Photonics PPP

Photonics21 Research and Innovation topics (RIA)

for the Horizon2020 PPP Work Programme 2018-2020
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Photonics21 Research and Innovation Actions – Summaries

Work Group proposed action 2018-2020, extract

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1. **What should be achieved by the funded projects under this proposed action?**

The projects should demonstrate, at TRL level 4-5, *novel optical network solutions that accelerate the digitalization of European factories.*

Key goals are:
- Establish European research consortia and value chains for the digitalization of European factory floors, comprising manufacturing, automation, IT, and communication companies along with universities and research institutes.
- Develop a novel network architecture for factories which unleashes the power of optical communications to connect machines, robots, and sensors in a modular, scalable, energy-efficient, easily adaptable, and EMI immune way.
- Seamlessly integrate photonic technologies ranging from novel optical fiber systems to free space optics to facilitate a distributed aggregation and processing of information.
- Showcase a factory floor application example with functioning prototypes achieving network interface capacities > 100 Gb/s, network latencies < 1 ms, strong encryption, and up to 99,999% availability.
- Demonstrate to the general public how photonic communications is a key enabler for the factory floor of the future.

2. **What are the relevance and expected impact of this proposed action?**

Digitizing European industry is one of the key pillars to achieve a European Digital Single Market. Recent studies estimate that the digitization of products and services can generate more than €110 billion of annual revenue in Europe in the next five years. The digitization will radically change and challenge many industries. This holds in particular for the manufacturing and production sector. Advanced technologies such as machine learning, collaborative robots, and 3D vision will revolutionize European factories of the future, if and only if massive amounts of data can be flexibly, reliably and securely collected and processed in real time. In Europe, new market opportunities are too often hampered by limiting communication capabilities of the past rather than exploited by a vision of unconstrained network connectivity in the future. The proposed action aims at changing this mindset. Focusing on a clearly identified use case with high social impact, it aims at developing value-added optical networking technology (as opposed to commodity products for mass market applications) for private factory floor networks and demonstrates its benefits in application showcases.

European optical network equipment vendors own >25% share of the $15 Billion global market (growth of ~10% /y ) and have a large footprint in Europe. Private optical networks are on the rise, as can be seen from the inter-data centre interconnect (DCI) market with 45% CAGR, to reach $4.7 Billion in 2019. Combining these facts, the impact of the technologies targeted in this research action can be directly related to 100.000 jobs in Europe and several Billion USD market volume along the value chain.
1. What should be achieved by the funded projects under this proposed action?
The projects should develop, at TRL level 4-6, integrated photonic technologies for intra-data centre connectivity, which can be migrated into consumer application spaces, as part of digitalisation of European society. The key goals are:

- **Migration** – Develop photonic interconnection technologies including very small size transceivers for generic photonically enhanced information nodes in high volume, low cost domain of exascale data centres, in order to migrate into consumer application spaces as part of society wide consolidation of information resources
- **Integration** - Develop system embedded photonic integration solutions at chip and board level including coupling and assembly of photonic integrated circuits (PIC) and optical printed circuit boards
- **Architectures** - Develop disruptive solutions for agnostic, scalable, flexible networking between photonically enabled information nodes in exascale volume domains including switchless or torus architectures
- **Standardisation** - Create and lead international industrial and conformity standards and establish cross-discipline consortia to allow strong interaction with other complementary H2020 initiatives including pilot lines, in order to seamlessly migrate these technologies and architectures and create value chains promoting digitalisation in those industries

