Development of a custom CMOS modulated light camera and its application to picosecond ultrasonics

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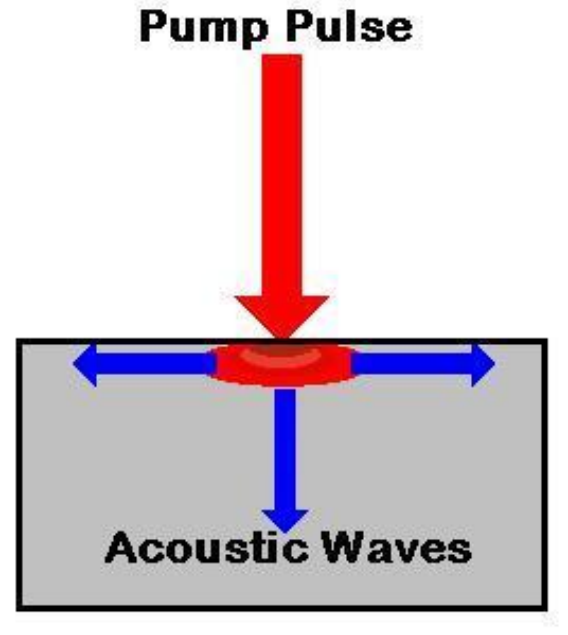
Talk Outline

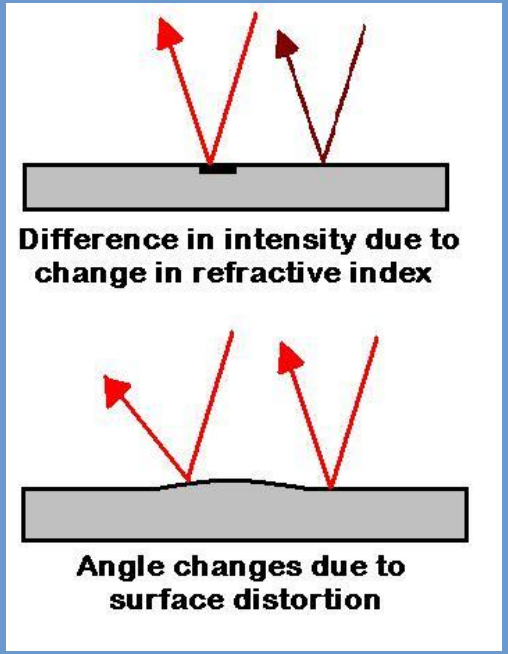
- Introduction
- Custom detector
- Coating thickness
- 2D thickness maps
- Future work
- Conclusions

Introduction – Laser generation and detection of ultrasound

- Laser pulse absorbed
- Rapid local heating
- Heating causes expansion
- Expansion generates sound wave

