RESEARCH

METROLOGY

TESTING

CERTIFICATION

EXPERTISE
AND INNOVATION

TRAINING

WEBINAR

BUILDING TRUST

Standardisation & Validation made simple

Understanding the role of metrology to support the development of advance materials and nanomedicines

PART D - EXAMPLES FOR ADVANCED MATERIALS - WHAT'S THE ALTERNATIVE FOR LESS MATURE CASES?

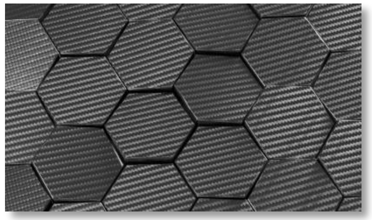
GEORGES FAVRE (LNE)

metrino

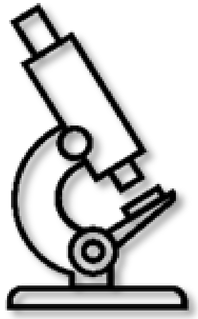
MACRAMÉ
Advanced Characterisation Methodologies to assess and predict the Health and Environmental Risks of Advanced Materials

Nano Mesure France

WHAT ABOUT VALIDATION AND RECOGNITION OF METHODS FOR LESS MATURE CASES?



- ❑ New and complex Advanced Materials



- ❑ New analytical technical or measurement method?

Only a few laboratories with expertise or relevant analytical tools, **that makes complicated the organisation of ILCs**…

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SOME EXAMPLES OF ADVANCED MATERIALS

DECREASING MATURITY REGARDING STANDARDISATION PROCESS

Cellulose NanoCrystals (CNCs)
→ Nanorods with HAR

- Nanocomposite materials
- Health and personal care products
- Paints
- Adhesive and thin films
- Rheology modifiers
- Optical films and devices

Graphene, bilayer graphene and graphene nanoplatelets

- Nanocomposite materials
- Battery/Electrode
- Thin films
- …

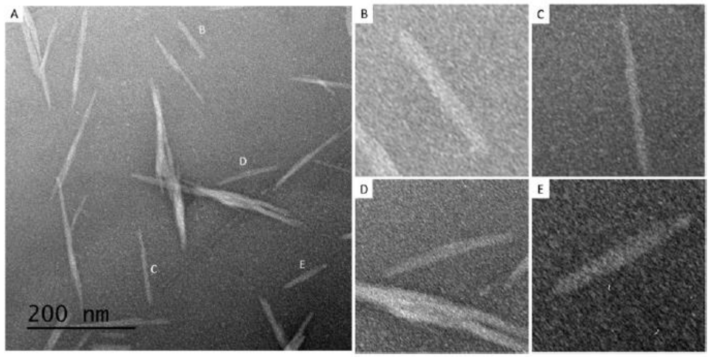
Complex-shaped nanoparticles

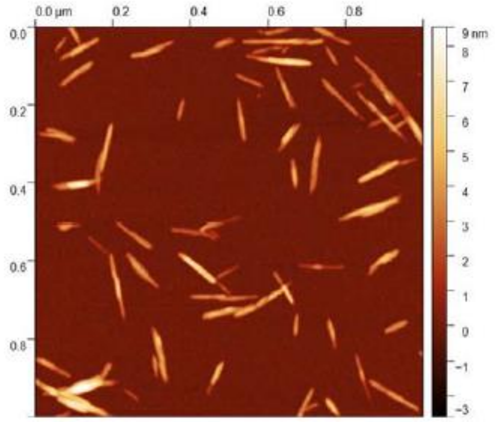
- Nanocomposite materials
- Nanomedecine
- Catalyst
- …

NEEDS REGARDING SIZE MEASUREMENT AT THE NANOSCALE

CELLULOSE NANOCRYSTALS (CNCs)

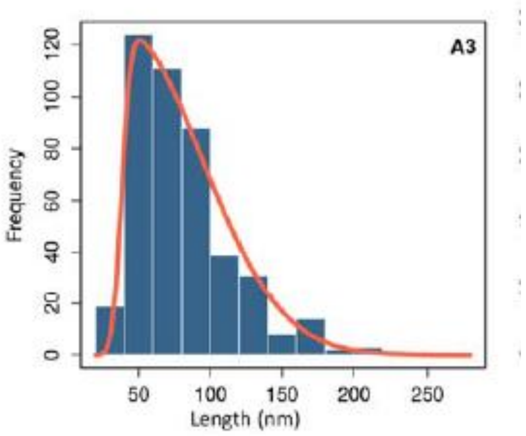
- ❑ DETERMINATION OF LENGTH & WIDTH BY **TEM**
- ❑ DETERMINATION OF HEIGHT BY **AFM**

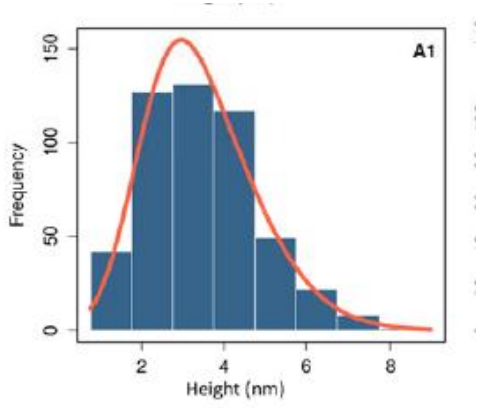




TEM

AFM





LIMITATION

2 DIFFERENT NANOROD POPULATIONS CONSIDERED

(1 FOR TEM & 1 FOR AFM)

