Imaging in picosecond laser ultrasonics with a custom parallel detector

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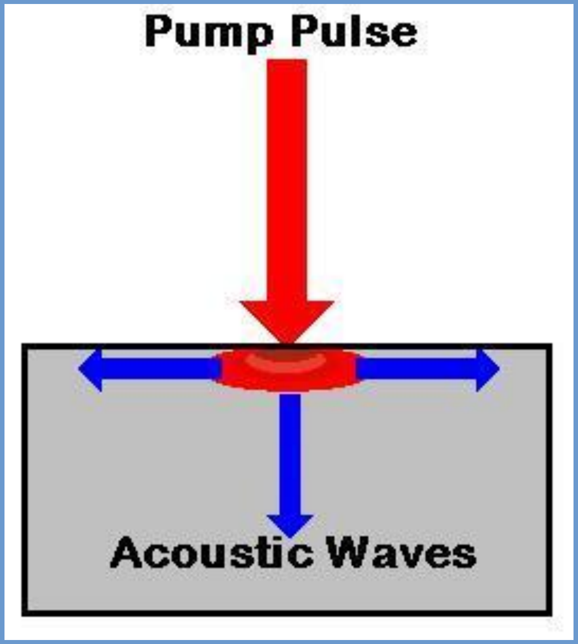
Talk Outline

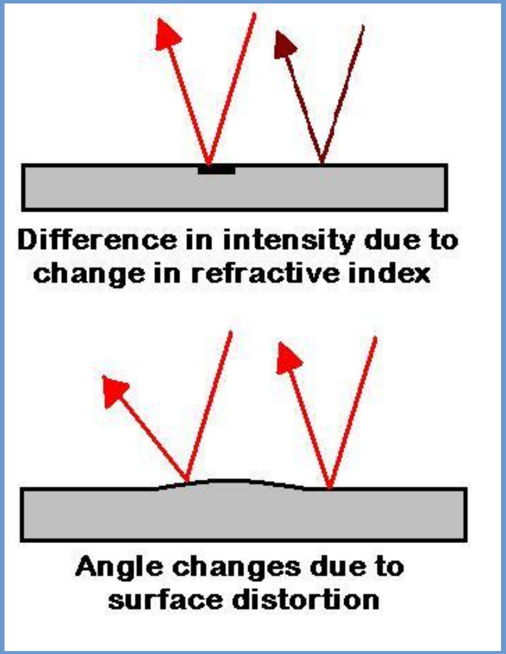
- Introduction
- Typical experiment setup
- Moving to parallel detection
- Custom detector
- Experimental results
- Conclusions

Introduction – Laser generation and detection of ultrasound

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

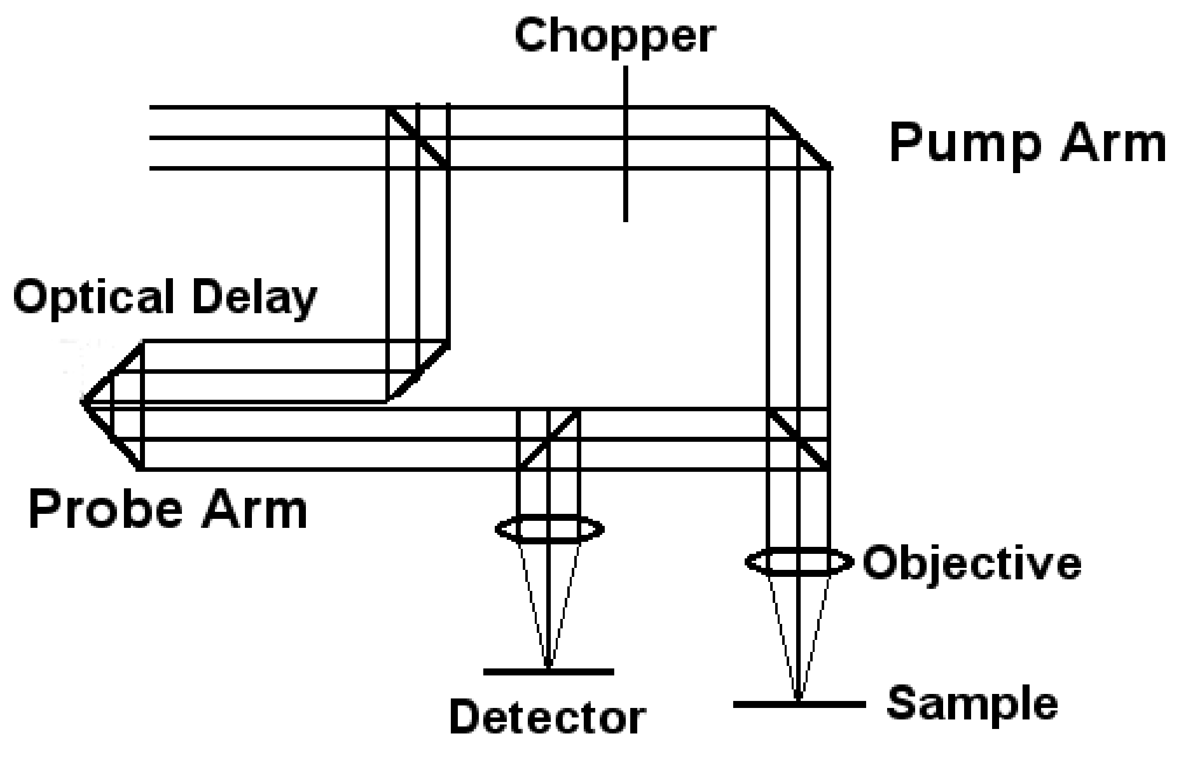
- Different mechanisms for detection
- Reflectivity
- Surface changes
- Very large background with small signal of interest





