



TC Length

Highlights and challenges

A. Lassila, TC-L chair
MIKES, Finland

1

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark

TC-L

Length
• EURAMET Technical Committee



Outline

- Highlights TC-L 2011/2
- Challenges in length metrology
 - Roadmap update
 - New triggers & targets

2

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark

TC-L

Length
• EURAMET Technical Committee





TC-L highlights: TC-L meeting & Macroscale 2011 conference

- **TC-L 2011** meeting was organized at METAS, Wabern 3.-4. October 2011
- It was immediately followed by **Macroscale 2011 conference** with ~100 participants from all RMO areas, industry and universities



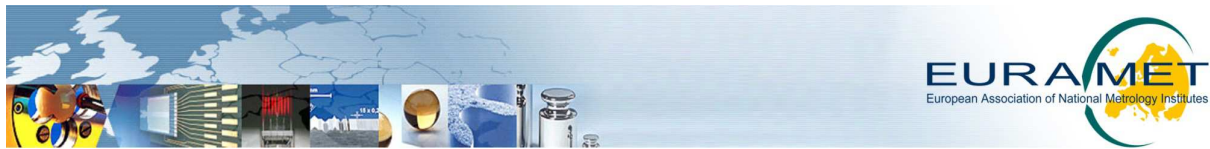
TC-L highlights: 2010 & 2011 EMRP calls

TC-L community was quite successful in 2010/2011 calls

- Funded projects have strong connections to Academia and industry
- In 7 length projects there are 17 university groups and 9 companies as partners
- These JRPs also had ~60 supporters from industry and academia
- In addition at least 6 JPRs with some dimensional metrology related research

First meeting of TC-L EMRP working group at PTB 2/2012

~open meeting with 40 participants



Funded length and length related JRPs

2010	IND05	MeProVisc	Dynamic Mechanical Properties and Long-term Deformation Behaviour of Viscous Materials
	IND10	Form metrology	Optical and tactile metrology for absolute form characterization
	IND11	MADES	Metrology to Assess the Durability and Function of Engineered Surfaces
	IND13	Thermal design and dimensional drift	Thermal design and time-dependent dimensional drift behaviour of sensors, materials and structures
	IND14	Frequency	New generation of frequency standards for industry
	IND17	Scatterometry	Metrology of small structures for the manufacturing of electronic and optical devices
2011	HLT02	MetVes	Metrological characterisation of micro-vesicles from body fluids as non-invasive diagnostic biomarkers
	SIB08	Subnano	Traceability of sub-nm length measurements
	NEW01	TReND	Traceable characterisation of nanostructured devices
	NEW05	MechProNO	Traceable measurement of mechanical properties of nano-objects
	NEW06	TraCIM	Traceability for computationally-intensive metrology
	NEW08	MetNEMS	Metrology with/for NEMS
	NEW09	METCO	Metrology of electro-thermal coupling for new functional materials technology

5

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark

TC-L

Length
EURAMET Technical Committee



EMRP call 2010; Metrology for industry: Form metrology

Optical and tactile metrology for absolute form characterization, Michael Schulz, PTB

Project Partners:

PTB, CMI, METAS, LNE, MKEH, SMD, VSL

Fraunhofer Institute for Production Technology, TNO, Technical University of Ilmenau, Universität of Stuttgart

XPRESS Precision Engineering, IBS Precision Engineering

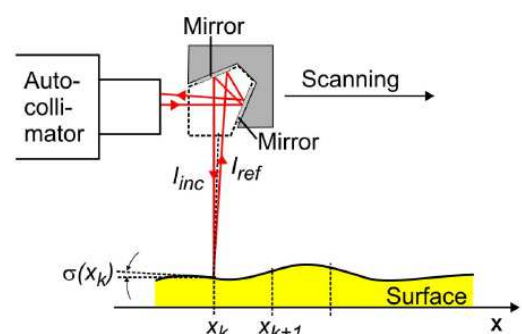
NMIs

Research inst. & Univ.

Form measurements:

- on flat surfaces with uncertainties < 1 nm and
 - on curved surfaces with uncertainties < 10 nm
- using imaging (interferometric) and scanning (optical and tactile) methods, developing software for the handling of a large number of data points, investigating error influences for interferometric and tactile scanning methods by modelling and simulation.