→ NOT THE SAME PARTICLES CONSIDERED TO DETERMINE THE PARTICLES' ASPECT RATIO
IMPACT ON THE ASSOCIATED UNCERTAINTIES

VAMAS ILC – CELLULOSE NANOCRYSTALS (CNCs)

VAMAS

Nanoparticle Populations
Technical Work Area 34

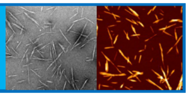
Project 12

Determination of Particle Size Distribution for Cellulose Nanocrystals (CNCs)

CALL FOR PARTICIPATION

Measurement Techniques

Atomic Force Microscopy (AFM)
Transmission Electron Microscopy (TEM)



Objectives

This interlaboratory comparison (ILC) will validate the performance of image acquisition protocols and image analysis methods for determining CNC particle size distributions by atomic force microscopy (AFM) and transmission electron microscopy (TEM). These methods are complementary in that AFM provides height and length measurements while TEM provides length and width measurements; all 3 dimensions are needed to assess CNC morphology. The ILC results will provide the pre-normative data for a technical specification on CNC particle size measurements.

Background and Standardisation needs

CNCs are one member of a family of emerging cellulose nanomaterials (CNM) with significant commercial potential. Realizing the potential of these materials requires methods to characterize a number of material properties, including particle morphology and size distribution. They control the properties of individual particles and their assemblies in suspensions, dry films and after incorporation in matrices, which are key factors for developing applications. The particle dimensions are also important for distinguishing between CNC grades and may provide information on the cellulose source and production method.

A series of CNM standards are currently being developed at ISO TC 229 (Nanotechnologies) and ISO TC 6 (Paper, Board and Pulp). These include terminology and nomenclature, a general overview of CNC characterization, determination of sulfur and sulfate half ester content for CNCs and dry matter and ash content for CNM. CNC particle size has been identified as a key priority in a survey of industrial producers of CNM (developed by ISO TC 6).

Work Programme

Phase 1 of the ILC will test image analysis methods using a single set of AFM and TEM images that are circulated to participants. The results will be used to optimize the analysis routines. The 2nd and 3rd phases will test the full image acquisition and analysis protocols. The protocols for image acquisition will be provided in advance to allow time for participants to seek clarification of the procedures with the project leader to modify the protocol.

Pre-deposited samples of CNCs on mica or TEM grids will be supplied to participants with requests to image within a specified time frame. The CNC will be sourced from an NRC certified reference material, CNCD-1, that will be dispersed using a standard sonication protocol to give a 2% by mass aqueous suspension that is diluted for preparation of microscopy samples. Duplicate sample slides (for each method) will be supplied to each participant.

Participants will be asked to image one of the two substrates (the second as a backup in case of any issues) and to obtain a sufficient number of images to measure the specified parameters (AFM, length and height; TEM, width and length) for the minimum number of particles specified in the protocol. Participants will be requested to provide details on the most recent microscope calibration. Excel templates to record all necessary data and calculations will be provided. Standard statistical methods will be used for further analysis of data sets returned by the participating laboratories. Participants must give permission for their data to be used in the final report and in publications or presentations arising from the ILC.

Deliverables and Dissemination

The ILC will validate the protocols for measuring particle size distributions for CNCs using AFM and TEM. The results of the study will be published in a peer reviewed journal and disseminated at relevant conferences. The ILC protocols and results will be used to determine uncertainty estimates, to develop ISO TS 23151[1] and to provide pre-normative validation data for this Technical Specification.

Participation / Funding

Participants with expertise in AFM and TEM will be recruited, aiming at a mix of participants with general expertise for imaging nanomaterials and with specific expertise in cellulose nanomaterials. Participation is funded by in-kind contributions from the participants.

Status

The project will start in January 2019. Samples will be provided in Feb/March 2019. Results should be reported within a month of receiving the samples.

Reference

1. ISO TS 23151 - Particle Size Distributions for Cellulose Nanocrystals .

For more information :

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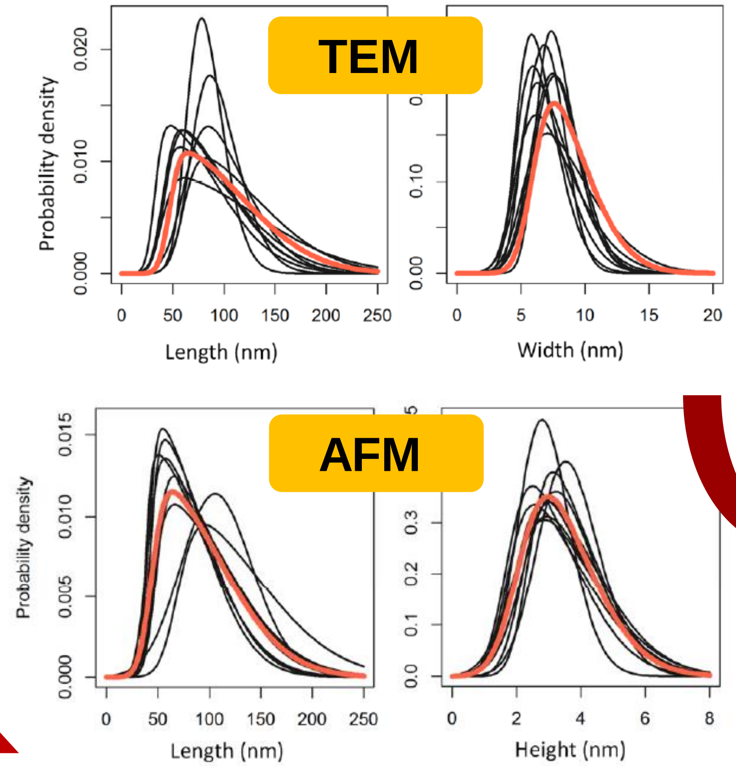
Dr. Jeff Fagan
Chair, VAMAS TWA 34
NIST, USA
jeffrey.fagan@nist.gov

www.vamas.org

December 2018

10 LABORATORIES



Reproducibility of the method assessed to support a meaningful ISO TS

TECHNICAL SPECIFICATION

ISO/TS 23151

First edition
2021-09

Nanotechnologies — Particle size distribution for cellulose nanocrystals

Nanotechnologies — Distribution en taille des particules pour les nanocristaux de cellulose

