Then in the 60's, the CMM hit the scene, man!

- CMMs allowed versatile, high accuracy measurements of geometry
- Could be used (almost) in-line as part of a controlled manufacturing process

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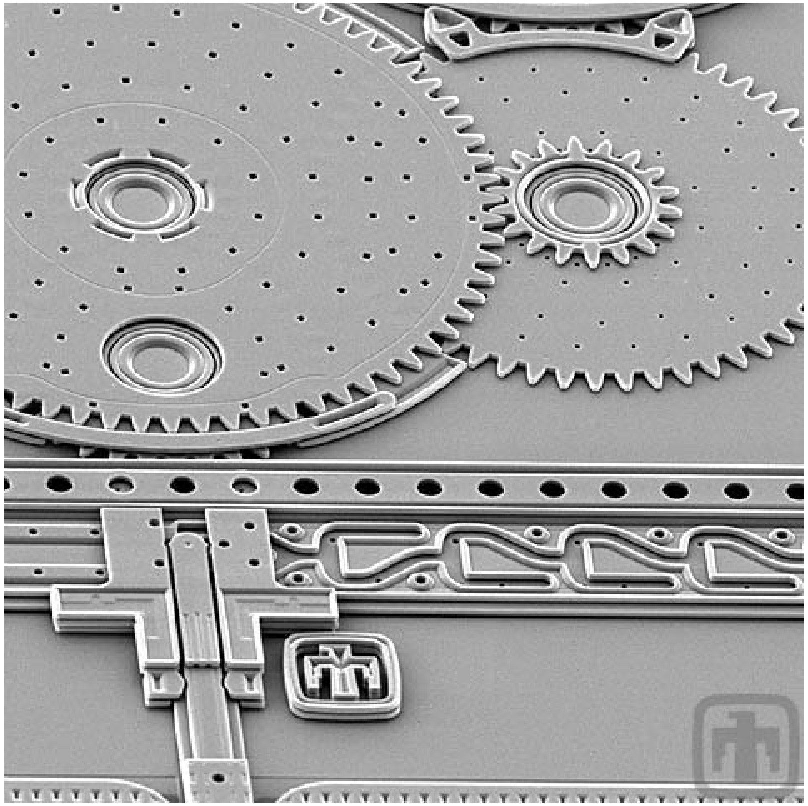
In the 70's and 80's there was the "CMM revolution"

- CMMs became integral part of manufacture
- Joined by CNC machining, CAD, in-line metrology, robotic handling, *etc.*

The 90's up to now – things started to shrink…

- Silicon electronic processes were applied to mechanical devices (MEMS)
- Products and components started to shrink
- Benefits include: lighter weight, better portability, less energy consumption, efficiency, more functionality, *etc.*



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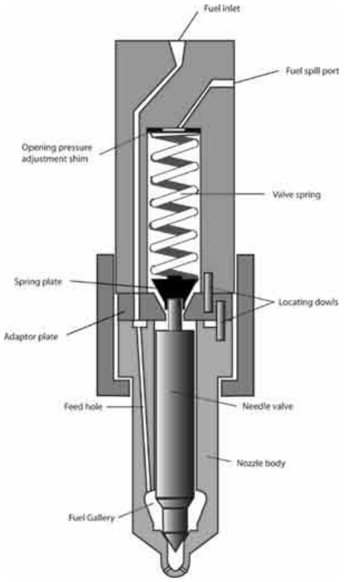
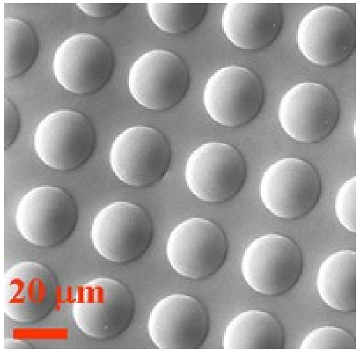
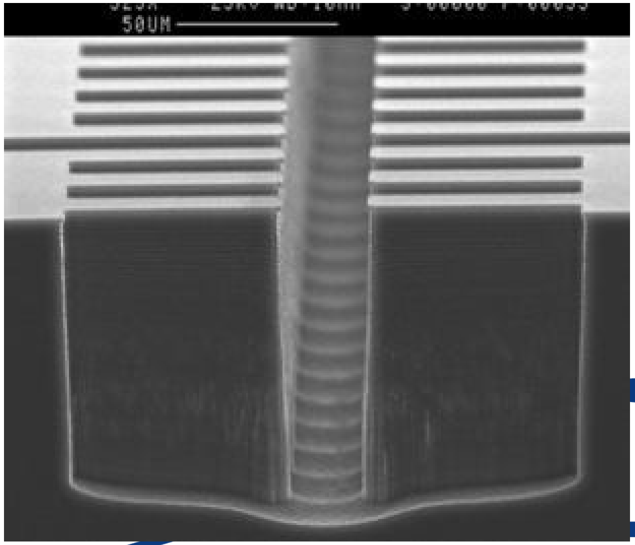
“True-3D” micro-metrology

