Metrological SPMs for quantitative traced measurements in the nanoscale

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Outline:

1. Need for quantitative dimensional determination at the nanoscale
2. Measurements at the nanoscale
3. How to get quantitative measurements
4. Traceability matters
5. SPMs
6. Calibration of SPMs and transfer standards
7. Metrological SPM at CEM

Metrology topics at the ITRS 2009 Metrology roadmap

microscopy - critical dimension (CD) and overlay - film thickness and profile - materials and contamination analysis - dopant profile - in situ sensors and cluster stations for process control - reference materials - correlation of physical and electrical measurements - packaging.

According to ITRS 2009 Report

- Critical dimension measurement with nm level precision is difficult to achieve.

- A variation in features size of 1/10 of the nominal dimension often results in significant changes in device properties.

- The fundamental challenge for factory metrology will be the measurement and control of atomic dimensions **while maintaining profitable high volume manufacturing**.

- Long-term research into nano-devices may provide both new measurement methods and potential test vehicles for metrology.

		2010	2012	2014	2016	2018
	Flash 1/2 pitch (nm)	***32***	***25***	***20***	***16***	***13***
	DRAM ½ Pitch (nm)	45	36	28	23	18.0
	MPU Printed Gate Length (nm)	41	31	25	20.0	16.0
	MPU Physical Gate Length (nm)	27	22	18.0	15.0	13.0
	Wafer Overlay Control (nm) - 20% DRAM	9.0	7.1	5.7	4.5	3.6
	Wafer Overlay Control Double Patterning (nm)	6	5	4	3	3
	Lithography Metrology					
Gate	Physical CD Control (nm) Allowed Litho Variance = 3/4 Total Variance	2.8	2.3	1.9	1.6	1.3
Gate	Wafer CD metrology tool **uncertainty** (3σ, nm) at P/T = 0.2	0.55	0.46	0.37	0.31	0.26
Gate	Etched Gate Line Width Roughness (nm) <6% of CD	2.1	1.8	1.4	1.2	1.0
Dense Lines	Printed CD Control (nm) Allowed Litho Variance = 3/4 Total Variance	3.3	2.6	2.1	1.7	1.3
Dense Lines	Wafer CD metrology tool **uncertainty** (3s, nm) at P/T = 0.2	0.7	0.6	0.5	0.4	0.3
	Double Patterning Overlay Metrology					
	Double Exposure and Etch - Process Range (nm)	6.4	5.1	4.0	3.2	2.5
	Double Exposure and Etch - **Uncertainty** (nm)	1.3	1.0	0.8	0.6	0.5
	Spacer PEE process					
	First pass CD control (after etch) - Process Variation (nm)	3.0	2.4	1.9	1.6	1.3
	First pass CD control (after etch) - Uncertainty (nm)	0.6	0.5	0.4	0.3	0.3
	Front End Processes Metrology					
	High Performance Logic EOT equivalent oxide thickness (EOT), nm	0.65	0.5	0.5	0.5	0.5
	Logic Dielectric EOT Precision 3σ nm	0.0026	0.002	0.002	0.002	0.002
	Interconnect Metrology					
	Barrier layer thick (nm)	3.3	2.4	1.7	1.3	1.1
	Void Size for 1% Voiding in Cu Lines	4.5	3.6	2.8	2.3	
	Detection of Killer Pores at (nm) size	4.5	3.6	2.8	2.3	

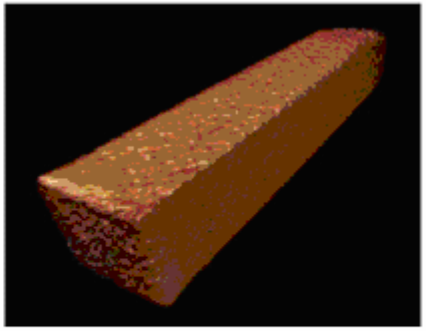
Manufacturable solutions exist, and are being optimized	
Manufacturable solutions are known	
Interim solutions are known	◆
Manufacturable solutions are NOT known	

Example: ITRS 2009 Metrology Roadmap

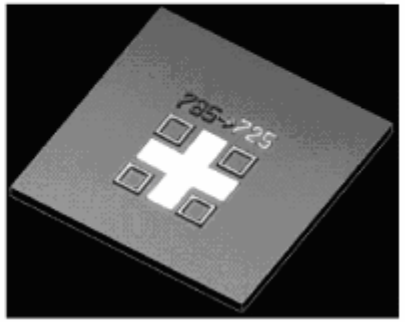
Interconnection Metrology

Replacing the silicon dioxide with a low-κ dielectric of the same thickness reduces parasitic capacitance, enabling faster switching speeds and lower heat dissipation

- **Existing Challenges**
  - Measurement Gap - Sidewall barrier thickness and sidewall damage (compositional changes in low k)
  - New - Porous low k is projected for 22 nm ½ Pitch
  - Detection of Voids after electroplating
  - Monolayer interface for new barrier-low k



- **Air Gap sacrificial layer does not require unique metrology**
- **Metrology is needed for 3D Integration**
  - TSV Depth and Profile through multiple layers
  - Alignment of chips for stacking – wafer level integration
  - Bond strength
  - Defects in bonding
  - Damage to metal layers
  - Defects in vias between wafers
  - Through Si via is high aspect ratio CD issue
  - Wafer thickness and TTV after thinning
  - Defects after thinning including wafer edge



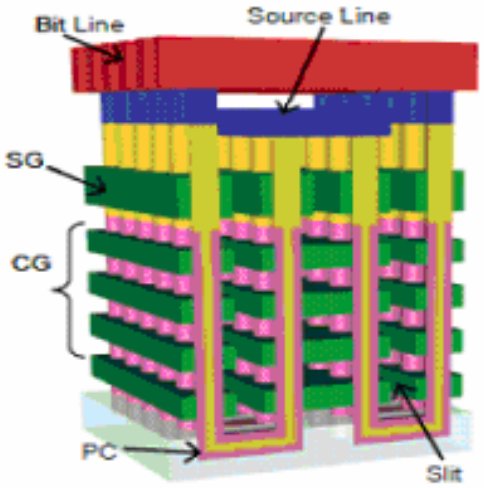
- **Emerging / Gated Interconnects**
  - Native Deice Interconnects

Example: ITRS 2009 Metrology Roadmap

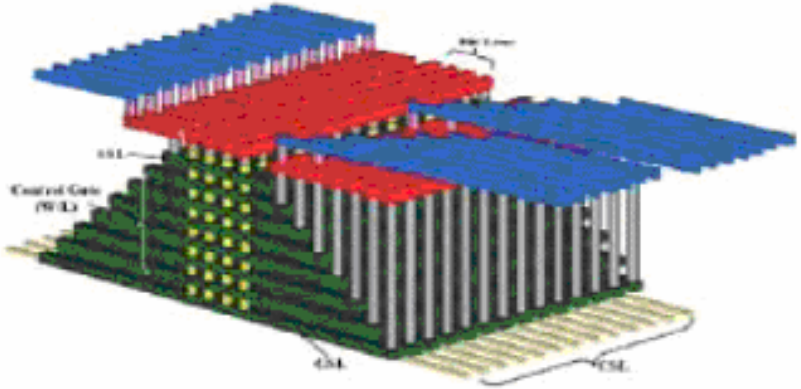
Front End Process (FEP) Metrology

3D Metrology – Complex structure measurement and inspection are required

e.g. high A/R holes, film thickness & properties on sidewall



Pipe-shaped BiCS Flash Memory
(R. Katsumata, Toshiba)



TCAT (Terabit Cell Array Transistor)
(J. Jang, Samsung)

Nanomedicine

a) Direct measurement of different elements in the nanoscale: cells, receptors, membranes, organelles, proteins, biomolecules

b) Topographical study of surfaces

c) New developments in this discipline (ref. K.K. Jain, Med Princ Pract 2008; 17:89-101)

- **Nanodiagnostics:** Molecular (and Nanomolecular) diagnostics as the nanothechnology-on-a-chip for total chemical analysis systems, Imaging with nanoparticle contrast materials, Nanobiosensors
- **Nanopharmaceuticals:** Nanotechnology-based drugs,Targeted drug delivery to site of action, Drug delivery from implanted nanopumps and nanocoated stents
- **Reconstructive surgery:** Tissue engineering with nanobiotechnology scaffolds, Implantation of rejection-resistant artificial tissues and organs
- **Nanorobotics:** Vascular surgery by nanorobots introduced into the vascular system, Remote controlled nanorobots for detection and destruction of cancer
- **Nanosurgery:** Tools for nanosurgery, Nanosensors implanted in catheters to provide real-time data during surgery, Nanolaser surgery

Chemical Nanometrology

Three priority areas to meet industrial needs:

- measurement of the chemical composition of thin films and concentration of species.
- characterisation of structural properties.
- granulometry of **nanoparticles** in different media (liquids, gases).

Challenging areas for surface chemical and structural analysis:
(identified by the Surface Analysis Working Group at the CCQM/BIPM)

- microelectronics (*key driver of metrology and standardisation developments in surface analysis for the last forty years*)
- life sciences, bio-nano-objects;
- manufactured nano-objects.

New certified reference materials useful for chemical analysis are needed.

Source: Co-Nanomet

Thin Films

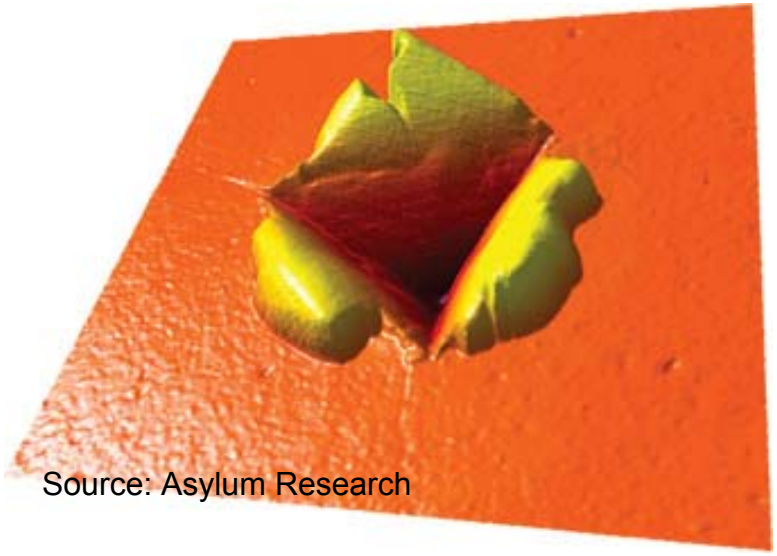
Large application and economic impact over a wide range of industry sectors:
- As buried layers, core to the performance of state-of-art microelectronics and magnetic data storage devices.
- As surface functional layers, employed for wear-, impact- and scratch-resistance, friction-control, lubrication, anti-reflection coatings, bio-activity or passivation, wettability and easy-to-clean or self-cleaning surfaces.

