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Measurement of the form and layer thickness of the target spheres for inertial confinement fusion

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Pictures: NPL

Outline

- Introduction
  - Proposed measurement solution
- Tactile measurements
  - Probing, procedure, results, conclusion
- Optical Measurements
  - Coherence scanning interferometry
  - Optical coherence tomography
- Outlook

Introduction

- Targets are required to contain the fusion materials (DT) in the form of liquid, solid or/and foam

- The targets are likely to be thin-walled spherical shells in glass or polymer and may have various mounting features

- The key measurement requirements for the targets are:
  - sphericity of the shell
  - thickness of fuel ice layer
  - internal roughness of fuel ice layer

- The nano-crystalinity of the fuel ice must also be measured, as well as the pore size and pore distribution of the foam seed layer

Proposed solution

- CLF, STFC supplied a vial of 10 polymer targets and representative polymer on glass flat samples

- 3 main tools used for measurement:
  - Zeiss F25 micro co-ordinate measuring machine (micro-CMM)
  - coherence scanning interferometer (CSI)
  - optical coherence tomography instrument (OCT)

  - laser scanning confocal microscope (LSCM) for inspection


Tactile measurements
- probing forces
- measurement procedure
- results
- conclusions

Picture: NPL

Probing forces

Picture: NPL

- Target fabrication always demanding non-invasive metrology

- However state-of-the-art µCMMs now promising low contact tactile measurement – forces ~ 10 mN

- F25 probing force < 5 mN
  - 3 mN on contact
  - 1.6 mN during measurement

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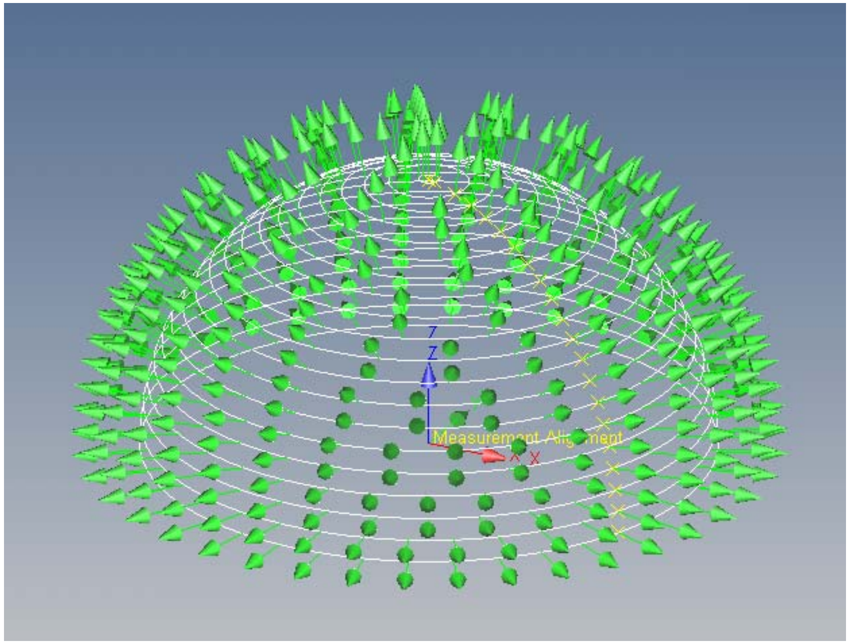
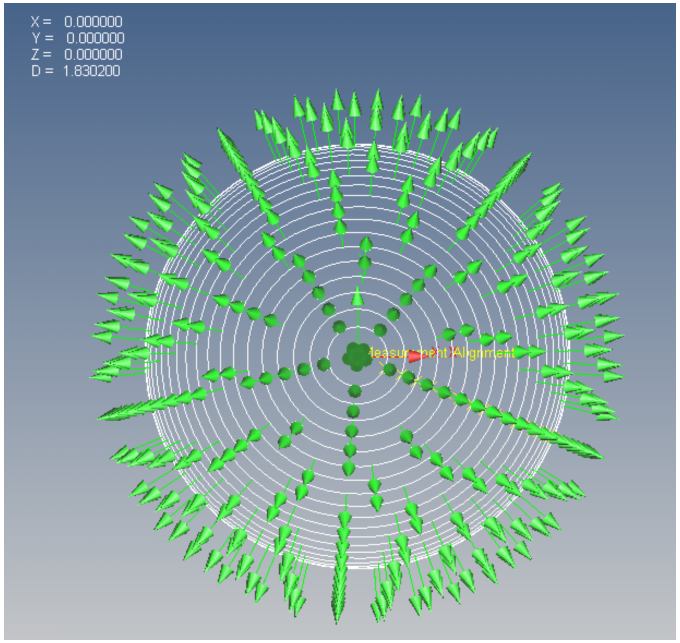
How low is low enough?

Picture: LSCM at NPL

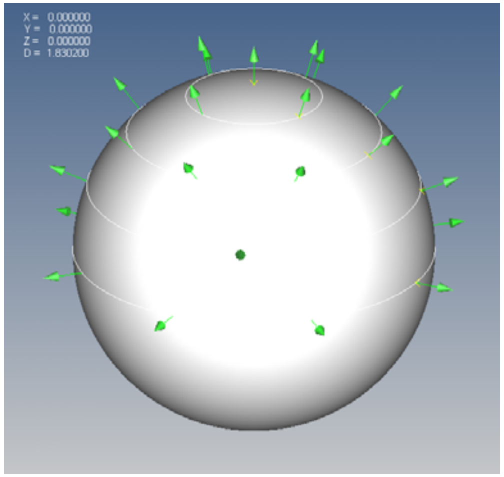
15 mN probing

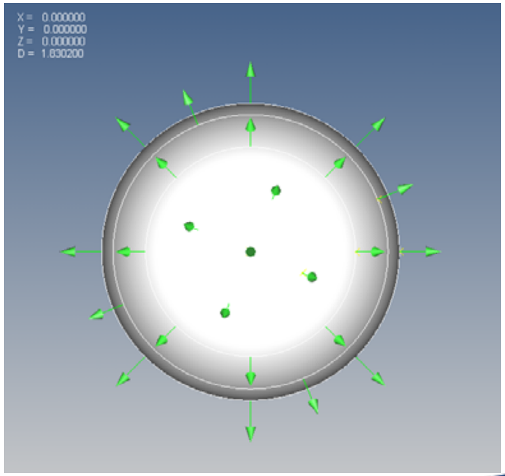
- Mounted the sphere within the volume of the F25
- From a set of single point measurements (not scanning) we wanted to extract:
  - Diameter
  - Form
- Two measurement strategies were trialed
  - 25 points – as suggested in ISO 10360
  - 395 points – evenly distributed





- 395 points – better for form





- 25 points – ideal for diameter

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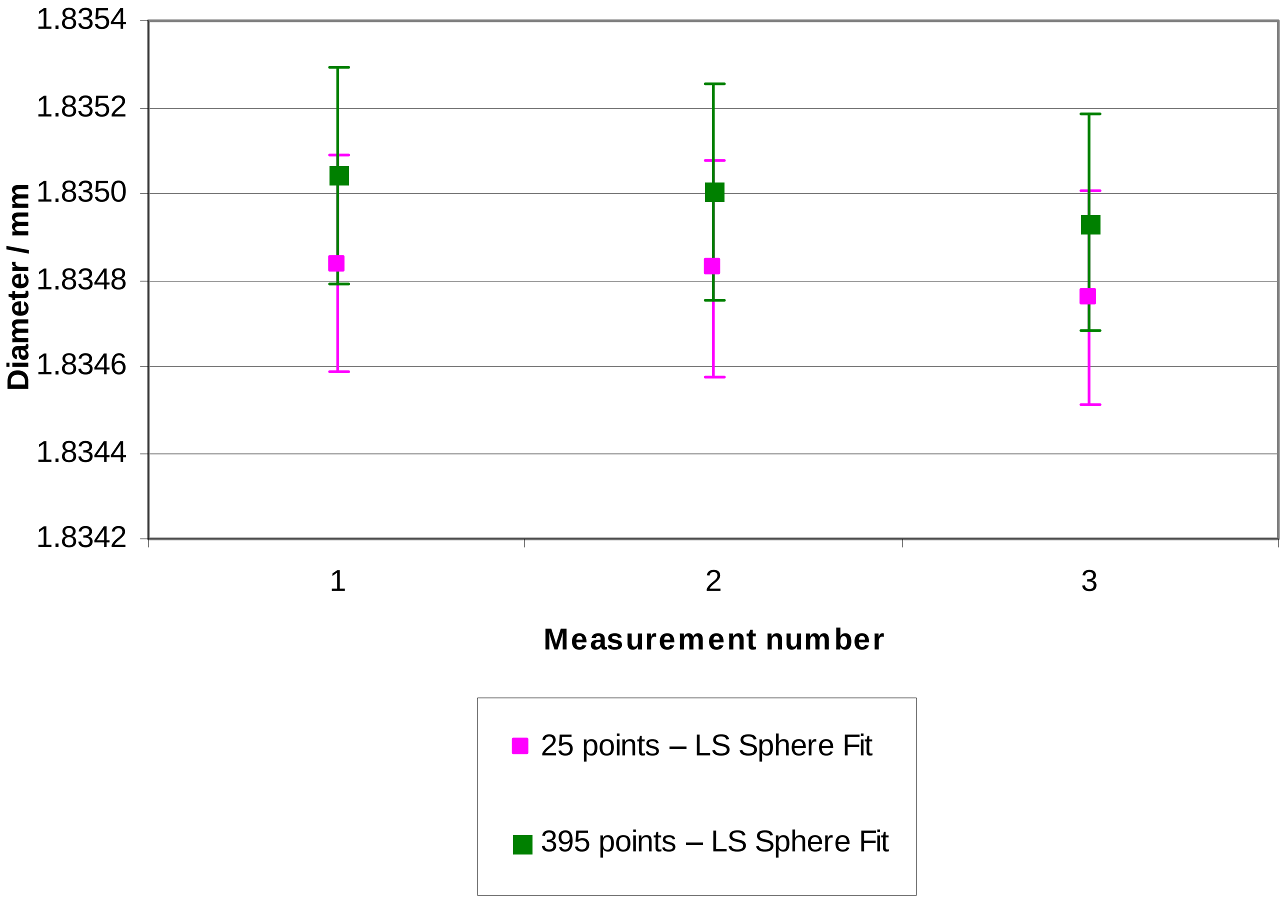
Results