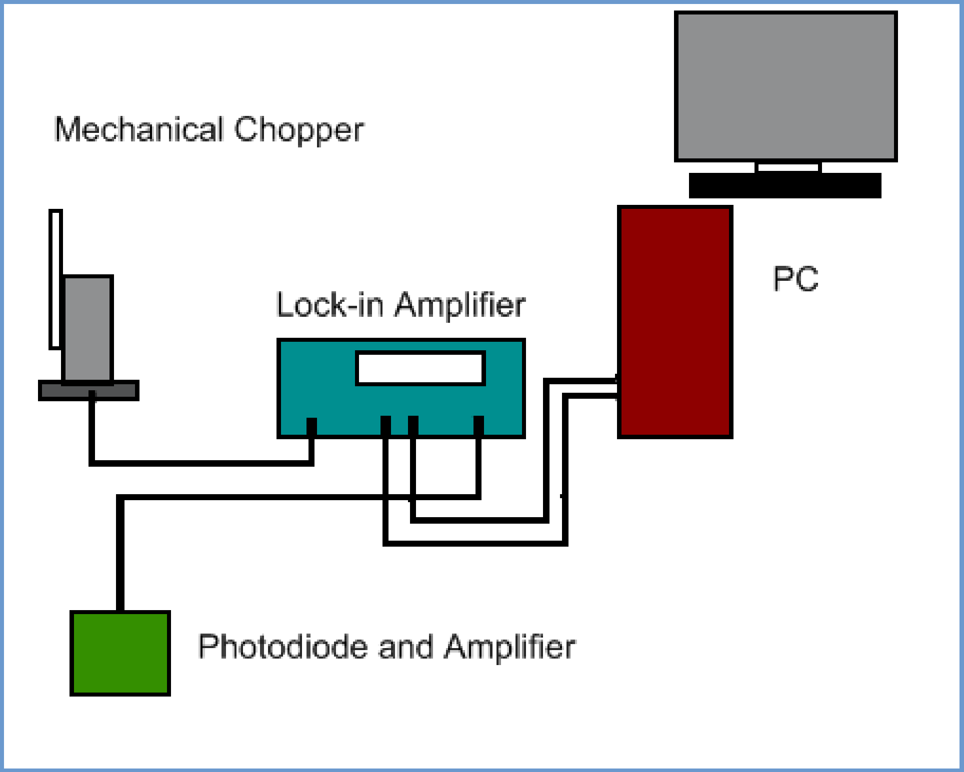
Experiment Setup

- 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



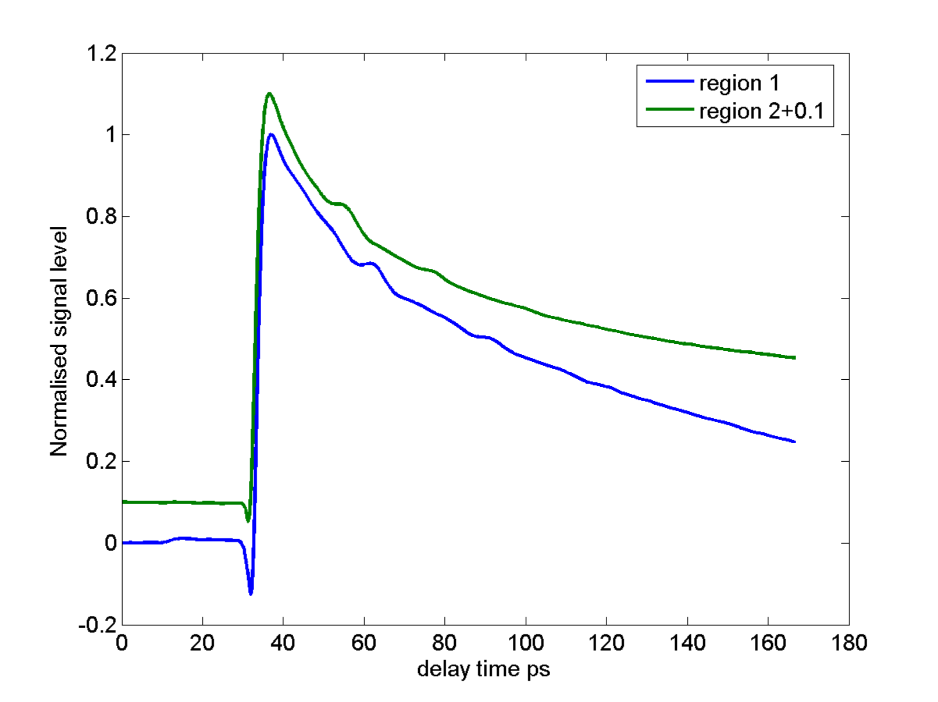
Single Channel Detection

- Single photodiode detector
- Lock-in amplifier with reference from pump arm chopper
- Sample is Chrome on Silicon
- 2 regions of different thickness one ~55nm the other ~75nm
- Interested in both regions and the transition between them



Single Channel Result

- 3 main components to signals
- Coincidence peak
- Thermal relaxation
- Acoustic Echoes
- Signal is $5\times10^{-5} \rightarrow 10^{-6}$ times smaller than DC light level



Moving to multiple channels

- Need another way to demodulate the signal as multiple lock-ins become impractical
- Need to capture many photons for required SNR
- 10^6 SNR needs 10^{12} photons per measurement point
- Our approach is to use an integrating detector to capture many photons and a suitable algorithm to demodulate the signal

- Phase stepping used to demodulate signal
- N steps per chopping cycle
- Usually only 3 or 4 steps are required for reconstruction of amplitude and phase
- Be careful if square wave modulation is used

