Position paper on

The need for measurement and testing in nanotechnology

Compiled by the High Level Expert Group on Measurement and Testing
Under the European Framework Programme for Research and Development

Abstract:
This report is prepared for the High Level Expert Group (HLEG) on the generic activity "Measurement and testing" for the European framework programme for Research and Technology Development with the aim of identifying new needs for research and development in metrology (including both measurement and testing) to support the demands from nanotechnology, which is foreseen to be one of the major new technologies of the coming decades. After a brief introduction to nanotechnology the report addresses nano metrology from the following perspectives:

Written standards
Scientific instrumentation
Validated measurement procedures
Measurement standards
Chemical analysis
Biology

It is suggested that despite the multi-disciplinary nature of nano-science and the multi-sector nature of its industrial applications, nano-metrology can focus on a few generic developments. Hence it is suggested that the same measurement standards can support the three different industrial sectors: Precision Engineering, Micro- and opto-electronics, as well as Bio-molecular technology.

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1. Executive Summary

The needs for measurement and testing that may be derived from the foreseen developments in nanotechnology are substantial and wide range. Prosperous industrial sectors such as Precision Engineering, Micro- & optoelectronics, as well as Bio-molecular technology will not be able to develop to their full potential in Europe without associated developments in measurement, testing and related disciplines.

As a generic technology, metrology in the broad sense of measurement and testing, should be explored within the concepts of the European Research Area ERA, including emphasis on centres of excellence. Specifically, we are here talking about "nano-technology."

This position paper, the third of its kind,[i] is compiled by the High Level Expert Group (HLEG), formed by the Commission to give advise on activities within the generic technology "Measurement and Testing"; and it reflects the common position of the HLEG-members on the importance of the development of proper measurement and testing techniques within the emerging technology nanotechnology. However, in its preparation the paper has been widely circulated and as such is the results of a broad effort.

The HLEG strongly recommends, that the Commission sees measurement and testing in general - and applied to nanotechnology in particular – as an integral part of the European Research Area, in order to strengthen European competitiveness on the global scene, as well as to contribute to bettering the living conditions of European citizens.

Nanometrology should (must) be seen as an indispensable part of all kind of nanotechnology. Any activity within science and technology must be accompanied be reference measurements to ensure that quantitative results are comparable and products interchangeable.

Further, the HLEG recommends to the Commission that a substantial fraction of the funding for nanotechnology should be particularly addressing the related measurement and testing needs based on open calls for proposals. Simultaneously, the nanometrology within the ERA should be explored by building upon existing European networks and centres of excellence. Also, systematic dissemination of knowledge is desirable. Finally must be stated, that nanotechnology in its different relevant areas and in total is an extremely dynamic technology. Basic research, applied technical development, innovation and commercialisation happen nearly simultaneously. In general it is an investment intensive technology and needs highly skilled people. And that holds for measurement and testing in nanotechnology as well. The Commission is recommended to accept the challenge and support research and development for maintaining European researchers and industry ahead of the global development - and business of a very often overseen enabling technology, namely measurement and testing, in this case measurement and testing for and in nanotechnology.

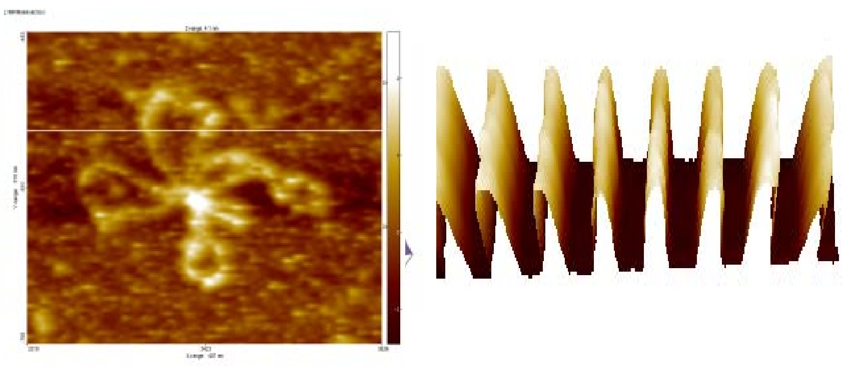

Figure 1. Three examples of currently applied "nano metrology" taken from *precision engineering, opto-electronics*, and *biotechnology*