- Modern manufacturing involves 3D integration of 3D micro-parts
- Have you ever taken apart your mobile telephone?
- Small optics, micro-mirrors
- Micro-fluidic components, lab-on-a-chip
- Medical devices
- MEMS structures
- Ink-jet/diesel injectors
- Small parts with ever-decreasing tolerances







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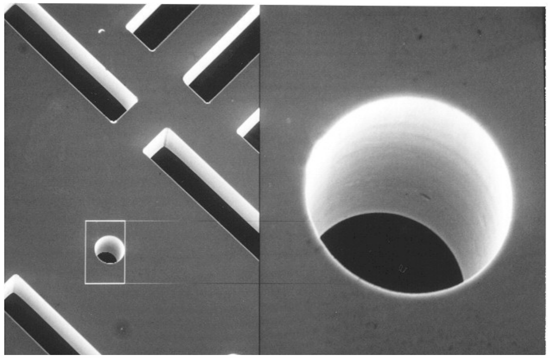
Micro-coordinate metrology

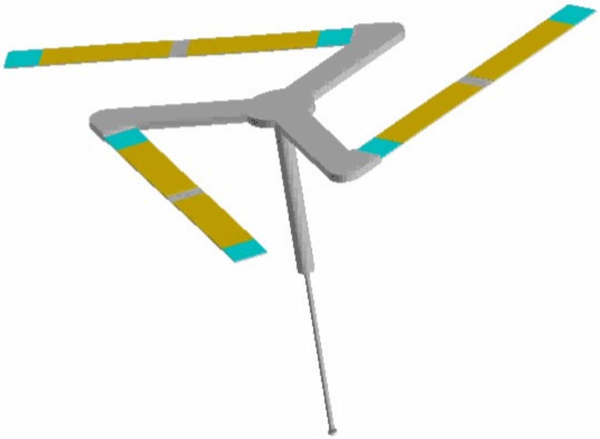
- As part of the TSB-funded CEMMNT project, NPL has procured a Zeiss F25 micro-CMM
- Range 100 mm x 100 mm x 100 mm
- Existing mechanical probes down to 0.3 mm diameter – need smaller
- Accuracy stated as 250 nm but this is conservative
- Probe resolution 10 nm
- Probing force a few μN
- Also incorporates an optical “vision” probe

So why not just shrink the probe?

- The laws of physics are not simply scaleable, there are jumps
- Aspect ratio becomes a problem
- Surface forces dominate over gravitational (stiction)
- Basically, things get too floppy

Micro-probe for micro-CMM





- Need for HAR structures, e.g. ink-jet nozzle, injectors, micro-fluidics, micro-optics
- Developing vibrating micro-CMM probe to interface with Zeiss F25 micro-CMM (1 mm length, $\phi < 50\ \mu m$)
- F25 also has a vision probe – essential for location on part
- Collaboration with Cardiff, Greenwich, Cranfield, Cambridge, Nottingham and Taipei
- Applying for patent – licence to Zeiss