Generic measurement tasks: Thickness, chemical composition, structure, conformity, uniformity and integrity, surfaces and interfaces (chemistry, structure, roughness, inter-diffusion, etc.), impurities and dopants, mechanical properties, ...
Techniques available in the sub-100 nm range:
• length-based methods, potentially traceable to the SI unit of length, and
• areal-mass based methods, potentially traceable to mass or mole (per unit area)

Source: Co-Nanomet

Nanomechanics

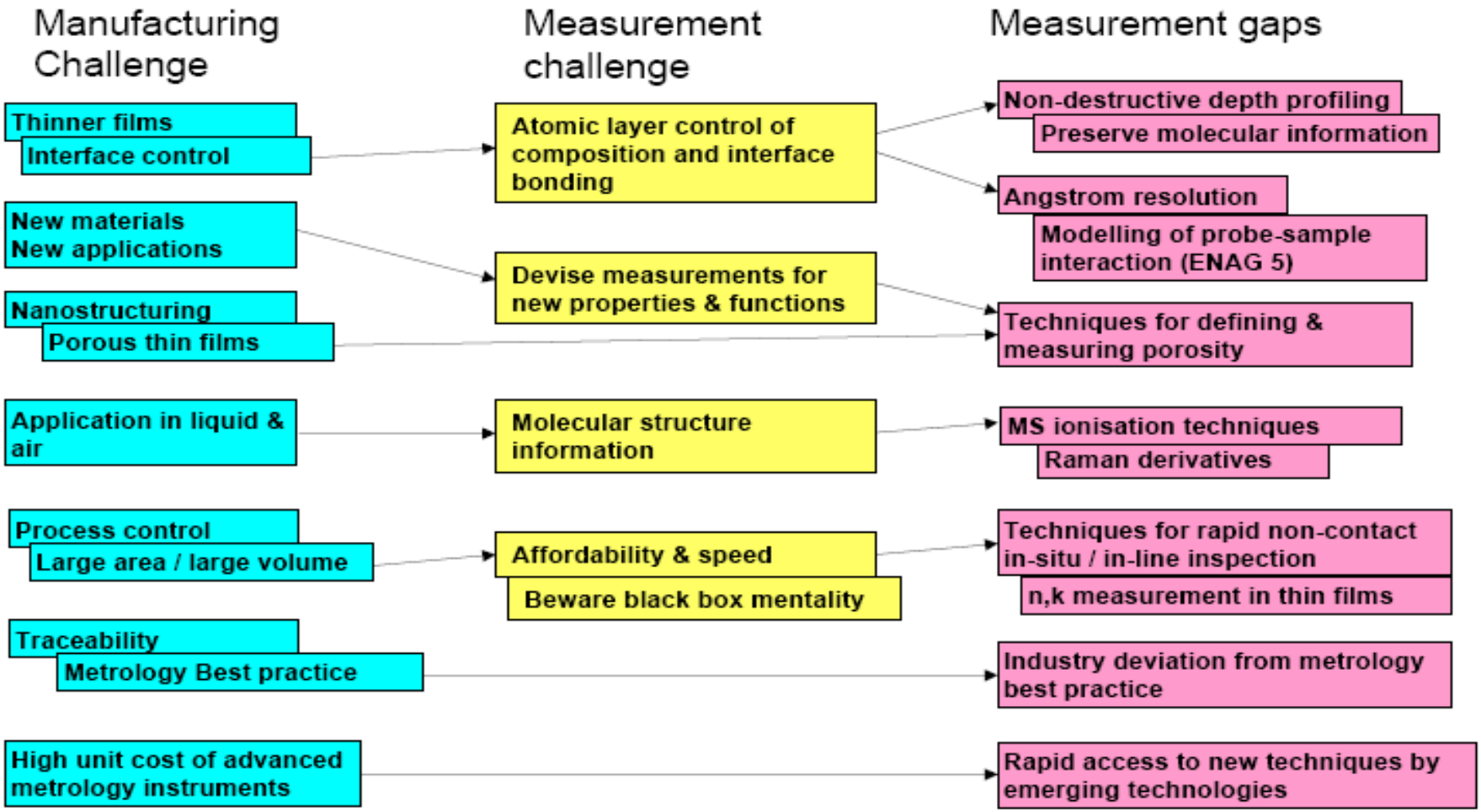
Key technology for the support of important industrial sectors as thin films and coatings in industrial applications. Also important for the development of micro and nanotechnology devices and components.
Most advanced areas: nanoindentation and AFM indentation measurements



Source: Asylum Research

Source: Co-Nanomet

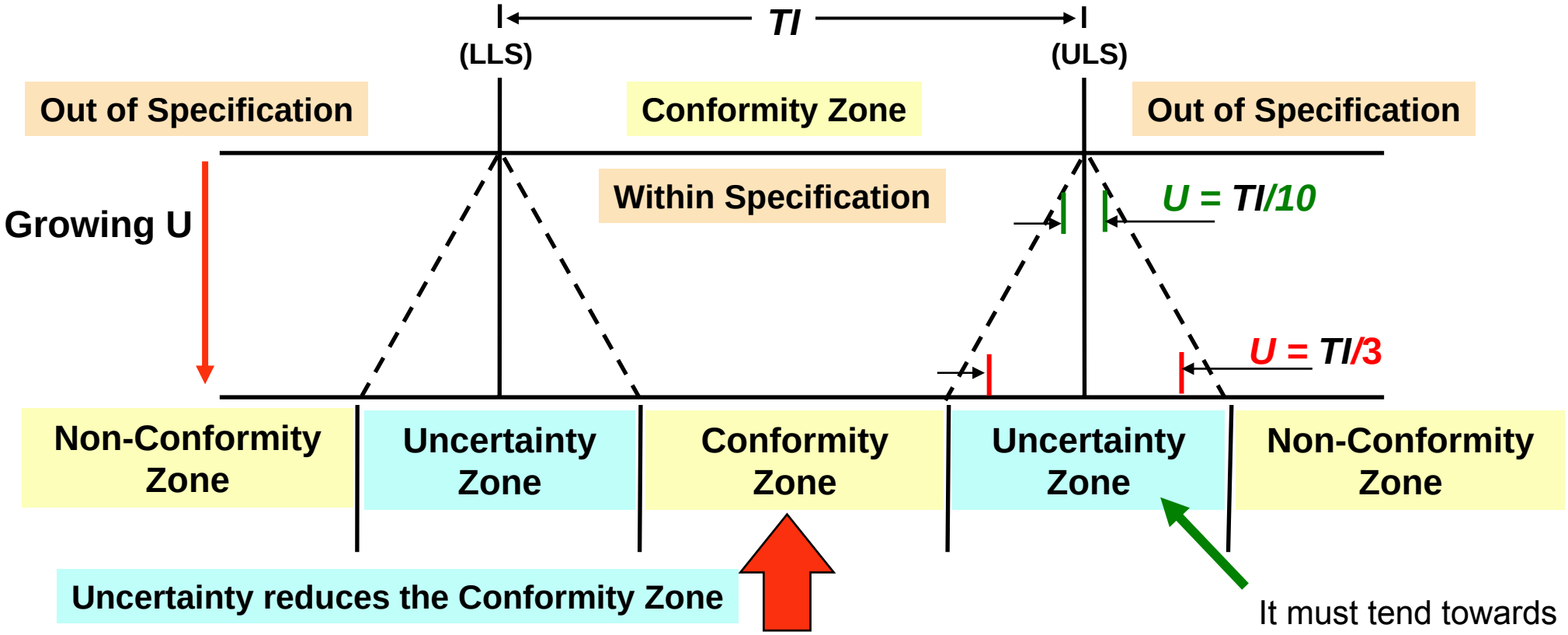
Tendencies and Challenges in nanometrology



