GOBIERNO DE ESPAÑA
MINISTERIO DE INDUSTRIA, TURISMO Y COMERCIO

CEM Centro Español de Metrología

Nanometrology, nanotoxicology and standardization
A general updated view

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Member of ISO TC229 "Nanotechnologies" and
Chairman of AENOR GET15 "Nanotecnologías"

Outline:

- Standardized Definitions
- Difficulties and Challenges
- Main Research Areas
- What are NMIs doing
- Toxicology issues
- Standardization issues
- Conclusions

Definitions

nanoscale: Size range from approximately 1 nm to 100 nm.

NOTE 2 The lower limit in this definition (approximately 1 nm) is introduced to avoid single and small groups of atoms from being designated as **nano-objects** or elements of nanostructures, which might be implied by the absence of a lower limit.

Within this size region, materials can exhibit **new and unusual properties**.

ISO/TS 27687:2008 / UNE CEN **ISO/TS 27687**:2010 (in Spanish)

nanoscale property: measurable characteristic emerging predominantly in a nano-object or nanoscale region

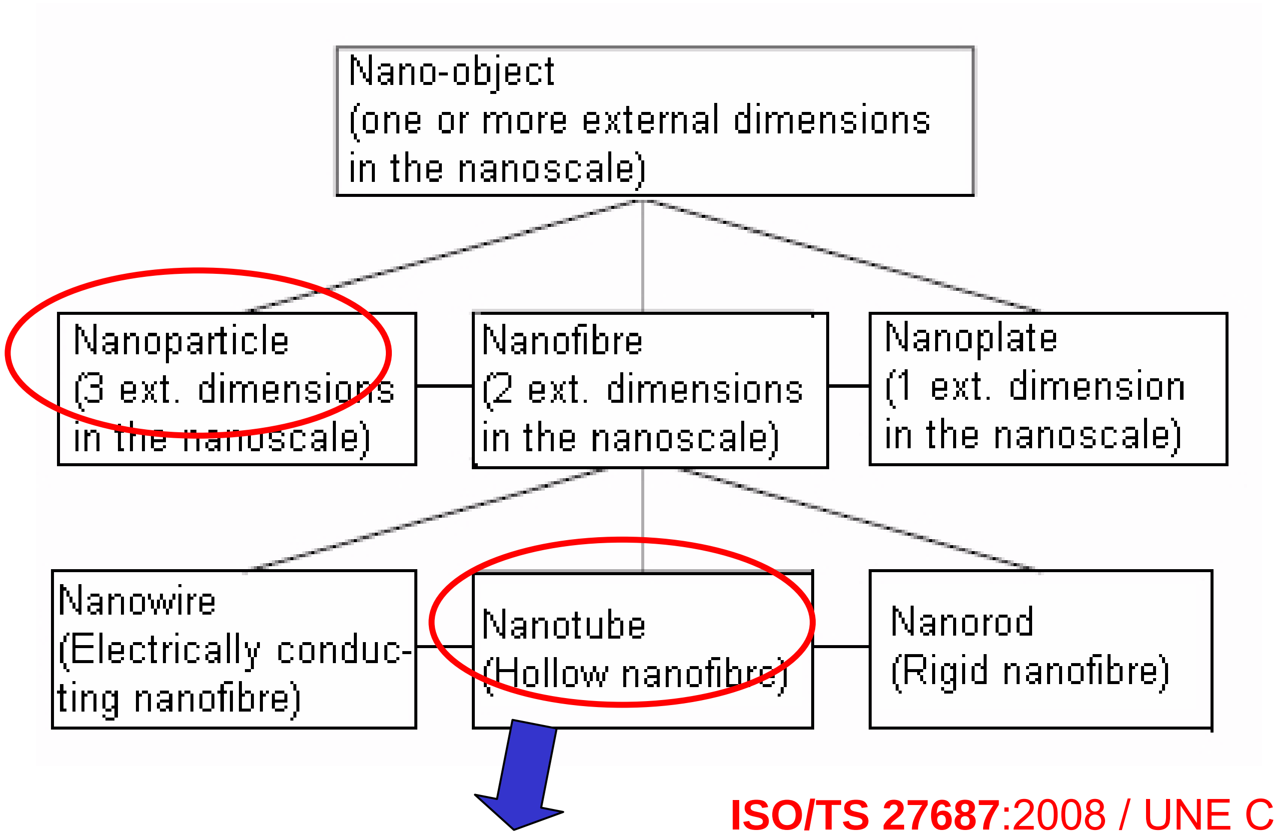
(ISO/DTS 80004-1)

NOTE - A region is defined by a boundary representing a discontinuity in properties.

nanometrology: the science of measurement at the nanoscale level.

It has a crucial role in order to produce nanomaterials and devices with a high degree of accuracy and reliability (nanomanufacturing).

nano-object: material with one, two or three external dimensions in the nanoscale



ISO/TS 27687:2008 / UNE CEN **ISO/TS 27687**:2010 (in Spanish)

CNT ≠ HARNP

Why properties change at the nanoscale

Gravitational forces are negligible. Electromagnetic forces dominate

F_G = f(m) and hence week between nanoparticles

F_{em} are not depending on mass, but on charge

F_{em} between 2 protons are 10^{36} times stronger than F_G

Motion and energy is described by quantum mechanics, not by classical mechanics

Discreteness of energy

Wave-particle duality of light and matter

Quantum tunneling

Great surface to volume ratio

Better catalysts (a greater proportion of material is exposed to potential reaction)

Random molecular motion becomes more important

Large compared to the size of the object

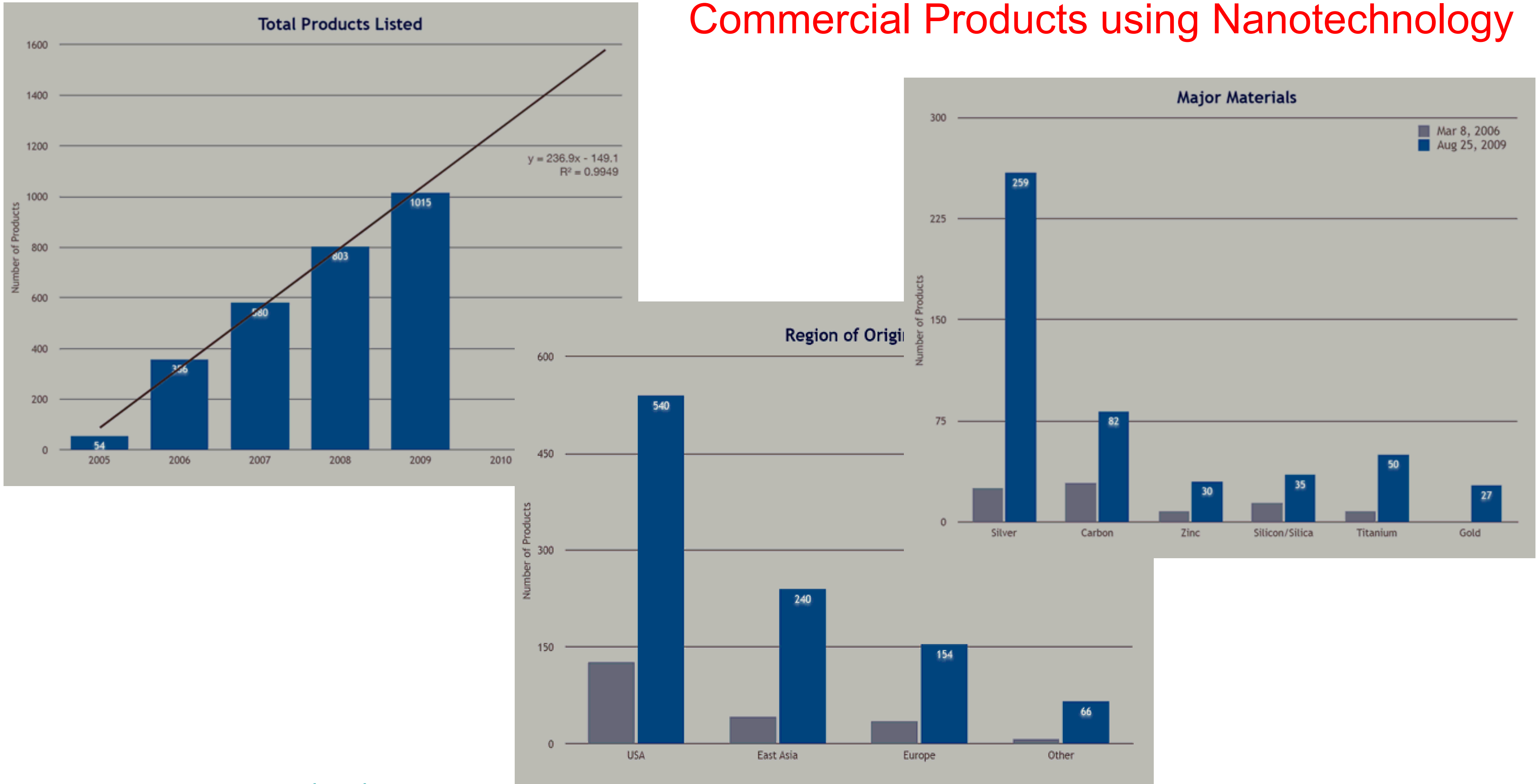
Nanotechnology has Impact on

- Economy: production, trade, import, export
- Environment: air, earth, water
- Health and Safety

Important tasks are:

- anticipate and address public concerns
- study production impact
- environmental toxicology
- regulation, product test
- human toxicology

Commercial Products using Nanotechnology



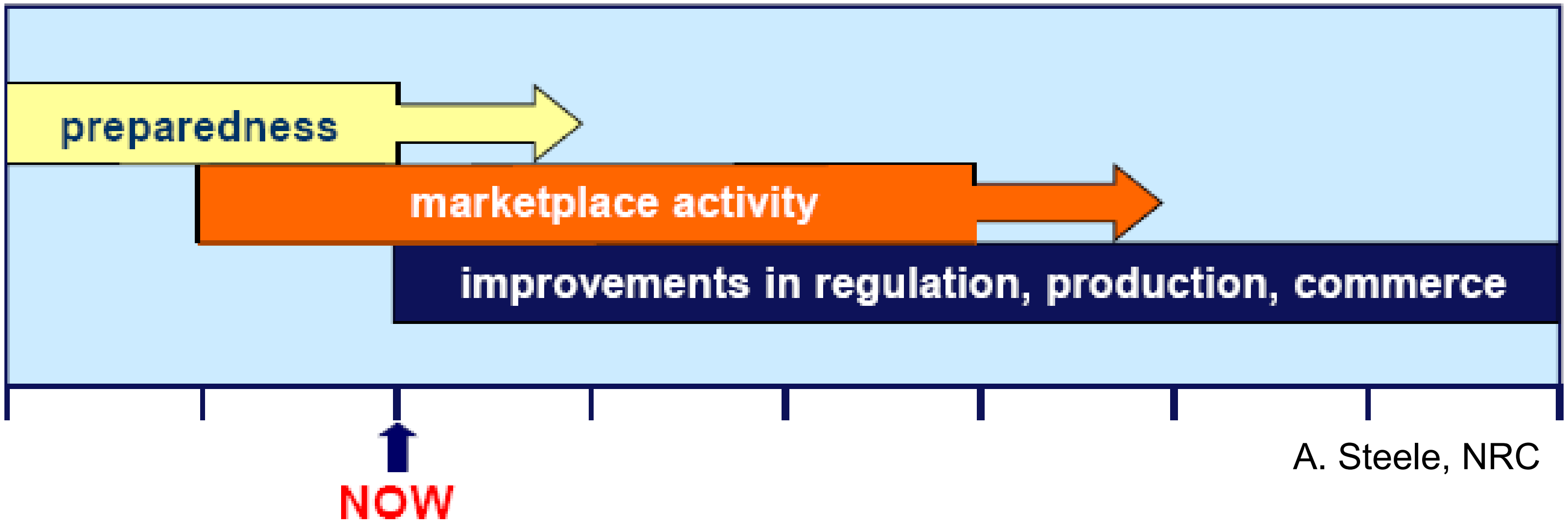
Source: www.nanotechproject.org

BUT nanotechnology has not emerged yet as massive production due to both

a) the difficulty of developing a solid nanometrology infrastructure,

b) the fear of the effects on Environment, Health and Safety.