ISO

Reference number
ISO/TS 23151:2021(E)

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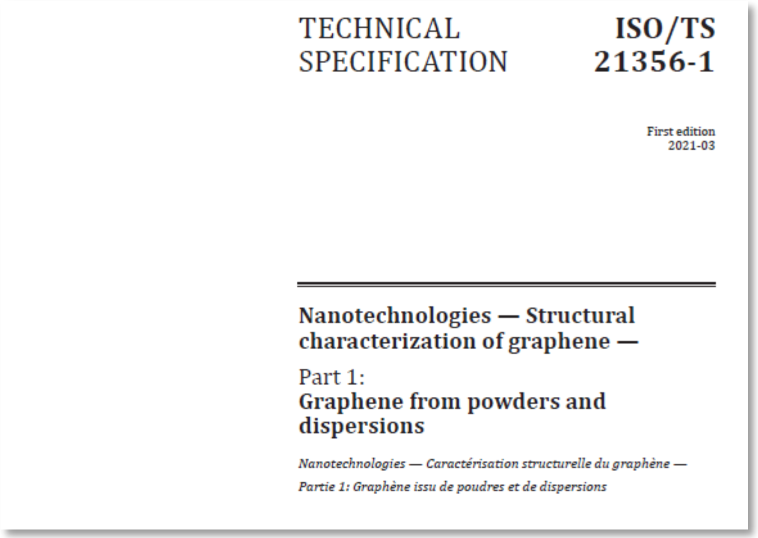
GRAPHENE, BILAYER GRAPHENE AND GRAPHENE NANOPLATELETS


TECHNICAL SPECIFICATION

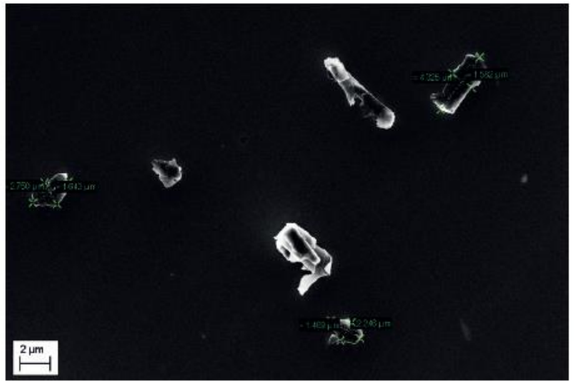
ISO/TS 21356-1

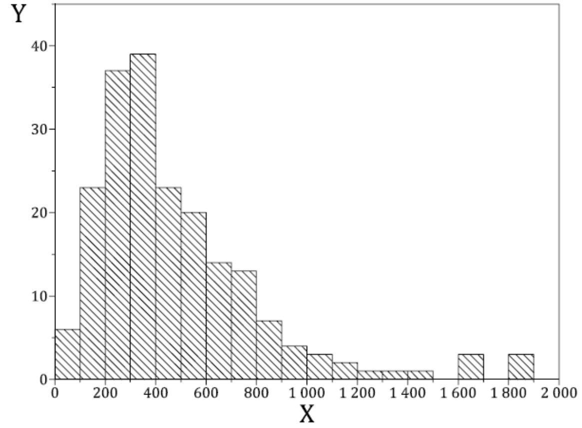
First edition
2021-03

Nanotechnologies — Structural characterization of graphene —

Part 1:
Graphene from powders and dispersions

Nanotechnologies — Caractérisation structurelle du graphène — Partie 1: Graphène issu de poudres et de dispersions

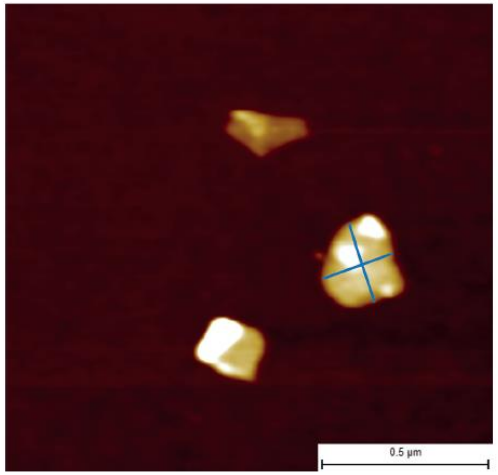


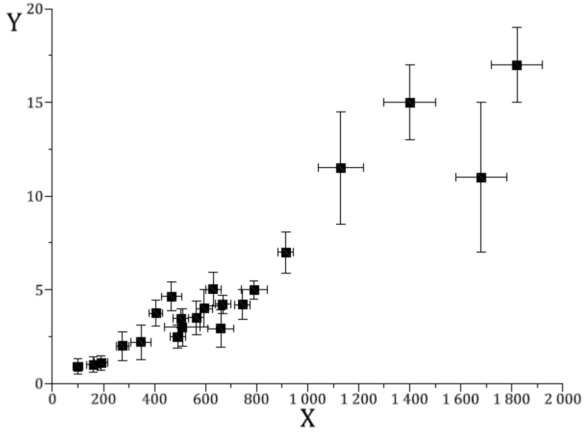


Key
X lateral flake size, nm
Y number of flakes

- ❑ DETERMINATION OF LATERAL SIZES AND THICKNESS USING TEM/SEM & AFM, RESPECTIVELY

→ **FROM 2 DIFFERENT GRAPHENE PARTICLES POPULATIONS** (1 for TEM/SEM & 1 for AFM)





