

Co-Nanomet

Co-ordination of Nanometrology in Europe

**European Nanometrology Action Group:
Annual Meeting Reports 2009**



Preface

Funded under the European Commission Framework Programme 7, Co-Nanomet is a programme of work which is addressing the need within Europe to develop the required measurement framework to successfully support the development and economic exploitation of nanotechnology.

The field of nanotechnology covers a breadth of markets and applications each of which has specific and varying metrological needs. A key challenge for metrology in supporting nanotechnology is to disseminate the measurement techniques that have been developed at national metrology institutes and research institutions to industry; to invent practical instruments that can perform in an industrial environment at a speed that allows production control, and to create the tools that enable the control of measurement quality. Given the breadth of markets, products and applications into which nanotechnologies feed, the process chain for dissemination of metrology techniques as well as traceability to national standards and internationally harmonised standard methods are specific to the particular nanotechnology area addressed.

To this end, 5 European Nanometrology Action Groups have been established in 2009 under the Co-Nanomet programme, focussing on a set of core nanometrology fields, namely:

- Engineered Nanoparticles
- Nanobiotechnology
- Thin Films and Structured Surfaces
- Critical Dimension and Scanning Probe Techniques
- Modelling and Simulation

Each action group aims to raise awareness of current capabilities, emerging regulatory needs/developments and identify community issues relating to:

- Measurement technologies
- Instrumentation

- Standardisation requirements
- Traceability and equivalence
- Identification, development and implementation of tools for the assurance of measurement quality

In November 2009 the action groups held a meeting with key stakeholders working in the field. These stakeholder meetings were held in parallel with a European Workshop in Nanometrology held by the Co-Nanomet partners at PTB, Braunschweig.

Prior to the stakeholder meetings, the action groups published a series of discussion papers addressing the current status, future needs and opportunities in each nanometrology area.

Enclosed are the stakeholder meeting reports for the action groups followed by the discussion paper published by each group. Where these have been updated following feedback from the meeting, the latest version is enclosed. We hope that you will find these documents a valuable status review on a range of key nanometrology fields.

Feedback on the discussion papers and the activities of the actions groups is welcomed and contacts to the authors are provided for responses.

Dr Theresa Burke
euspen Ltd
on behalf of the Co-Nanomet Consortium

For further information on Co-Nanomet activities please visit:

www.co-nanomet.eu

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European Nanometrology Meeting Report

Action Group: Engineered Nanoparticles

Meeting Date: 20th November 2009

Meeting Venue: Physikalisch-Technische Bundesanstalt (PTB),
Braunschweig, Germany

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Action Group Aims:

The European Nanometrology Action Group on Engineered Nanoparticles (ENP) addresses the classification and characterisation of nanoparticles for production control and for EHS issues with the purpose of identifying and promoting metrology solutions for both airborne and suspended ENPs. Topics covered by the group are existing measurement methods, standardisation, operational practises, traceability and reference materials.

Meeting Report

a) Items addressed

In November 2009, the action group published a discussion paper 'Engineered Nanoparticles: Nanometrology Status and Future Needs Within Europe'. This paper was intended to capture the current status, future needs and opportunities in this area of nanometrology and was used as a starting point for discussions held during this meeting with key stakeholders. Discussions and feedback from the meeting delegates addressed:

- Content and structure of the discussion paper
- Key measurands for engineered nanoparticles
- Measurement techniques
- Online measurement
- Current and future needs in the field of engineered nanoparticles

b) Summary of Discussions

General remark:

- In contrast to ENP manufacturers, the EHS experts have no clear idea, which measurands and techniques are really needed for their purposes → discussion was dominated by manufacturers of ENPs and instruments

Comments on content and structure of the discussion paper:

- The discussion paper was accepted as a valuable guide, but it should continue to be kept as brief as possible ("stay with bullet points and headlines")

- Bulk properties, which are required for data analysis (e.g. refractive index), should be included.
- Existing guidelines should be considered.

Comments on measurands:

- A distinction should be made between between measurands and descriptors.
- A further distinction should be made between individual and “collective” measurands.
- Important measurands (depending on application) are:
 - Size (distribution)
 - Morphology and shape
 - Compositional analysis (elements, molecules)
 - Internal surface
 - Surface charge
 - Agglomeration state
- Referring to OECD- and ISO- lists, in addition to the measurands and the relevant standards, and an evaluation of the methods for their selection, purpose and limits are recommended.

Comments on techniques / methods:

- Detection limits should be given (with regard to size, concentration etc.)
- Certified methods may be required when regulatory authorities are asking for.
- Distinguish between online and off-line methods.
- Online methods for monitoring:
 - Process control, occupational health care, environmental monitoring
 - Online = 8000 hours a year
 - Online = fouling, varying background signal, cross-sensitivities, ...
 - Appropriate methods must be developed in big, international communities.

Future Needs:

- Research and development projects necessary:
 - New online techniques for nano dispersions
 - Environmental measurement techniques
 - Comparability of results from different techniques
 - Reference materials
 - International and inter-laboratory comparability
 - Novel techniques for assessing agglomeration
- Maximum output would be traceable, multidimensional online techniques.
 - But keep in mind: costs for industrial usage.

c) Agreed Future Directions and Activities

- Existing guidelines / classification schemes to be reviewed (e.g. by OECD)
- Further ENP characterisation projects (e.g. NanoDevice, http://www.safenano.org/SafeNanoFP7Proj_NanoDevice.aspx) to be taken into consideration.
- Workshop on “Instruments, standard methods and reference materials for traceable nanoparticle characterisation” to be held on April 28 & 29, 2010 in Nuremberg/DE

d) Publications

Prior to this meeting a discussion document ‘Engineered Nanoparticles: Nanometrology Status and Future Needs within Europe’ was published by the action group addressing the current status, future needs and opportunities in the field. This discussion paper is included at Appendix 1 of this document. Following feedback from the above meeting, and the broader stakeholder community, the document is being updated. Latest published versions of the paper may be accessed at: www.co-nanomet.eu/DiscussionPapers .

e) Further feedback

Following on from this meeting, further feedback has been taken in December 2009 from the Engineered Nanoparticles Action Group stakeholders in regard to the published discussion paper. Key comments are:

1. It covers most important topics and is very broad in its scope.
2. A key limitation in this nanometrology area remains the need for cheap, large quantities of test powders (kg) as soon as possible, even if not full reference powders. The timescale for producing standard references is too long for an efficient use of research power in the next 4 years where nanoparticle technology oriented projects are many.
3. To maximise the value derived from this group, following the initial review, a limited number (maximum 4) of specific short term goals should now be outlined and concentrated on. Otherwise it will remain very difficult to move forward in such a broad area.