2. Nano technology is emerging[iii][iii][iv][v]

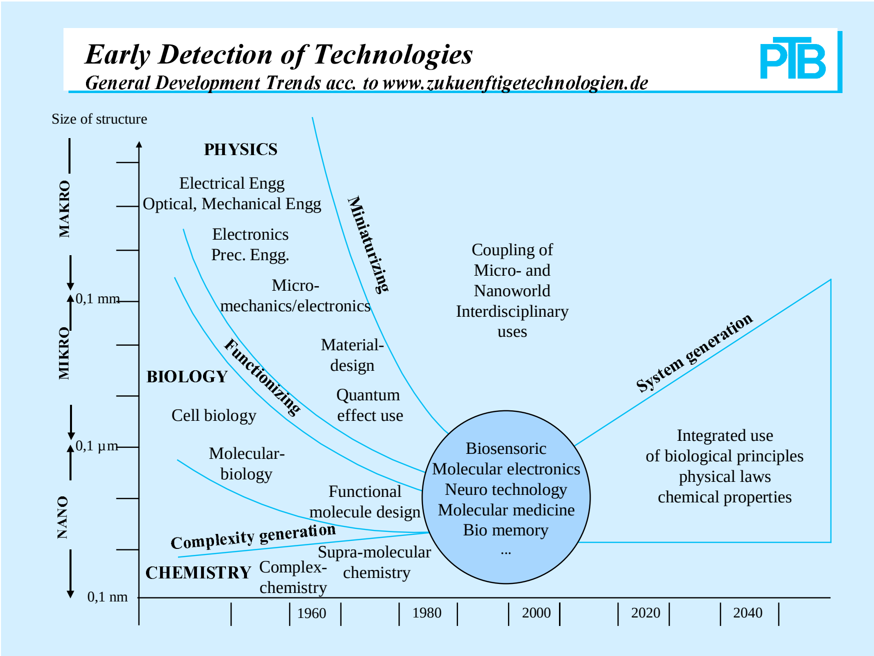

Figure 2 Development of the traditional scientific fields such as Physics, Biology and Chemistry into nano-science and technology[vi]

The term "nanotechnology" means different things to different people.

The most common context for nanotechnology is within manufacturing engineering, where nanotechnology has evolved gradually from microtechnology. Here any physical phenomenon, functional behaviour of a technical process or product, to be subsumed under the term nanotechnology depends on at least one-dimensional quantity (critical quantity) that is expressed in the length unit nanometer (1 nm is 10^{-9}m and one µm is 10^{-6} m).

This characterization includes the investigation and manufacture of any mechanical, electronic, chemical, and biological system by molecular assembly, the so-called bottom-up approach, as well as the so-called top-down approach by miniaturization of processes and products, like machining and multi step processes of bulk materials, e.g. optical components of form precision and surface integrity with nanometer and even subnanometer accuracy for ultra violet (UV) and extended ultraviolet (EUV) lithography.

The critical dimension is to be read as that interesting dimension of a specimen that is important for its function, and not necessarily restricted to very small-sized samples. Examples of critical dimensions are:

- Roughness of a sheet metal for car body production where paintability is the required function
- The edge in an optical filter for telecommunication, where the edge itself may be several µm
- Porosity of polymer molecular membranes for advanced drug delivery
- Distances in molecules, where the function is associated with a particular configuration

The continuous miniaturization in manufacturing technologies now allows fabrication of nano-sized samples as well as nanoscale precision and nanoscale features. This progress is achieved by a variety of techniques such as ultra precision grinding and honing of automotive parts, plasma and ion beam finish of UV and EUV for a new generation of optics lithography, beam sputtering, and photolithography as well as molecular manipulation. Nano-technology products are now found in pharmaceutical industry, microelectronics, and in precision engineering.

Nano-technology is not only a simple continuation of micro technology. It marks the ultimate end of materials science (where properties of individual atoms disappear for the benefit of the continuum of many atoms), namely the dimensions where materials properties stop and molecular properties start. One can also say that nano-technology is where molecular features (including atoms) and materials meet. However, the relevance of molecular features is often implicit. Whereas the study of DNA is obviously related to nano-technology, the "nano"-aspects of sheet metal for its paintability, and the "nano"-aspects of a honed car-engine cylinder easily escaped the uninitiated eye. Nevertheless the two latter examples have been projects within measurement and testing under previous framework programs.

To support nano technology in the above sense with measurement and testing means to provide "rulers" that allow measurements of very small dimensions. These rulers must measure "correctly" meaning that they must be traceable to the definition of the meter in the SI (Système Internationals des Unités). Also the angle must be measured to characterize dimensions correctly.

Nano-chemistry

Chemical analysis at the nanometer scale is a subject of great potential. In biological cells, in ever smaller semiconductor devices, attention is now being given to the chemical analysis within very small dimensions. Currently, no general instrumentation allows a satisfactory spatial resolution for such analysis. And recently, the concept of nano technology has been broadened to deal with other quantities than length, for instance very small amounts of substance leading to the term nanochemistry. Also proper procedures and reference materials must support this new technology.

Nano-biology

Nano-technology concepts have found rapid acceptance in the field of molecular biology, particularly as a means of delivering the vast numbers of high-speed, automated analyses required by applications such as the Human Genome Project and proteomics. For example, by using microscope slides, precision robots and other off-the-shelf equipment, researchers have created gene or protein microarrays that can measure the function of thousands of genes or proteins simultaneously. These "gene chips" and "protein chips" are much publicized in the popular scientific press and are propelling the next wave of medical and pharmaceutical research.

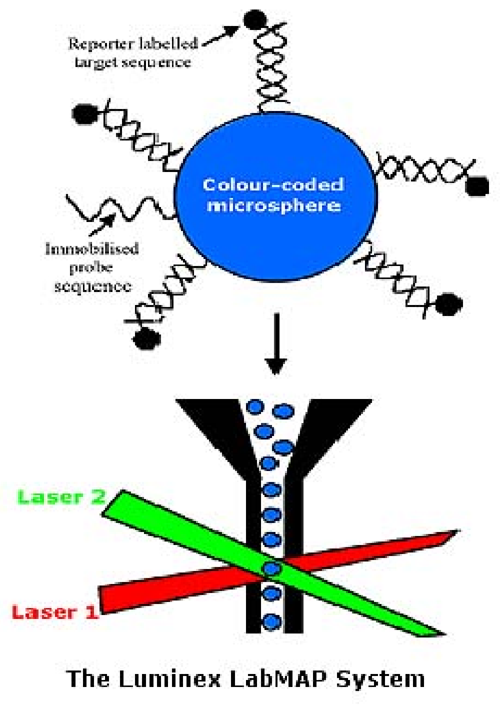

Figure 3 Conceptual device to detect DNA sequence changes at the single base-pair level.[vii]

DNA microarrays have predominantly been used to monitor gene expression levels as many genes can be examined simultaneously. However, arrays can also be used to detect DNA sequence changes at the single base level. An example of one of the many platforms currently available is shown above. Molecular reactions take place on the surface of microscopic beads called microspheres. For each reaction in a profile, thousands of molecules are attached to the surface of colour-coded microspheres. The assigned colour-code identifies the reaction throughout the test that uses lasers to monitor the reaction. The magnitude of the biomolecular reaction is measured using a second reporter molecule, which is incorporated into the target during a polymerase chain reaction (PCR). The reporter molecule signals the extent of the reaction by hybridising to the probes on the microspheres. As the reporter's signal is also a colour, there are two sources of colour, the colour-code of the microsphere and the reporter colour on the surface of the microsphere.

