EMPIR Call 2020 – Fundamental, Industry and Normative

Selected Research Topic number: **SRT-i11**
Version: 1.0

Title: Traceable metrology of soft-X-ray to IR optical constants and nanofilms for advanced manufacturing

Abstract

Next generation materials and ultra-thin films with tailored optical properties for integrated circuits will rely on innovations in nanotechnologies including extreme UV (EUV) lithography. Knowledge of their properties is key for innovations based on size-dependent material parameters with an increasing importance placed on quantum effects. Photonic measurement methods in the soft-X ray to IR wavelength range that approach theoretical limits need better traceability coupled with rigorous uncertainty estimations to provide the tools needed to characterise novel optical materials. Whilst the mathematical modelling approaches these rely on require improvement to increase technique applicability.

Keywords

nanotechnologies, nanofilms, advanced manufacturing, photonics, optical constants, traceability, uncertainty estimation, reflectometry, Mueller ellipsometry, scatterometry, soft-X ray to IR, mathematical models

Background to the Metrological Challenges

Optical components and integrated circuits are essential for the introduction of the factory of the future where machines will sense, operate, confirm product quality and self-correct production errors. At the heart of these advances is the EU photonics industry. Currently employing 300 000 highly skilled workers, it generates 60 billion of € in turnover annually. To maintain the nano-electronics industry at the forefront of technological advances, the extreme UV technologies used must evolve to enable the production of next generation photomasks and the development of innovative optical materials. These will increase microprocessor energy efficiency and facilitate access to quantum computation and communications.

The light-based techniques of scatterometry, reflectometry and ellipsometry provide metrological traceability for nanostructures via indirect assessments based on modelling but as feature sizes reduce new measurement challenges must be overcome. These include the provision of Gum-compliant uncertainty evaluations for spectroscopic ellipsometry and resolving discrepancies between it and other techniques operating in the soft X-ray to IR spectral range such as X-ray reflectometry (XRR), X-ray photoelectron spectroscopy, and transmission electron microscopy.

Interlayer effects and created geometries in nanofilms coupled with the increasing use of materials exhibiting absorption edges in the EUV spectral range introduce measurement challenges that require the development of improved modelling methods. To investigate the performance of advanced photometry techniques and introduce greater comparability between them, thin film systems and nanostructures with traceable optical constants need development. Working at close to theoretical measurement limits, new modelling tools potentially based on machine learning, and Bayesian approaches are needed to convert the reflected light generated into meaningful measurements of optical constants.

Publicly available optical constant databases have been established for novel optical materials across different wavelength ranges to assist photonic industry developments of innovative materials, However, the underlying data sets can be of poor quality relying on calculated and estimated values without robust traceability or reliable uncertainty estimations. Industrial users require a database containing high quality and traceable data to assist in the development of tailored next generation materials suitable for advanced photonics applications.

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 protocol.

The JRP shall focus on the development of traceable measurement techniques for optical constants of thin-film systems and nanostructures and to use these techniques to support the introduction of an improved optical properties database for industrial users. This should assist in the development of novel optical materials with tailored properties.

The specific objectives are:

1. To identify, select and produce test samples including ultra-thin layer systems, complex nanostructures (e.g. pillar-halls) and novel materials (high k-materials and other materials, e.g. 2D nanosheets). In addition, to provide metrologically characterised optical response data for use in the existing databases and models that are used by industry.
2. To develop reflectometry, Mueller ellipsometry and scatterometry as reliable and traceable thin-film metrology techniques, in the soft X-ray to IR spectral range, for determining the layer thickness, optical constants (such as the refractive index, absorption coefficient, reflectivity) and dielectric tensors of the test samples developed in objective 1. This should include the development of reference materials that are suitable for industrial use.
3. To develop and apply advanced mathematical models to virtual and real measurements in order to determine the optical response of the test samples developed in objective 1 and their dependence on complex (nano)structures. The uncertainties associated with ab initio methods, interlayer roughness, crystal structures, model reduction techniques, surrogate modelling, machine learning and inverse modelling should also be determined.
4. To determine the optical constants and the corresponding measurement uncertainties of thin stratified layer systems and to estimate the geometrical parameters of these complex (nano)structures in the soft-X ray to IR spectral range. In addition, to assemble a database of optical constants, dielectric tensors and estimated geometrical parameters, including both measurement values and virtual/simulated measurement data.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain (photonics industry), standards developing organisations (DIN, ISO) and end users (photovoltaics, advanced manufacturing and healthcare sectors).

Proposers shall give priority to work that meets documented industrial needs and include measures to support transfer into industry by cooperation and by standardisation. An active involvement of industrial stakeholders is expected in order to align the project with their needs – both through project steering boards and participation in the research activities.

Proposers should establish the current state of the art, and explain how their proposed project goes beyond this. In particular, proposers should outline the achievements of the EMPIR project 15SIB09 3DNano and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 1.5 M€, and has defined an upper limit of 1.8 M€ for this project.

EURAMET also expects the EU Contribution to the external funded partners to not exceed 30 % of the total EU Contribution across all selected projects in this TP.

Any industrial partners that will receive significant benefit from the results of the proposed project are expected to be unfunded partners.

Potential Impact

Proposals must demonstrate adequate and appropriate participation/links to the “end user” community, describing how the project partners will engage with relevant communities during the project to facilitate knowledge transfer and accelerate the uptake of project outputs. Evidence of support from the “end user” community (e.g. letters of support) is also encouraged.

You should detail how your JRP results are going to:

- Address the SRT objectives and deliver solutions to the documented needs,
- Feed into the development of urgent documentary standards through appropriate standards bodies,
- Transfer knowledge to the photonics and electronics sectors.

You should detail other impacts of your proposed JRP as specified in the document “Guide 4: Writing Joint Research Projects (JRPs)”

You should also detail how your approach to realising the objectives will further the aim of EMPIR to develop a coherent approach at the European level in the field of metrology and include 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 EURAMET Member States whose metrology programmes are at an early stage of development to be increased
- organisations other than NMIs and DIs to be involved in the work.

Time-scale

The project should be of up to 3 years duration.