Further feedback is welcomed to the author of this report.

f) Meeting Attendees

| Surname | First Name | Title | Organisation |
|-----------|------------|----------|---|
| Babick | Frank | Dr | TU Dresden, DE |
| Discherl | Kai | | Danish Fundamental Metrology Ltd, DK |
| Hagenhoff | Birgit | Dr. | Tascon GmbH, DE |
| Hasselov | Martin | Dr | University of Gothenburg, SE |
| Ho | Hsin-Chia | Ph.D. | Industrial Technology Research Inst., TW |
| Hoffmann | Erich | | BASF, SE |
| Horn | Hans-Georg | Dr.-Ing. | TSI GmbH, DE |
| Johnstone | James | Dr | NanoKTN c/o Centre for Process Innovation, UK |
| Krinke | Thomas | Dr.-Ing. | TSI GmbH, DE |
| Krumrey | Michael | Dr | PTB, DE |
| Lamberty | Andree | Dr | JRC-IRMM, BE |
| Ludwig | Frank | Dr | TU Braunschweig, DE |
| Miles | John | Dr | National Measurement Inst. Australia, AU |

| | | | |
|-------------|-----------|-----------|--|
| Mirande | Werner | | PTB, DE |
| Niewohner | Ludwig | Dr. | Bundeskriminalamt; KT, DE |
| Oesterle | Werner | Dr. | BAM, DE |
| Orts Gil | Guillermo | Dr. | BAM, DE |
| Put | Stijn | Dr | Umicore, BE |
| Rieseemeier | Heinrich | Dr. | BAM, DE |
| Roebben | Gert | Dr | Institute for Reference Materials and Measurements, BE |
| Ruijl | Theo | Dr Ir | FEI COMPANY, NL |
| Sachweh | Bernd | Prof. Dr. | BASF, SE |
| Stintz | Michael | PD Dr. | TU Dresden, DE |
| Wirtz | Klaus | Dr | Umweltbundesamt, DE |
| Lerche | Dietmar | Prof. Dr. | LUM GmbH, DE |
| Witt | Wolfgang | Dr | Sympatec GmbH, DE |

European Nanometrology Meeting Report

Action Group: Nanobiotechnology

Meeting Date: 20th November 2009

Meeting Venue: Physikalisch-Technische Bundesanstalt (PTB),
Braunschweig, Germany

Author:

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Action Group Aims:

The European Nanometrology Action Group in Nanobiotechnology addresses metrology needs and solutions to further the development of biomedicine and other areas related to bioscience and bio-technology, where the structures, chemical properties and biological activities of biomolecules are important. This is of particular importance for the pharmaceutical industry, health care applications such as imaging technology, clinical diagnostics, and medical devices (e.g. implants), as well as for food safety. Measurement challenges include the measurement of dimensions of biological structures, localization and measurement of relevant levels of biologically important substances such as drugs, biomarkers, and toxins, and the biological variability in the systems that are measured. The action group aims at providing an overview of the current metrological status in nanobiotechnology and the identification of current and future needs of industry and end-users.

Meeting Report

a) Items addressed:

This action group meeting was held in parallel with a European Nanometrology Workshop held at PTB, Braunschweig, 19th-20th Nov 2009. During the nanobiotechnology session of the workshop four presentations were given:

Jukka Lausmaa, SP Sweden and Co-Nanomet, gave an overview of the broad field of nanobiotechnology, and highlighted some characteristics and challenges within the field. He also discussed drivers for the field and gave examples of measurement needs within three main categories: analysis and diagnostics, localization and imaging, and interactions between biological entities.

Felix Kollmer, representing an instrument manufacturer, held a presentation about SIMS imaging at the nanoscale. He demonstrated how recently developed ion beam technologies can be used for achieving better efficiency and higher lateral resolution, which is needed for nano-analysis of biological surfaces. A number of biological/medical ToF-SIMS imaging applications were demonstrated. The importance of access to good reference materials in the technology development was emphasized together with a description of currently existing as well as needed reference materials.

Richard Moore, responsible for nanomedicine at the Institute for Nanomedicine, talked about “Emerging nanomedical applications and their metrology needs”. Both current applications and possible trends and timelines were presented. The area of nanomedicine has a very wide range of measurement needs, depending on the applications. Several such applications were mentioned, e.g. nanoparticles, nanoscale coatings, nanostructuring of implant surfaces, nanobiosensors, imaging, lab on a chip, regenerative medicine and novel medical devices. Highly important are safety issues (e.g. toxicology) and risk management. Currently there are no specific guidance documents on nanomedicinal products.

Hans Lingnert, research manager at the Swedish Institute for Food and Biotechnology, gave a talk about nanotechnology in food. Potential applications of nanoscience and technology in food are both as nanostructures in the food itself and in food contact materials. The most acute measurement requirements were identified as those needed to assess functional and safety properties. A challenge for the area are the consumer concerns.

The action group meeting, which followed after the presentations, addressed the following items:

- Scope of the discussion paper published by the Nanobiotechnology Action Group in Nov 2009, prior to this meeting
- Broad and interdisciplinary nature of the field
- Different needs for different user groups – the importance of identifying and categorizing these groups
- Lack of awareness of metrology aspects/needs among many nanobiotechnology users
- How to raise awareness of metrology aspects in the field
- Regulatory and toxicological aspects
- Reference samples

b) Summary of Discussions

The meeting started with a short presentation of all participants, including a brief description of their interest in the field of bionanometrology. Next, the discussion paper was briefly presented by Jukka Lausmaa, followed by a discussion about the metrology needs in the area of bionanotechnology. Generally the stakeholders were happy both with workshop presentations and the overview of the field presented in the discussion paper. The chosen definition of the term ‘nanbiotechnology’ was considered appropriate. Below is a summary of the most important issues discussed during the meeting:

The area of bionanotechnology covers a very broad range of technologies and applications. Europe has several strengths in this area, for example a modern health care system that is continuously incorporating new technologies, including nano-enabled ones. Also industrially, Europe holds a strong position with several market leaders in areas such as analytical instrumentation, pharmaceutical industry, and medical devices.

Regarding the scope of the discussion paper, there was agreement that due to the broad range of technologies and applications it would not be possible to describe the entire area in the discussion paper, but more appropriate to focus on a few selected topical areas. However, it is still important to specify what we do not consider to be included in the field or what is neglected. For example, many medical imaging technologies are not nanotechnologies per se, however, they are still considered through the novel use of nanoparticles as contrast agents. Because of the broad nature of the field, engagement with other nanometrology areas is advantageous, since there are strong overlaps in the technologies used.

It was agreed that is not necessary to have a too strict definition on what is nanometrology and what is not for the scope of the discussion paper, since many biological entities interact at length scales also outside the nanoscale, defined as <100 nm. However measurements at the nanoscale are required for comprehensive understanding to their behaviour.

It is also important to be aware of the fact that the industry and user groups in the area are not a homogeneous group. It is therefore appropriate to identify and categorize

them since different groups (such as medicine, biology, biotechnology, food) have different needs, e.g., the food area has a quite special situation with strong consumer concerns related to nanotechnologies. Further, some categories of users might not be aware of the metrology needs. It is important to ask for feedback from end-user groups, for example in the health care sector and biomedical research community, since their needs and opinions strongly influence the industrial activity.

Another point that was discussed was that a broader engagement with the bio- and medical communities is needed to raise the awareness of metrology. A strategy for this should be developed. For example, it would be good to liaise with the BIPM activities to connect with the medical community, and EURAMET for chemical measurements. It was also suggested to approach trade associations like EUCOMED (European Association for Medical Device Industries) and EDMA (European Diagnostic Manufacturers Association).

Regulatory and toxicology aspects are important. Current standards are not necessarily relevant for nano-enabled devices, and there is a strong need for standards in the bionanotechnology field. It is important to estimate the risks associated with nanotechnology, ultimately resulting in standards. For the purpose of the discussion paper, the recent work of OECD and ISO TC 229 on bionanometrology (mainly related to nanoparticles) should be reviewed. However, it was agreed on that the area of nanotoxicology was outside the scope of the discussion paper, but that bionanometrology still may help the toxicologists in their work.

The importance of good reference samples was pointed out. Good reference samples facilitate the work of nanotechnology based companies, who can focus on the core activities instead. Important drivers for reference samples will be the regulatory system. Although there was not general agreement, it was not considered essential that all reference materials should be traceable to the primary SI-normals.