- Diameter measurement
- Invariant to measurement procedure (± 250 nm)

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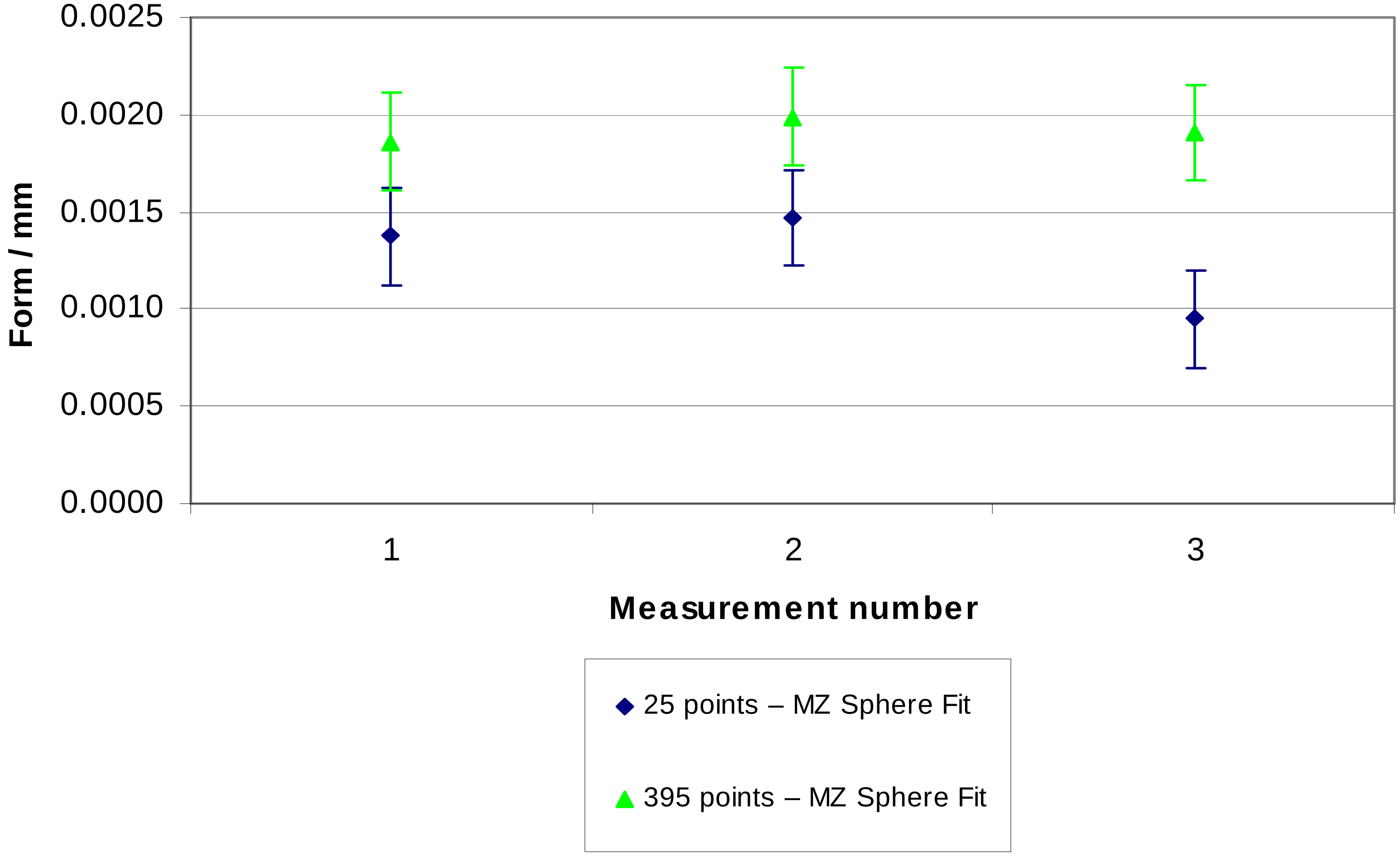
Results



- Form measurement
- Dependant on measurement procedure
- 395 point measurement likely to be more accurate

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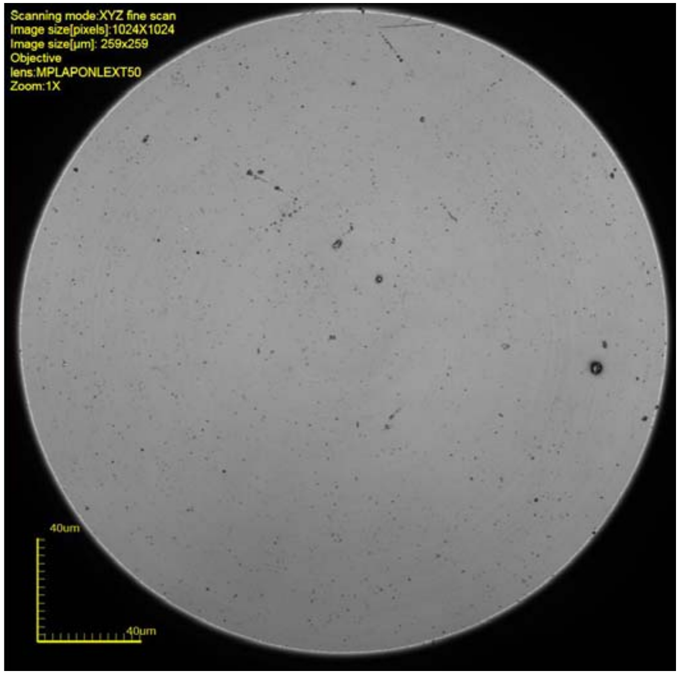
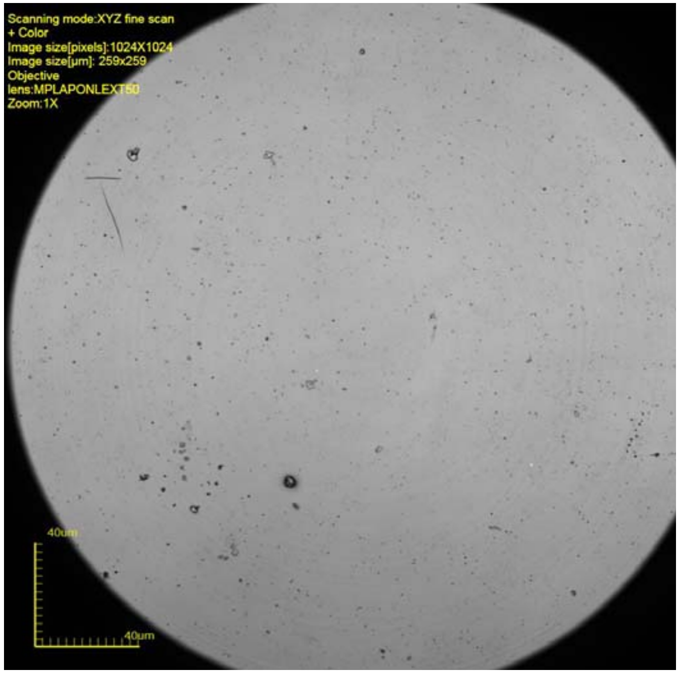
Forces: How low is low enough?

external surface



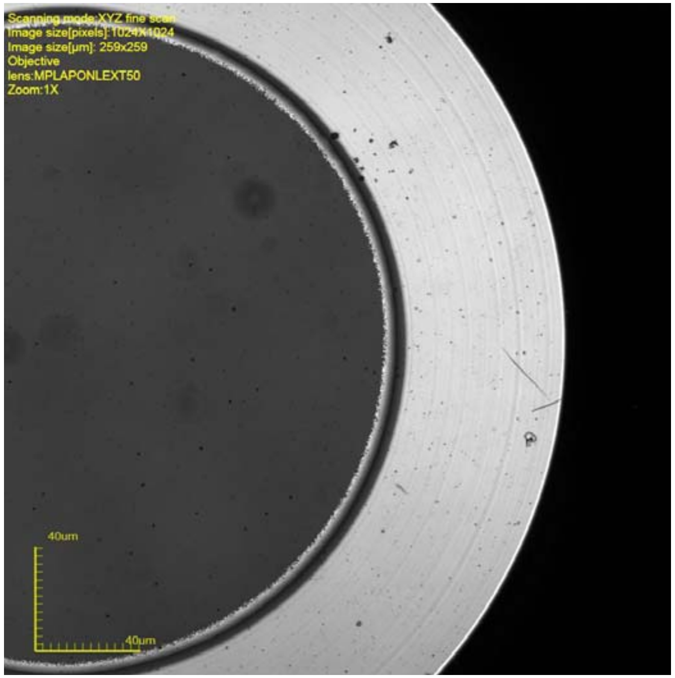


Pre-measurement

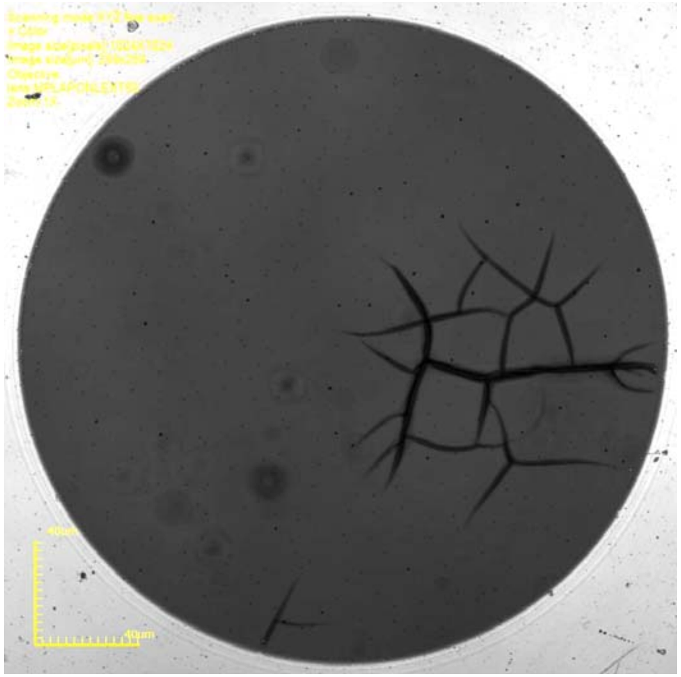
Post-measurement

Forces: How low is low enough?

