European Partnership on Metrology
Call 2023 –Fundamental Metrology, Industry, Normative and Research Potential

Selected Research Topic number: **SRT-f09**
Version: 1.0

Title: Unified nanometrology in classical and quantum regimes

Abstract

We are on the verge of a technological revolution entirely driven by the next generations of electronic chips, which will be faster, smaller, more energy efficient, and more sustainable. The fabrication of these chips happens at dimensional scales below 10 nm and requires scientific and technological progress that cannot be realised without fast, non-invasive, highly reliable optical metrology. Therefore, the development of the next generation of optical metrology is needed to enable such technological progress. This includes solving fundamental challenges in inverse problems, developing metrology for complicated layer structures and the characterisation of emerging advanced materials.

Keywords

Optical nanometrology, quantum optical metrology, diffraction limit, optical scatterometry, inverse scattering, super-resolution microscopy

Background to the Metrological Challenges

Over the last three years worldwide lock-downs, escalating geopolitical tensions and the high demand of raw materials have resulted in a shortage of electronic chips. This shortage has impacted the production of home appliances, cars, computing facilities, and the whole technology sector, with negative consequences for mobile networks, renewable energy production, health care, and digitalisation. Such a shortage has never been experienced by modern societies before and hence autonomous chip production, and the technologies that enable it, the most important being optical lithography and optical dimensional metrology, have become strategically important for the world's largest economies. Since 2000, Europe's semiconductor manufacturing has declined from 24 % of global production capacity to 8 %. In addition, it is currently primarily focussed on mature microchip technology, with only a small fraction on advanced chip technologies.

In order to fill this technological gap, the EU put in place the EU Chip Act (2023-2030), which aims to re-gain Europe's leading role in the design and manufacturing of the next generation of microchips, down to 2 nm nodes and below. When it comes to the actual deployment of the EU Chip Act plans, a major role is played by dimensional metrology of nanostructures which is critical for the lithographic production of electronic devices. Currently, optical measurement techniques are the only viable option for in-line, fast and non-invasive dimensional metrology, which is a key part of the chips fabrication chain. Thus, without accurate metrological tools for monitoring and correcting production imperfections (e.g. overlay errors, critical dimension defects, edge placement errors) the reliable production of the next generations of electronic devices will not be possible.

Current chips consist of complicated structures stacked on top of each other, with often limited knowledge of the thickness and compositions of layers in between. Only by accurate alignment of the different structures can the correct functioning of the final device can be guaranteed. Furthermore, the current level of overlay error needs to be improved in future advanced devices.

Nanoelectronics and most photonic devices are often surrounded by other structures that significantly influence, the signal measured by an optical probe. This makes measuring the dimensions of these nanostructures through light extremely cumbersome. Therefore, novel, robust optical metrology techniques are needed for non-periodic deep-subwavelength geometries.

Modern optical metrology techniques have an inverse problem for target sizes below the diffraction limit. With the shrinking of physical dimensions to nanostructures, the inverse problem grows exponentially. There is currently no solution for this, thus, fundamental concepts and new measurements channels (both from classical and quantum effects) are needed to mitigate the complexity of the problem and preserve accuracy at adequate levels.

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 traceable measurement and characterisation of nanometrology in classical and quantum regimes.

The specific objectives are

1. To develop methods for the use of quantum correlations combined with strong electromagnetic scattering interactions, with high-accuracy errors (target 1 nm) in deep subwavelength (< 10 nm) geometries. The methods should surpass the limitations of existing optical techniques and allow the overlay of error estimation of periodically patterned layers in a device, with a target subwavelength pitch accuracy of 0.3 nm and precision (k=3) of 0.1 nm. In addition, to investigate the synergic integration of quantum and classical technologies for polarisation shaping/mapping including quantum ellipsometry and scatterometry.
2. To establish low-volume (< 1 μm3), high-resolution (< 10 nm) localised microscopy for novel complex 3D structures in the sub 10 nm regime including tackling the fundamental limits of signal-to-noise ratio versus spatial resolution. This includes (i) improving state-of-the-art scattering-based techniques, (ii) enhancing the sensitivity of highly localised optical nanometrology with far-field detection schemes, (ii) the development of new localised measurement methods (e.g., novel label-free super-resolution microscopy, highly localised controllable photonic nano-jets) and (iv) the design of novel metamaterial-based fiducials exploiting resonance by merging classical and quantum technologies.
3. To develop novel far-field light-matter-scattering-based methods for the reliable reconstruction of complex 3D nano-geometries and emerging materials. This will require:

   (i) exploiting information channels in a light field (e.g. polarisation, light-field mode projection, phase information) using novel approaches such as by single-shot intensity measurements,

   (ii) investigating the constraints from fundamental principles, such as non-trivial symmetries or topological conservation laws,

   (iii) analysis of emerging advanced materials (e.g. anisotropic or 2D) including meta-materials and their interaction with light,

   (iv) numerical simulations of measurements for interpretation of experimental results.
4. To develop reliable and computationally efficient solutions for inverse problems (i) in estimations of parameters of interest (e.g. constraints imposed by device geometry or the technology used for fabrication), and (ii) the mitigation of noise, corruption, and incompleteness of data. In addition, to develop improved inversion methods for going beyond maximum entropy, and improved methods for symmetry transformation, then to use these improved methods to study the dimensionality reduction of the parameter space for specific targets of interest.
5. To facilitate the take up of the technology and measurement infrastructure developed in the project by the measurement supply chain, research organisations (EMN Quantum), standards developing organisations (ISO/TC 229 Nanotechnologies, CEN/TC 352 Nanotechnologies), metrology community (EURAMET TC-L, BIPM CCL), and end users (quantum and nanotechnology sectors).

These objectives will require large-scale approaches that are beyond the capabilities of single National Metrology Institutes and Designated Institutes. Proposers shall give priority to work that aims at excellent science exploring new techniques or methods for metrology and novel primary measurement standards, and brings together the best scientists in Europe and beyond, including other European Partnerships, whilst exploiting the unique capabilities of the National Metrology Institutes and Designated Institutes.

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 projects 17FUN01 BeCOMe and 20FUN02 POLight and how their proposal will build on those.

EURAMET expects the average EU Contribution for the selected JRPs in this TP to be 2.0 M€ and has defined an upper limit of 2.5 M€ for this project.

EURAMET also expects the EU Contribution to the external funded beneficiaries to not exceed 40 % of the total EU Contribution across all selected projects in this TP.

Any industrial beneficiaries that will receive significant benefit from the results of the proposed project are expected to be beneficiaries without receiving funding or associated 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,
- Facilitate improved industrial capability or improved quality of life for European citizens in terms of personal health, protection of the environment and the climate, or energy security,
- Transfer knowledge to the quantum and nanotechnology 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 the Partnership 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.