Companies



6

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark



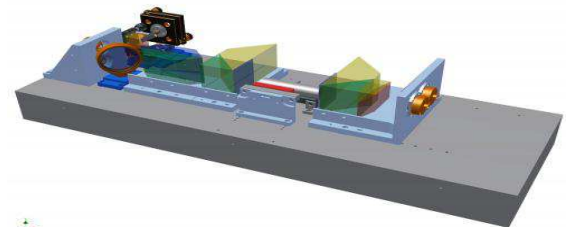
EMRP call 2010; Metrology for industry: Thermal design and dimensional drift

Thermal design and time-dependent dimensional drift behavior of sensors, materials and structures, Jens Flügge (PTB)

Project Partners:

PTB, LNE, NPL, VSL, ENSMA, FhG, TU Ilmenau

- Development of test facilities, techniques and procedures for measurements of dimensional drift
- Investigation of long term drift properties of sensors, materials and structures;
- Measurement of thermal behaviour of materials and structures, modelling and optimisation of thermal design.



Collaborators



7

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, D



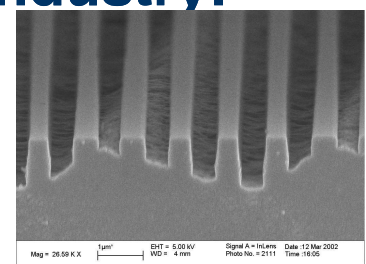
EMRP call 2010; Metrology for industry: Scatterometry

Metrology of Small Structures for the Manufacturing of Electronic and Optical Devices, Bernd Bodermann (PTB)

Project Partners:

PTB, CMI, DFM, MIKES, VSL, NPL, UEF, DUT, Nanocomp, JCMwave

- Scatterometry and CD-SEM for metrology of advanced functional structures in the sub micrometer-range: micro-structured surfaces, IC processing, diffractive optical elements
- Validation and optimisation for applications in industry
- Development of "golden" reference standards for metrology in wafer processing



Collaborators



8

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark



EMRP call 2010; Metrology for industry: MADES

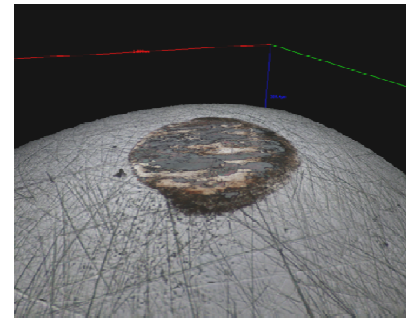
Metrology to Assess the Durability and Function of Engineered Surfaces, Mark Gee (NPL)

Project Partners:

NPL, BAM, CNAM, DTI, INRIM, MIKES, PTB, FAU, VTT, Alicona

Fundamental aspects of metrology for tribology:

- measurement of very small wear volumes
- long term measurement of low friction
- measurement of the temperature at wear interfaces
- measurement of changes in chemistry that occur at the contact interface between surfaces
- development of methods for the assessment of the durability of tribological surfaces



TecVac - IonBond - Teer Coatings
Phoenix Tribology - Tetra - Airbus
Rolls Royce - Aero Engine Controls
Sandvik - Glud - Marstrand
nCATS - E-Surf! - VITO VAMAS

9

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark



EMRP call 2011; SI broader scope: Subnano

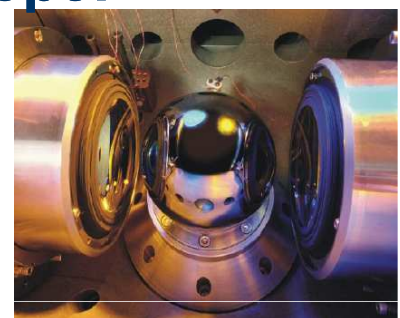
Traceability of sub-nm length measurements, Birk Andreas (PTB)

Project Partners:

PTB, CMI, MIKES, NPL, UME, VSL, INRIM, TUDelft, Università di Torino

The purpose of this JRP is to enable traceable measurements in the sub-nm range for optical interferometers as well as improved capacitive sensors.