<u>internal surface</u>



Pre-measurement



Post-measurement

Forces: How low is low enough?

Answer: Not low enough!

Solution:

- The F25 ***might*** be able to probe at lower forces – ~1 mN
- Low force probes exist, but they are not capable of 3D measurement
- NPL is developing a true 3D non-contact micro-CMM probe

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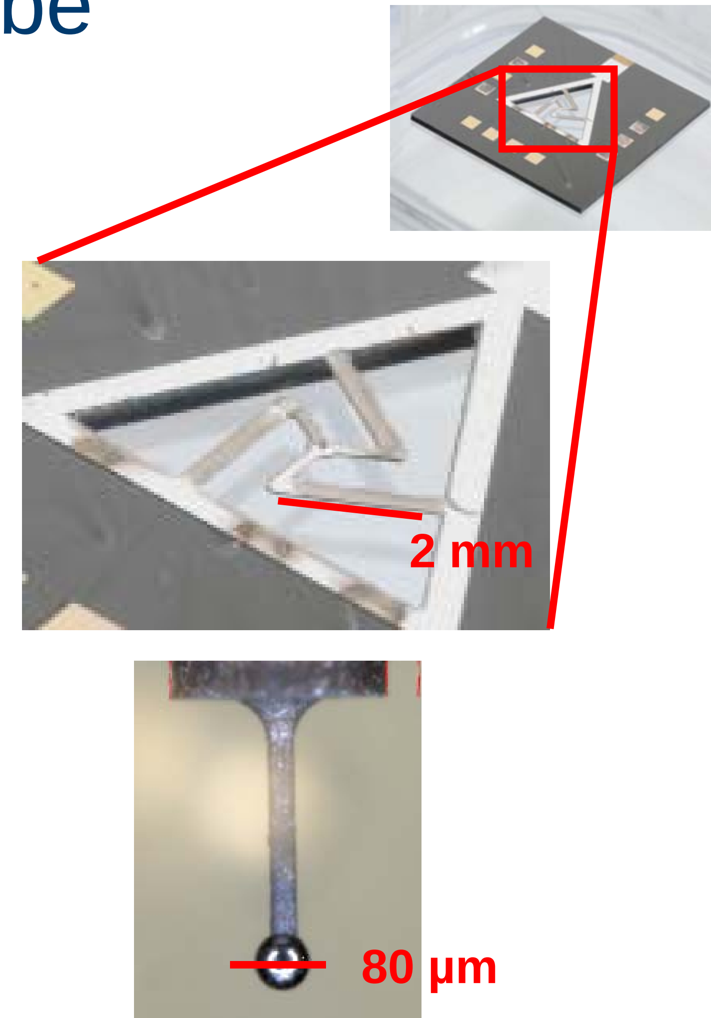
A vibrating micro-CMM probe

- Aims to bring tactile CMM probe technology in-line with current state-of-the-art micro CMMs
- Accuracy:
  - Current micro-CMM probes ~200 nm
  - Current micro CMMs < 20 nm
  - Aim for vibrating micro-CMM probe < 50 nm
- Triskelion device, Ni flexures, PZT actuators and sensors
- 70 µm diameter sphere attached to 50 µm diameter, 2 mm long shaft
- Vibration of device controlled to be normal to the measurement surface and to also “counteract” the surface forces.



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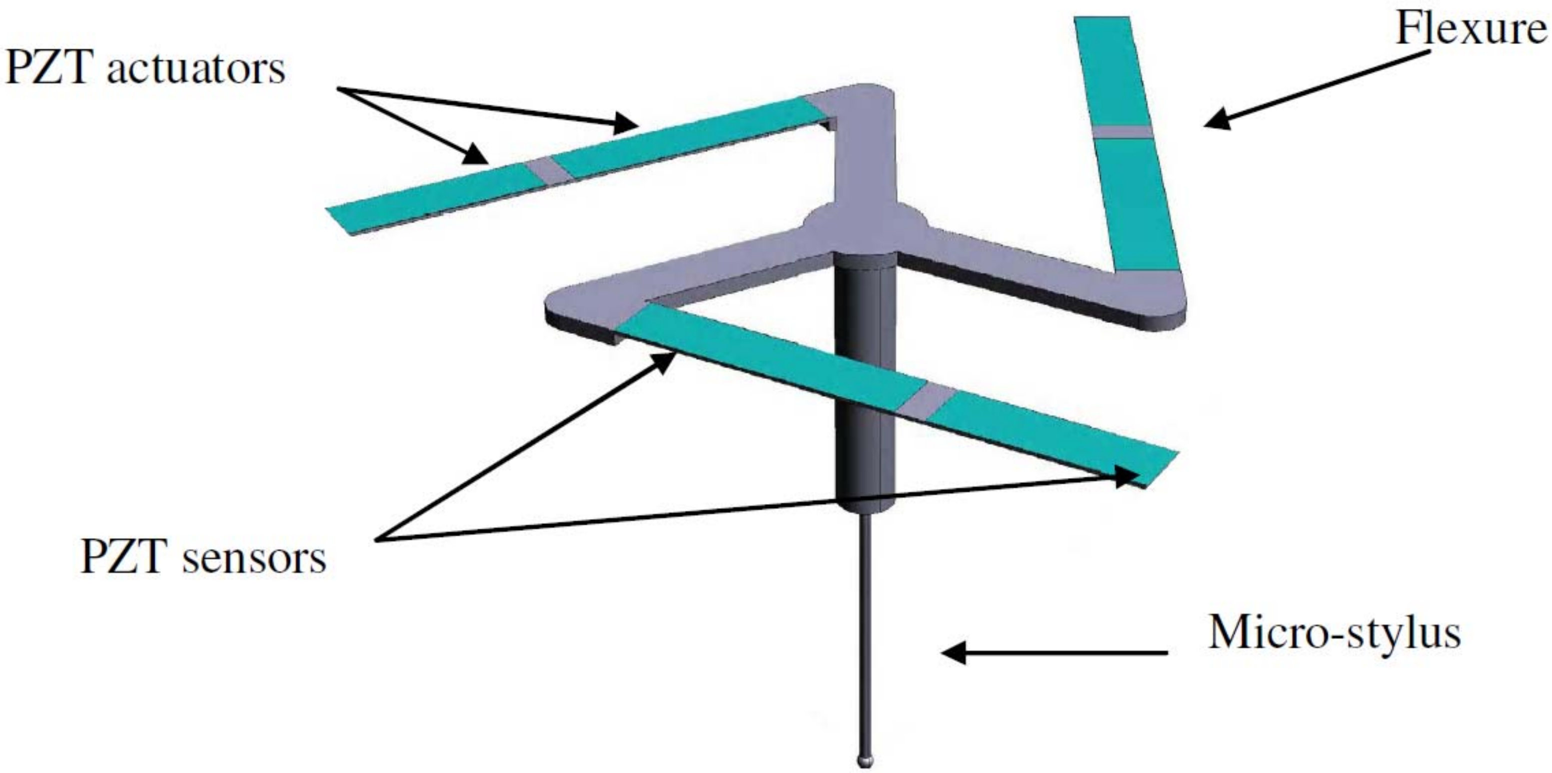
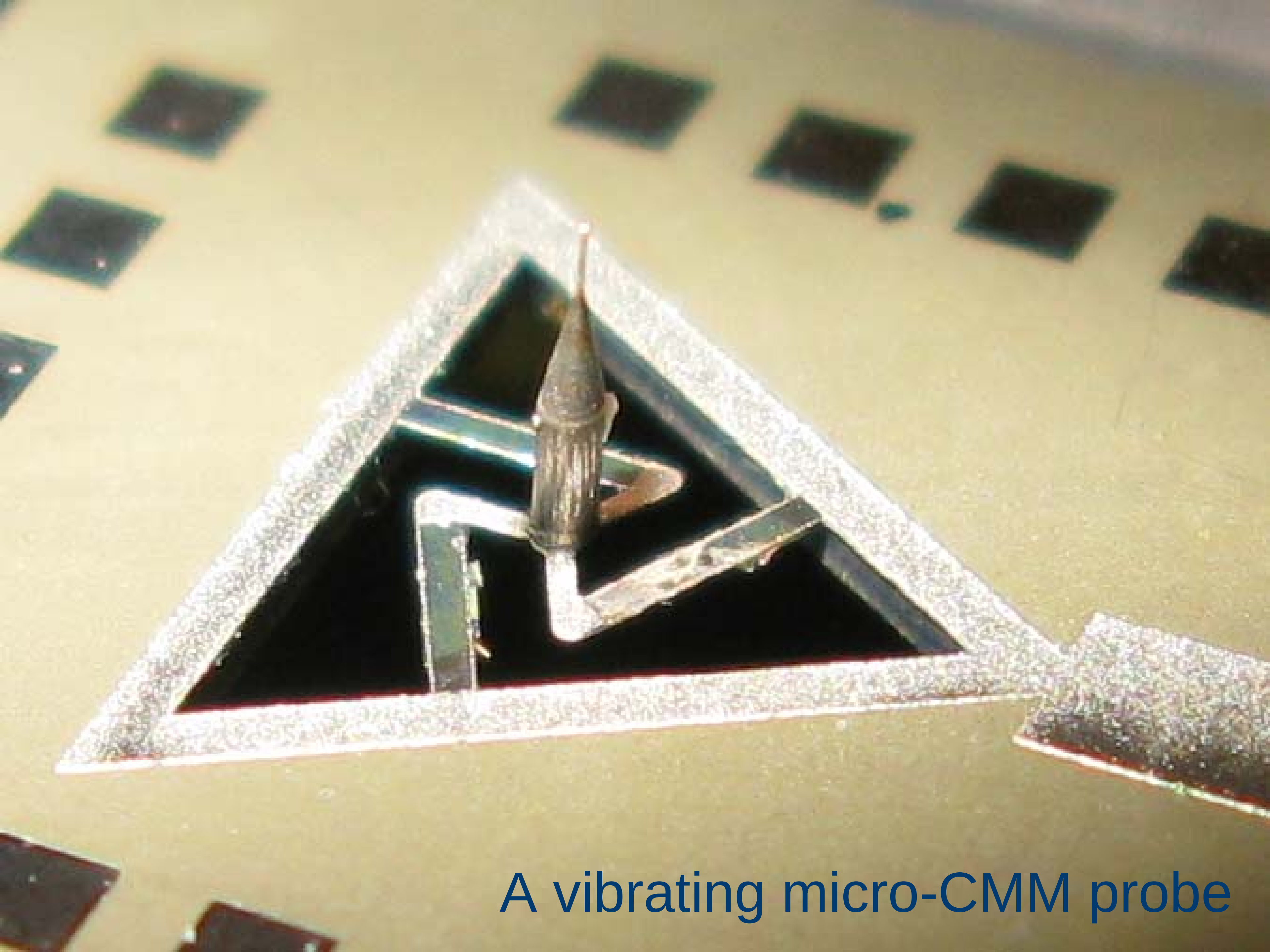
The NPL vibrating micro-CMM probe