Key
X lateral flake size, nm
Y flake thickness, nm

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VAMAS ILC - GRAPHENE, BILAYER GRAPHENE AND GRAPHENE NANOPLATELETS

HOWEVER NO ILC TO SUPPORT THE DEVELOPMENT OF ISO/TS 21356-1

→ The TS remains **informative** until the typical variations in values obtained by different user/equipment can be validated through a VAMAS study

EU Project ISO-G-SCoPe

to support complementary work and the ILC between expert labs at VAMAS level

https://empir.npl.co.uk/isogscope/

VAMAS

Graphene and related 2D materials
Technical Work Area 41

CALL FOR PARTICIPATION

Project 12

Distribution of lateral size and thickness of few-layer graphene flakes using SEM and AFM

Objectives

The aim of this international interlaboratory comparison is to determine the lateral flake size distribution of graphene nanoplatelets (GNPs) using scanning electron microscopy (SEM), and correlate these to measurements of lateral flake size and thickness, using atomic force microscopy (AFM).

The results of the study will be used directly for future revision of ISO/TS 21356-1 with a validated measurement procedure. This work is undertaken as part of the EMPIR project ISO-G-SCoPe.

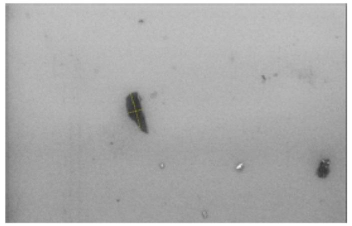
Background

Graphene is an exciting advanced material, present in the form of flakes in powders or liquid dispersions and in larger sheets grown through bottom-up processes. GNPs in flake form are already starting to find commercial application via small-to-medium enterprises (SMEs) to multi-national corporations, for a large range of application areas. There are currently over 100 commercial 'graphene' producers worldwide, including leading graphene producers in Europe, with an 'on paper' offering of materials with vastly different properties and types. However, many suppliers (and buyers) are hindered due to uncharacterised or poorly characterised material that can be more often graphite rather than GNPs or have large batch-to-batch variations. Products and applications suffer as a result. The aim is to produce validated measurement methods of GNPs.

Standardisation Needs

The recently published ISO/TS 21356-1 'Structural characterisation of graphene from powders and liquid dispersions' details protocols to characterise the lateral size and thickness of graphene and few-layer graphene flakes. However, these sections remain informative, until the typical variation in values obtained by different users/equipment can be validated through a VAMAS study.

Issues addressed by this standard include structural determination on the number of layers present, their thickness, homogeneity and flake size distribution between the batches. These are all issues at the nanoscale, especially thickness where a combination of measurement method, metrology and correlative imaging is needed.



Example SEM image focused on an individual flake. The yellow lines drawn on the flake indicate the lateral size measurements.

Work Programme

GNPs deposited onto different Si/ SiO_2 substrates will be provided for each participant for SEM and AFM measurements.

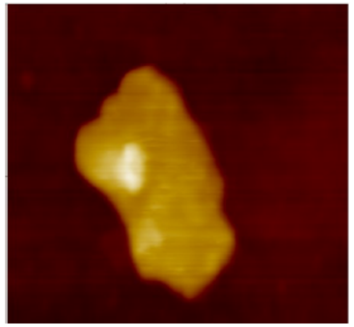
Participants will be asked to measure these samples along with calibration check samples and report the lateral flake size and thickness observed.

Duration

One year beginning June 2022.

Deliverables and Dissemination

Report will evaluate the variance observed of the associated measurement protocol, to guide further development. Results will be published in a peer-reviewed journal and will be directly used in ISO/IEC standards.



High resolution topographic AFM image of an individual flake.

Funding

Participants in the interlaboratory comparison will fund their own involvement (approx. 4 days' work).

International Participation

Current participants represent the UK, EU, China and the USA. Wider regional participation would be greatly welcomed.

For more information:

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Project Leaders,
National Physical Laboratory, UK

www.vamas.org
April 2022

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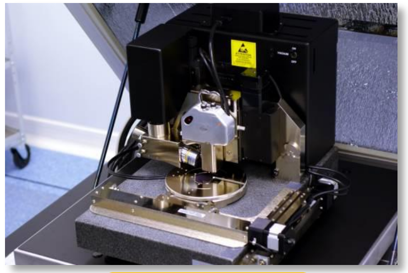
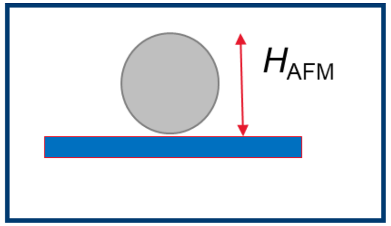
COMPLEX-SHAPED NANOPARTICLES

- ❑ HOW TO COLLECT MORE INFORMATION ON THE DIMENSIONS OF COMPLEX-SHAPED NANOPARTCLES
- ❑ HOW TO REDUCE THE MEASUREMENT UNCERTAINTIES ON ASPECT RATIO MEASUREMENT?