2. What are the relevance and expected impact of this proposed action?
Our global impact as an information affluent society will be determined by our ability to consolidate and control distribution, storage, processing and switching of digital information on a massive scale. The consolidation of information resources enabled by advanced integrated photonics will be indispensable to achieving this “digitalisation” of society, however in order to sustain digital data growth and keep up with surging traffic it will be imperative to fully scale deployment of integrated photonic interconnect by removing prevailing commercial barriers. Integrated photonics for Datacom is now highly competitive with increased global governmental funding posing fierce competition to Europe. The USA’s AIM programme is funding integrated photonics at $610m, while APAC are doubling their research funding from €2.1 billion in 2014 to €4.2 billion in 2020, well in excess of H2020’s €0.6-1B. Europe and the USA currently lead the world in integrated photonics research. By promoting digitalisation of European society through ubiquitous photonic interconnect, this action will be a central technology pillar of the **European Digital Single Market**, contributing EUR 415 billion and hundreds of thousands of new jobs in EU and **ultimately enabling a European single data market where movement of data occurs freely across Europe.**

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1. **What should be achieved by the funded projects under this proposed action?**

Short and ultra-short pulse lasers (with pulses of ns to <10ps) have the potential to take an important role in industrial laser manufacturing. With “cold ablation” by high photonic energy pulses a new area of industrial applications could be reached. But the relatively low average power of about 100 W of available systems is not sufficient to use these laser systems for productive industrial processes. To access new industrial applications future laser sources and belonging system elements have to reach and withstand significant higher average power levels of more than a factor of 10, i.e. at least 1 kW, with

- Pulse energies, in the range of Joules, depending on the application (or down to mJ with multi-MHz pulse repetition rate)
- High speed and flexible pulse modulation and beam deflection systems
- Peripheral elements, i.e. beam transport, delivery fibers, beam shaping optics
- Standard (IR) wavelengths (or UV / mid-IR)
- Monitoring systems (components and process) and closed-loop control down to the work piece (supporting digitalisation aspects of “Industrie 4.0”)

The emphasis of the funded projects should lay on the laser source and all elements down to the work piece, including the necessary monitoring and closed-loop control (TRL < 5). A relevant industrial application should be used as a demonstration example (process development itself should not be included). The complexity of projects may be reduced by a combination of at least 3 connected work areas (between laser and work piece). In line with the WG2 roadmap this call topic points out the ongoing relevance of ultra-short pulse lasers for industrial processes.

2. **What are the relevance and expected impact of this proposed action?**

Lasers and related processes and tools are key elements in production processes. One leading edge in this field are ultra-short pulse lasers, which are starting to gain relevance. First applications in production have been demonstrated like drilling precise micro holes in metallic material (injection nozzle, increasing the engine efficiency by >10%) or cutting brittle material (hardened glass for mobile devices, replacing mechanical processes which create huge amounts of fine dust emissions).

The main restriction for further industrial applications is the current limitation in available output power and productivity of these laser systems and related elements. This includes achieving technology that delivers high average power in combination with fast beam deflection or beam splitting for parallel processing.

High power laser systems are needed to pave the way for a broad and totally new area of applications on industrial scale. European research institutes and technological leading companies in Europe are leading in the field of ultra-short pulse lasers. This gives the chance for Europe: projects in this field will lead to innovation on a fast track in order to enter and establish new applications in industrial scale.
1. **What should be achieved by the funded projects under this proposed action?**
   - Increased manufacturing productivity, by using precise and tailored deposition of laser energy, for well-controlled and efficient processes, with lot sizes beginning with one.
   - Increased flexibility in manufacturing, enabling highly individualised products, in mass and specialised markets, across a wide range of consumer markets.

This research action focuses on the continuing necessity to explore new methods and schemes of beam shaping, for materials processing with today’s flexible and more powerful laser systems. The fundamental requirement is to provide the right distribution of photons at the right place and at the right time, producing a high resolution, temporal and spatial deposition of energy, thereby enhancing process efficiency over and above the use of a simple circularly symmetric focussed spot. This could be realised for example, using diffractive beam forming elements, advances in spatial light modulators, arrays of beams or laser sources, novel optical fibres or by distributions produced by rapid beam scanning. Mathematical modelling should be involved, to enhance the process of determining the correct energy distribution required for any particular application. Process development will be required, in order to demonstrate and validate the benefits of applying a tailored laser beam. Application areas are expected to be wide. This call topic has been carefully selected to embrace some challenges in the WG2 roadmap previously included in calls but not covered in the resulting projects.

