Optical Absorption in Silicon

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Optical absorption in silicon

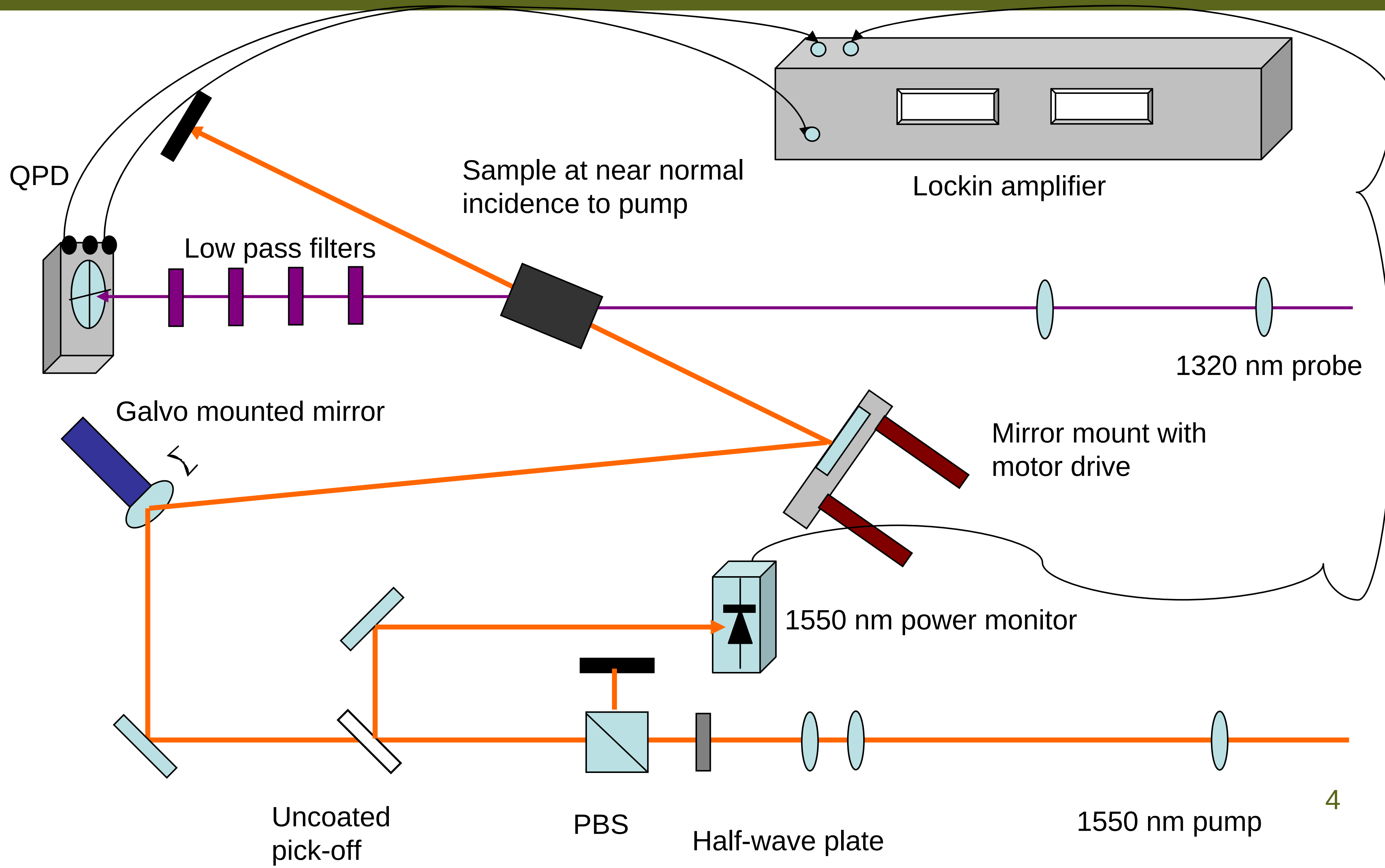
- Outline
  - Introduction
  - Our apparatus
  - Sample measurements
  - Discussion
  - Future directions

Introduction

- Previous work in Glasgow
  - Photothermal Commonpath Interferometer
    - **Initially used for bulk silicon absorption measurements**
    - **Issues with high irradiance causing multi-photon effects**
    - **Currently focussing on coating measurements on various substrates with this instrument**
- All this work
  - Photothermal Deflection or “Mirage”
  - Mainly using position modulation[1]
    - **Maximum signal when beams are aligned and not offset**
    - **Nominally more signal per watt than amplitude modulation (although that is often not the limitation)**

[1]Vincent Loriette and Claude Boccara, APPLIED OPTICS Vol. 42, p649, (2003)

Our apparatus



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Room Temperature Measurement of:

- resistivity

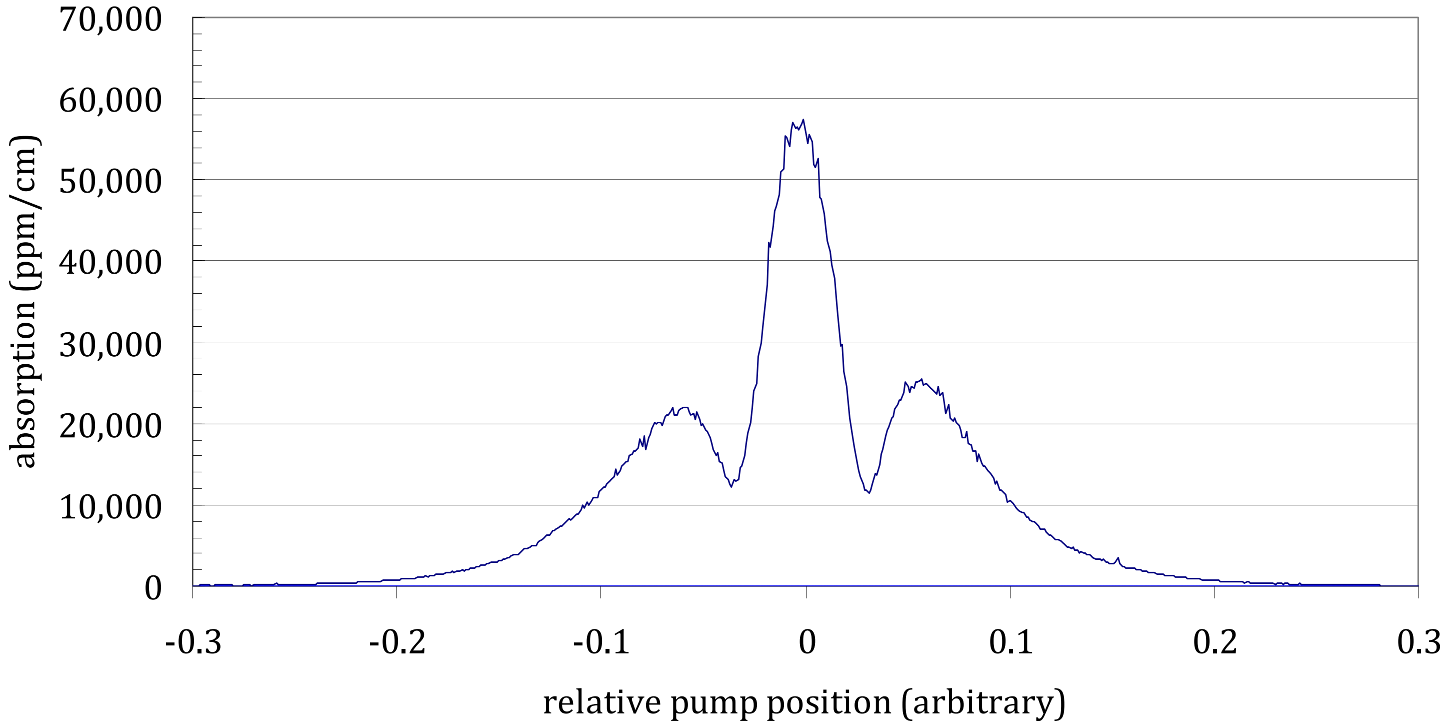
- AEI samples (5 kΩ.cm, & ~30k - 80 kΩ.cm)
  - Some interesting surface effects
- Glasgow sample (>10 kΩ.cm)
- LMA sample (?)
  - Cross reference calibration sample