→ BY CHARACTERIZING **THE SAME SET OF NANOPARTICLES** BY SEM & AFM

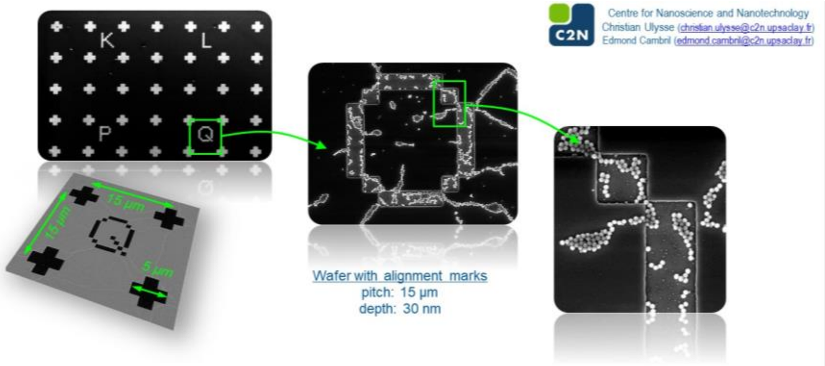


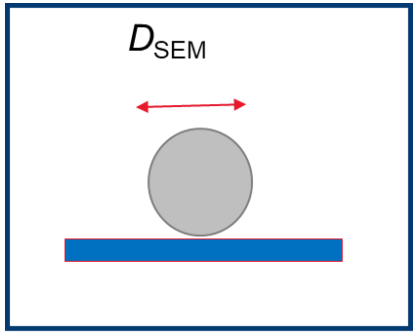
AFM



NP Height measurement

+ Re-positioning crosses **+**





NP Lateral diameter measurement

SEM

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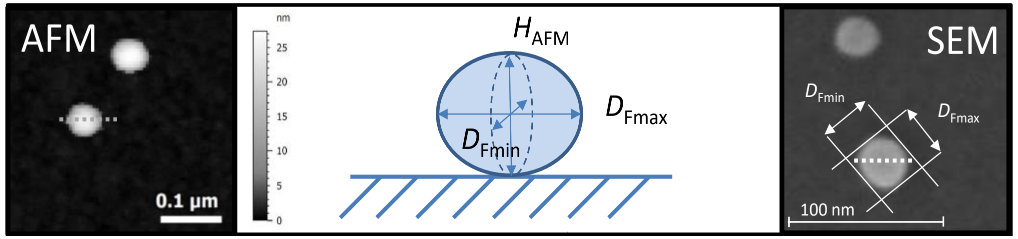
HYBRID METROLOGY COMBINING AFM/SEM FOR 3D NP SIZE MEASUREMENTS



BEILSTEIN JOURNAL OF NANOTECHNOLOGY

Development of a new hybrid approach combining AFM and SEM for the nanoparticle dimensional metrology

Loïc Crouzier*[1,2], Alexandra Delvallée[1], Sébastien Ducourtieux[1], Laurent Devoille[1], Guillaume Noircler[1], Christian Ulysse[3], Olivier Taché[4], Elodie Barruet[4], Christophe Tromas[2] and Nicolas Feltin[1]

Full Research Paper

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Keywords:
AFM; hybrid metrology; nanoparticles; SEM; size distribution; uncertainty budget

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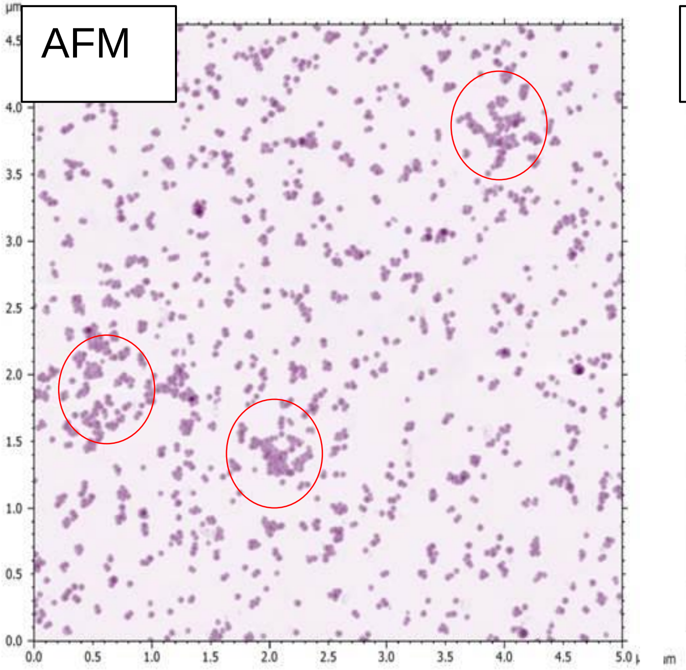
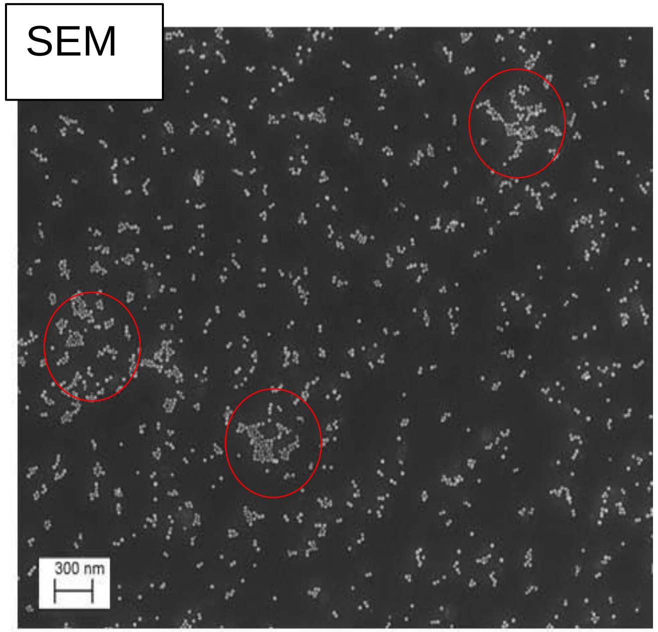
PROOF OF CONCEPT FOR HYBRID METROLOGY





