Nanotechnologies

Metrology and the challenge of the nanoscale

by Jean-Marc Aublant, Delegate for International Affairs and Standardization of LNE, the French National Metrology Institute

Metrology as the science of measurement is one of the main challenges of the nanoscale. Referring to measurement needs and measurement devices, scientists and engineers often quote Lord Kelvin, Sir William Thomson: "In physical science the first essential step in the direction of learning any subject is to find principles of numerical reckoning and practical methods for measuring some quality connected with it. I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of Science, whatever the matter may be." [PLA, vol. 1, "Electrical Units of Measurement", 1883-05-03]

But these needs are in fact important to much more than just scientists and engineers. For instance, nanotechnology-based industry requires instrumentation as accurate, cheap and reliable as possible associated with internationally accepted standards.

Manufacturers, public authorities and non-governmental organizations also demand sampling and test methods, measurements and instrumentation, regulations and standards to prevent human beings to suffer from this new nanotechnological development.

In any case, measurement and characterization are needed at the top of any process. Regarding nanotechnologies where everything is at nanoscale whatever the field (physics, chemistry, biology, mechanics, medical diagnosis, etc.), it has rapidly been shown that there is a major breakthrough in measurement capabilities and instrumentation; tools are being used at the limits of their resolution to probe materials and phenomena, resulting in large measurement errors.

The challenge of nanoscale

Here is the challenge for the metrology world to be capable to supply researchers, toxicologists and manufacturers with measures and numerical reckoning for the characterization of any nanoproducts.

In addition, besides the traditional measurement disciplines and quantities (length, mass, magnetism, etc.) and because properties are different when materials have some nanoscale dimension, there are new technological requirements to characterize nanomaterials.

> **“Metrology has never failed any technical challenge and for sure will overcome any new challenges measuring at nanoscale.”**

It may concern for example shape, volume, surface area and topography, adsorption, porosity, resistivity, resilience and force. And finally, last but not least, all measures must be traceable in a way to the International System of Units (SI).

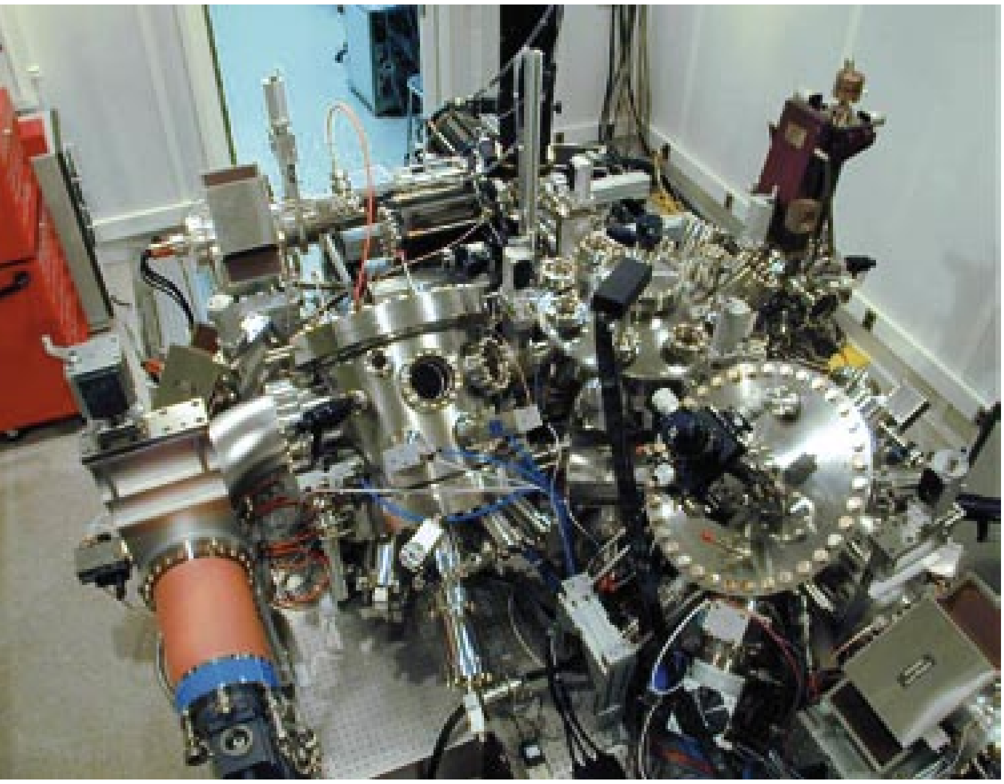
A nanometre (nm) is one billionth (1 x 10^{-9}) of a metre. It is 1/80 000th of the thickness of a human hair, equivalent to the length of ten atoms lined up side-by-side.

It is thus obvious that measuring at nanoscale would be an invisible manipulation process whatever the measurement device and technology.

As far as instrumentation is currently designed and operated, many technologies are being used based on X-Ray, microscopy, spectrometry, spectroscopy and optics.

The self-designed LNE Nanometer Reference Measuring Machine combines a 300mm x 300mm x 50 µm measuring volume with the AFM technology in a clean room facility and a very stable and controlled environnement. All X, Y, Z displacement is traceable to SI units by laser interferometry.

