EURAMET

TC for Metrology in Length: Highlights and Challenges

Harald Bosse, TC-L Chair
PTB, Germany

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Length

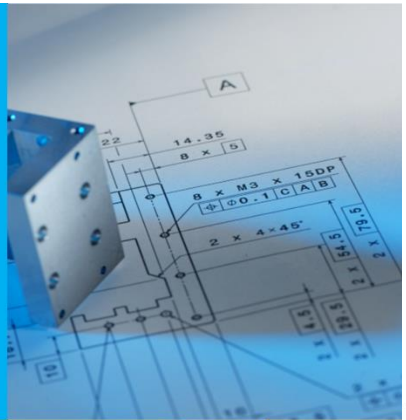
OUTLINE

- TC-L contributions to the redefined SI
- EMRP project results from Calls 2014 (to be finished in 2018)
- TC-L activities related to digitalization
- Macroscale 2017 & Nanoscale 2019 conferences

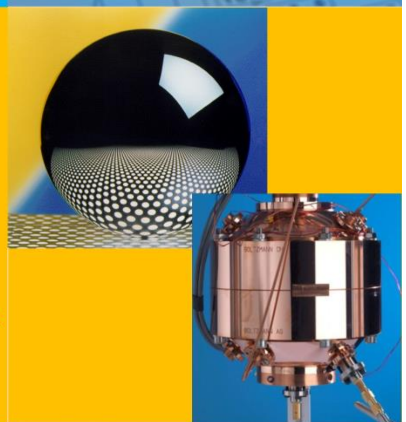
Length

Length metrology - Areas of Impact

Traceability in dimensional measurements underpins all manufacturing, engineering and assembly industry worldwide, ensuring compatibility & interchangeability of parts.



Precision engineering and dimensional metrology are key to 3 SI re-definitions based on fundamental constants: form & dimension of Avogadro spheres and Boltzmann resonators, Planck balance interferometry

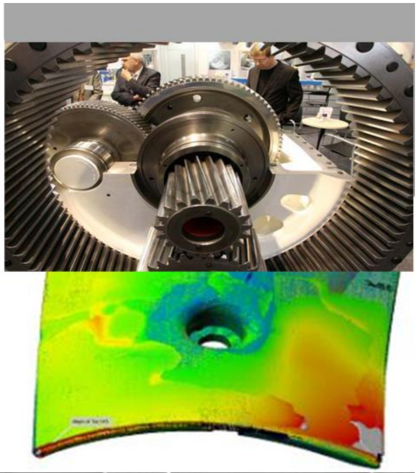


In aerospace, improving accuracy in aircraft assembly is reducing weight, reducing fuel burn (lower environmental impact, better energy efficiency). Key needs are accuracy and traceability for parts up to 40 m size.

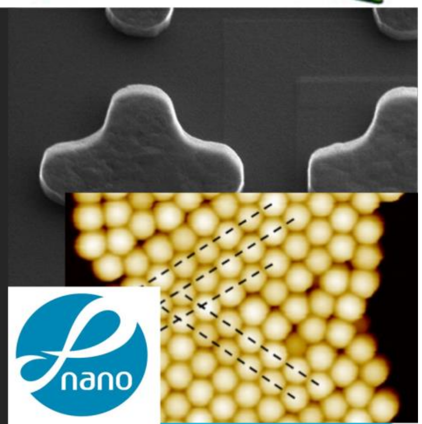
CCL Strategy Document
with input from **EURAMET TC-L members of WG-S**

Topics are dealt with in **four TC-L Roadmaps**

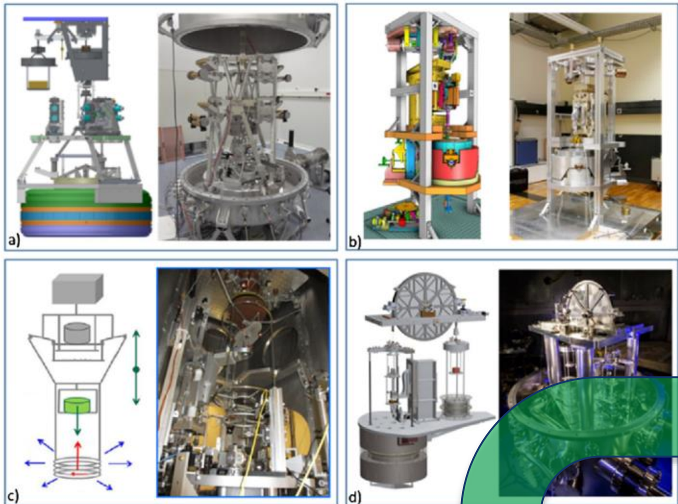
For new science (particle accelerators), energy generation (wind, civil nuclear), better accuracy & *in situ* calibration are speeding up manufacturing and enabling better efficiency, longer lifetimes. Solving gearbox problems is key to wind energy.