Finally, everyone was encouraged to send stakeholder contacts for the workshop to be held by this action group in April.

c) Agreed Future Directions and Activities

- Identify and categorize different users of nanobiotechnology and their needs.
- Metrologists should aim for more close collaboration with the bio- and medical communities, as well as trade associations like ECOMED and EDMA.
- Broaden the contacts with stakeholders, in particular with regard to end users
- Provide input to and from the work on regulatory and toxicological aspects by e.g. ISO TC 229
- Update of discussion paper
- Co-Nanomet Nanobiotechnology ENAG workshop at NPL, UK April 13-14 2010.

d) Publications

Prior to this meeting, a discussion document 'European Nanometrology for Nanobiotechnology: Current Status and Future Challenges' was published by the action group addressing the current status, future needs and opportunities in the field. Following feedback from the above meeting, and the broader stakeholder community, this discussion paper has been updated and is published in Appendix 1 of this document. Further feedback is welcomed to the authors of this report.

e) Meeting Attendees

| | |
|------------------|--|
| Nils Anspach | DME Nanotechnologie GmbH, DE |
| Uwe Brand | PTB, DE |
| Emma Eriksson | SP Technical Research Institute of Sweden, SE |
| Poul Erik Hansen | Danish Fundamental Metrology Ltd, DK |
| Frank de Jong | FEI Company, NE |
| Karin Jungnikl | OAW, IT |
| Felix Kollmer | ION-TOF GmbH, DE |
| Jukka Lausmaa | SP Technical Research Institute of Sweden, SE |
| Hans Lingnert | SIK Swedish Institute for Food and Biotechnology, SE |
| Richard Moore | Institute of Nanotechnology, UK |

| | |
|-----------------|---|
| Leslie Pendrill | SP Technical Research Institute of Sweden, SE |
| Debdulal Roy | National Physical Laboratories UK |
| Alan Steele | National Research Council, CA |
| Gerhard Ulm | PTB, DE |
| Elwood Vogt | CEMMNT HUB LTD, UK |

European Nanometrology Meeting Report

Action Group: Thin Films and Structured Surfaces

Meeting Date: 20th November 2009

Meeting Venue: Physikalisch-Technische Bundesanstalt (PTB),
Braunschweig, Germany

Author:

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Action Group Aims:

This action group focuses on the measurement and characterisation of surfaces and layers/coatings that have features with sizes (lateral and depth) of 100 nm and less. This includes both topographic features, and structural and functional films. All essential material classes, layer systems and measurement techniques will be covered. Its aim is to raise awareness of current capabilities, emerging needs/developments and identify community issues relating to:

- Measurement technologies
- Instrumentation
- Standardisation requirements
- Traceability and equivalence
- Identification, development and implementation of tools for the assurance of measurement quality

Meeting Report

a) Items addressed

Discussion during the meeting was focussed first on a number of specific thin film related topics detailed below in Fig 1. Following this some further general nanometrology related issues were covered.

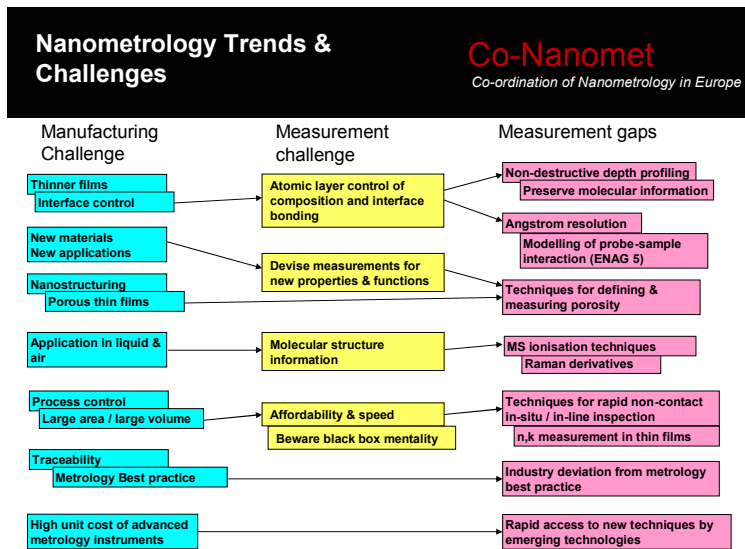


Figure 1: Specific thin film related topics covered by meeting

The topics detailed in Figure 1 are derived from the discussion paper ‘Measurement of Thin Film Thickness & Other Parameters: Nanometrology Status and Future Needs within Europe’, published by the action group in November 2009 and circulated to the attendees prior to this meeting.

The meeting addressed the industrial importance, measurement gaps or challenges and possible solutions for a series of thin film specific areas, followed by a number of general nanometrology aspects. Topics included:

Applications for special types of thin films

- Thin functional organic films – surface monolayer; multilayer
- Porous films with pore size or nanoparticles in the 2 to 200 nm range

Measurement techniques

- Rapid non-destructive measurements of thin film thickness
- TEM for thin film thickness measurements
- New or improved high resolution techniques
- 3D imaging of nanostructures

- High capital cost of advanced nanometrology instruments
- Advances in / novel measurement techniques
- Calibration of instruments, traceability of measurements, transfer artefacts
- Standardisation
- Establishing take-up of best metrology practice in industry

b) Summary of Discussions

A summary of the discussion outcomes is detailed below in Tables 1 and 2.

Table 1: Discussion Summary - Thin Film Specific Topics

| Topic area | Industrial importance | Challenge / Gap | Proposed solutions |
|--|--|--|---|
| Thin functional organic films – surface monolayer | Anti-stiction films (eg MEMS); Low-friction films Biofluidic chips; surface for cell adhesion & biocompatibility (combined with surface texture) | Surface molecular characterisation is well-advanced using vacuum techniques eg TOF-SIMS, but some applications (eg bio-related) require structure determination in a liquid environment. Spatial resolution also useful. | |
| Thin functional organic films - multilayers | OLEDs; Structures for organic solar cells; Polymer surface treatments & coatings | Preserving molecular information whilst depth profiling (elemental depth profiling already available). Spatial resolution also desirable. | Advances in TOF-SIMS including cluster ion sources. |
| Porous films | Films with pore sizes or nanoparticles in the 2-200nm size range. Total thickness of film (or free-standing membrane) can be from nm | 1. Measurement of surface area & pore sizes: standardisation to traditional BET & other bulk sorption methods (which can't easily be applied to thin film material). | 1. Development of promising techniques (such as spectroscopic ellipsometry, ion scattering, NMR) to solve these problems. Needs comparison with bulk methods on specially |

| | | | |
|--|--|--|--|
| upwards, to tens of microns. | microbatteries (mostly as membranes) | 2. How to describe porous structures – what are the key parameters? (expected to be application dependent) | designed samples. 2. Define 3D measurement parameters relevant to porous structures & their applications |
| Rapid non-destructive measurements of film thickness & other parameters | Most high volume industries where thin films are important, for example: 1. Optical surfaces 2. Displays 3. Photovoltaics | Non-destructive & non-invasive techniques suitable for rapid large area inspection. For some applications, surfaces may be non-flat or non-homogeneous. | Optical techniques particularly attractive. White-light microinterferometry & spectroscopic ellipsometry provide solutions. Need refractive index determination. |
| TEM for thin film thickness measurement | TEM is a core tool for all nanotechnologies | CCQM Pilot Study P38 outcome showed discrepancy in SiO ₂ /Si TEM thickness measurement compared with other methods. As TEM is sometimes the only method available for certain nano-dimensional measurements it seems important to resolve this. | Study (possibly a limited inter-laboratory comparison) examining the possible contributing factors: statistical effects, preparation effects, strain & damage effects, contrast effects (contrast modelling required here), material effects (eg nanoparticles vs thin films). |

