University of Glasgow

Some optical properties of hydroxide catalysis bonds

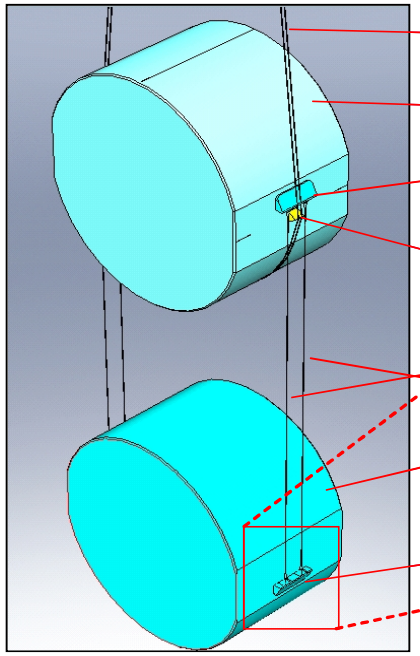
Mariëlle van Veggel on behalf
Jessica Steinlechner and Valentina Mangano and
the rest of the Glasgow bonding research team

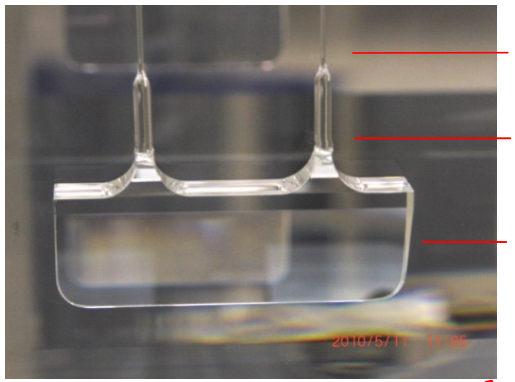
Contents

- Introduction
- How is hydroxide catalysis bonding used in the detectors
- Chemistry of Hydroxide catalysis bonding (HCB)
- But hydroxide catalysis bonds are invisible by eye between fused silica. This is very! Interesting. What about optical applications?
- Two interesting properties
  - Optical absorption
  - Reflectivity
- How could this be interesting for our gravitational wave detectors?

Introduction to hydroxide catalysis bonding

- GEO600, aLIGO, and advanced VIRGO have quasi-monolithic test mass suspensions in fused silica which show superior thermal noise performance at room temperature
- Hydroxide catalysis bonding is used in all to attach some form of interface piece to the mirror to allow attachment of the fibres (which are welded)



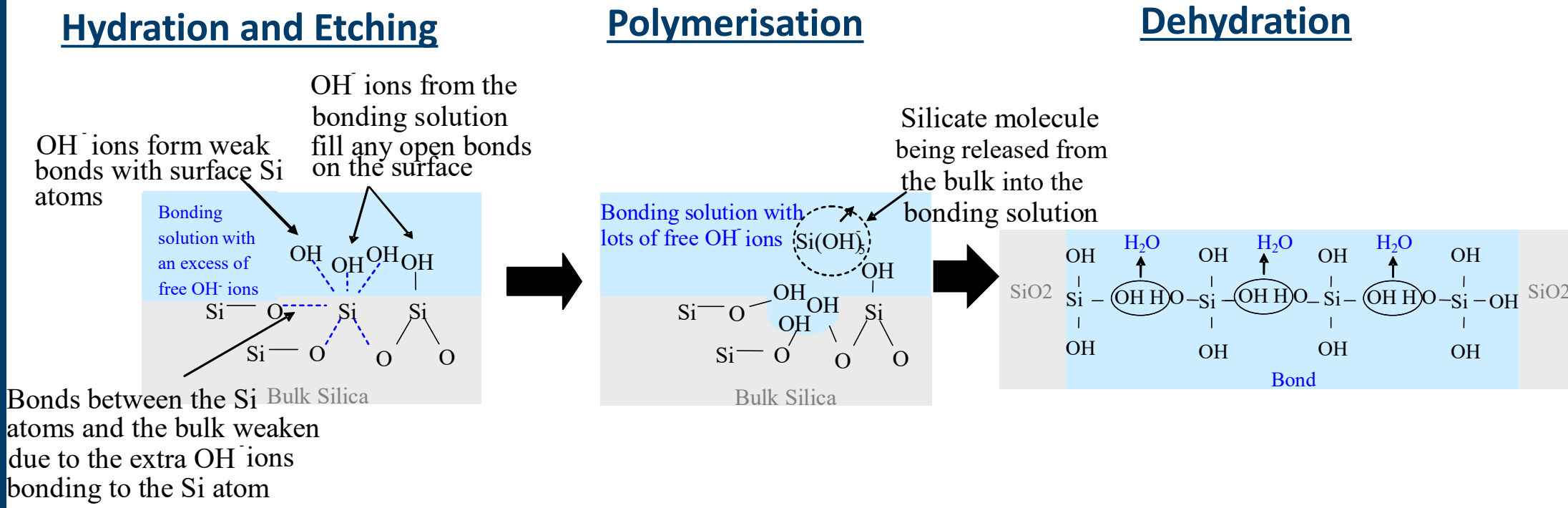


aLIGO monolithic mirror (ETM and ITM) suspension

Chemistry of hydroxide catalysis bonding

This method can create strong, durable bonds.

Chemistry of bonding between silica surfaces:



In aLIGO sodium silicate solution is used as the bonding solution. In advanced Virgo potassium hydroxide and sodium silicate solution is used [van Veggel & Killow, Adv. Opt. Appl., 2014].

Optical properties

Hydroxide catalysis bonds between fused silica components look highly transparent to the naked eye.

Optical applications could be highly interesting

e.g. fibre coupling, laser gain media, optical filters

In Glasgow we are working on two different measurements

1) Optical reflectivity of bonds

also very interesting as gives possibility of in situ measuring bond thickness

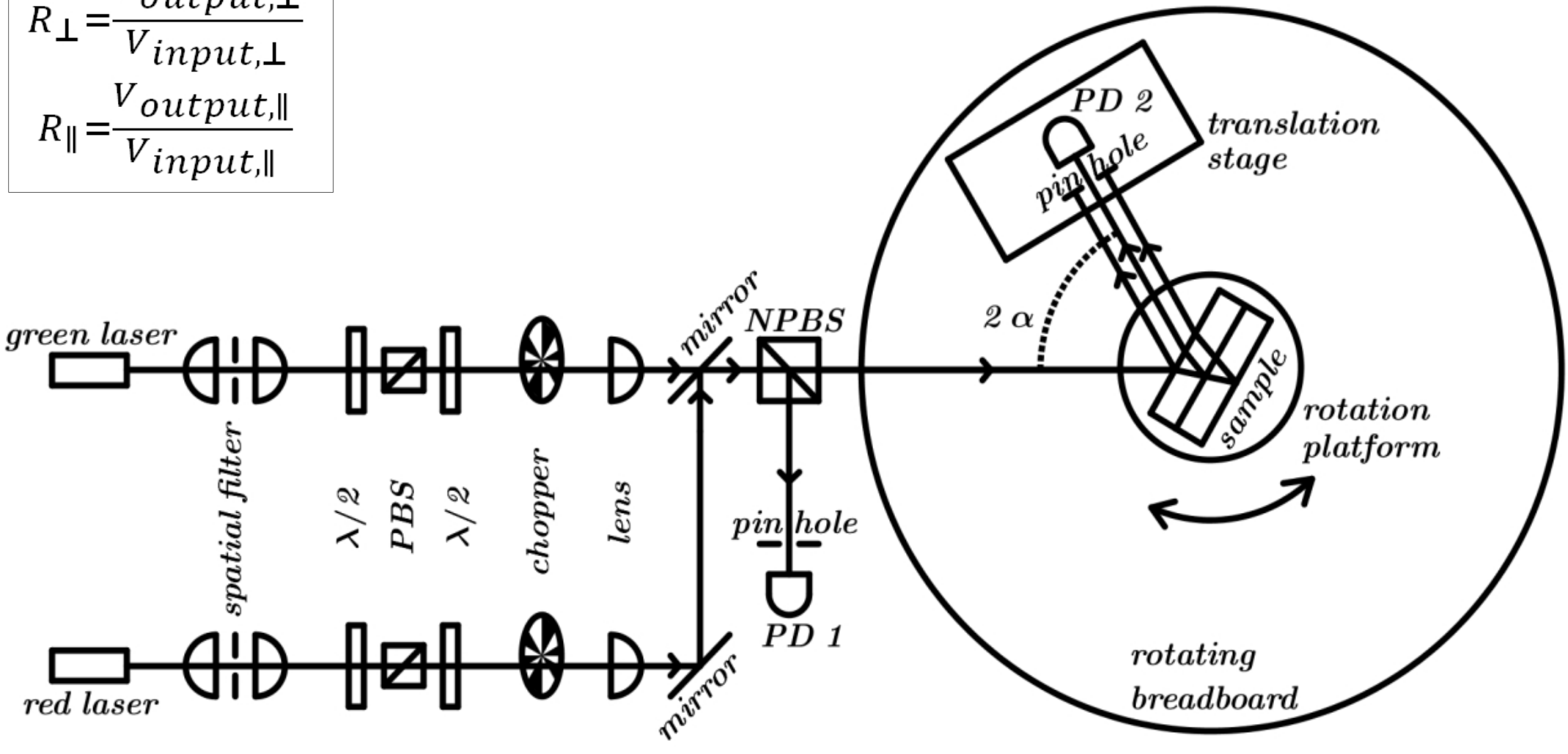
2) Optical absorption of bonds

Very much ongoing research, but we present some results here.