Surface form and texture are critical to many nano-scale devices, particularly for *in-vivo* applications for health. Traceability infrastructure for 3D surface texture and simple dimensions on nano particles



Length metrology and precision manufact.: – Support of Revised SI



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ELSEVIER

Contributions of precision engineering to the revision of the SI

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Harald Bosse (3)[a,*], Horst Kunzmann (1)[a], Jon R. Pratt (3)[b], Stephan Schlamminger (3)[b], Ian Robinson (3)[c], Michael de Podesta (3)[c], Paul Shore (3)[c], Alessandro Balsamo (1)[d], Paul Morantz[e]

[a] Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany
[b] National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA
[c] National Physical Laboratory (NPL), Teddington, United Kingdom
[d] Istituto Nazionale di Ricerca Metrologica (INRIM), Torino, Italy
[e] Cranfield University, Cranfield, United Kingdom

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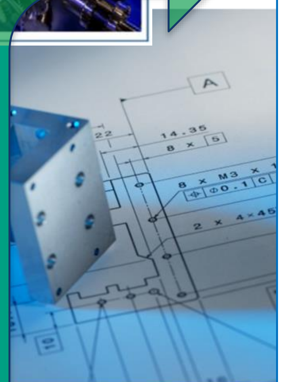
ABSTRACT

All measurements performed in science and industry are based on the International System of Units, the SI. It has been proposed to revise the SI following an approach which was implemented for the redefinition of the unit of length, the metre, namely to define the SI units by fixing the numerical values of so-called defining constants, including c, h, e, k and N_A. We will discuss the reasoning behind the revision, which will likely be put into force in 2018. Precision engineering was crucial to achieve the required small measurement uncertainties and agreement of measurement results for the defining constants.



Traceability in dimensional measurements underpins all manufacturing, engineering and assembly industry worldwide, ensuring compatibility & interchangeability of parts.

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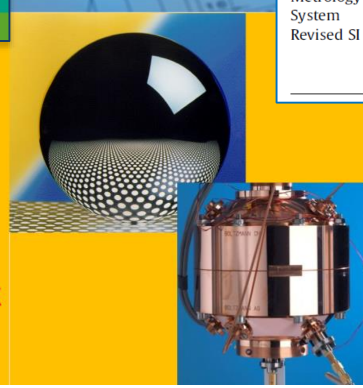
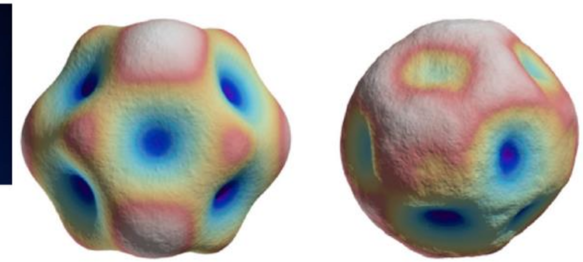




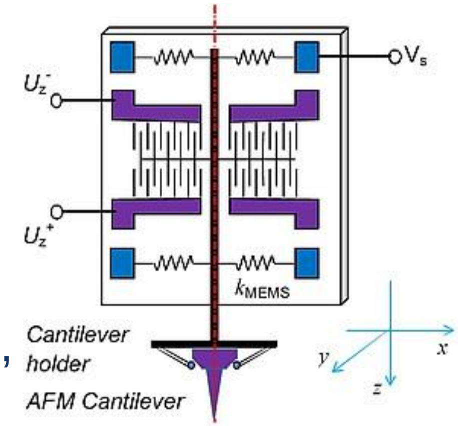
StrengthABLE, IND03, Call 2014

Strength Achieved By Length-Scale Engineering

Metrology for length-scale engineering of materials

Main Challenge: length-scale engineer materials into more sustainable industrial components that are lighter, stronger, fatigue and wear resistant.

