MMC2014 – Advanced Measurement Technology in the 21st Century

Optical Microscopy For Engineering Measurement - Numbers With Confidence

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Loughborough University

The Queen's Anniversary Prizes For Higher and Further Education 2013

The Story in Brief

- Metrology at Loughborough University
- Measurement Capability – Changing Capability
- HVM Industrial Demand
- Optics, Lasers & Microscopes
- Confidence in Measurement
- Current Research and Future Developments
- Summary
- Acknowledgements

Metrology at Loughborough University

- **Fundamental Metrology** – The SI system (m, s, kg, K, A, cd, mol) – (NPL/NEL/LGC).
- **New Metrology** – Invention and prototyping of new ideas
- **Applied (Functional) Metrology** – Metrology being applied in companies.
- **Legal Metrology** – Metrology related to the commercial sale of goods and products.
- **Knowledge & Communication** – Academic Papers, NPL GPGs, Books, Trade Articles
- **National Measurement System** – NMS Working Group membership

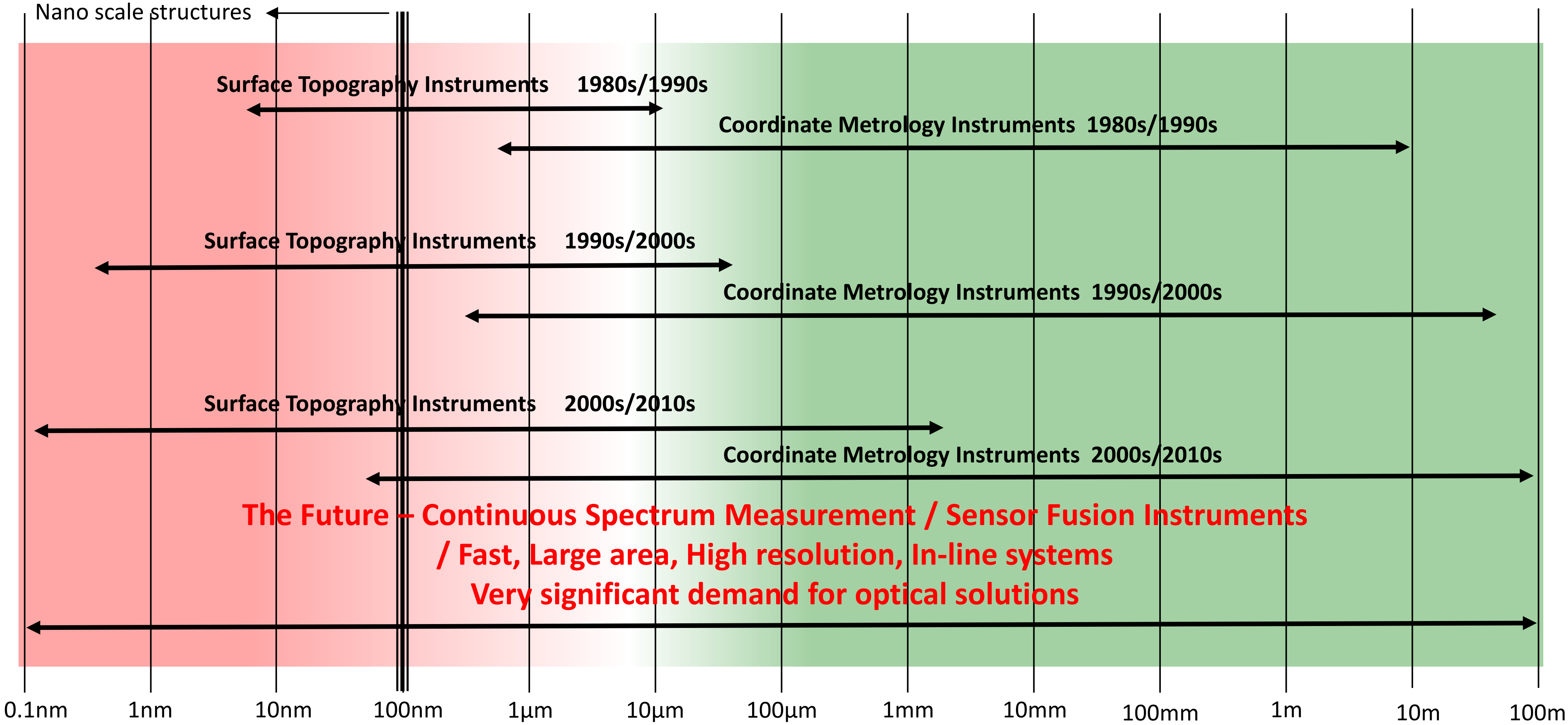
Metrology at Loughborough University

- Dimensional
- Geometric
- Surface
- Pressure
- Acoustic
- Fluid (liquid + gas)
- Vibration
- Optical
- Biological
- Chemical