Where we are:



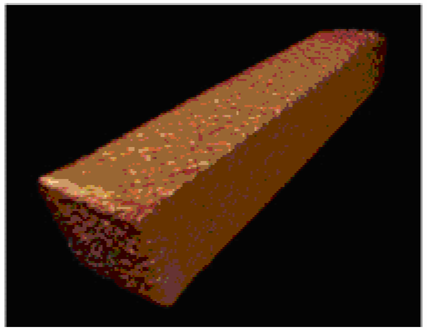
A. Steele, NRC

Example: ITRS 2009 Metrology Roadmap

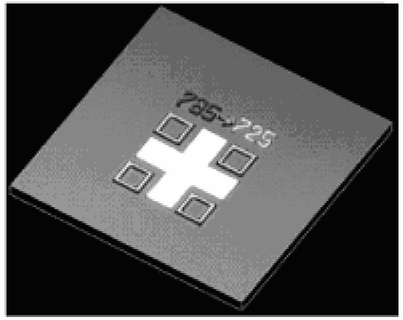
Interconnection Metrology

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



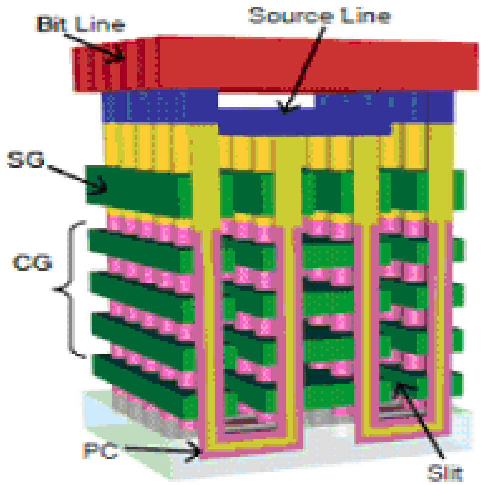
- Emerging / Gated Interconnects
  - Native Deice Interconnects

Example: **ITRS 2009 Metrology Roadmap**

Front End Process (FEP) Metrology

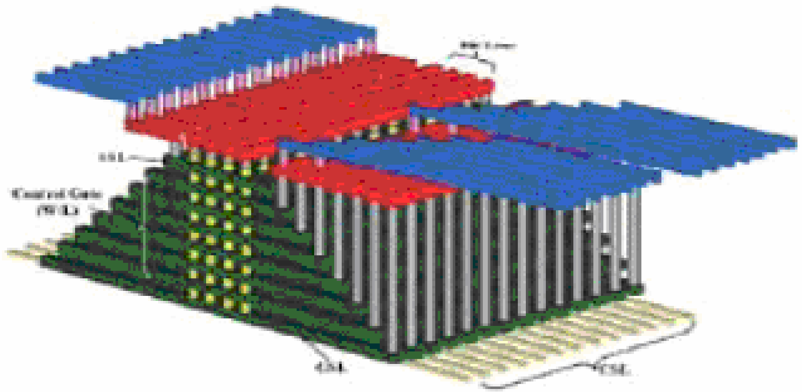
3D Metrology – Complex structure measurement and inspection are required

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)

ITRS 2009 Report

- **Difficult to achieve critical dimension measurement with nm level precision**.

- A variation in features size one tenth of the nominal dimension often results in significant changes in device properties **(reproducibility and quality control)**.

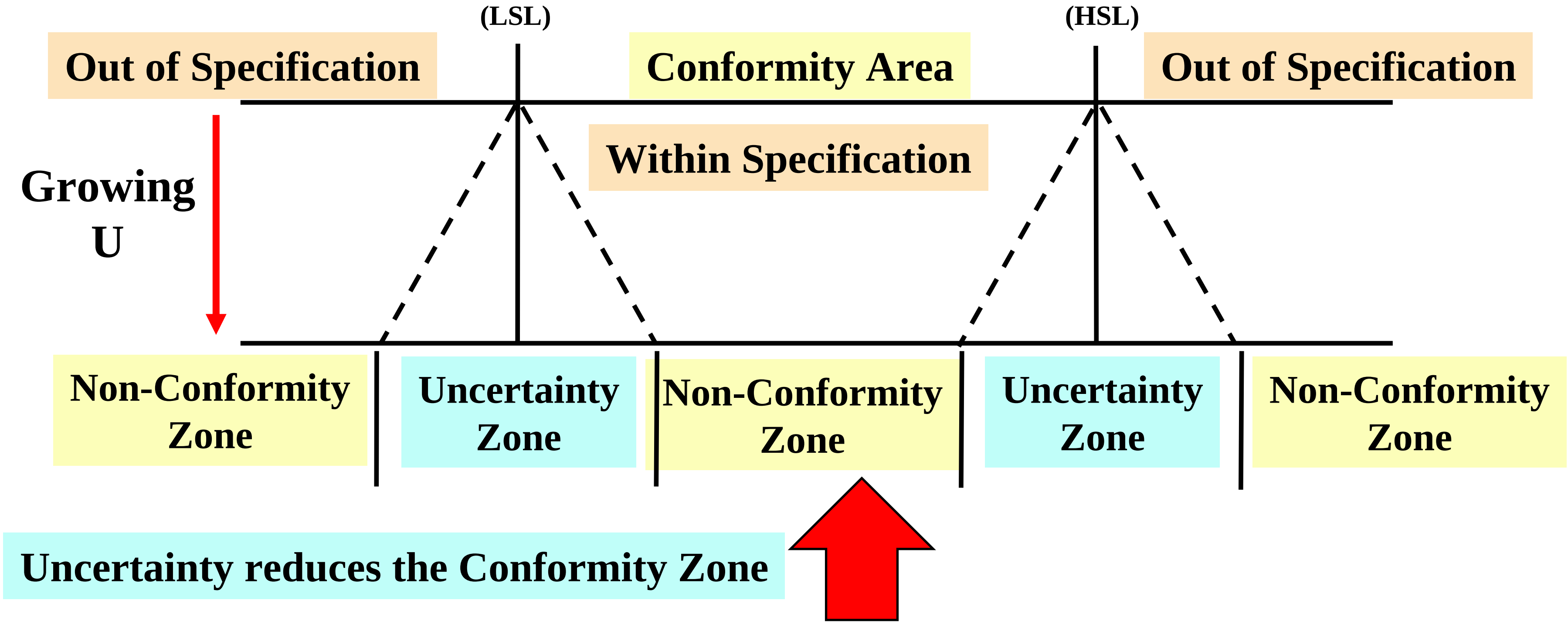
- The fundamental challenge for factory metrology is the **measurement and control of atomic dimensions while maintaining profitable high volume manufacturing**.

ITRS 2009

		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) <8% 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	

EN-ISO 14253-1

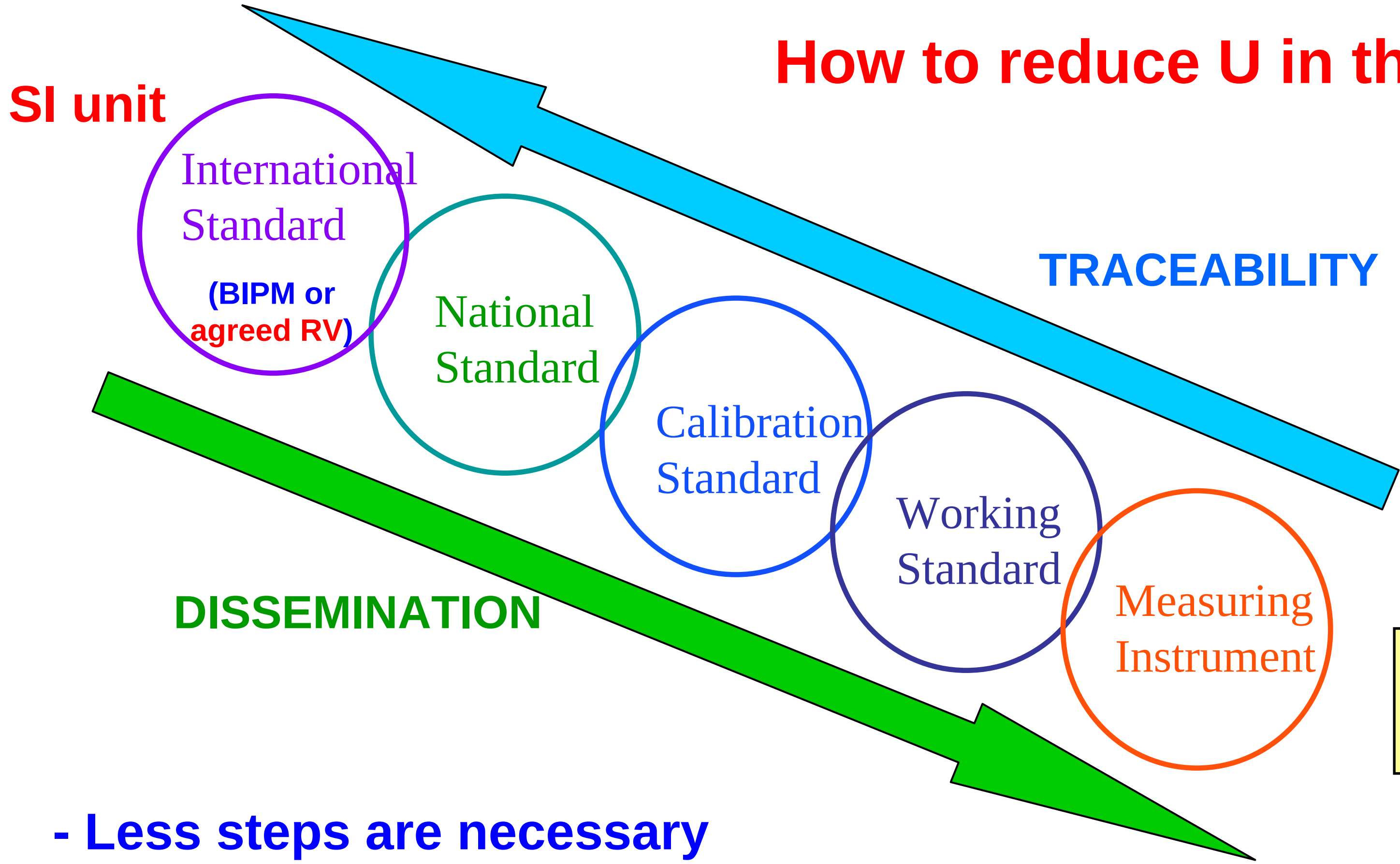
Difficulties derive from the small ratio Tolerance/Uncertainty



In classical industrial Metrology, optimal ratio T/U = 10

In Nanotechnology, T/U typically less than 4 and eventually pointing to 1

How to reduce U in the nanoscale ?