2. **What are the relevance and expected impact of this proposed action?**
   The results of these projects will address the challenging combination of flexibility with productivity, precision and a trend to zero-defect manufacturing, required by factories of the future. The impact of the proposed projects will be in an increase in the position of Europe in high value added and customised manufacturing, thus strengthening the European Economy in general but especially in the field of laser machine tools and within all laser markets. With full digital photonic production “First time right” and customized products will be possible with a minimum of set up and production time, resulting in reduced manufacturing costs. The development and application of the innovative manufacturing solutions proposed above will open new ways of producing more goods with fewer raw materials, less energy and less waste. The results of the projects will impact on several of the overarching H2020 Societal Challenges, in particular in the areas of health, security, clean and efficient energy, smart, green and integrated transport and the environment. For example, tailored energy distributions could be used to manufacture new medical and healthcare products, improve the efficiency of joining in equipment used to produce energy and to contribute to weight reduction and less CO2 emissions in the transport areas of rail, automotive and aerospace.
1. What should be achieved by the funded projects under this proposed action?

The action will achieve a sustainable eco system of research and innovation support, as an innovation hub for the benefit of SMEs, which aims to provide innovative laser-based equipment and related processes to manufacturing industry. Such eco systems should operate from laser competence centers to facilitate a broad uptake and a deep integration of digitized laser manufacturing, that goes beyond Industry 4.0, to serve challenges of individualization in production and change in product features, on the background of an ageing society and ecological demands. As an evolution of I4MS projects such as LASHARE and APPolo, Digital Innovation Hubs will support a rapid evolution of innovative ideas and achieve significant market readiness levels for new manufacturing solutions within a minimum time frame. Based on specific sets of technologies, the services provided by a DIH will be interdisciplinary at a European level and need to span from business model development support, across technology assessment, towards assistance in achieving capital investment for market entry and industrial uptake. The business cases considered in the DIH can be market driven by end user challenges, can be innovation ideas at equipment supplying SMEs, or technology driven from the scientific community. Each business case needs to be evaluated under industrial conditions, with a significant benefit to the entire manufacturing chain. The business cases can include equipment and new laser processing solutions but always must include an industrialization step to a technology and market readiness level of 7-8.

2. What is the relevance and expected impact of this proposed action?

Digital Innovation Hubs (DIH), in the context of laser based manufacturing, will provide hot-beds for rapid evolution of unprecedented digitized laser based manufacturing technologies. The research and resulting innovation will support a large number of SMEs, to enable new product features and higher productivity on both the manufacturing side and the equipment supplier side. As for 3D printing, the context of Industrie 4.0 will drive end-to-end integration of manufacturing for transparent individualization and modularization. European connected DIHs will result in reduced raw material consumption by lightweight components, efficient energy generation by feature enhanced components, education of a young and re-education of an ageing workforce and create new business cases. DIH’s professional handling of time, cost, risks and future engagement, from idea to production, will ensure viable business models to be a driver of innovation and impact within these eco-systems.

Complementing smart specialization strategies and regional resources, from infrastructure to structural funds, it is expected that with an indicative RIA budget of 20 MEuros, new sustainable and interconnected Digital Innovation Hubs can be implemented that would provide support to more than 500 SMEs with a corresponding 500+ innovations, that multiply impact by paving the market entry after the DIH support phase.

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3 I4MS.EU;LASHARE.EU;APPolo-FP7.EU
Title: Next generation of biophotonic methods and tools to understand the cellular origin of diseases

1. What should be achieved by the funded projects under this proposed action?
   Activities will focus on advanced imaging instruments and methods to understand the cellular reasons for the origin of diseases on all levels from cells to tissue and whole organs to stop diseases even before their onset. This is a long-term and fundamental challenge, which can be solved only by sustained effort.