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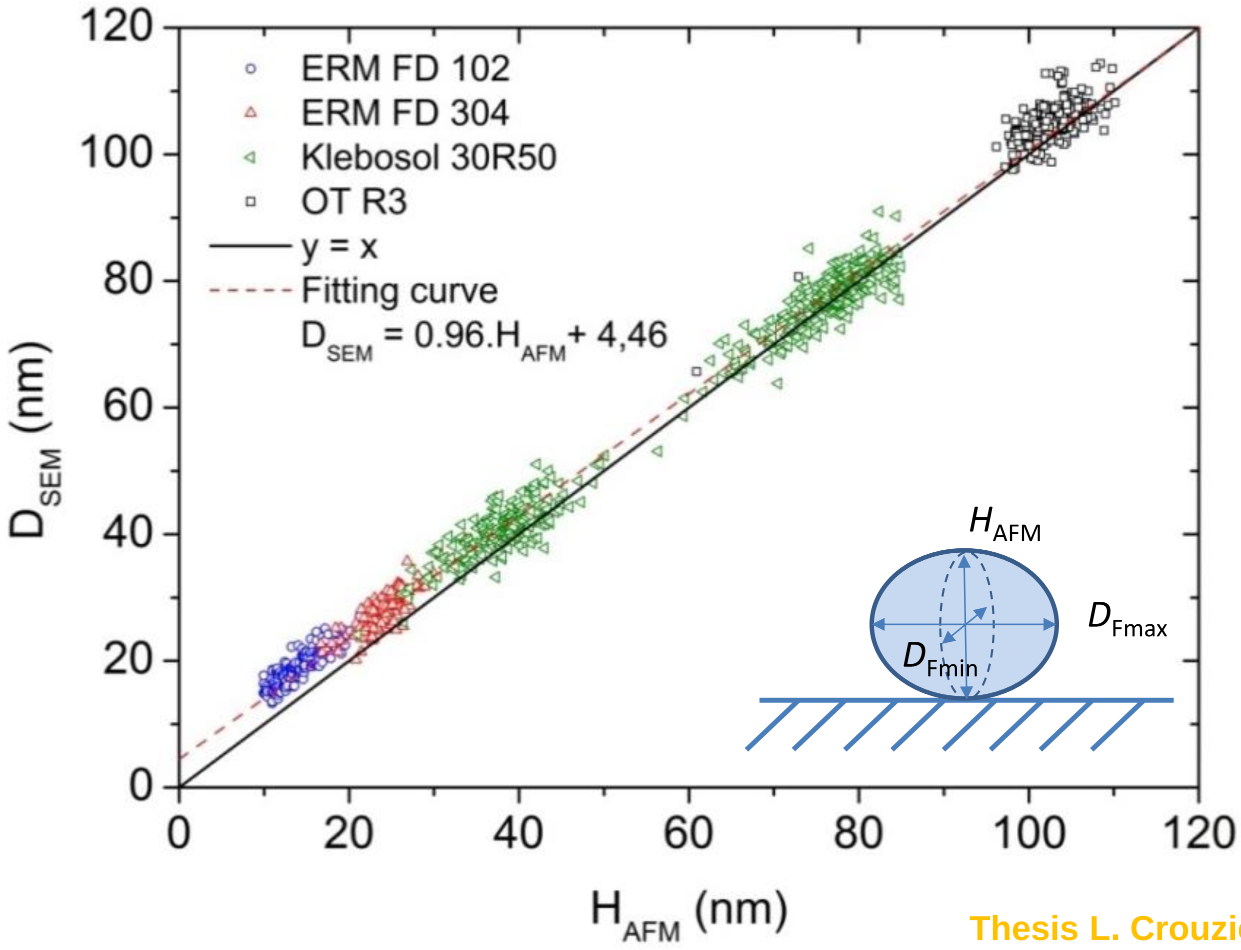
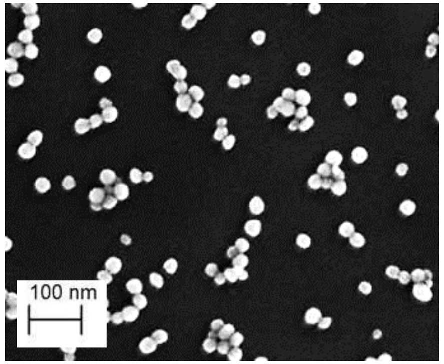
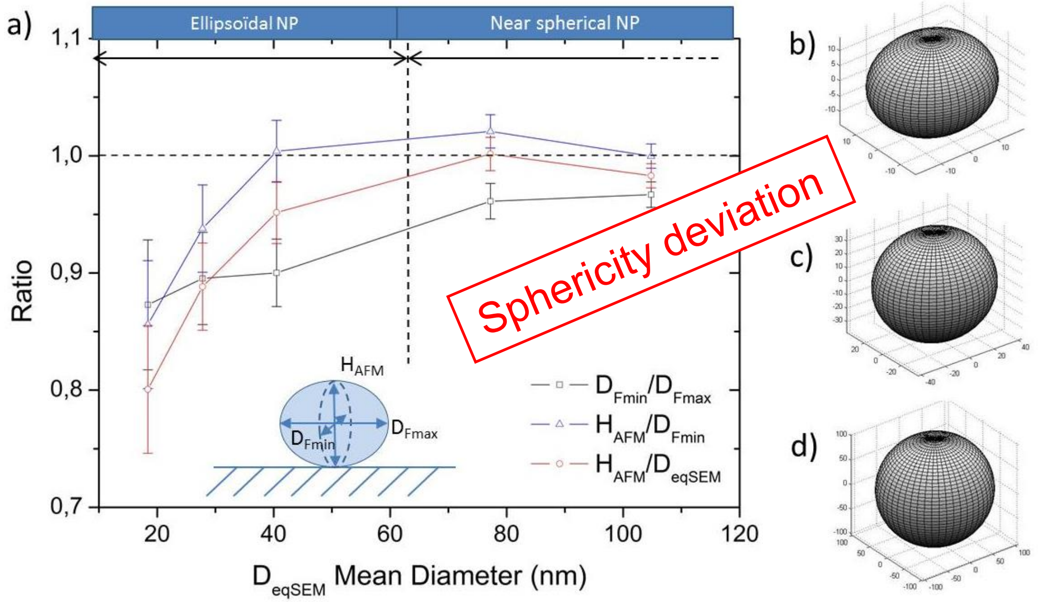
PROOF OF CONCEPT FOR HYBRID METROLOGY