Further examples

In order to illustrate the variation in problems we give below some examples of problems, which can only be properly addressed when proper scales in the nanometer range are available:

Nanotubes and fullerenes is an interesting example of novel materials made from networks of carbon atoms. This has already led to macromolecules of complex shapes and properties and to wires of unusual strength. The manufacturing technique is based on chemical replication; and one of the challenges of nano-technology is to control replication techniques for the general manufacture of products.

Face recognition for safety supervision is a very actual problem, which needs to be very fast concerning opto-electrical image detection, data compression, analysis, storage and recall. Any solution requires extremely high quality optical systems, ultra high integrated computer electronics and peripheral components, manufactured partly down to dimensions of a few nanometres or at least to tolerances expressed in nanometres.

Another example of chemistry at the nano scale is catalysis. It involves reactions at surfaces between molecules in several phases and cannot only be understood in terms of traditional solid state chemistry or reactions kinetics.

SIMS (Secondary Ion Mass Spectrometry) is, nowadays, the only technique suitable to analyze the dopants introduced by the semi –conductor industry. With the developments in this field, devices such as "transistors" may soon be created over less than 10 nm underneath the surface of the silicon wafer. Currently, SIMS faces severe limitations, which may or may not be overcome, and hence does not provide quantitative data in such case. Hence, this is a field where new instruments to characterize nano materials is needed.

In the same way a typical coating on glasses is ZnO/Ti/Cr/Ag/Ti/ZnSnOx/TiO2/Glass with the entire layer stack over some 200nm and some layers such as Ag being less than 5nm in thickness. No instrument allows determining the elemental composition of these layers with sufficient quantification and resolution.

To change completely the field of "materials", a last example where investigation at the nm level is required is found in the Alzheimer disease. Renowned scientists believe that Al is the chemical element causing this disease. Other scientists disagree. For the time being, existing instruments do not provide sufficient resolution to investigate the Al alternative. It requires the ability to map elements with nm scale resolution in order to "look" inside the cells.

3. Nano technology needs measurement and testing

To demonstrate that any product or manufacturing process meets a specified functional demand requires quantitative measurements traceable to an agreed metrology scale. Hence, to bring nanotechnology into a successful business, calls for access to the relevant metrology tools that give ability to measure in three dimensions with atomic resolution over large areas. Measurements are required of all important physical, chemical and biological quantities at various stages in the development of nano-systems, from design, prototype evaluation, and implementation.

Therefore, nanometrology should be seen as an indispensable part of nanotechnology. It should develop hand in hand with the development of nano-science and -technology, respectively.

In order to apply practical metrology the field of nano technology *i.e.,* to make measurement in the nanometer range traceable to the SI units (of length, angle, quantity of matter, and force) practical measurement standards must be constructed. So far the following areas have been identified, each of which are elaborated in Appendix 1:

- Written standards
- Scientific instrumentation.
- Validated measurement methods
- Measurement standards
- Chemical analysis
- Biology

It is also important to notice that nano technology will be a global enterprise. Therefore, standards – both written and measurement standards – should be developed in global consensus. In particular, efforts in the US and EU should be coordinated.

It goes without saying that nano-metrology without nano-technology is not meaningful. Without a measurement-demanding technology there is no need for metrology; but further, practical nano-metrology relies to a large degree upon the technology to manufacture practical standards.

Three examples taken from precision engineering, electro-optics, and biotechnology illustrate the usefulness of nano metrology:

Figure 4 shows a Scanning Probe Microscope (SPM) picture of the 50 µm x 50 µm surface of a silicon wafer after initial diamond cutting from the ingot (left). The height span at this stage is 1.8 µm. After etching and diamond polishing the surface (10 µm x 10 µm x 3.4 nm) appears as shown to the right with a Roughness Sq = 0.247 nm. The roughness is a competitive parameter for the wafer manufacturer, because it is important for the subsequent mask making on the chip.

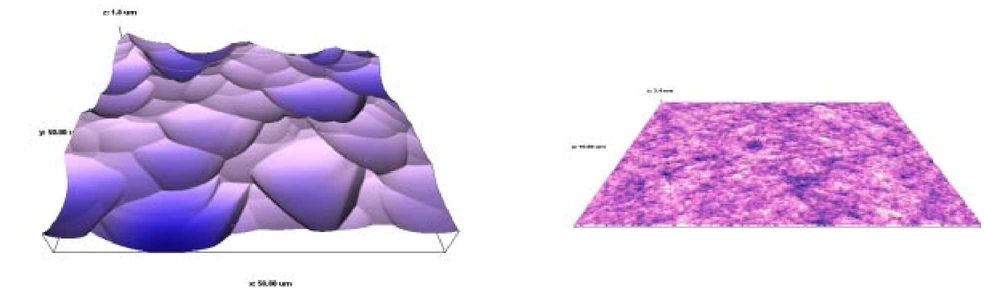

Figure 4. Diamond cutting and polishing of silicon wafers[viii]