Vertical scans

- Absorption signal at a single position

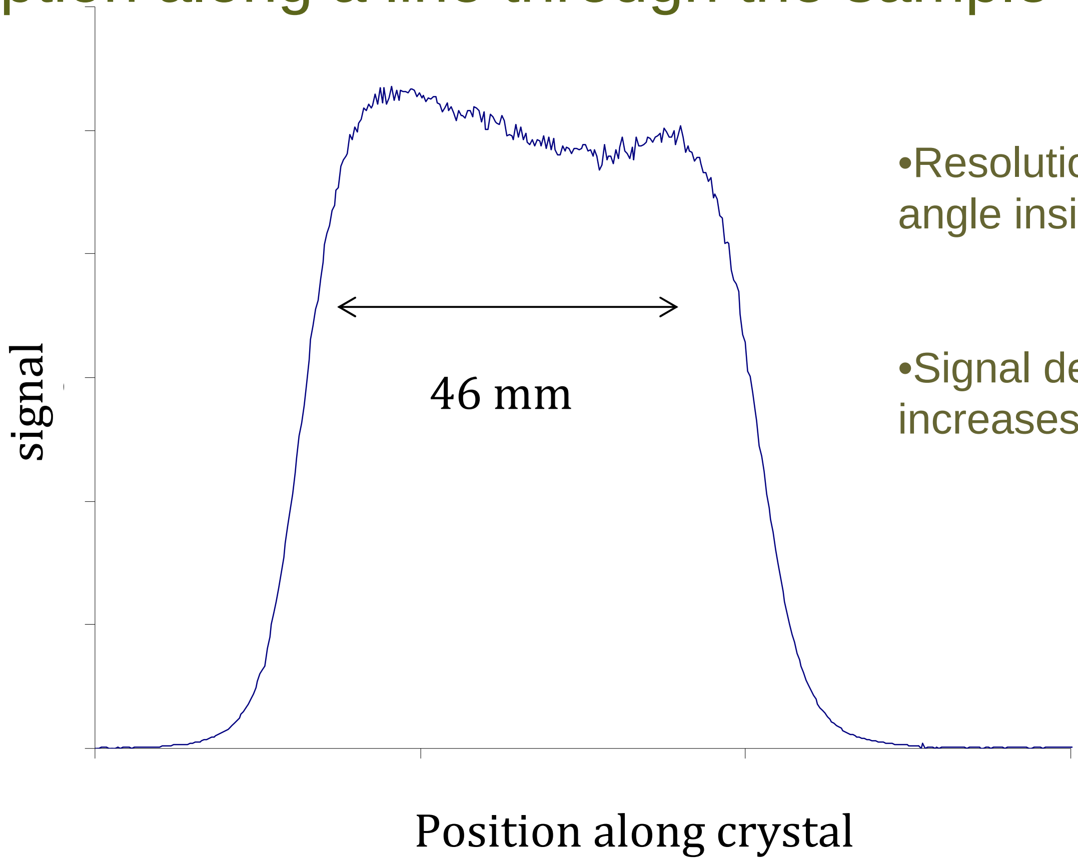
•Normalise signal from lock-in amplifier to pump and probe power