Table 2: Discussion Summary – General Nanometrology Topics

| Topic area | Industrial importance | Challenge / Gap | Proposed solutions |
|---|-----------------------|--|---|
| New or improved high resolution techniques | All nanotechnologies | Techniques to give better resolution, better contrast, better elemental & molecular analysis information | 1. Development needed of He Ion Microscopy techniques & applications. 2. Simulation of probe-sample interaction & contrast to assist measurement at highest resolutions. |

| | | | |
|--|----------------------|---|--|
| 3D imaging of nanostructures | All nanotechnologies | 1. 3D nano-topographic measurement status & gaps: XCT resolution too poor; TEM tomography v. slow; automated FIB-SEM slow & destructive; SEM images show qualitative 3D information which can't easily be quantified 2. What measurement parameters should be defined & extracted from 3D image data? | 1. Improved nano-tomography / holography techniques (incl automation) are required 2. Develop improved methods for extraction of 3D information from SEM images of nano-features. 3. Define 3D parameters relevant to structures & applications, and protocols for their determination from 3D images. |
| High capital cost of advanced nanometrology instruments | All nanotechnologies | Important advances are being made in ease of use, automation & sensitivity. These increase measurement speed & throughput, & lower the cost per measurement. However, nano-technologies may demand more measurements per sample for statistical reasons. This leaves a gap in the access to the advances in instrumentation by emerging technology companies. | Suggest re-introduction of scheme whereby instruments can be placed at industrial node sites to allow open access evaluation by industry. Benefits instrument manufacturer, industry node (otherwise not able to afford the equipment) and the wider access users (e.g. EC Semiconductor Equipment Assessment scheme (SEA)). |
| Standards | All nanotechnologies | More physical standards requested | More relevant structures could be considered, e.g. multilayers |

| | | | |
|--|----------------------|--|--|
| Establishing take-up of best metrology practice in industry | All nanotechnologies | Gap between measurement methods as actually applied in practice (eg in industry) and internationally agreed standards. | Broadened measurement round-robins, organised by NMIs but including industry partners. Industry should be funded to take part to ensure that this is allocated priority. |
|--|----------------------|--|--|

c) Conclusions

The meeting concluded that:

- World-leading manufacturers of nanometrology equipment are strongly represented within the EC (see Table 3 below). Europe is thus well positioned to offer solutions to many of the measurement challenges identified in the areas of thin film measurement as well as in general nanometrology.

Table 3: European Nanometrology Equipment Manufacturers Capabilities

| Nanometrology topic area | Advanced nanometrology techniques offered by European manufacturers |
|--|--|
| Molecular information | TOF-SIMS; Raman |
| Optical techniques for rapid non-destructive measurement | SE; Interferometry |
| Porous films | SE; MEIS / LEIS |
| High resolution imaging techniques | SEM, TEM, FIB, He Ion Microscopy |
| Mechanical properties | AFM; Nanoindentation |
| Non-destructive depth profiling | MEIS; LEIS |

- EC funding would be highly beneficial to accelerate the technique developments needed, as well as to facilitate the introduction, take-up and application of these advances at the earliest opportunity by European industry (especially by emerging technology companies). This would provide a mechanism for positive economic feedback. Firstly this would promote

growth of European nanotechnology-related manufacturing industry. European nanometrology companies would then benefit from international growth of this market sector. Funding could encompass new ways of collaborative working in order to surmount barriers associated with the very high capital cost of advanced nanometrology instrumentation (the Semiconductor Equipment Assessment scheme is proposed as a model for this).

- To ensure industry take-up of best metrology practice as developed and defined within NMIs, funding for industry to participate directly in working with NMIs may be of benefit.

d) Agreed Future Directions and Activities

A list of additional topics highlighted but without time for discussion was also captured which included:

- Stability & lifetime of materials
- Mechanical measurements

These topics will be incorporated into future activity of the action group.

Some topics were necessarily covered in more depth than others. The group wished to develop these by circulation after the meeting.

e) Publications

Prior to this meeting a discussion document '*Measurement of Thin Film Thickness & Other Parameters: Nanometrology Status and Future Needs Within Europe*' was published addressing the current status, future needs and opportunities in the field. This discussion paper is included at Appendix 1 of this document. Following feedback from the above meeting, and the broader stakeholder community, the document is being updated. Latest published versions of the paper may be accessed at: www.co-nanomet.eu/DiscussionPapers.

Further feedback is welcomed to the author(s) of this report.

f) Meeting Attendees

| Surname | First Name | Title | Organisation |
|----------------|-------------------|--------------|---------------------------|
| Conroy | Mike | Dr | Taylor Hobson Ltd, UK |
| Damiao | Alvaro | Dr | IEAv-CTA, Brazil |
| de Jong* | Frank | Dr | FEI, Eindhoven, NL |
| Depero* | Laura | Prof | Uni of Brescia /INSTM, IT |
| Fowler | Chantal | Mrs | STFC Harwell, UK |
| Gee | Mark | Dr | National Physical Lab, UK |
| Koenders* | Ludger | Dr | PTB, Braunschweig, DE |
| Niehuis | Ewald | Dr. | ION-TOF GmbH, DE |
| Pidduck | Allan | Dr. | QinetiQ, Malvern, UK |
| Stehle | Jean-Louis | Dr | Sopralab, Paris, FR |
| Unger | Wolfgang | Dipl.- | BAM, Berlin, DE |
| van Veghel | Marijn | Dr. | VSL, Delft, NL |

* not present at the meeting but requested inclusion in the group

European Nanometrology Meeting Report

Action Group: Critical Dimension and Scanning Probe Techniques

Meeting Date: 20th November 2009

Meeting Venue: Physikalisch-Technische Bundesanstalt (PTB),
Braunschweig, Germany

Author:

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Action Group Aims:

European Nanometrology Action Groups (ENAG's) have been established under the Co-Nanomet programme focussing on a set of core technology fields (Engineered Nanoparticles, Nanobiotechnology, Thin Films and Structured Surfaces, Critical Dimension and Scanning Probe Techniques, as well as Modelling and Simulation). Each action group addresses the process chain for dissemination of metrology techniques as well as traceability to national standards and internationally harmonised methods.

This action group will ensure effective and well organised pan European nanometrology in the area of critical dimension and scanning electron/probe techniques. The topics to be addressed are:

- Critical Dimensions- measurements and limits.
- Scanning electron/probe microscopy used for other tasks in dimensional nanometrology.
- Transfer of critical dimension measurements to other applications (for example: nanoparticles, length of nanotubes).
- Calibration of instruments, guidelines, written and artificial standards, traceability and uncertainty.
- Modelling and simulation, in particular to take into account the interaction between probes and surfaces.

Meeting Report

a) Items Addressed

In parallel with the European Nanotechnology Workshop held by Co-Nanomet at PTB in Nov. 2009, a meeting of the "European Nanometrology Action Group on Critical Dimension and Scanning Probe Techniques" was held. The meeting discussion covered: instrument development (3D-AFM, large sample SPM, ...), measurement strategies (combining multi-sensor information,...), novel probes incl. their characterization as well as standards and calibration.

b) Summary of Discussions

In the following, the trends and directions which emerged from the meeting are summarized. It is worth pointing out that users as well as manufacturers actively contributed to the discussion.