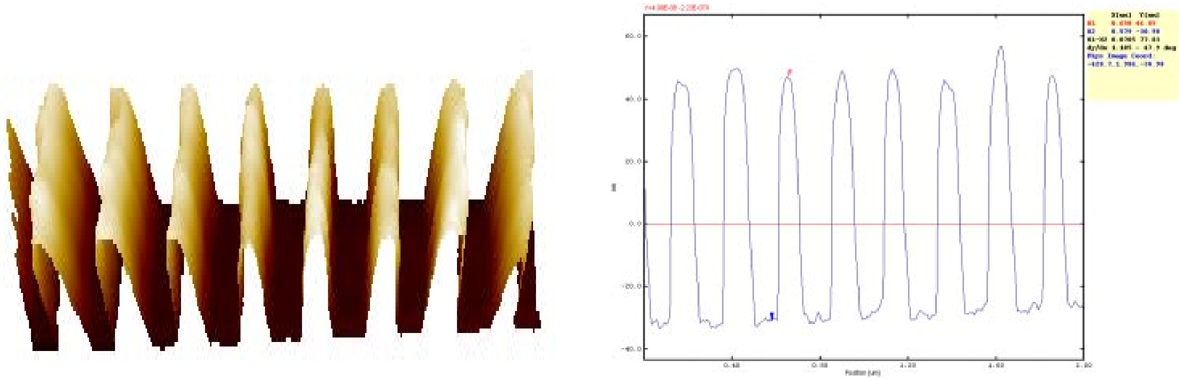

Figure 5. Ridges of photoresist on silicon wafer approximately 80 nm high, approximately 100 nm wide and spaced with approximately 250 nm. The trace to the left shows details of importance for the performance of the device.[ix]

Masters for electro-optical components are manufactured by photolithographic methods shown in figure 5 as measured by scanning probe microscope, SPM. Details of the profiles (left) are important for the functional quality of the device and are important to measure quantitatively correct. This is done by an SPM that has been calibrated with traceability to the meter.

Plasmides, which are components in bacteria, are composed of entangled double spiral DNA molecules. A traceable measurement as shown in figure 6, allows the accurate determination of the length of the individual DNA, which in turn tells the number of base-pairs; and for unknown DNA’s the quantitative height measurement tells whether they are composed of single or double spirals.

As nanotechnology is a complex technology, relevant for many different fields as shown in Fig. 1 and Table 1in appendix 2, it seems to be indispensable to formulate as soon as possible an adequate system of written standards, norms and regulations for a common understanding of terms, descriptions, quantitative and qualitative information etc.

Hence written standards are necessary and must be from the very beginning international – at least European – standards.

As far as possible, those standards should be included in the format of existing standards, e. g. for dimensional specifications it should be implemented into the format of the GPS (Geometric Product Specifications). In general it seems to us necessary to generate or support pre-normative research, which should have unequivocally a European dimension.

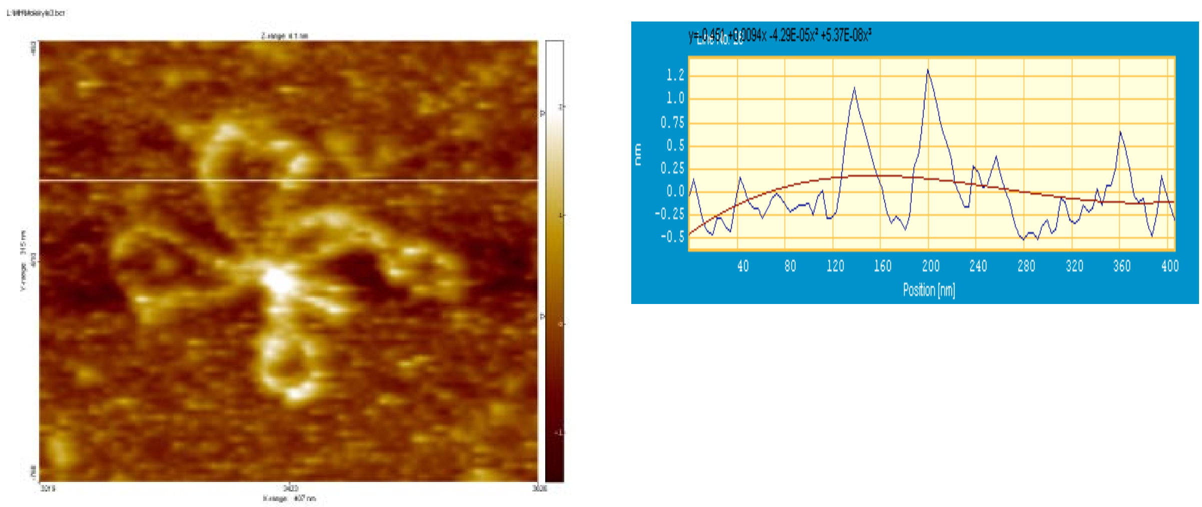

Figure 6. Scanning probe microscope investigations of Plasmide DNA on mica surface.[x]

Reliability of and confidence in measuring results depend strongly on the experience, gained from collaboration and knowledge about what partners are doing.

Measurement standards and standard instruments have turned out to being very important measures for establishing reliability and confidence.