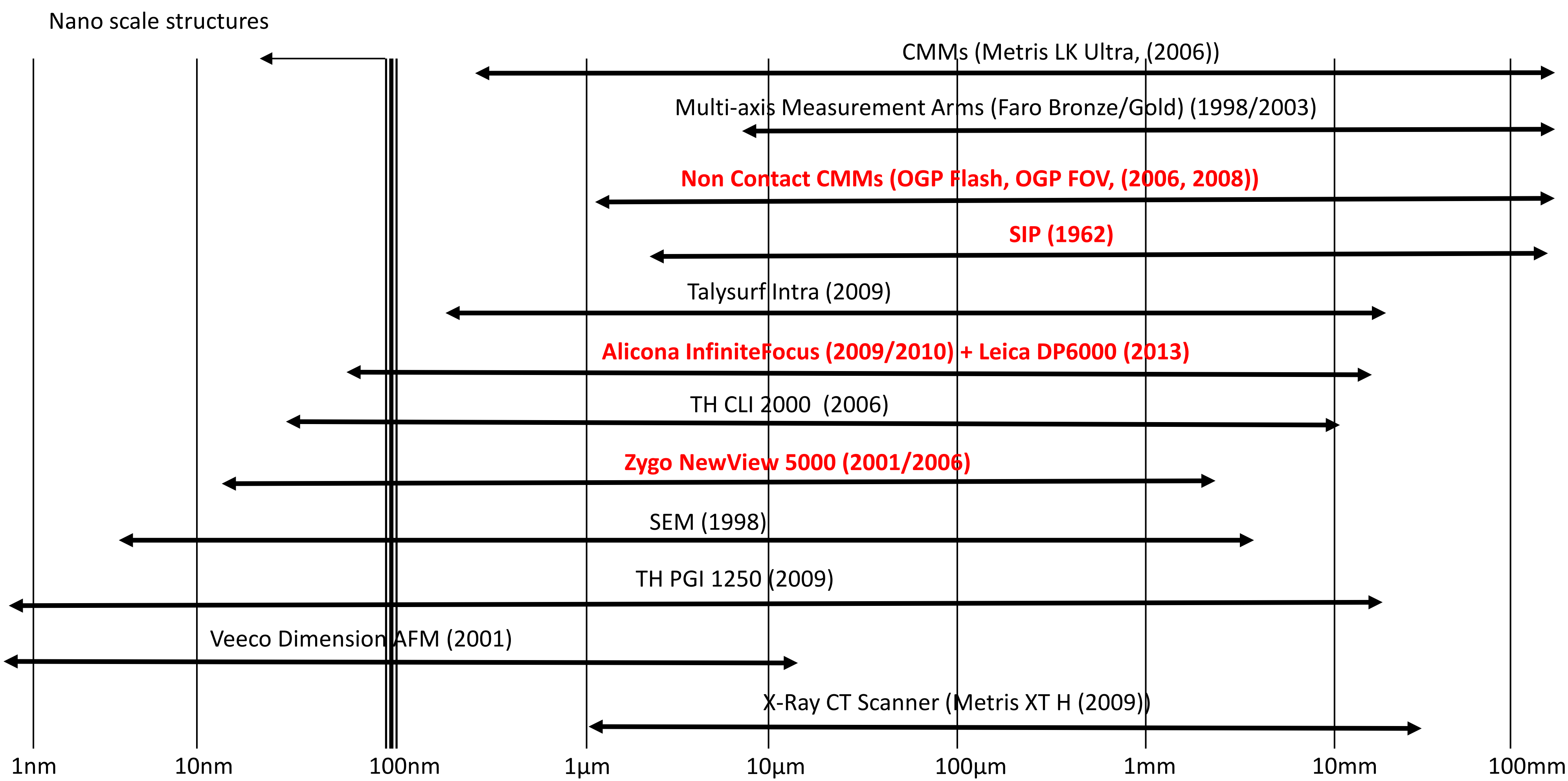
- 12 academics involved in metrology
- 10 PhD students directly involved in metrology
- 40+ other PhD students require metrology support
- EPSRC, EMRP, EMPIR, Industry funding

All within the Wolfson School of Mechanical & Manufacturing Engineering

Changing Times – Dimensional Metrology



Dimensional Measurement Capability – Nanometres to Metres



HVM Industrial Demand

Some of the High Value Manufacturing (HVM) measurement challenges:

- In-line / On-line
- Robotically interfaced
- Large area
- High resolution
- Real-time data processing
- Multiple DOFs
- One sensor measures all
- Calibration / Traceability
- Health-checking
- Artefacts / Soft Gauges
- Uncertainties / Errors

Microscope based solutions (or equivalent) in green
Problems in red

Optics And Lasers – Modern Metrology Opportunities

The good bits:

- Non-contact.
- High density data (megapixels).
- Often high resolution (nanometres).
- Quick for one field of view.
- New types of measurement / data.
- Can look at really small things.
- Can look at really big things.
- Looks great.
- Easier to sell because it is new.
- Produces great pictures.
- Lots of new metrology.