Co-Nanomet, A. J. Pidduck, L. Koenders, T. Dziomba, L. E. Depero and M. Gee

UNE EN-ISO 14253-1

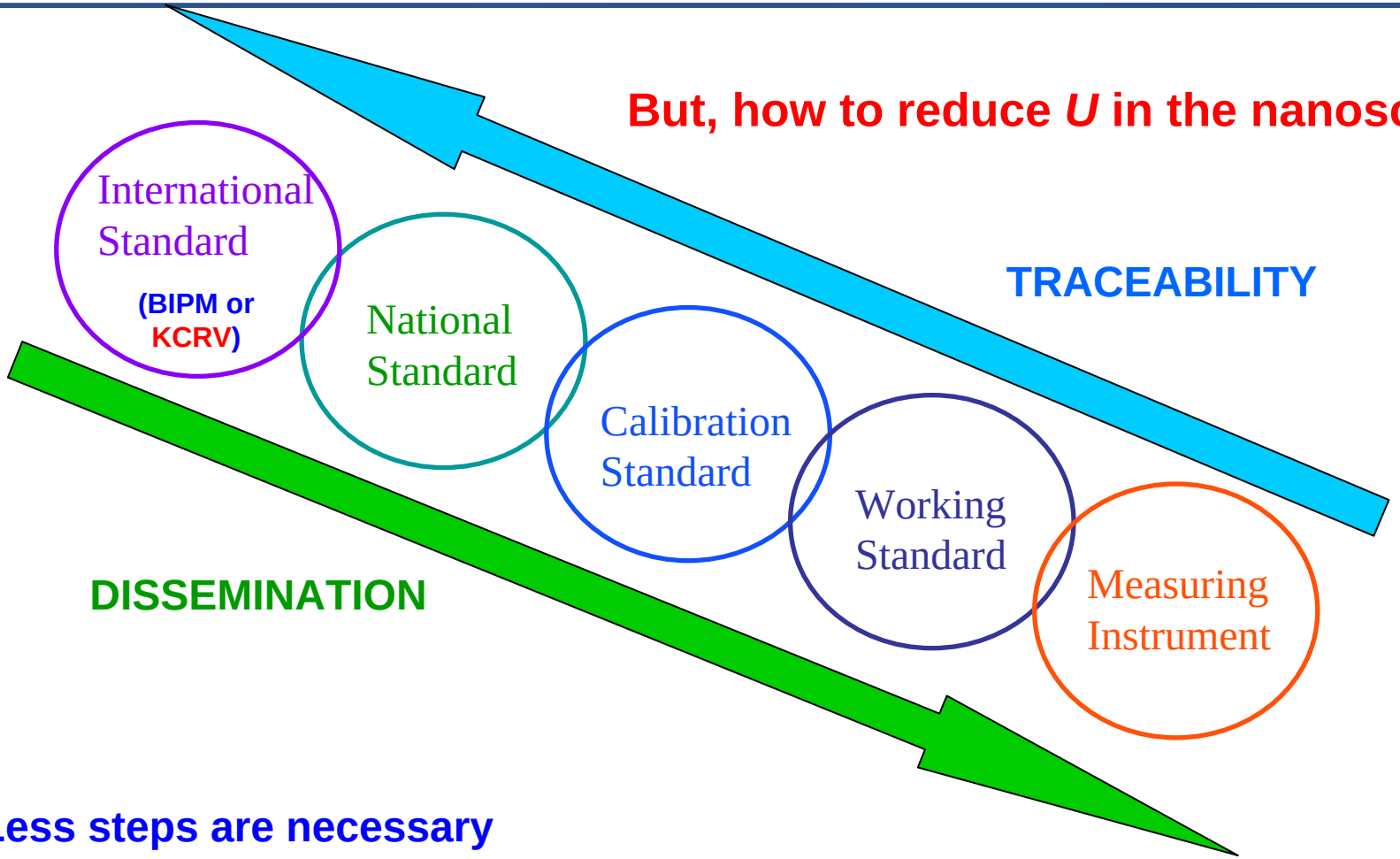
Uncertainty is INHERENT in measurement



In classical industrial Metrology, optimal *TI/U* = 10

In nanotechnology, *TI/U* typically ≤ 4 and eventually pointing to 1

But, how to reduce *U* in the nanoscale ?



- **Less steps are necessary**
- Production machines **MUST BE** measuring instruments too
- **Metrological Design getting direct traceability to SI Units**

Estimation (1st) and **Reduction** (2nd) of *U* should be applied to all measurement and characterization techniques used in nanometrology

- **laser interferometry (visible and X-ray),**
- **laser Doppler,**
- **inductive and capacitive sensors, piezoelectrics (PZTs),**
- **ellipsometry, *variable-angle spectroscopic ellipsometry* (VASE),**
- **optical spectroscopy**
- **optical microscopy: Nomarski, *total internal reflection microscopy* (TIRM), confocal, …**
- **contact profilometry,**
- ***total integrated and angle-resolved scatterometry* (TIS, ARS),**
- **STM, AFM, SNOM, …**
- **X-ray diffraction,**
- **electronic and diffraction microscopy (XTEM, STEM, SEM, HRSEM),**
- **Raman spectroscopy and *Fourier transform infrared absorption*,**
- ***Auger* (AES), *X-ray photoelectron* (SPS) & *backscattering* (RBS) spectroscopies,**
- **X-ray fluorescence**
- **…/…**

- Quality System acc. ISO 17025
- Interlaboratory Comparisons

Accurate Measurements

- No sistematic errors
- Precision (repeatability)

Validated Measurement Procedures

QUANTITATIVE MEASUREMENTS

Traced Measurements

- Linked to a SI unit (calibrated)
- Estimation of Uncertainty

Dimensional Nanometrology Needs

Increasing the lateral scanning range of AFMs to several tens of millimetres to allow the measurement of large area structured surfaces, wafers and optics.

(higher scanning speed, intelligent probing and control systems, sampling strategies including combining SPMs with other instrumentation, intelligent multi-sensor concepts, improved data fusion algorithms, etc.)

Improved SPM resolution (**repeatability** & **reproducibility**) to allow the measurement of smaller structures with higher accuracy. Better theoretical understanding of surface-probe interactions and refined probe characterization for a true quantification of dimensional measurements.

Source: Co-Nanomet

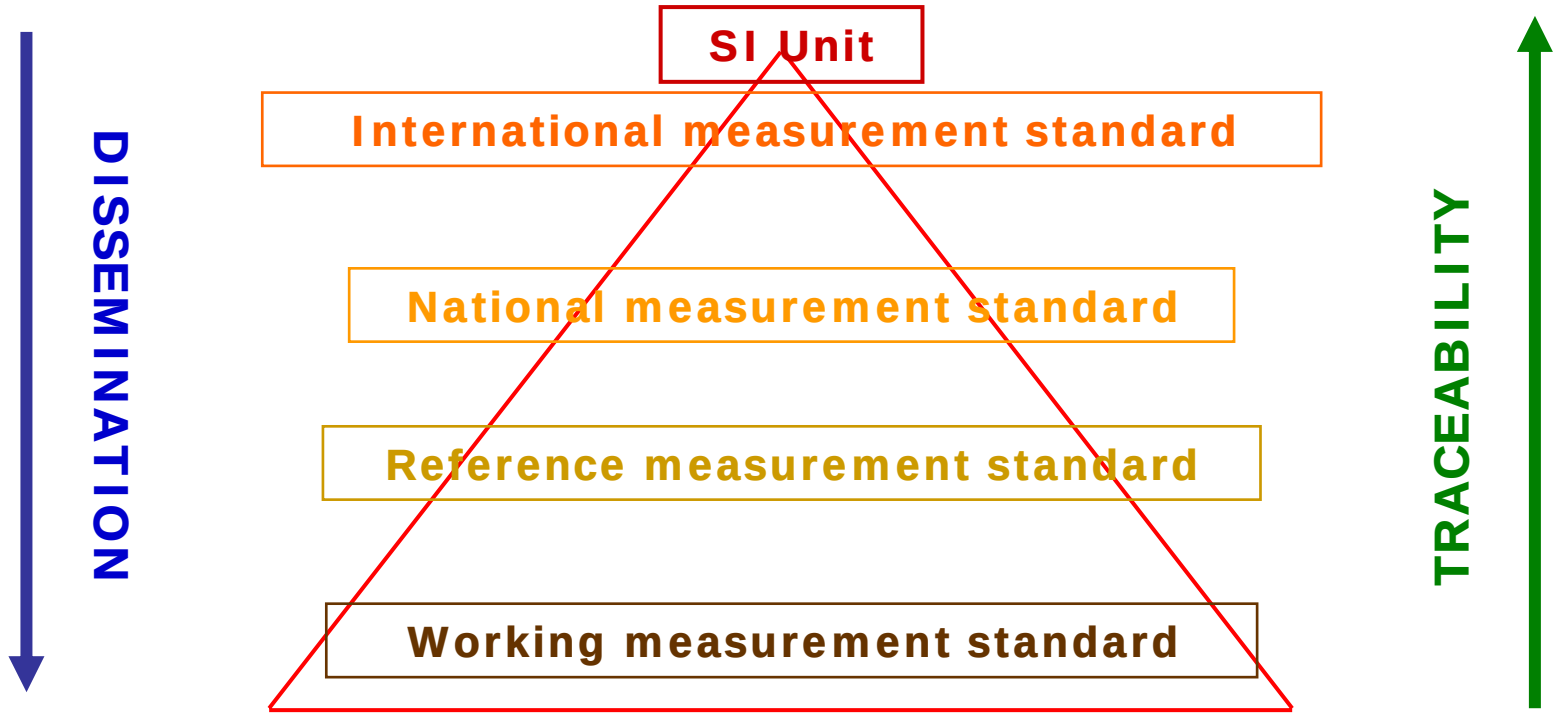
Dimensional Nanometrology (cont.)

Increasing true 3D-measurements: Semiconductor industry needs to measure high aspect ratio (HAR) structures and critical dimensions (CDs). Development of MEMS and NEMS.
Development/Improvement of new 3D nano machines (nano CMMs)

Appropriate traceability infrastructure (development of metrological AFMs, transfer artefacts, optical interferometers, …).

Fast and accurate areal measurement and characterisation techniques (technical specifications and standards coming soon).

Source: Co-Nanomet



If Traceability Chain too long, Uncertainty too high
Need of direct link to SI unit (1 to 2 steps)

Traceability at CEM

optical frequency synthesizer

10^{-13}

SI unit
the metre

He-Ne iodine stabilized lasers

10^{-11}

lasers used in interferometry

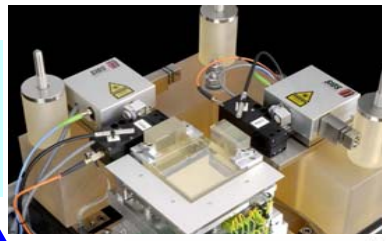
calibration of lasers

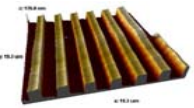
DISSEMINATION

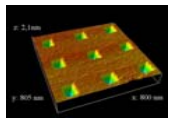
TRACEABILITY

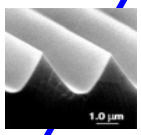
interferential microscope

metrological SPM
(integrated lasers + nanopositioning)

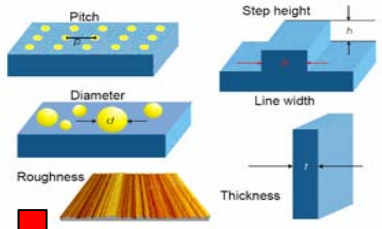






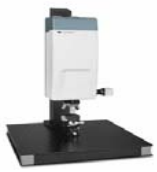


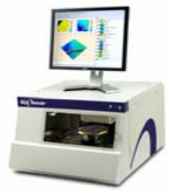
transfer standards: step heights, grooves, 1D&2D gratings, ...

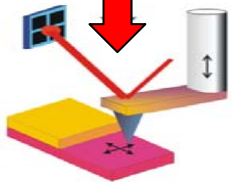


Industries and Research Centres

SPMs, profilometers, microscopes, SEMs, ...