MEMS picoindenter

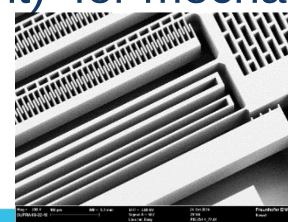


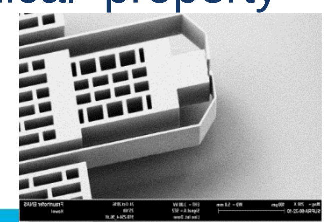
Approach:

- develop validated design rules for combining different size effects
- AFM & MEMS-scale instrument and test method improvement (develop diamond-based probes + MEMS-based IIT system)
- obtain materials, produce samples + generate data to determine the functional relationships between material internal length scales, test-piece external dimensions + mechanical test response

Main Results:

- new method for separation + quantification of plasticity size effect (pile-up and sink-in), Indentation Size Effect (increase of hardness at smaller indenter radii) and residual stress (often involved in machining and heat treatment) for mechanical property mapping (U Coventry)
- new MEMS picoindenter with exchangeable indenter tip (PTB)





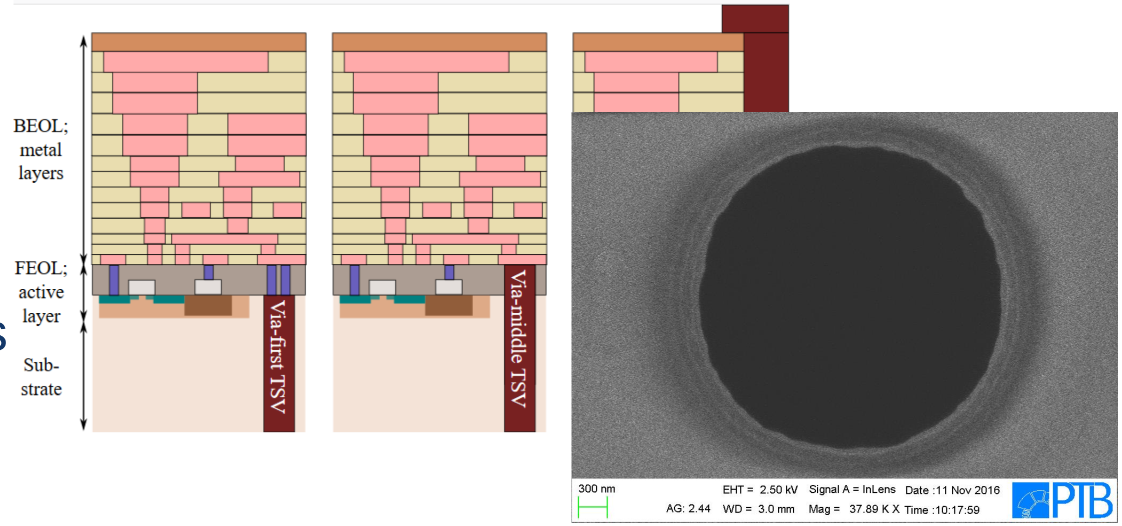
Details

3D Stack, 14IND07, EMPIR Call 2014

3D Stack

Main Challenge:

- Develop metrology solutions to support 3D chip (HAR>10) integration technol.:
- Through Silicon Vias (TSV) to electrically connect a stack of chips on wafers



Approach:

- Develop reference materials,
- new measurement methods and
- new type of calibration standards

Main Results:

- Fast 3D-AFM with small tips for metrology in Through Silicon Vias (TSV)
- Simulation of SEM signals from TSV (analysis of additional extraction fields)
- X-ray fluorescence and Raman spectroscopy for thin film quality measurement

Details

MetHPM, 14IND09, EMPIR Call 2014

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MetHPM

Metrology for highly-parallel manufacturing

Main Challenge: Process-speed inspection and metrology for process control of:

e.g. printed electronics, fingers on PV cells, and injection-moulded nanostructures

(these are all functional parts made competitively in bulk using reduced-cost methods)

Approach and main results (not exhaustive!) (* = Macroscale special issue):