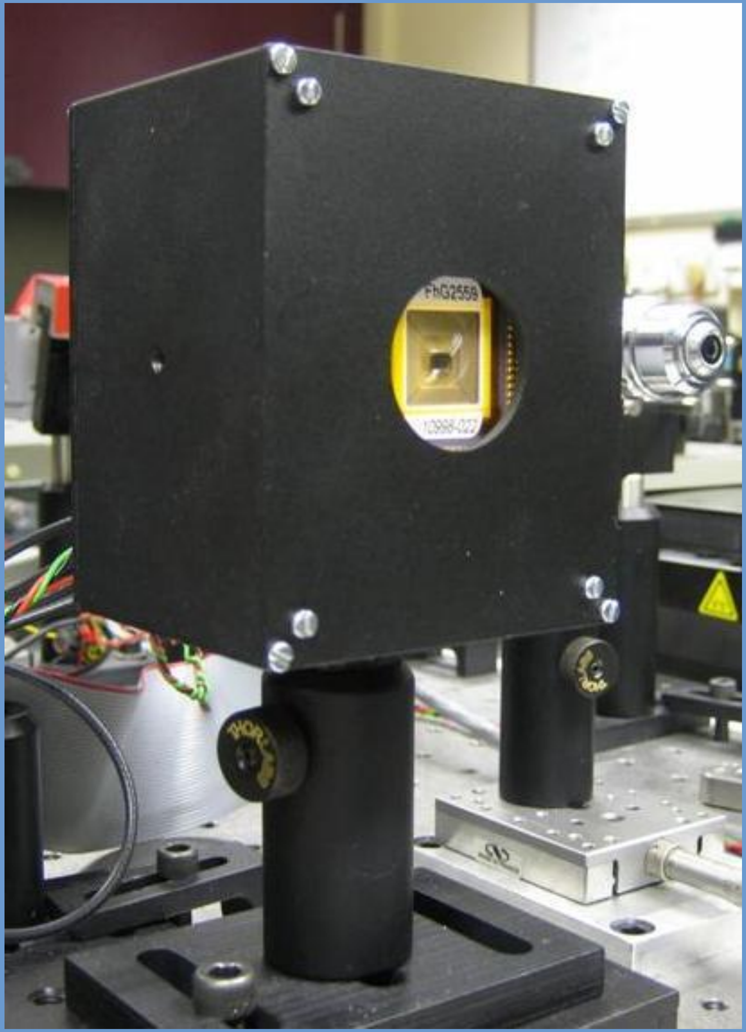
$$\text{Amplitude} = \sqrt{(S_3 - S_1)^2 + (S_4 - S_2)^2}$$