Optical reflectivity set-up

$$R_{\perp} = \frac{V_{output,\perp}}{V_{input,\perp}}$$

$$R_{\parallel} = \frac{V_{output,\parallel}}{V_{input,\parallel}}$$

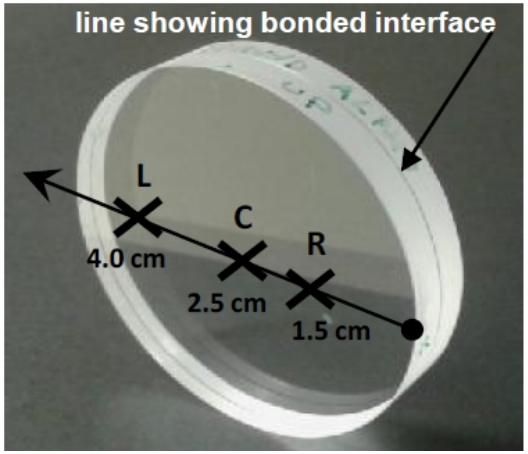


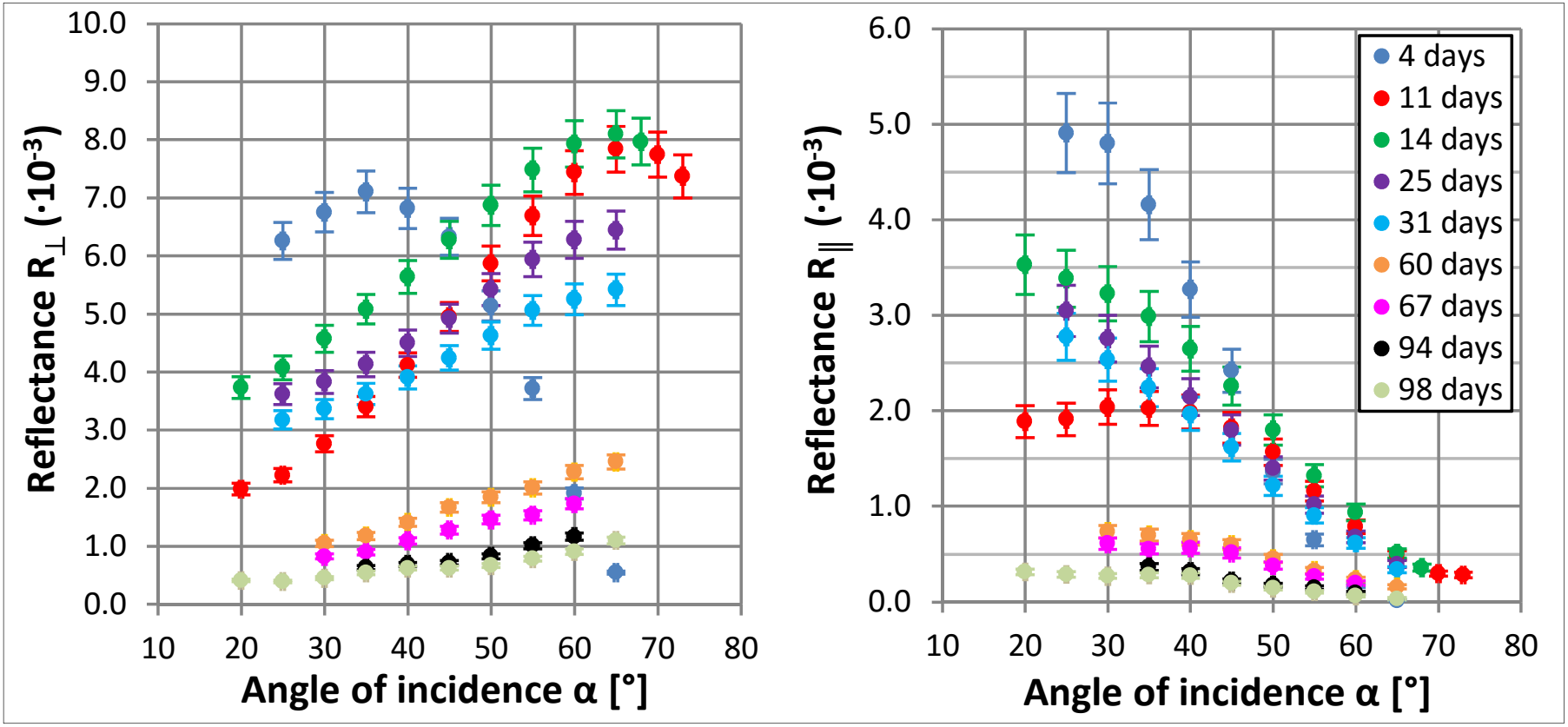
Reflectivity

Two pairs of fused silica discs

(∅50 mm, 5 mm thick, produced by Edmund optics)

Bonded using 1:6 sodium silicate solution





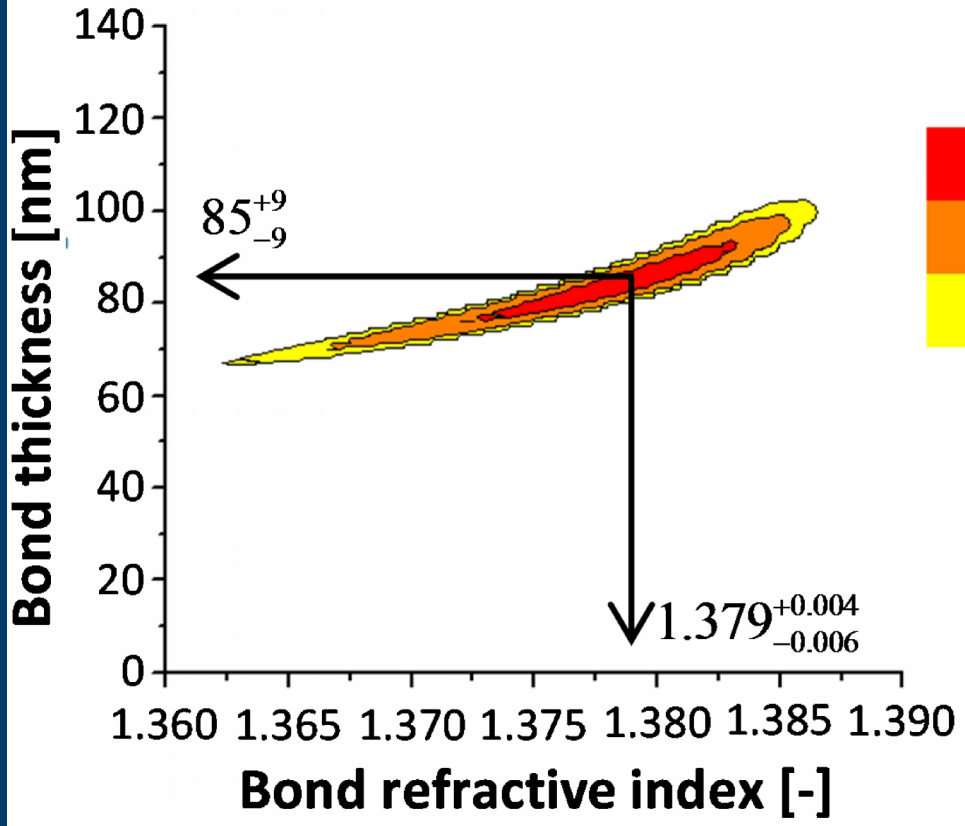
Optical reflectivity set-up

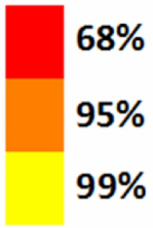
Model used is that for Fresnel reflection with thin film interference for the bond layer.

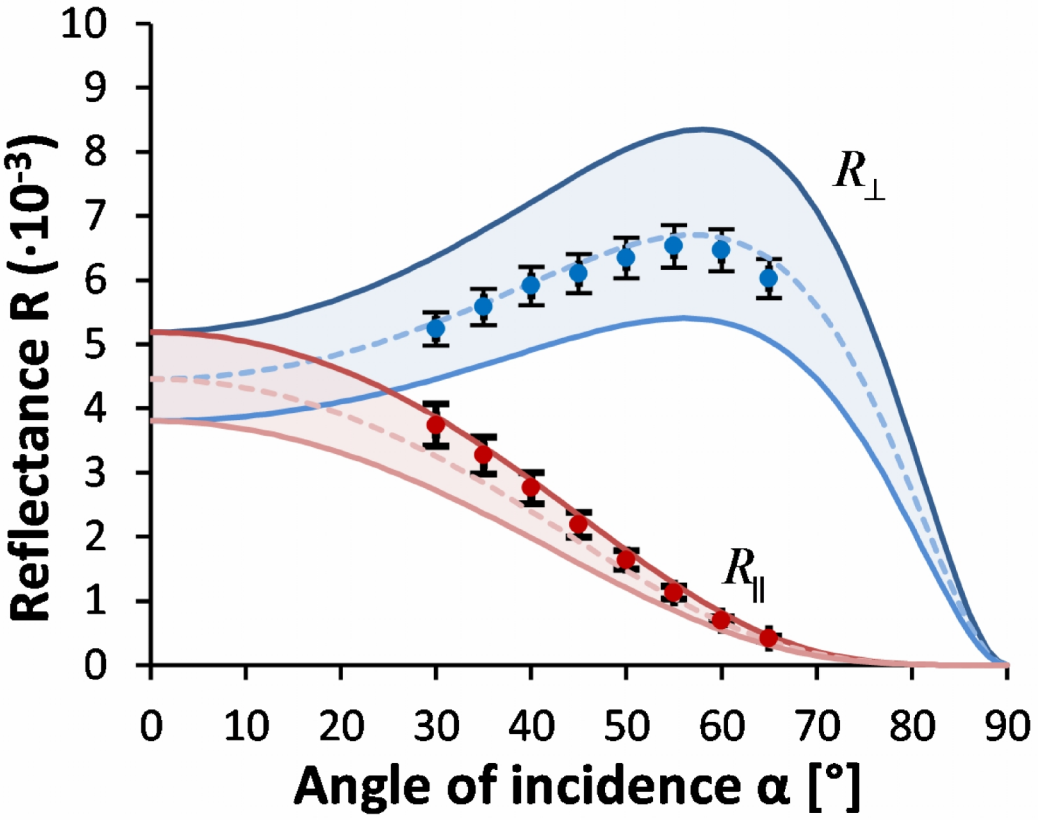
Bayesian likelihood analysis using the least squares method

$$\chi^2 = \sum_{i=1}^{n} \frac{\left(R_i^{th} - R_i^{sper}\right)^2}{\sigma_{sper,i}^2}$$