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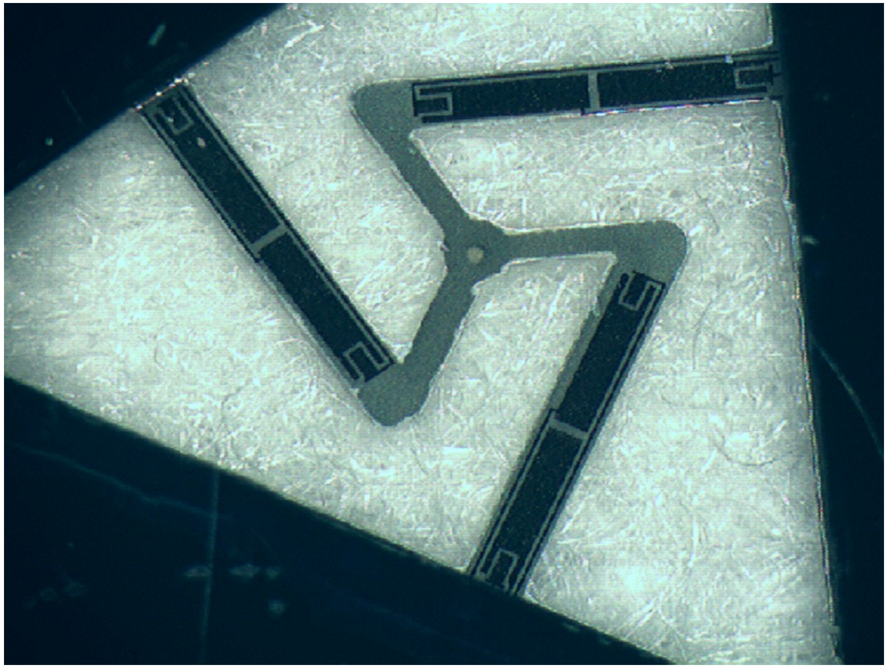
Working with so many academics is a bit like…

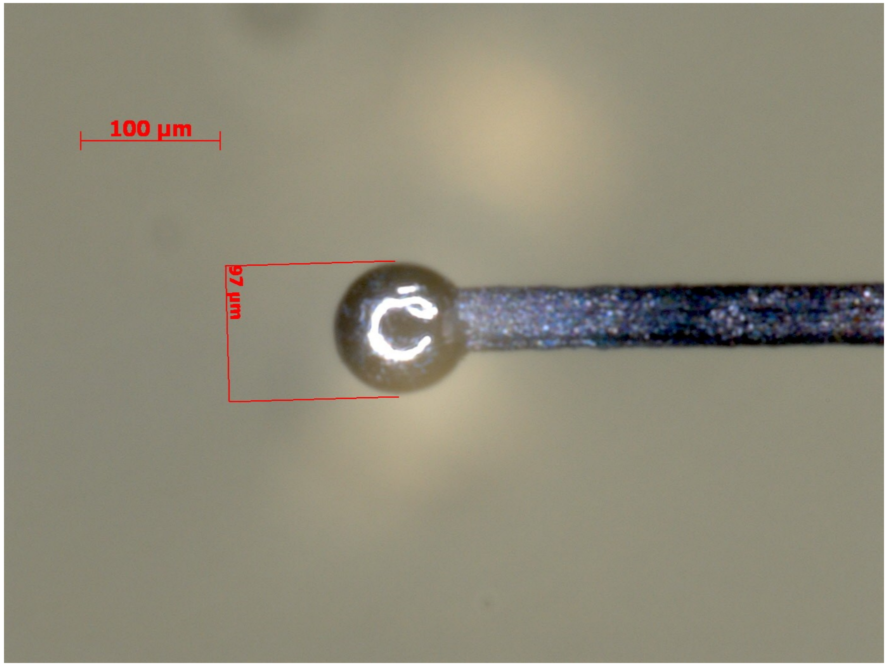
Prototype flexure manufacture

- Cranfield University
- PZT thin film layers on nickel using a silicon sacrificial substrate (removed using DRIE)
- Flexures now need electrical and mechanical testing and comparison with model



Stoyanov S *et al* 2008 Modelling and prototyping the conceptual design of a 3D CMM micro-probe *2nd ESITC Greenwich* 193-198

Micro-probe research



- Ball on stem manufactured using micro-EDM (Taipei, Cardiff)
- Ball direct machining led to rough and cracked end
- Attempting laser and etch methods to clean
- Ball also made by a melting and surface tension method