Traceability Chain to any SI unit

- **Less steps are necessary**
- Production machines **should be** measuring instrument themselves

Metrological Design needed to get direct traceability to SI Units

Estimation (and reduction) **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**
- **…/…**

Main Research Areas in Nanometrology:

Dimensional

Chemical

Thin Film

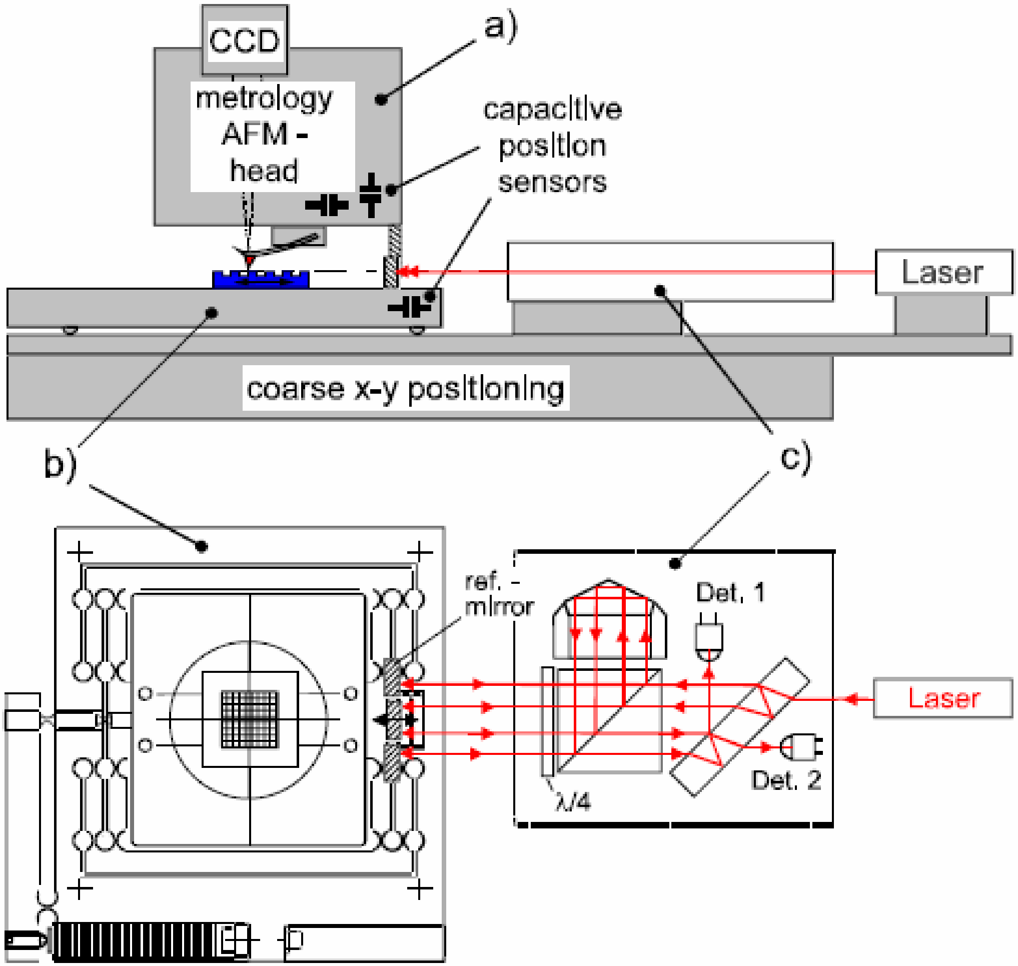
Mechanical

Most of the other properties (electrical, magnetic, etc.) depend on **dimensional**

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.

(Together with: 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.)



Long range metrological AFM at METAS

Source: Co-Nanomet

Dimensional Nanometrology Needs

short- and long-term behaviour.
Resolution is not sufficient

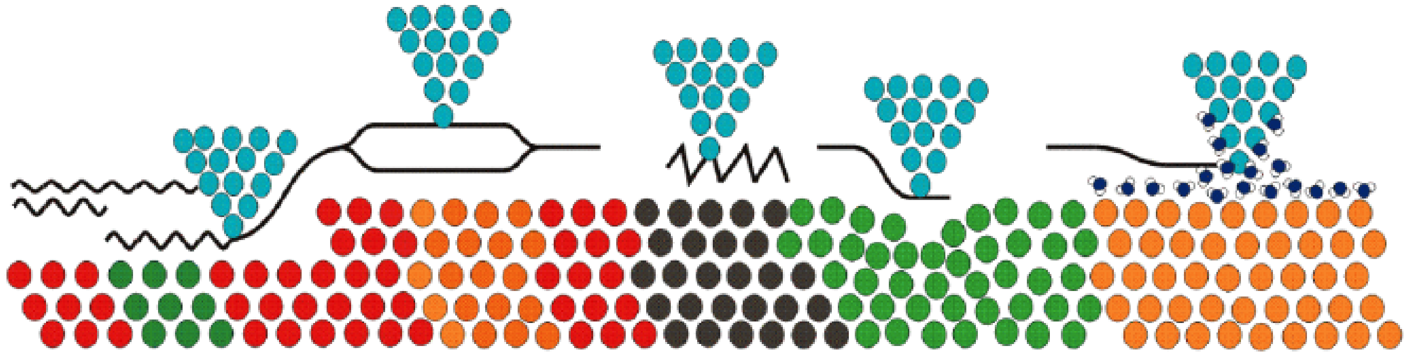
Improved SPM resolution (**repeatability** & **reproducibility**) to allow the measurement of smaller structures with higher accuracy.

Better theoretical understanding of surface-probe interactions and refined probe characterization for a true quantification of dimensional measurements.

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

Source: Co-Nanomet

Probe-Sample Interaction



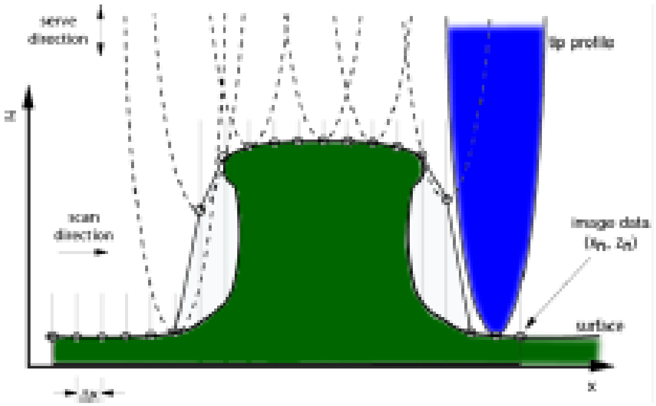
- **effects generally known and understood *individually***
- **BUT practically: superposition of a number of acting forces**
- **not all forces effective at every sample**
- **quantitative measurements/estimations valid for "ideal" cases only**
- **decisive to understand material-induced apparent height-contrasts**

Source: L. Koenders / A. Yacoot

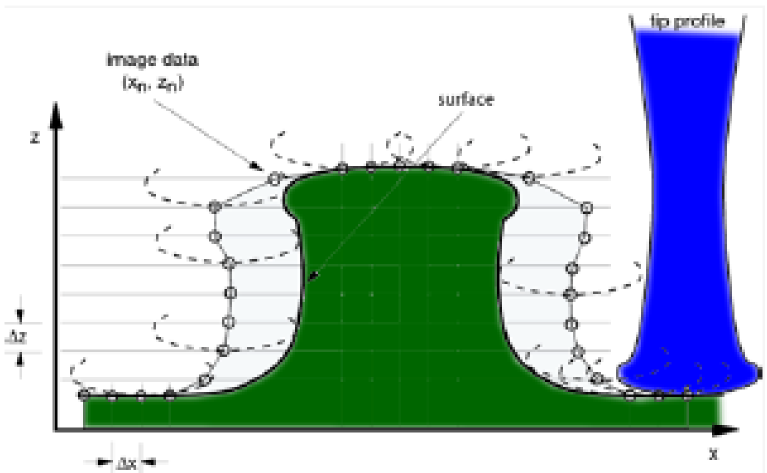
Challenges and tasks in 3D AFM

Applications ranging from linewidth metrology (classical CD metrology) to form measurement of micro and nano particles and structures

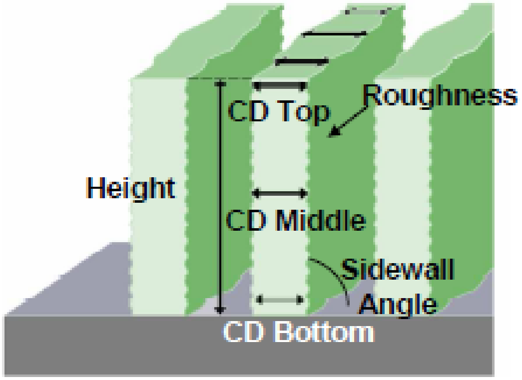
- **tip shape determination**
- **probe-sample interaction**
- **implementation of 3D scanning methods / use of special probes**
- **clear definition of the measurement task**
- **model-based analysis based on different physical and chemical information**



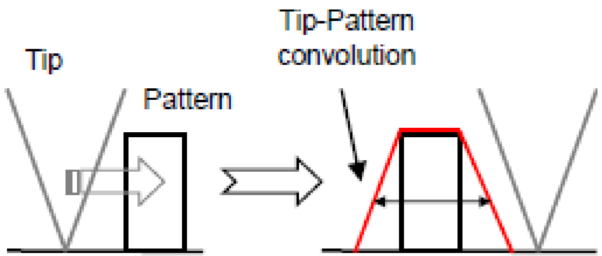
no result in vertical and concave walls !!