   With regard to technology, the ultimate goal of this kind of preclinical research is to expand the ‘triangle of compromises’ concerning imaging:
   - speed: detection in 3D and in real time, real-time processing, automation;
   - resolution: filling the gaps between the macro, micro and nano scales, handling of large amounts of data;
   - increasing sensitivity and specificity, higher penetration depths.

   With this topic, we correspondingly want to develop further photonic imaging instruments and methods to investigate the cellular origin of diseases (i.e. the understanding of processes within the cell, which lead eventually to the outbreak of diseases) from TRL 2 (technology concept formulated) to TRL 5 (technology validated in relevant environment). The goal is to provide the biochemical end-user and the medical doctors engaged in research with new tools towards a better understanding of the origin of diseases.

2. What are the relevance and expected impact of this proposed action?
   Most European countries will see a strong demographic change in the near future with drastic consequences for the health and well-being of the European citizens and for their healthcare systems. E.g. the number of new cancer cases and corresponding incidences will rise steeply every year as a consequence. The same is true for other age-related diseases such as cardiovascular, osteoarticular and cerebrovascular diseases and many others. Early detection, precise diagnostics is key to an appropriate and successful treatment. Of particular concern are the falling birth rates and the increasingly aged population. The latter is causing an increase of the number of people with degenerative diseases (Alzheimer’s, Parkinson’s etc) and the former decreases the ability of the working population to support retirees. On average, the last 7-10 years of one’s life span are spent in the status of disease, which strongly limits the quality of life. Quite often, the cure from a serious disease allows the patience just to face another one. The problem is that treatment can set in just after the outbreak of a disease. An important part of preventive medicine is certainly to have a healthy lifestyle, but at least as important would be the ability to detect a certain illness far before its outbreak and to be able to take appropriate countermeasures. These abilities require a far better knowledge of the cellular processes than the one we have nowadays.
Work Group proposed action 2018-2020, extract

**Work Group:** 3

**Title:** Photonics enabled, more accurate quantified diagnosis during interventions and treatment – Research actions

1. **What should be achieved by the funded projects under this proposed action?**
   The projects should advance therapies towards stratified medicine by enabling or further developing:
   
   - Therapy and diagnostics driven therapy (including, e.g., image guidance during surgical interventions, medical laser systems etc.)
   - Point-of-care diagnostic tools and instruments for minimally invasive as well as non-invasive longitudinal monitoring and/or companion diagnostics

   The corresponding devices should be more reliable and precise than current ‘gold standard’ methods allow, without substantially increasing the examination costs or duration. The focus is on diseases where photonics can make a difference like cancer (with the exception of skin cancer), infectious diseases and cardiovascular diseases.

   Research projects are envisaged to start at TRL 3 and to promote solutions to a TRL level where product development can pick up (i.e. a TRL level of 5 to 6).

2. **What are the relevance and expected impact of this proposed action?**
   Most European countries will see a strong demographic change in the near future with drastic consequences for the health and well-being of the European citizens and for their healthcare systems. Early detection and precise diagnostics is key to an appropriate and successful treatment. However, also treatment can be improved in several ways. On the one hand, we need gentler and stronger focused therapeutic methods. In particular, we are looking for advanced photonic methods which support surgical procedures e.g. by helping to delineate tumor borders or areas with a perfusion deficit, to guide navigation of devices, to develop new surgical tools for navigation and treatment, or to locally apply drugs. On the other hand, the challenge is to improve therapy by longitudinally monitoring the therapeutic progress while administering a drug and/or by working towards stratified medicine, i.e. to include and measure individual dispositions, including genetic dispositions, with regard to the effectiveness of drugs using photonics. Another important issue for many diseases is the aftercare phase in order to prevent a relapse. Here, it would be of advantage to detect first signs of changes in the health condition well before the symptomatic manifestation of a relapse. Detection of the health status could be facilitated by minimally or non-invasive longitudinal monitoring of biomarker panels in a decentralized manner employing photonic technologies.
1. What should be achieved by the funded projects under this proposed action?