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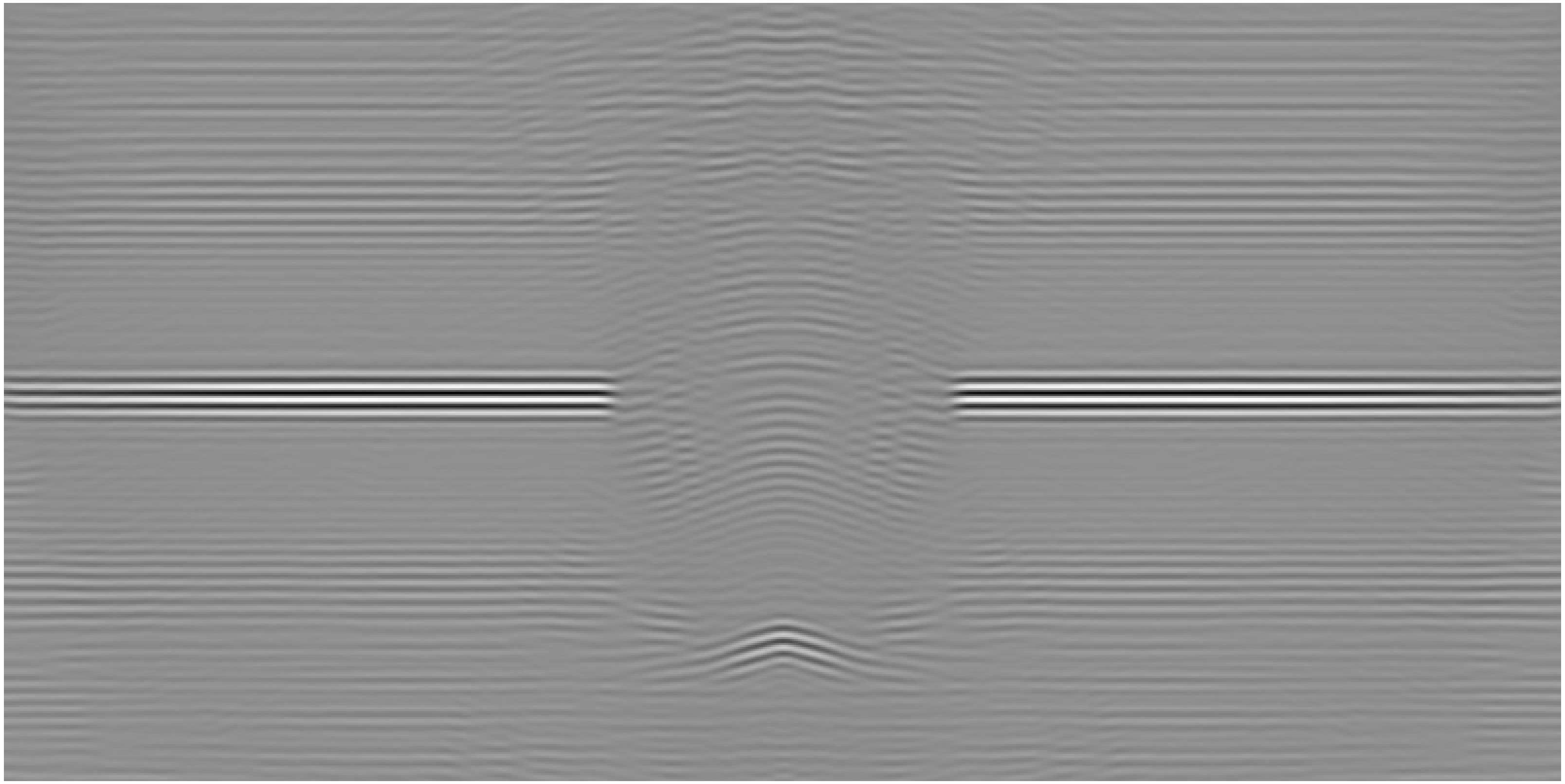
Interferogram 70 Degree V-groove



