Publishable Summary for 20FUN02 POLight
Pushing boundaries of nano-dimensional metrology by light

Overview

Innovative devices, such as nanochips, high-capacity memories, novel materials and future point-of-care tools all rely on our ability to shape matter at the nanoscale. Thus, the European Commission has identified four Key Enabling Technologies (KETs) (i.e., nanotechnology, micro-nanoelectronics, photonics and advanced materials) as strategically important for the European Union (EU). However, the fast-paced technological progress of these four KETs is currently creating a “metrology gap” when compared to the progress in developing metrology methods, critical for validating the development of KETs. This project addresses this issue by developing novel methods to help bridge the metrology gap and in turn foster KET innovation. More specifically, this project will push the boundaries of optical measurement methods by realising a new generation of optical metrology systems, with unprecedented performances in terms of spatial resolution, traceability, reliability, and robustness.

Need

KETs are technological domains identified and prioritised by the EU because they drive innovation throughout the economy and cut across industries. These KETs are transforming our economies and generating new markets and their total economic impact is huge. In 2015, the global KETs market was evaluated to be 1 trillion Euros and at this time the EU produced 23 % of the world’s exports in KETs-based products. However, the competition in these KETs is fierce, and Europe is currently struggling to keep up with East-Asia and the US. Therefore, the EU is calling for urgent action to regain a worldwide leading position on these technologies.

This project aligns with the EU’s request for action by developing the next generation of optical metrology methods which can cope with the challenges represented by the evolution foreseen in the KETs. Indeed, the development of the four KETs; Nanotechnology, Micro-nanoelectronics, Photonics and Advanced materials is strongly underpinned by optics-based measurement methods.

These four KETs build on the manipulation of matter at the nanoscale, in a predictable, reliable, and reproducible way, and hence require appropriate optical metrology solutions in place to support them. Despite the many advantages of optical systems (e.g. speed, non-invasiveness, high-precision, affordable investments involved, integrability) their spatial resolution is continuously challenged by the increasingly smaller sizes of the new generation of devices fabricated. The result of this is an endless race between technical demands and metrological responses. But only by developing, new metrology solutions can we confidently push technologies to the next level and pave the route for even better advances in KETs.

Objectives

This project aims to push the boundaries of optical measurement methods by realising a new generation of optical metrology systems, with unprecedented performances in terms of spatial resolution, traceability, reliability, and robustness. The objectives of the project are:

1. To develop accurate methods for measuring lateral features size below 10 nm at uncertainty levels of 0.1 nm using two types of far-field illumination far-field detection optical methods.
    - diffraction-based optical methods within the classical Rayleigh regime (e.g. optical scatterometry with structured illumination, 3D through focus microscopy, hybrid/holistic metrology (e.g. combined spectral Mueller Matrix Ellipsometry and goniometric scatterometry), coherent scatterometry (CFS) and Multi Angle Light Scattering (MALS) for particle metrology) or
    - super-resolution through multiple scattering beyond the Born regime (e.g. ptychography).

This includes developing advanced inversion algorithms. Both the diffraction-based and super-resolution optical methods (i) should 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, and polarisation diversity. Furthermore, to create new artefacts to validate and test the performance of the optical methods developed and investigated.

2. To develop innovative inelastic, non-linear or resonant optical metrology methods with a target uncertainty level of 1 nm, such as linear and non-linear SIM, and pump-probe Super Resolution Microscopy (SRM) techniques (e.g. Surface plasmon resonances (SPR) assisted Raman, coherent multiphoton-Raman and Stimulated Emission Depletion (STED). This should include the integration of non-linear effects with super-resolution metamaterials-enhanced scattering with methods such as enhanced scatterometry, enhanced internal reflection ellipsometry, multispectral plasmonic lenses and Photonic Nanojet (PNJ) illumination in SRM). The targeted spatial resolution of the different imaging methods will be below a tenth of the wavelength.

3. To develop innovative imaging methods (e.g. a wide field SIM microscope exploiting single photon emission from colour centres in diamond or quantum correlated beams) based on engineering the spatial shape of light in the classical and quantum domains in order to achieve either super-sensitivity or super-resolution (or both) in nano-dimensional measurements. Such methods should fully exploit the spatial degrees of freedom of the classical or quantum field, respectively and achieve sub-Poisson sensitivity in the quantum regime. These innovative methods should enable traceable classical and quantum-based absolute phase-sensitive optical measurements.