•Use known absorption of calibration sample to get our calibration factor



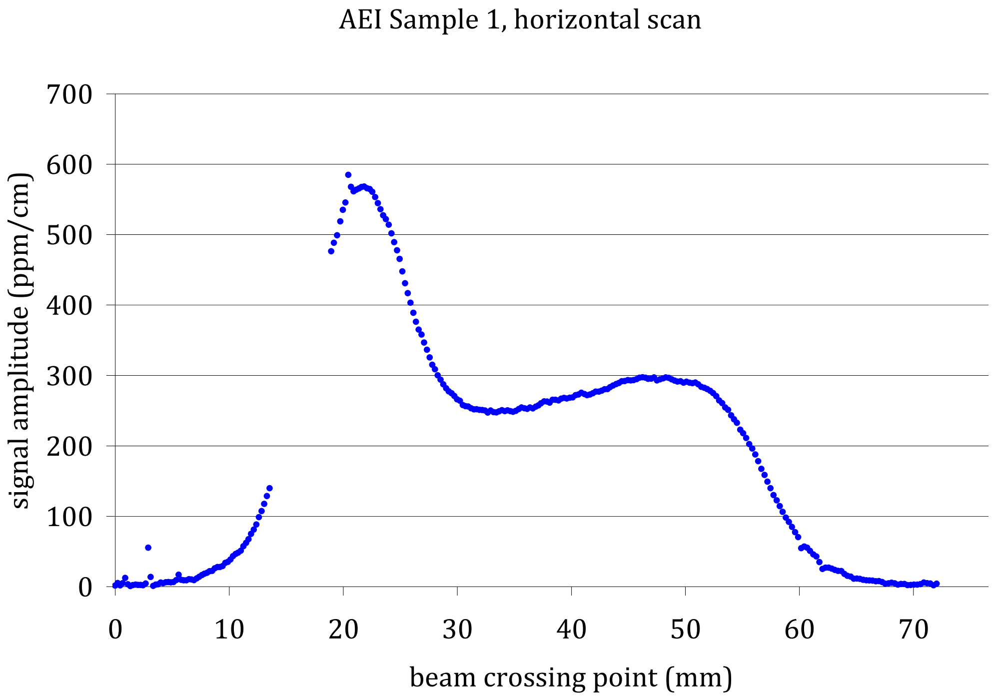
Horizontal scan

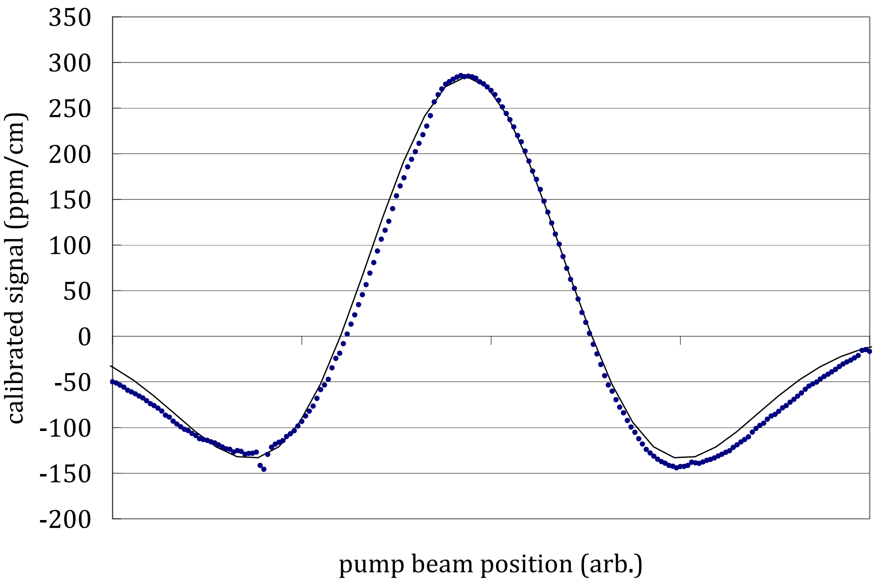
- Absorption along a line through the sample



- Resolution improves as crossing angle inside material increases
- Signal decreases as angle increases

AEI sample #1, horizontal & vertical scans (5 kΩ.cm)