- Faster, more accurate surface structure measurement, for <u>critical dimensions of tracks and channels</u> and for <u>production-speed quality control of micro-/nanostructures</u>
  - Hybrid 2D/3D in process metrology demo built (NPL) [*Jones & O'Connor 2018 *MST* **29** 074004]
  - Alignment-free characterization of 2D gratings (DFM) [Madsen et al. 2016 *Appl. Opt.* **55** 317-322]
  - All-optical difference engine for defect detection [Feng *et al.* 2018 *Opt. Express* **26** 13927-13937]
- 1 µm substrate tracking for 10 µm overlay alignment
  - Measurement and control targets surpassed (VTT, NPL) [e.g. O'Connor *et al.* 2016 *Proc. 31 ASPE AM*]
- Process optimisation, inline feedback exploiting defect-function correlation
  - Topography vs. resistance for PV cell electrodes (INRIM) [Bellotti et al. 2018 *STMP* **6** 025002]
  - Process-speed control of gratings on clear plastic discs (DFM) [Madsen et al. 2017 J. Microm. Microe. 27 85004]
- Traceability, standards and metrology guidance
  - e.g. Calibration & study of application-specific behaviour (VTT) [*Seppä et al 2018 *MST* **29** 054008]

<u>Details</u>

PhotInd, 14IND22, EMPIR Call 2014

Metrology for the photonics industry

Main Challenge:

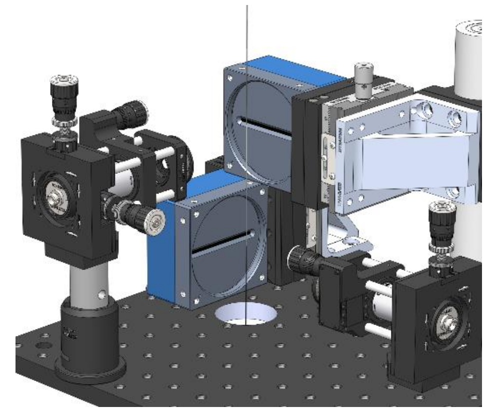
- New meas. methods for modern photonic components
- Improved metrology for measurement instruments

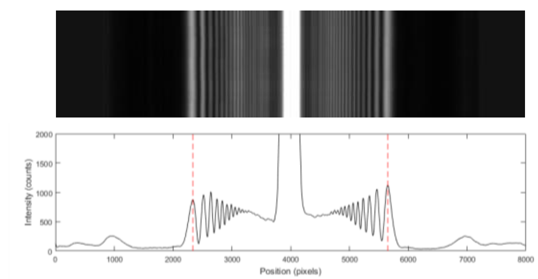
Approach:

- Fibre dimensional measurements based on scatterometry
- Metrology for waveguides, THz links (SNR, BER…)
- Traceability for EAF, OTDR, absolute power...

Main Results:

- Instrument for online measurement of fibre coating **geometry**
- Novel setups for dispersion, high-power, cladding light, EAF, optical power, planar waveguide charac.
- Calibration artefacts: OTDR, OLCR
- New components: fibre-to-chip couplers, SWG devices, THz link tests





EAF = encircled angular flux, OTDR = optical time-domain reflectometry, OLCR = optical low coherence reflectometry, BER = bit-error ratio, FEM = finite element method, SWG = subwavelength grating

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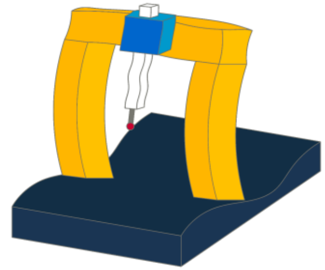
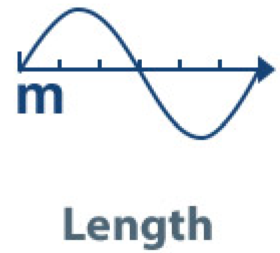
Digitalization



Virtual instruments were already developed in the late 90s

- **VCMM** (virtual Coordinate Measuring Machine)
- Complex instrument behaviour due to 21 DoF
- Need to determine task-specific measurement uncertainties by Monte Carlo simulation approach (GUM Suppl. 2)
- Transferred to industry in 2002 (PTB)
- Later extensions for scanning modi, other sensors and other dimensional instruments (gear, laser tracer, AFM, SEM)
- **VCMM 2** launched at Control fair in April 2018



Macroscale 2017 Conference

- Organised by VTT-MIKES, and PTB in co-operation with EURAMET TC-L

- October 17th to 19th, 2017
- VTT-MIKES, Espoo, Finland

- > 80 participants

Thank you

for your attention!

TC-L Oct. 2017, VTT-MIKES, FI

=> TC-L Report 2018:
Detailed information

=> TC-L Meeting 2018:
15-16 Oct. 2018, LNE, FR

=> TC-L Meeting 2019:
14-15 Oct. 2019, PTB, DE

=> In conjunction with Nanoscale 2019 conference (15-16 Oct)
and CCL WG-MRA and WG-N meetings (17-18 Oct)

Length