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,

$$\text{Error} = \sum \left(E_S^{m} - E_S^{calc.} \right)^2$$

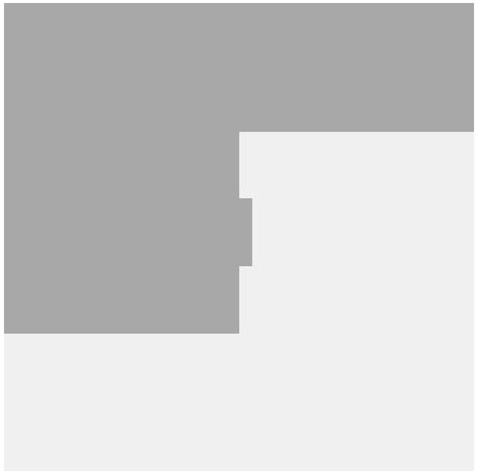
Measured scattered field

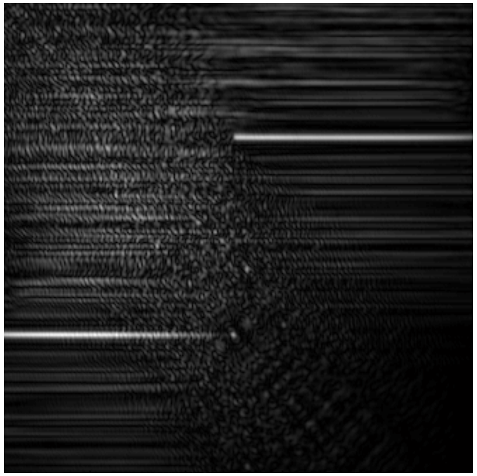
Calculated scattered field

A. Sometimes!

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

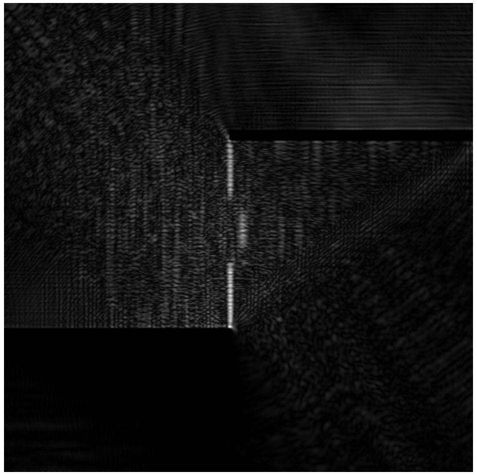
Object: 15 µm step with a 5 µm x 1 µm groove. Illumination from the top.





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”