The not quite so good bits:

- What is the light doing ?
- Where is the light going ?
- High density data (megapixels).
- Big data processing (gigabytes)
- Limited traceability.
- Challenges conservative engineering.
- Challenges existing specifications.
- New types of error
- Uncertainty budgets not developed.
- Expensive.
- Requires new staff / expertise.
- May be more complex.
- Traceability not developed.

Many of these are the current research challenge questions

Commercial Advances In Microscope Based Metrology

- 1960s – Laser invented.
- 1990's – significant development of optical platforms and techniques + PCs.
- 2000's - techniques developing into more robust engineering metrology solutions:
    - o Chromatic Length Aberration Gauging
    - o Coherence scanning interferometry
    - o Confocal microscopy
    - o Focus Variation
    - o Laser Triangulation
    - o pOCT
    - o Plus more……..

Alicona / Bruker / Mahr / Taylor Hobson / Zygo

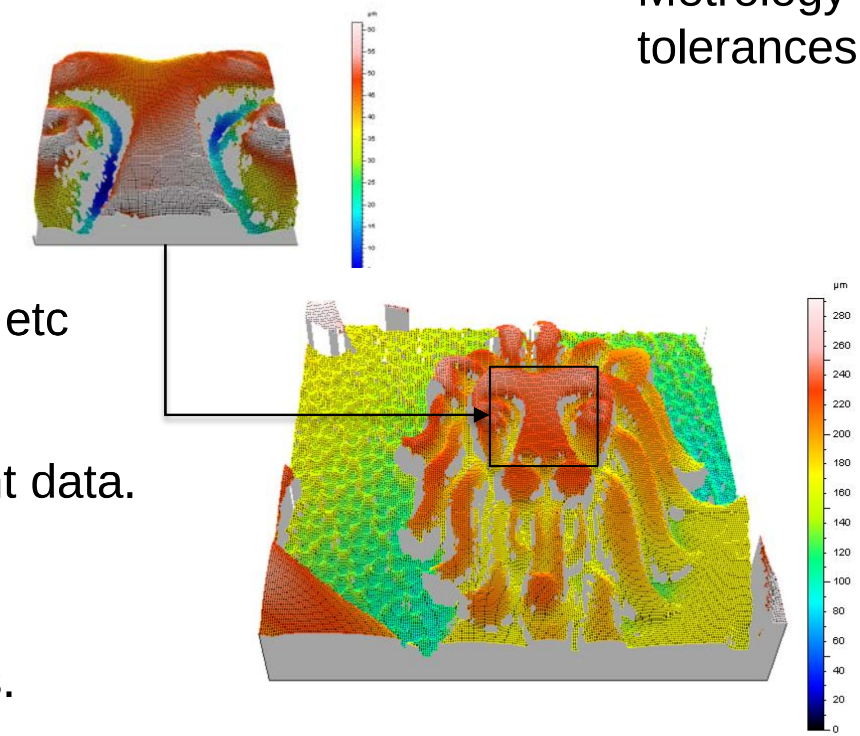
Metrology Is About Communication

The Customer / The Engineering problem

Manufacturing - datums / dimensions / tolerances.

Metrology - datums / dimensions / tolerances / errors / uncertainties.

Management – SOPs.



NMIs – NPL / PTB / NIST etc

Metrology - measurement data.

Instrumentation Manufacturers

Designers - datums / dimensions / tolerances.