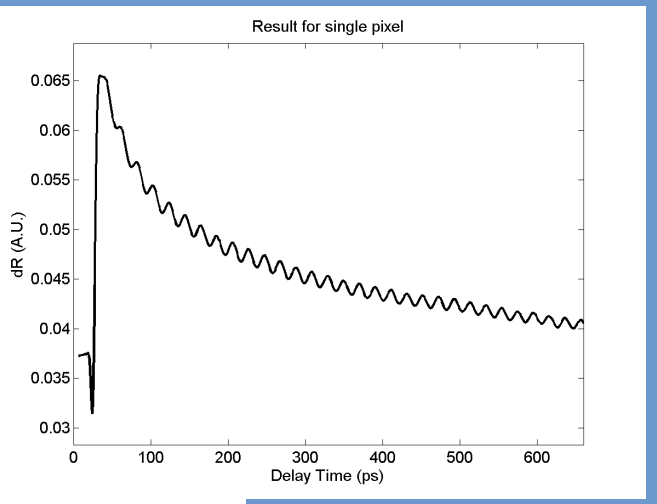


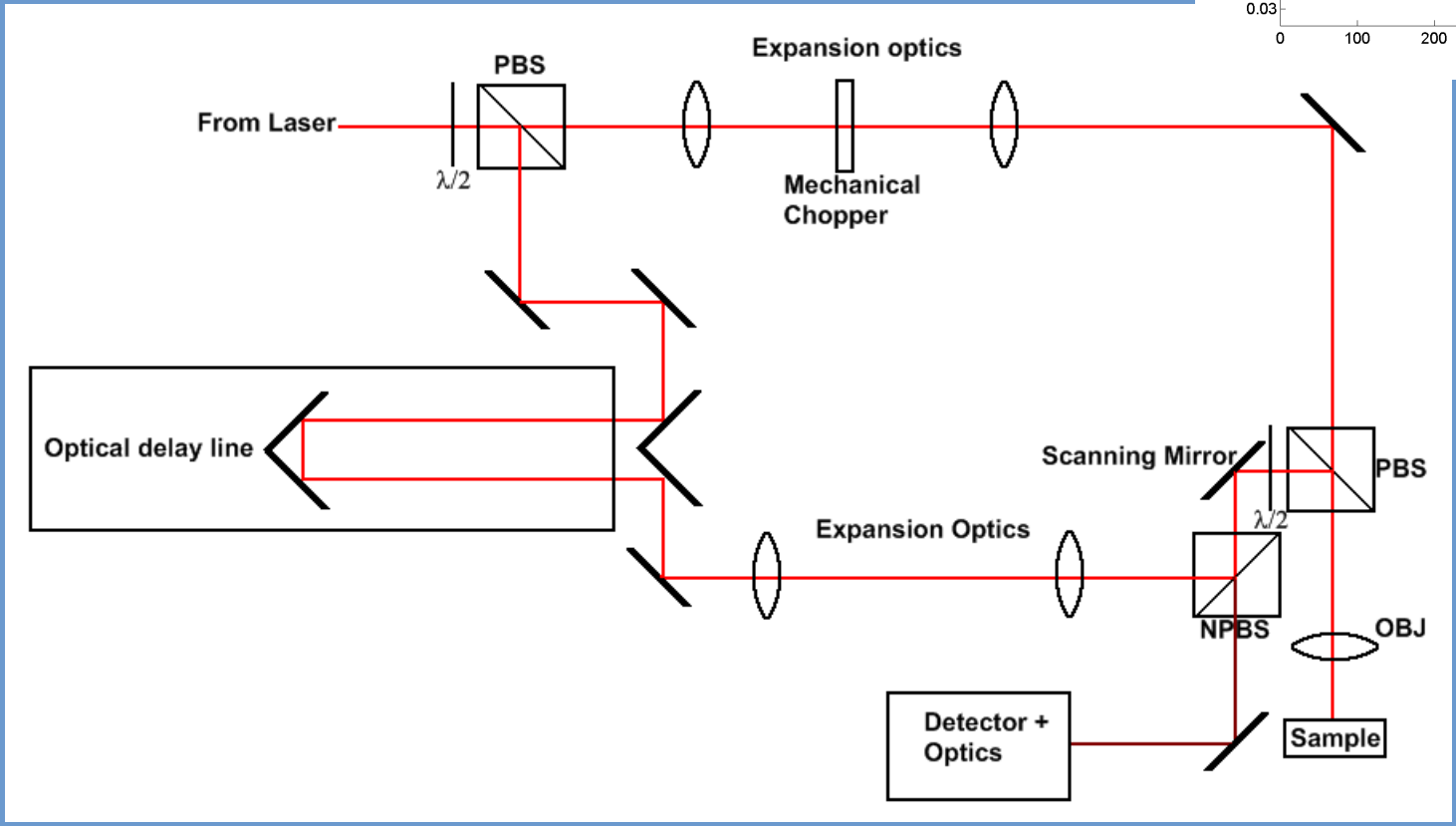
- Different mechanisms for detection
- Reflectivity
- Surface changes
- Very large background with small signal of interest



Experiment Setup

- Typical pump/probe setup
- Time delay between pump and probe imposed by mechanical scan of delay line mirror
- Pump beam modulated by mechanical chopper
- Pump and probe beams separated by polarisation optics
- Detection usually consists of photodiode and lock in amplifier





