Title: Crystalline and self-assembled structures as length standards

Abstract

The nanotechnology industry uses methods such as high resolution optical interference microscopes, scanning electron microscopes and scanning probe microscopes (e.g. Atomic Force Microscopy (AFM) and Scanning Tunnelling Microscopy (STM)) for imaging nano-objects. However, there are currently no lateral transfer standards of less than 25 nm and no vertical standards smaller than 6 nm, for use with such methods and this prevents the characterisation of nano-objects. Crystalline structures have the potential to be used as calibration standards based on their lattice parameters. Self-assembled nanostructures and the new technique of nano-origami could also be used to create patterns on surfaces, of 2 nm to 50 nm for lateral and 1 nm - 6 nm for vertical calibration standards. But before such structures can be used as length standards, they need to be fully characterised and their stability assessed.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on "Grand Challenges" related to Industry & Fundamental Metrology on pages 13 and 38.

Keywords

Dimensional nanometrology, calibration standards, crystalline transfer standards, self-assembled structures, nano-origami, scanning probe microscopy, interference microscopes, laser interferometry

Background to the Metrological Challenges

Currently, optical interference microscopes are able to resolve the atomic steps of crystalline surfaces of silicon after careful alignment or correction of the reference plane. The flatness of such surfaces together with the atomic steps as boundary enables correction of the reference plane as well as adjustment of the vertical axes. However, this is not possible for conventionally flat plane surfaces and commercially available crystalline silicon artefacts with monoatomic steps of 0.314 nm in height only show small, single step terraces of approximately 300 nm in width, which are too small for use with optical instruments. Current step height calibration standards start at 6 nm and have an uncertainty of 1 nm and are of a comparable size to many objects examined using AFM e.g. single wall carbon nanotubes and nanoparticles. However, the ideal calibration standard should have an uncertainty of at least a factor of ten less than the object under examination and such calibration standards do not yet exist.

Gratings produced by lithographic or other techniques and used as transfer standards for the calibration of high resolution instruments are limited to 25 nm. These standards can be calibrated with uncertainties of a few 10 pm by measurements over a large area. However, with the limited scan range (tens of micrometres) of most AFM, the measurement uncertainty is greater than 0.1 nm. Laser-interferometry and X-ray interferometry (XRI) methods could be used to overcome this, but they are very expensive and typical industrial users need lower cost, easy-to-use calibration standards. Therefore, new, stable lateral and vertical calibration standards with an uncertainty of less than 0.1 nm and that are able to meet the specifications of ISO 5436-1 [1] need to be developed. These could be provided by using crystalline surfaces, nano-origami (a technique based on the folding of DNA in a defined way that generates a pattern in the range of 2 nm - 25 nm) and self-assembled structures (self-assembly is based on the ordering of atoms and molecules on a surface or in distinct adsorption places, such as the adsorption of metallic atoms on silicon surfaces).

Scientific and Technological Objectives

Proposers should address the objectives stated below, which are based on the PRT submissions. Proposers may identify amendments to the objectives or choose to address a subset of them in order to maximise the overall impact, or address budgetary or scientific / technical constraints, but the reasons for this should be clearly stated in the JRP-Protocol.

The JRP shall focus on the metrology required for using crystalline and self-assembled structures as length standards.

The specific objectives are

1. To produce stable and reliable crystalline structures for use as length standards. To achieve this crystalline samples should be:
    a. large (>2 µm) flat, clean crystalline surfaces, partly with self-assembled nanostructures and under ultra-high vacuum conditions,
    b. single and multi-stepped surfaces in specific crystallographic orientations with the ability to transfer with a thin homogenous passivation layer from vacuum to air without compromising surface topography,
    c. able to produce traceable measurements of the lateral pitch of the atomic lattice, the pitch of the self-assembled nanostructures, and the height of steps as well as comparative step height measurements on a range of scanning probe microscopes,
    d. able to provide traceable measurements of monoatomic steps and the pitch of larger nanostructures produced in air, using AFM, STM and combined XRI,
2. To produce stable and reliable self-assembled structures for use as length standards. To achieve this self-assembled samples should be:
    a. nanostructures self-assembled on clean, flat (crystalline) surfaces with pitch in the range of 2 to 50 nm or step heights in the range of 1 to 10 nm,
    b. complex regular patterns between 5 and 100 nm using self-assembly of DNA structures (nano-origami),
    c. able to provide reliable pattern, pitch and height based on known sample parameters (lattice constant, step height) using STM, AFM or XRI with AFM,
3. To develop reliable and accurate methods to locate the calibration structure on crystalline and self-assembled structure samples and to characterise scanning microscopy (SPM and SEM) and optical microscopes using such samples.
4. To determine the uncertainty budget for pitch and step height measurements using crystalline and self-assembled structures as length standards.
5. To produce good practice guides for the use and storage of crystalline and self-assembled samples and calibration standards.

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. To enhance the impact of the research work, the involvement of the larger community of metrology R&D resources outside Europe is recommended. A strong industry involvement is expected in order to align the project with their needs and guarantee an efficient knowledge transfer into industry.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this and the iMERA-Plus JRP T3 J1.4 ‘New Traceability Routes for Nanometrology’.

The total eligible cost of any proposal received for this SRT is expected to be around the 2.7 M€ guideline for proposals in this call. The available budget for integral Research Excellence Grants is 42 months of effort.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community. This may be through the inclusion of unfunded JRP partners or collaborators, or by including links to industrial/policy advisory committees, standards committees or other bodies. Evidence of support from the “end user” community (e.g. letters of support) is encouraged.

You should detail how your JRP results are going to:

- feed into the development of urgent documentary standards through appropriate standards bodies
- transfer knowledge to the nanotechnology sector.

You should detail other impacts of your proposed JRP as detailed in the document “Guide 4: Writing a Joint Research Project”

You should also detail how your approach to realising the objectives will further the aim of the EMRP to develop a coherent approach at the European level in the field of metrology and includes the best available contributions from across the metrology community. Specifically the opportunities for:

- improvement of the efficiency of use of available resources to better meet metrological needs and to assure the traceability of national standards
- the metrology capacity of Member States and countries associated with the Seventh Framework Programme whose metrology programmes are at an early stage of development to be increased
- outside researchers & research organisations other than NMIs and DIs to be involved in the work

Time-scale

The project should be of up to 3 years duration.

Additional information

The references were provided by PRT submitters; proposers should therefore establish the relevance of any references.

[1] ISO 5436-1:2000 Geometrical Product Specifications (GPS) -- Surface texture: Profile method; Measurement standards -- Part 1: Material measures