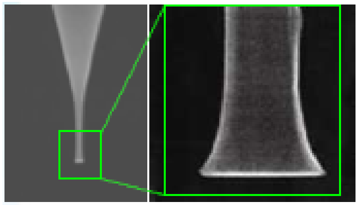
3D-AFM enhancement for sub-32 nm node requirements



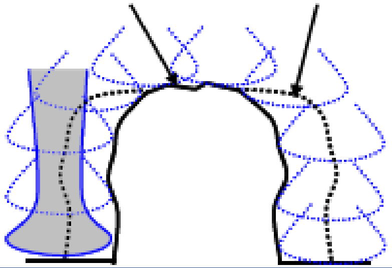
3D-AFM reference metrology

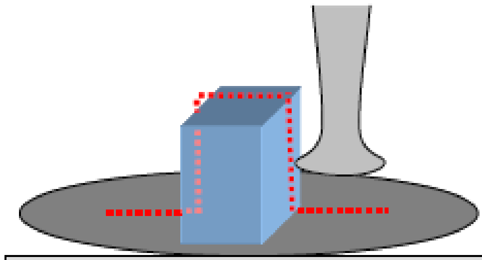


Boot shape AFM tips

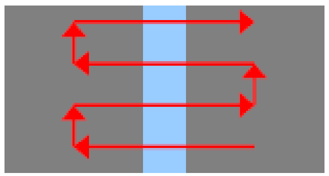


Pattern Convoluted pattern



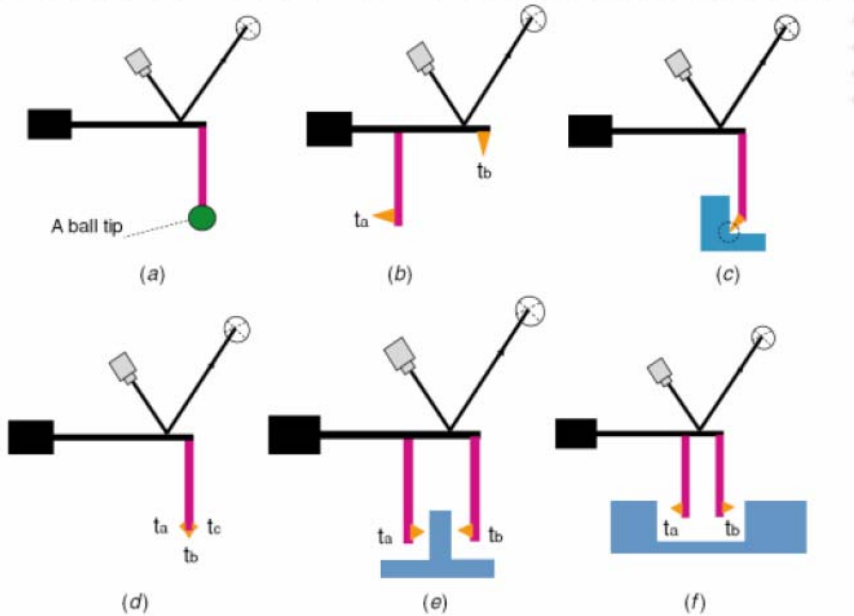


3D-AFM technology from Veeco Instruments



Johann Foucher – LETI, Advanced Metrology Group

Various probing designs to access more easily to surfaces and features



G. Dai et al, Meas. Sci. Techn. 18, 2007

Dimensional Nanometrology (cont.)

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

NMIs having and developing metrological AFMs

Large Range

NMI	Country	Range	Status
Europe – SFM in service			
DFM	Denmark	70 x 70 x 6 μm³	In service
METAS	Switzerland	400 x 70 x 5 μm³	In service
NPL	United Kingdom	100 x 100 x 5 μm³	In service
PTB	Germany	25 x 25 x 5 mm³	In service
Europe – SFM under construction			
CEM	Spain	25 x 25 x 5 mm³	under development
CMI	Czech Republic	200 x 200 x 10 μm³	1st comparison (height, pitch)
INRIM	Italy	100 x100 x 15 μm³	2nd comparison (height, pitch)
MIKES	Finland	100 x 100 x 16 μm³	1st comparison (height, pitch)
LNE	France	300 x 300 mm² x 50 μm	
VSL	Netherlands	100 x 100 x 20 μm³	
Non European region			
NIST	United States	50 x 50 x 5 μm³	In service
NMIJ	Japan	100 x 100 x 12 μm³	In service
NMC/A*STAR	Singapore	25 x 25 x 5 mm³	1st comparison (height, pitch)

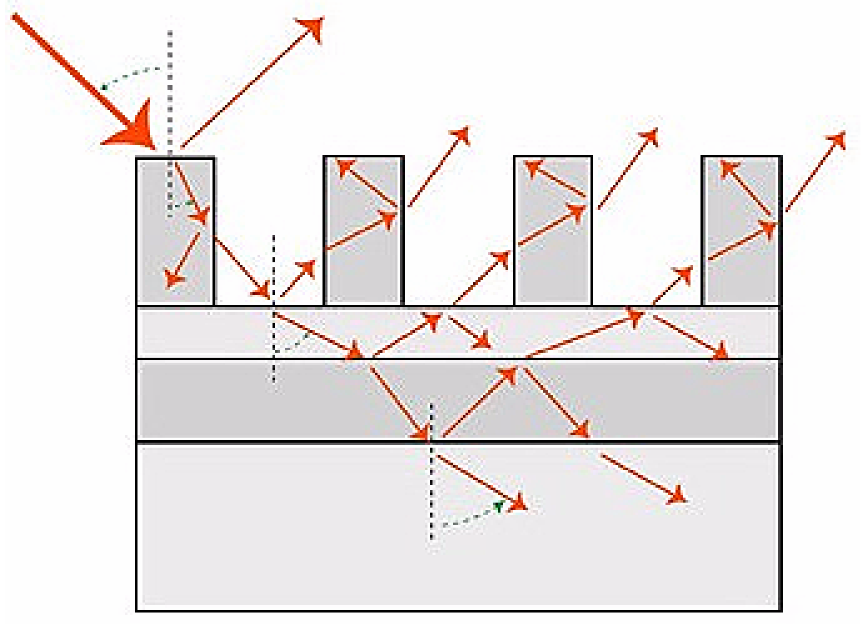
Dimensional Nanometrology (cont.)

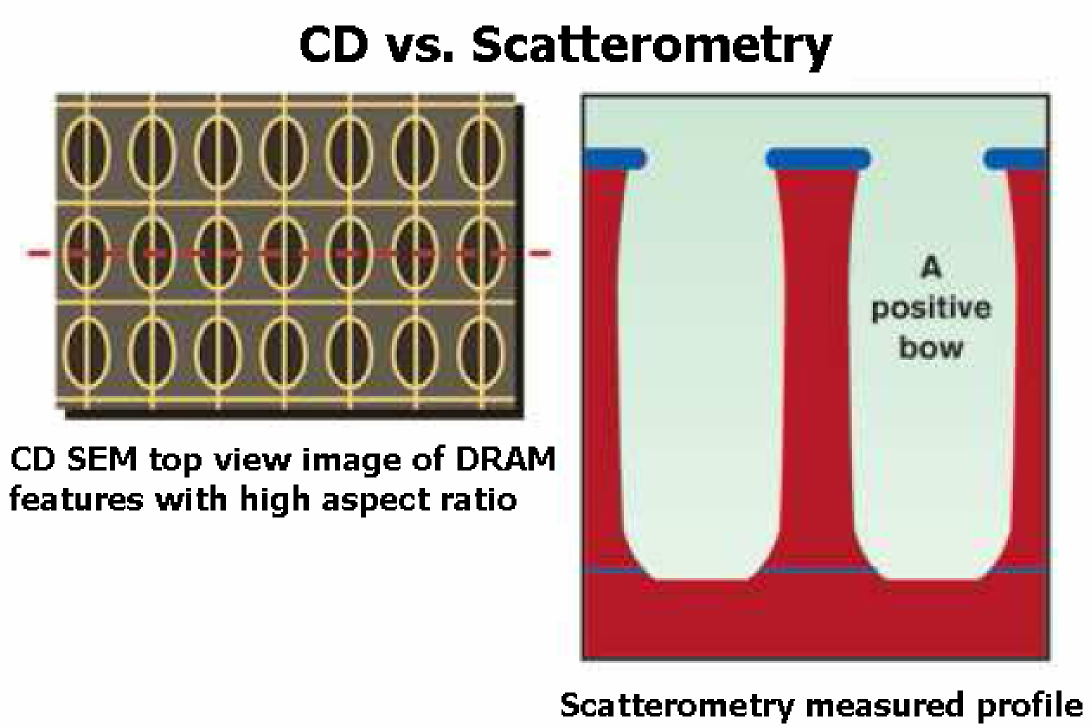
Standardisation of scatterometry techniques (used in the semiconductor industry to measure grating periods and structured surfaces) to compare them to other optical and contact methods. Further research (effect of imperfections, how to measure smaller areas, less computing time) is required.

Development of sub-nanometre resolution interferometers with their non-linearity determined using X-ray interferometry facilities (EMRP NANOTRACE JRP). (Difficulty: how to disseminate these requirements to users outside NMIs and to make displacement measurements with picometre resolution and accuracy).

Source: Co-Nanomet

CD scatterometry provides highly resolved shape detail
since each feature attribute contributes to the unique ellipsometry data

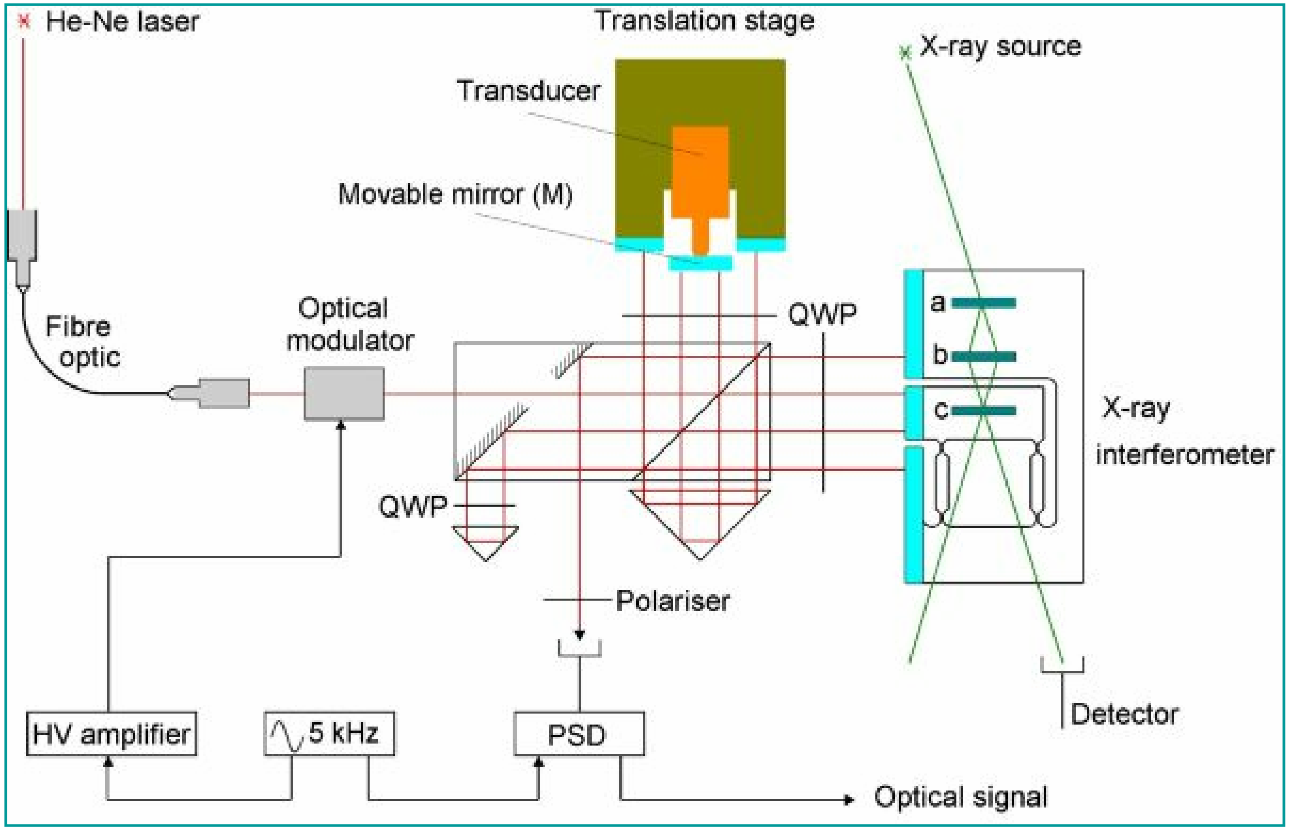




Source: Scatterometry-based critical dimension and profile metrology, *Andrew H. Shih, Therma-Wave Inc.*