This seems to be a particular challenge and is combined with manifold difficulties, because the nanometer range (0.1 nm till 100 nm) is that area where the atomic world starts and continuum mechanics ends. This transient area is the so-called mesoscopic area, where it is extremely difficult to describe the interaction of sensors with the measurand precisely. But this is a necessary precondition to derive from this interaction correct and reliable measurement results.

Physical standards for surface roughness, subsurface properties, form (flatness, sphericity, asphericity) glass, ceramics and metals are urgently needed.

Besides those standards, made of anorganic materials, equivalent standards are very desired for nanotechnology in all kind of processes (manufacture, monitoring, measurement) of organic materials including living cells in special cases.

When it turns out that those reference standards are impossible to be realized, is it possible to substitute those by validated measurement and testing methods? Which physical and chemical quantities need to be quantitatively detected and measured? Which are the optimum physical principles to measure the requested functional behaviour? When does a nanotechnological process need to be controlled through in-process measurements and/or observation?

4. Available resources and facilities to cope with the needs

Several member states and applicant countries have set up programs and networks for nano technology and are actively funding dedicated project, including nano metrology[xi] As an example figure 5 shows the annual funding of the German Government supporting RTD-projects of nano technology for the period 1997 to 2001

However, a coherent European approach is missing and urgently needed for a Europe-wide coordinated development, although the M&T generic activity of the 5^{th} framework program and its predecessors in the 3^{rd} and 4^{th} framework programs has funded several projects within nano technology. In few special cases a traceability chain for dimensional measurements in the nm range have been established, so that examples of all five areas (given by bullets above) have been addressed.

Within COST, Nanoforum has formulated challenges, particularly within nano-science and biomolecular sciences. Nanoforum forms the core of the advisory group nanoSTAG which is in the process of formulating tasks for the 6^{th} framework program. Nanoforum has recently incorporated metrology in its scope of work.

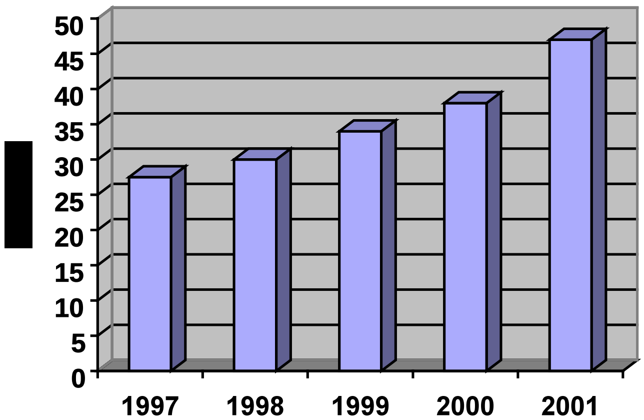

Figure 7. German support for nanotechnology.

Annual budgets of the German Government for sponsorship of nano technology projects. Industrial partners provide a nearly equivalent amount of money. Amounts are in millions euro.

European organizations such as EUROMET (European collaboration on measurement standards), Eurachem (A focus for analytical chemistry in Europe), Eurolab (European Federation of National Association of Measurement, Testing, and Analytical ;aboratories), and euspen (European Society for Precision engineering and nanotechnology) are addressing various aspects of nano-measurement and testing. EUROMET is investigating in detail the available measurement capabilities and forecasting the needs, and a global workshop is being planned, and a EUROMET project is being formulated to get things started, but these activities are not funded as yet.[xii] [xiii] [xiv] [xv]. eu**spen** is setting up an educational program that includes nano metrology, funded by the 5th framework program.

5. Suggestion for a work plan

Nanomeasurement and testing is an obvious example of a science and technology subject that should be explores within the European Research Area (ERA) and it will be a cornerstone in the further development of European competitiveness. Particular attention should therefore be given to modalities foreseen in the 6th framework program such as virtual institutes, centres of excellence, as well as a adequate fraction of funding for measurement and testing within the foreseen specific nano technology program. Therefore, in the following we outline a work plan based on the foreseen needs as well as the currently available resources. I is proposed to take the following aspects into account:

Workshop

Immediately, a workshop should be arranged to get a comprehensive view of state of the art in measurement and testing in the nano range. As nano science and technology develops quite dynamically, the workshop may generate a series of meetings on dedicated topics, in which scientists and practitioners exchange experiences

Inventory

An inventory of current activities in Europe would be very useful, in particular when compared to the foreseen needs.[xvi]

Other actions

The development of a roadmap would be very helpful indicating milestones of required measurement capabilities for in-process and post-process applications in the manifold disciplines of nano technologies. Further actions are subsumed in the following chapter.

6. Recommendations:

The HLEG recommends to the Commission that a substantial fraction of the funding for nanotechnology should be particularly addressing the related measurement and testing needs based on open calls for proposals. Simultaneously, the nanometrology within the ERA should be explored by building upon existing European networks and centers of excellence. Also, systematic dissemination of knowledge is desirable.

Specific actions should be supported by studies so they fall within areas where European impact may be expected to be greatest. Those identifications should also take into account and reflect global aspects, such as what are the situations and the trends in other regions, as in the Americas and East Asia. The situation in the U.S. should be taken to be particularly interesting. But also the state of science and technology in Russia and the Middle and East European States should be treated.

European organisations such as EUROMET, Eurachem, Eurolab, and eu**spen** should be engaged. Other regional or national organisations such as NIST (National Institute for Standards and Technology) of the US will be involved. Contacts should be established with the Bureau International des Poids et Mesures BIPM who have set up two initiatives within nanometrology.