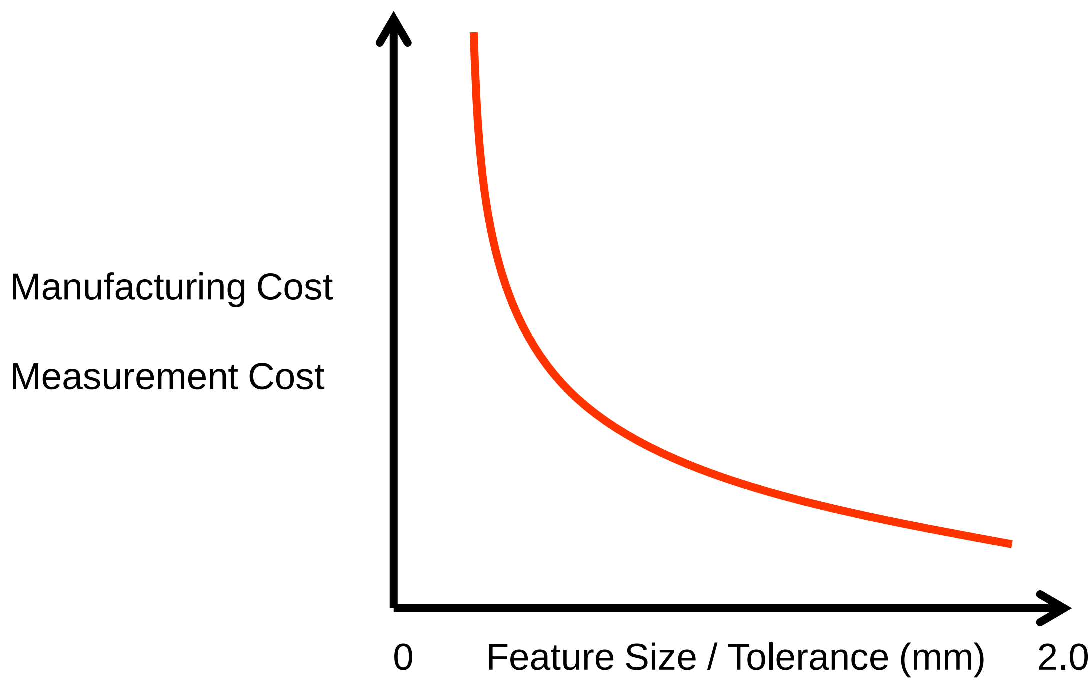
ISO/BSI

Engineers/Scientists - functionality

Traceability / Calibration / Health Checking

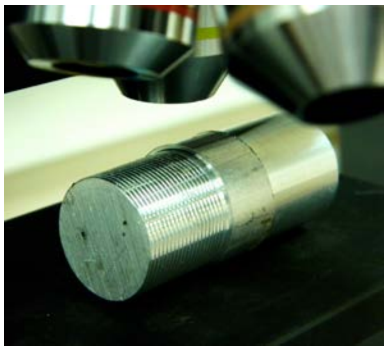
Small Features - New Solutions

- HVM is causing smaller feature sizes and tighter tolerances
- This demands new optical solutions, but at a price !