Scatterometry excels in the capability to measure bowing in 3-D structures, which are invisible to CD-SEM. (Source: Nova Measuring Instruments)

COXI (Combined Optical & X-ray Interferometer)



Measurement range	U (2σ)
< 10 µm	30 pm
100 µm	40 pm
1 mm	170 pm

(Courtesy of NPL, PTB & IMRIM)

X-ray interferometry permits to linearly interpolate fringes generated by the optical interferometer, reaching a measurement resolution of 0.2 nm, using as space standard a Si (220) surface.

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 also needed.

Source: Co-Nanomet

What about NATIONAL METROLOGY INSTITUTES (NMIs)

What are NMIs doing in nanometrology?

- **Developing special equipment with focus on TRACEABILITY**
- **Refining physical models for probe/sample interaction**
- **Developing suitable models for uncertainty evaluation (*a challenge*)**
- **Developing appropriate transfer standards & calibration methods**
- **Organising and running international COMPARISONS in nanometrology**
- **Proposing calibration guidelines, international standardization**

visit http://kcdb.bipm.org

EURAMET NMIs having CMCs in the "nano" field

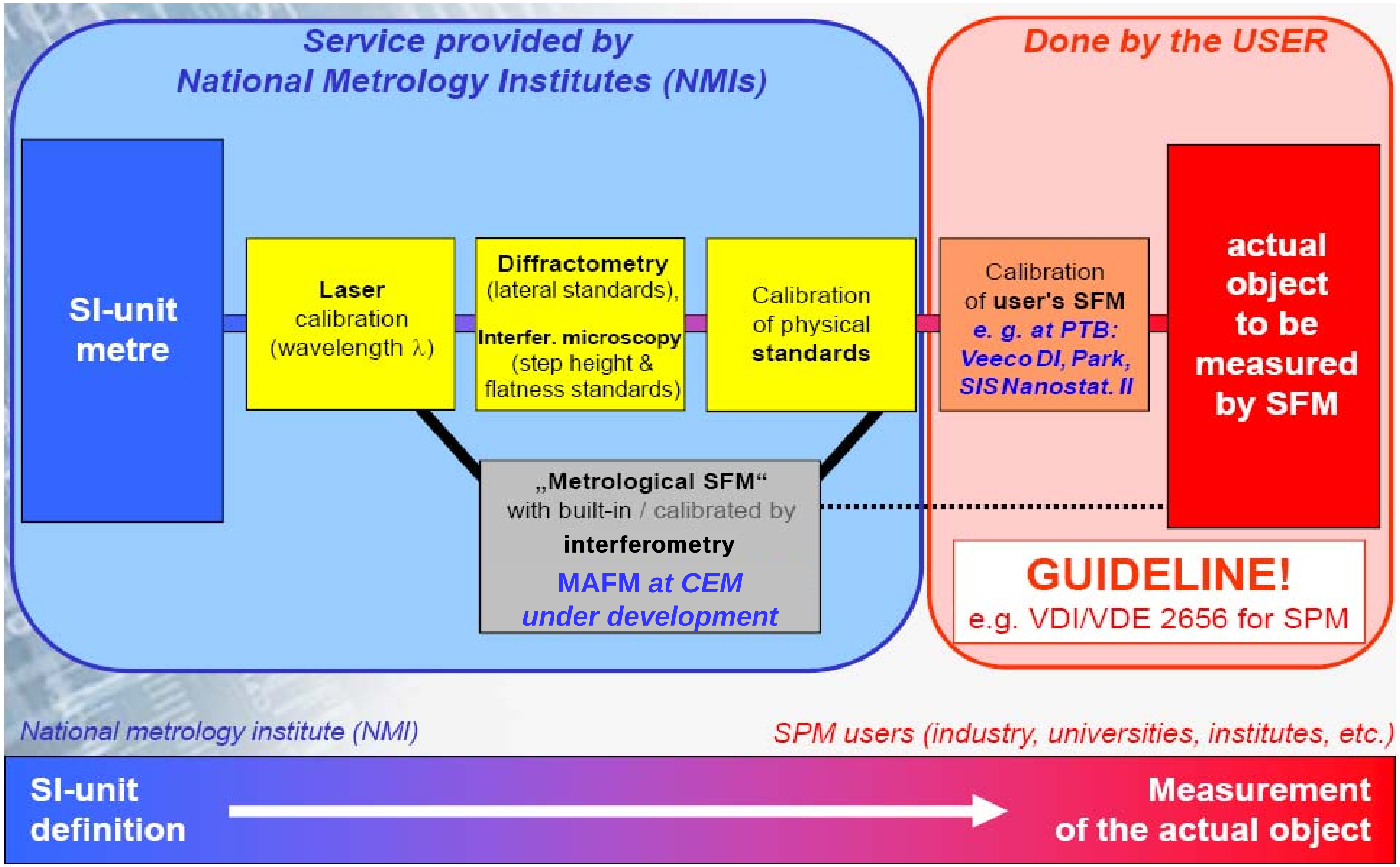
	NMIs	Comments
Linewidth	METAS, PTB, LNE, NPL, UME, MIKES	$U \leq 20$ nm
Step height	BEV, METAS, PTB, CMI, INRIM, VSL, GUM, SP, **CEM**, UME, DTU, MIKES	$U \leq 10$ nm
Line scales	METAS, PTB, **CEM**, LNE, NPL, INRIM, CMI, VSL, SP, INM, MIRS	$U \leq 70$ nm
1-D gratings	METAS, NPL, INRIM, MIKES, PTB, CMI	$U \leq 50$ nm
2-D gratings	PTB, METAS, NPL, INRIM, MIKES, DTU	$U \leq 50$ nm
Displacement sensors	PTB, VSL, **CEM** (to be submitted)	$U \leq 20$ nm
Flatness	BEV, PTB, **CEM**, VSL, SP, UME, MIRS, NPL, CMI, MIKES, INM, METAS	$U \leq 20$ nm
Layer thickness	PTB	$U \leq 10$ nm

visit http://kcdb.bipm.org

International KCs in the field of nanometrology

	Measurand/Artefact	Status/Results published
Nano 1	**Line width**	In preparation
Nano 2	**Step height**	Comparison on Nanometrology: Nano 2 — Step height — L. Koenders et al., 2003 Metrologia 40
Nano 3	**Line scales**	Final report on CCL-S3 supplementary line scale comparison Nano3 — H. Bosse et al., 2003 Metrologia 40
Nano 4	**1D gratings**	Nano4: 1D gratings — Final report — F. Meli et al.
Nano 5	**2D gratings**	NANO5 — 2D Grating — Final report, J. Garnaes et al. 2008, Metrologia 45
Nano 6	**SPM Linewidth Standards**	In preparation

Typical traceability chain in dimensional nanometrology



SPM Categories

A. Metrological SPM with integrated laser-interferometers in all 3 axes.
direct traceability to the SI-unit (m) through the wavelength of the laser used

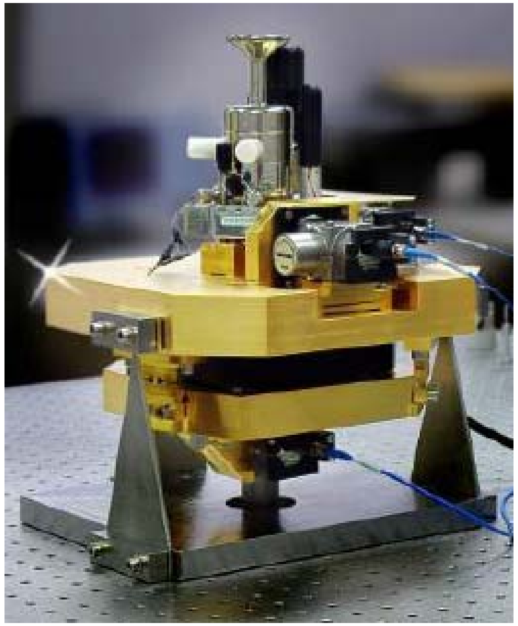
B. SPM with integrated position sensors.
(strain gauges, encoders, capacitive/inductive sensors)
calibration by:
a) attaching interferometers, or
b) physical transfer standardards

- closed-loop: active position control with feedback loop
- open-loop: monitoring of position with no active feedback

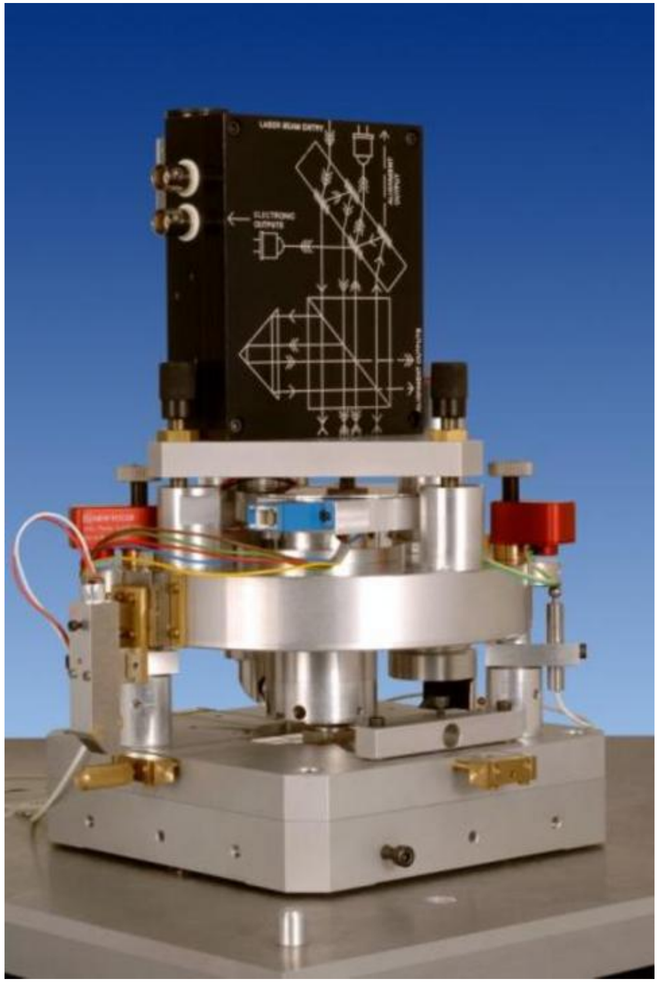
C. Conventional SPMs with positioning by the voltage applied to piezos.
calibration: usually by physical transfer standards