Pictures: NPL



A vibrating micro-CMM probe

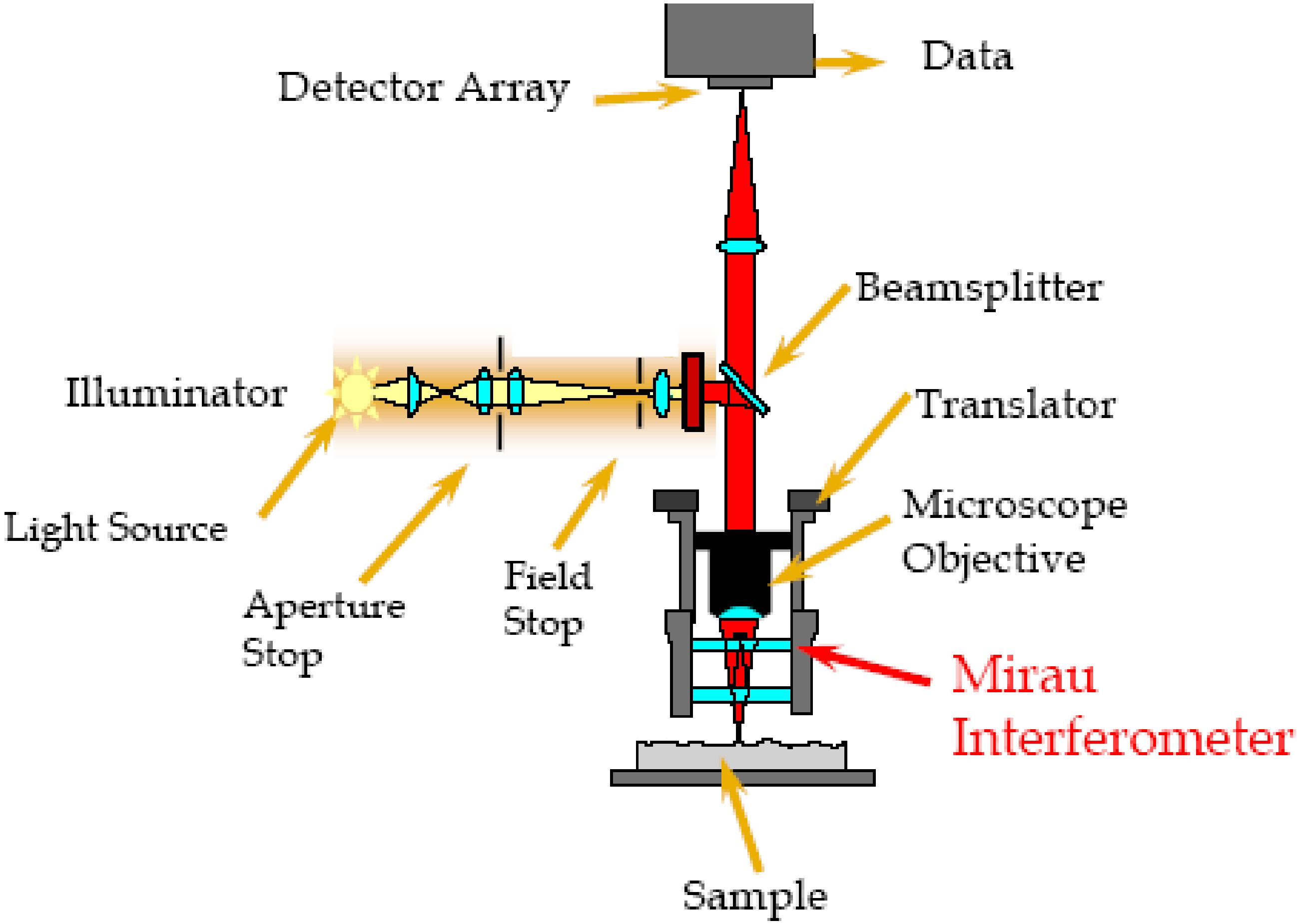
Optical measurements

- Used to measure
  - the thickness of representative flat polymer on glass samples
  - 1.8 mm diameter polymer shells

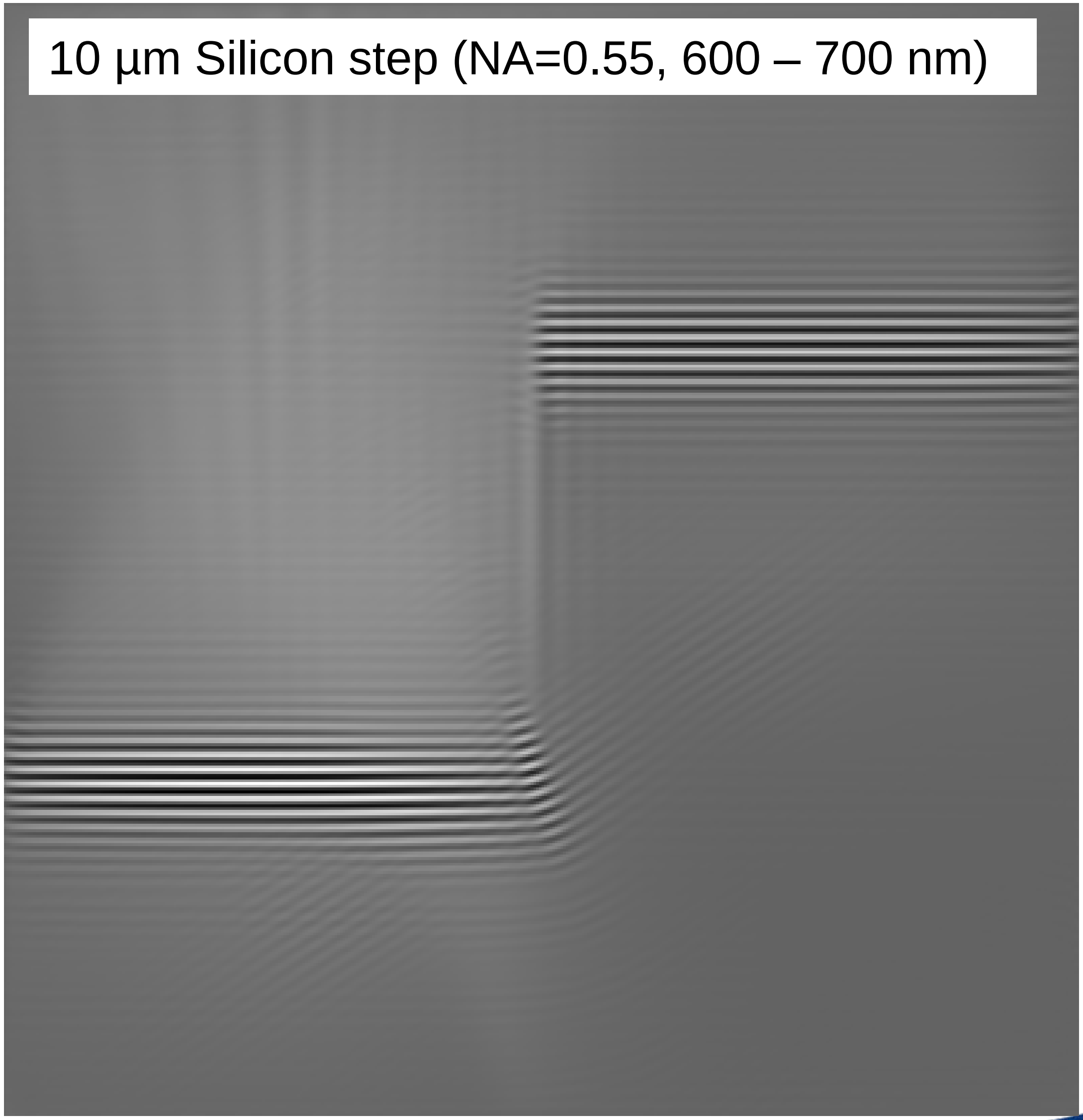
- Coherence scanning interferometry
  - a white-light interference microscope that scans the object through focus
  - increasingly popular method used to measure surface profile

- Optical coherence tomography
  - a scanning Michelson interferometer that records the intensity modulation in the interference as the source changes frequency

Optical example
- coherence scanning interferometer



Step Interferogram



The information present in the interferogram is related to

- the step height by estimating the position of peak visibility (called vertical scanning interferometry (VSI) mode)

And/or

- the phase of the interference fringes (called phase shifting inteferometry (PSI) mode).