Appendix 1 Further examples for nano metrological needs

First examples concerning quality control of drug production have shown that it is possible to replace testing of the pharmaceutical effects at living animals through "Well Characterized Biological Products" (WCBP). Those characterizations by nanoanalytical measurements need to be extremely sensitive and accurate following standardized measuring procedures.[xvii]

EUV lithography needs large mechanical and x-ray optical components to be manufactured in tolerances best given in nanometers, partially in subnanometers, for surface roughness of the x-ray mirrors in particular. European industry is in front of the worldwide competition, as long as lithography equipment is concerned. There are clear indications that the lack of adequate measurement instruments and technologies are being bottle necks for some very promising manufacturing processes, e. g. ion beam machining[xviii] and similar technologies.

Machines will be required to measure forms, displacements and distances referring to a defined reference point as well as small angles (a kind of cmm on nanometer scale). The majority of what now has been specified under 2 scientific instrumentation regards analytical techniques to look to objects of nanometer dimensions. But to manufacture and reproduce things on a nanometer scale, more is needed. Prototypes of measuring machines already exists, one is at Zeiss, as an example – but a lot still have or be find out. For instance, probes and "tasters" need to be developed, as well as steering software. I cannot see how these aspects can be addressed in your present specification, But I am convinced that these aspects have to be addressed.

In surface chemical analysis there are a range of needs and requirements identified from the point of view of documentary standards and some metrology aspects within the business plan for ISO Technical Committee 201 on Surface Chemical Analysis. There are a range of documentary standards from this TC, some of which address the needs identified in nanotechnology.[xix]

The following needs have been pointed out during the course of writing this report. The are listed under the headings indicated in section 3.

- Written standards

This could eventually be included in the general format of geometric product specification (GPS)

- Scientific instrumentation. Nanotechnology at the same time offers completely new mechanisms and instruments for the measurement of new phenomena on the sub-atomic scale. This is a field in which Europe is working actively. It will include:

  Scanning probe microscopes where there are several manufacturers in Europe, US and Japan. New instrumentation should include SNOM (Scanning Near-field Optical Microscopy) which is currently being produced in Germany. Parallel SPM techniques for investigations of details of microscopes.

  Static SIMS with currently one manufacturer in the US, UK, and Germany. Magnetic sector SIMS (for depth profiling in semiconductors): Manufacturer in France, US, and Germany.

  XPS which is produced in Sweden, Germany, and U.K (as well as USA and Japan).

  Auger which is manufactured in the U.K and Japan, USA

  SEM techniques for further developments to perform dimensional measurements of high aspect ratios.

  TEM's which are produced in the Netherlands, Germany, Japan

  X-ray interferometers, which are produced in Germany and Italy

  Ellipsometers with manufacturers in France, Germany, and US.

  VUV and EUV lithography

Laser interference microscopy such as Laser Scan Confocal Microscopy, which we find interesting and promising for non-destructive measurement of the thickness of thin coatings.

Focused Ion Beam" (FIB) technology in the list of "Scientific Instrumentation", since FIB-technology allows to "open the third dimension". It allows to create cross-sections from nearly any specimen and is used more and more in preparing specimens for Transmission Electron Microscopy (TEM) and SEM. The combination of TEM and FIB allows for example, to prepare and measure layered specimens with sub-nanometre resolution

Measurement of displacement and probably small angles is required for nanopositioning and manipulation (manufacturers of nanopositioning stages in the UK and Germany, manufacturers of displacement measuring systems in Europe + USA).

Surface texture measuring instruments have been omitted from the list of Scientific Instrumentation (manufacturers UK, Germany, USA + others), instrumentation for low-force measurement and micro-/nano-CMM systems.

- Validated measurement methods

  Mask metrology

  On-wafer metrology

  Test and development of calibration software for nano metrology.

- Measurement standards

  Surface standards such as roughness and flatness standards for optics and sheet metal

  Thickness standards for coating and painting, applicable also in depth profilometry used for microanalysis

  Methods for thickness measurement of thin layers from molecular scale to approx. 10 my, especially non-destructive methods for transparent polymer layers.

  Characterization of topography and nanostructures on surfaces, especially blood or tissue compatible surfaces.

  Characterization of surface modifications, on the nano scale and in depth profilometry

  X, Y, Z standards for use in microelectronics and precision engineering, and biochemistry

  Standards applicable in micro-hardness and other techniques for the determination of mechanical properties like elasticity.

  Particle size standards.

  Accurate force standards for measurements in the nN-range

  Soft gauges for surface texture and similar software checks for other instrumentation and 3D stuctures for calibrating micro-/nano-CMMs

  Novel nanometrology of macroscopic physical, chemical and biological quantities. Nanometrology also covers the use of nanosystems in enabling considerably more accurate measurement of macroscopic physical, chemical and biological quantities. Examples:

  New electrical standards based on single electron nanodevices (such as SET) – see EUROMET electrical nanometrology initiative proposed by NMi (NL), 010621

  New thermometers based on coulomb blockade in tunnel junctions [Pekola et al.1994, Bergsten et al.1999]

  Josephson array magnetometers

  Other novel sensors (electronic noses e.g.[http://nose.uia.ac.be/] where a special interest group has been formed to study the metrological characterisation of electronic noses)

Pore size distributions and porosity in filtration membranes.