$$\text{Phase} = \arctan\left(\frac{S_3 - S_1}{S_2 - S_4}\right)$$

$$\text{DC} = \frac{S_1 + S_2 + S_3 + S_4}{4}$$

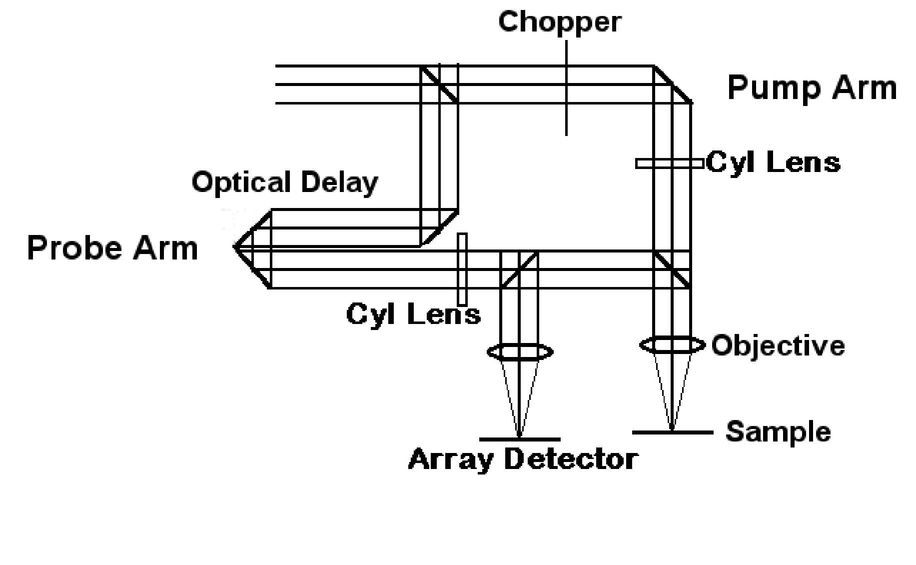
Custom detector

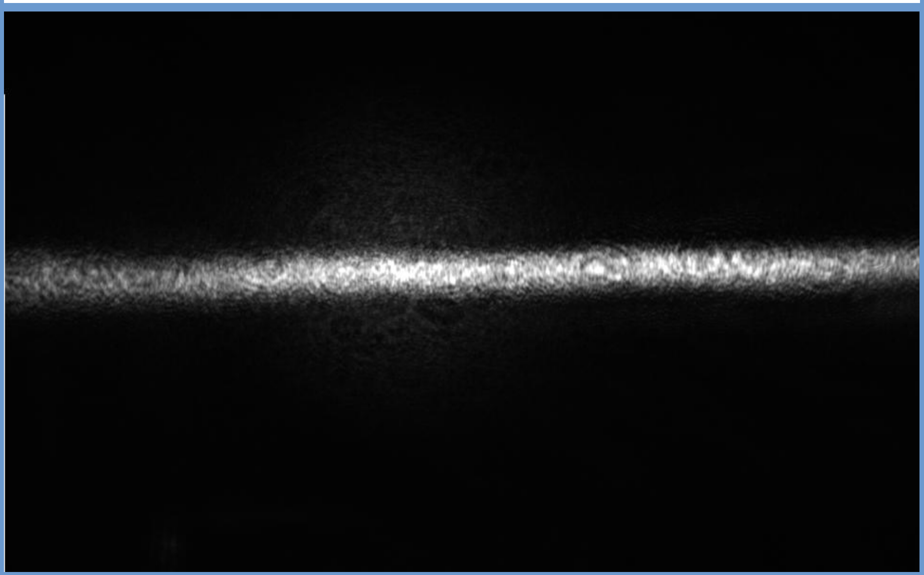
- 64x1 linear array detector
- Global shutter means all pixels are in phase so only 4 phase steps are required
- Pixels built on active sensor principle with 4 large independently switchable capacitors to increase well depth (1 for each phase step)
- 4 phase mode of operation : reset, integration, idle and readout
- Pixels are randomly addressable
- Fast readout speeds