Some SWLI limitations

- Edge Artefacts – The Bat Wing Effect
- Ghost Steps – Dispersion Effects
- Material Effects
- Multiple Scattering / Surface Roughness Measurement

Gao F, Leach R K, Petzing J,Coupland M 2008 Surface measurement errors using commercial scanning white light interferometers *Meas. Sci. Technol*. **19**

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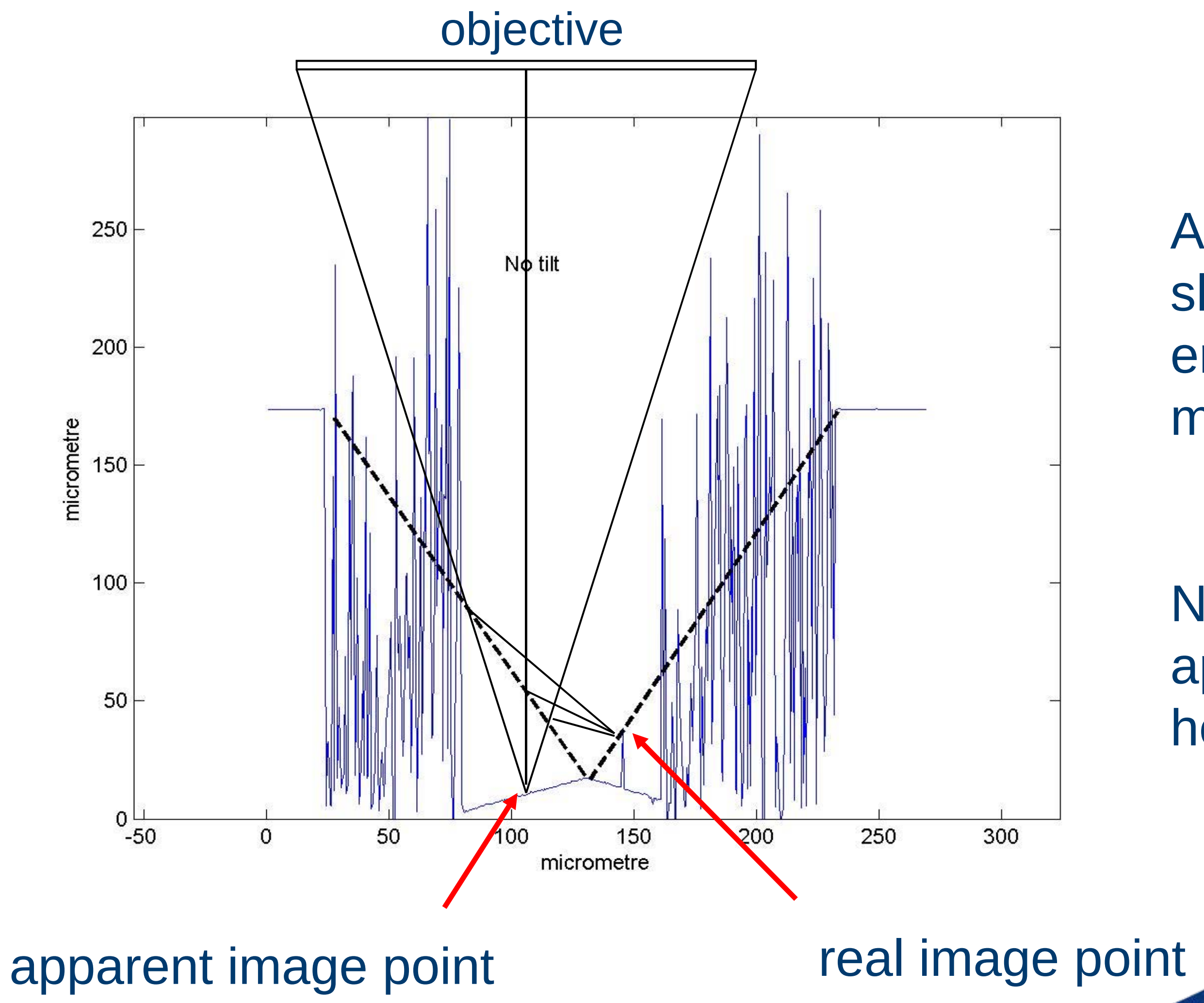
Optical limitations – vee-groove example

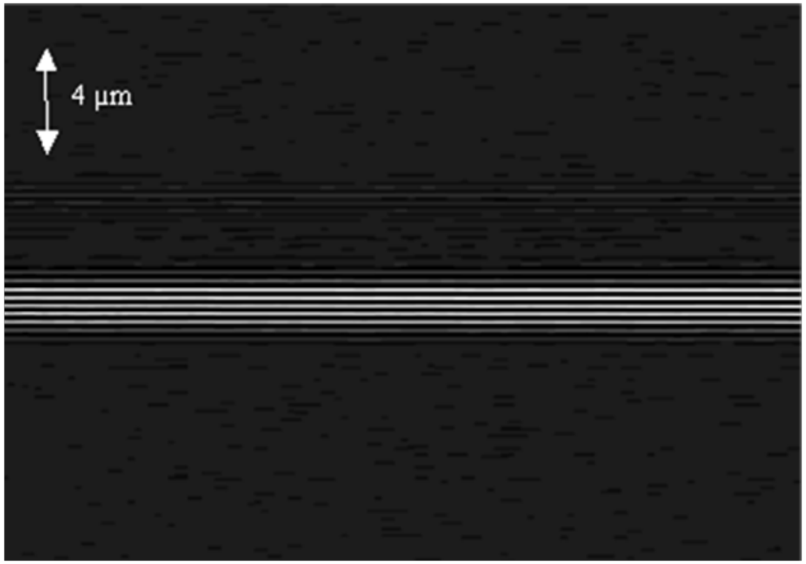


A basic ray analysis shows this type of error is due to multiple reflection

Note the error is approximately 100 μm here!

CSI

- Zygo Newview 5000 CSI fitted with a 0.55NA objective (50×), which gives a lateral resolution of around 0.5 µm
- the raw interference data (interferograms) were taken from the instrument and processed in MATLAB™



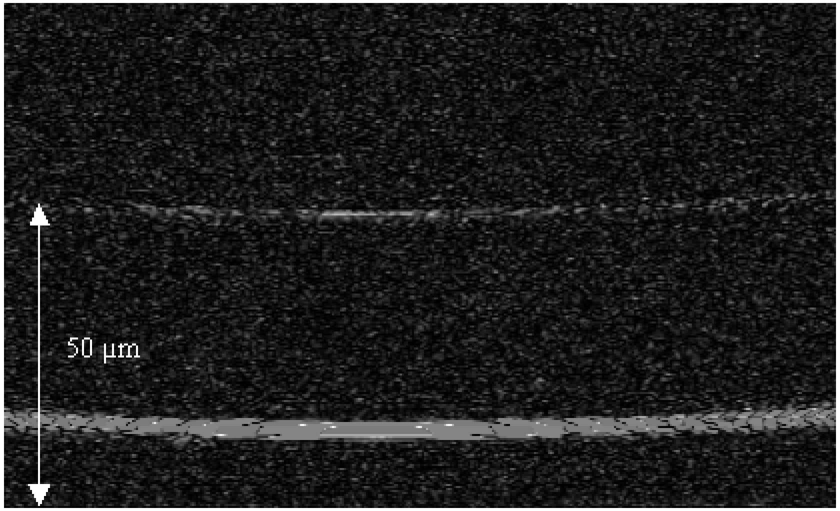
Air/polymer interface

Glass/polymer interface

Separation measured at ~ 4 µm

2 µm thick polymer layer on glass

CSI



40 µm thick polymer sphere – 1.8 mm dia

Air/polymer interface

Polymer/glass interface

Should have same level signal, but the do not

CSI

- Not measuring what was made… why?

- Coherence scanning interferometry can be used to measure the *external* surfaces of the targets to nanometre precision

- HOWEVER: Care must be taken when measuring the internal surfaces

  - Aside: Confocal microscopy can be considered to derive 3D information from the response of the object to a set of different wavefronts while OCT derives its image from the response to differing frequencies.

- When using a large numerical aperture objective, CSI uses a combination of both approaches to form an image, and evidence for this is apparent in the results obtained here.