- Chemical analysis.

  traceability of measurements results provided by a lab on a chip; also when it is the intent to re-use the chip and reproducibility aspects are also to be addressed (repeatability)

  surfaces of catalysts and their functionality

  measurement of the influence of the 3D configuration structures of an enzyme in relation to its effectiveness

  measurement of the structure and properties of fullurenes and nano tubes to understand and predict their behaviour and to study modification properties

  better spatial resolution

  better depth resolution

  improved sensitivity

  greater chemical information

  simplification of complex molecular information

  bio-dimensional information

  analysis of structure and position at the atomic level

  non-vacuum methods, methods in air and in water

  time-resolved methods – high speed

- Bio-molecular technology

  Surface morphology of blood gas sensor membranes.

  Surface structure of hypodermic needles.

  Surface and sub-surface structure of catheters and skin adhesives (block co-polymers)

  Distribution of active sites (recipient molecules) in diagnostic testers (bioassays, biosensors)

Appendix 2 The socio-economic impact of nanotechnology

Experts are convinced that it is absolutely acceptable to characterize nanotechnology being one of the key technologies of the first country of the new resources` [xx]

The technology has enormous economic potentials[xxi] but creates besides optimistic expectations also uncertainties and fear because of its absolutely new level of complexity and extremely high level of knowledge required to understand the physical context.

Economical drivers of Nanotechnology are (amongst others)

Medicine, Pharmaceuticals, Biology

New drugs and active agents (incl. cosmetics and light filter substances), medical adhesive surfaces (eg. allergic band aids; drugs and active agents that can be dosed locally; bio-compatible implant surfaces; multi functional sensors (e. g. in environmental/medical technology, for analysis of DNA).

Apparatus construction (ultra precision machines, analysis and positioning systems); Optics (stepper optics, aspherics, x-ray optics, mirrors); polished wafers and substrate; abrasion-minimized pillows (possibly free of lubricants).

Chemistry, Materials

Ceramics, pigments, powder, wires, …(lighter, more resistant, more buoyant, switchable; corrosion inhibitors and corrosion resistant materials; chloride-free gluing technologies (e. g. for bags) and new welding techniques, functional layers (thermal insulating, anti-adhesive, anti-static); membranes for material separation (wastewater treatment, nutrient technique, dialysis, ionic) structured catalysts with optimal harmful substance conversion (also for cars).

Highly dense data memory (bit) and minimized processors; fast, portable PCs and brilliant displays (e.g. FEDs); new solar cells, batteries and combustible cells; opto electronic components (laser, opto couplers,…); ultra fast parallel computation (quantum computing, face recognition).

Automobile Technology

Easy portable and structure components; electric- and magnetic rheological liquids (e. g. for buffers); field emitter allocations for ignition systems and air refinement; painting (colour effects, scratch and wear-resistant, air-conditioning, elastic) adhesive conciliator (glue and joint processes, layer adherence).

Biotechnology: Science for a better living

Europe in total is amongst the leading world regions in Biotechnology. Germany is one of the driving forces in Europe within this very innovative and knowledge based technology.

In Germany alone there are more than 500 SMEs, engaged in Biotechnology. German Biotech-Enterprises employ in total more than 200.000 people. Their annual turnover is more than 40.10^9 EURO and they invest approximately $5 \cdot 10^9$ EURO in Research and Technical Development. It is typical for Germany that for the time being, the most substantial part of resources available for Biotechnology belongs to a few large companies, in particular from the pharmaceutical industry. [xxii]

But the momentary booming in Biotechnology in Germany is driven by an increasing number of small and medium enterprises that perform capital-intensive research of very innovative products and processes, which they sell mostly to large companies.

The efficient production of biotechnological products depends to a high percentage on nanotechnological processes.

Fig. 1 sketches the general development from the recent past to the next future showing the remarkable paradigm change, that takes place momentarily. E. g. the merging of miniaturizing, functionizing and the increasing of complexity to system generating technologies when it comes to nanotechnologies.

At this point it should be stated that nanotechnology must be seen as an enabling technology making a. m. technologies possible or at least more effective.

The Social Aspects

The social aspects may be subdivided into those more relevant for societies – global, European, national or more relevant for the individuals.

Societal opportunities for the better living conditions are seen by the increasing application of nanotechnologies for

- cleaner ecology
- more spare exploitation of natural ` esources
- more efficient energy generation and storage
- better manufacturing processes and process safety
- increasing information exchanges and better communication
- better medical treatment through
- more reliable diagnoses
- more specific therapeutics

Table 1 below gives a few examples to illustrate those fields

The public concern.

Aside from economic and social opportunities that nanotechnology offers, like any new technology it also raises a considerable public concern and fear. Examples are:

There was at least one case brought to court already in Germany in March 2000[xxiii]. One person wanted to have withdrawn by justice the official permission of nanopowder production in his neighbourhood because of assumed possible problems of emission protection. The complaint was sustained in the first court of first instance, but the complainant fears risks for his health and wants to have the case treated by a higher court.

Those individual fears are fed by discussions amongst scientists and engineers, who discuss nano technology having constructive as well as destructive potentials. There is no doubt about the necessity of such controversial discussions.

In a non-public workshop of the US American National Science Foundation that dilemma was discussed in September 2000. Much of the two-day workshop focused on the promise of nano technology to help solve such intractable social problems as poverty and hunger and to bring forth medical advances to fight disease and to improve overall human health. But the workshop also dealt with some of the fear surrounding nano technology".