Multiple channel detection

- Multiple lock-ins become impractical – use phase stepping to demodulate signal
- Capture enough photons to achieve required SNR – use integrating detectors with large well depth
- Be aware of amplitude phase cross talk issues when using squarewave modulation

$$Phase = \tan^{-1}\left(\frac{S_2}{S_1}\right) \qquad Amplitude = \sqrt{S_1^{\,2} + S_2^{\,2}}$$

α= angle

Δα = change in α between steps

S1 = real part of signal

S2 = imaginary part of signal

N = number of steps

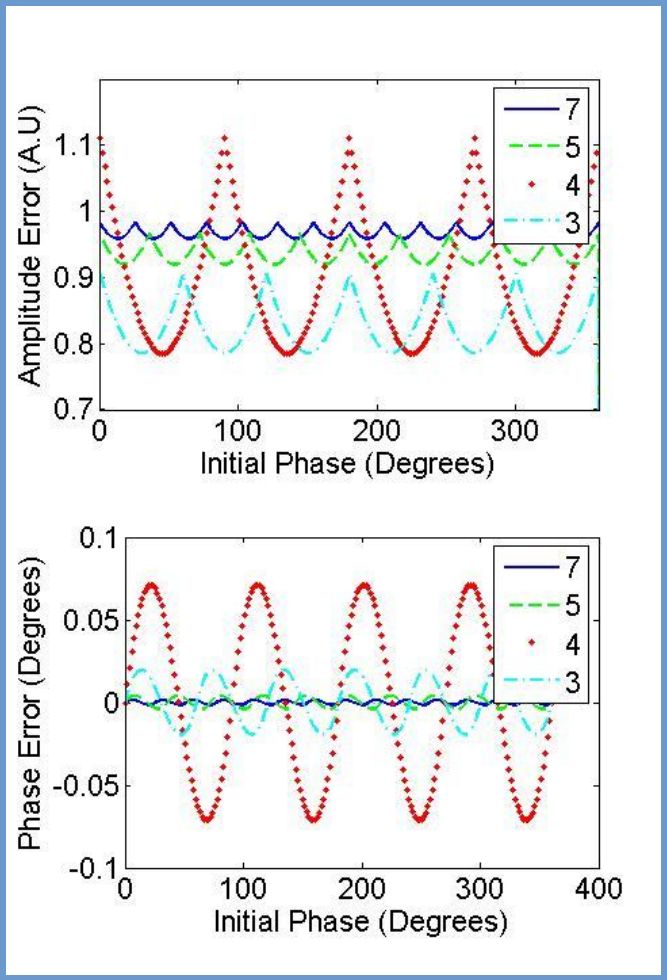
m=current step

I = measured intensity

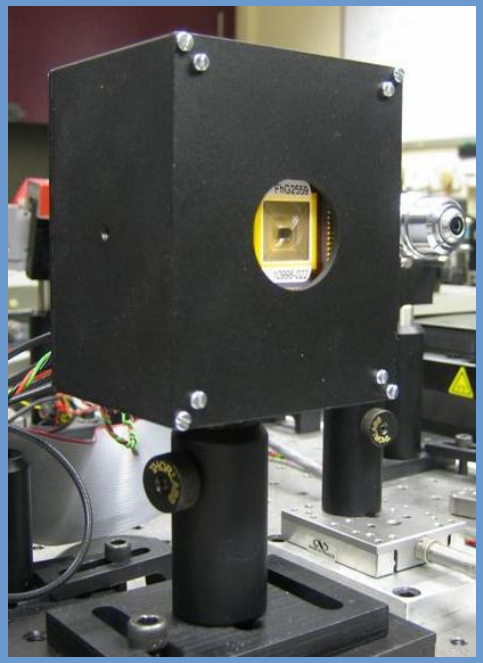
$$\Delta\alpha = \frac{2\pi}{N}$$

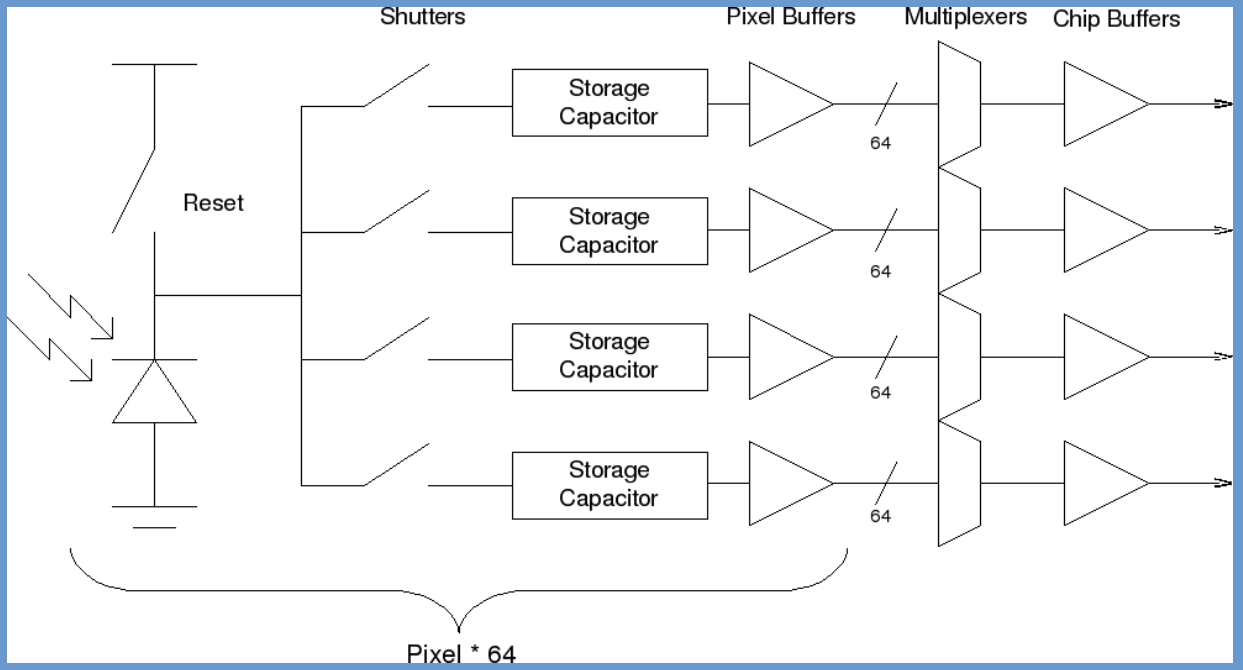
$$S_1 = \sum_{m=0}^{N-1} I_m \cos\alpha_m$$