- Modeling: wave front aberration for interferometers, capacitive sensors alignment & environment
- Measurement devices technology: wave front sensor, interferometers development, capacitive sensor studies, x-ray interferometer
- Cross validation



ASML

IBS
Precision Engineering

OPTICSII
Look on the top of a tower

OPTOCRAFT
OPTICAL METROLOGY

QUEENSGATE
INSTRUMENTS

SIOS
Hochschule Bochum

130 jaar **VU** **VIJDE**
UNIVERSITEIT
AMSTERDAM

10

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark



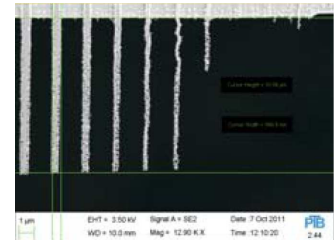
EMRP call 2011; New Technologies: MechProNo

Traceable measurement of mechanical properties of nano-objects, Ludger Koenders (PTB)

Project Partners:

PTB, BAM, CMI, MIKES, NPL, TU Dresden, Uni Helsinki

- Traceable force and displacement calibration of nanomechanical test systems (force range 10 mN to 10 pN, displacement resolution 0.1 nm)
- Provision of reference materials
- Development of validated modeling techniques
- Validated procedures to characterize size, shape and mechanical properties of nano-objects
- Intercomparison to evaluate the effectiveness of using reference materials



11

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark

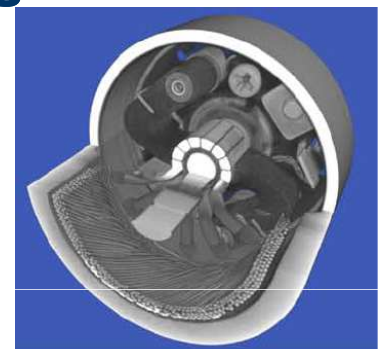


EMRP call 2011; New Technologies: TraCIM

Traceability for computationally intensive metrology, Alistair Forbes (NPL)

Project Partners:

**NPL, CMI, INRIM, PTB, UM, VSL, Uni Huddersfield, Uni Zwickau
Hexagon, Mitutoyo, Werth, Zeiss**



- Developing a coherent framework for establishing traceability in computationally-intensive metrology, like e.g. 3D coordinate metrology
- Encoding formal statements of computational aims in clear, unambiguous terms
- Reference data (or numerical artefacts, numerical standards, softgauges) associated with computational aims, Data Generators
- Criteria to assess the performance of software
- Enabling ICT to perform the software validation or 'numerical calibration'

12

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark



Challenges of length metrology

- TC-L WG EMRP 2/2012
 - Decided to maintain the topics of EMRP roadmaps, but to update content
 - Draft versions of the updated roadmaps ready last week

13

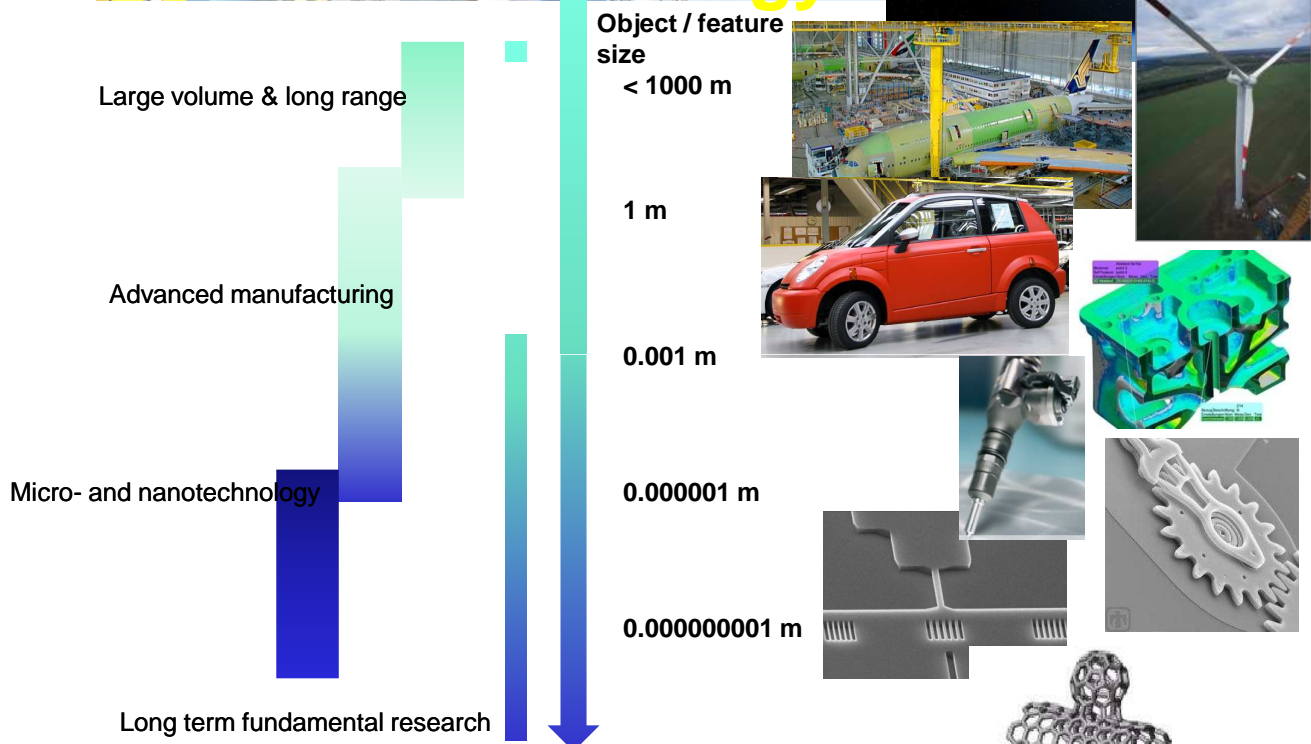
6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark

TC-L

Length
• EURAMET Technical Committee



Dimensional metrology for



14

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark

• EURAMET Technical Committee





Large volume & long range metrology

New triggers:

- Next generation '**super jumbo**' aircraft are now routinely manufactured: needs to improve automation and assembly accuracy
- Increasing need of **renewable energy sources (wind, future fusion, re-consideration of nuclear fission new build)**. => **large scale civil engineering**.
- **Galileo** satellites have been launched => validated **improvement in accuracy**
- European industry focusing to **lower-volume, high-value, customised manufacturing** – the concept of the 'smart factory' which uses omnipresent metrology.



Denmark

TC-L

Length
• EURAMET Technical Committee



Large volume & long range metrology



New targets:

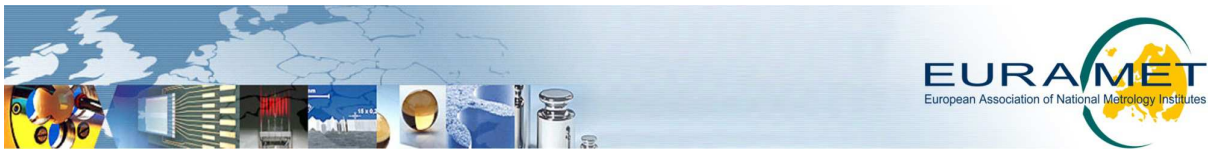
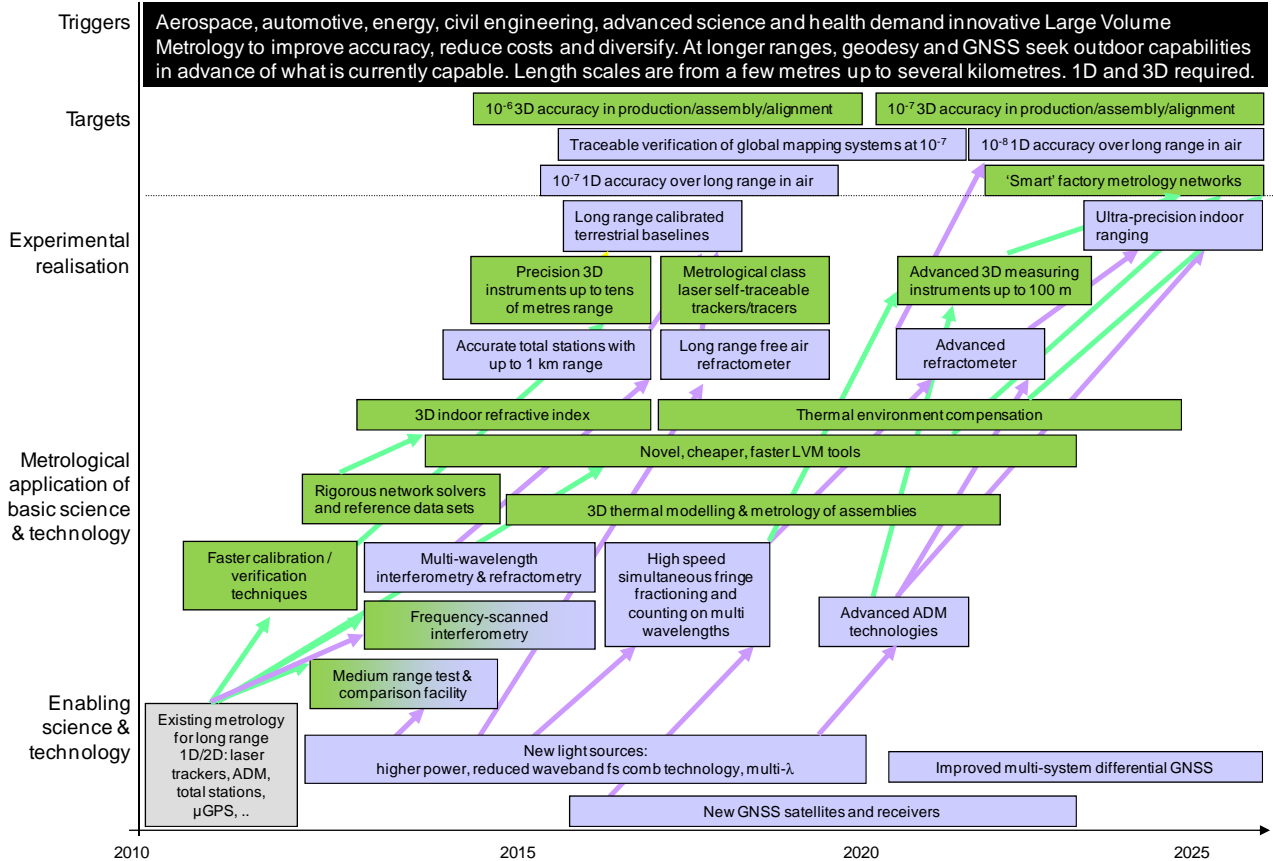
- **3D refractive index** covering the typical working volume of a factory, eventually to 10^{-6} or 10^{-7} accuracy level, to enable omnipresent optical metrology systems.
- Techniques for **thermal compensation of large structures** which cannot be assembled in controlled environments.
- Novel measuring systems based on innovative technologies, taking **accurate metrology directly to the shop-floor**, whilst lowering costs, to extend the uptake by smaller companies (SMEs).

