Title: Traceable measurement of mechanical properties of nano-objects

Abstract

Accurate knowledge of the mechanical properties of nano-objects, such as elasticity and hardness, is critical to the development of devices and materials with new capabilities.

Mechanical properties of nano-objects and biomaterials are investigated by nanoindentation and scanning force microscopy (SFM). Due to its potential of high resolution and high sensitivity to forces, SFMs are used in a variety of investigations of mechanical properties. Significant variations are observed between the different methods and absolute values of a number of parameters, such as very small forces and stiffness of the cantilever in an SFM, cannot currently be determined with sufficient accuracy. Additional reference techniques and procedures therefore need to be developed to measure mechanical properties together with the appropriate reference materials to verify the quality of the instrumentation.

Conformity with the Work Programme

This Call for JRPs conforms to the EMRP Outline 2008, section on “Grand Challenges” related to Health, New Technologies & Fundamental Metrology on pages 9 and 25.

Keywords

Nano-objects, biomaterial, mechanical properties, scanning force microscopy, reference material, force calibration, cantilever stiffness, tip-sample interaction, guideline, interlaboratory comparison, validated models.

Background to the Metrological Challenges

The physical properties of nano-objects (nanoparticles, nanotubes, nanowires, ultra thin films and membranes) and biomaterials are of great interest for the development of new products or improved products such as hard coatings and wear protective layers, wear resistant particles used in chemical mechanical polishing (CMP), nano-composites to improve lifetime or reduce weight, nanohole membranes for purification of water and other liquids or energy production, small actuators and sensors in nanorobots, piezoelectric and semiconducting nanowires or arrays (e.g. ZnO) to generate electrical power.

The measurement of the physical properties of these nano- and bio-materials is a major challenge for nanometrology due to their small size and lack of appropriate measurement techniques. At the nanoscale the physical properties correlate strongly with the size of objects, hence both the physical quantity and the size of the object under investigation have to be determined with high accuracy. The correlation of mechanical properties with size is predicted by theory and observed experimentally, however there are serious discrepancies between the theoretical predictions and experimental measurements.

To investigate mechanical properties like elasticity and hardness various techniques like nanoindentation, beam-bending techniques, etc. such as contact-resonance SFM (CR-SFM) are applied, however significant variations between the various techniques are observed. Testing mechanical properties by nanoindentation is limited to thin films and a tenth of the film thickness otherwise the result is strongly influenced by bulk/substrate properties. In the case of nano-objects the surface of the nano-object is already very thin and the bulk-to-surface ratio is very large. It will be necessary to improve the simulation of nanoindentation/nanohardness measurements down to molecular size, i.e. from finite-element-analysis to molecular dynamics. Scanning force microscopy with its fine probe combined with measurements of various physical forces has a great potential to measure both mechanical properties and size. In order to determine the material properties of nano-objects using SFM it will be necessary to calibrate the cantilever's stiffness accurately for the small forces encountered (down to piconewtons). Measurements of nano-objects fixed on a substrate include inherent effects of forces between tip and nano-object and substrate that will affect the dimensional determination. These tip-sample interaction effects have to be investigated, simulated by theoretical models, and a correction applied in order to obtain more accurate determination of the size of the nano-objects. Reference materials will be required for the in-situ calibration of instruments.

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 provision of reference procedures to measure mechanical properties of nano-objects (e.g. elastic modulus, hardness and stress-strain behaviour) by nanomechanical test techniques including AFM and nano-indentation (milli to pico-newtons).

The specific objectives are

1. Traceable force and displacement calibration of nano-mechanical test systems (force range 10 mN to 10 pN, displacement resolution 0.1 nm).
2. Provision of reference materials and/or structures for the validation of nano-mechanical testing of nano-objects.
3. Development of validated modelling techniques to provide valid simulation of the test system and sample mechanical response in order to extract property values for the tested nano-objects. Potential techniques include analytical stress analysis, Finite-Element-Methods dislocation dynamics, and molecular dynamics.
4. Validated procedures to characterise size, shape and mechanical properties of nano-objects by SFM, and electron microscopy.
5. Intercomparison to evaluate the effectiveness of using reference materials for validation of instrument performance at the nano-scale.

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, the involvement of the appropriate user community such as industry, and standardisation and regulatory bodies, is strongly recommended.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. The proposed JRP should clearly explain any relationship with existing results delivered from previously funded EMRP JRPs and demonstrate how it extends any relevant outputs from such JRPs, in particular related to

- T3 J1.1 Nanoparticles: Traceable characterization of nanoparticles
- T3 J1.4 NANOTRACE: New Traceability Routes for Nanometrology

The total eligible cost of any proposal received for this SRT is expected to be significantly below the 2.7 M€ guideline for proposals in this call.

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 (eg letters of support) is encouraged.

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

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 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. 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.