Title: Metrology of small structures for the manufacturing of electronic and optical devices

Abstract

Scatterometers and CD-SEM are key technologies for dimensional metrology of advanced functional structures in the sub micrometer-range, required to support further development of technologies for optics and semiconductor industry. Currently there are no universal product-independent standards for characterisation and calibration of scatterometers available. In scatterometry the application of wavelength ranges down to X-rays gives access to smaller regular and stochastically distributed feature details. For the further refinement of SEM and scatterometric algorithms, the impact of the structure form and local deviations must be taken into account.

Conformity with the Work Programme

This Call for JRPs addresses the improvement in the metrology of small structures (required to support the manufacturing of optical and semiconductor devices) was identified in the following sections of the EMRP Outline 2008:

Page 13 "Development of measurement techniques and sensors for the measurement in the micro- and nanometre range, supporting the increasing level of integration and miniaturization"

Page 13 "Improvement of dimensional metrology for advanced manufacturing in well-controlled to harsh production environments;"

Page 38 "Dimensional measurements play a crucial role in almost every aspects of modern life. From nanometre (nm) tolerances for sub-micrometer (sub-µm) device features like in semiconductor production"

Page 39 "Multi-parametric metrology (i.e.: dimensional plus optical, electrical or magnetic properties) is required if feature sizes approach the nm-scale"

Keywords

Scatterometry, AFM, CD-SEM, structured surfaces, Inverse methods, critical dimensions, line edge roughness, curved structured surfaces, deep structures, none-periodic structures and defects.

Background to the Metrological Challenges

Dimensional metrology of small structures is a cross-discipline that may be applied within a wide variety of areas mainly in the semiconductor and optical industries but also in mechanical engineering (length and angle encoders), biological and medical industry. Dimensional metrology of high-end laterally structured functional surfaces is a constant challenge due to the ongoing miniaturisation of feature size.

Several reports have been published on the challenges of measuring small structures. The main document for the future need of metrology in semiconductor metrology is the ITRS roadmap [1], in which the CD (Critical Dimension) measurement is denoted as one critical component. But also other reports (e.g. European Technology Platform Nanoelectronics [2], NNI instrumentation workshop, Nanostrand report, Co-Nanomet Consulting paper) agree, that the global challenge topics for the optical and semiconductor industries include measurement of 3D structures with an uncertainty below one nanometre, characterisation of structured miniaturised curved surfaces, standardised methods for diffractive optical microstructure characterisation suitable for the semiconductor industry, and sub-nanometre precision measurements over a range of several millimetres fast enough for in-line measurement.

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The roadmaps state that the improvements to the current techniques of scatterometry (on-line), CD-SEMs (off-line) and AFMs (off-line) are the preferred solution for solving the continued metrology demand for smaller structure sizes. They also note:

1) Scatterometry is the main in-line metrology tool for studying surface properties. Optical scatterometry is commonly applied to directly study coherent optical effects, i.e. the intended optical action of structured surfaces, e.g. diffractive optical elements, gratings, holograms or layered structures. The speed and non-destructiveness of the measurements are key parameters that make scatterometry an excellent choice for process control in industrial applications.
2) CD-SEM is widely used for CD measurement on wafers as well as on photomasks. At energies smaller than 1 keV a resolution down to 1.5 nm and reproducibility in the subnanometre range can be achieved. Contour extraction algorithms are used for shape measurements. Due to the speed of operation CD-SEM is used as an off-line tool. 3D measurements are undertaken by tilt beam methods but are up to now not widely used for reasons of complexity and increased measurement uncertainty.
3) AFM is used as an off-line tool, due to the speed of operation. AFMs probe surfaces in either static or dynamic measurement mode. When a surface is scanned the structure form is calculated from the 3D coordinates of the scanning stage, which can be traceably and accurately measured by state-of-the-art interferometers. Although conventional AFMs have a small measurement range of typically less than 100 µm, long range AFMs are available with a capable measurement range up to 25 mm. In addition, special AFM probes such as flared AFM tips, carbon nanotube (CNT) AFM tips and the assembled cantilever probes are in use for measuring the 3D shape of structures, high-aspect ratio structures and at sidewalls. AFM can be used for the direct and non-destructive measurements of 3D structure parameters, which are essential for refining the SEM and scatterometric methods and algorithms.

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 overall aim of the JRP is to develop production measurements for small structures; e.g. for the semiconductor and optics industry. It should provide validated and reliable measurements/methods with traceability wherever it is practicable to do so.

The specific objectives are:

1. Improvement of the accuracy of scatterometric, inverse and SEM methods in the context of the ITRS roadmap and to broaden the use of these methods for example on micro-structured surfaces for optical industry.
2. Validation and optimisation of the scatterometric, inverse and SEM methods for application in industry with the help of ultra-high resolution SEM and AFM. For this aim, probing strategies for AFM to detect e.g. sidewall angles and vertical surface roughness of sidewalls should be developed.
3. The JRP may also include the development the design and methods for manufacturing and characterisation of ”golden” reference standards for metrology in wafer processing making use of the above-mentioned technologies.

Proposers shall give priority to work that meets documented industrial needs and that which supports transfer into industry e.g. by cooperation and/or by standardisation.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this.

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.

Where a European Directive is referenced in the proposal, the relevant paragraphs of the Directive identifying the need for the project should be quoted and referenced. It is not sufficient to quote the entire Directive per se as the rationale for the metrology need. Proposals must also clearly link the identified need in the Directive with the expected outputs from the project.

You should also detail the impact that your JRP outputs would have on European semiconductor industry, optics/ photonics industry, mechanical engineering industry and so on as detailed in the document "Guidance for writing a JRP"

In additions how will the JRP results:

- feed into the development of standards through appropriate standards bodies
- transfer knowledge to the European semiconductor industry, optics/ photonics industry, mechanical engineering industry

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 3 years duration.

Additional information

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

[1] International Technology Roadmap for Semiconductors ITRS http://public.itrs.net/Links/2009ITRS/Home2009.htm

[2] European Technology Platform Nanoelectronics (2007) http://cordis.europa.eu/technology-platforms/pdf/eniac.pdf