4. 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.

Progress beyond the state of the art

The state-of-the-art in optical nanometrology at the beginning of the project was that imaging optical measurements on technical objects were limited in resolution, so that structures with a size below about 100 nm could have hardly been measured and non-imaging methods (being not principally limited by a resolution limit) are in many cases limited by the obtainable signal-to-noise (S/N) ratio. The above-mentioned metrology gap cannot be solved simply by reducing the wavelength of the light source used in optical measurement methods since for imaging tools the achievable resolution is limited to a few 10 nm due to manufacturing issues and non-imaging tools show some practical issues such as source performance and sensitivity limitations.

This project is addressing this problem by developing optical metrology to access spatial resolution and measurement sensitivity for structure sizes at 10 nm level and pushes the boundaries of current state-of-the-art by:

- Realising novel methods that concurrently exploit the full diversity of information available in electromagnetic fields in the optical domain. This encompasses spectral diversity (broad and continuous range of wavelengths), angular diversity, spatial diversity (engineered amplitude and phase profiles to exploit topological information carried by a field), polarisation diversity (non-trivial local polarisation states) and metamaterials-enhanced scattering
- Exploring the potential of diffraction-based optical methods (like optical scatterometry, Mueller matrix ellipsometry, bright field and phase sensitive imaging) that integrate the classical Rayleigh regime with inelastic, non-linear, and resonant regimes. The goal is to establish novel techniques, such as coherent or incoherent Raman scatterometry, to exploit non-linear effects for super-resolution and integrate them with methods based on multiple scattering beyond the Born regime
- Setting the metrological foundations of iterative phase-sensitive methods, structured-illumination (linear or non-linear) and pump-probe microscopy. This includes mapping of the transfer of the phase information from the near-field to the far-field in light-matter interaction processes as well as creating new artefacts and advanced inversion algorithms (e.g. Bayesian inversion, machine learning-based), defining the calibration uncertainty and establishing the appropriate metrology chain to validate these methods

- Realising quantum-optics measurement schemes that use engineered quantum states of light to achieve super-sensitivity in dimensional measurements. This encompasses the combination of spatial entanglement with phase sensitive methods (ptychography, through-focus, self-referencing interferometry, ellipsometry etc.) by using modern tools, such as Spatial Light Modulators (SLM) or Digital Micromirror Devices (DMD). The goal is to obtain a full exploitation of the spatial (amplitude and phase) degrees of freedom of a quantum field through deep sub-Poisson sensitivity.

Up to now we have achieved many important steps to advance beyond the state-of-the art the direction of S/N improvement and resolution enhancements. So by systematically applying different resonance effects we could achieve an increase of the S/N by typical more than an order of magnitude, which will lead to a reduction of the measurement uncertainty of a comparable order of magnitude and significantly enhance the measurement capability for structures << 100 nm. With-it, this is a significant improvement and an important step towards a measurement capability of structures as small as 10 nm with uncertainty << 1 nm.

Results

To develop accurate methods for measuring lateral features size below 10 nm at uncertainty levels of 0.1 nm using two types of far-field illumination far-field detection optical methods

Based on specifications discussed and agreed within the consortium, 5 different reference artefacts have been designed, and their fabrication has begun. These artefacts are to be used to assess the metrological value of the measurement methods and inversion algorithms developed within this project (in objectives 1 & 2) and measurements using these reference artefacts are planned to start this summer.

A reliable, mechanically stable system based on multiple SLMs for an independent amplitude and phase control of an input light field was designed. This design was followed by building the system, which is still in progress. Also, the method for applying the structured illumination based on Helmholtz Natural modes (HNMs) is being developed and implemented in the system in obtain o obtain the first results. The preliminary scatterometry and ptychography measurements of the fabricated samples were performed using a hyperspectral scatterometer. Respective data processing techniques are now being implemented. The measurement results are being compared among project partners. A working single wavelength setup to measure the amplitude and phase of the scattered field has been developed to calculate the coefficients of the topological mode expansion to investigate the robustness of grating geometric parameter reconstruction. A method for structured illumination based on a field modal decomposition in topological modes (Helmholtz Natural Modes (HNMs) is in progress. A combined parallel data analysis (i.e., hybrid metrology) for spectroscopic Mueller ellipsometry and goniometric DUV scatterometry has also been successfully developed and implemented. Thus, the first step towards hybrid metrology is available and will be tested for sub-10 nm structures in the future.