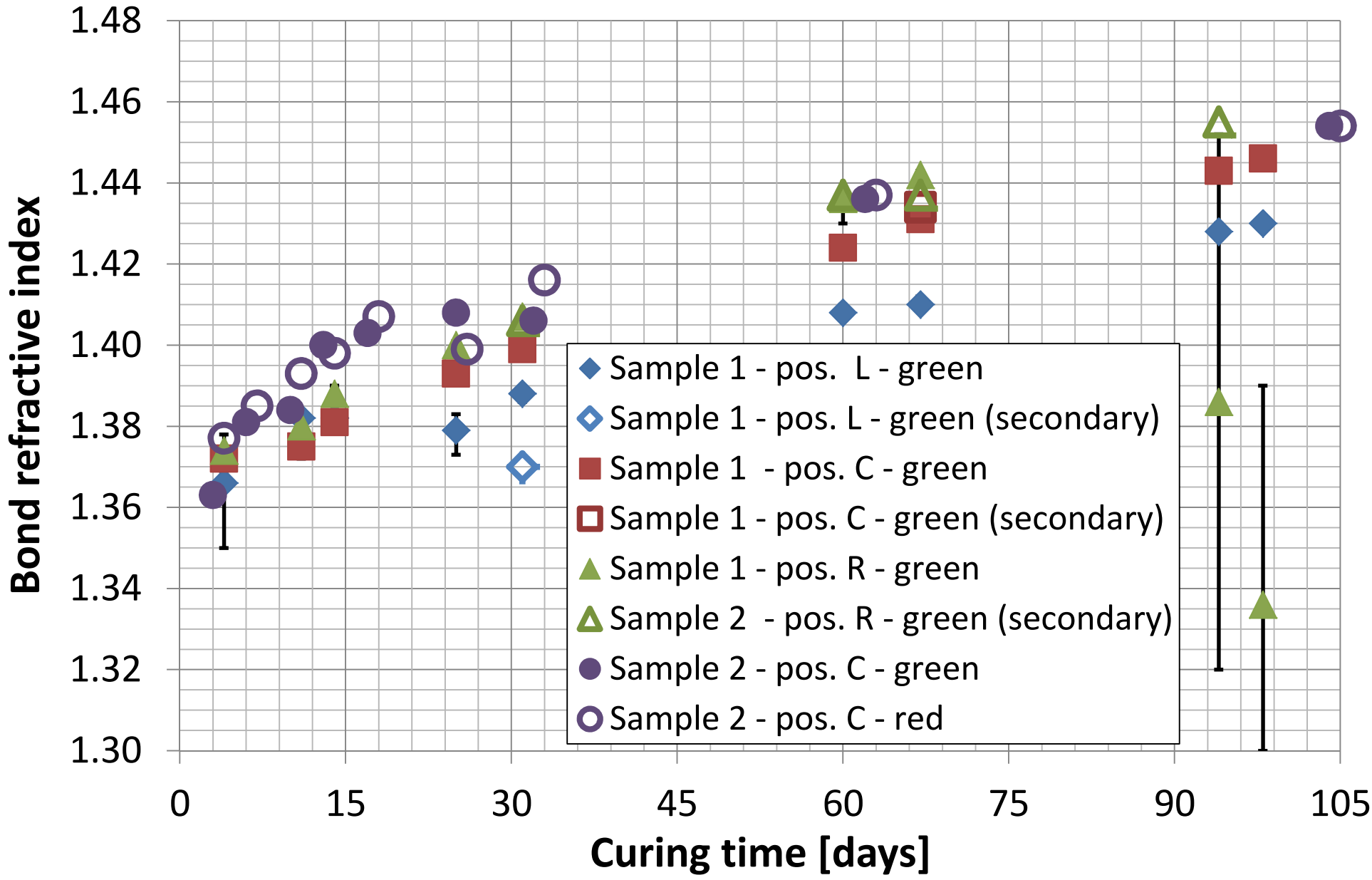
$$P_n = exp\left[-\frac{1}{2}(\chi^2 - \chi^2_{min})\right]$$



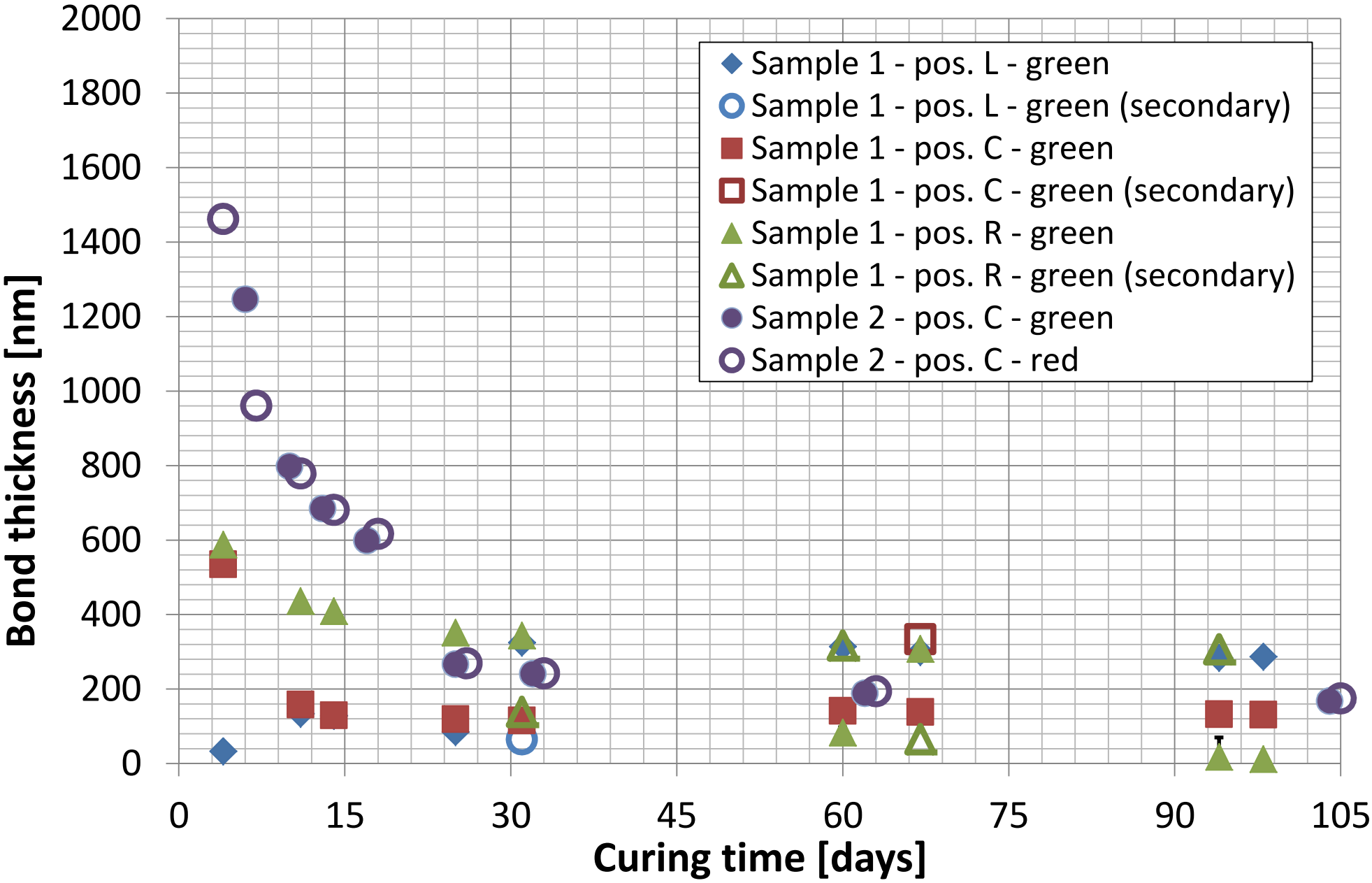




Bond refractive index a.f.o. curing time



Bond thickness a.f.o. curing time



Conclusions reflectivity measurements

- We have a non-destructive method of determining bond thickness and refractive index from reflectivity measurements
- Reflectivity of 1:6 sodium silicate bond has a settling period up to the 20th day after which it gradually drops to below 10^{-5} after about 3 months.
- The bond thickness settles as well (can vary up and down in the first 20 days), but overall drops to a constant value.
- The refractive index increases over time from a value of 1.36 to 1.45 . 1.34 can be shown to be the refractive index of the solution, 1.45 approaches the refractive index of fused silica

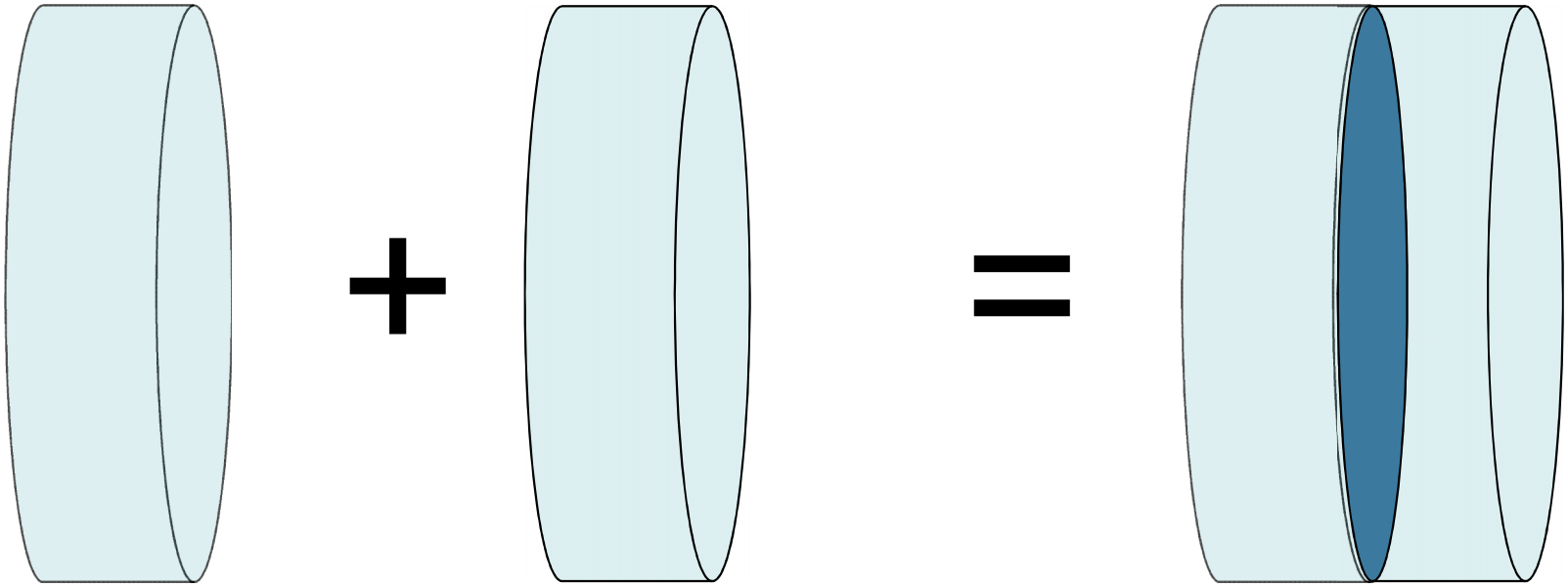
- Look at this in 'peace and quiet' at the poster session.
  G1601717 – Valentina Mangano