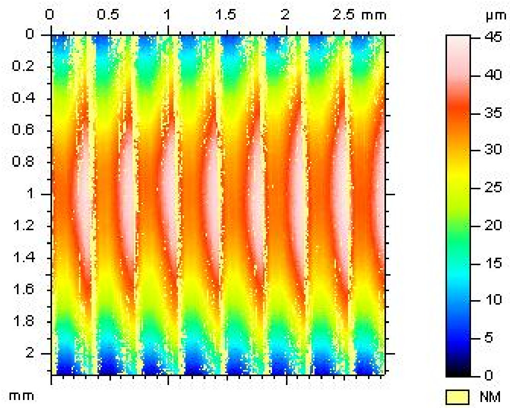


Measurement Tasks – 2D Surface Profiles

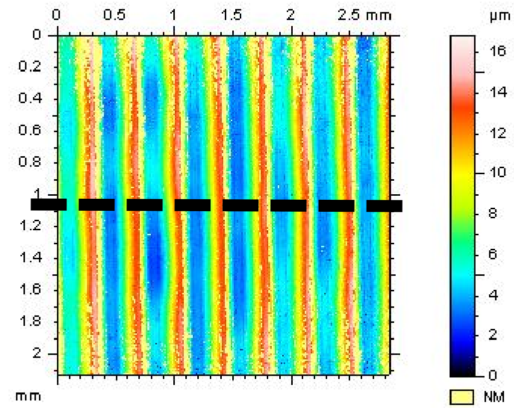
Turned Aluminium



Measure

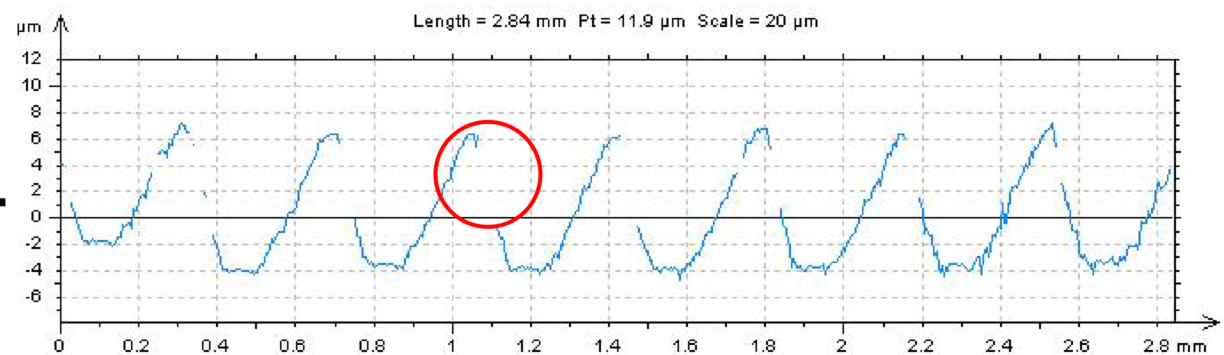


Form removal



Line Profile

ISO 25178:2 Areal Parameters

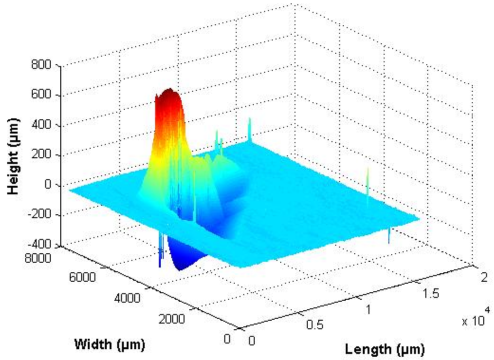


Numbers

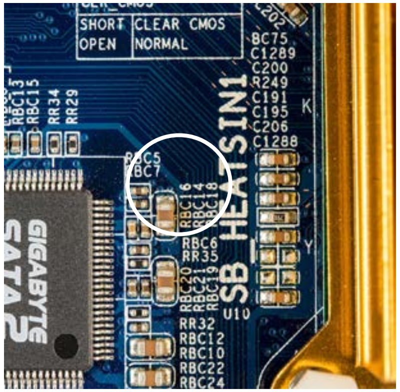
Ra (GS 0.8 mm)	µm	3.2
Rq (GS 0.8 mm)	µm	3.5
Rp (GS 0.8 mm)	µm	6.3
Rv (GS 0.8 mm)	µm	4.4
Rt (GS 0.8 mm)	µm	10.9
Rsk (GS 0.8 mm)	<no unit>	0.3
Rku (GS 0.8 mm)	<no unit>	1.7
Rz (GS 0.8 mm)	µm	10.7

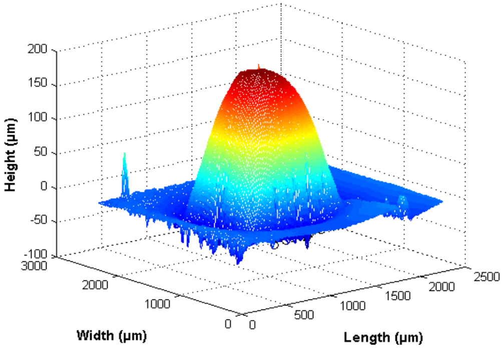
ISO 4287 Roughness Parameters

Measurement Tasks – 3D Defects / Features

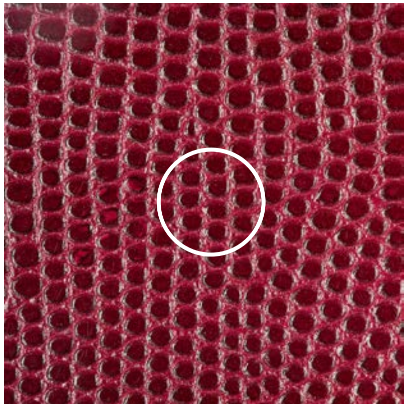


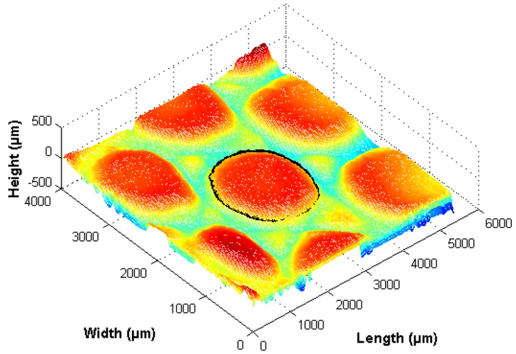
Manufacturing Defects





PCB Solder Bumps





Organic Materials

Metrology Is Not Just About The Microscope !

Ancillary equipment

Data processing (MB/GB)