A set-up for plasmonic lens-assisted microscopy for defect and contamination inspection was developed and successfully tested. Additionally, a method to combine the resolution advantage given by structured illumination with the quantum advantage of measuring high-order correlation functions in the detection plane has been investigated.

The project has successfully developed a way to project the patterns, generated by a SLM and an aperture mask in a sample of single photon emitters to retrieve the parameter (k-vectors and phases) of the patterns in the single photon emission-detection regime. A discrete Fourier transformation that transforms the scattered field from a periodic structure to the image plane has been made and is currently being integrated into the simulation software. The preliminary results on combinatorial plasmonic samples in Kretschmann geometry were generated and successfully indicated a promising performance. A forward model has also been made, and the resonances were clearly observed.

Furthermore, combinatorial Silver Aluminium (AgAl) layers were created and studied by moving focusing spot within a multi-angle ellipsometric arrangement. The results showed that the spectral position of the resonance can be shifted by laterally scanning the focal spot, due to the gradually changing optical properties of the graded combinatorial surface. Hot electron properties in a gold layer during plasmon excitation were investigated using multilayer models. A dispersion which is different from that of thermalized electrons was revealed by reference measurements on the high-temperature optical properties of gold. Periodic gold nanostructures have been defined using simulations to identify best sensing structures for ellipsometry in both Kretschmann and standard reflection configurations to measure processes at solid-liquid interfaces. Sensitivity has been determined on combinatorial plasmonic nanostructures by optical modelling and inversion for sensing at solid-liquid interface.

An internal comparison between the forward solvers used by project partners has been successfully undertaken to eliminate possible programming errors and identify systematic method-specific errors. The comparison showed an excellent agreement, and no significant systematic differences have been observed. Additionally, efficient, and adaptive numerical methods for computing scatterometric data via modal expansions have been developed.

For enhanced metrology on nanoparticle samples the proprietary file format for MALS-DLS has been adapted to enable (i) data exchange and (ii) the inversion algorithm of the size distribution to be set up by project partners. Samples for reference measurements were chosen for the testing of the inversion algorithm for batch MALS-DLS and subsequently, the samples and procedure of a measurement comparison to validate the investigated optical methods for nanoparticle characterisation have been successfully discussed and prepared. The first version of the algorithm has been developed, taking into account the uncertainty due to new challenges that arose during the practical implementation active steps were taken to stabilize the fit and to decrease the noise level. Hence, progress was made, and the preliminary results have been presented. Also, while performing and developing inverse scattering, advanced inversion, and inference methods, partners investigated the gap in models for several shapes.

The setup FDTD models for buried gratings was discussed among the partners. The new SNOM head usable for large area scanning was finalized and the first topography measurements were acquired. Currently the new optical setup containing the new SNOM head is under development. The prior data is being used for the development of neural network methodology.

To develop innovative inelastic, non-linear or resonant optical metrology methods with a target uncertainty level of 1 nm

Five different metamaterial supporting devices have been successfully designed and are currently being manufactured. Additionally, a first design of a grating coupling device for TERS tips has been designed. The design is currently being optimised using FEM simulations and different manufacturing strategies based on the results are being discussed.

Different methods and materials for resonance-enhanced scatterometry with a specific focus on high-k (high dielectric constant) materials such as hafnia, silicon and titania, both uncoated as well as buried by oxide, have been successfully investigated and show excellent results for the enhancement of the signal-to-noise ratio (SNR) of typically more than an order of magnitude. The related sensitivity enhancement for the corresponding dimensional parameters (e.g. duty cycle, height, oxide thickness) has been evaluated to be more than an order magnitude, resulting in significantly increased measurement uncertainties.

A theory for precise and rapid steering a photonic nanojet using computed structured illumination has been successfully developed. The detection and lateral measurement of sub-classical nanoparticles, as well as the vertical measurement of sub-classical thin films, using scanning photonic nanojets have been simulated. An uncertainty quantification of the photonic nanojet design using heterogeneous micro-lenses with production defects has been performed and the lens design has been adopted correspondingly. Microsphere-assisted microscopy with photonic jet illumination has been simulated by a 3D near-field and far-field semi-classical approach. The required spheres and sphere holders for testing this technique have been designed and are currently being fabricated.