SPM Calibration according to VDI/VDE 2656–1

Some applications of SPMs

- **precision engineering** (e. g. form/waviness/roughness, surface finish, film/layer thickness; products & tools)
- **micro-fabrication** (e. g. sensors, optical gratings, micro-lenses, micro-sieves, MEMS; master & product)
- **semiconductor fabrication** (e. g. critical dimension CD, pitch, line edge roughness LER, overlay; masks & wafers)
- **material science** (e. g. grain size distribution, roughness, hardness/nano-indentation, force spectroscopy)
- **crystallography, solid state physics** (arrangement of atoms, molecules, clusters)
- **chemistry** (e. g. polymer research: elasticity, local chemical sensitivity and dispersion)
- **life sciences** (features of tissue and local chemical activity, often studied in liquids)
- **nano-science/nano-engineering** (nanostructured or nanometrically functionalized surfaces, nanoparticles, nanorods, carbon nanotubes -CNT, etc.)
- **Calibration of reference structures (standards) for *other* measurement techniques**

SPM Categories, attending to its Traceability

A

Reference SPMs with integrated laser interferometers.
Often referred to as “metrological SPMs” (no Abbe error).
Direct Traceability, via the wavelength of the laser used, to the SI unit of length.

B

SPMs with integrated sensors for positioning monitoring, e.g. capacitive and inductive sensors, strain gauges, encoders.
Calibrated either by temporarily attaching laser interferometers to the scan or by using high-quality physical transfer standards.
Two subcategories are distinguished:

- **B1.** Active position, tracking to the scheduled position by means of a closed- loop, usually called “closed –loop” configuration.
- **B2.** Includes position measurements but without closed loop.

C

SPMs in which the position is determined from the **electrical voltage applied** to the adjusting elements.
Calibration usually with physical transfer standards.

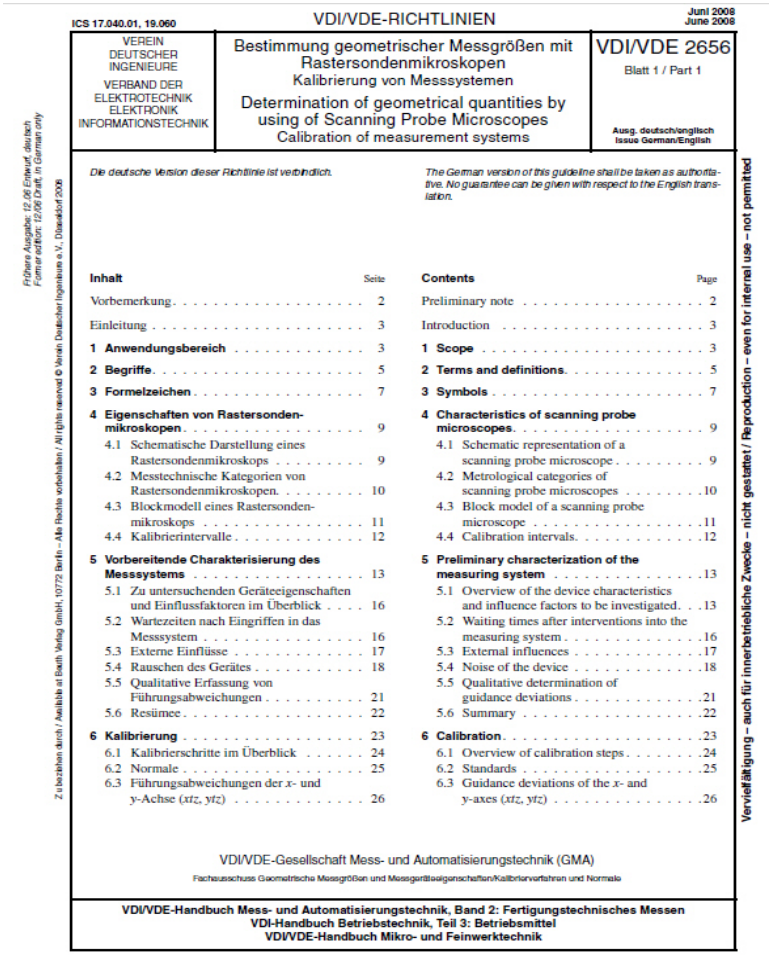
SPM Main Elements		
casing / mounting	mechanical, acoustic, electromagnetic, thermal characteristics	C, B, A
sample with sample holder	object under study	C, B, A
x-y coarse positioning	rotational deviations	C, B, A
x-y scanner	to displace the probe or alternatively the sample	C, B, A
z coarse approach	to decrease distance between the probe and the sample up to a value where the z actuator can operate	C, B, A
z actuator	element to keep the probe under constant conditions while scanning the sample	C, B, A
probe	tip to investigate sample properties	C, B, A
detector loop	element to detect small changes in the property under study (as a photodiode)	C, B, A
x-y and/or z displacement transducer	encoders, capacitive or inductive displacement transducers, strain gauges	B1, B2
closed loop	active position control	B1
laser interferometers	position measurement and control (closed loop)	A
angular sensors	tilt measurement and control (closed loop)	A

VDI/VDE 2656-Part1: Determination of geometrical quantities by using of Scanning Probe Microscopes

Calibration of measurement systems

Objectives of the guideline:

- Comparability of measurements of geometrical quantities by traceability to the unit of length
- Definition of minimum requirements for the calibration process and the conditions of acceptance
- Ascertainment of the calibratability (assignment to calibratability categories)
- Fixing of the scope of a calibration (conditions of measurement and environments, ranges of measurement, temporal stability, transferability)
- Provision of a model according to GUM to calculate the uncertainty for simple geometrical quantities in measurements using a scanning probe microscope
- Definition of the requirements for a result report



ICS 17.040.01, 19.060

VDI/VDE-RICHTLINIEN

Juni 2008
June 2008

VEREIN DEUTSCHER INGENIEURE
VERBAND DER ELEKTROTECHNIK ELEKTRONIK INFORMATIONSTECHNIK

Bestimmung geometrischer Messgrößen mit Rastersondenmikroskopen
Kalibrierung von Messsystemen

Determination of geometrical quantities by using of Scanning Probe Microscopes
Calibration of measurement systems

VDI/VDE 2656
Blatt 1 / Part 1

Ausg. deutsch/englisch
Issue German/English

Die deutsche Version dieser Richtlinie ist verbindlich.

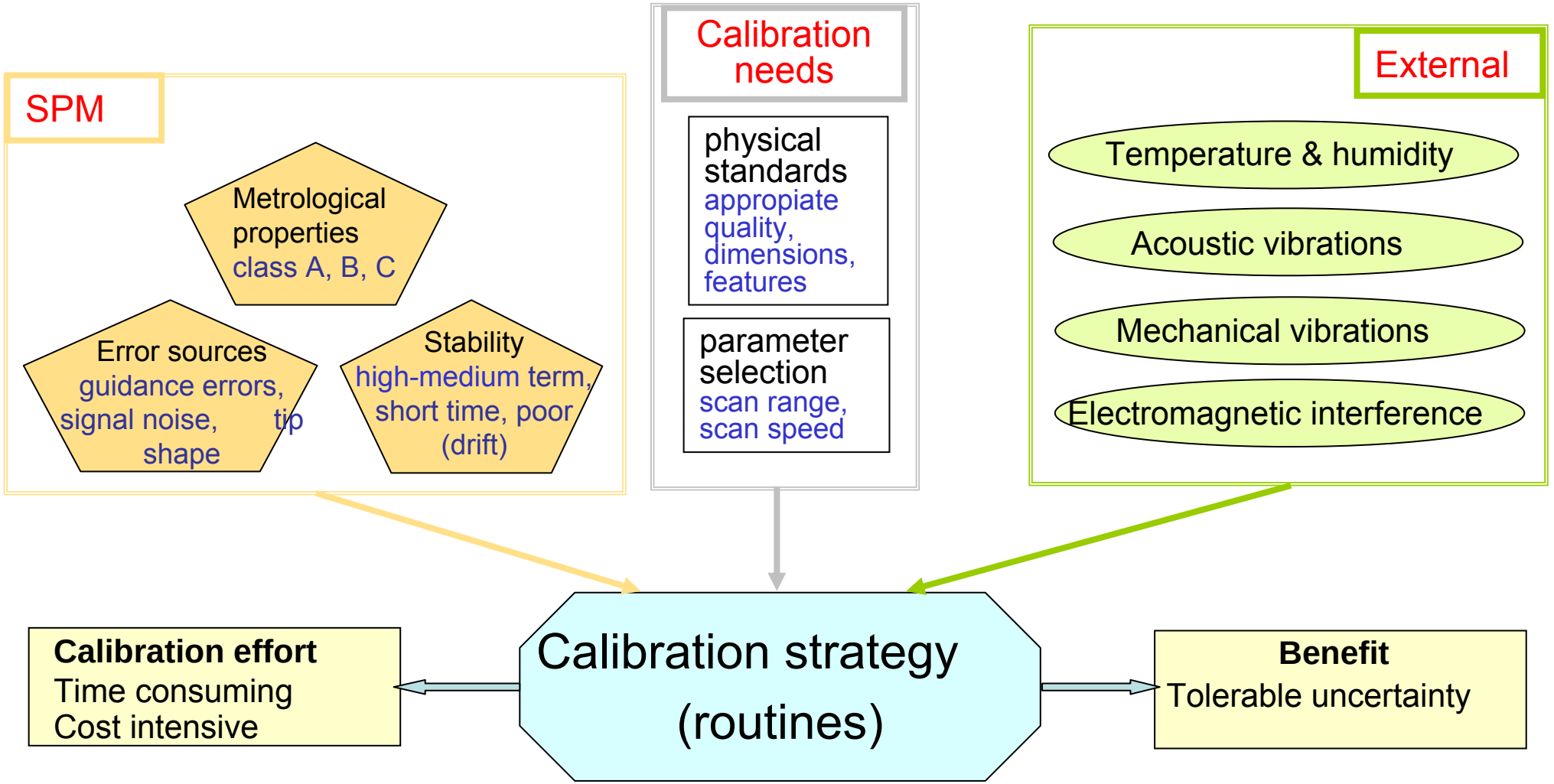
The German version of this guideline shall be taken as authoritative. No guarantee can be given with respect to the English translation.