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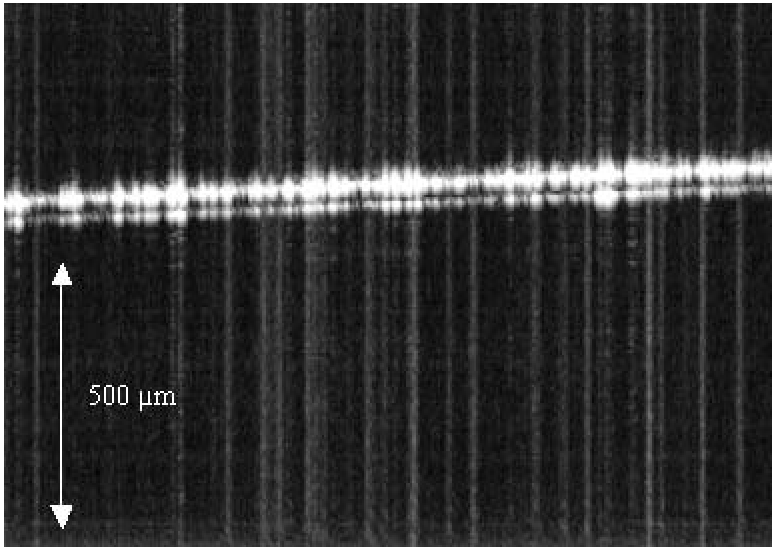
OCT

- OCT system used for this work was a Thorlabs swept source instrument operating at 1325 nm
- Compared with CSI, OCT has relatively poor lateral resolution (25 µm). The axial resolution depends on the source bandwidth and in this case is specified to be 12 µm (in air)



Air/polymer interface

Polymer/glass interface

Only resolvable sample. Could not resolve 10 µm or below

20 µm thick polymer on glass (TILTED)

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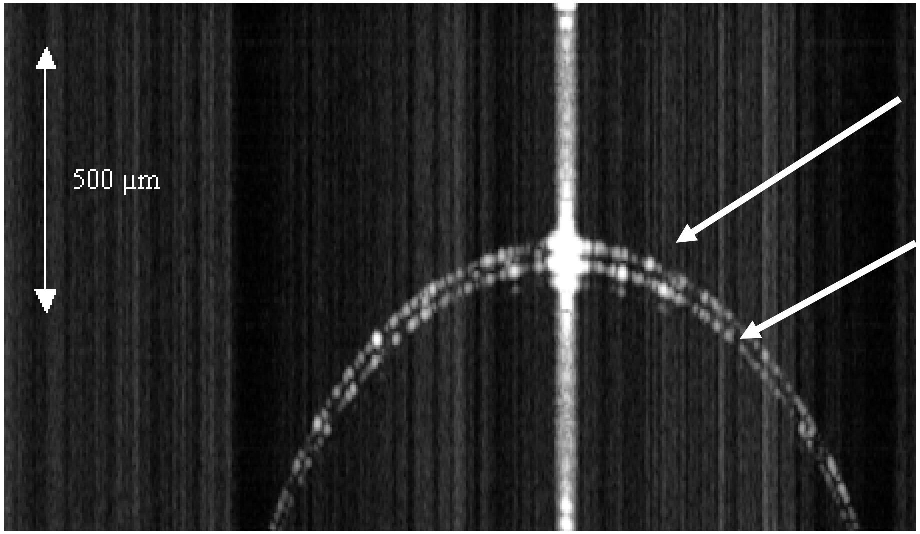
OCT



40 µm thick polymer shell

The central line is due to the large specular reflection that was not observed with the tilted glass samples

OCT

- the OCT system for the case of the 20 µm coating and the target clearly shows the internal surface

- however, the instrument essentially measures the optical path length along the line of sight which will deviate as it passes through each interface and for this reason the thickness of the target appears to be less at the edges

- so the 20 µm coating appears to be about 32 µm thick

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Outlook

- Tactile
  - Current low force probing is not low enough
  - New probes are being developed
  - There is hope for tactile measurement of the external geometry of these targets
- Optical
  - CSI, confocal and OCT can be used to measure the target geometries and films
  - But the commercial instruments will need to be modified (source, polarization)
  - Can use inverse modelling with a priori data to get more information than conventional CSI

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Thank you for your attention

I will be happy to answer any questions

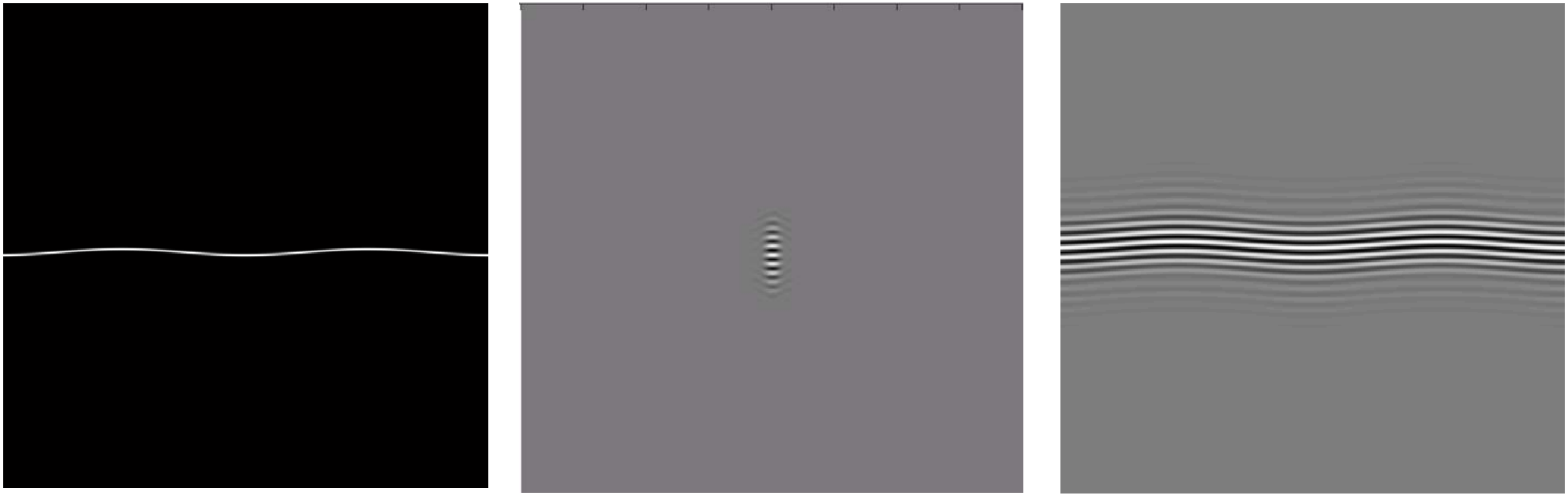
Also, please do not hesitate to contact James:

james.claverley@npl.co.uk

Can we calibrate an optical profilometer?

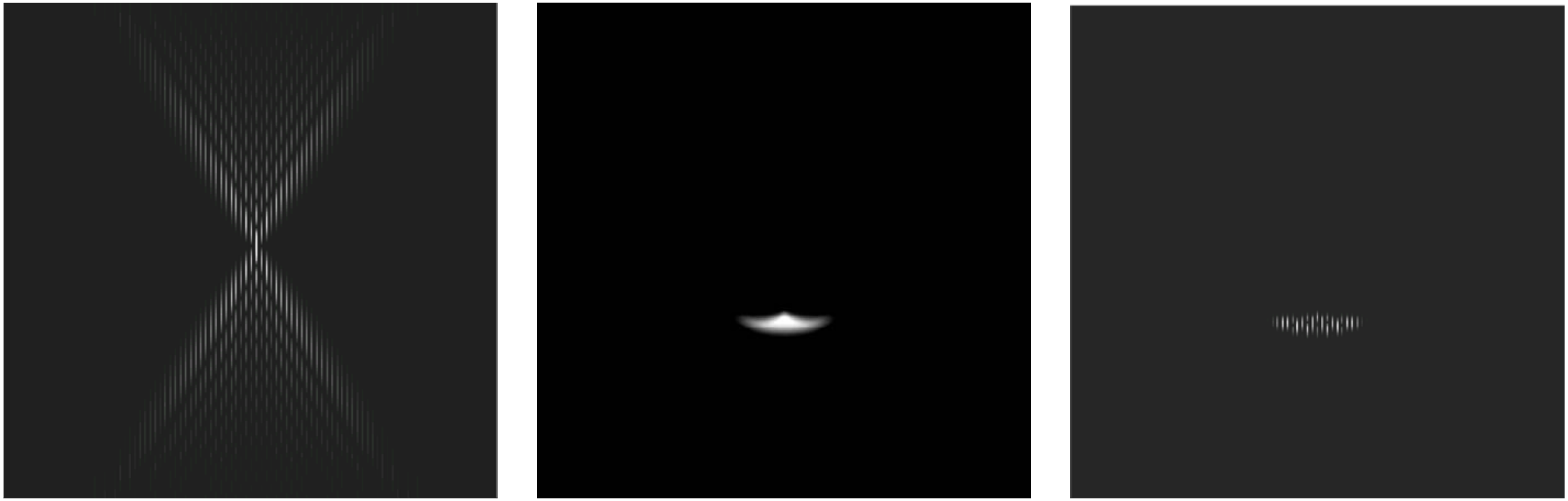
- Yes, we think so…
- But let's think about the question…
- We can calibrate the lateral and axial scales (for linearity) using calibrated specimens. We can measure a sample with "known" surface roughness.
- But can we then go one to measure a complex rough surface?
- What about traceability?