Probe development & characterization:

- Development of special probes for 3D AFM is required
- Probe characterization is of highest relevance in semiconductor industry
- Different methods for probe characterization are in use: SEM, direct imaging of test structures, blind reconstruction
- Using SEM: better SEM calibration required, better understanding of SEM image formation required
- Using test samples: better understanding of probe-sample interaction required

Instrument development & measurement strategies:

- Gap between micro- and nano-measuring methods still not closed
- Large area scans demanded: intelligent multi-sensor strategies needed, as SPM not ideal to scan large surfaces (tip wear, time,...)
- Except for some few special realizations, SPM still 2½D, but 3D urgently needed (sidewalls e. g. of MEMS/NEMS, micro-bores, contour scans of micro/nano-objects, surface of micro/nano-wires, etc.)
- Depending on application, combinations with other measurement techniques are needed (with optical microscopy, scatterometry, CMM, profilometry, SEM, etc.)
- 3D SPM as well as other special SPM modes may require novel probe concepts
- Intelligent measurement strategies needed: localization of regions of interest (manual selection, automated based on criteria); procedures to estimate the minimum number of data points needed for a certain task; data fusion, documentation and visualization of data obtained by different methods/on different scales

Standards & Calibration:

- SPM manufacturers typically calibrate their systems before/upon delivery to the customer, usually provide some (cheaper) standards/reference samples to the customer with the instrument
- Some (basic) calibration procedures are described in manuals
- Few users attach great importance to calibration (e.g. semiconductor industry), while large majority of users cares rather little about calibration (particularly in academia), do not have routine recalibration schedules, etc.
- Transfer standards often not used correctly: handling and application instructions needed
- Documentary standards and guidelines such as VDI/VDE 2656 – Part 1 hardly known among users: more communication and education might be needed to increase awareness of calibration issues and give users practical advice (best practice) especially for quality management and uncertainty determination
- Increasing demand for topography-free resolution standards for modes such as SNOM, MFM, KPM, etc.
- Cheap “golden standard” for everyday verification desirable (this is more realistic in semiconductor industry than in nanotechnology (NT) due to the large variety of materials involved in NT)

c) Agreed Future Directions and Activities

Next open workshop will be held by the action group: end of October 2010 in Brno, Czech Republic, in conjunction with NanoScale 2010 (Oct 27th-29th, 2010) – for additional information see: www.nanoscale.de.

d) Publications

Prior to this meeting a discussion document ‘Scanning Probe Microscopy, Scanning Electron Microscopy and Critical Dimension: Nanometrology Status and Future Needs within Europe’ was published addressing the current status, future needs and opportunities in the field. Following feedback from the above meeting, and the broader stakeholder community, the document has been updated and is included at Appendix 1 of this document. Further feedback is welcomed by the authors of this report.

e) Meeting Attendees

| Surname | First Name | Title | Organisation |
|-------------|-------------|------------|---|
| Africh | Cristina | Dr. | CNR-INFN TASC National Laboratory, IT |
| Asar | Muharrem | Dr. | TUBITAK, TR |
| Besmens | Peter | Mr. | Nanoworld Services GmbH, DE |
| Borgardt | Nikolai | Prof | Moscow Institute of Electronic Technology, RU |
| Bosse | Harald | Dr | PTB, DE |
| Chen | Xiaomei | | PTB, DE |
| Ciancio | Regina | Dr | CNR-INFN TASC National Laboratory, IT |
| Damiao | Alvaro | Dr | IEAv-CTA, BR |
| Dai | Gaoliang | Dr. | PTB, DE |
| Danzebrink | Hans-Ulrich | Dr. | PTB, DE |
| Dziomba | Thorsten | | PTB, DE |
| Fluegge | Jens | Dr | PTB, DE |
| Foucher | Johann | Dr | CEA/LETI, FR |
| Fuss | Hans-Achim | Dr. | Bruker nano, DE |
| Golubev | Sergey | Mr | FGUP VNIIMS, RU |
| Hemmler | Matthias | Dr.-Ing. | m2c GbR, DE |
| Hitzel | Frank | Dr. | DME Nanotechnologie GmbH, DE |
| Johnsen | Klaus-Peter | Dr. | PTB, DE |
| Kehoe | Timothy | Dr | Catalan Institute of Nanotechnology, ES |
| Koenders | Ludger | Dr | PTB, DE |
| Korpelainen | Virpi | | MIKES, FI |
| Kunz | Ernst | Mr. | Kunz-precision AG, CH |
| Leach | Richard | Prof. | National Physical Laboratory, UK |
| Liebrich | Thomas | M.Sc. | inspire, ETH Zurich, CH |
| Mei | Dongbin | Eng. | Academy of Opto-electronics, CAS, CN |
| Meli | Felix | Dr | Swiss Federal Office of Metrology, CH |
| Meyer | Maik | Dipl.-Ing. | AMETEK GmbH, GB Taylor Hobson, DE |
| Niehuis | Ewald | Dr. | ION-TOF GmbH, DE |
| Noli | Werner | Dr. | Plano GmbH, DE |

| | | | |
|---------|-------------|------------|---|
| Petry | Jasmine | Dr. | SPF Economie - Metrologie Scientifique, BE |
| Picotto | Gianbartolo | Dr | INRIM Istituto Nazionale di Ricerca Metrologia, IT |
| Piot | Jan | | KULeuven, BE |
| Prieto | Emilio | Dr. | Centro Espanol de Metrologia (CEM), ES |
| Revtova | Elena A. | Dr. | VSL, NL |
| Rohn | Michael | Dipl.-Ing. | Profactor GmbH, AT |
| Schade | Sebastian | | nanotools GmbH, DE |
| Spaan | Henny | Dr | IBS Precision Engineering B.V., NL |
| Viallon | Joele | Dr | BIPM, FR |
| Zhou | Weihu | Prof. | Academy of Opto-electronics ,Chinese Academy of Science, CN |

f) Further minutes of the discussion and meeting

LK gave a short introduction to the subject area.

HD gave an overview of the topics to be discussed.

HD: Starting with the general topic "calibration procedure". Do the instrument manufacturers and users use the VDI/VDE 2656 guide for calibration? Do they have/provide calibration procedures?

Several manufacturers: Calibration usually according to manual, so far no reference to VDI/VDE 2656.

LK: Is calibration of different AFM modes, e.g. contact, tapping, required?

FH: yes, but the users are either not interested or not aware of the importance.

RL: Need for good practice guidance and education: instructions need to be short and precise

HD: How often do users calibrate?

JF: High demands for calibration in semiconductor industry, e. g. at CEA-LETI 3D AFM calibrated every day for 1 hour – automatic routine using three VLSI standards of nominal CD 25 nm to 70 nm. Calibration of tip-shape decisive in this business, need precise vertical structures. But different modes (e.g. CD or DT) need different samples.

WN: Most users only calibrate because of their QS, majority of other users have calibration samples, but hardly use them at all unless they run into trouble.

HB: Do they use different calibration for different materials, e. g. for resist structures and silicon surfaces?

JF: Yes, very important.

FH: DME performs factory test of new systems, calibrates them and issues a certificate on the calibration. Software reinstallation equals axes calibration parameters (Cx, Cy, Cz) to (1,1,1) to motivate users to perform calibration. There are 2 types of users, those that want to calibrate and those that do not and may thus accept errors of 20 % – application dependent.

HD: Users believe the specifications given by the manufacturers... and too often the numbers on the screen...

EP: Some users do not have to care about calibration (mainly academics), use SPM mainly qualitatively. NanoSPAIN tries to make people more aware of calibration issues, provides help

WN: When installing, engineers much prefer not to have to calibrate (too much work, too time-consuming, effort might not be understood by the user).

LK: Do manufacturers check the stability of the instruments over time?
FH: No, only linearity is important to most users.

HD: Which transfer standards do the manufacturers or their users use to calibrate their SPMs?
Several attendees: pitch and step height standards, e. g. TGZ (HF),

JF: 3 x VLSI step height standards 10 nm to 1 µm, 3 x CD, 3 x periodic.
Several manufacturers: test samples such as TGZ provided upon instrument delivery

HF: Use their own calibration samples.