Inhalt — Seite

Contents — Page

VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (GMA)
Fachausschuss Geometrische Messgrößen und Messgerätseigenschaften/Kalibrierverfahren und Normale

VDI/VDE-Handbuch Mess- und Automatisierungstechnik, Band 2: Fertigungstechnisches Messen
VDI-Handbuch Betriebstechnik, Teil 3: Betriebsmittel
VDI/VDE-Handbuch Mikro- und Feinwerktechnik


SPM
Metrological properties
class A, B, C
Error sources
guidance errors, signal noise, tip shape
Stability
high-medium term, short time, poor (drift)
Calibration needs
physical standards
appropiate quality, dimensions, features
parameter selection
scan range, scan speed
External
Temperature & humidity
Acoustic vibrations
Mechanical vibrations
Electromagnetic interference
Calibration strategy (routines)
Calibration effort
Time consuming
Cost intensive
Benefit
Tolerable uncertainty

PRELIMINARY CHARACTERIZATION OF THE MEASURING SYSTEM

(prior to the calibration process)

Study of the waiting time before putting into operation (warm-up, initial drift)

Waiting time after change of sample / probe or other interventions to reach stable conditions

Noise of the system is one of the limiting factors of the metrological capabilities of an SPM.

- Investigate z-noise by using two measuring modes: standstill (scan off) and record z signal, and dynamic mode (with scanning motion) on a flat surface, scan the same line twice and take the difference. Scan speed, scan range and measurement rate should be set to typical values.
- x-y noise is usually of lesser importance than z noise. It can be investigated using a sample with straight edge or a line with small step height, aligning the edge of the sample to one axis (for example y axis) and doing the scan in the x axis and checking by means of succesively recorded profiles the variation of the location of the edge.

Guidance deviations can be identified by measurement at standards or with additional equipment (as autocollimators). For example out of z plane can be investigated by using a flat standard with a well defined reference area calibrated by interference microscope. Subtraction of the reference data from the actual SPM data yields that information. By repeating this process it is possible to distinguish between temporary efects or permanent cross-talk.

Evaluation of the effect of ambient conditions (changes in temperature, humidity, air flow, mechanical and acoustic vibrations, electromagnetic interferences, etc,)

Long time stability (reproducibility)

Verification and calibration of SPM with samples and standards

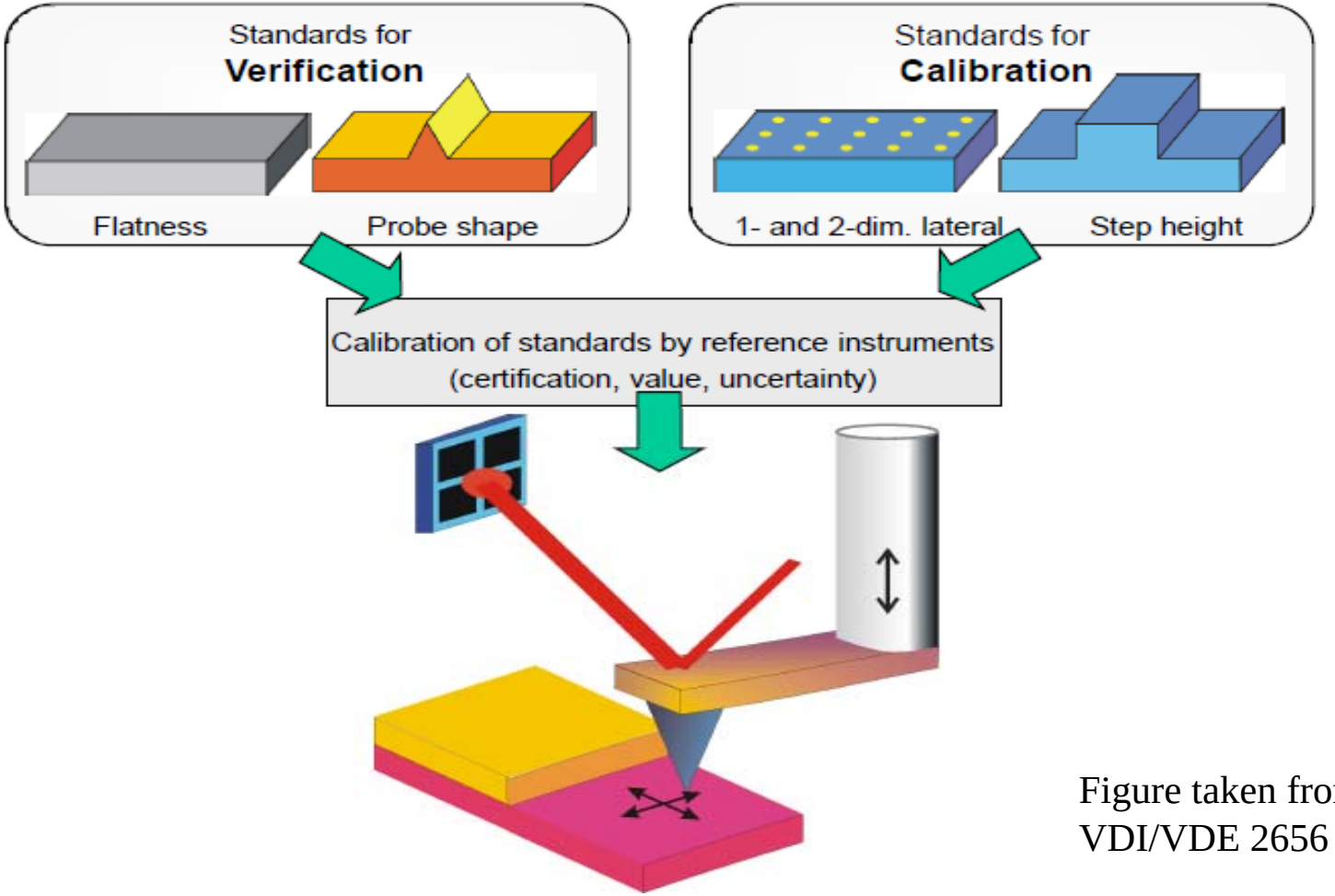


Figure taken from
VDI/VDE 2656 page 14

Aim of the SPM calibration: determination of the calibration factors C_x, C_y, C_z

However…a total of 21 deviations or degrees of freedom can be identified (as in any 3D coordinate measuring machine)

3	positional deviations (non linearities)	*xtx, yty, ztz*
6	straightness deviations (underlined cross-talk of lateral scan movemements to vertical z axis)	*xty, xtz, ytx, ytz, xtx, zty*
9	rotational deviations	*xrx, xry, xrz* *yrx, yry, yrz* *zrx, zry, zrz*
3	rectangularity deviations	*ywx, zwx, zwy*

To determine		Type of Standard	Explanation	Section
C_z	Calibration of the z axis	Step height standard	Step height measurement, linearity	6.5, 6.6
ztz	Non-linearity z axis	Set of step height standards		
C_x	Calibration of the x axis	1D or 2D lateral standard	Pitch measurement, rotation, linearity	6.4, 6.6
C_y	Calibration of the y axis			
xtx	Non-linearity x axis			
yty	Non-linearity y axis			
xty	Cross talk of the lateral axes	2D lateral standard	Pitch measurement, rotation, linearity	6.4, 6.6
ytx				
xtz	Cross talk of the lateral movements to the z axis	Flatness standard	Guidance error (out of plane: temporary drift or scanner bow)	6.3
ytz				
ywx	Rectangularity deviation	2D standard	Angle formed by the two axes on orthogonal structures	6.4, 6.6
zwx	Rectangularity deviation	3D standard	Angle formed by the two axes on orthogonal structures	6.4, 6.6
zwy				

LATERAL CALIBRATION

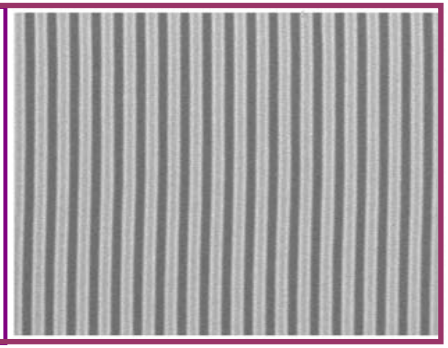
★By interferometers

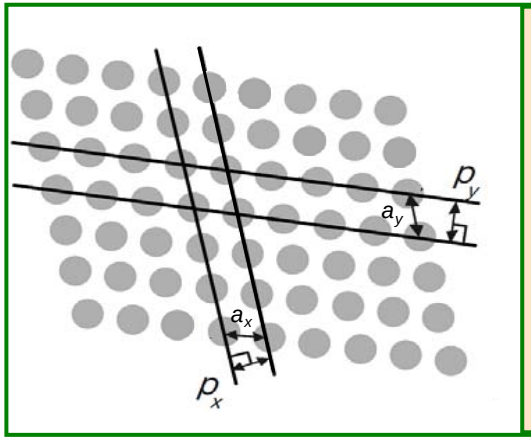
★By Physical Standards

It is important not only the selection of the scan range but also the scan speed or the measurement rate as the calibration factors are strongly influenced by dynamic non linearities and image distortions.

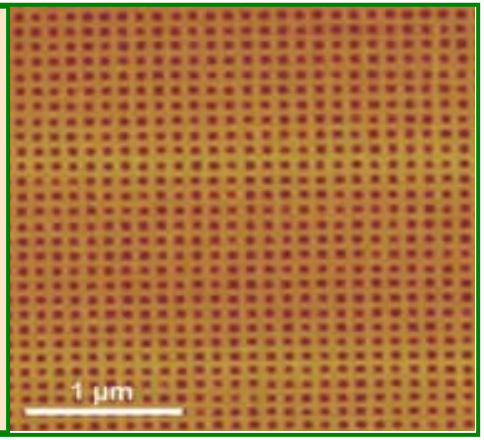
The **periods** of the standards to be used should be selected according to the measurement purpose and to the evaluation method available.

With 1D standards the calibration factors can be determined only succesively in **two measurements** with the standards being rotated by 90º.