Different concepts for the extension of plasmonic lenses to multiwavelength applications have been explored. First simulations have shown promising behaviours from a merged lens design.

Suitable test structures have been designed and manufactured for conventional and Kretschmann-Raether ellipsometry measurements at solid-gas and solid-liquid interfaces. Measurements on different structure types of combined plasmonic-waveguide structures have been successfully performed at multiple angles of incidence and show promising results on spectroscopic sensitivity patterns. Plasmon-resonance enhancements of more than one order of magnitude have been observed.

Sensitivity of ellipsometry suitable for determination of monolayer adsorption on highly oriented pyrolytic graphite was successfully demonstrated. The long terms stability, reproducibility, and location of the spot on the sample has been optimised for this purpose.

Different types of artificial diamond substrates for the implementation of processes for selective graphitisation in microscopic regions have been tested and from the results, a protocol was developed for the selective graphitisation of diamond in micrometre-sized regions embedded in the diamond crystal. Mono-elemental (i.e.

all-carbon) samples consisting of artificial single-crystal-diamond substrates incorporating polycrystalline graphitic areas at different depths below the surface have been fabricated and systematically and successfully pre-characterization using Kelvin Probe Microscopy (KPM). The structural properties of the graphitic micro-regions embedded in diamond have been determined so that these samples are now available for Raman imaging tests.

First concepts on label-free SRM have been considered and theoretical investigation have been started. A wide-field hyperspectral imaging instrument that exploits interference technique instead of a monochromator has been successfully implemented that exploits interference techniques instead of a monochromator. This concept will be extended to structured illumination for super-resolution imaging. A promising concept is the use of NV centres which will be probed by conventional STED microscopy. Two other concepts using label-free SIM have been investigated, either with a fast-scanning sub-diffraction spot or applying non-linear SIM. For the fast-scanning sub-diffraction spot both the application of photonic nanojet spot as well as the focal spot of a plasmonic lens are discussed.

To develop innovative imaging methods

Two novel phase imaging techniques, based on genuine quantum features, have been proposed and demonstrated experimentally.

One method is a quantum version of Differential Interference Contrast (DIC) microscopy that uses the Hong-Ou-Mandel effect for phase retrieval. Contrary to other methods that use the HOM effect for imaging, our scheme does not require either the use of a reference photon with a well-characterized spatial shape, neither numerical processing of the signal measured. The method can generate images of samples with subwavelength thickness, and these images can be straightforwardly obtained from experimental data.

In the second method, entanglement has been exploited to enhance imaging of a pure phase object in a non-interferometric setting, only measuring the phase effect on the free-propagating field intensity. The phase reconstruction is obtained by the Transport of Intensity Equation (TIE), while quantum correlation allows to remove quantum noise. Beside a general improvement of the signal-to-noise ratio at a fixed photon flux, the quantum enhancement is especially effective for the higher spatial frequencies, resulting in a better discrimination of small details. This method is quantitative, since provides the absolute value of the phase and operates in wide field mode, so does not need time consuming raster scanning. Moreover, it does not require spatial and temporal coherence of the incident light.

To test the investigated methods with classical and quantum light, phase objects are required. In order to not distribute the entangled photons, the surfaces on the outside of the phase object structures need to be very smooth. Therefore, different structure types, gratings, pillars and, a π-letter, have been fabricated for the phase objects.

A simple spectrometer has been realized using an aluminium coated reflective diffraction grating and a Corrected Triplet Lens of fused Silica to extract the m = 1 order reflection from the grating. We record the spectrum on an Alphalas Digital CCD Line Camera.

Finally, a first setup has been developed for super-resolution microscopy (SRM) using structured illumination and quantum antibunching from colour centres in diamond Currently, the SNR is too low to see the desired quantum effect. New investigation has been done in order to increase the brightness of the centres. First, optically active defects based on the incorporation of Sn impurities in "electronic grade" diamond substrates have been developed. Then, the effects of thermal processing (annealing treatment in different atmosphere conditions) and surface termination (oxidation/hydrogenation) were extensively investigated. It was found that higher oxidation levels resulted correlated with enhanced NV-center fluorescence. A tendency to saturation was observed at the highest oxidation degrees, probably due to the almost complete removal of surface quenching phases. Moreover, excessive oxidation resulted in a slight decrease in fluorescence, as also the diamond core phases could have been affected. NV-/NV0 ratio showed the highest value in the mildly oxidized samples, thus suggesting them as preferable when a high concentration of NV- is required.