Other reflectivity measurements

- For a potassium hydroxide bond the reflectivity is immediately (within 3 days after bonding) below 10^{-5} and drops to a few times 10^{-7} after two months (analysis of this data is underway)
- Measurements of sapphire substrates (C-axis along the optical axis) bonded using sodium silicate are also underway.
  - Reflectivity of order 10^{-2} are measured and levels remain high over curing time.
- Aim to measure bond reflectivity, thickness and refractive index for
  - baking at elevated temperature
  - varied concentration of solution with silica substrates
  - other solutions for sapphire substrates
  - other substrate materials (e.g. phosphate glass, YAG)

Absorption of a bond between fused silica substrates

The sample:



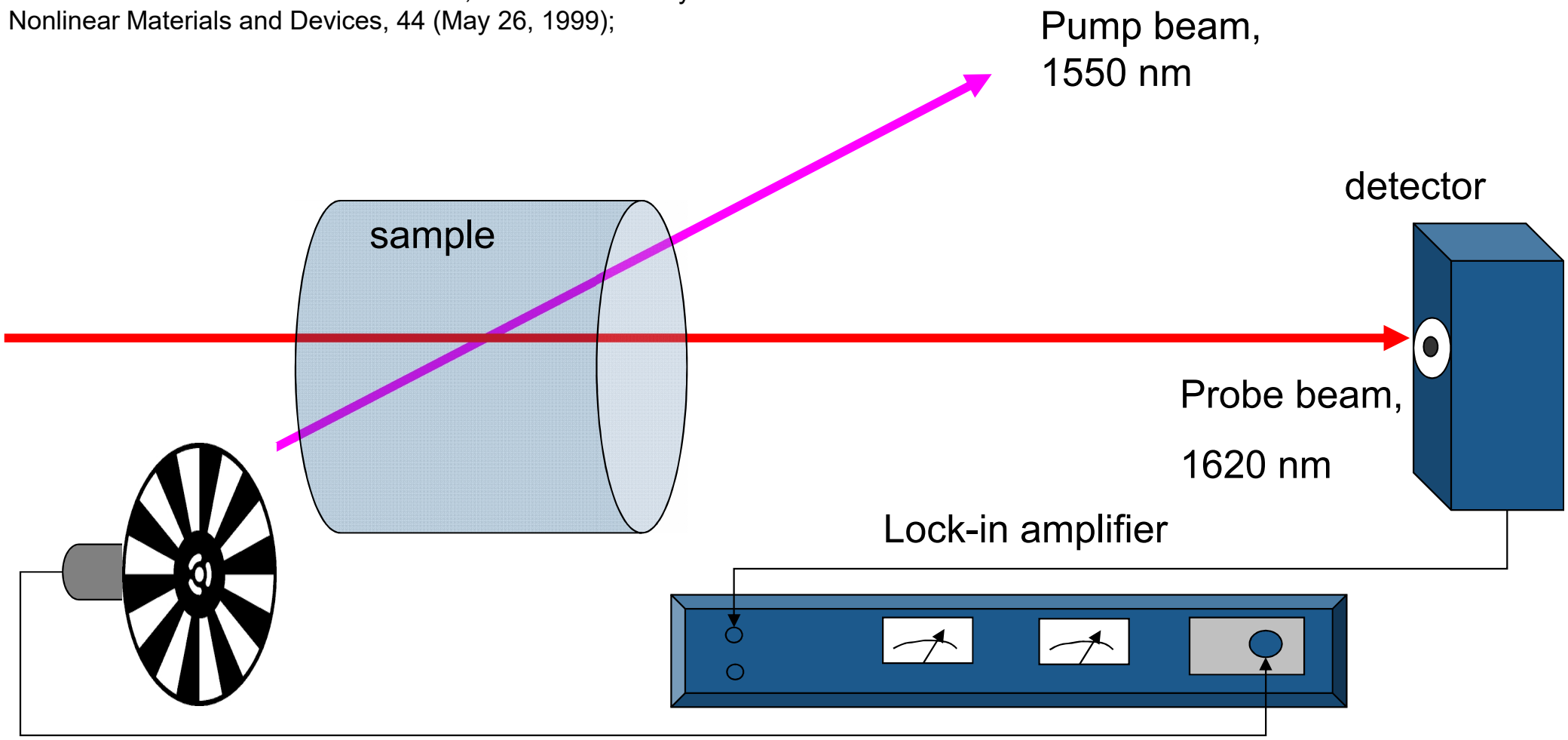
Fused silica substrates (Corning 7979) (∅25 mm, 6.35 mm thick)

Bond is equivalent to a thin film between the two substrates

Bond made using 1:6 sodium silicate solution (0.8 µl/cm^2)

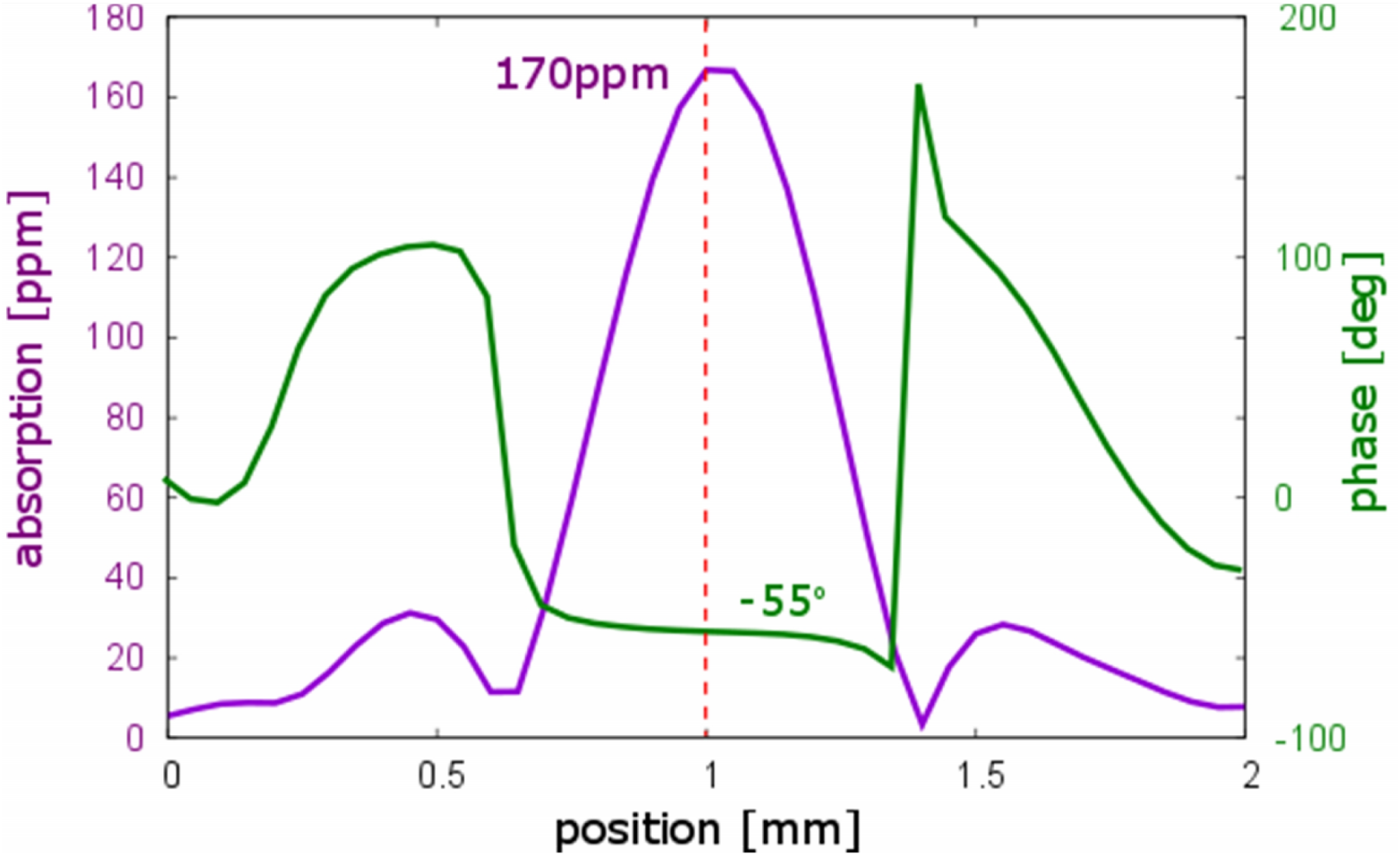
Photo-thermal commonpath interferometry (PCI)

A. Alexandrovski et al. *Proc. SPIE* 3610, Laser Material Crystal Growth and Nonlinear Materials and Devices, 44 (May 26, 1999);