For 2D structures it is possible to determine in **one measurement** the calibration factors and the non-orthogonality of the grating γ_{xy} (angle formed by the p_x period in the x direction of the grating, and p_y vectors differing from 90º)



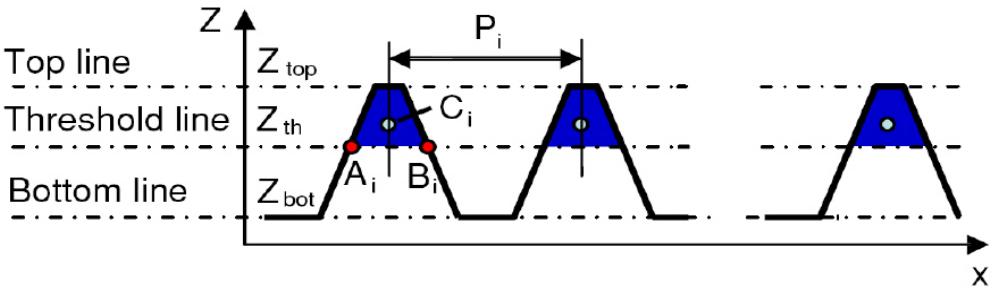
LATERAL CALIBRATION

Evaluation methods

Centre of gravity (GC)

In the local space

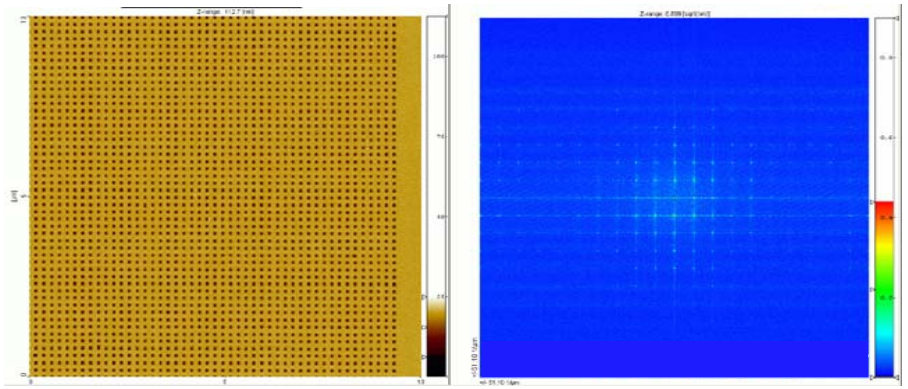
To determine for example p_{xmeas} : fit two paralell regresion lines g_0 (close to the left of the image) and g_n (close to the right) through columns of grating structures. Rise a vertical line s_x to g_0 and g_n lines. Determine p_{xmeas} by dividing the distance of the points of intersection of s_x with g_0 and g_n by the number of enclosed grating periods



Fast Fourier Transform (FFT)

In the Fourier space

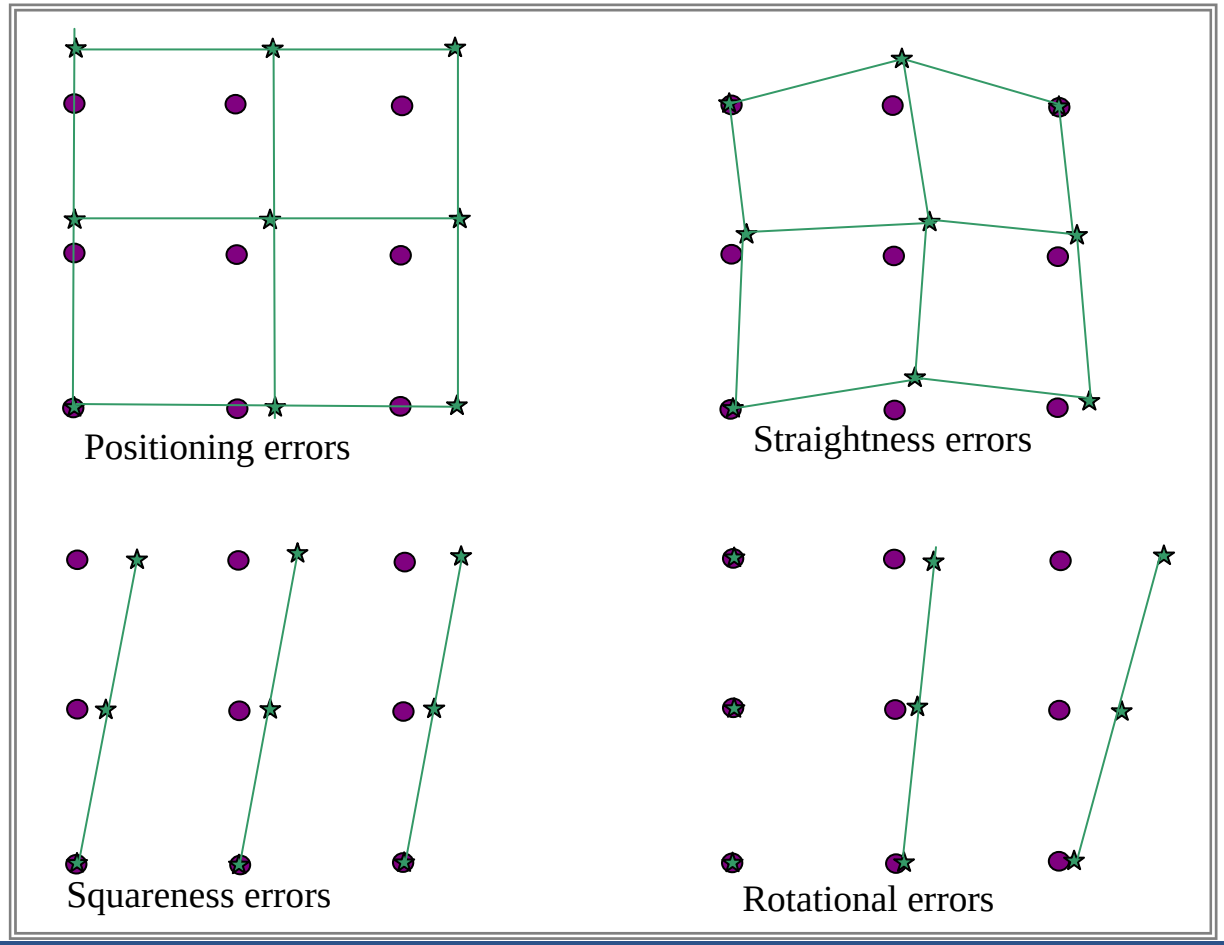
Determination of the measurand mean grating periods by measurement of the position of the appurtenant peak



A combination of both

FFT + cross correlation

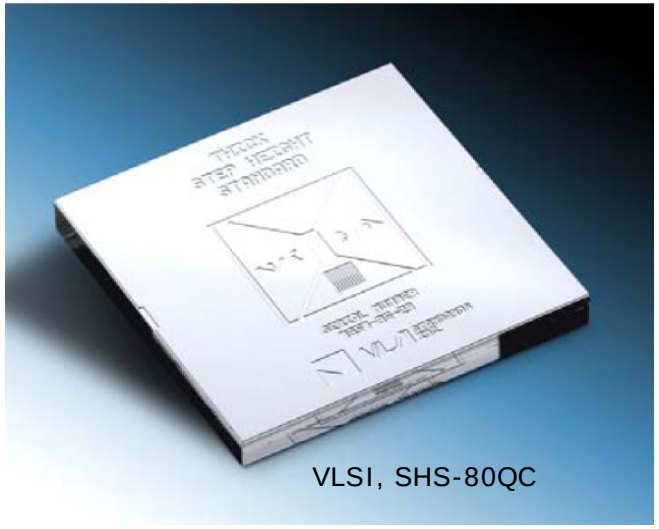
- Lateral standards allow to determine also **distorsions** in the measured image
- Depending on their origin these errors are **temporary**, **permanent** or **dynamic**

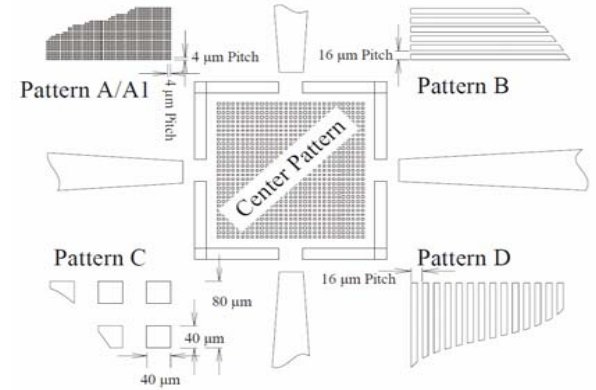


VERTICAL CALIBRATION

The elongation of the z piezo can in some systems be directly measured **by laser interferometry**.
The calibration is done by applying voltage externally to the z-actuator and recording simultaneosuly the signal from the interferometer. **Non linearity** of the z piezo scan can be studied by increasing the voltage in equal steps. The **dynamics of the z scan** can be investigated by changing the duration of the voltage steps.

Physical standards, step height standards, are easier to handle than optical interferometers but the traceability chain is longer and the uncertainty of the transfer standard must be added to the uncertainty of the SPM calibration. In order to account for the **nonlinearities** of the z scan it is necessary to use a **set of standards** of different height.


VLSI, SHS-80QC



Nanosensors,H8 height standard
Sketch of the central region

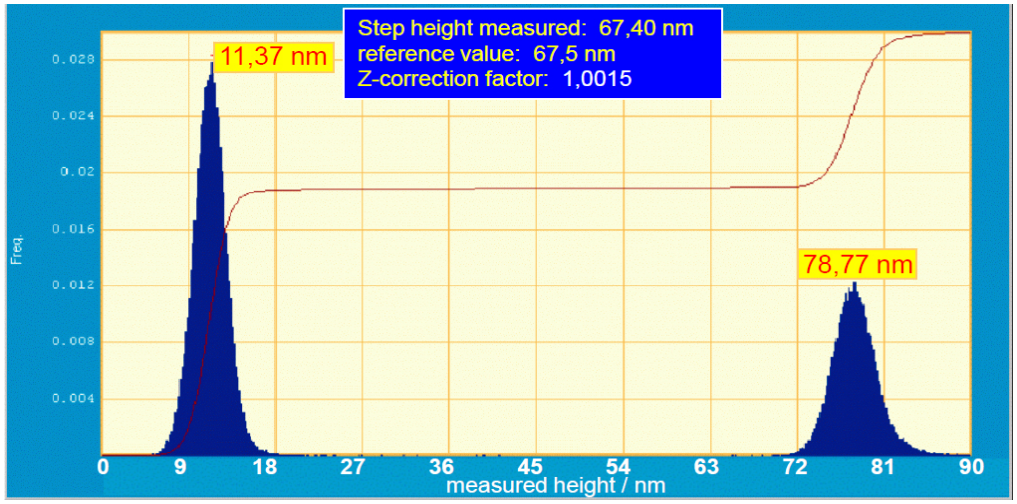
Vertical movements must follow the surface topography and are usually much faster than lateral scan movement, so **z-axis dynamic properties play an important role**.