Impact

A website containing general information about the project has been set up at PTB (https://www.ptb.de/empir2021/polight/home/) and news stories and articles highlights, and other news will be presented here. A project flyer has been designed and is available on the website as well.

Early project results have already been published in 13 peer-reviewed publications, 3 more have been submitted or drafted and more results have been published in 5 open access conference proceedings,. Additionally, 22 talks or posters have been presented at conferences in Europe (17), USA (1), ROK (1) and Japan (1).

Moreover, 5 dedicated training activities for students and young scientists at summer/winter schools or workshops.

Impact on industrial and other user communities

The European high-tech industry must continue to innovate if it is to be competitive in the global market. In recent years the EU has experienced a problem with its innovation capacity, currently lagging behind East-Asia and the lack of proper innovation" […] *is generally attributed to the EU having its economic structure concentrated in medium-technology sectors, and failing to move into new, higher technology sectors with more scope for innovation-based growth*."

This project targets the semiconductor, photonics and nanoelectronics sectors due to their strong dependence on the availability of advanced optical measurement techniques. These advanced optical measurement methods are typically used for process control, accurate alignment of parts, and detection of defects. This project performs fundamental research on nano-dimensional metrology using light to tackle the current metrology limits of advanced optical systems and to go beyond the current state of the art. The project results will help European high-tech industries to remain competitive and regain a dominant position on the KETs.

The project aims to achieve impact by engaging, at early-stage, with key stakeholders operating in the targeted KETs and hence applications relevant to such end-users can be assessed and tested in a relatively short time. This is supported by the implementation of a stakeholder committee, which will provide helpful end-user feedback to the project as well as help promote the outputs of the project. So far, the project has been engaging with stakeholders such as Mitutoyo, ASML, or Zeiss. An employee from Mitutoyo will be a guest for one day a week at partner TU Delft, in order to facilitate knowledge transfer.

Additionally, the project is organising end user focused events to disseminate its results such as a topical meeting on international conferences. In September 2022, for example, the project organised the topical meeting *Frontiers in Optical Metrology* on optics-based dimensional metrology within the Annual Meeting of the European Optical Society (EOSAM2022) in Porto. Many partners have joined this event and have presented current project results to a mixed scientific and industrial audience. Another conference on phase sensitive measurements again with a mixed audience has been successfully organised in November 2022 in Delft (Face2Phase3), again with many presentations of latest project results by different partners.

Impact on the metrology and scientific communities

This project encourages collaboration between the scientific communities working in materials science, instruments design, classical and quantum optics, and is stimulating these communities to unite their efforts to advanced innovation in optical nanometrology.

The project's results will go far beyond the current state-of-the-art, particularly the novel measurement paradigms proposed for nano-scale dimensional metrology by light. The project's work on extending the "measurement space" of optical methods (objectives 1 and 2) and the inception of classical and quantum phase-sensitive measurement methods (objectives 3 and 4), along with the assessment of their metrological value, also have high scientific potential.

The project's impact on the metrology and scientific communities will be promoted via several training activities, including a school of physics (which is planned in 2023), lectures within a course on *Advanced Photonics* offered at partner TU Delft, several screencasts and a dedicated session on project topics organised at the Nanoscale conference in 2023.

So far, POLight partners have organised the 14th Annual Meeting Photonic Devices, where first results have been presented and discussed with a broader scientific audience. Moreover, a training course on FEM modelling of photonic devices has been held, and other training on quantum lectures has been held online in May 2022 and at the *Quantum 2022: Summer School on Quantum Optical Technologies in Apulia* in Trani, Italy. The dissemination of project results has been further supported e.g., by presentations at a "Summer school" (Denmark, Okt. 2021) and the "Quantum Night" (Torino 2022). Finally, the 15th Annual Meeting Photonic Devices will be organised in March 2022 in Berlin and in June a topical meeting on *Modelling Aspects in Optical Metrology* a topical meeting at the conference of Optical Metrology and the World of Photonics congress in Munich. Many partners will again use both events w to disseminate the latest project results to a broad scientific community.