Metrological SPMs

MIKES's

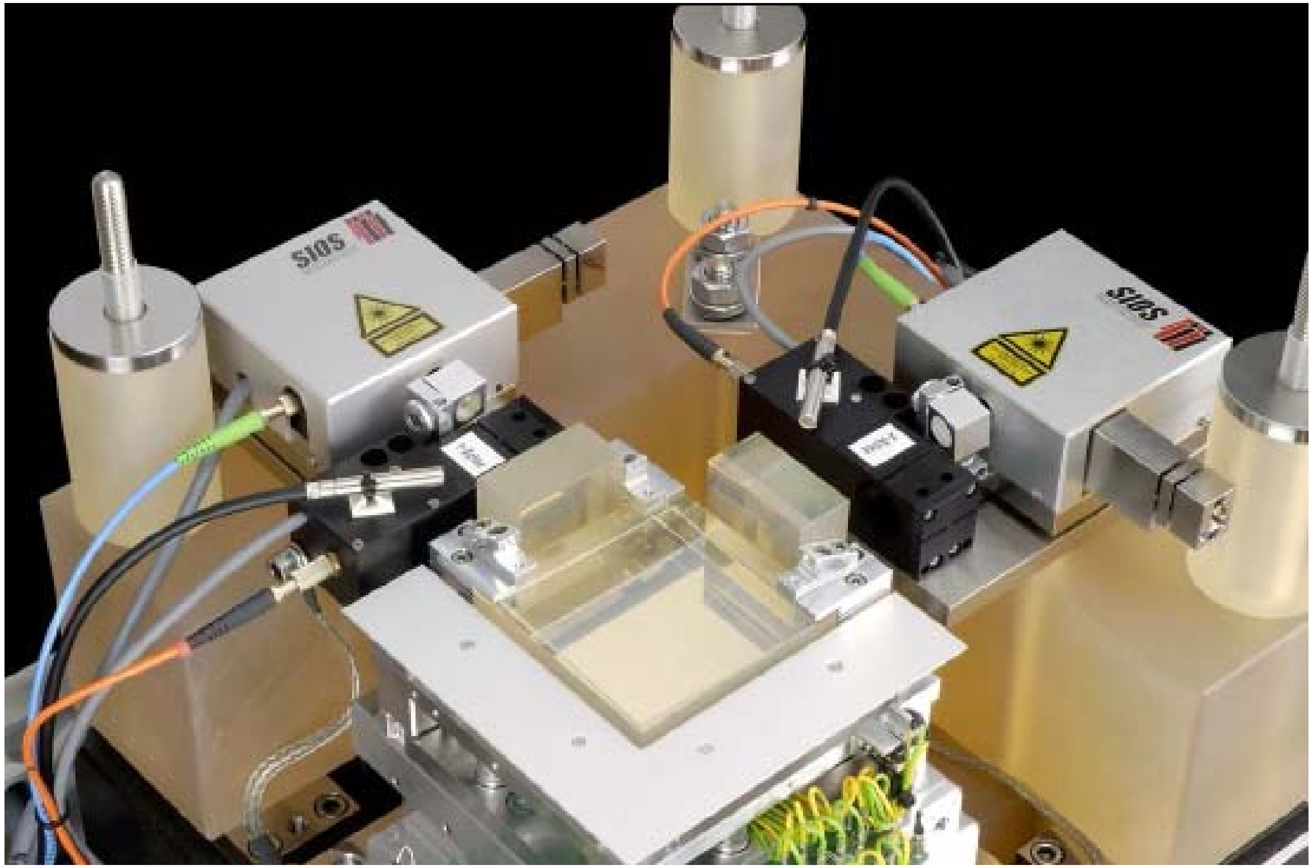


VSL's

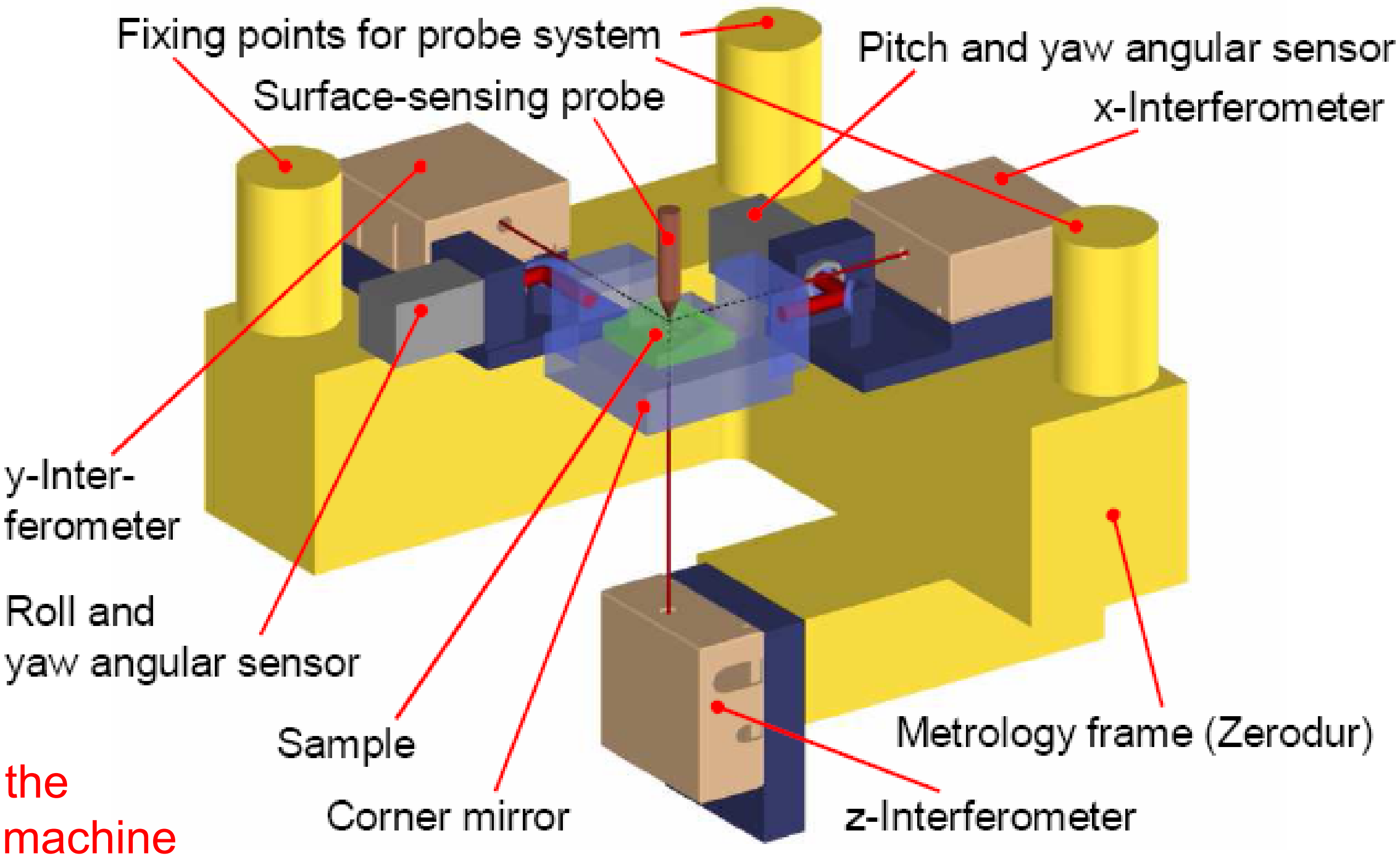


NPL's

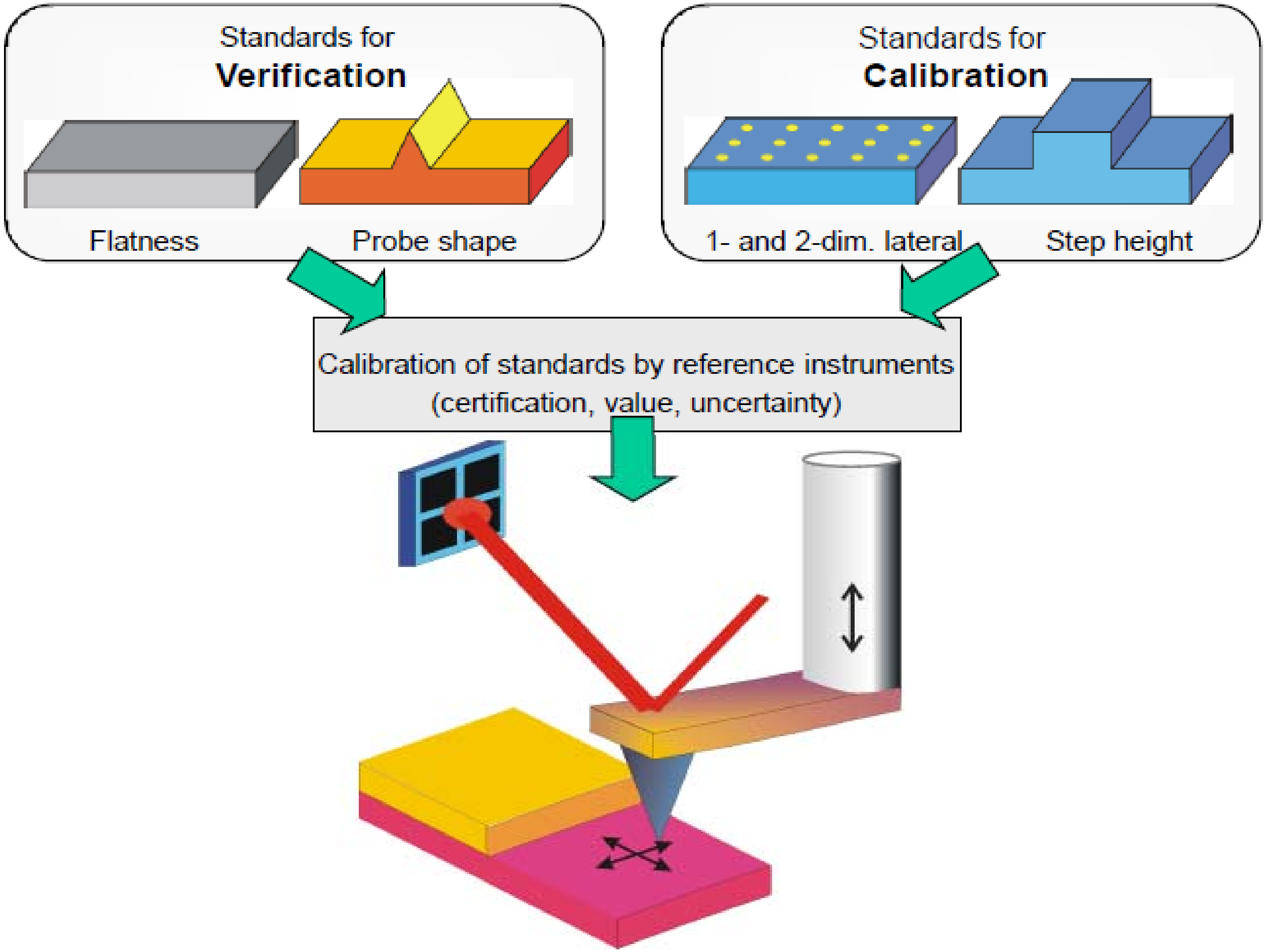
CEM's MAFM : Spanish AFM (Nanotec) + nanopositioning machine (SIOS)