VERTICAL CALIBRATION

Methods of data analysis

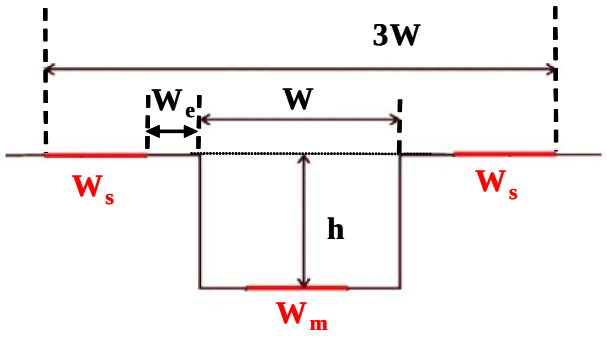
Hystogram method

The sample tilt has to be previously substracted. In the histogram plot of the height value distribution it must be identified the two peaks corresponding to the two height levels. The center of gravity in each of these two peaks is determined and their difference is calculated.

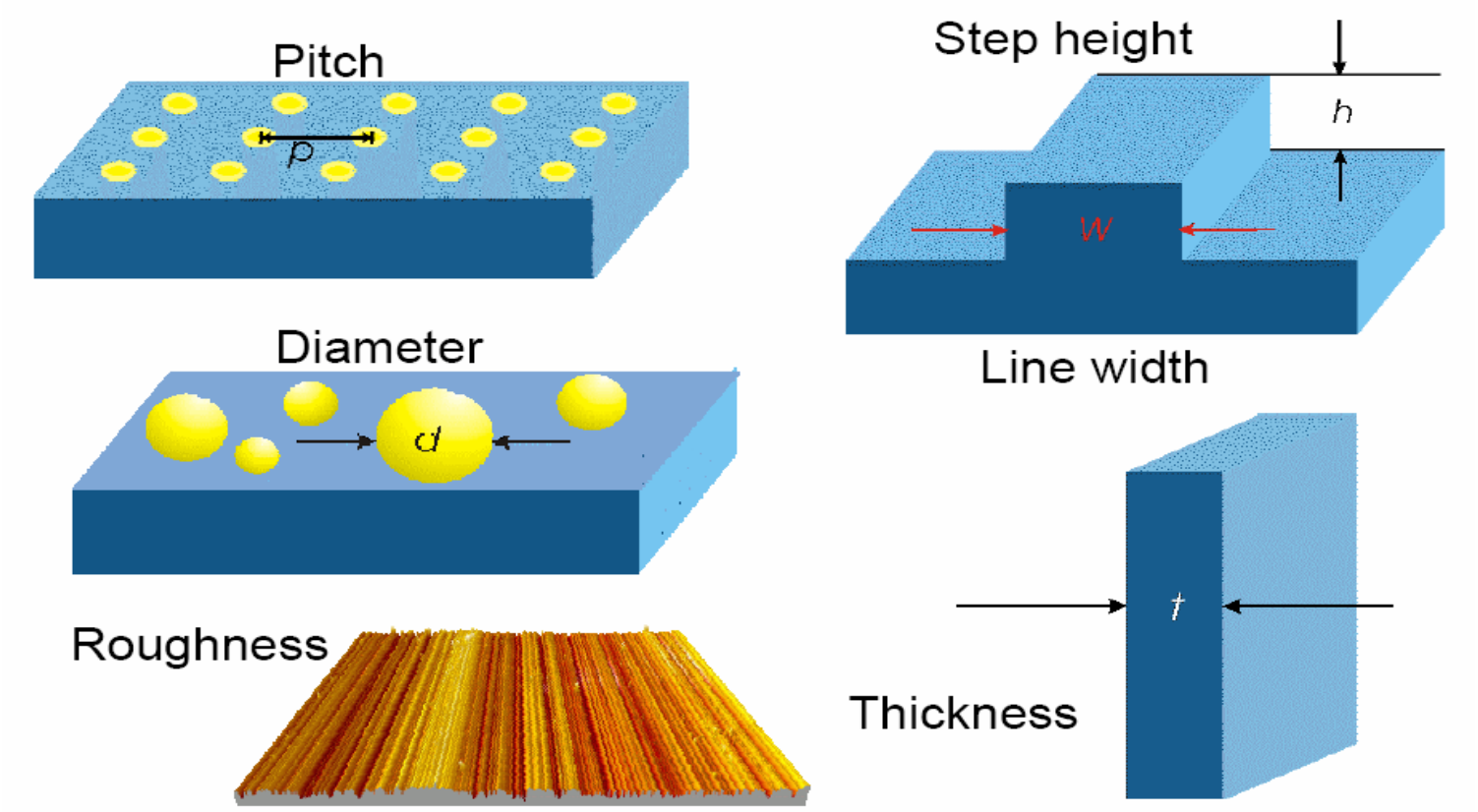


ISO 5436

Application is done by fitting a line through the central part (Wm) of a positive or negative bar. As reference two equally sized sections (Ws) on both sides of the bar are selected with equal distance to the edges of the bar (We), and a line is also fitted through these values. In this way the edges are not taken into consideration. The height of the bar is defined as the normal distance of both lines.

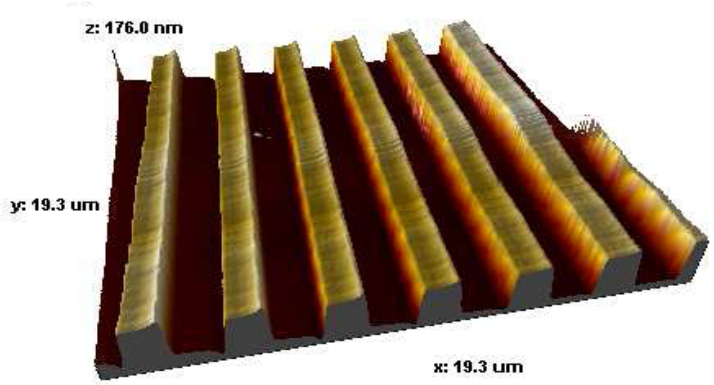


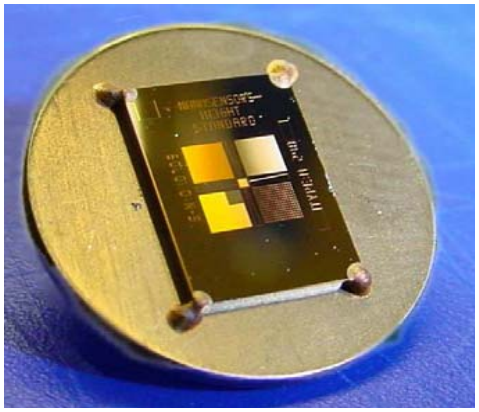
Main calibration standards

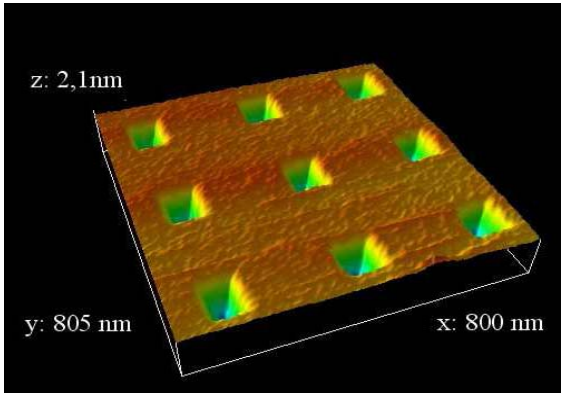


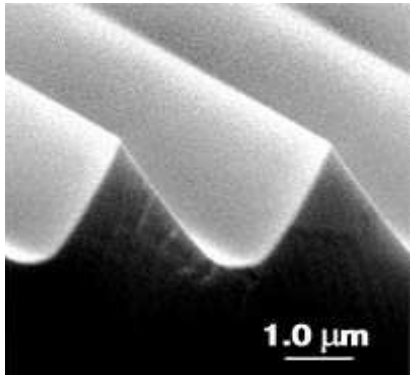
Different kinds of standards

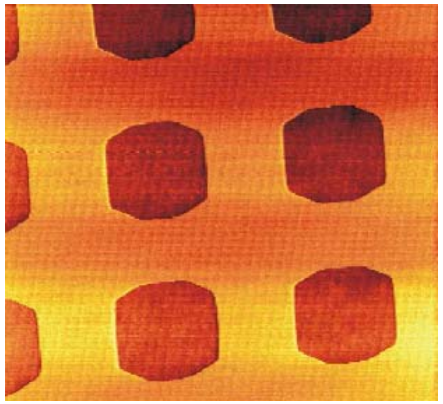
(www.nanoscale.de)