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



Custom CMOS detector

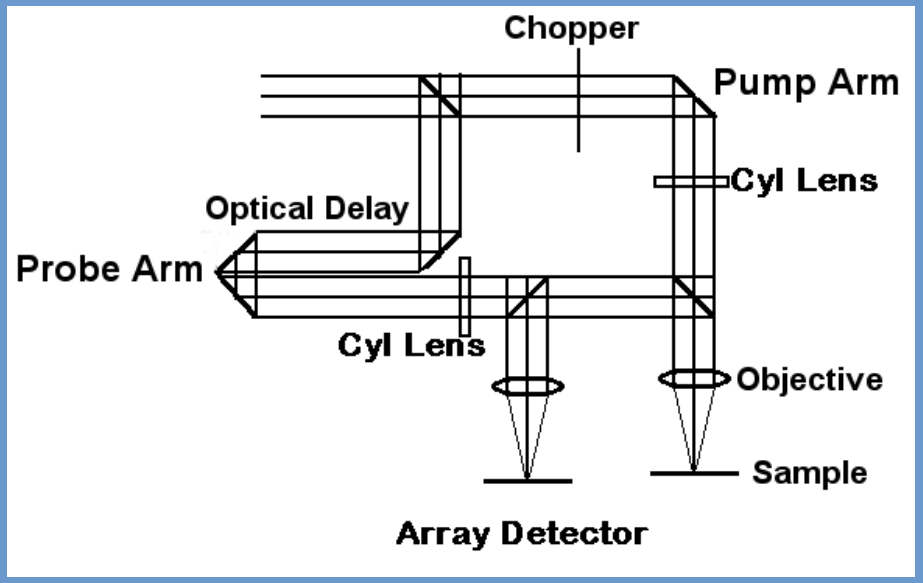


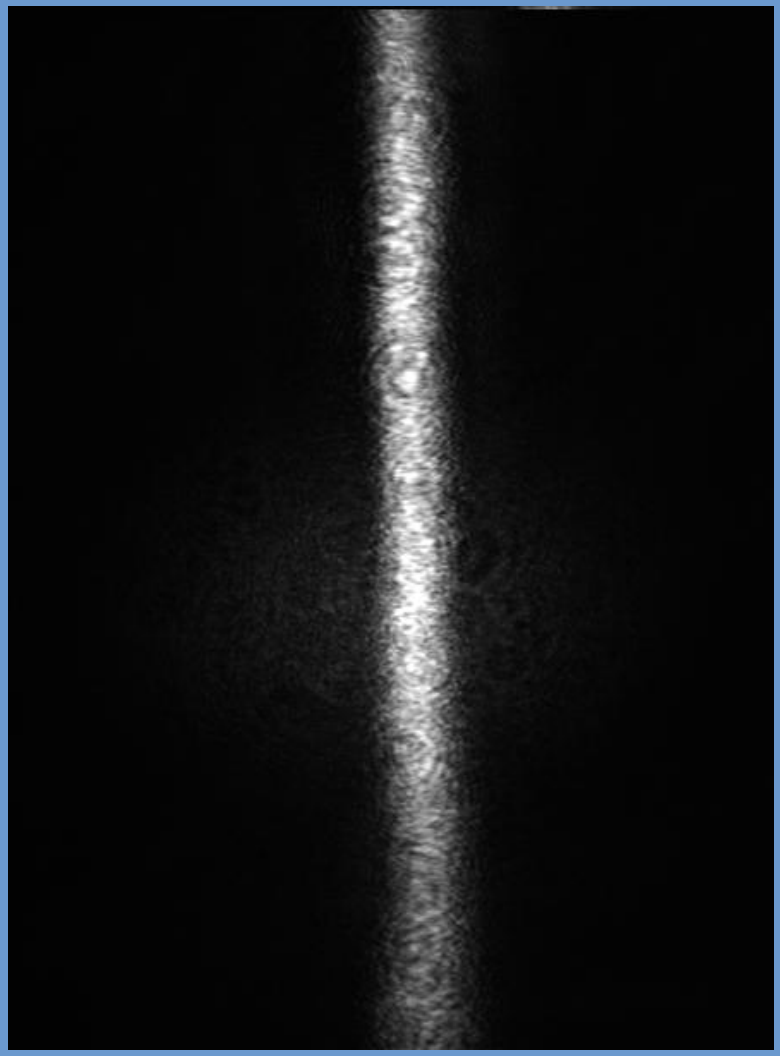


- 64x1 linear array detector
- Pixels built on active sensor principle with 4 large independently switchable capacitors to increase well depth
- 4 phase mode of operation : reset, integration, idle and readout
- Global shutter removes the phase shift between pixels caused by the rolling shutter in commercial detector
- Pixels are randomly addressable
- Faster readout (frame rate of 160KHz /10MHz pixel rate)

Spatial information

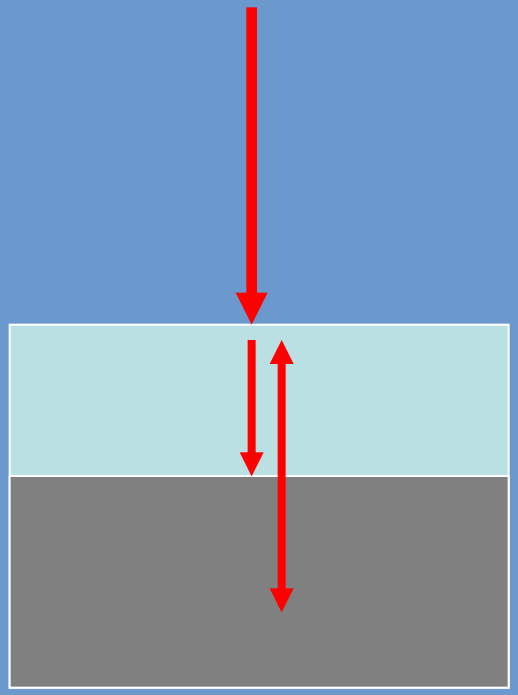
- Cylindrical lenses added to produce line focus for both pump and probe beams
- Each pixel now corresponds to a different spatial location on the surface of the sample
- Increase the overall optical power used in the system as the light is spread out over an extended region