Environment

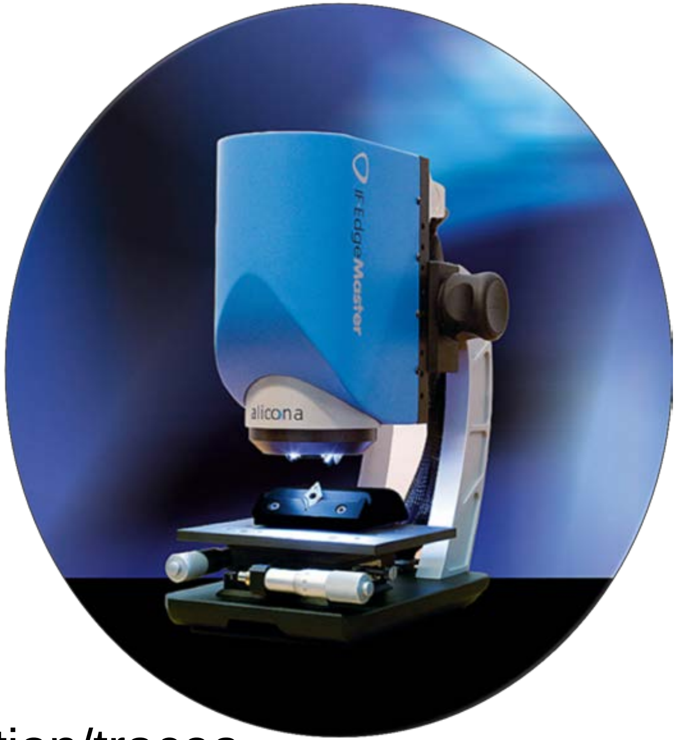
Management structure

Inspection Planning

SOPs

Experienced personnel

Gauge R&R



Verification/calibration/traceability

Uncertainty budgets

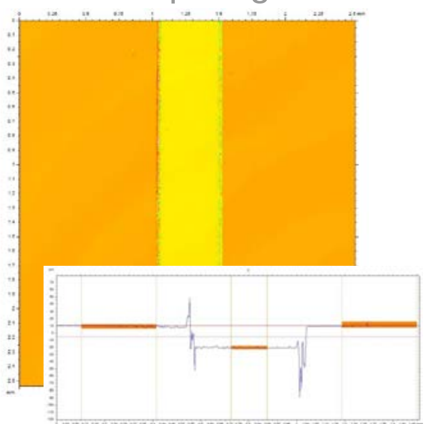
Confidence

We Need Confidence in the Metrology

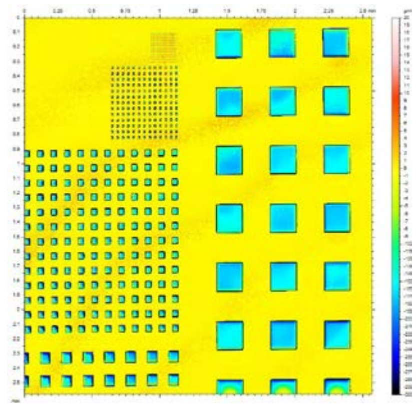
- A key challenge is developing data confidence.
- Data confidence is required so that the next engineering decision can be made.
- Data confidence can be achieved by:
    - Completing instrument/technique uncertainty analysis (GUM)
    - Completing Monte Carlo simulations
    - Defining traceability to the metre (in our case) beyond step heights
    - Developing appropriate traceable artefacts
    - Understanding light/surface interactions
    - Choosing between Calibration and Verification
    - Authoring ISO standards to generate commonality of approach
    - Specifying Health-Checking procedures for frequent equipment test

Increasing the Confidence In Measurement - 1

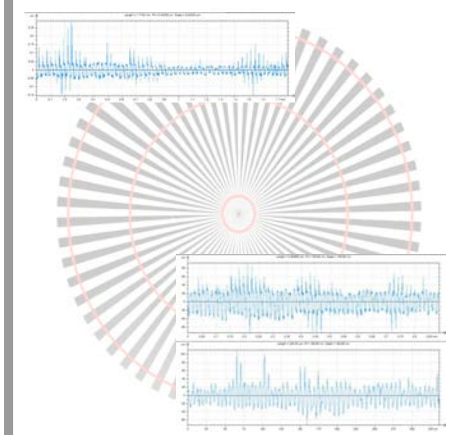
Step heights



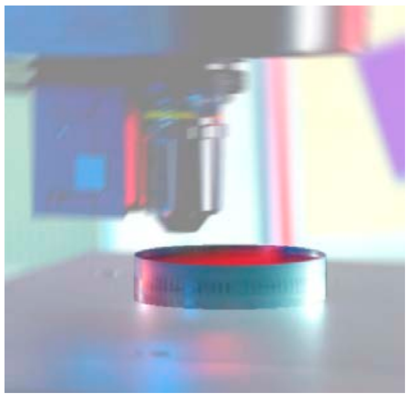
Cross gratings



Resolution artefact



Optical flat



Good Practice Guide

Recommended by NPL for your instrument

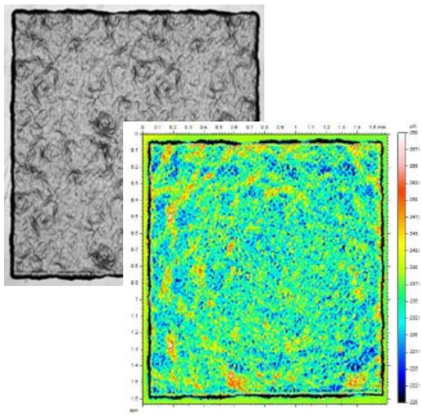
NPL Artefacts

for the calibration of the metrological characteristics areal surface texture measuring instruments to ISO 25178