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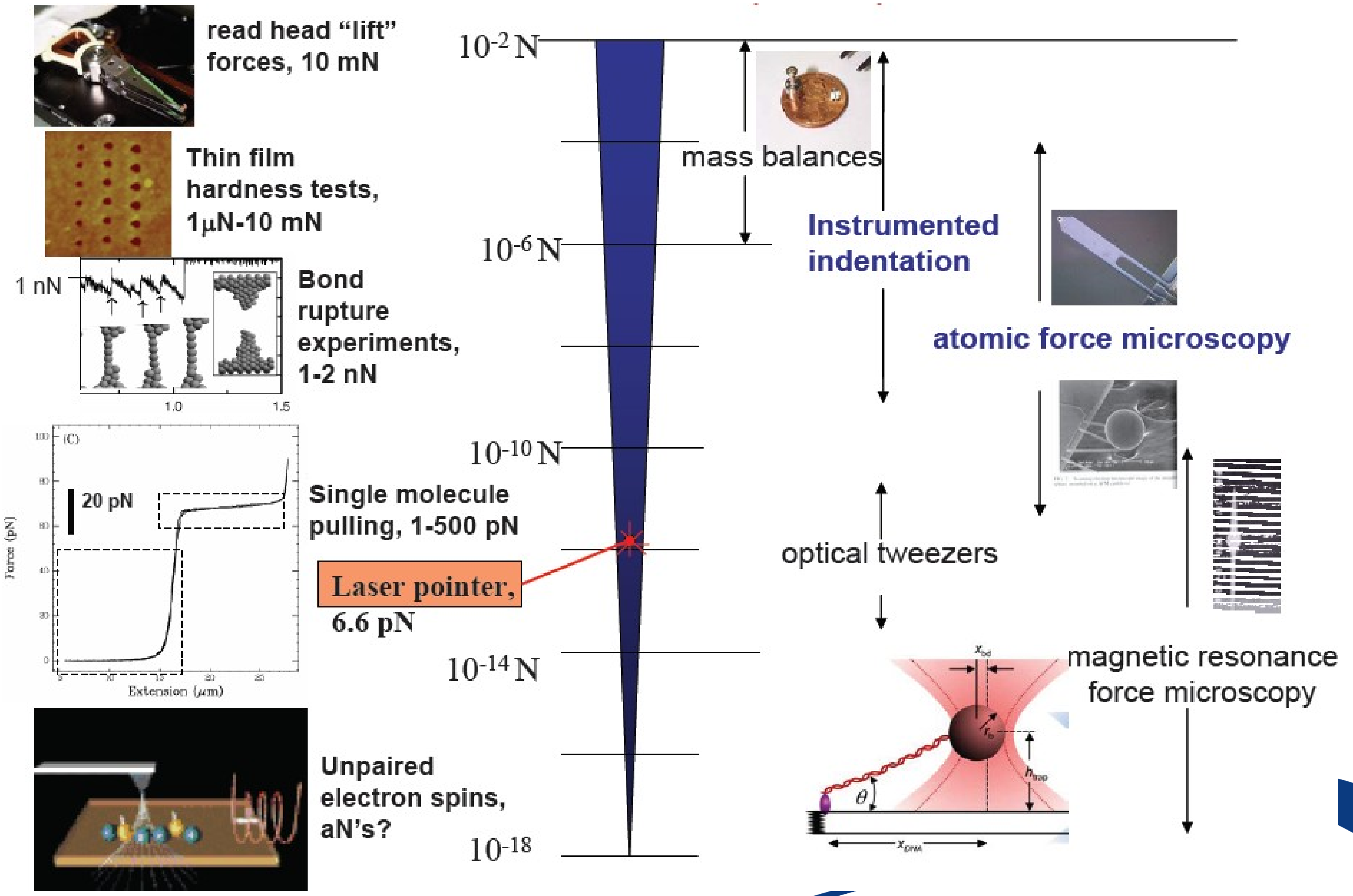
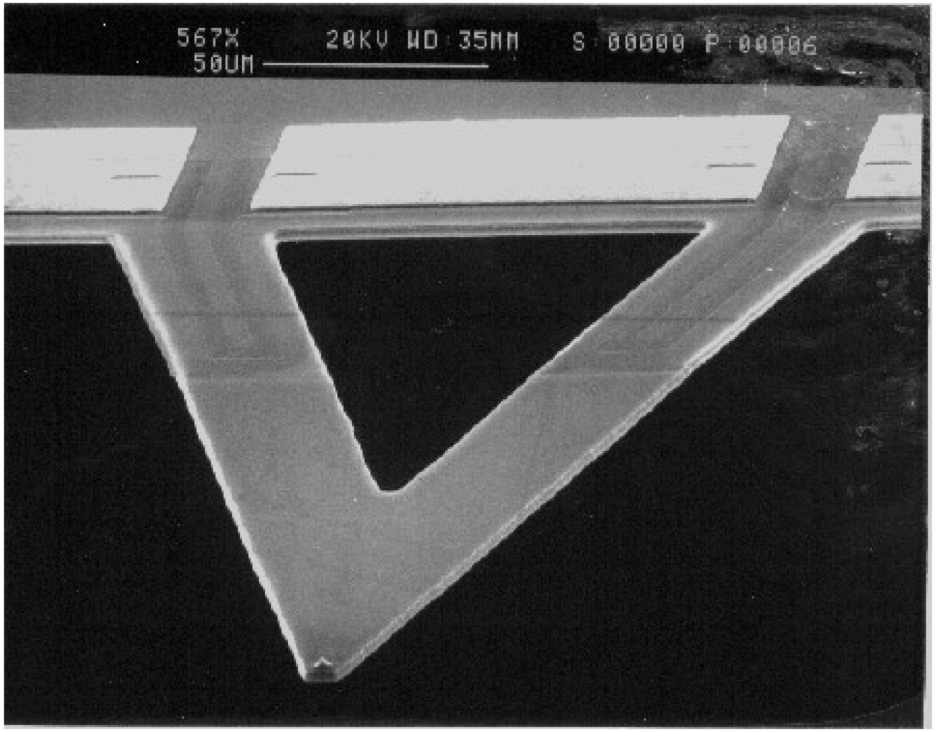
Low force ranges



Who needs low force measurement?

