EMRP Call 2011 - Health, SI Broader Scope & New Technologies

Selected Research Topic number: **SRT-n03**
Version: 1.0

Title: Metrological 3D characterisation of nanostructures

Abstract

Nanostructures are becoming increasing complex and characterisation of 3D nanostructures is required. The uncertainty for measurements of single structures of a few nanometres must be reduced below one nanometre in order to meet the demanding current and future applications mainly from the fabrication of semiconductor devices. Scanning probe microscopy (SPM) is complementing fast methods like scanning electron microscopy (SEM) and optical scatterometry in measurements of nanostructures in industry, science and basic metrology, however both methods have limitations for practical applications. Research is therefore required to significantly reduce uncertainties and enhance measurement capabilities necessary for traceable characterisation of nanostructures (complex 3D features and material combinations) to enable better control of lithographic fabrication of devices and further scientific progress in nanotechnology.

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

Scanning probe microscopy (SPM), scanning electron microscopy (SEM), critical dimension (CD) Metrology, nanostructures, atomic force microscopy (AFM), nanostructures, lithography, probe sample interaction, tip characterisation, tip wear, material characterisation, SEM modelling, SEM image formation, EBSD, surface morphology, interferometry, dynamic processes, adaptive scanning, video rate

Background to the Metrological Challenges

Dimensional metrology of high-end nanoscale structures is an incessant challenge due to the perpetual miniaturisation of features and devices combined with an increasing impact of feature details on the functionality of these devices. The development of nanotechnology and advanced lithography for electronic devices and diffractive and nano optics with structure sizes down to 15 nm requires characterisation of the respective 3D nanoscale objects with a target uncertainty of around a few nm and sometimes even below one nanometre.

Scanning probe microscopy (SPM) is the only non-destructive method, which allows the direct measurement of the 3D shape of nanostructures, however it has a number of limitations. One key issue for improving the uncertainty of SPM metrology is tip characterisation and image reconstruction. This also plays a crucial role for the important critical dimension (CD) metrology. The tip diameter and the interaction distance between sample and probe must be known at the nanometre level. Instabilities in the tip position can be misinterpreted as a surface feature, therefore a stable SPM head design is a prerequisite for accurate measurements of complex structures. For the measurement of small structures with high aspect ratios, fine probes are required and possible deformations of probe and/or sample structures have to be taken into account. Change of the probe shape during measurement, the so called tip wear, is a critical factor in the performance of SPM and advanced methods for monitoring tip wear are needed to evaluate methods for tip wear reduction. The measurement of 3D structures introduces extra challenges due to the measurement at sidewalls or corner roundings, where the interaction forces and the vibration modes can change substantially. SPM is regarded as a very slow technique compared to optical microscopy or scanning electron microscopy where a video rate imaging is regularly used, while the frame rate of scanning probe microscopes is rarely larger than 0.01 Hz. This currently limits the use of SPM in many applications where real-time phenomena need to be observed or where a large amount of data needs be collected (e.g. 3D mapping of tip-sample interactions).

Due to its high lateral resolution with beam diameters below 2 nm and its high measurement speed, Scanning Electron Microscopy (SEM) is a standard instrument for Critical Dimension (CD, i.e. structure size) metrology in the semiconductor industry. However, absolute CD measurements are only feasible if a definite correlation between SEM signal profile and specimen topography can be established by physical modelling based on Monte Carlo simulations. The critical point of CD evaluation at the nanometre level is that structure size and structure shape cannot be examined independently, i.e. the shape of the structure strongly influences the SEM image and thus the CD evaluation. Different nanostructures sharing the same physical size (diameter) but having different geometrical shape (sidewall angle, corner rounding) will produce different CD evaluation results, dependent on the CD evaluation algorithm. Therefore, it is crucial to verify the SEM modelling and CD evaluation using real measurements of well-defined nanostructures

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 significantly reducing uncertainties and enhancing measurement capabilities necessary for traceable characterisation of nanostructures (complex 3D features and material combinations) to enable better control of lithographic fabrication of devices and further scientific progress in nanotechnology. Scientific work will be focused on SPM and SEM, understanding tip-sample interactions, optimising both methods and utilising their complementary features.

The specific objectives are:

1. For SPM, to improve measurements and significantly reduce uncertainties through
    - Tip characterisation and image reconstruction
    - Investigating the influence of measurement conditions and sample characteristics on surface and tip forces
    - Improving measurements of small structures with high aspect ratios
    - Understanding and reducing tip wear and tip position instability
    - Significantly increasing scan speeds
2. For SEM, to improve measurements and significantly reduce uncertainties by
    - Manufacturing and calibrating traceable reference artefacts with atomic resolution
    - Optimising test structures by modelling of SEM image formation validated by SPM and dual beam FIB/SEM
    - Investigating effect of material composition and structures of artefacts on SEM measurements

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

- IND17 Scatterometry**:** Metrology of small structures for the manufacturing of electronic and optical devices
- T3 J1.4 NANOTRACE: 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.

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 semiconductor and nano-optics industries, nanotechnology sector, SPM and SEM instrument manufacturers
- transfer knowledge to organisations and groupings such as CoNanoMet and euspen.

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.