Ecology	**Exploitation of Resources**	**Energy Generation**
Selective chemistry	Aimed material design	Gas memory
Colloidal membranes	Switchable material properties	Photovoltaic cells from nano-particle combinations
Selective catalysts	New layers/materials	Compact batteries and combustible cells with large inner surface
Sensitive emission protection	Lighter carrying and structure components	
Functional, non-toxic layers		
Process security	**Health**	**Information/communication**
Compact zeolith reactors	Dialysis membranes	Flat displays
New gluing technologies	Tailor-made drugs	Pocket library
Copy protection (CD, money bills)	Precise substance positioning in the body	Silicium/organic couplings
Adjustment standard on atomic scale	Preventive medicine with highly sensitive mini sensors	Digital logical components
Self-organizational processes	Biocompatible layers and materials	Multi-layer staple laser
More precise processing procedures	Medical nano machines	Ultra fast compact computers
Quality control on atomic scale	Analysis of DNA and manipulation of DNA (Gene technology)	Quantum wires/quantum electronics

Table 1: Ecological, commercial and technological fields connected to nano technologies

Appendix 3 Circulation during the preparation of this report

This paper has been distributed for comments to a number of persons and organisations according to the following groupings:

Members of the High Level Expert Group and officers within the European Commission.
EUROMET contact persons for Length and key persons
*eu**spen** members (persons and organizations) interested in nanotechnology and metrology*
A number of individuals that have indicated interest.

The following persons and institutions have contributed with text and comments:

Name	**Affiliation**	**Country**
Kim Carneiro	DFM, Danish Institute of Fundamental Metrology	DK
Horst Kunzmann	PTB, Physikalisch Technische Bundesanstalt	DE
Richard Leach	NPL, National Physical Laboratory	UK
Edit Banreti	OMH, Office of metrology in Hungary	HU
Deborah Corker	eu**spen,** European society for precision engineering and nanotechnology	UK
A. Korsgaard & Holger Rasmussen)	Ministry for Research	DK
Kjeld Schaumburg	Copenhagen University	DK
Rudolf.Thalmann	METAS, Swiss Institute of Metrology and Accreditation	CH
Alessandro Balsamo	IMGC, Istituto di Metrologia “G. Colonetti”	IT
Peter Samuelsen	Coloplast A/S	DK
Maire.Walsh	State Laboratory	IE
Claes Bankwall and Hans Andersson	SP, National Testing & Research Institute	SE
Martin P Seah and G N Peggs	NPL, National Physical Laboratory	UK
Bernd Volbert	FEI Company – Structural Process Management Solutions	NL
Menno Plantenga	Nederlands Meetinstitut, Van Swinden Laboratories	NL
Håkan Nilsson and Leslie Pendrill	SP, National Testing & Research Institute	SE
Anders Kühle	COMF, Centre for Surface Metrology and Functionality	DK
Lydia Clausen	Radiometer Medical A/S	DK
Jan Friis Jørgensen	Image Metrology ApS	DK
Dr Robin Devonshire	Chemistry Department, University of Sheffield	UK
Maria Holmberg	MIC, Microelectronics Centre	DK
Paolo Salieri	Measurement and Testing	EUC
Mike Sargent	LGC, Laboratory of the Government Chemist	UK

Notes

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[i] Previously, the High Level Expert Group has issued position papers on "Metrology in Chemistry" and "Metrology for Anti-fraud"

[ii] An overview of current activities is given at the following home pages:

COST project nanofurum; http:// www.nanoforum.org

The US national nanotechnology initiative : http://www.nano.gov/

Vision for Nanotechnology Research and Development in the Next Decade: http://itri.loyola.edu/nano

"Technology Roadmap for nanoelectronics" (Editor: R. Compañó) http://www.cordis.lu/ist/fetnid.htm.

[iii] Recent reports from the Commission:

"Applications of micro and nano technologies general view" (MINATECH report from a EU project, May 2001)

"International Technology Roadmap for Semiconductors - Metrology" (1999)

[iv] Nanotechnology was described in a series of articles in TIME (European Edition 3. July 2000, pp 58-63)

[v] See also "Current Initiatives Launched at the European Level, funding Opportunities"

[vi] BMBF: F&E-Strategien in der Nanotechnologie 16./17. Mai 2001 BMBF Bonn

[vii] Courtesy of Luminex Corp.

[viii] Courtesy of Topsil A/S

[ix] Courtesy of Ibsen Photonics

[x] Maria Holmberg, private communication

[xi] This includes amongst other, Germany, France, United Kingdom, and Czech Republic.

[xii] R. Thalmann: EUROMET Initiative on Nanometrology (EUROMET project #630)

[xiii] See http://www.euromet.ch

[xiv] See http://www.euspen.org

[xv] H. van den Brom, EUROMET initiative on electrical nanometrology (EUROMET project # 631)

[xvi] The Czech Metrology Institute has made a draft of such an information inventory, which might serve as a starting point for e wider European study.

[xvii] M. Milton (NPL) personal communication, Sept. 2001

[xviii] A. Schindler (IOM) personal communication, March 2001

[xix] http://www.npl.co.uk/npl/cmmt/sis/index.html and http://www.npl.co.uk/npl/cmmt/sis/iso_standards.html

[xx] N. Malanowsky: Vorstudie für eine Innovations- und Technikanalyse (ITA) Nanotechnology (in German) VDI-Technologiezentrum, 2001, Düsseldorf, ISSN 1436-5928 (Prestudy of an Innovation and Technology Analysis (ITA) of Nanotechnology)

[xxi] G. Bachmann, A. Zweck: Nanotechnologie – Novitäten aus der Micro Welt. Wechselwirkung, Heft Mai/Juni 2001, S. 28-35

[xxii] U. Heinrich: Wissenschaft für ein besseres Leben, Fraunhofer Magazin 2.2001, Fraunhofer Gesellschaft, München

[xxiii]Nanotechnology, Chemical & Engineering News, 16.10.2000)