- Surface texture measurement and small CMMs
- Scanning probe microscopy, especially AFM
- Materials characterisation using indentation techniques
- Micro-electromechanical systems sensors
- Biotechnology, e.g. measurement of protein elasticity
- Thruster technology, e.g. ion engines for space
- Nanomanipulation and assembly



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Deadweights: the traditional force standard

- Weight of a known mass
- 1 nN ≡ 0.1 μg ≡ 0.1 mm x 0.1 mm x 5 μm Al
  …. not practical!
- Suitable for comparison only at NMIs

- Mass defined in terms of a lump of metal – not ideal
- Not future proof

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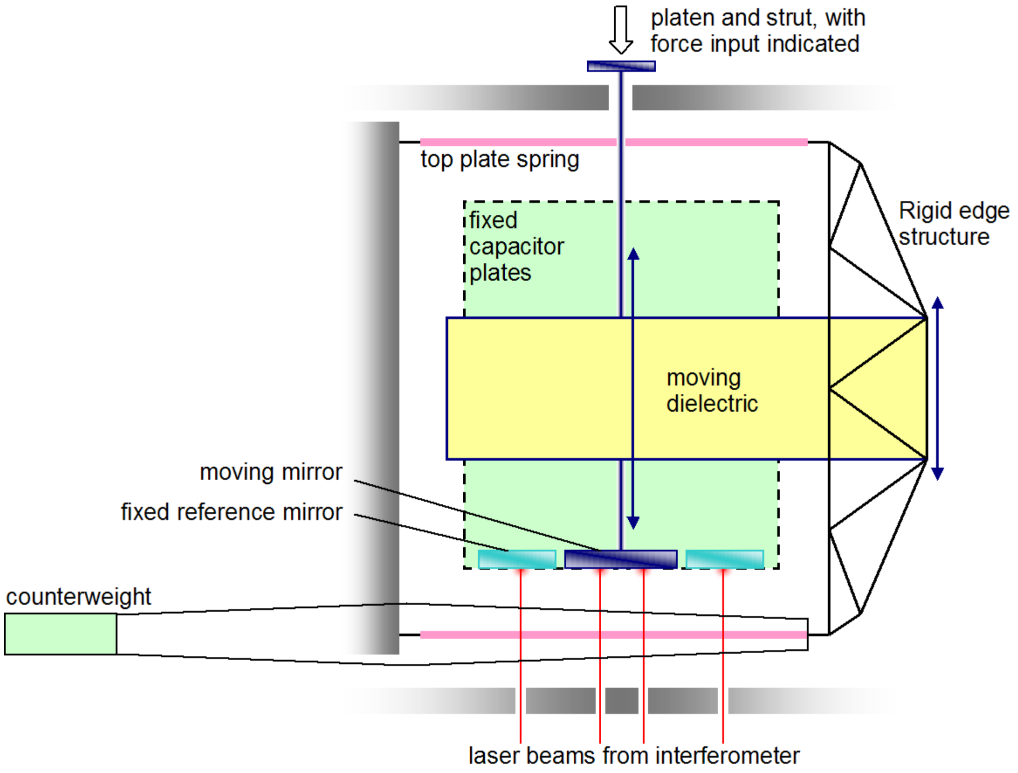
The NPL Primary Low Force Balance

- NPL has existing low force balance
- Range: 1 nN to 10 μN
- Resolution: 50 pN
- Need to compare to standard masses and radiation pressure

$$F = -\frac{1}{2}V^2\frac{dC}{dz}$$



Leach R K *et al* 2006 Recent advances in traceable nanoscale dimension and force metrology in the UK **17** 467-476

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