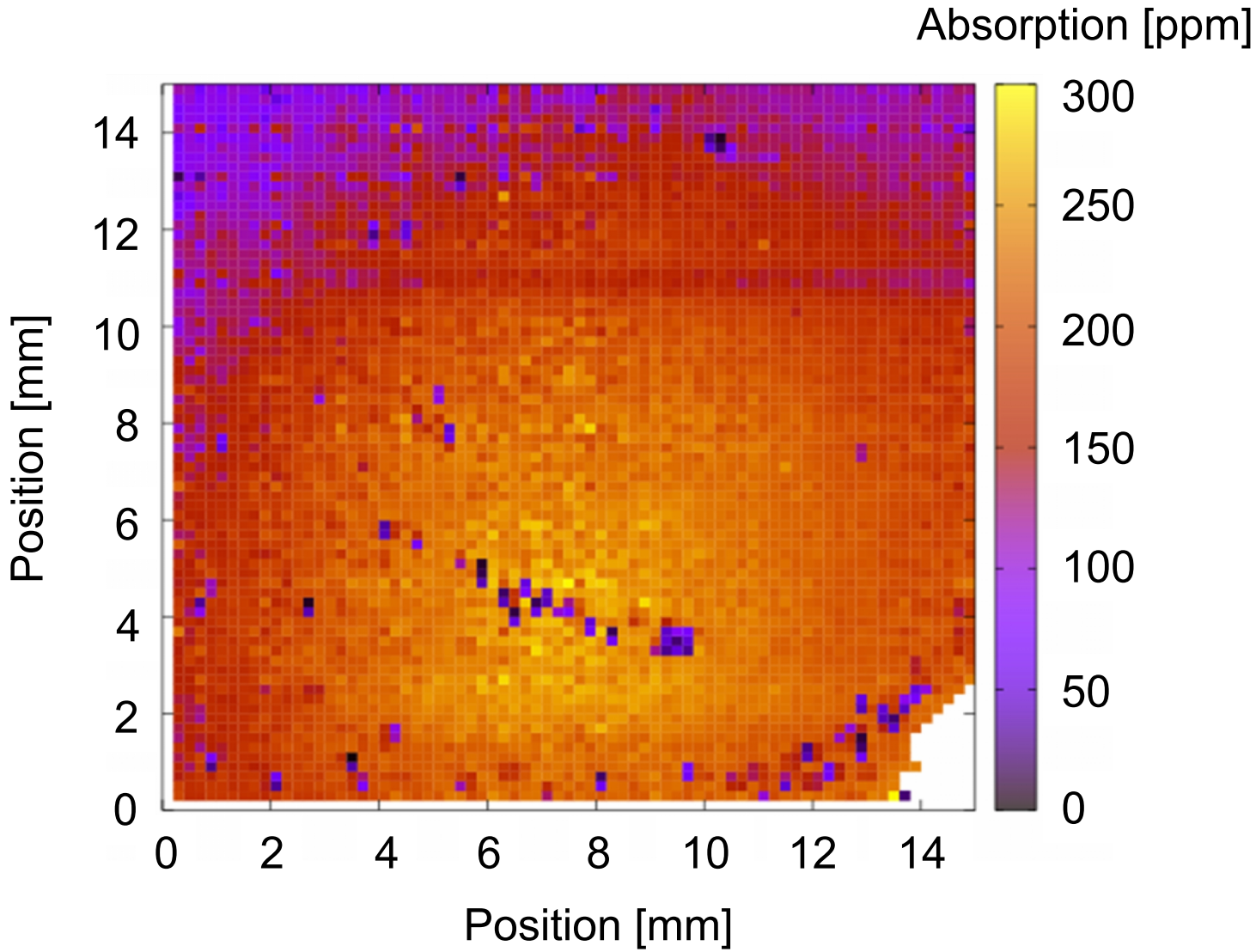
A typical PCI signal

A typical PCI signal:

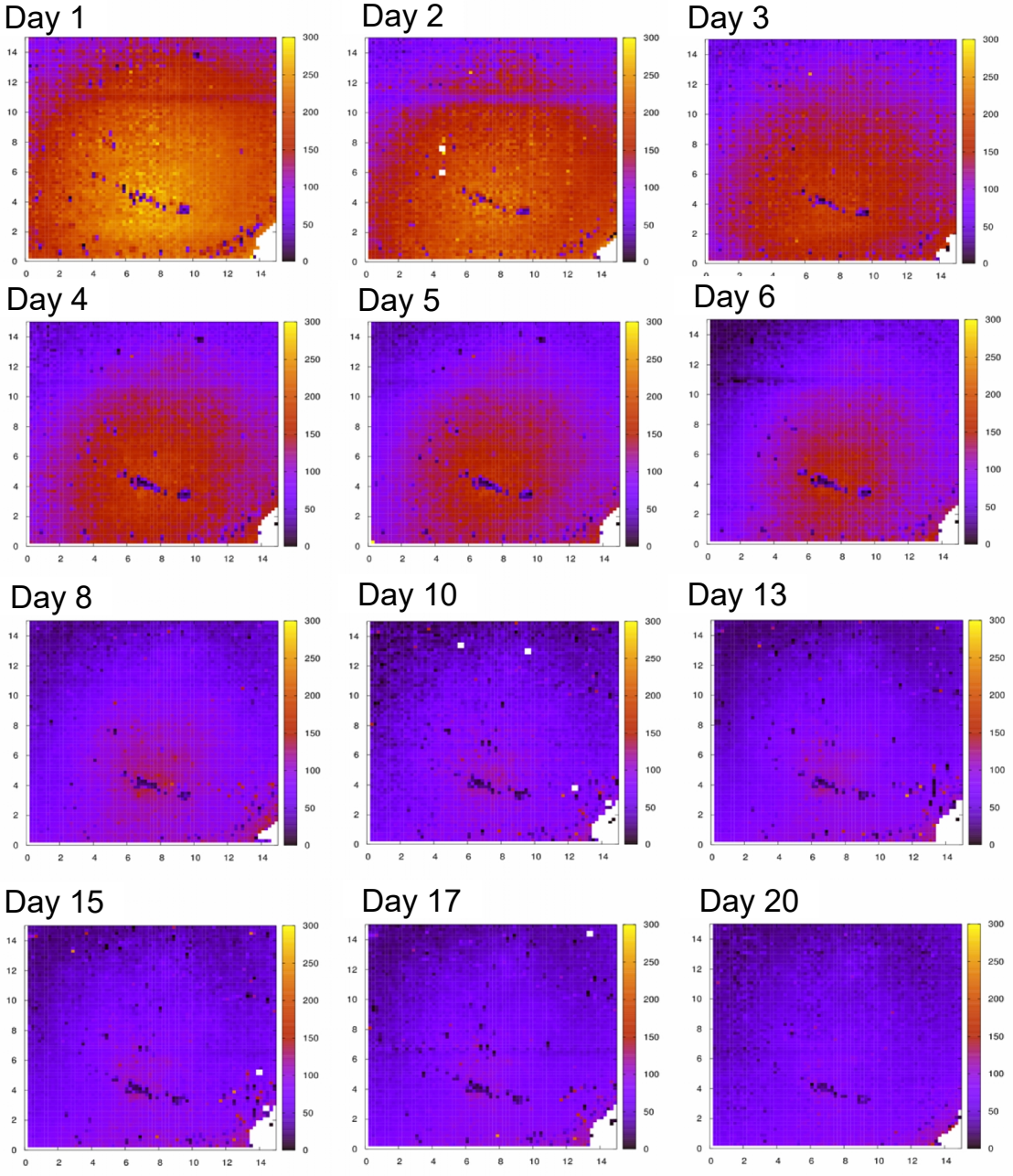


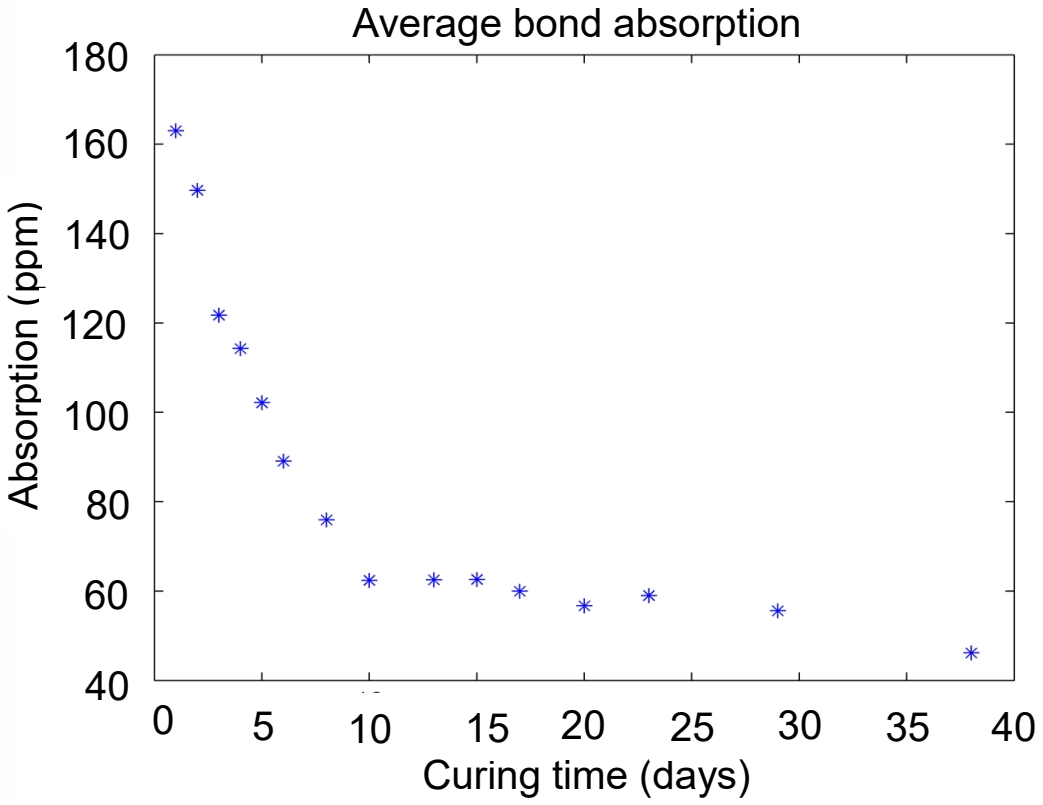
This is an example measurement from the Corning 7979 bonded sample

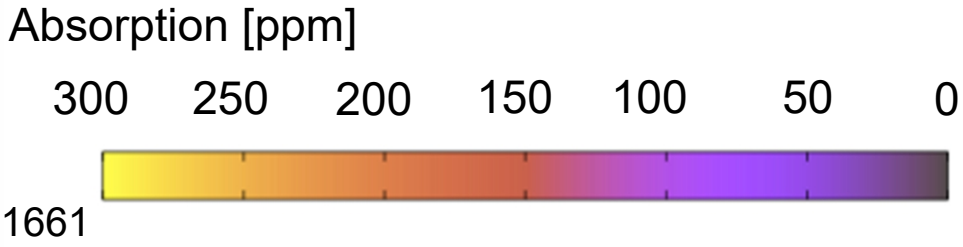
The bond absorption measurement @ 1550 nm