TC-L

Length
• EURAMET Technical Committee



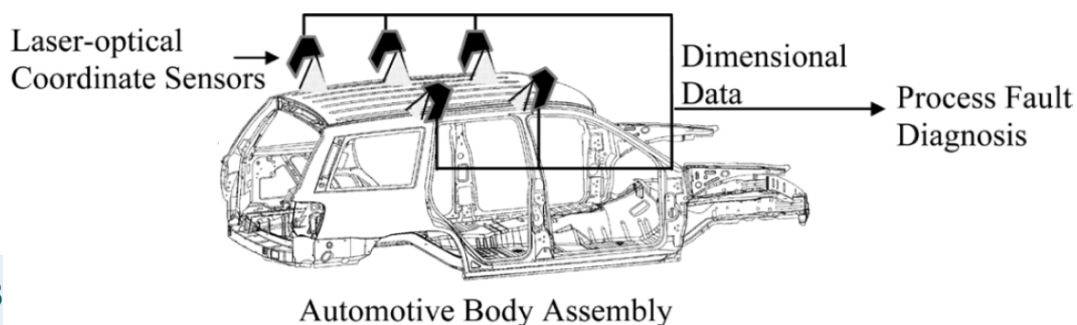
Large Volume and Long Range Dimensional Metrology – DRAFT C 2012



Advance manufacturing

New triggers:

- European industry focusing to **lower-volume, high-value, customized manufacturing** – the concept of the 'smart factory' which uses omnipresent metrology.
- **In process coordinate measurement** is becoming an important tendency of high accurate and cost efficient production.
- **Lean calibration concept** is spreading in car and aviation industry, requires new inline concepts





Advance manufacturing

New targets:

- traceable **inline metrology tools in production** environment
- traceable **lean calibration methods** for industry
 - transfer standards, artefacts
 - probe sample interaction with various sensors
 - software validation
 - etc.

19

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark

TC-L
Length
EURAMET Technical Committee



Dimensional metrology for advanced manufacturing technologies

Triggers

Economic and sustainable manufacturing of innovative and energy efficient products with complex structures down to 1 μm and up to 20 m, facing requirements of increased complexity, extended information content, higher measuring speed and reduced tolerances both at measuring room and production environment