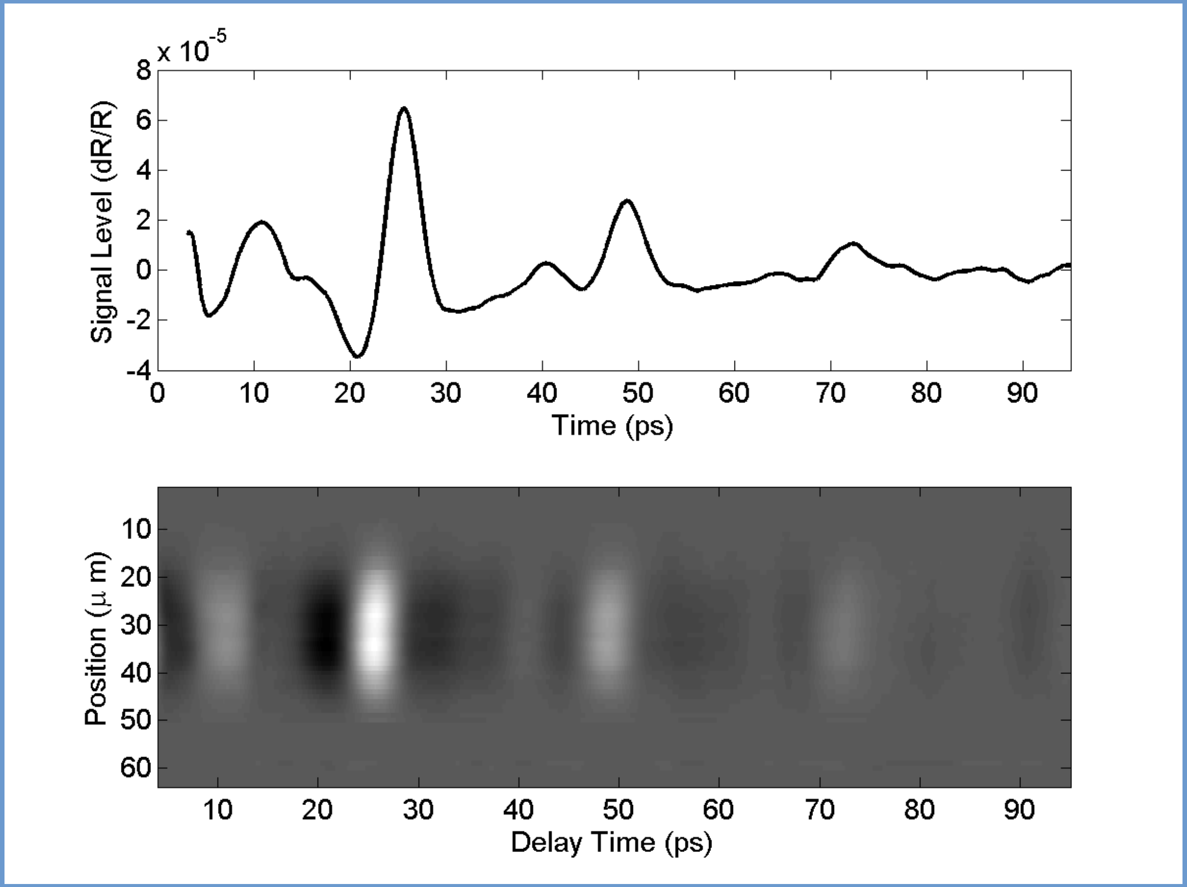
Changes to the optical setup

- Point focus of single detector case is changed to line focus for both the generation and detection arms by the insertion of weakly astigmatic lenses into both illumination arms
- Line focus is approx ~ 60 microns long by 2.6 microns wide
- Pump power onto sample is 240mW
- Probe beam total power on the sample is 2.5mW
- Light onto detector ~60μW