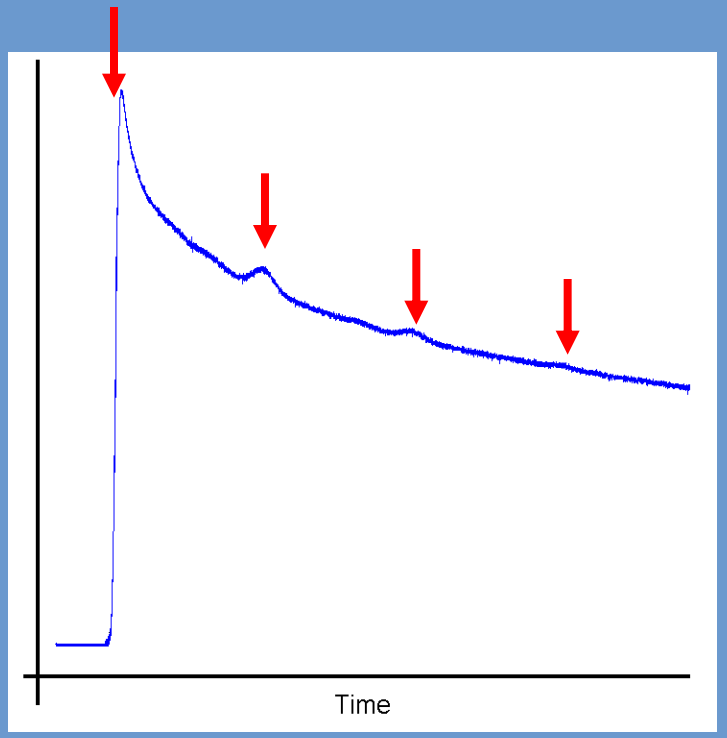




Layer Thickness

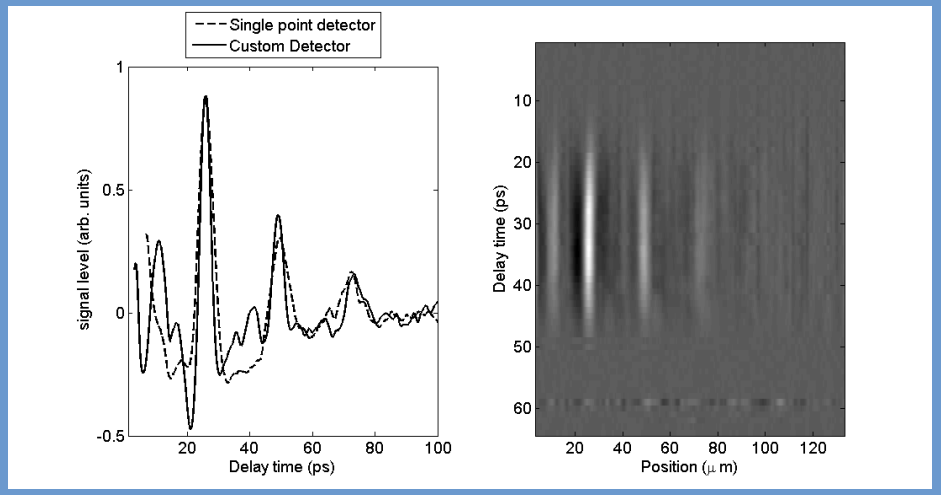
- Pump light is absorbed by the top layer
- Acoustic pulse travels through the layer and is partially reflected by interface
- When pulse arrives back at top surface it changes the amount of probe light reflected back to the detector