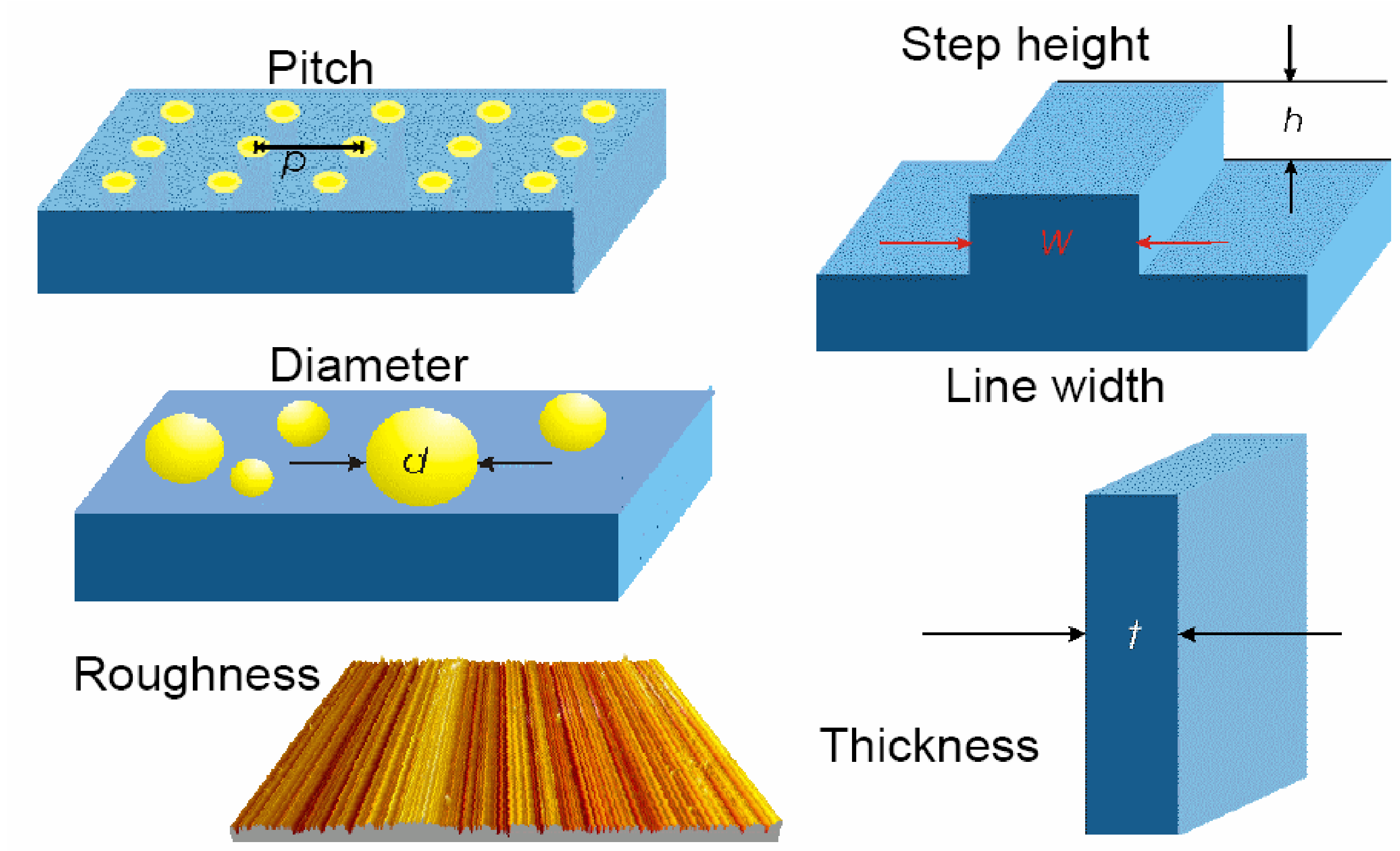
CEM's MAFM : Spanish AFM (Nanotec) + nanopositioning machine (SIOS)



metrological design of the
SIOS nanopositioning machine

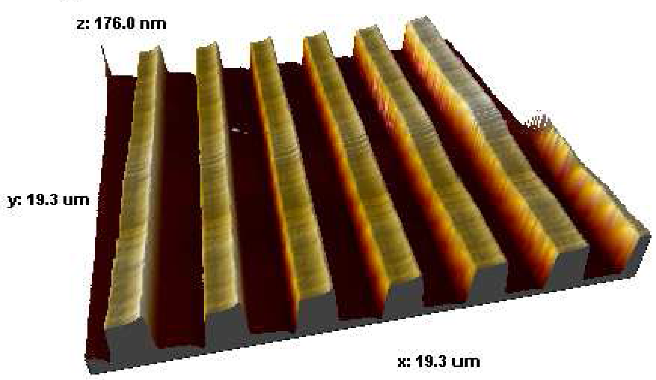

Standards for
Verification
Flatness
Probe shape
Standards for
Calibration
1- and 2-dim. lateral
Step height
Calibration of standards by reference instruments
(certification, value, uncertainty)

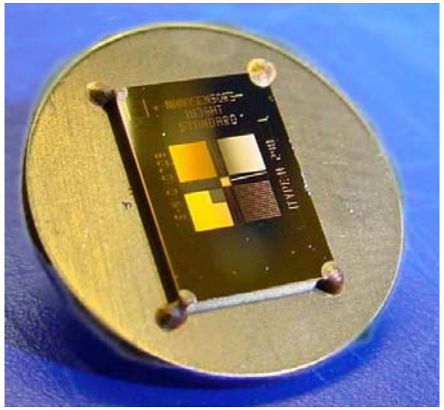
Main physical transfer standards

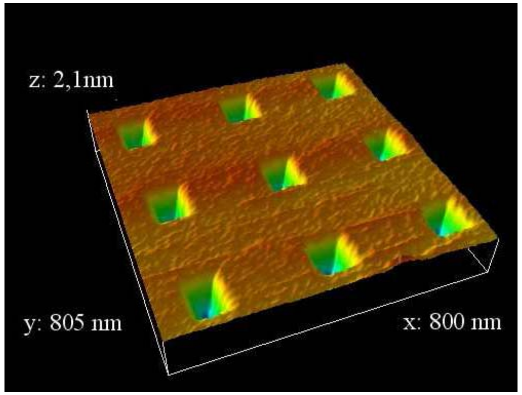


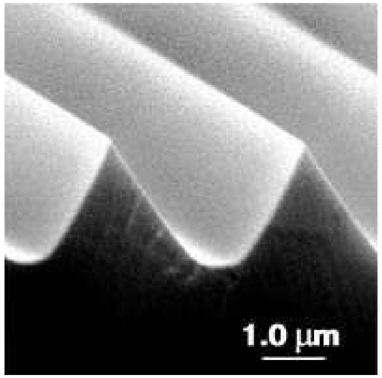
Different kinds of standards

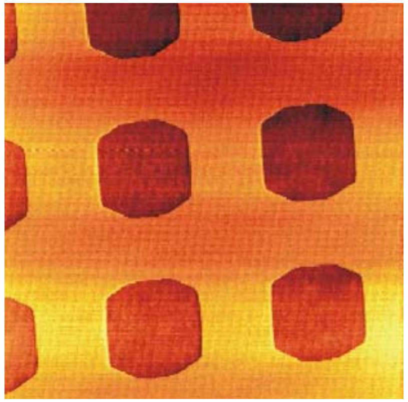
(www.nanoscale.de)
(www.nano-refmat.bam.de)

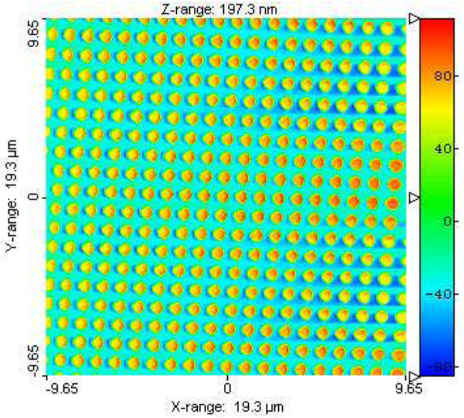












First SPM calibration guideline worldwide
(German/English) since June 2008

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

SPM Characterization & Calibration (VDI/VDE 2656 – Part 1)

- **Ambient conditions, preparatory characterization:**

temperature, noise, turbulences of air, dust & dirt, acoustics, staff...

- **Flatness, signal noise & drift:**

guidance errors in *z* (out-of-plane movement), mechanic & electronic noise

- **Lateral calibration (by interferometers or physical standards)**

Cx, Cy, Cxy, positioning /straightness / squareness / rotational / linearity...

- **Vertical calibration (by interferometers or physical standards)**

Cz, linearity...

- **3D calibration („landmark-based“ concept, e. g. by „Ritter“ pyramids)**

Cx, Cy, Cz; Cxy, Czx, Czy,

- **Uncertainty of measurements (SPM properties, probe shape, standards)**

see "Guide to the Expression of Uncertainty in Measurements" (GUM)

- **Repetition rate**

depending on SPM's stability, tolerable uncertainty, calibration effort

T. Dziomba

Errors and Uncertainty Contributions

(VDI/VDE 2656 – Part 1)

- **Scanning system:**
  guidance errors (out-of-plane motion, cross-talk),
  creeping, hysteresis, non-linearity, mechanic & electronic noise,
  position measurement (laser wavelength, non-linearity, calibration...),
  coordinate systems (straightness / squareness /rotational errors),
  Abbe offset
- **Alignment:**
  Abbe & cosine errors due to (operator!):
  misalignment of coordinate axes (e.g. laser interferometers)
  (wrong) sample (mis)orientation
- **Quality of sample:**
  contamination (dust, dirt and films), chemical stability of the surface
  scratches, homogeneity of properties (tip/sample interaction...)
- **Probing process:**
  control parameters, tip/sample interaction (forces, edge effects,...)
- **Effective tip shape:**
  determination of tip shape, tip wear, tip material
- **Data analysis:**
  filtering, levelling, calculations (incl. determination of uncertainties)
- **Ambient conditions:**
  temperature, turbulences of air, dust & dirt, acoustics noise, staff...