FH: Sample handling identified as critical (contamination, application procedure)

TD: VDI/VDE 2656 gives advise on how to select standards and how to handle them to avoid contamination and ensure uniform application procedures

HD: What are the problems arising from the use of existing SPM standards?
Several attendees: Analysis of measurement critical among users, e. g. many users still simply click into one profile recorded over a step for step height analysis instead of applying more global analysis such as histogram method or ISO 5436-1 as described in VDI/VDE 2656.

HB: Are they satisfied with the samples? Sufficient traceability?

JF: They are too expensive (refers to their VLSI standards).

HB: Would the users like a “golden wafer” with all the relevant structures on one wafer?

JF: Yes, mounted inside the AFM. Especially useful for daily checks. Should therefore be cheap, as it contaminates/wears quickly due to frequent use and may need to be exchanged against a new one every two weeks, e. g. 200 €/each.

TD: Are standards for different special SPM types required, e.g, SNOM, KPM, MFM?

FH: SNOM and KPM resolution is a problem – need appropriate samples: good contrast in SNOM, KPM, etc. while being topographically flat.

LK: Can use BAM stripe sample for KPM and some other special modes (has been tested for KPM by T. Machleidt, Technical University of Ilmenau).
TD: ISO/TC 201/SC 9 works on documentary standards for these special SPM modes, but sometimes proposes only one specific kind of standard for that purpose. This issue may therefore deserve more attention in future.

LK: How do users calibrate CNT probes?

PB: Using SEM.

SS: Compare with data from customers and SEM/TEM images
Others: fusion of information from different methods might be difficult due to different interactions, resolutions, etc.

HD: What types of tip characterisers are used?

SS: Golden wafer from RC2 as tip characterizer (This is one sample taken out of the process which is used again and again for reference, i. e. this sample is not generally available).

JF: Tip diameter from SEM, but with low accuracy. CD-SEM calibration is via pitch artefacts but not for CD, therefore uncertainties of up to 10 nm. Demand for CD-SEM standards to allow for reproducible and standardized characterization of tips. Which algorithms to be used? How to get realizable values?
Furthermore: No standards for scatterometry available, but needed.

Further comments: SiO₂ challenge on many standards, CD-SEM can probably not be calibrated by just one standard... therefore many standards needed... or one “golden standard”...

HS: Need to consider 3D measurements in more depth, scope should be widened from traditional SPM-view to broader scope, meet with top-down strategies of

other measurement techniques: There is a gap somewhere in micro-nano measurement techniques, e. g. when it comes to characterize roughness, haptics, etc. – there is a large market to fill this gap.

RL: should address areal measurement and aim to fill the gap between AFM and micro-CMMs.

HD: gap between SPM and methods at larger scales: striking difference are the forces involved (high lateral resolution results in high surface pressure)

RL: AFM does not provide real isotropic 3D probing (unlike CMM), may need to develop in this direction e. g. like G. Dai with his probing techniques.

LK: Do we need to extend the scanning range and speed? Do we need specialized probes for larger dimensions / higher scan rates? We certainly need real 3D standards.

FH: AFM is always high resolution, so speed will always be an issue. Compared to SEM operating over a large dynamic range of scales, AFM scan range rather limited, and if larger scans possible, the AFM tip still needs to trace the surface precisely in order to avoid tip damage.

GP: AFM is 2½D. Would there be a market for 3D nano instrument?

HD: Yes, e. g. coatings on surfaces, roughness of sidewalls, microholes, etc.

RL: Yes, a big one including MEMS and NEMS.

JF: Yes, SEM is a start (for some applications) but does not have the accuracy. Could one make a true 3D AFM?

HS: Yes, e.g. form of small wires.

JF: Yes, true 3D-AFM has a market, but what about the accuracy of such measurements? One task: contour scans around an object urgently needed e. g. for MEMS, in semiconductor industry, for the characterization of micro- and nanowires

RL: Probably this 3D-probing does not work with cantilevers, alternative probe concepts needed.

LK: At least tilting AFM exists to measure e. g. at sidewalls. Interaction deserves attention especially when expanding to 3D: e. g. influence of water layers

HD: combination of methods required to cover different scales and to understand probe sample interactions

RL: Intelligent sampling strategies required.

HD: merge different methods to fill the gap, 3D measurement strategies needed, special software, clever ways to define the regions where to zoom in.

GP: Hybrid is the way to go to be able to follow/locate features.

HS: There is a market – and much money to be made!

GP: Combination of AFM and optical microscopy, or SEM and AFM

LK: Combination of AFM with CMM and SEM?

HF: No demand so far.

RL: Minimum number of data points to get desired information?

FH: DME has system with optical microscope, user can mark 20 points in optical image which are subsequently scanned by AFM. Much potential and market chances in further combinations.

...unfortunately the discussion had to be stopped due to time constraints

LK summed up the meeting.

European Nanometrology Meeting Report

Action Group: Modelling & Simulation

Meeting Date: 20th November 2009

Meeting Venue: Physikalisch-Technische Bundesanstalt (PTB),
Braunschweig, Germany

Author:

Prof. Dr. Ana Proykova
University of Sofia, BG

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Action Group Aims:

The aims of this action group are to consolidate European efforts in modelling and simulation of nanoscale materials and structures that take into account fabrication and integration processes, production equipment and characterisation of instrumentation. The meetings of the action group, including virtual web- and tele-conferences, will consolidate the stakeholders

1. to account for real requirements driven by industrial applications
2. to address modelling techniques for probing porous materials
3. to monitor the state-of-the art in modelling of AFM behaviour in nanoscale measurements
4. to address multi-scale modelling

Meeting Report

a) Items addressed

The purpose of the meeting was to stimulate debate and obtain feedback on the current status, future needs and opportunities for modelling and simulations in nanometrology. Items addressed:

- Modelling technologies widely used in nanometrology
- Software available
- Modelling and simulation requirements
- Sustainable computations – possibility to include the temperature dependence in the computer codes, which mostly consider the zero temperature of the environment only
- Identification, development and implementation of modeling techniques in Nanometrology

Modelling technologies widely used in nanometrology

The following widely used modelling techniques have been considered by the action group:

i) Modelling related to nanoparticle properties:

Modelling efforts include large-scale finite element methods, multiscale Green's function methods, classical atomistic simulations (special purpose Monte Carlo Methods, Molecular Dynamics), *ab initio* quantum mechanical calculations, spin

or/and time-dependent density functional theory, to mention the most frequently used techniques.

ii) Computational methods to reconstruct the original images obtained with:

- Electron microscopy: Scanning Electron Microscopy - SEM, Transmission Electron Microscopy - TEM, Low Energy Electron Microscopy – LEEM
- X-ray and neutron scattering
- light (IR, Raman, FT-IR) spectroscopy and light diffraction (inverse problem in scatterometry)
- near edge X-ray absorption fine-structure spectroscopy (NEXFAS).

b) Summary of Discussions

The following suggestions, comments, and questions have been raised during the meeting:

- Needs for communication protocol between measurement equipment and calculations of the final result.

Example: Diverse measurements of flow properties, nanometer-scale diameter of particles, surface area reactivity, agglomeration ability; resulting measurements indicating a potential toxicity. Should modelling be mandatory on all issues?

- Modelling of the measurement results should estimate the particle diameter using different methods consistent within the range of 10 nm.
- Coupling different-scale models like DFT and Monte Carlo with macroscale modelling like CDF or standard FEM: take the relevant output from quantum modelling and feed it into continuum modelling
- A better use in academia of modelling tools that are already used in industry such as those given in the list below
- Europe is leading in modelling software development in academia perhaps due to education focused on theory. However, many companies

commercialising modelling software are based in the US and thus Europe does not benefit enough in commercialisation.