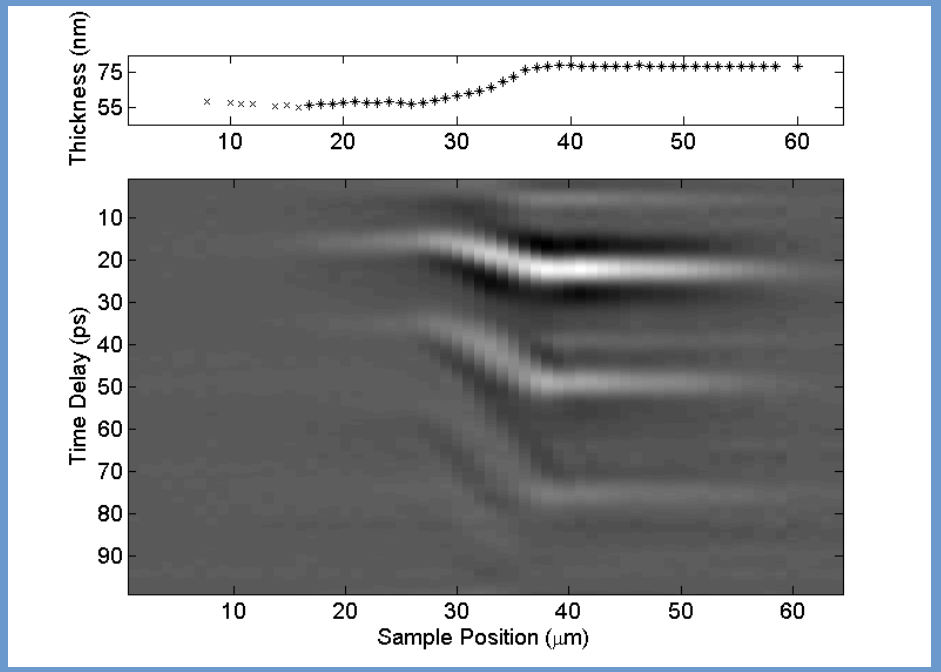




Layer Thickness

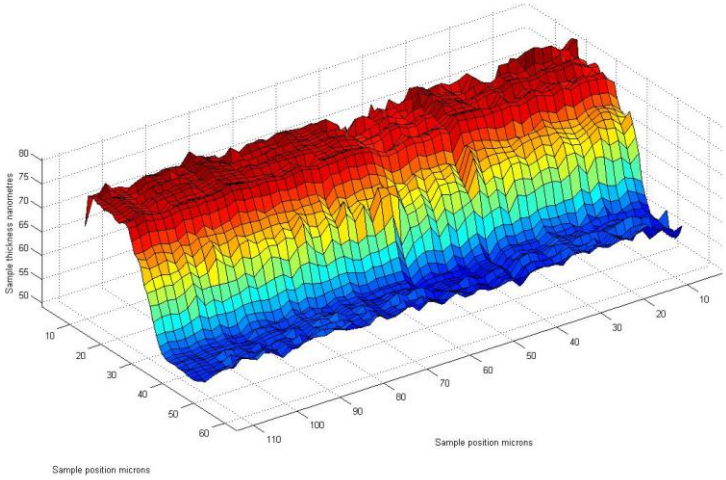
- Chromium on silicon sample
- First 3 echoes are visible
- ~30 times faster than single point detector in this case (112 seconds for array data)
- Signals at extremities are smaller due to reduced light intensities
- Sample has two regions of different thickness
- Echoes from the different regions and the transition between them clearly visible
- Echo locations can be converted into thicknesses if the velocity is known