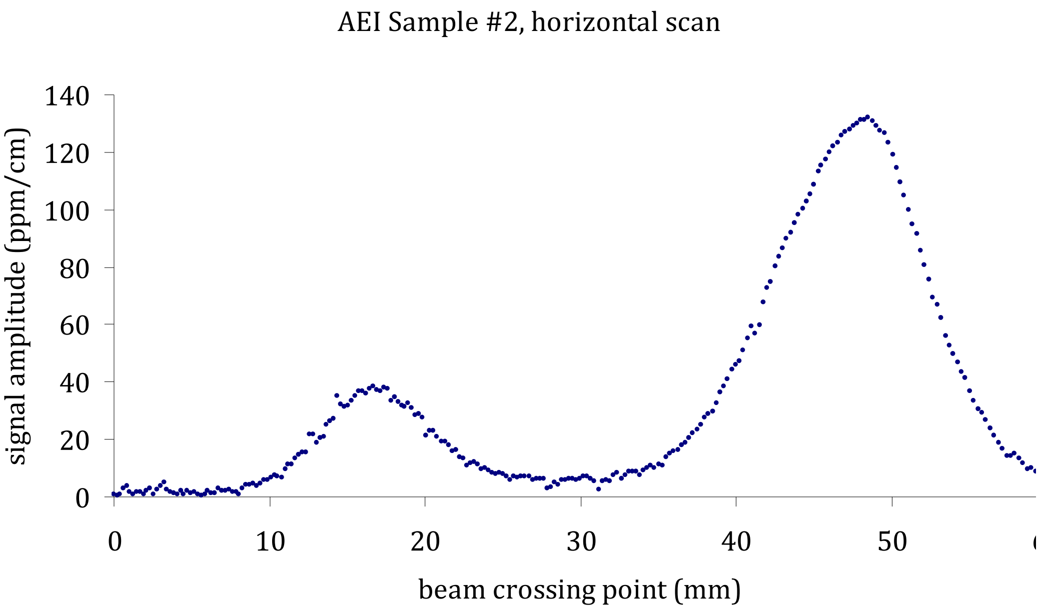


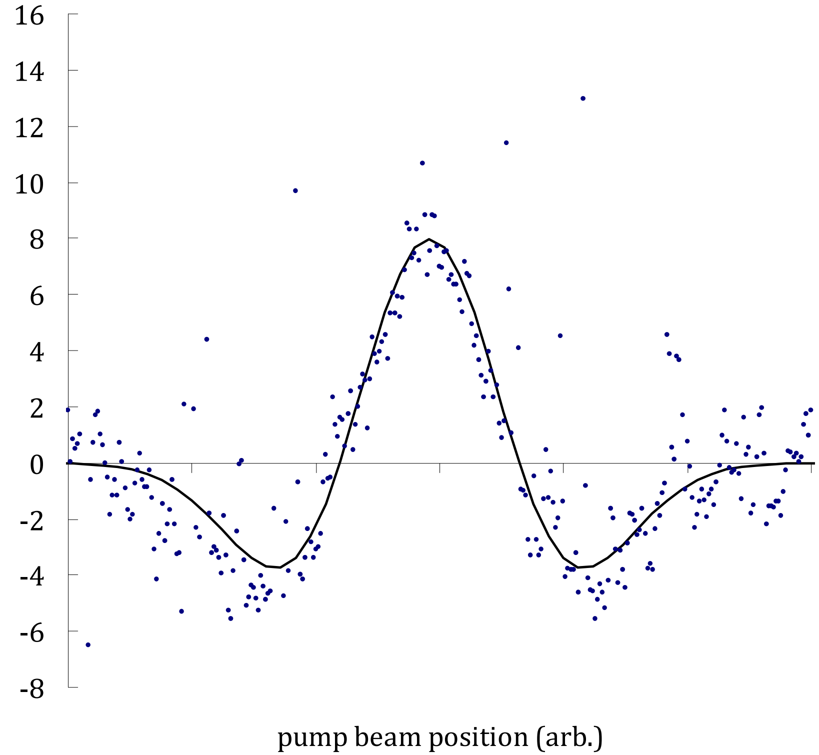
Horizontal scan

Vertical scan near centre

All subsequent horizontal scans shown were taken at ~ 7 mm horizontal resolution

AEI sample #2, horizontal & vertical scans (30-80 kΩ.cm)