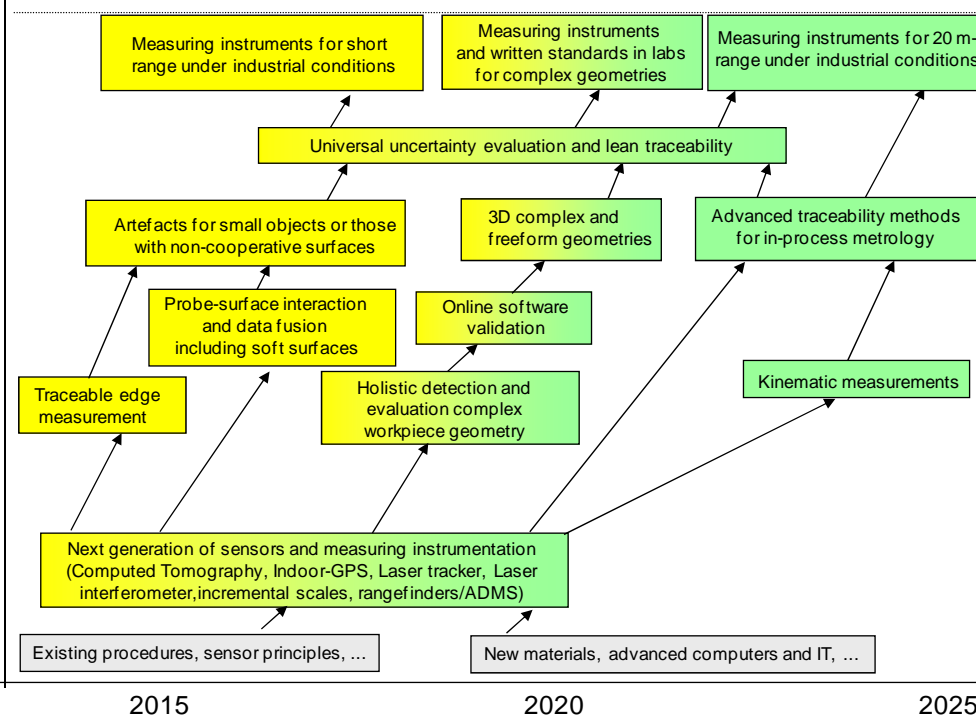
Targets

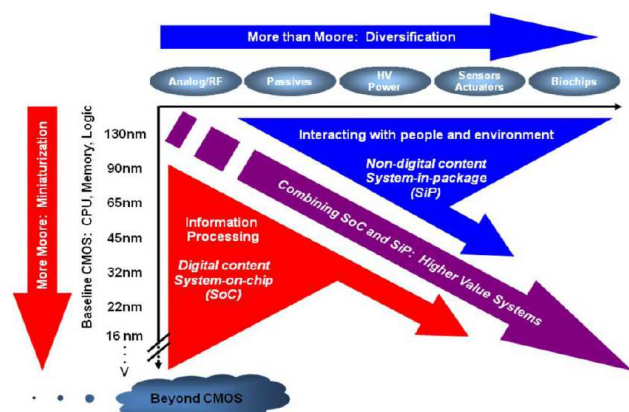
Dim. metrology < 20 m	in measuring room ($U < 10^{-7}$)	in production environment ($U < 10^{-6}$)	in process ($U < 10^{-6}$)
Short range dimensional metrology > 1 μm < 10 mm	$U < 0.05 \mu\text{m}$	$U < 0.01 \mu\text{m}$	$U < 0.005 \mu\text{m}$

Experimental Realisation

Metrological application of basic science & technology

Enabling science & technology





Micro- and nanotechnology

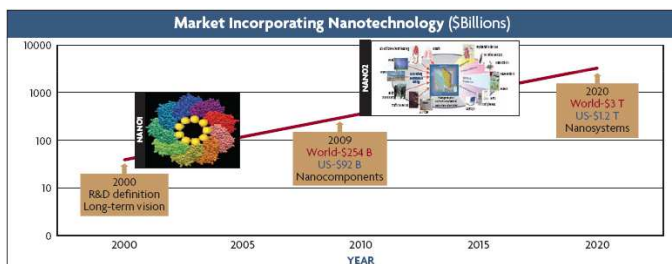
New triggers:

Semiconductor Industry.:

- ITRS2011
 - **Every year 5-10%** higher accuracy demand
 - Nanoelectronics: size is critical

Nanotechnology:

- WTEC report
 - **Nano2 phase 2010-2020**
 - Production **doubles every 3rd years**
 - **Improved metrology tools needed**
- CEN-352
 - **Standardization** for nanotechnology
 - Health, safety and environmental concerns



EURAMET General Assembly
25 May 2012, Kongens Lyngby, Denmark

TC-L
Length
EURAMET Technical Committee



Micro- and nanotechnology

New targets:

- **Multiparametric metrology of nanostructures** : size(3D), shape, thickness, overlay and materials characteristics at the sub-nm level
- **6 DOF metrology stages with sub-nm uncertainty** and thermal- and long-term stability in ambient and vacuum conditions
- **Shape and form** measurements of nano-particles and **nano-objects**, like fibres, rods, wires, plates or surfaces
- **Traceability for the shop floor**
- Multi-parameter **measurements in different media** (solid, air, liquid) and state (individual or agglomerate): Dimensional: (size, size-distribution, shape morphology, porosity, concentration)



Dimensional metrology for micro-nano technology

Triggers

European micro- and nano-technology is reaching increasing levels of miniaturisation and encountering new issues of health, production feasibility, quality and efficiency; for control and manuf. on $\mu\text{m}/\text{nm}$ -scale **metrology is needed!**

Targets

Nanoparticles in **complex** matrices: size, size-distribution, **shape/form and concentration** on 1 nm acc. level

3D multiparametric metrology of nano- and microstructures at sub-nm accuracy over sub-mm

2D metrology at sub-nm acc. up to 450 mm range

3D metrology at (few)-nm acc. over several 100 mm range

Exp. Realisation

Traceable **robust and broadly applicable** instrumentation for micro&nano-particles

Single probe 3D instrumentation with mm range

Single probe 2D/3D instrumentation over longer range

Instrumentation for multiparametrical characterization of nanostandards and new functional nanomaterials

Improved & new high resolution microscopy methods

Cross calibration of sensors and tool matching

Nanoparticle standards

Nanostandards over sub-mm range

Nanostructured standards over several 100 mm range

Metrological application of basic science & technology

Probe surface interaction modelling in **different surroundings**

Modeling of functional properties dependent on material **matrix and dimension**

Correlation of local and global particle metrology methods for **non-spherical particles**

Nano force metrology

UHV capable 6DoF positioning systems and sensors/probes

Enabling science & technology

Existing high resolution microscopy, position measurement, probes, data evaluation and micronano-fabrication methods (topdown)

New sensors/probes

Methods for self calibration and error separation

High dynamic 6DOF positioning capabilities

Stable materials/ structures & design principles

Nanoanalytics

Improved Nano fabrication (top down & bottom up)

2010

2015

2020

2025

Dimensional Nano /Micro technology: Functionalized surfaces and membranes

European nanotechnology has improved the functionalization of surfaces (superhydrophobic, self-cleaning, scratchresistance, low reflectance, low friction) and membranes used for filtering or in energy productions to save resources due to improved lifetime and/or energy saving properties. Furthermore new functionalized surfaces and techniques are produced to provide improved feeling (haptic, fingerprint free surfaces) or are under investigation to save resources or reduce energy (bio-fouling). All those need an improved 3D resolution capability, a more multi-instrumental characterization of nanostructured surfaces of different materials. This includes the characterization of thin films, porous surfaces, thin membranes including the filtering characterization.

Triggers

3D surface metrology over 100 μm (flat, form corr.)

3D surface metrology of curved surfaces over 1 mm

3D surface metrology of curved and structured surfaces over several 1 mm

Targets

2D surface metrology of flat surfaces

2D surface metrology on curved surfaces

2D surface topography on samples with heterogeneously surfaces

3D surface topography on samples with heterogeneously structured surfaces

Exp. Realisation

Improved high resolution measurement of thin membranes ($U < 10 \text{ nm}$)

Improved measurement of thin membranes ($U < 1 \text{ nm}$)

Improved high resolution low noise microscopes

Cross calibration of probes & sensors

Multi probe 2D(3D) instrumentation over longer range

Metrological application of basic science & technology

Improved calibration techniques for microscopes (tactile, optical, AFM probes)

Improved data fusion (tactile, optical, AFM probes)

Instrumentation for multiparametrical characterization of new functional nanomaterials

2D(3D) positioning capabilities; self calibration

Standards over sub-mm rang (μ -forms (sphere, cylinder) nano-roughness)

Standards over sub-mm range with heterogeneously structured surfaces

Improved characterization of side wall thin film or layers

Transferstandards for μ and n-force cal.