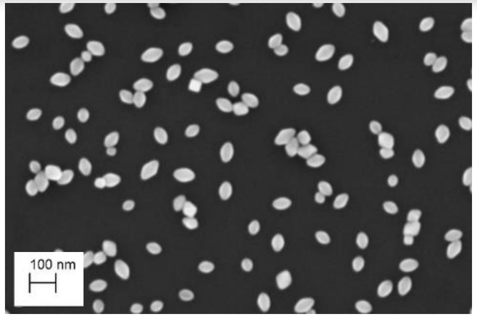
Thesis L. Crouzier



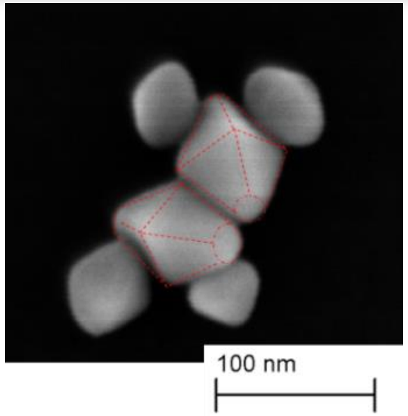
FD-304 : certified reference population of silica NP



USING HYBRID METROLOGY TO MEASURE NPs WITH COMPLEX SHAPES



nanobipyramides (UNITO) - NPSize

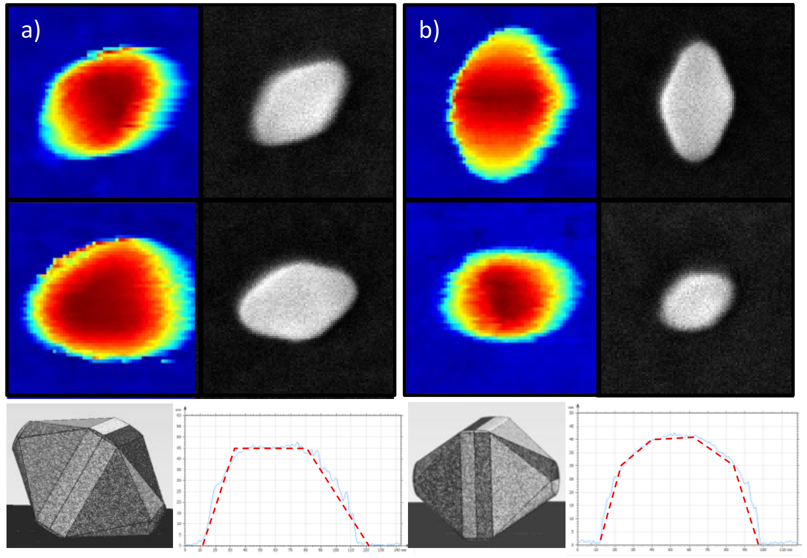


EU Project

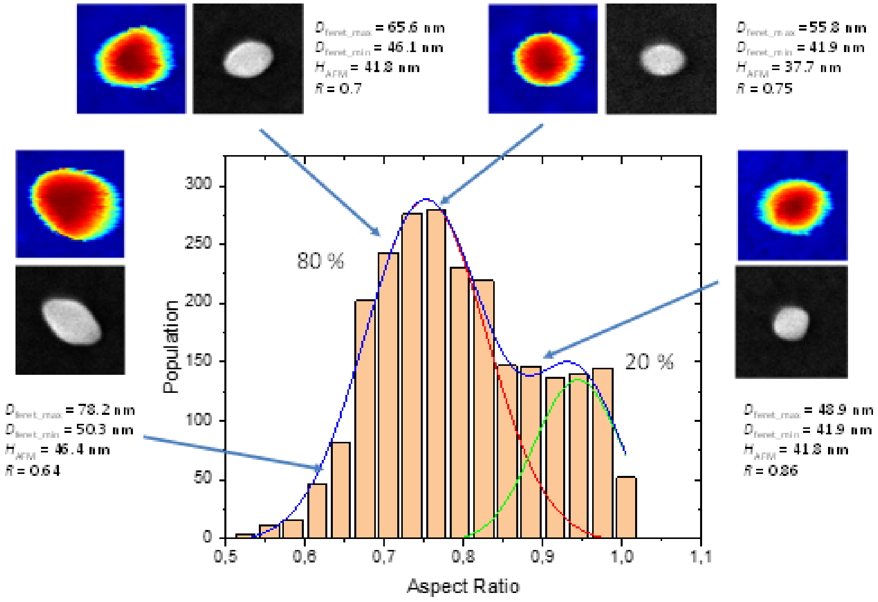
nPSize

TWO DISTINCT POPULATIONS OBSERVED

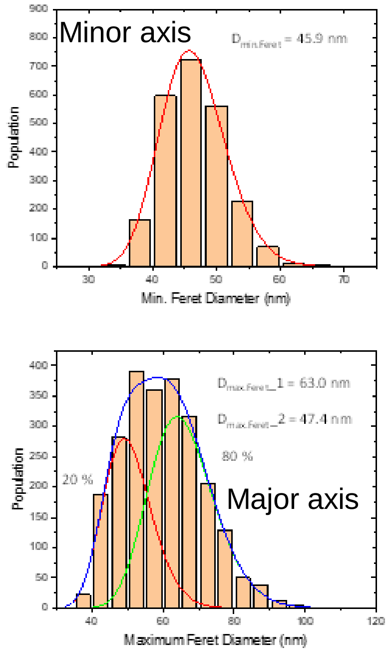
75 %	25 %
Anisotropic +large	Isotropic +small

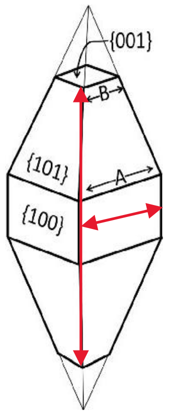


③



④





Truncated Bipyramidal structure

①

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HIGHLY INNOVATIVE & POWERFUL METHOD

- ❑ DEMAND FROM INDUSTRY TO CHARACTERISE **NPs FOR MEDICINAL APPLICATION**

- ❑ **REQUIREMENTS FROM FDA** TO PRODUCE ADDITIONAL DATA REGARDING NPs ASPECT RATIO DISTRIBUTION & FRACTION OF SMALLS NPs

AFM/SEM HYBRID METROLOGY
CONSIDERED AS HIGHLY RELEVANT BY THE COMPANY AND FDA
+
ORTHOGONAL TO DLS

BUT HOW TO PROVIDE CONFIDENCE IN THE PERFORMANCE OF TECHNOLOGY **DEVELOPED AND USED UNTIL NOW IN A SINGLE LABORATORY**

(EVEN IF IT IS A **NATIONAL METROLOGY INSTITUTE** SUCH AS **LNE**)?

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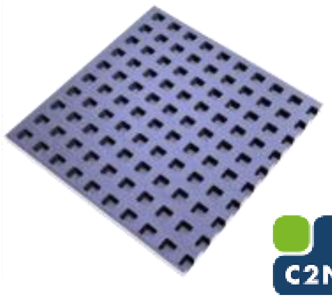
HIGHLY INNOVATIVE & POWERFUL METHOD

- **CALIBRATION OF SEM & AFM** with a Certified standard traceable to SI Unit (meter) through metrological AFM

P900H60



- **FULL UNCERTAINTIES ASSESSMENT** for SEM & AFM

AFM uncertainty budget

Rang	Composante	Estimation	Distribution	Contribution sur la mesure de la hauteur
TYPE A				
1	Répétabilité	0,35		0,35
TYPE B				
1	Certificat d'étalonnage VLSI	0,7 nm		0,7 nm
2	Influence de la vitesse de balayage (4 µm.s^{-1})	0,24 nm		0,24 nm