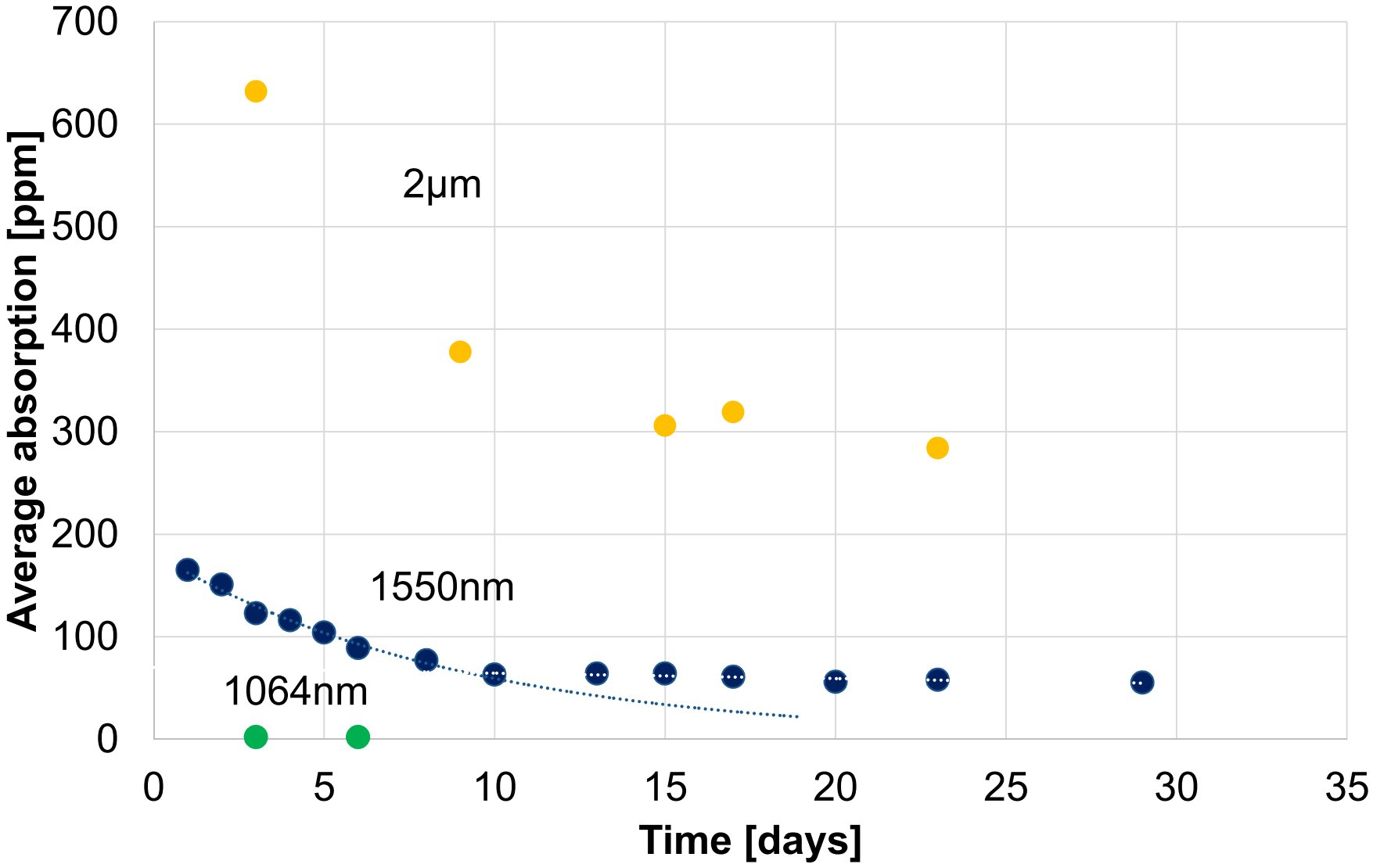
The bond absorption measurement – time development







The bond absorption measurement – different wavelengths



Conclusions absorption measurements

- Absorption measurements of Corning 7979 substrates bonded with 1:6 sodium silicate solution as a function of curing time (about 1 month) show
  - @1550 nm a drop in absorption from 165 ppm down to 55 ppm
  - @ 2 µm the absorption is 5 x higher than @ 1550 nm
  - @ 1064 nm the absorption is < 2 ppm
- Drop in absorption is probably dominated by the migration of water out of the bond area (evaporation)
- Two different apparent mechanisms appear; cause is under investigation
- Reason for baseline level is under investigation; sodium absorption??

How could this be interesting in GW science?

- We have a non destructive measurement method to measure bond thickness which we could potentially develop further to measure bond thicknesses in actual suspensions for more accurate bond thermal noise calculations.

Interesting further afield as well…

- Direct coupling of fibre optics.
- Laser gain medium development.
  - We want low absorption so bonds can withstand high light power levels
  - We want ability to tailor reflectivity levels to optimise optical performance

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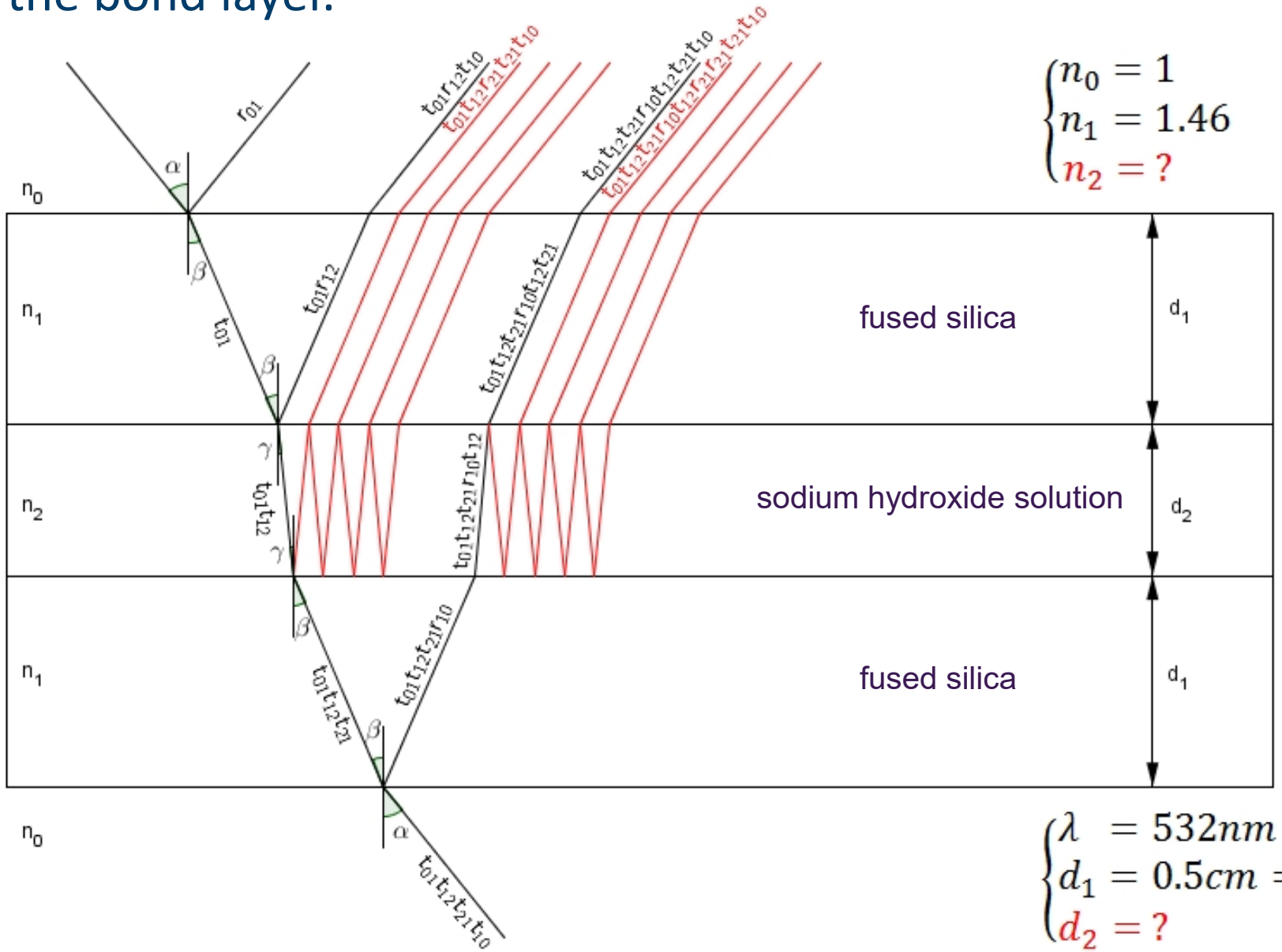
THANK YOU!

Optical reflectivity set-up

Model used is that for Fresnel reflection with thin film interference for the bond layer.