Linear Theory: The Foil Model



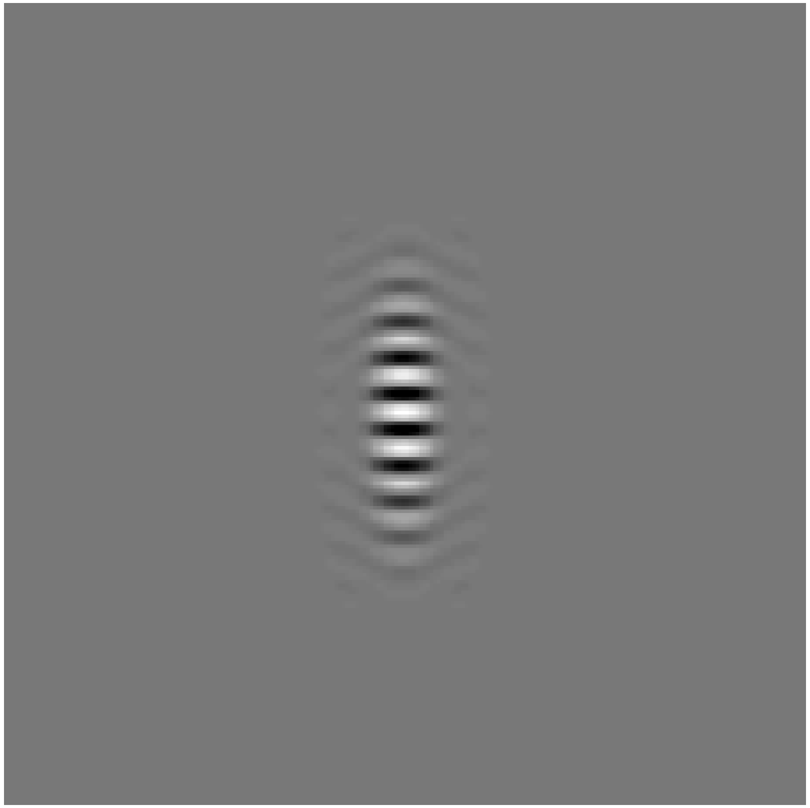
$$Foil \otimes PSF = Fringes$$

In the Frequency Domain (k-space)

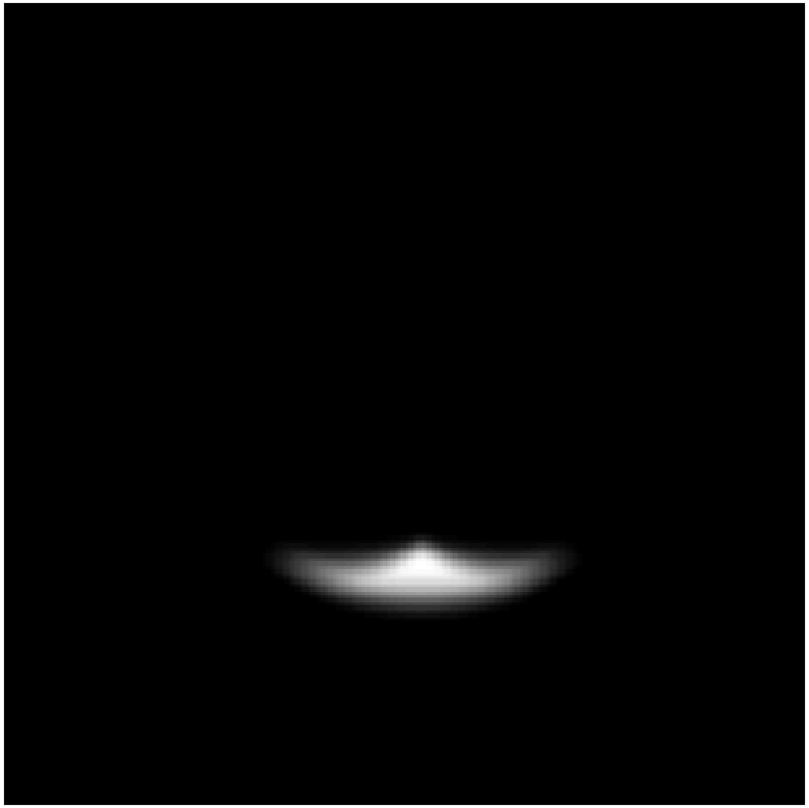


$$\mathrm{F.T.}\left\{\mathrm{Foil}\right\} \times \mathrm{TF} = \mathrm{F.T.}\left\{\mathrm{Fringes}\right\}$$

Ideal Point Spread Function (PSF)/Transfer Function (TF)



PSF



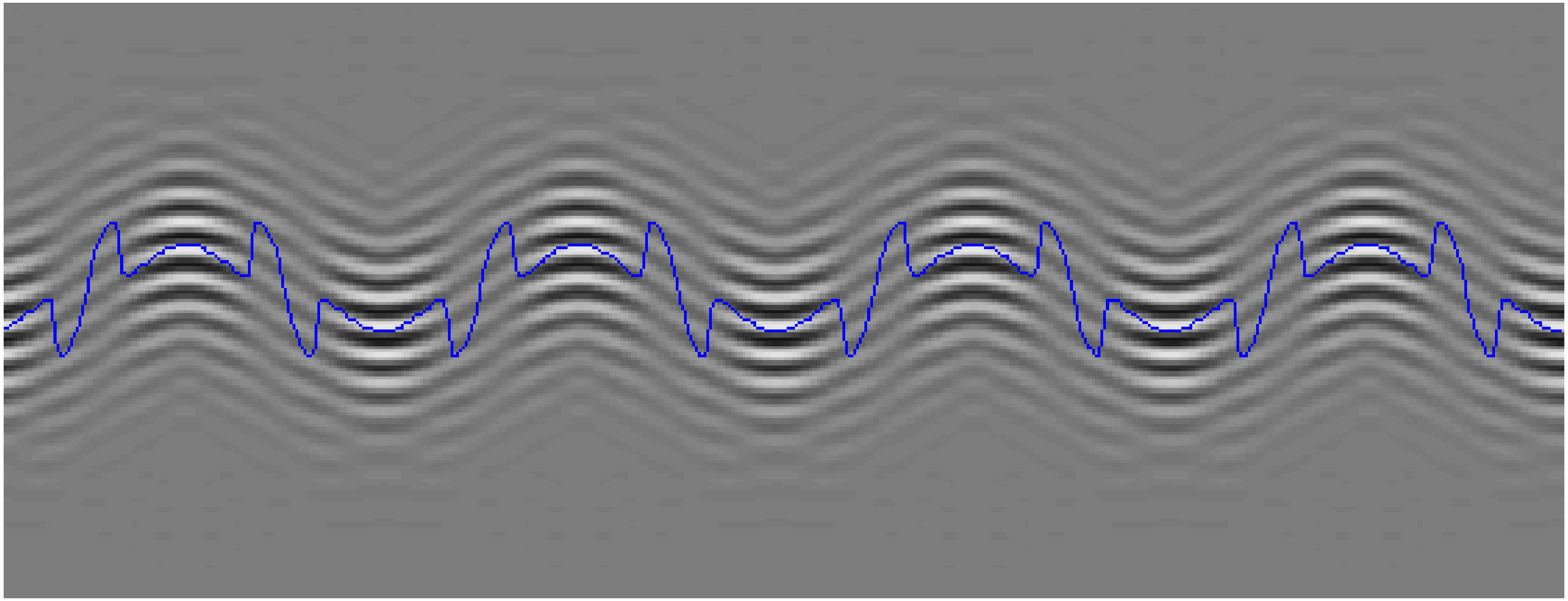
TF

Why is PSF/TF important?

- Because is governs the way CSI works when there are gradients viz:

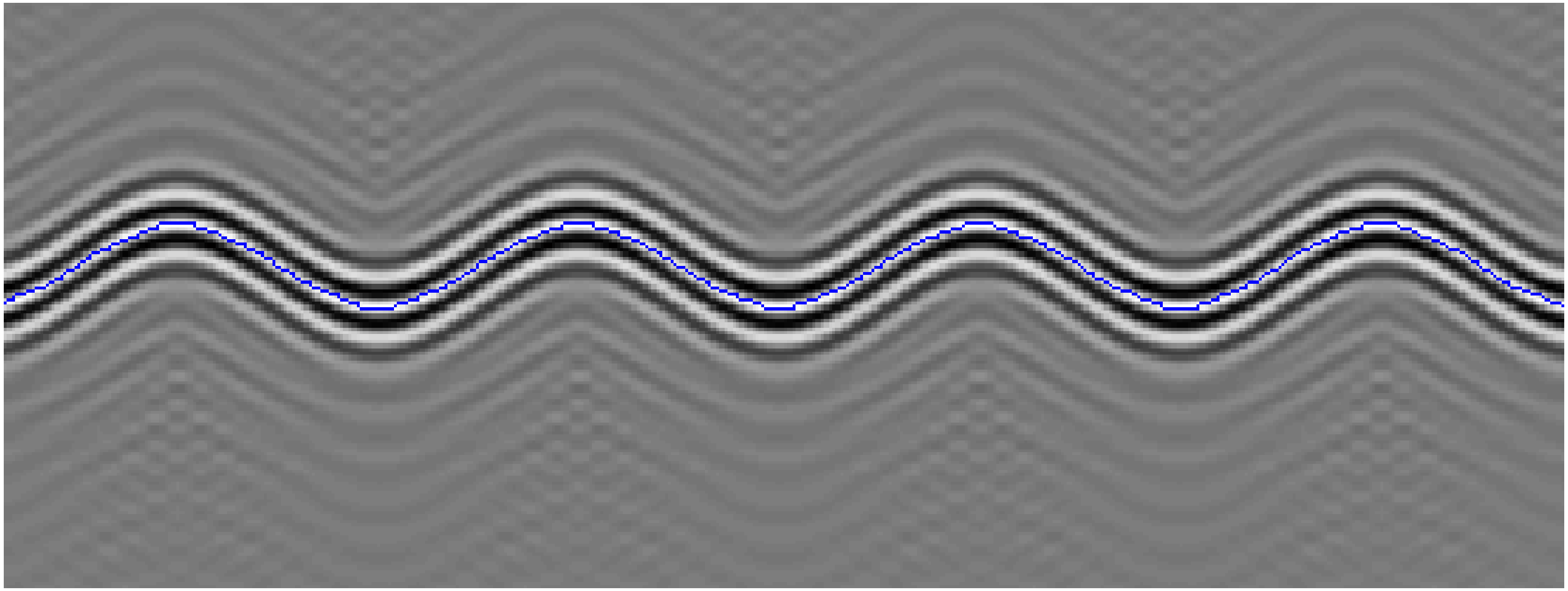
8 μm pitch sinusoidal grating measured with Zygo NewView 5000

Or Foil Model – Ideal PSF



Blue is the surface deduced from fringes (using the “normal” Zygo mode)

“Equalisation” of the TF cures this;

