EMPIR Call 2020 – Fundamental, Industry and Normative

Selected Research Topic number: **SRT-f10**
Version: 1.0

Title: Pushing boundaries of nano-dimensional metrology by light

Abstract

Innovative batteries and sensors, high-capacity memories, novel textiles, advanced leisure and health-care products all rely on our ability to shape matter at the nanoscale. Consequently, the EC has identified Key Enabling Technologies (KETs) including nanotechnology, micro-nanoelectronics, photonics and advanced materials where the EU needs to remain dominant for future society. Such KETs have a "significant impact on how Europeans will live and work, and on how European industries and economies will grow to provide sustainable employment for its citizens". However, currently Europe is reaching a "metrology gap", where existing optical metrology methods for these KETs, are unable to underpin the associated technological progress. Therefore, new optical methods are urgently needed for nano-dimensional metrology to help bridge this gap.

Keywords

Spatial super-resolution, nano-dimensional metrology, phase-retrieval, light-matter interaction, inelastic scattering, topology-driven metrology, far-field, near-field, metamaterials, quantum measurements

Background to the Metrological Challenges

Contactless optics-based measurement methods are the metrological backbone for the development of 4 of the KETs identified by the EC (i.e. nanotechnology, micro-nanoelectronics, photonics and advanced materials). These 4 KETs are the preferred tool to determine, with high precision and accuracy, the sizes, geometries and physical properties of the nanostructures which represent the building blocks of innovative devices. Optical measurement methods are also convenient as they are fast, non-damaging, and have appropriate penetration depth in matter: all of which are leads to their widespread use within academia and industry. In particular, the requirements for fast metrology negate the use of high-resolution methods such as scanning near-field optical microscopy (SNOM) and atomic force microscopy (AFM) in industrial applications and means that far-field optical methods are the only option.

The main challenge with the current technological progress in nanotechnology, micro-nanoelectronics, photonics and advanced materials is the shrinkage of the dimensions of fabricated structures (e.g. < 50 nm in the semiconductor industry). Consequently, the control of production processes relies on the measurement of increasingly smaller dimensions. which in turn requires accurate alignment of nanostructures. Traditionally, the demand for creating smaller structures has been addressed by increasing the numerical aperture (NA) of optical systems and by scaling down the wavelength of the light source used. Thus, in principle, shorter wavelengths could also be used for nano-dimensional metrology. However, this would dramatically increase instrument complexity and more importantly the penetration depths and optical contrast of matter are drastically reduced at shorter wavelengths and some material properties become less apparent.

The spatial resolution of optical imaging metrology is limited by the diffraction of light to about half of the wavelength e.g. 200 nm spatial resolution when using 400 nm wavelength light. In non-imaging methods, this resolution limit is overcome by combining prior knowledge on the object to be measured with rigorous modelling, an approach known as "holistic metrology". This is currently the standard way that non-imaging methods, such as optical scatterometry operate. Sub-20 nm dimensional metrology of objects has been proven through this approach and this makes these methods the current de facto in high-tech industries. However, to date, no optical methods have been proven able to reach such levels for nano-dimensional metrology.

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 optical methods for nano-dimensional metrology.

The specific objectives are

1. To develop accurate methods for measuring lateral features size below 10 nm at uncertainty levels of 0.1 nm using far-field illumination far-field detection optical methods. Such methods should (i) allow nanoscale-level metrology of objects located at different penetration depths in media and in the presence of intermediate layers, and (ii) encompass spectral diversity, angular diversity, spatial diversity, polarisation diversity and metamaterials-enhanced scattering.
2. To investigate the use of diffraction-based optical methods that integrate the classical Rayleigh regime with inelastic, nonlinear and resonant regimes for nano-dimensional metrology. Such methods should include coherent or incoherent Raman scatterometry, and the integration of non-linear effects with super-resolution through multiple scattering beyond the Born regime. The targeted spatial resolution will be below a tenth of the wavelength.
3. To determine the accuracy (a target of 1 nm) and traceability of novel optical methods, such as iterative phase-sensitive methods, structured-illumination and pump-probe microscopy. This should include (i) mapping the transfer of the phase information from the near-field to the far-field in light-matter interaction processes, (ii) creating new artefacts, and (iii) developing advanced inversion algorithms.
4. To develop traceable quantum-optics measurement methods using engineered quantum states of light in order to achieve super-sensitivity in nanodimensional measurements. Such methods should fully exploit the spatial degrees of freedom of a quantum field and achieve sub-Poisson sensitivity.
5. To facilitate the take up of the knowledge, technology and measurement infrastructure developed in the project by the measurement supply chain, standards developing organisations (ISO, CEN) and end users in nanotechnology, micro-nanoelectronics, photonics and advanced materials.

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, 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 project 17FUN01 BeCOMe and how their proposal will build on this.

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 40 % of the total EU Contribution across all selected projects in this TP.

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 nanotechnology, micro-nanoelectronics, photonics and advanced materials 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.