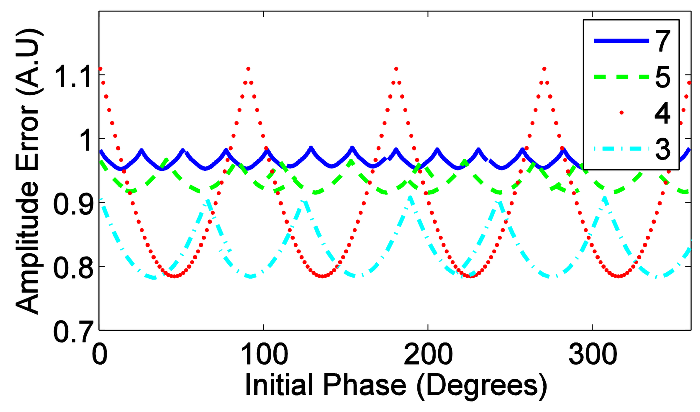
$$\Delta\alpha = \frac{2\pi}{N}$$

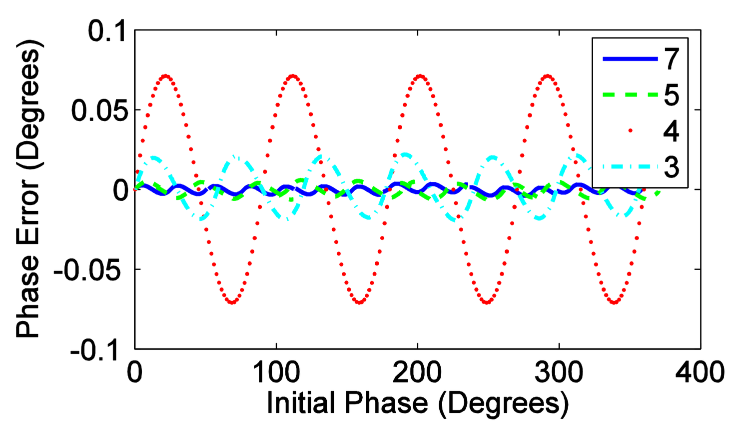
$$S_1 = \sum_{m=0}^{N-1} I_m \cos\alpha_m$$

$$S_2 = \sum_{m=0}^{N-1} I_m \sin\alpha_m$$

$$Amplitude = \sqrt{S_1^2 + S_2^2}$$

$$Phase = \tan^{-1}\left(\frac{S_2}{S_1}\right)$$





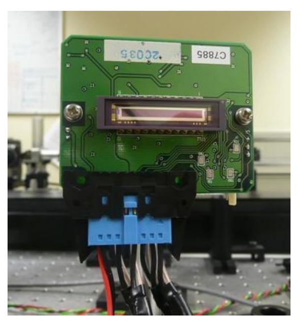
Phase Stepping

•Typically 3 or 4 samples (or integration regions) per modulation cycle are required for error free reconstruction of the amplitude and phase of the signal - assuming sinusoidal modulation.

•With squarewave modulation, amplitude/phase cross talk is introduced due to the additional harmonics present.

•Increasing and using an odd number of steps reduces the impact of the amplitude phase cross talk so that an acceptable error level can be chosen.

Commercial Detector



The Hamamatsu S3924-512Q,F linear array detector was used for our experiments. The detector has the following specifications:
- •The detector has 512 pixels (2500x50um).
- •The detector can capture 3.125x10^8 electrons before saturating.
- •The pixel read rate is 500kHz leading to a frame rate of ~969Hz.
- •The detector employs a rolling shutter so that data can be read in serial.

The rolling shutter introduces a phase shifted between the pixels and so we are using a 7 step phase stepping algorithm to reduce the effect of amplitude/phase cross talk.

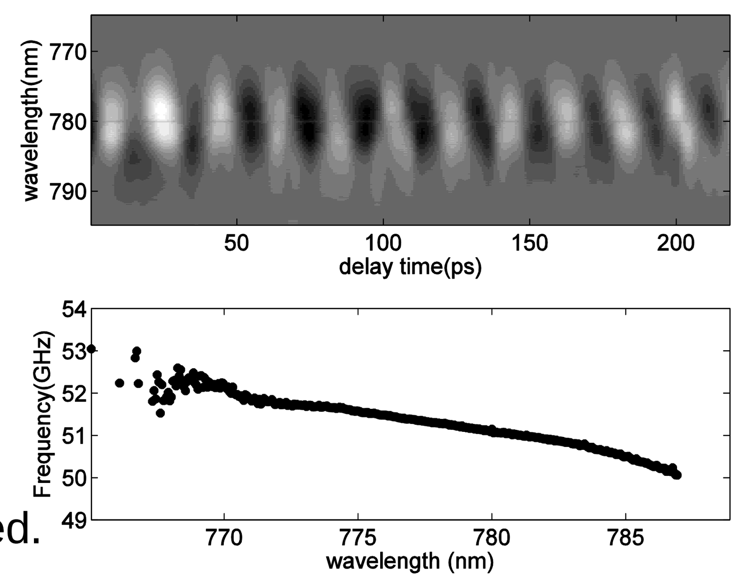
We use a custom made clock generation board. This provides all of the clocks to the main detector driver board and also a clock for synchronising the mechanical chopper.