Improved characterization of effects due to water layers

Nano force metrology

Development of techniques for water layer and carbon characterization

Enabling science & technology

Micro force metrology

High resolution characterization of thin films by ellipsometry & XRR

Modeling of functional properties dependent on material **and dimension**

Existing high resolution microscopy and surface analysis, position measurement, data fusion

Improved measurement of optical properties of materials (n & k)

Probe - surface interaction modelling (MDC & FEA)

2012

2015

2020

2025



Dimensional metrology for fundamental research

New targets & triggers:

Re-definition of the SI

- mass unit, kg, Avogadro route (sphere d), Watt balance route (weight v)
- temperature scale, Boltzmann constant k , Dielectric-Constant Gas Thermometry (DCGT) route (piston A), Acoustic Gas Thermometry (AGT) route (resonator d)

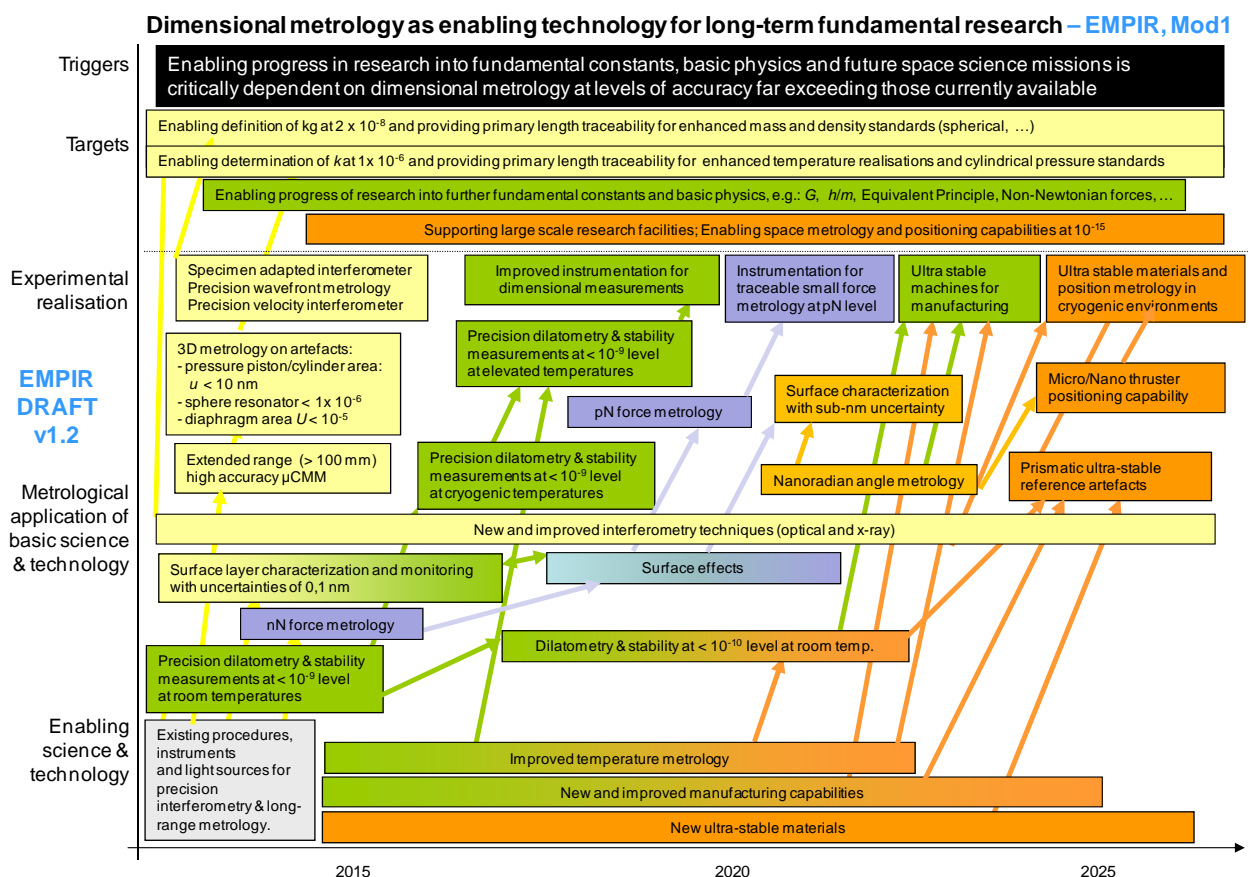
Fundamental research

- Gravitational constant G (torsion balance l, α)
- $N_A \cdot h, (\alpha, \text{nrad})$
- equivalent principle
- non-Newtonian forces
- ...

25

6th EURAMET General Assembly
21 - 25 May 2012, Kongens Lyngby, Denmark

TC-L
Length
EURAMET Technical Committee





Extraordinary Length comparison between Finland and Denmark

**Thank you for your
attention!**



Height comparison
October 30, 2010

Allure of Seas from
STX Europe's Turku
Shipyard, FI
Nominal height
 $H = 64.85 \text{ m}$

Meets ($v = 40 \text{ km/h}$)

Great Belt Bridge, DK
Nominal height
 $H = 65 \text{ m}$