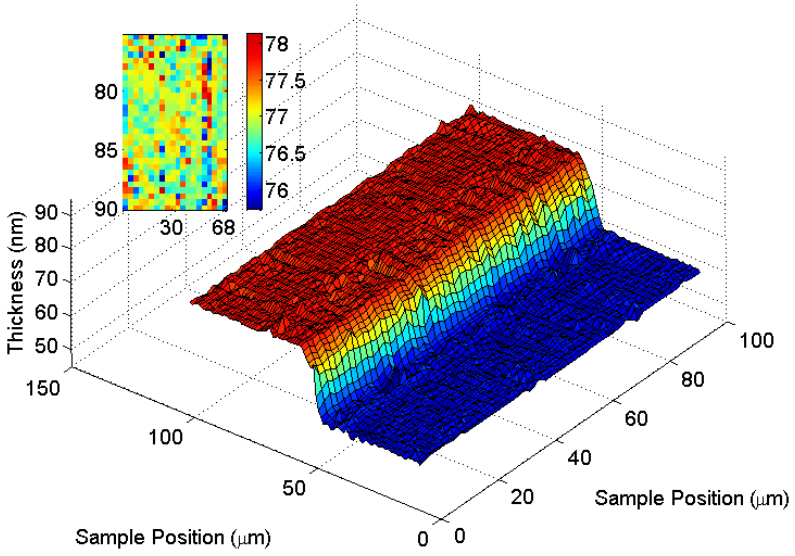




2D Thickness maps

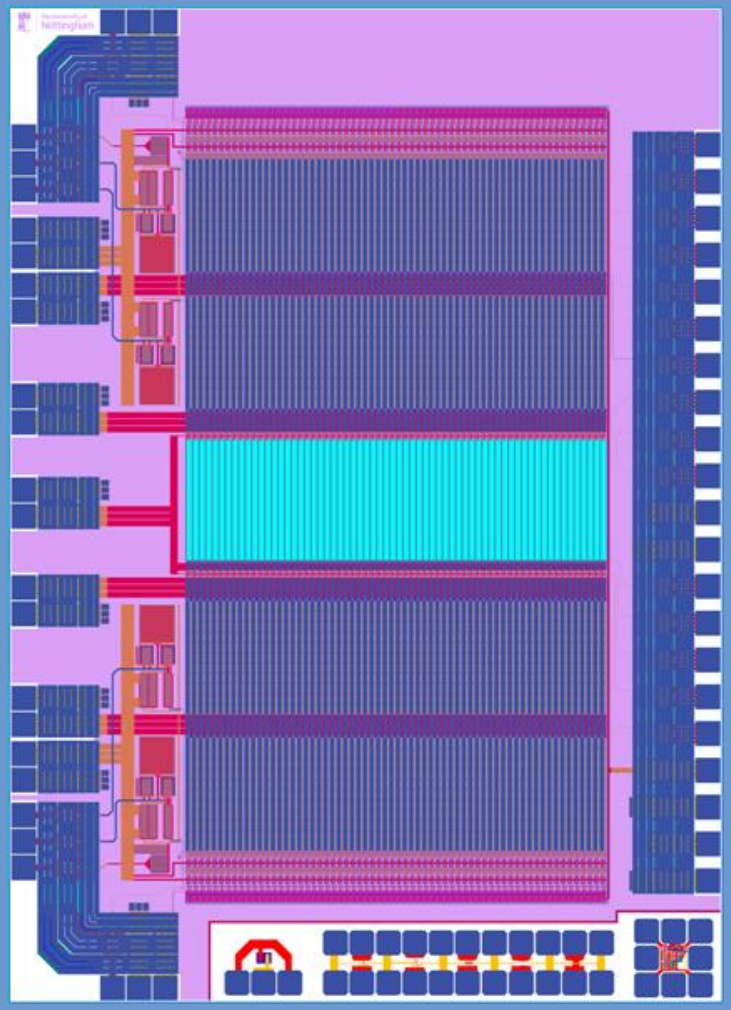
- Using the first echo location we can use fewer averages
- This allows the possibility of mapping a large area of the sample in a practical amount of time.
- Top figure took a couple of hours and shows a region of the sample where the thicker layer has a region of damage (probably a surface scratch)
- The bottom figure shows a composite image mapping regions either side and across the transition
- The results on the flat region are still good even with the reduced averaging– the standard deviation of the thickness in the inset is ~0.25nm
- This image took ~2.45hrs to acquire





Future Work

- The current limit to speed of this system is the ADC and delay stage we employ.
- An additional speed increase of at least ~ 5x is possible if these are replaced.
- Improve base SNR by looking into laser noise cancellation
- Frequency double one beam to allow more complex detection schemes and completely remove pump laser noise.



Conclusions

- Our detector is ~ 30 times faster than our single point detector system
- We can now perform measurements such as thickness maps on thin coatings over a large area of sample
- Additional speed increases of ~5 times should be easy to achieve

- Any Questions?

Acknowledgements:

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