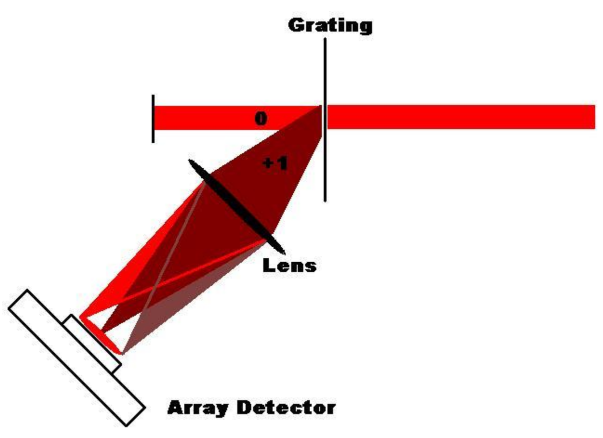
The sample signal is passed though a custom made sample and hold circuit that reduces the requirements on the ADC employed by extending the time the sample voltage is held from 1/6 of the pixel period to almost the full period.

Experimental Results

Each pixel measures the signal for a different probe wavelength.

This produces an oscillation frequency corresponding to an interaction with a different acoustic frequency.





•400 averages used.

•400 data points taken per scan.

•Experiment time ~ 22 minutes.

•~10 times faster than obtaining the same data with a single channel setup.

The oscillations recorded across the array after the thermal background was been removed are shown above. The corresponding acoustic frequency is shown in the bottom of the figure. The edges are noisier as there is less light falling on these pixels.

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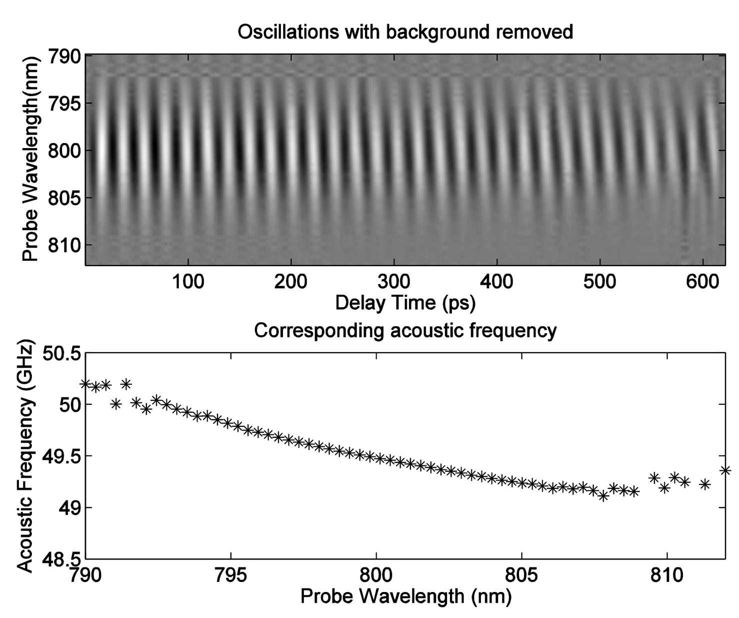
Custom Detector

We have fabricated a detector chip in an attempt to improve on the Hamamatsu detector. The detector has the following characteristics:
- •The detector has 64x1 pixels, each pixel is 460x22um.
- •The detector uses a global shutter.
- •The pixels are randomly addressable.
- •The pixel read rate is 10MHz giving a theoretical maximum chopping frequency of ~40kHz.
- •The well depth has been increased (approx. 0.88x10^9 photons before saturating).

The pixels are built on the active pixel principle. The photodiode and one of four independently connected capacitors are charged up during the reset phase.
During the integration phase the photocurrent from the incident light discharges the capacitor.
The value after integration is held during the idle phase and then the data is read out.
Each of the 4 switchable capacitors follows this routine but is out of step by one phase.
This allows continuous readout of the detector and maximum use of the available light

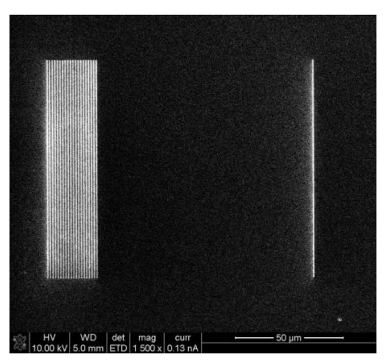


•The oscillations are very clear and the frequencies obtained are as expected from theory.
•The edges are noisier as there is less light falling on these pixels.
•For this experiment 50 averages were used, the data took 7 minutes to acquire.
•The detector is x2 faster than the commercial device.
•The inclusion of a multiplexer will increase the speed of the device by an additional factor of 4.
•To increase speed still further will require a faster ADC card.

Future Work

Use detectors for measuring high frequency surface waves generated by patterned light from a spatial light modulator.

Use detectors for measuring very high frequency surface waves where the acoustic wavelength is smaller than the optical wavelength.



Acknowledgements

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EPSRC