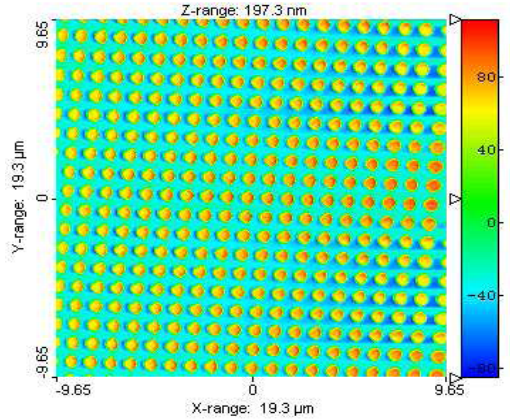








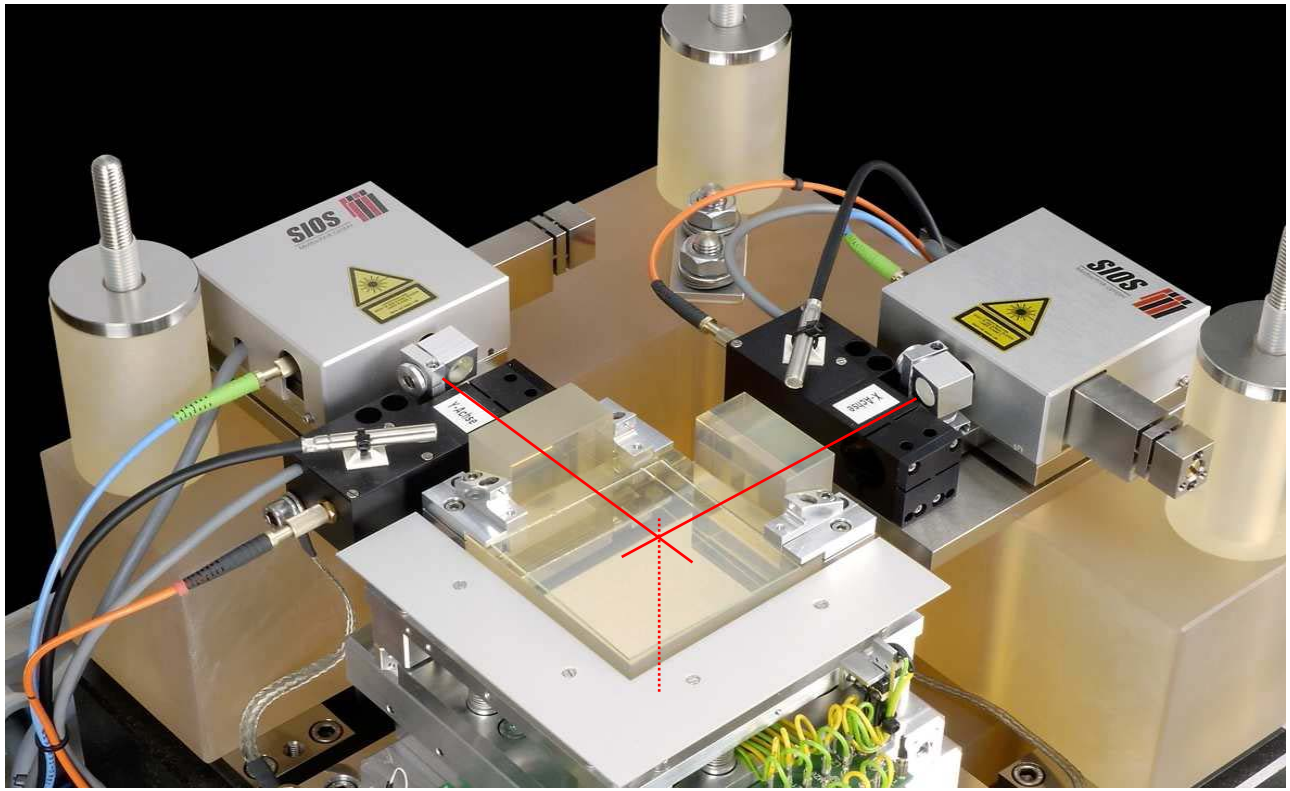




Metrological large range SPM at CEM

MAIN FEATURES

- Three dimensional positioning and measurement of samples in the range **25 mm x 25 mm x 5 mm**
- **Open architecture** to apply different probe sensors or tools
- Three dimensional **Abbe offset free** design, intersection of measuring beams at contact point of the probe sensor (offset less than 0.1 mm)
- Resolution below 0.1 nm



INTEGRATION OF TWO SYSTEMS

- Nanopositioning and nanomeasuring machine *NMM-1 from SIOS*
- SPM Probe *Dualscope DS-95-50-E from DME*

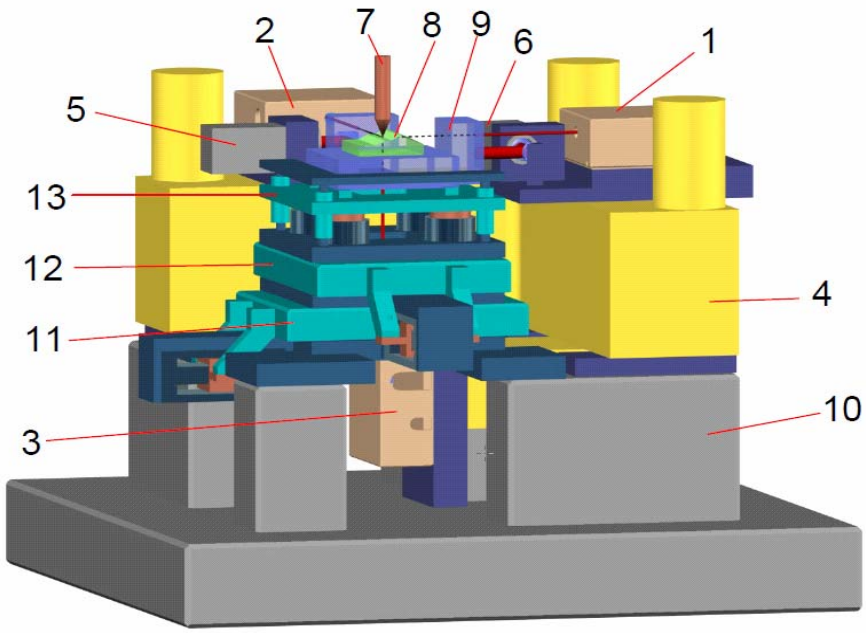
NMM SET UP

1) **Metrology frame:** Zerodur frame mounted on a granite foundation

2) **Interferometry and traceability:** three miniature interferometers (one for each axis) with HeNe stabilized lasers. The measuring mirrors are put together forming a corner mirror structure with the outer reflecting surfaces. The sample object is placed on the base plate of the corner mirror. Calibration of the z scanner against the z interferometer is done previous to measuring.

3) **Actuation and guidance:** 3D stacked arrangement (x, y and z on top) for the guide driving system. The position of the corner mirror is measured by the interferometers and the signals are used as control variables to avoid translatory errors. Two angular sensors and four z drivers keep the angles of the z stage constant.

4) **Electronics control:** NMM stage control coarse surface slopes and holds SPM iin the middle of its measuring range, SPM probe system act as zero point indicator.

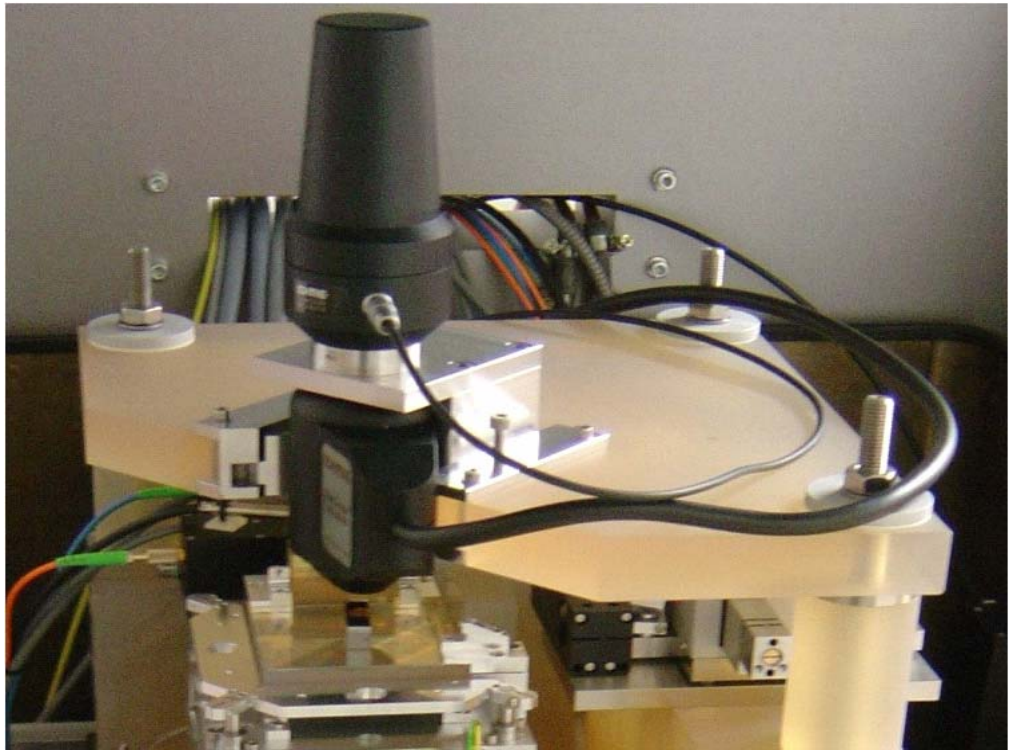


Basic set-up of the NMM machine: 1 x-interferometer, 2 y-interferometer, 3 z-interferometer, 4 Zerodur® frame, 5 Roll and yaw angle sensor, 6 Pitch and yaw sensor, 7 probe system, 8 Measuring object, 9 Corner mirror, 10 Foundation, guide-drive systems of the 11 x-axis, 12 y-axis 13 z-axis

NMM-1, SIOS

SPM

1) **Scan range** 50 µm x 50 µm x 5 µm
2) When coupled to NMM, the **movement is restricted** to 2.7 µm in z direction
3) **Coarse approach** to the sample is done with piezo motors to use the z range of the scanner optimally.
4) Different **operation modes**: DC (contact and non contact) AC, STM
5) Scanner with a **built-in linearization sensor** calibrated against the z axis interferometer



DS-95-50-E, DME

NMIs with metrological SPMs

NMI	Country	Range	Status
Europe – SFM in service			
DFM	Denmark	70 x 70 x 6 μm^3	In service
METAS	Switzerland	400 x 70 x 5 μm^3	In service
NPL	United Kingdom	100 x 100 x 5 μm^3	In service
PTB	Germany	25 x 25 x 5 mm^3	In service
Europe – SFM under construction			
CEM	Spain	25 x 25 x 5 mm^3	
CMI	Czech Republic	200 x 200 x 10 μm^3	1st comparison (height, pitch)
INRIM	Italy	100 x100 x 15 μm^3	2nd comparison (height, pitch)
MIKES	Finland	100 x 100 x 16 μm^3	1st comparison (height, pitch)
LNE	France	300 x 300 mm^2 x 50 μm	
VSL	Netherlands	100 x 100 x 20 μm^3	
Non European region			
NIST	United States	50 x 50 x 5 μm^3	In service
NMIJ	Japan	100 x 100 x 12 μm^3	In service
NMC/A*STAR	Singapore	25 x 25 x 5 mm^3	1st comparison (height, pitch)

Large Range

Conclusions:

1. There is a need for quantitative measurements at the nanoscale
2. Many properties depend on Critical Dimensions
3. Traceability is a crucial matter. The shorter the chain to SI unit, the lower the uncertainty
4. Calibration standards needed for maintaining the performance of SPMs and other instrumentation
5. CEM and other NMIs developing metrological instruments and offering low-*U* calibration services to R&D and industry
6. No Metrology (infrastructure), no Development
7. Researchers should become Metrologists too

Thank you for your attention

eprieto@cem.mityc.es