Example: ACCELRY'S doing quantum and electrical modelling is largest in this field

- Modelling is becoming a more predominant need but manufactures of measurement equipment do not typically integrate the necessary modelling.
- There are many good equipment manufactures in Europe. Specific coordination action or a project should bring modelling people and equipment manufactures together. Limitations due to computational resources will be overcome in the next years with GRID and HPC platforms but those due to inherent difficulties at the nanoscale will need special research.

Example: Many measurements in biology are too complicated and understanding the output requires modelling.

The following list of software developers and nanomaterial producers has been generated prior the European Nanometrology Workshop in November 2009 (PTB, Germany) and distributed to the registered participants. The aim has been to match the demands and competences of both groups.

Software developers:

Process Systems Enterprise Limited (PSE) is a provider of advanced modelling technology and model-based services to the process industries and their technology suppliers: <http://www.psenderprise.com/company/index.html>

Materials Studio® is a software environment that brings the world's most advanced and validated materials simulation technology to desktop computing, solving key problems throughout the R&D process. Offering advanced visualization tools and access to the complete range of computational materials science methods, Materials Studio is designed for structural and computational researchers in chemicals and materials R&D who need to perform expert-level modelling and simulations tasks in an easy-to-learn yet powerful environment.

<http://accelrys.com/products/materials-studio/#>

Rensselaer focuses on automated adaptive modeling and computation, has built a \$100 million supercomputer as part of the Computational Center for Nanotechnology Innovation (CCNI). It was recently ranked seventh in the world, and it's the most powerful of any system based exclusively at a university. In the CCNI, Rensselaer is developing simulation technologies for the latest generation of high-performance computing equipment, creating advanced simulations and models for nanoelectronic devices and circuitry, and seeking to understand how proteins, DNA, and other biological systems behave at the molecular level. Unprecedented computing power is making it possible to model entire systems, taking into account interactions at almost every scale.

<http://www.rpi.edu/research/computation/index.html>

The Centre for Nano-Device Modelling at the University of Leeds coordinates the work of nanotechnology device modelling within the University. It is currently supported principally by the Department of Applied Mathematics, the School of Electronic and Electrical Engineering, the Department of Physics and Astronomy, and the Centre for Self-organising Molecular Systems (SOMS). Its first Director is Dr E A B Cole of the Department of Applied Mathematics.

<http://www.maths.leeds.ac.uk/cndm/>

"Modelling for Nanotechnology" (M4nano) is a WEB-based initiative led by four Spanish Institutions: Phantoms Foundation, Parque Científico de Madrid (PCM), Universidad Autónoma de Madrid (UAM) and Universidad Complutense to maintain a systematic flow of information among research groups and therefore avoid that research efforts in Nanomodelling remain fragmented.

http://www.m4nano.com/m4nanoc_m4/index.php

EECS research and academic programs seek to develop improved methods of nanoscale simulation and modelling, including *ab initio* calculations.

<http://www.eecs.mit.edu/nanoeecs/nanoscale.html>

'Nanoproduct' Manufacturers

After more than twenty years of basic and applied research, nanotechnologies are gaining in commercial use. Nanoscale materials now are in electronic, cosmetics,

automotive and medical products. But it has been difficult to find out how many "nano" consumer products are on the market and which merchandise could be called "nano" and what standards should the products meet.

While not comprehensive, this inventory of nanotechnology-based consumer products currently on the market gives the public the best available look at the 1,000+ manufacturer-identified nanotechnology-based consumer products currently available:

<http://www.nanotechproject.org/inventories/consumer/>

Nanotechnology Concept is a site where one can learn about and buy the nanotechnology related products. It has a growing product base and present many new products for all industries. All products are the result of breakthroughs in research on the nano-level.

<http://www.nanoconcept.no/>

Nanoproduct Manufacturers: do they need Modelling and Simulations?

A number of nanoproduct manufacturers have been contacted by the action group to understand their needs for modelling and simulation. Most of the respondents did not discuss metrological aspects at all.

Bonderite NT is a flurozirconic-based chemistry that provides a "nanoceramic" coating on clean metal substrates.

<http://www.bonderitent.com/eng/index.html>

The new type of MINOTEC multicoating, which is a nanotechnology application, helps to repel dust, water and soiling from the external glass surfaces. Pin-sharp optics with natural color rendition puts the new APO-HG binoculars from MINOX in a class of their own and first in the top league. The APO-HG 8.5x43 BR and the APO-HG 10x43 BR models impressively represent the latest technologies in binocular design. Featuring SCHOTT fluoride ED-glass lens elements these apochromatically-corrected binoculars deliver a brilliant color-fringe-free image.

<http://www.minox.com/index.php?id=3520&L=1&O=>

The product micelle is proving to be an optimum carrier system of hydrophobic substances for a higher and faster intestinal and dermal resorption and penetration of active ingredients. The product micelle is stable with respect to pH and temperature and has a diameter of approximately 30 nm. Here, where microemulsions and liposomes prove to be problematical and unsuitable, the product micelle represents the optimum solution in the fields of foodstuffs (functional food), cosmetics, pharmaceuticals and biotechnology (nutritional solutions for cell and bacterial cultures). The 100% watersoluble micelle can be integrated directly and independently of recipe characteristics into final products in the quoted fields.

<http://www.aquanova.de/index.php?site=index.html&dir=&nav=53>

Black Chili is the name for a new compound containing carbon nano particles for road & MTB race tyres. Each particle of the filler agent (carbon) is only 1/10th of the size of standard carbon black particles.

http://www.conti-tyres.co.uk/conticycle/news_int_4.shtml

NANO-TEX fabric technology derives from a naturally occurring phenomenon. The surface of certain plants incorporates a "self-cleaning effect", where water droplets simply bead up and roll off the plant and dirt and grease do not adhere to it. This effect, which is based on a structural anomaly at the nano, or sub-micron, level is applied to fibre technology to produce a similar repellent effect. NANO-TEX fabric technology allows the enhancement to permanently attach to the fibre at the molecular level to produce a structural change in the fibres of the fabric that renders it outstandingly and durably resistant to water, grease and dirt without adversely affecting the specific properties of the material, such as breathability, high abrasion resistance, soft hand or textured surface. These functions are retained in full and do not diminish with wear or washing.

http://www.jack-wolfskin.com/en/desktopdefault.aspx/tabid-104/96_read-217/

Finy glass and ceramic sealing consists of Nano particles with components associated with the solid surface and other components that repel dirt ed. These particles arrange themselves with the application automatically, the binding components to the surface, the push component focus outwards. The solution brings an invisible ultra-thin film layer on the surface.

<http://www.finy.nl/>

Geohumus is a patented water storing granulate, based on super absorbent nanotechnology. This new hybrid material combines volcanic rock material with super absorbent qualities.

<http://www.geohumus.com/>

Strong racquets are made with HEAD's innovative Nano technology. Equipped with the flat Top Cap, these racquets offer additional excellent hold and optimal grip control.

http://www.head.com/badminton/racquets.php?region=eu&tag=nano_pct

Herbol-Symbiotec, a genuine nano facade coating, is the result of many years of development collaboration between Akzo Nobel and BASF.

<http://www.herbol.de/produkte/symbiotec.htm>

Leveraging new innovations from the plastics industry, ADIDAS applied materials only previously used in the automotive and aerospace industries to design a carbon nanotubes reinforced full-length plate (nanoplate). This thinner and stronger one piece, full-length plate provides Wariner more stability, comfort, better torsion, safety and increased flexibility while minimizing the energy loss.

http://www.press.adidas.com/en/DesktopDefault.aspx/tabid-11/16_read-9399/

Anti-mist treatment for all glass, ceramic and plastic surfaces, including visors and goggles. EffectClear improved cleaning effect by the Nano particles. Clean using only with water, no cleaning agents necessary. Long effective duration, simple to use and higher „lotus-effect“.