H.-U. Danzebrink
L. Koenders
T. Dziomba

Some words on

Nanotoxicity

Manufactured nanomaterials (MNMs) are rapidly being incorporated into a wide variety of commercial products with significant potential for environmental release, which calls for eco-responsible design and disposal of nanoenabled products.

Nanotoxicity: Emerging discipline attempting to characterize and categorize the health effects caused by engineered nanomaterials in order to determine structure/function relationships between nanoparticles and toxicity.

The Royal Society of Chemistry, Analyst, 2009, **134**, p. 425

Main Agents:

OECD plays a central role in the coordination of research efforts for the development of test methodologies for risk assessment which will underpin the regulation of nanotechnologies.
OECD Database on Research into the Safety of Manufactured Nanomaterials (MNMs)

Spain is participating in some OECD Committees and Working Groups related to nanotechnology:

- Working Party on Chemicals, Pesticides and Biotechnology,
- Working Party on Manufactured Nanomaterials.
- Working Party on Nanotechnology.

SCENIHR (EU Scientific Committee on Emerging and Newly Identified Health Risks)

REACH—European Community legislation concerned with chemicals and their safe use—plays also a role, albeit limited, in regulating nanomaterials.

The general opinion today is that REACH can adequately regulate nanomaterials, but **there is a need for future revisions of REACH to move the focus of regulation from the size/shape of nanomaterials to also their functionality**

Royal Commission on Environmental Pollution (RCEP), UK, *Novel Materials in the Environment: The case of nanotechnology*, p 64, Nov. 2008

Critical research needs to advance this urgent priority include:

(1) structure−activity relationships to predict functional stability and chemistry of MNMs in the environment and to discern properties that increase their bioavailability, bioaccumulation, and toxicity;
(2) standardized protocols to assess MNM bioavailability, trophic transfer, and sublethal effects; and
(3) validated multiphase fate and transport models that consider various release scenarios and predict the form and concentration of MNMs at the point of exposure.

ACS Nano, **2009**, *3* (7), pp 1616–1619) "Research Priorities to Advance Eco-Responsible Nanotechnology", by Pedro J. J. Alvarez, Vicki Colvin, Jamie Lead and Vicki Stone.

Standardization

Why **standards** are important for nanotechnologies

- Standards help to ensure that nanotechnology is developed and commercialised in an **open, safe and responsible manner** by supporting:
  - safety testing, legislation and regulation
  - public and environmental safety
  - commercialisation
  - patenting and intellectual property rights (IPR)
  - communication about the benefits, opportunities and potential problems associated with nanotechnologies

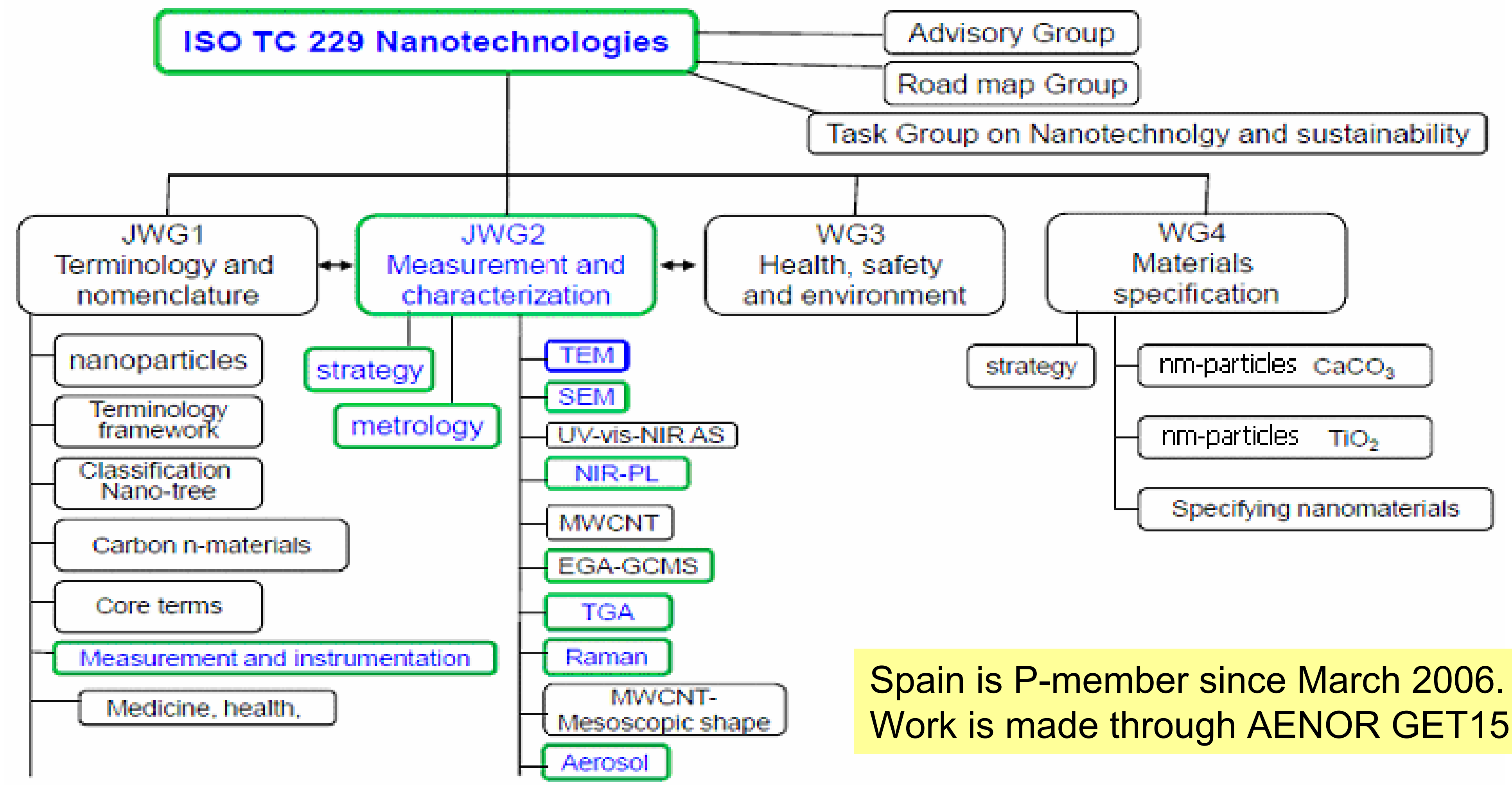
- This is achieved by providing **agreed ways** of:
  - Naming, describing and specifying things
  - Measuring and testing things
  - Health and environmental safety testing, risk assessment and risk management

Peter Hatto, 2007

'Who controls the standard controls the market'

Relevant committees and instruments

- ISO TC 229 – Nanotechnologies
  – ISO TC 201 – Surface Analysis (including SPM)
  – ISO TC 24 – Particle sizing
- CEN TC 352
- National Committees (AENOR GET15 in Spain)
- Formal Instruments – TS, TR, IS, PAS (ISO), IWA etc.
- Defined steps for development
- See www.iso.org for further information



Spain is P-member since March 2006.
Work is made through AENOR GET15

ISO TC 229 Working Plan (only measurement and characterization)

ISO/AWI TR 11808 Nanotechnologies -- Guidance on **nanoparticle measurement methods** and their limitations

ISO/AWI TR 11811 Nanotechnologies -- Guidance on methods for **nanotribology measurements**

ISO/NP TS 13080 Technical Specification for the **Electrical Characterization** of Carbon Nanotubes (CNTs) using 4-Probe Measurement

ISO/WD TS 10797 Nanotubes -- Use of transmission electron microscopy (**TEM**) in walled carbon nanotubes (SWCNTs)

ISO/WD TS 10798 Nanotubes -- Scanning electron microscopy (**SEM**) and energy dispersive X-ray analysis (**EDXA**) in the **charaterization** of single walled carbon nanotubes (SWCNTs)

ISO/AWI TS 10812 Nanotechnologies -- Use of Raman spectroscopy in the **characterization** of single-walled carbon nanotubes (SWCNTs)

ISO TC 229 Working Plan (only measurement and characterization)

ISO/CD TS 10867 Nanotubes -- Use of NIR-Photoluminescence (**NIR-PL**) Spectroscopy in the **characterization** of single-walled carbon nanotubes (SWCNTs)

ISO/CD TS 10868 Nanotubes - Use of **UV-Vis-NIR** absorption spectroscopy in the **characterization** of single-walled carbon nanotubes (SWCNTs)

ISO/CD TR 10929 **Measurement methods** for the characterization of multi-walled carbon nanotubes (MWCNTs)

ISO/CD TS 11251 Nanotechnologies -- Use of evolved gas analysis-gas chromatograph mass spectrometry (**EGA-GCMS**) in the **characterization** of single-walled carbon nanotubes (SWCNTs)

ISO/NP TS 13126 Artificial gratings used in nanotechnology -- Description and **measurement of dimensional quality parameters**

ISO/NP TR 14110 Use of **UV-VIS-NIR** absorption spectroscopy in the **measurement** of composition of metalllic and semiconducting Single Wall Carbon Nanotubes (SWCNTs)

Conclusions:

- Advances in fundamental nanoscience, design of new nanomaterials, and manufacturing of new nanoscale products all depend on the capability to accurately and reproducibly measure properties and performance characteristics at the nanoscale.

- Instrumentation and metrology are both integral to the emerging nanotechnology enterprise and are two of the main areas critical to the success of nanotechnology.

- New techniques, tools, instruments and infrastructure is needed to support a successful nanomanufacturing industry.

- Classical metrology tools have just reached the limits of resolution and accuracy and are not suitable to meet new and future requirements for nanotechnology or nanomanufacturing.

Conclusions:

- NMIs will continue
  - Developing physical standards, methods and calibration services.
  - Confirming their capabilities by participation in key comparisons
  - Supporting R&D Centres and Industry with traceability
  - Collaborating with standardization bodies
  - Participating in Networks and Programmes related to nanometrology
- International standards on nanotechnology are being produced by ISO and CEN, covering terminology & nomenclature, measurement & characterization, environmental, health & safety issues.
- Involvement of all interested parties is needed. You can collaborate through your national standardization Body.

GOBIERNO DE ESPAÑA
MINISTERIO DE INDUSTRIA, TURISMO Y COMERCIO

CEM Centro Español de Metrología

Thank you very much for your attention !

Emilio Prieto

eprieto@cem.mityc.es

Please, visit:

- http://kcdb.bipm.org
- http://www.co-nanomet.eu
- http://www.nanoscale.de
- http://ec.europa.eu/health
- http://www.oecd.org