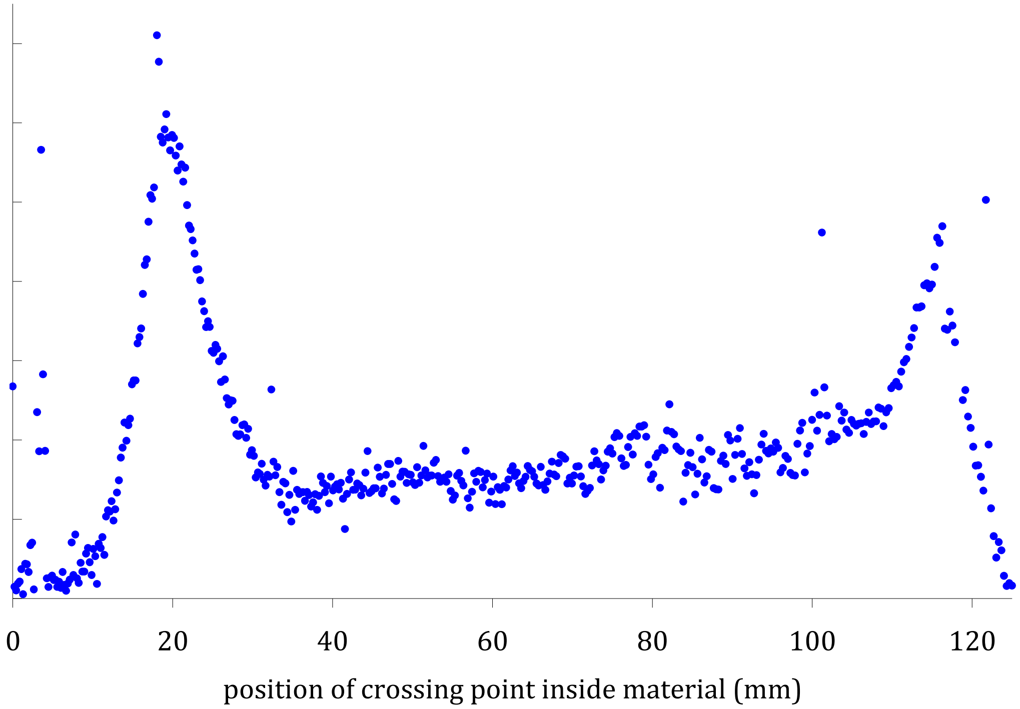




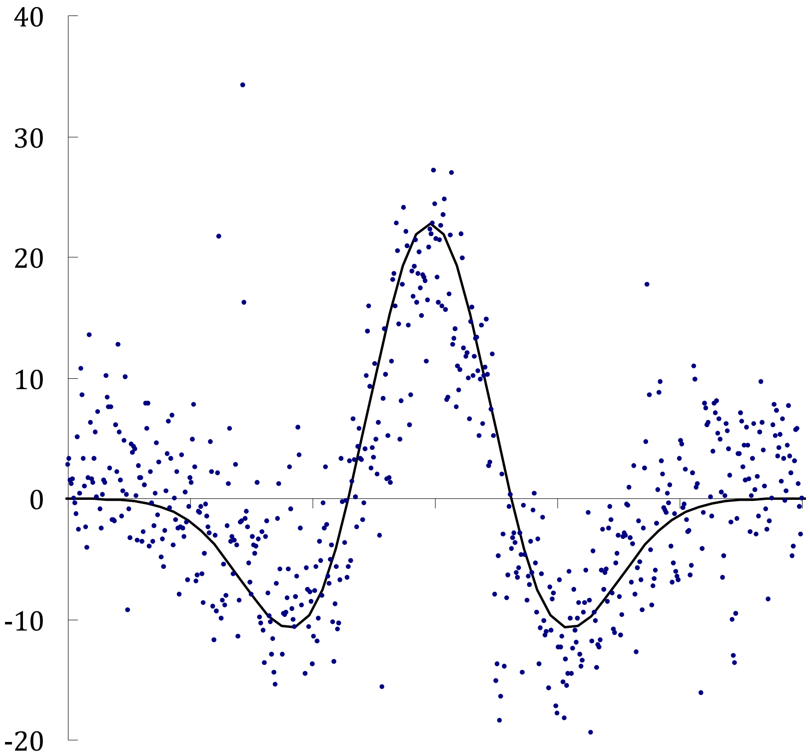
Horizontal scan

Vertical scan near centre

AEI sample #3, horizontal & vertical scans (30-80 kΩ.cm)

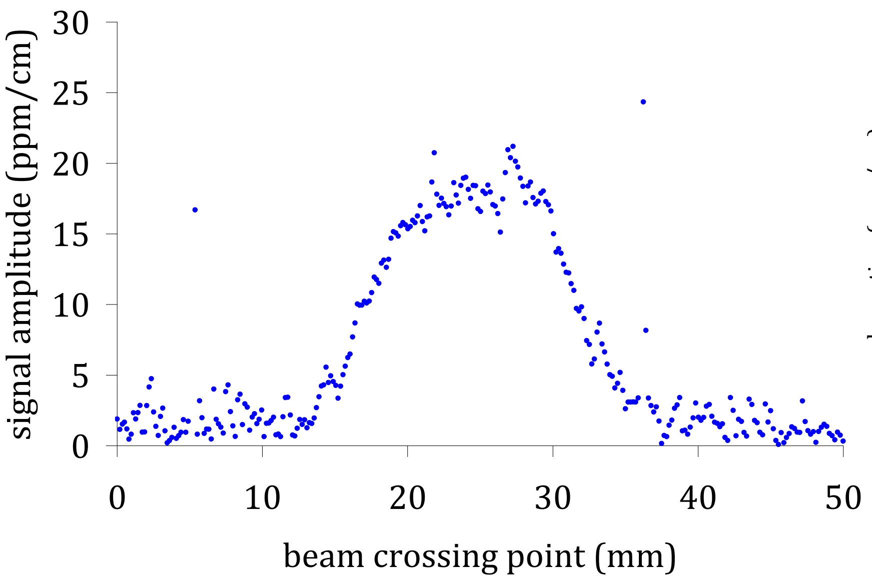


Horizontal scan

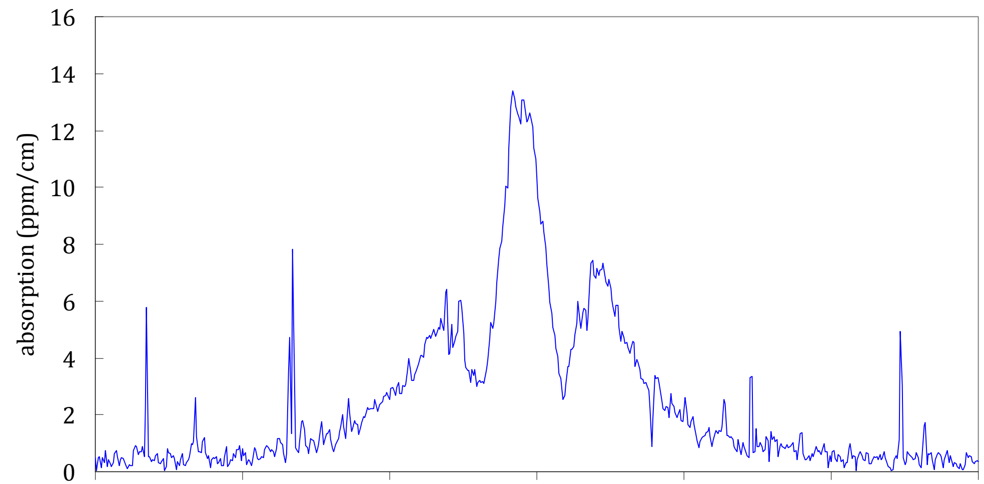


Vertical scan near centre

Glasgow sample, horizontal & vertical scans (>10 kΩ.cm)