$$\begin{cases} n_0 = 1 \\ n_1 = 1.46 \\ n_2 = ? \end{cases}$$

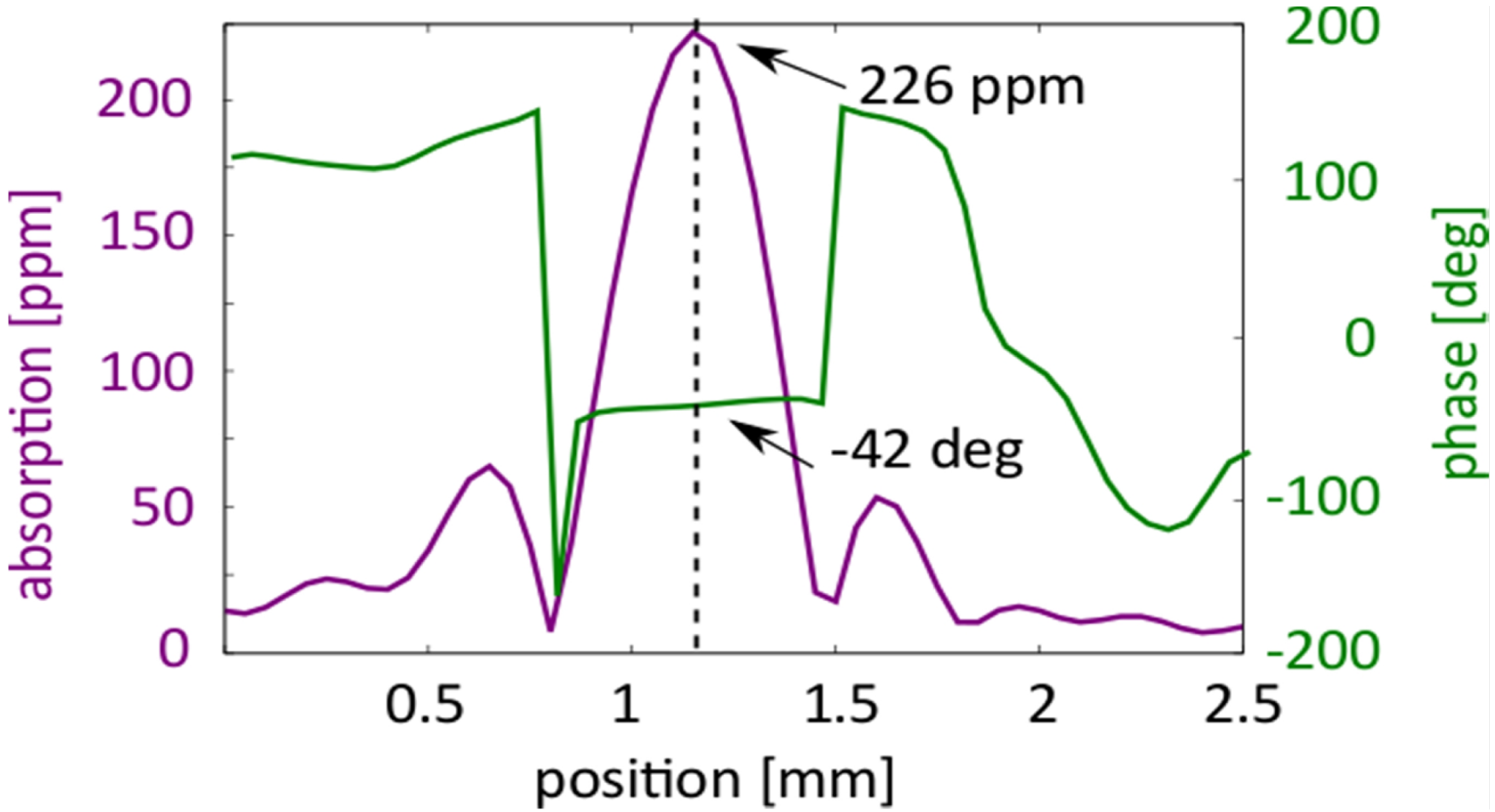
$$\begin{cases} \lambda = 532nm \\ d_1 = 0.5cm = 5 \cdot 10^6 nm \\ d_2 = ? \end{cases}$$

Optical reflectivity set-up

The refractive index of mixed liquids can be considered proportional to the volumes of each liquid used.
Sodium silicate solution is made of Na_2O ~ 10.6% (no effect on the refractive index), SiO_2 ~ 26.5% (n_{SiO2} = 1.55) and H_2O ~ 62.9% (n_{H2O} = 1.33) and, therefore, the refractive index of the sodium silicate solution is: $26.5x1.55 + 62.9x1.33 = 89.4xn_{sodium\ silicate}$ -> $n_{sodium\ silicate}$ = 1.39. The bonding solution is composed of 2 ml of sodium silicate solution and 12 ml of DI water, and its refractive index is: $n_{solution}$ = 1.34. The value obtained is the starting point (within error) of refractive index of the bond material.

A typical PCI signal

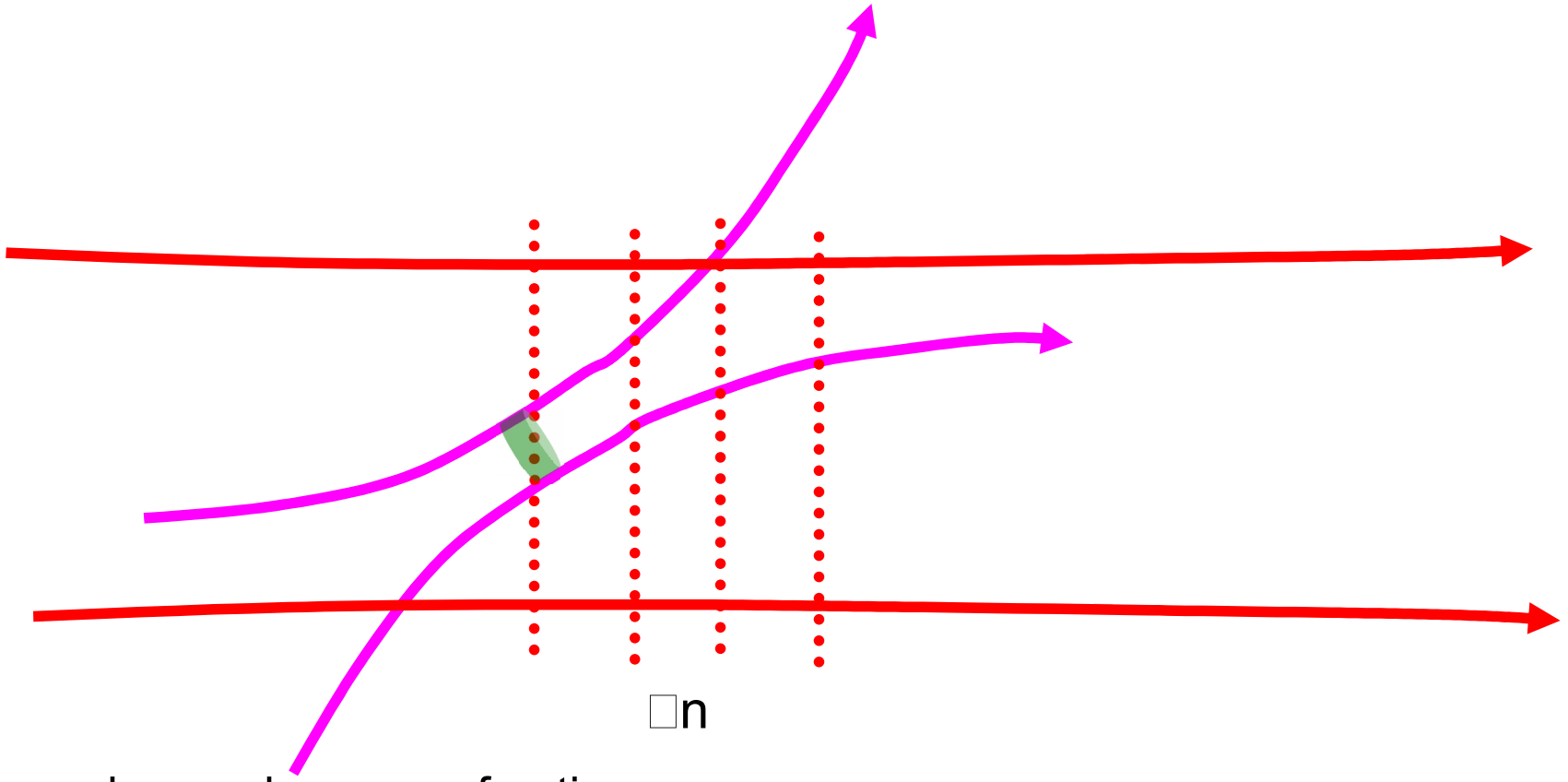
A typical PCI signal:



This is an example from a different sample (silicon nitride) for illustration purposes

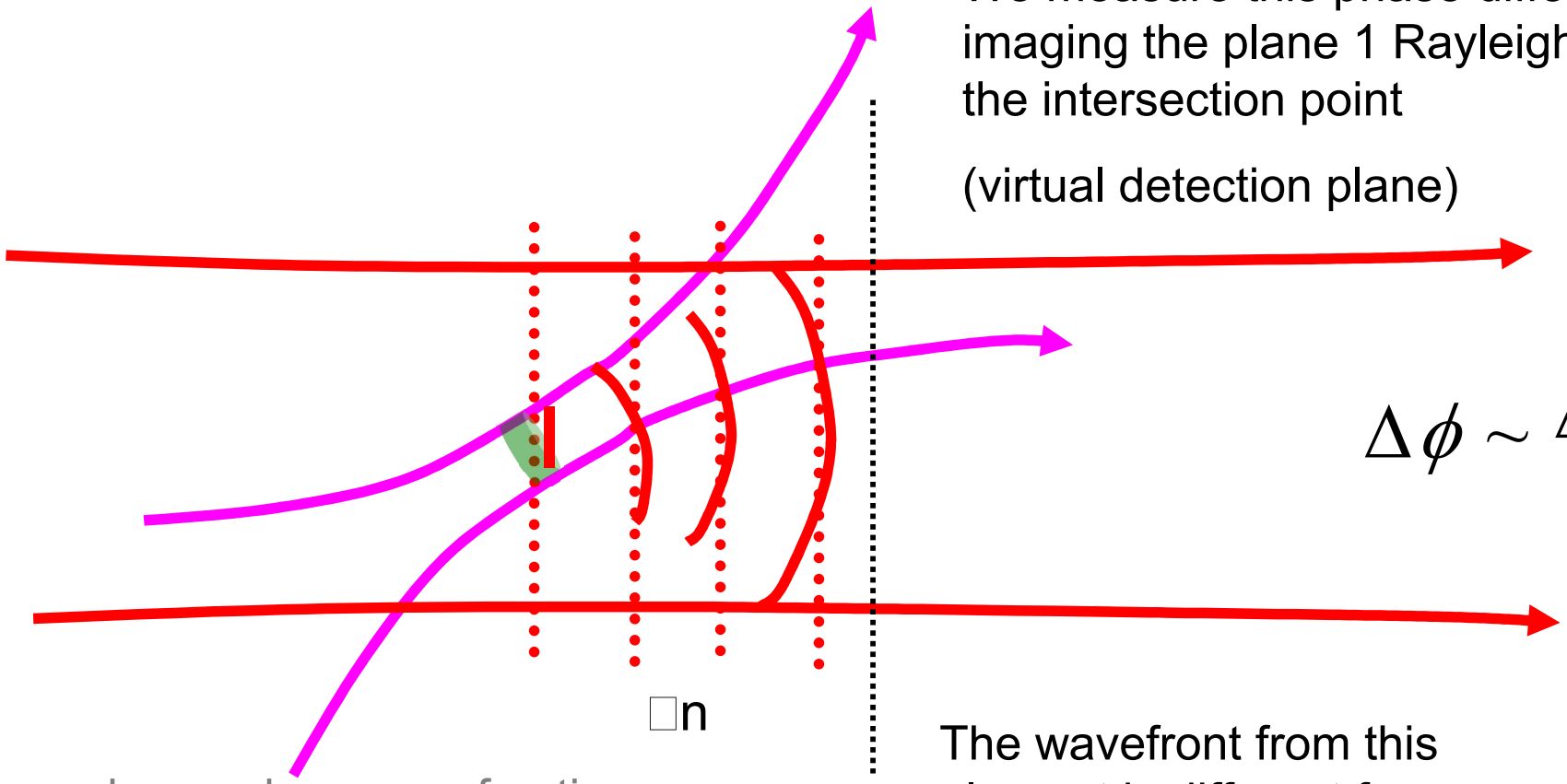
Photo-thermal common path interferometry