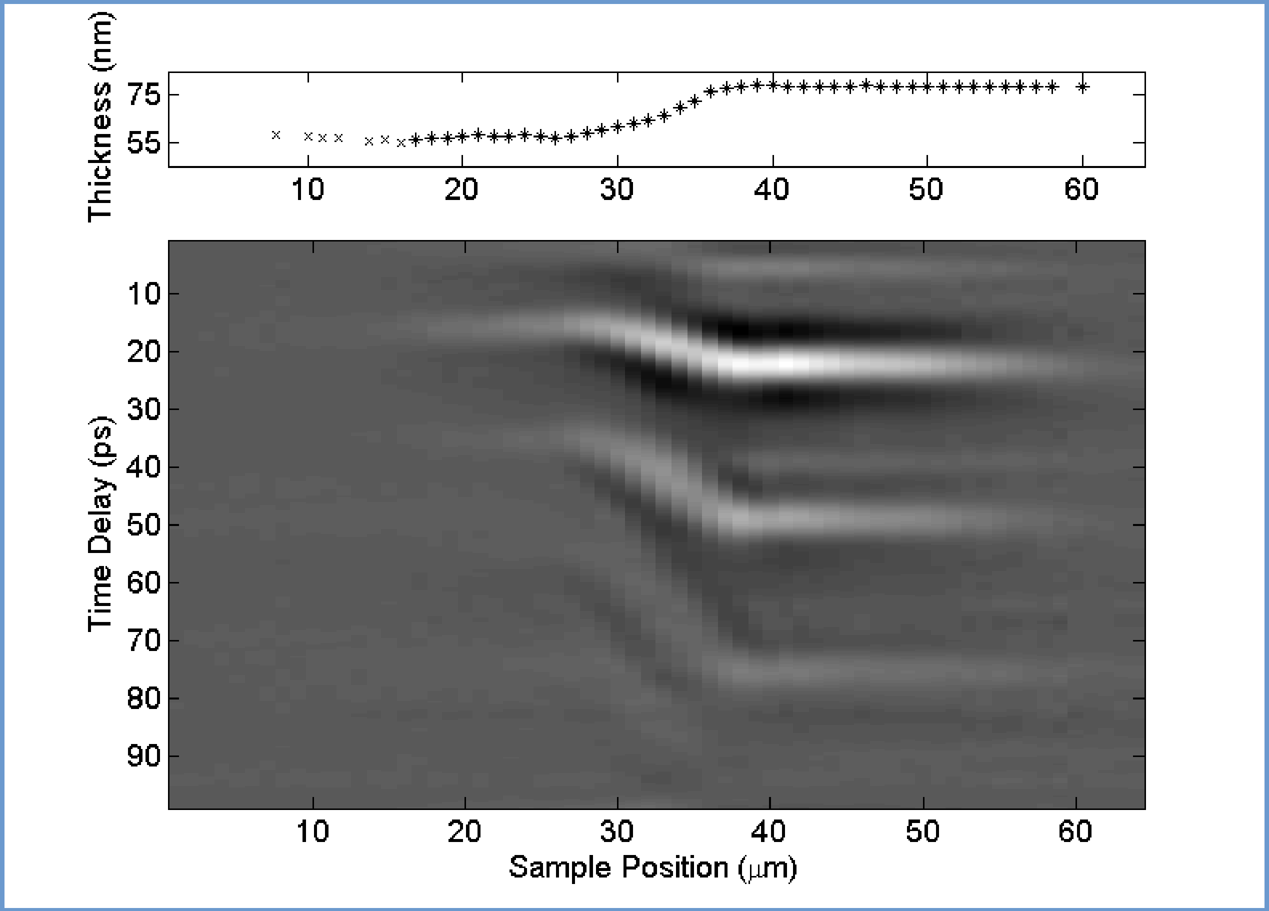


Custom detector result



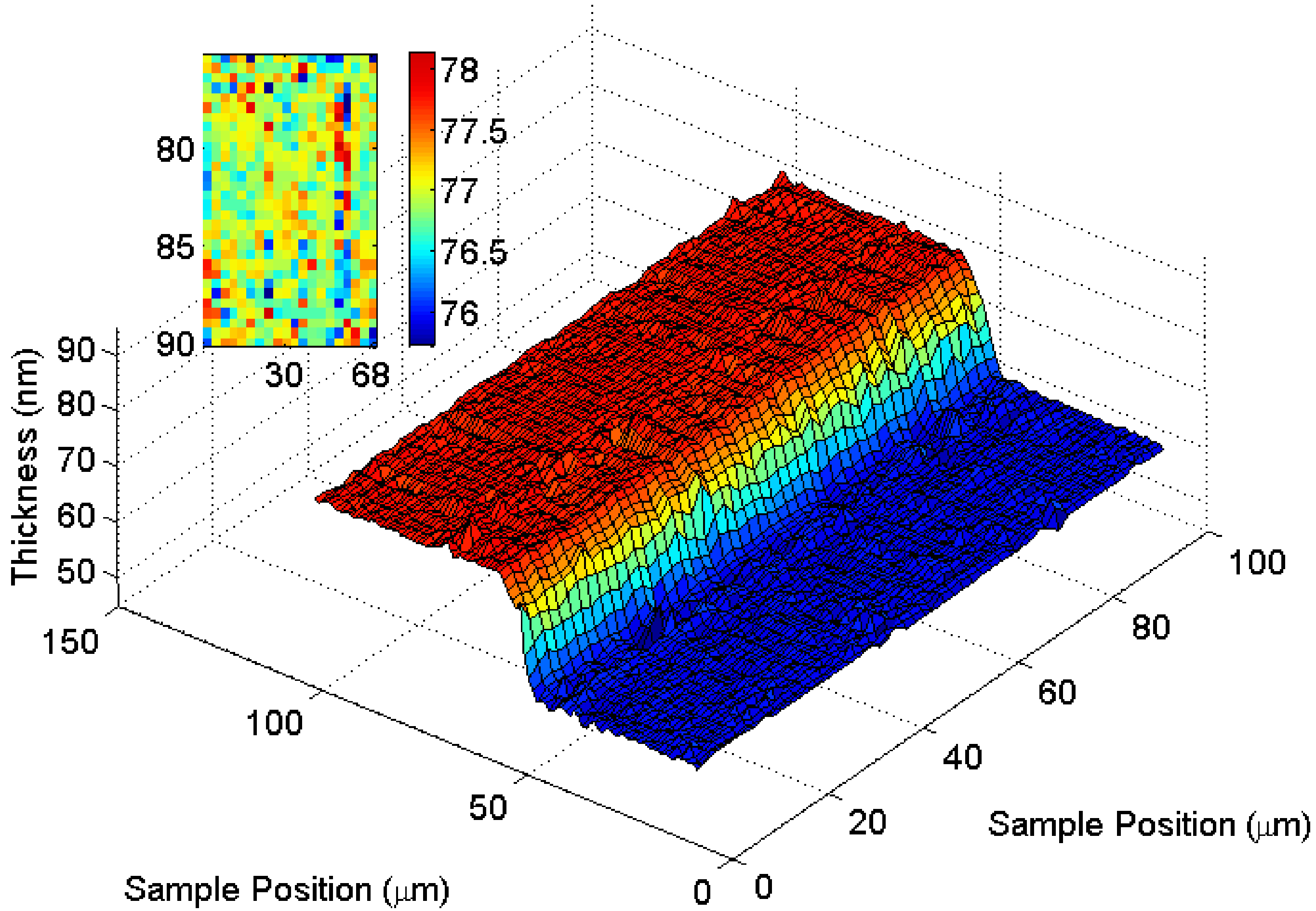
- Single trace 2 echoes can be seen
- After removing back ground 3 are visible
- Edges of array were not sufficiently illuminated