National Measurement System

NPL National Physical Laboratory

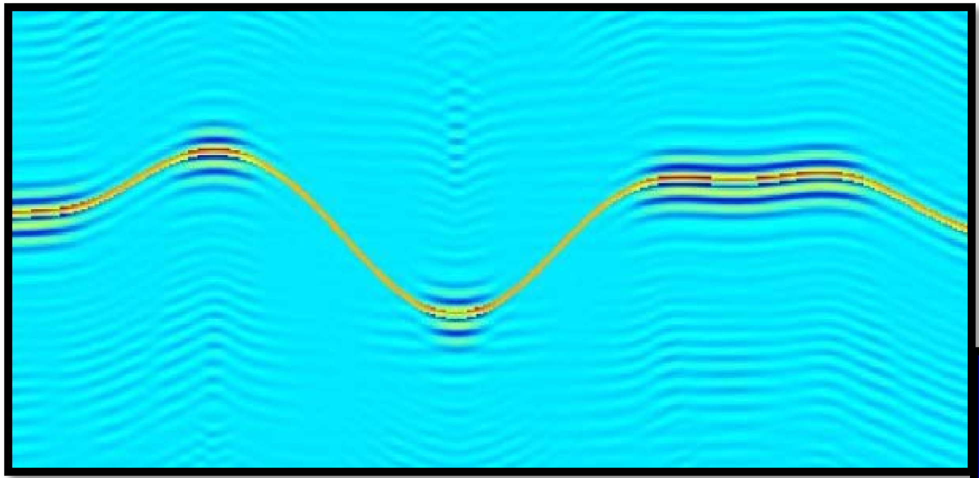
Deterministic artefact



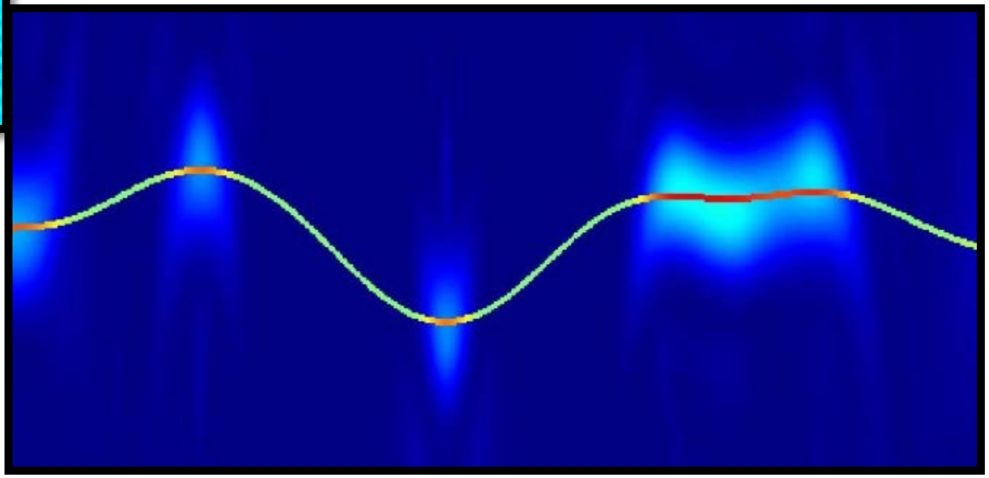
2013 - NPL developed ‘Bento Box’ of 3D reference artefacts for various microscope systems (ISO 25178) (R Leach)

Increasing the Confidence In Measurement - 2

- Understanding light/surface interactions – what are the microscopes really measuring ?



Coherence Scanning Interferometry



Confocal Microscopy

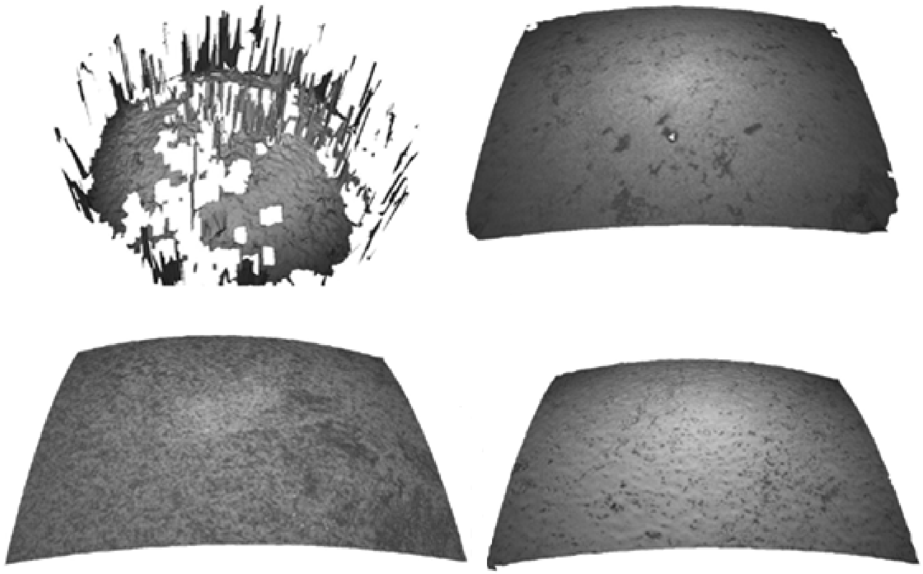
Models that calculate (rigorously) light scattering for arbitrary prismatic surfaces for TE and TM waves.