The method:



Pump beam changes refractive index of an element in the probe beam

Photo-thermal commonpath interferometry



We measure this phase difference by imaging the plane 1 Rayleigh range from the intersection point

(virtual detection plane)

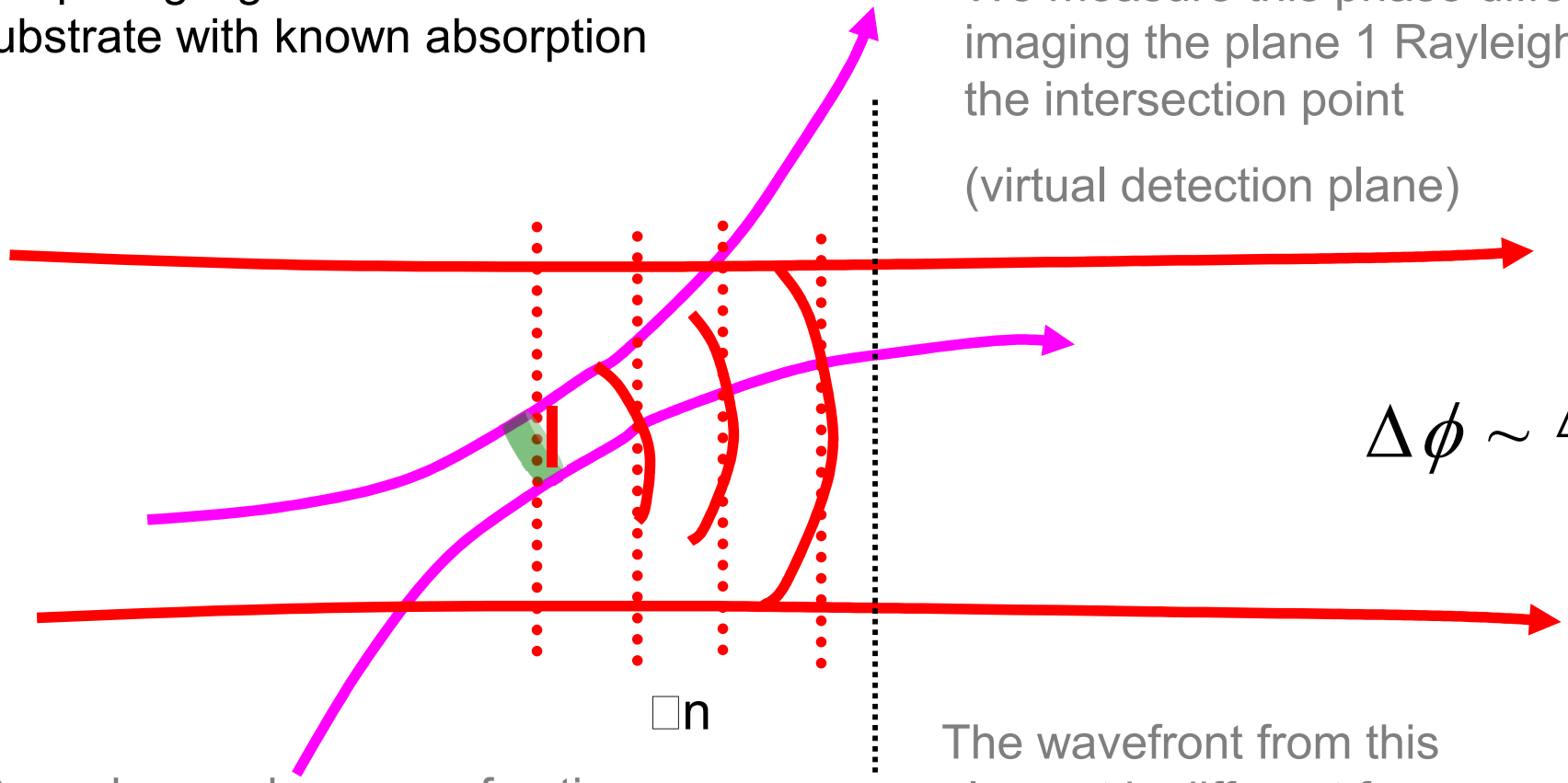
$$\Delta\phi \sim \Delta I / I$$

The wavefront from this element is different from the rest of the beam

Pump beam changes refractive index of an element in the probe beam

Photo-Thermal Commonpath Interferometry

Getting absorption by comparing signal to calibration substrate with known absorption



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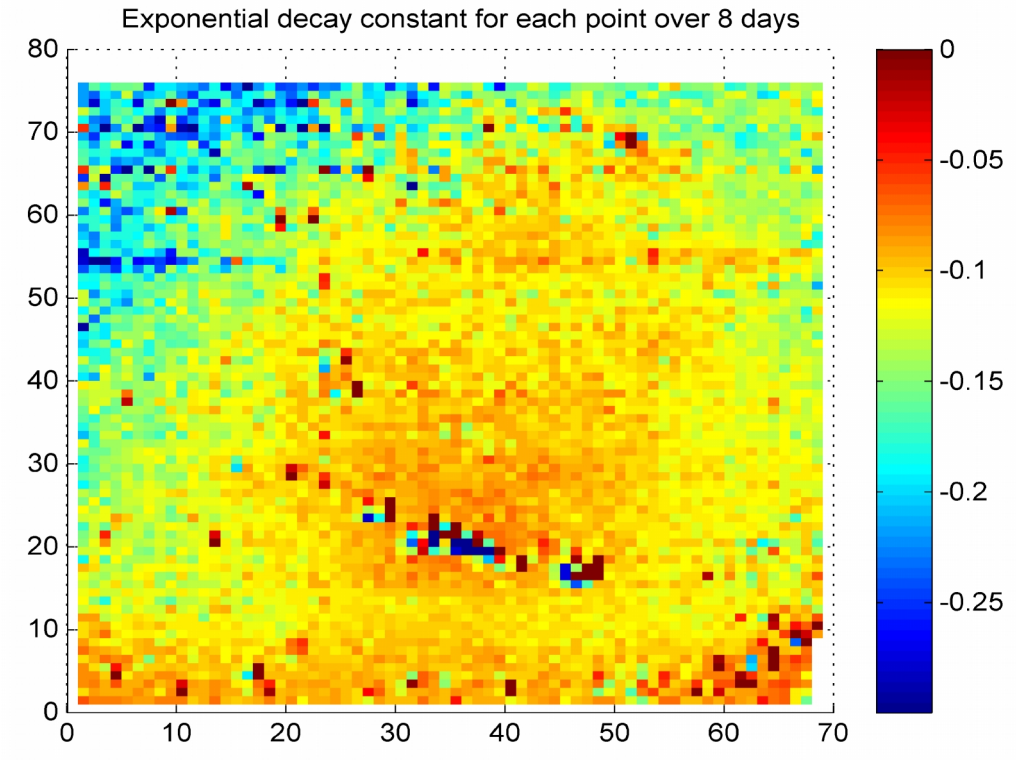

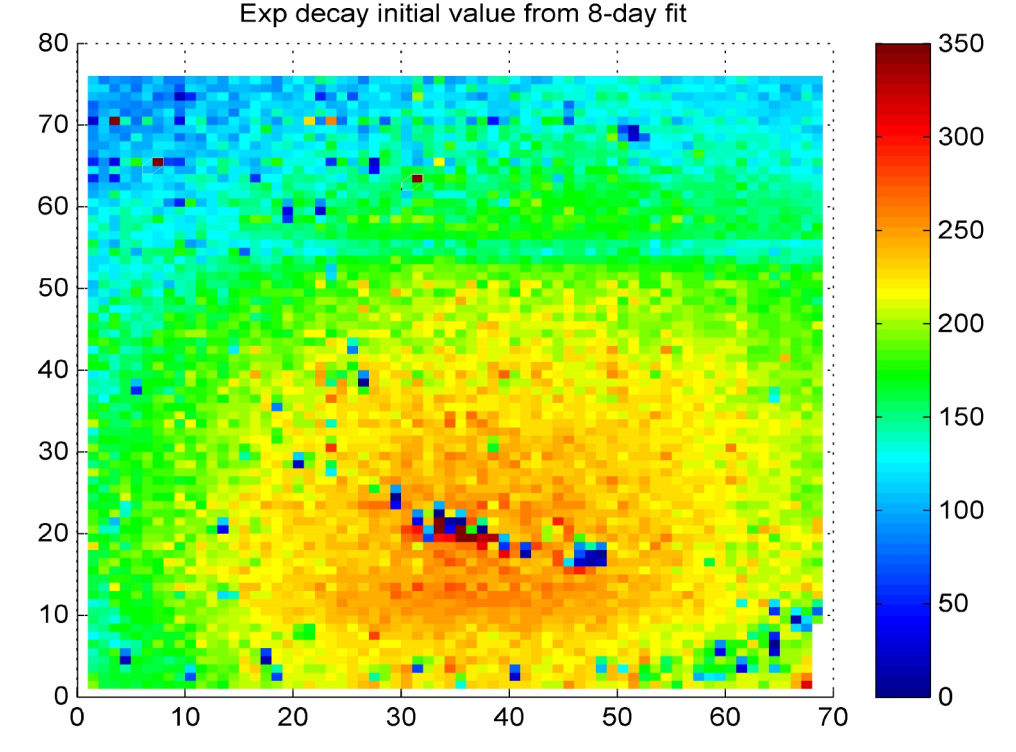

Exponential fit to each point for the first 8 days:

- top: exponential decay constant
- bottom: initial absorption value (in ppm)

- higher initial absorption decreases slower (for most of the area)
- supports assumption of absorption due to water
  - higher water content close to centre of sample: water in centre drifts out slower (further away from edges)
  - ???