Results continued



- Transition clearly visible in first echoes
- Echoes times can be converted to a thickness measurements if velocity is known

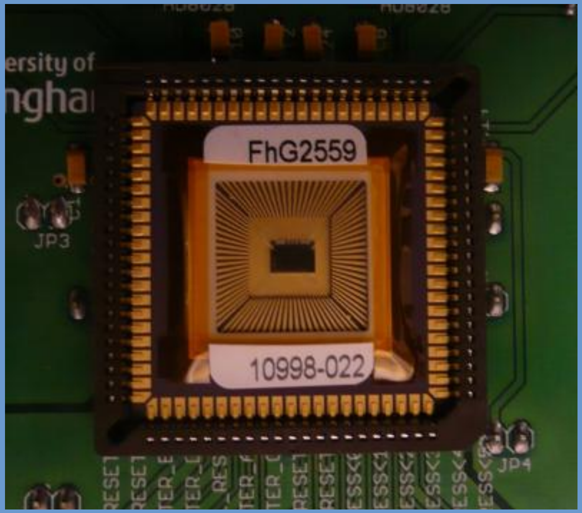
2D Image

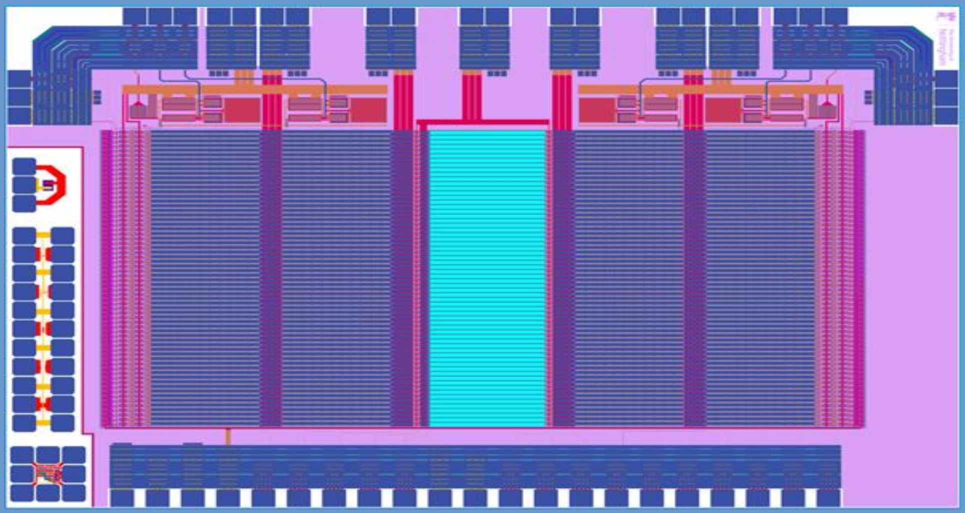


80
85
90
30
68
78
77.5
77
76.5
76
Thickness (nm)
90
80
70
60
50
150
100
50
0
Sample Position (µm)
0
20
40
60
80
100
Sample Position (µm)

Custom detector continued

- A new 256 pixel device with programmable well depth for each pixel has just been fabricated .
- The ADC card is the limiting factor in the data acquisition speed.
- Currently capture 1700 frames a second, The max is ~40K frames/sec
- To reach these speeds would require: more light in the probe beam, a faster delay stage and a faster pump beam modulator





Comparison to Single detector

- The single shot SNR of the single channel system is better than the array detector as it captures more photons per measurement point.
- However due to capturing data in parallel our detector is significantly faster over all.
- The image on the transition taken wit the array is ~12 times faster than using single point detector even though we are limited in speed by our ADC card
- Speed increases of ~35 times are possible if a faster ADC was available
- 2D images over large regions of coating can already be taken in only a few hours.

Conclusions

- We have developed a 64x1 linear array detector
- Performance equalling that of single photodiode & lock-in amplifier can be obtained
- The parallel approach we have adopted reduces experiment time by more than an order of magnitude, with further reductions possible
- Now possible to use picosecond ultrasonics to image coating thickness over an extended area

- Thank you for your attention
- Any questions?

Acknowledgements:

We wish to thank Dr Teti Stratoudaki for making the sample

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