Surfaces with roughness above and below the resolution of the instruments have been generated and instrument performance modelled.

J Coupland / N Nikolaev

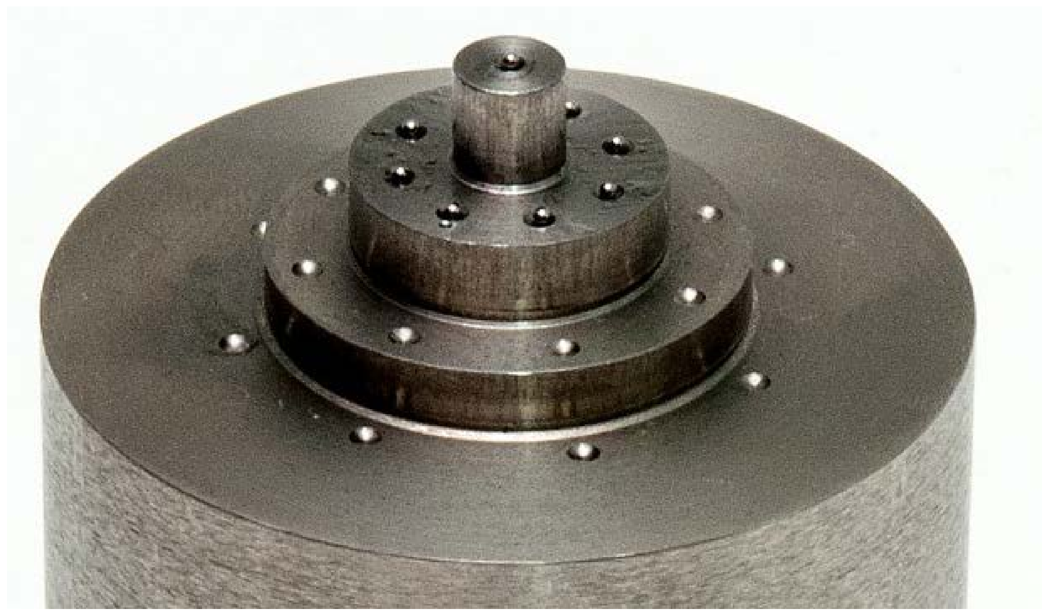
Increasing the Confidence In Measurement – 3

- Using spheres as reference artefacts – for all instruments – beyond ISO10360-8



Top left to right: ruby and zirconia
Bottom left to right: silicon nitride and stainless steel

CSI and FV ability to measure small spheres has been investigated



How do you build reference artefacts for microscope systems ?

Do you calibrate, or, verify, and, health-check ?

Artefact design can be linked to specific instrument characteristics (Bento Box), or be Measurement Task Specific.

Current Metrology Research

- Optical micro-CMM development
- CSI traceability
- Large volume geometry measurement
- Automated surface defect analysis
- Fluid flow diagnostics
- Biological metrology for manufacturing
- Focus variation standards development
- Robotically enabled metrology
- Metrology assisted production
- Robust intelligent metrology
- And more…..

- EPSRC Centre for Innovative Manufacturing in Intelligent Automation
- EPSRC Centre for Innovative Manufacturing in Regenerative Medicine
- Innovative Electronics Manufacturing Research Centre
- The Manufacturing Technology Centre
- High Value Manufacturing Catapult

The Current “Holy Grail” of Metrology

100nm 1µm 10µm 100µm 1mm 10mm 100mm 1m 10m

Large area analysis
(square metres or more)

Data that is traceable
and with high
confidence

Not asking too
much then !

Massive challenge to instrumentation
manufacturers, users, NMIs and legislators

High resolution
(micrometres or less)

Very quickly
(ideally seconds)

In-line on the
production line

Summary

In summary, there is a:

- Growing engineering demand for microscope based dimensional metrology.
- Range of companies developing and offering microscope based metrology.
- Need to generate further confidence in the microscope based metrology data.
- Requirement to further understand light/surface interactions – what is happening ?
- Necessity to develop uncertainty analysis and budgets.
- Demand for developing or inventing new optical transducers.
- Desire to increase microscope based transducers on robots and in-cell.

Acknowledgements

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