Title: Light-matter interplay for optical metrology beyond the classical spatial resolution limits

Abstract

The finite spatial resolution of optical systems represents a major obstacle for optical metrology in the nanoworld. Scaling down the wavelength towards the soft x-ray range can partly compensate this limit, but without providing the richness and diversity of information offered by optical measurements. New paradigms, combining the interplay between light and metamaterials, exploiting the topological information encoded in optical fields and recent advances in the fields of quantum optics and inverse problems show promise for disruptive achievements in classical optical systems.

Keywords

Light-matter interaction, nanometrology, topology in optical fields, homogenisation, near fields, quantum measurements

Background to the Metrological Challenges

Dimensional optical measurement methods are, by far, among the most vastly adopted and most reliable existing metrology tools. They investigate light-matter interaction at the fundamental level and are used, for example, in optical microscopy for biological applications and in semiconductor industry for inline nanometrology. The spatial resolution attainable in optical metrology is limited by the wavelength used for the optical probe (the Rayleigh Criterion). For instance, in common imaging systems that results in a spatial resolution not better than 200 nm with a 400 nm wavelength. For non-imaging systems, such as in Fourier microscopy or optical scatterometry, better spatial resolutions can be reached, but at the costs of a higher computational effort and only though a massive use *of a priori* information, something which is better known as holistic metrology.

To improve the resolution, shorter wavelengths can be used, a trend that has now reached the few nanometre scale (EUV/Soft-X-ray range). However, the complexity of the system grows enormously at such shorter wavelengths (vacuum conditions requirements, EUV/X-ray hazard etc.) and so do the required investments. But, as physical parameters do not scale with the wavelength, some material properties are not necessarily unveiled with shorter wavelengths. Shorter wavelengths result in shorter penetration depths, less sensitivity, more invasiveness. Light also gives insights into the structure of matter, especially in the ultraviolet, visible and infrared part of the electromagnetic spectrum, due to the fact that most of the electronics and molecular transitions fall in that spectral range.

It is debated whether the Rayleigh criterion is a fundamental limit or a technological limit and research is suggesting possible ways to circumvent it and let far-field optical techniques compete with near-field methods for practical improvements in spatial resolution. Metamaterials research has also developed methods for obtaining the spatial resolution typical of near-field techniques in far-field techniques. Some suggest that by encoding invariant and robust topological information into a light probe, greater spatial information can be extracted. Exploiting peculiar properties of quantum optical states could also be a route to beat classical optical limits. This topic should bring together the diverse scientific communities working on classical and quantum optics to explore a common route forward.

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 developing different research activities to tackle the current limitations in spatial resolution of optical systems.

The specific objectives are

1. To exploit light-matter interaction under the strong coupling regime, and achieve an operational spatial resolution well below 100 nm, and subnanometer uncertainty, for optical systems working in the visible range, in a far-field illumination far-field detection scheme. A traceable spatial resolution at $\lambda/10$ level should be targeted (λ being the wavelength of the light probe).
2. To study the creation, annihilation or transformation of topological information in optical fields due to the interaction with matter. To realise, also for the spatial degrees of freedom, novel spectroscopy-like measurement concepts, leading to robust and high-precision dimensional and physical measurement results.
3. To apply coherent (phase-locked) links between the optical scale and the nanoscale (<< 100 nm), enabling dimensional measurements of nanostructures with accuracies in the nm range.
4. To realise input fields with spatially-entangled optical channels and to map their coupling with the geometry of nano-targets. To explore the potential of quantum metrology optical schemes based on spatial mode entanglement and its integration into existing optical systems.
5. To facilitate the take up of the technology developed in the project by end users.

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.

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 to the project.

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,

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.