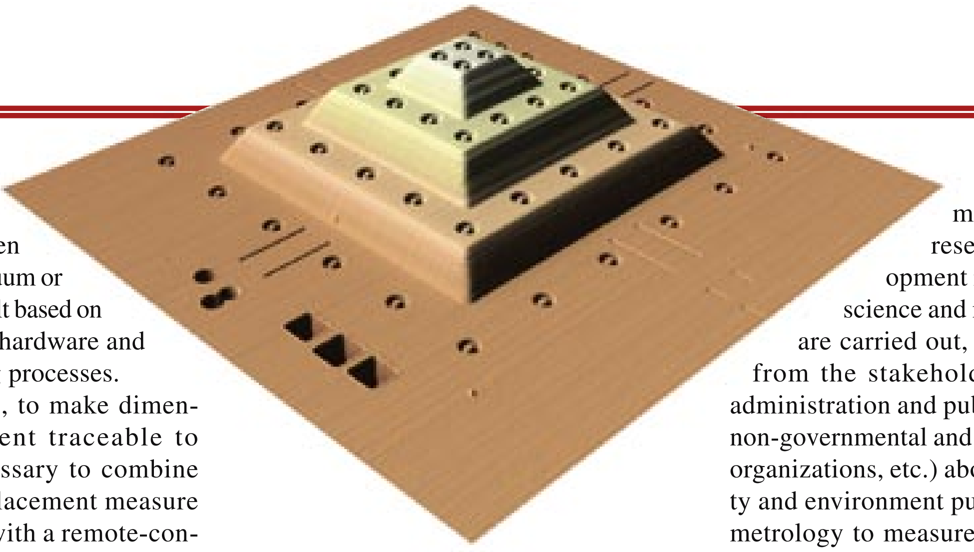
Courtesy of S. Ducourtieux and F. Larsonnier (LNE; dimensional nano-metrology laboratory)



The NIST Nanoscale Physics Facility is a unique state-of-the-art instrument for the fabrication, characterization, and manipulation of novel structures, with the following specific capabilities:

- *scanning tunnelling microscope operating at ultra-high vacuum and control temperatures from –270°C to –150°C*
- *superconducting magnet system with 1.5 Tesla vector magnetic fields at the microscope position and 10 Tesla vertical magnetic fields at the microscope position*
- *molecular beam epitaxy system to deposit semiconductors and metals with* in-situ *transfer of samples to the scanning tunnelling*
- *tip preparation system to image the atomic structure of tips with in-situ transfer of tips to the scanning tunnelling microscope system*
- *acoustically and electrically shielded measurement environment with extraordinarily high attenuation of external environmental disturbances.*

Courtesy of J.A. Stroscio and R.J. Celotta, NIST Physics Laboratory



Landmark-based 3D calibration structure providing spatial coordinates (X,Y,Z)

Publication in MST from Ritter M ; Dziomba T ; Kranzmann A ; Koenders L : (2007) A landmark-based 3D calibration strategy for SPM. Meas. Sci. Technol. 18, p. 404-414.

Courtesy of M. Ritter (BAM Berlin), Th. Dziomba (PTB Braunschweig) and M. Hemmleb (m2c Potsdam)

All instrumentation operating at nanoscale often needs ultra-high vacuum or clean room and is built based on a complex chain of hardware and software interacting processes.

For instance, to make dimensional measurement traceable to SI units, it is necessary to combine either a direct displacement measure by interferometry with a remote-controlled tipping process or a comparative displacement measure between a nanoproduct (measurand) and a certified reference material (standard), both with extraordinarily high attenuation or control of external environmental disturbances.

Practical considerations

Once it has been done, but not yet for the time being as regards nanotechnologies, the metrologists give the results of the measurement that is only an approximation or estimate of the value of the measure and thus should be complete only when accompanied by a statement of the uncertainty of that estimate.

The uncertainty of the results of a measurement reflects the lack of exact knowledge of the value of the measurand. Concerning nanoscale measurement, the uncertainty evaluation is much more complicated than it used to be for existing instrumentation.

In practice, there are many possible sources of uncertainty in a measurement and along the chain of signal and data processing. They need to be identified, evaluated and taken on board within the algorithm.

It is clear that the challenge for metrology is also to work within the same timeframe as academic and industrial research and development.

In fact, apart from a very few technological niche applications, there is a recent and ongoing development of new technology-based instrumentation and devices dedicated to characterize nanoproducts and nanomaterials.

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About the author

Jean-Marc Aublant is the delegate for International Affairs and Standardization to the Managing Director of LNE, the French National Metrology Institute. He is currently the leader of a European-funded project, Nano-strand, dedicated to standardization related to research and development for nanotechnologies. He is also the Secretary of EUROLAB, the European Federation of National associations of Measurement, Testing and Analytical Laboratories.

Furthermore, as far as research and development related to nanoscience and nanotechnology are carried out, many concerns from the stakeholders (industry, administration and public authorities, non-governmental and standardization organizations, etc.) about health, safety and environment put the burden on metrology to measure and characterize innovative nanoproduct as soon as it blossoms from the laboratory.

The way forward

Metrology has never failed any technical challenge and for sure will overcome any new challenges coming from nanotechnology and measuring at nanoscale. But in front of such a huge amount of requirements arising at the same time from so many sectorial fields, metrologists need a better visibility on such requirements.

They suggest under the umbrella of international standardization organizations, international, regional and national research initiatives and programmes to roadmap and prioritize all the existing needs of measurements traceable to SI units.

The concerns regarding the development of nanoscience and nanotechnology centre around societal needs, health, safety and the environment ; therefore, there will be future risk analysis requirements related to the manufactured nanomaterials.

A classification of nanoproducts, nanomaterials and nanoparticles needs to be set up based on comprehensive criteria in order to identify and differentiate needs, apparatus and measurement devices, sampling and measurement methods.

Then metrologists should assess performance, accuracy, repeatability, reproducibility of the appropriate and relevant instrumentation and reference materials. They should focus on accuracy, uncertainty and traceability to SI units and they also should assure reliability and comparability.