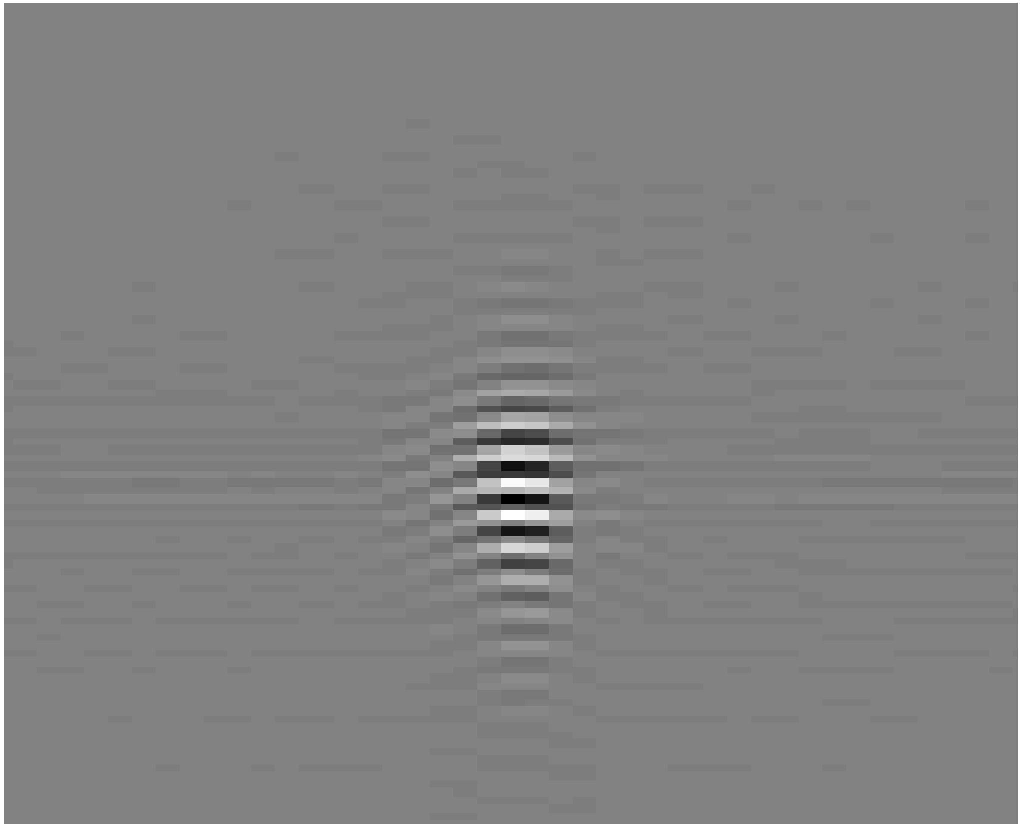


How Do You Measure PSF?

- You could use a small particle in space but they tend to get lost!
- Better to use a surface (foil) with a near uniform Fourier Transform – a ball

$$\mathrm{PSF} = \mathrm{F.T.}^{-1}\left\{\frac{\mathrm{F.T.}\{\mathrm{Fringes}\}}{\mathrm{F.T.}\{\mathrm{Foil}\}}\right\}$$

Zygo NewView 5000 PSF - Measured



Knowledge of PSF allows us to:

- Characterise the system
- Check for instrument alignment errors
- Measure lens aberration
- Compensate for some types of aberration
- Improve the measurement capability

- It is also necessary to know the characteristics of the system to properly implement polarisation sensitive techniques and multiple scattering analysis (that’s where we’re heading now)

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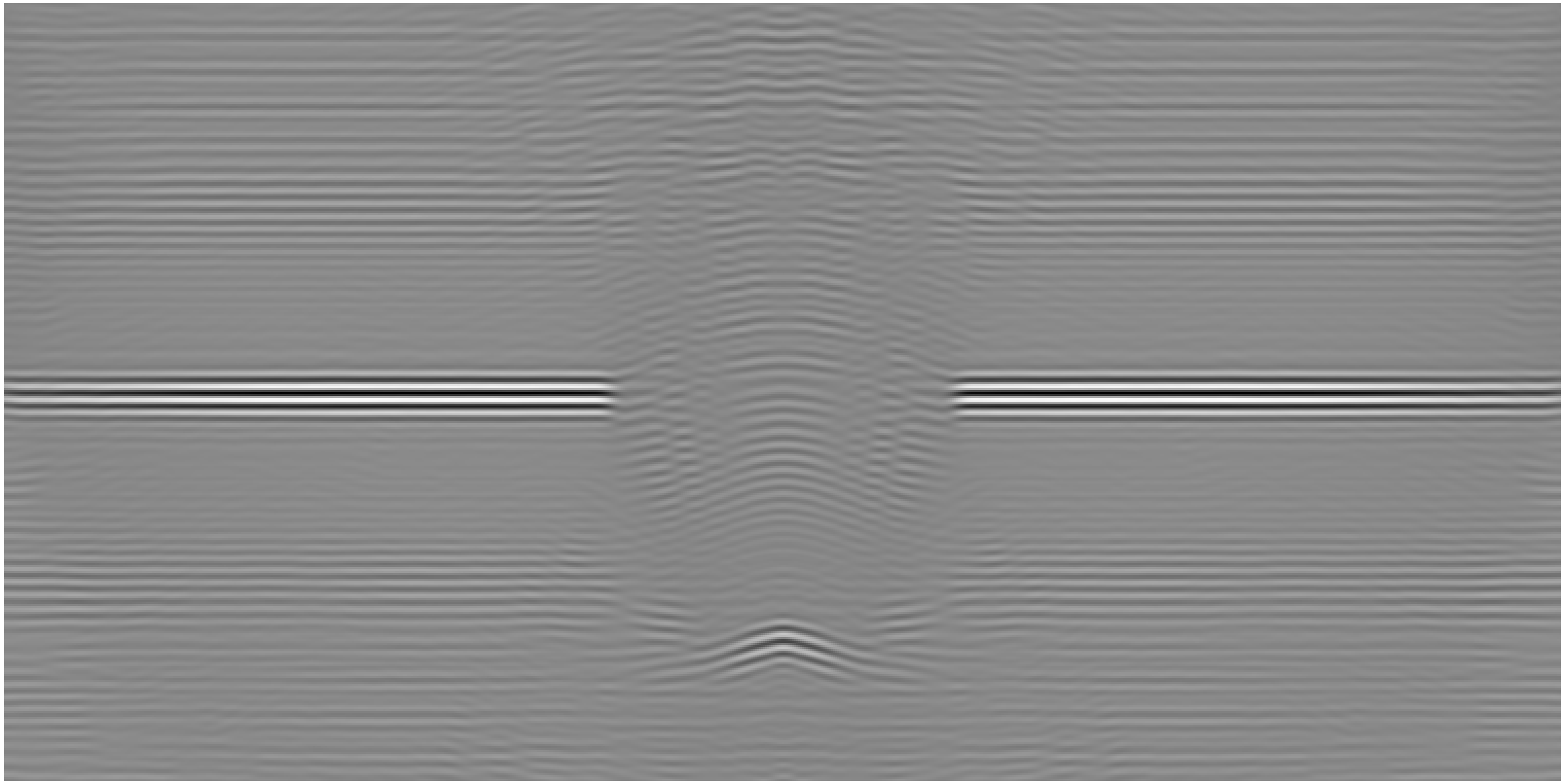
Now for the really clever stuff…

- We think we can use the linear information (the PSF and TF) to calibrate an optical instrument, but what about the non-linear information (multiple scattering)?
- Can we use the “bad” data?
- Let’s return to the nasty V-groove…

Interferogram 70 Degree V-groove



Illuminating and Observation NA=0.5

Inverse Problem

So we know we can produce interferograms that show the surface related problems of WLI using FEM/BEM to solve *the forward problem.*

Q. Can we calculate the surface accurately from one or more interferograms?

This is *the inverse problem*. Mathematically it is the solution that minimises an error function such as,

$$\mathrm{Error} = \sum \left(\mathrm{E}_{\mathrm{S}}^{\mathrm{m}} - \mathrm{E}_{\mathrm{S}}^{\mathrm{calc.}} \right)^2$$

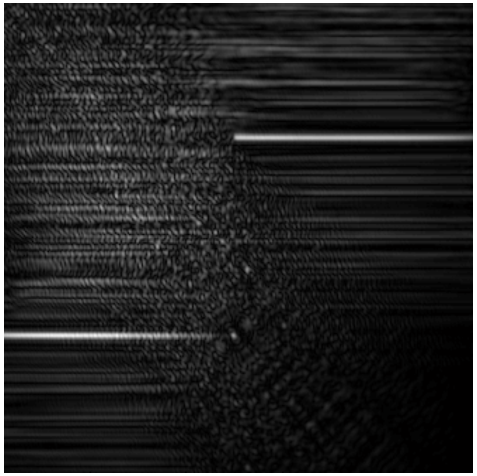
Measured scattered field

Calculated scattered field

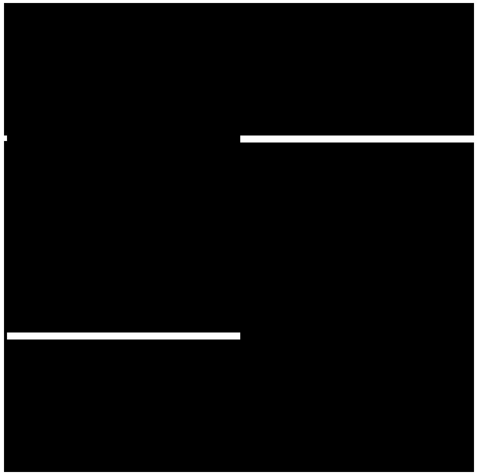
A. Sometimes!

Optical trickery: the profile of a vertical wall (2 iterations)

Object: 15 µm step with a 5 µm x 1 µm groove. Illumination from the top.



SWLI results (abs. value): top and bottom surfaces are found.



New object calculated from SWLI data using updated model shows the profile of the “vertical wall”