3	Niveau de bruit en Z	0,16 nm		0,16 nm
4	Répétabilité en Z (mode statique)	0,08 nm	N	0,08 nm
5	Contribution des facteurs XY sur la mesure de hauteur : - Limite de résolution suivant XY - Taille du pixel - Bruit suivant les axes XY	0,11 nm 4,9 nm 6 nm pic à pic		0,058 nm
6	Limite de résolution du capteur suivant Z (1.5 LSB / 16 bit, domaine de mesure 7.62 µm)	0,17 nm pic à pic	R	0,05 nm
7	Rugosité (S_q)	0,05 nm	N	0,079 nm
8	Contribution de la force d'appui de la pointe en tapping sur la déformation de la particule	0,26 nN		0,05 nm
10	Dilatation de la nanoparticule (@ 32 °C au lieu de 20 °C)	500 nm. m^{-1}.K^{-1} (coefficient de dilatation thermique du matériau massif)		5.10^{-4} nm
	Total U (95%)			**1,7 nm**

A. Delvallée *et al*, Metrologia, (2016)

SEM uncertainty budget

Source	Symbol	Unit	Value	Standard Uncertainty ui	Sensitivity coefficient ci	ci*ui	ci²*ui²	Contribution / %
a (Pixel Size)	C_{PS}	-	-0.3215	0.014	1.40	0.0196	0.0004	0.0
Repeatability – FD304	$C_{rsample}$	nm	0	0.6	1.0	0.6	0.36	10.0
Magnification – FD304	$C_{msample}$	nm	0	0.26	1.0	0.25982	0.0675	2.0
Beam Width – FD304	C_{bWsamp}	nm	0	1.7	1.0	1.7	2.89	85.1
Threshold selection – FD304	C_{IAsamp}	nm	0	0.2	1.0	0.2	0.04	1.2
Man Power – FD304	C_{MPsamp}	nm	0	0.2	1.0	0.2	0.04	1.2
			$d_{noncorrigé}$	23.05	nm	Variance	3.36	nm
						Std unc	1.84	nm
						k	2	
						Exp Unc	3.69	nm

L. Crouzier *et al*, Meas. Sci. Technol, (2019)

- **ACCREDITATION** ACCORDING TO ISO/IEC 17025 *General requirements for the competence of testing and calibration laboratories*

https://www.lne.fr/en/node/4732

The factor that helped convince stakeholders involved that the method was fully validated, **as it was assessed by an external expert.**

Thank you for attention