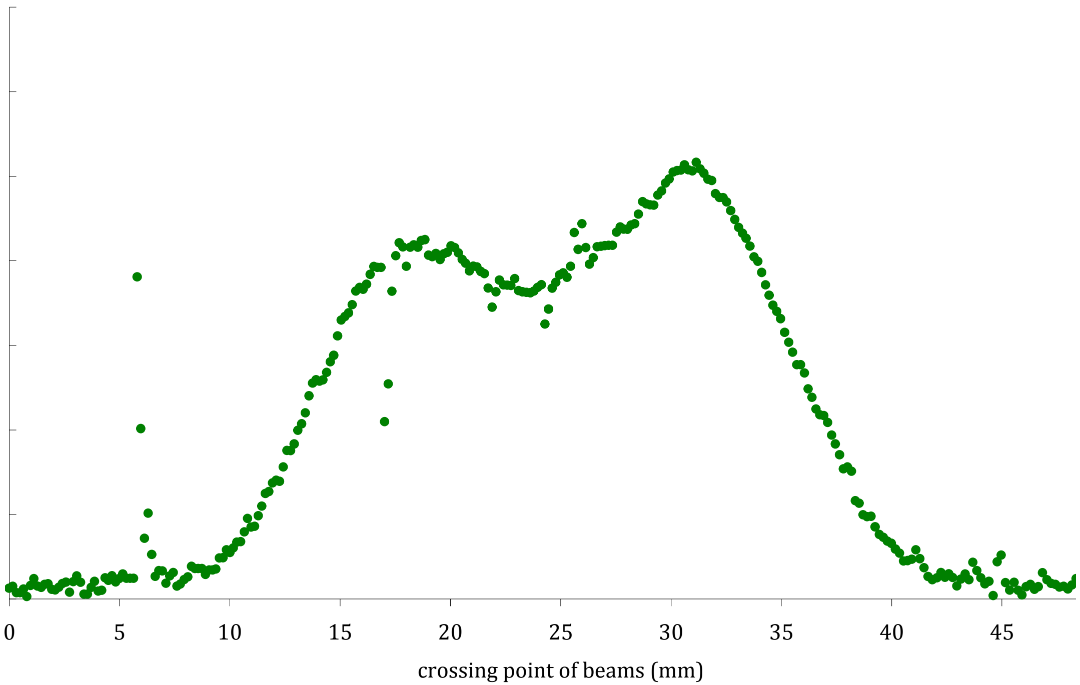
Horizontal scan



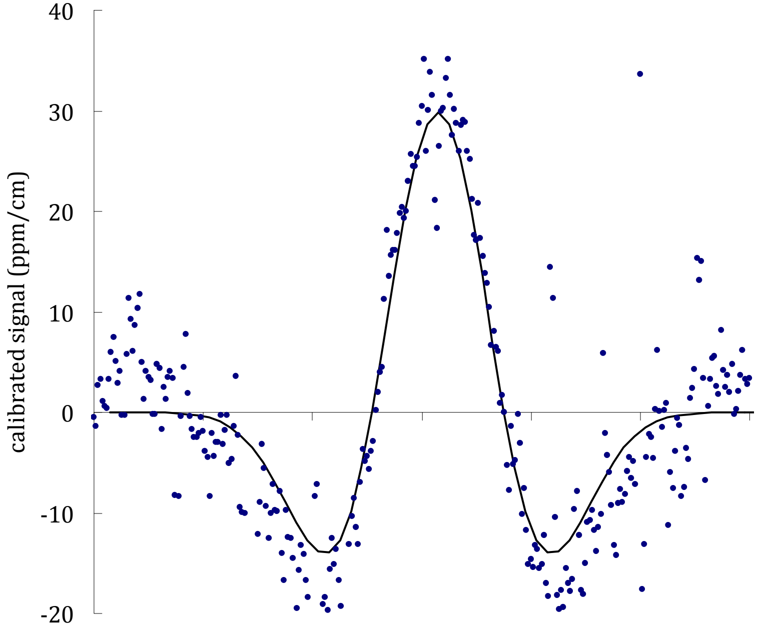
Vertical scan near centre

2-photon effects becoming significant – horizontal scan is taken with higher pump power and has contribution of several ppm/cm due to this

LMA sample, horizontal & vertical scans



Horizontal scan



Vertical scan near centre

Sample previously measured at LMA as between 20 & 30 ppm/cm
This measurement gives about 28 ppm/cm and if we remove ~2 ppm/cm due to non-linear effects -> 26 ppm/cm