<http://www.kleinmann.net/pages/en/products/best-protect/automotive/nano-anti-mist.php?lang=EN>

Functional coatings tailored to all types of requirements are being developed with the application of chemical nanotechnology. This facilitates completely new product properties, which can be used for any industrial application. "Intelligent", environmentally-friendly and cost-effective solutions are aimed at securing competitive

advantages. **Properties:** long lasting activation, flexible in terms of different shapes of the substrates. **Applications:** PE, PA, PP, PMMA, PVC, ABS, PEEK, POM, epoxides, rubber.

http://www.starnberger.de/en/kat/uid_kategorien/0000134/id_matchcode/nanofinish_chapter/bop/0/chksum/13a5c12d52959f5851a71a71294935b1/beetools.html

At present nanogate is "on top" in three hi-tech application areas: permanent non-stick coatings on glass, ceramics, metals or polymers, non-scratch systems for plastics and in anti-corrosion systems for light metals.

<http://www.nanogate.de/en/>

'Percenta Nano Multi Foam Antibacterial' is a cleaning and sealing foam based on nanotechnology. It quickly cleans and preserves almost all kinds of surfaces.

<http://en.percenta.com/nanotechnology-multi-foam.php>

Nanofibrils are the key to the performance possibilities of TENCEL®. The unique technology of nanofibrils allows the production of textiles, which, until now, could only be dreamed of. This is the first cellulose fiber to use this nano technology. Controlled and regular arrangement of nanofibrils in the TENCEL® fiber leads to new functional properties. The nanofibrils are hydrophilic and optimize absorption of moisture with excellent cooling properties

<http://www.tencel.at/index.php?id=80&L=1>

An interdisciplinary team of researchers from SusTech Darmstadt and Henkel has successfully developed a nanotechnology based material Nanit@active and its oral care products.

This innovative new substance is composed of calcium phosphate nanoparticles (apatite) and protein – the same components as found in natural teeth. Nanit@active owes its unusual properties to the size of its nanoparticles and its special composite structure. It is therefore eminently suitable for dental applications.

<http://www.nanit-active.com/forschung.html>

SCF is playing an active part in the research done in the areas of Energy and Advanced Materials. We are pleased to contribute knowledge and to collaborate in several officially approved and funded research projects. Research projects are typically long term and strategic in nature in which complementary and new knowledge both support SCF's existing business areas and permit testing and maturation of new ideas. These projects also give us access to basic science and advanced analytical and characterizing techniques. Especially with respect to our most important technological applications, Advanced Materials and Energy, we have established several joint projects. This means amongst other things that we are cutting the time-to-market for our solutions. In a collaboration with i-Nano at Århus University, for example, we have acquired knowledge on how to apply SCF high pressure technology to develop nanostructured materials with entirely new properties.

<http://www.scf-technologies.com/default.asp?id=218>

Sandvik Nanoflex® is a revolutionary metal alloy from Sandvik Materials Technology. Exploiting the latest advances in nanotechnology, Sandvik Nanoflex® offers a unique combination, matching high strength and hardness with exceptional formability.

<http://www.smt.sandvik.com/nanoflex>

In collaboration with specialized companies, Bianchi simulated a structural analysis on carbon products aimed at obtaining, during the design phase, the elements necessary for the correct development of its products. This made it possible to find the most suitable position of the fibers thus maximizing the final product characteristics. Intensive laboratory tests confirmed the preliminary simulations. The pre-impregnated carbon fibers (prepreg – one-way carbon fibers soaked into a partly polymerized epoxy resin) are cut per the design drawing specifications and placed into a mold accordingly.

<http://www.bianchiusa.com/technology/tech-materials.html>

For the new NanoSphere®, the research team from Clariant and Schoeller have combined the latest technologies and developed a product that meets the highest demands of everyday life and is oriented toward the environmentally relevant demands of the future. The nanoparticle mix has been newly defined and a new generation of nanoparticles in a very stable matrix has come into use. Consequently

the abrasion resistance has been increased. Through the use of future considered C6 fluorochemicals, the NanoSphere® finish is free of PFOA and PFOS. Due to the new recipe and nanoparticle mix, it still achieves an extremely high level of water, dirt and oil repellency and meets the most demanding washing and dry cleaning requirements. The finish is highly abrasion resistant and the protective function remains lastingly active, even when exposed to considerable load and after frequent washings.

<http://www.nanosphere.ch/index.php?id=44>

Patented nano technology: Nanoxyd® (= calcium peroxide in nano size) penetrates into the most minute of gaps, ensuring an optimum bleaching result. Colour pigments (e.g. from coffee, tea, tobacco) are whitened. Enzymes (papain and bromelain) gently remove the plaque, meaning that the Nanoxyd® can take maximum effect.

<http://www.swissdent.com/index.php?id=48&L=1>

Envirox™ Fuel Borne Catalyst is a scientifically and commercially proven diesel fuel combustion improve which reduces fuel consumption and also reduces harmful exhaust emissions. These benefits are achieved by using a patented catalyst technology based on cerium oxide, a well-known industrial catalyst, which is also used within the automotive sector in gasoline engine three-way catalytic converters. Envirox™ is delivered into the combustion chamber pre-mixed with the fuel and improves fuel consumption using two mechanisms: (a) cerium oxide modifies the combustion profile so that more useful work is delivered from each combustion cycle for a given quantity of fuel; (b) cerium oxide lowers the temperature at which carbon combusts which causes a progressive clean up of the engine allowing the engine to operate with optimum efficiency.

http://www.oxonica.com/energy/energy_envirox_intro.php

c) Summary of Discussions

1) The need for SME's to use easy packages that provide 80% of the solution of a specific problem. Then the user might need to call in the academic experts to help refine things later.

2) The need to embed modelling into industrial collaborative projects at national and European level as funding authorities are unlikely to call modelling topics in isolation

except for certain areas such as nanotoxicology, for example, where the field is more academic.

3) The development of new data mining processes and procedures to cope with the sheer amount of data that can be generated today.

4) Modeling is good for the sustainability agenda as it reduces the amount of expensive experimentation for industry and academia alike.

3. Agreed Future Directions and Activities

Next open workshop will be held by the action group in the first week of June 2010. Meanwhile the scoping paper will be distributed through the nanometrology network focusing on the end-users who do not belong to academia in order to collect feedback and analyze opinions which will flag possible directions.

The ENAG will consider the suggestions and, after a critical analysis, will send the reasonable ones in a concise form to the software developers. Additions, opinions, and comments on the software will be collected before the second workshop which will be organized by this action group in June 2010.

A brief (1-2 pages) proposal for collaborative project and coordination action to combine the efforts of manufacturers and software developers to be prepared by the ENAG5 leader and send to the Commission after extensive consultations. The work program for the 2011 is already in its final stage but the ideas could be included in the WP for 2012.

4. Publications

Prior to this meeting a discussion document '*Modeling and simulations: Nanometrology needs and future needs within Europe*' was published addressing the current status, future needs and opportunities in the field. Following feedback from the above meeting, and the broader stakeholder community, this discussion paper has been updated and is included in Appendix 1 of this document. Further feedback is welcomed to the author of this report.

5. Meeting Attendees

| Surname | First Name | Title | Organisation |
|------------------|------------|-------|----------------------------------|
| Blom | Anders | Dr | QuantumWise A/S |
| Burke | Theresa | Dr | euspen |
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