Further, the project results will be distributed within the ellipsometry community via communication within the German Association on Ellipsometry, the AK Ellipsometrie Paul-Drude e. V. and presentations on the next AKE workshops from 19th to 21st September in Prague (https://indico.eli-beams.eu/event/441/). Project partners are also members of the European Materials Characterisation Council (EMCC), working group 1, "Instrumentation and Metrology," and will disseminate the project's results through this working group.

In addition, the project will benefit the metrology community through the direct engagement of European NMIs and Technical Committees. The use of optics-based measurement methods is expected to grow in the future, therefore early engagement of the metrology community with the most recent advances in this area could lead to new Calibration and Measurement Capabilities (CMCs). Furthermore, the project is aligned with the EURAMET Strategic Research Agenda for Metrology in Europe "*Nanotechnologies and nanoscience are triggered by diverse fields and applications. Miniaturisation in industrial environments and the relentless requirements of the International Technology Semiconductor Roadmap (ITRS) are driving processes to sub-nm accuracy level for critical features and positioning tasks"*.

Impact on relevant standards

As a fundamental metrology project, achieving a broad impact on written standards is not expected. However, the project's results will be disseminated to standardisation bodies where project partners are involved. These include the EURAMET Technical Committee Length (TC-L), the BIPM Consultative Committee for Length Working Group on Dimensional Nanometrology (CCL-WG-N), the Technical Work Area (TWA) Versailles Project on Advanced Materials and Standards (VAMAS) 42-TWA on Raman and microscopy, ISO/TC 229 Nanotechnologies, CEN/TC 352 Nanotechnologies, DIN NA062- 01- 61 AA Materials Testing - Measuring and test methods for coatings and coating systems and IMEKO TC 21 Mathematical Tools for Measurements.

The project partners, who are members of these technical committees, will regularly inform them about the project results and will endeavour to ensure they are incorporated in any updates to standards.

Longer-term economic, social and environmental impacts

The European Commission (EC) formally recognised the importance of Nanotechnology, Micro-Nanoelectronics, Photonics and Advanced materials by designating them as four KETs. The total economic impact of these four KETs is huge and in 2015, the EU contributed approx. 23 % of the world's exports in KETs-based products. However, the EU is facing fierce competition from East-Asia e.g., between 2002 to 2015 the share in total KETs exports for East-Asia increased from 45.86 % to 62.7 1%, whereas that of the EU only increased from 21.61 % to 22.14 % Furthermore the share of total KETs patents, in the same period, increased for East-Asia from 36.86 % to 43.56 % while that of the EU reduced from 25.71 % to 21.74 %. These figures indicate East-Asian countries' large-scale investments in KETs and have in KETs and have led to intense pressure exerted on European high-tech companies to innovate and protect their novel technologies.

This project will support the metrological innovation needed for these strategic KET sectors and to help the scientific community and European industries sustain a worldwide competitive position. By pushing forward the boundaries of optical measurement methods and realising a new generation of optical metrology systems, with unprecedented performances in terms of spatial resolution, traceability, reliability and robustness, this project will help to place the EU at the forefront of advanced and sustainable economies. This is vital as KETs are expected to "[…] *contribute to achieving reindustrialisation, energy, and climate change targets simultaneously, making them compatible and reinforcing their impact on growth and job creation*".

List of publications

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This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:	September 2021, 36 months	
Coordinator: Bernd Bodermann, PTB Tel: +49 5315924222 E-mail: bernd.bodermann@ptb.de Project website address: https://www.ptb.de/empir2021/polight/home/		
Internal Funded Partners: 1. PTB, Germany 2. CMI, Czech Republic 3. DFM, Denmark 4. INRIM, Italy 5. SMD, Belgium 6. VSL, Netherlands	External Funded Partners: 7. DTU, Denmark 8. EK, Hungary 9. FSU Jena, Germany 10. ICFO, Spain 11. JCM, Germany 12. SwanU, United Kingdom 13. TU Delft, Netherlands 14. TUBS, Germany 15. UNITO, Italy	Unfunded partners
RMG – 20FUN02 – RMG1		