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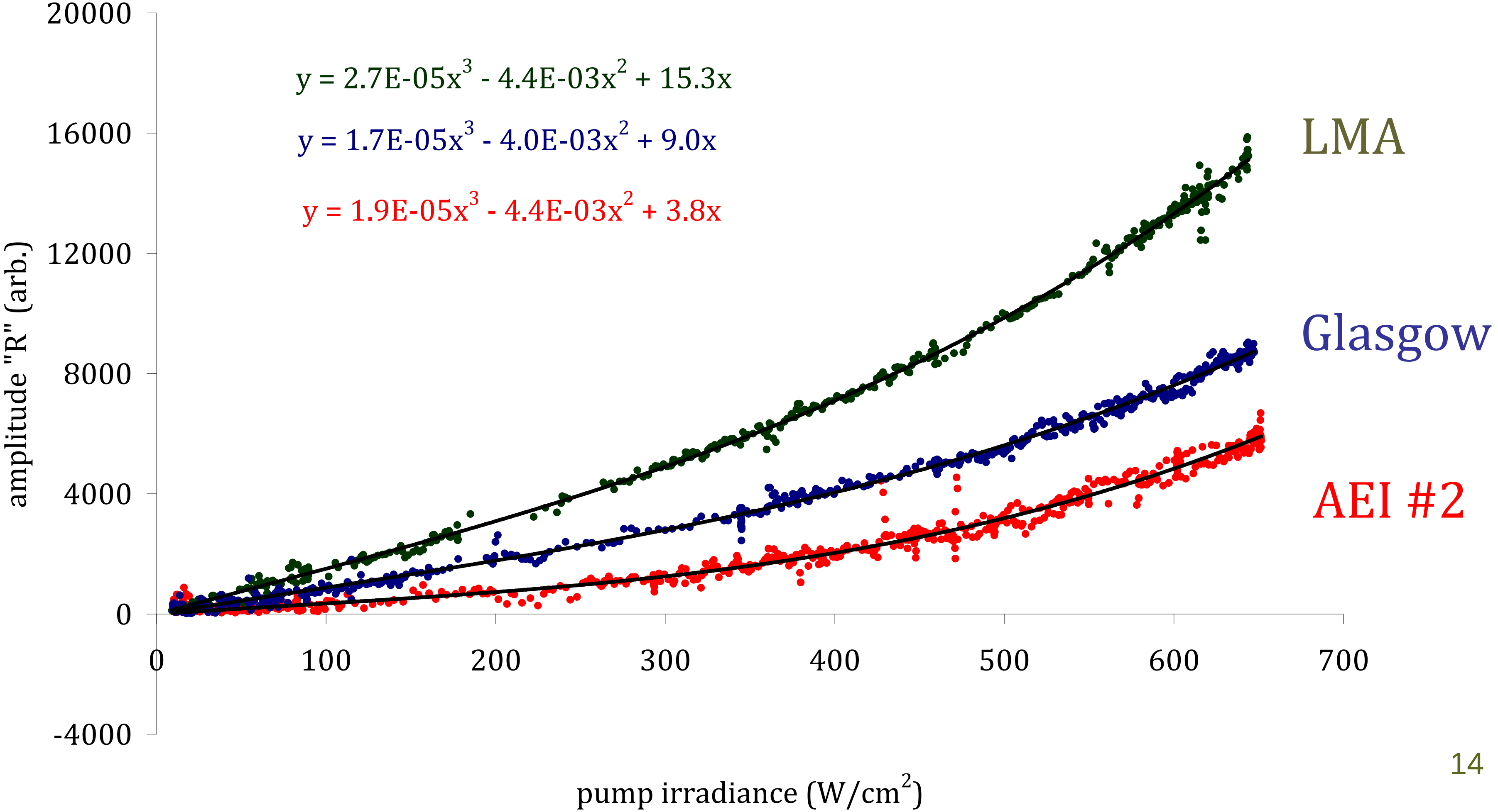
Linearity of signal



Discussion

- Some samples show surface absorption
- Understand the differences between samples and determine where surface absorption comes from (not intrinsic)

- Surface absorption
  - Use etching to help determine where absorption occurs
    - **Oxide layer first**
    - **First few/several nanometers of silicon**
    - **Further polish or etch as required**

Discussion

- In our set-up we want to look at:
  - Signal size vs position – better understanding
  - Geometric effects (e.g. change in beam size for longer samples)
    - **Enable better measurement of absorption through the sample**
  - Further increase beam size to reduce non-linearities
    - **Currently see equivalent of a few ppm/cm extra absorption for ~5 watts pump**
- Look at more detail at resistivity and absorption
  - Seems that resitivities of 1kΩ.cm and less correlate well with absorption but not higher values?

Future work

- Cryogenic measurements
  - Cryostat just setup
  - Started looking at a highly doped sample
    - **Alpha ~ 0.05 /cm**
  - Indications are that our measurement confirms absorption does not decrease with temperature

Conclusions

- Swapped samples for testing with LMA and agree on absorption values to within 20%
- Measured room temperature loss of sub-10 ppm/cm in “intrinsic” silicon (Hanover sample)
- Aiming to provide understanding of (non-intrinsic) surfaces losses in these samples
- Starting to look at cryogenic absorption

Thank-you