Objective of this call is the development of 3D light field or holographic systems for natural unaided visualization with non-intrusive, intuitive user-interaction. The primary application field is hereby automotive, healthcare, telecommunication and gaming. As the technology matures and costs are further reduced, it might replace conventional display technologies in the broader field of consumer electronics and entertainment as well. Main goals are to:

- Establish innovation consortia including industry and research along the entire value chain, from components and subsystems to end product and service providers.
- Development of components and systems featuring various photonics technologies to enable natural 3D impressions with a limitation-free user experience, namely: (i) 3D diffractive, projection optics to realize natural depth-of-field view (ii) high-speed/high-resolution microdisplays for light-field or holographic imaging, (iii) embedded SW and HW solutions for in-/outdoor localization, scene recognition, secure and ubiquitous connectivity, intuitive user-interaction, incl. human feature recognition, haptics, recognition of situation awareness.
- Creation of application scenarios for public, home and professional environments and verification in Living Labs including end-users.
- Development of service-focused business cases, e.g. for 3D Head-up-Displays and 3D control room applications for smart transportation, next-generation visualization solutions for education, health, Smart Home, entertainment, automotive, etc.

2. What are the relevance and expected impact of this proposed action?

Providing natural 3D visualization (neither requiring headgears, nor limiting the number or position of users) going beyond the limitations of current 3D systems will have a huge impact on several social and industrial challenges. Namely for personal health (image-based diagnostics, personal remote doctor, visual surgery assistance, robotic/remote surgery), for mobility (smart transportation integrated at vehicle and control level), or for prevention of climate change (analysis and interpretation of large 3D metrological datasets and 3D simulation). In a more general manner, it will enhance social interaction in real world spaces empowered by virtual information presentation (education, gaming), without suffering limitations in user experience or comfort.

We expect the outcome of the research and innovation actions to enable European system manufacturers to bring to market highly competitive products by integrating novel visualization solutions for systems and user-centric services in the business cases listed above, and to build a Europe-centered value chain by strengthen domestic manufacturing of optical & semiconductor components, and software up to the already strong system integrators and end users, e.g. from telecom, medical, or transportation industry.

The global 3D display market is to reach 113 B-EUR by 2020 (Allied Market Research) with the chance of European companies capturing a market share beyond 20% based on the strength of the European industry in the application field of Automotive and Healthcare. Next-generation 3D light-field and holographic systems represent a complex area with cross-connections strengthening components and subsystems manufacturing, developing systems and system integration. This is therefore not a simple Asian flat panel display topic and EU still leads thinking. EU-level funding will ensure European companies to compete with US and Asia in the emerging next-generation 3D visualization markets, create high-end jobs and cultivate a skill base in Europe. This will contribute to further foster Europe’s world-wide credibility to gain a leading position.
1. **What should be achieved by the funded projects under this proposed action?**

The focus is on lighting applications – based on LED/OLED/Laser – with enhanced functionalities going beyond pure illumination. Application areas could be indoor and outdoor and includes human centric lighting, medical as well as other industrial applications, e.g. automotive and agriculture. Projects should demonstrate innovative light-based applications that bring the user experience to new qualitative dimensions. This includes but is not limited to a potential extension of the spectral range to UV and IR, integration of sensors and intelligence. It is expected that projects are aiming a TRL level of 3 – 5.

**Key goals are:**

- Development of exceptional user centric experiences based on lighting solutions allowing the users to control the quality of light and its functionalities in a broad variety.
- Development of innovative lighting solutions that combine light sources (with application specific form factors) with other components like sensors, mirrors, lenses, … allowing for new functionalities, such as e.g. spatial and spectral steering.
- This could also include the development of smart and highly integrated devices, merging CMOS and illumination technologies on chip- and wafer-level resulting in unseen dynamical properties of steering and driving systems.
- Demonstration of technical and economic feasibility of the product (including challenges in production and assembly) with functioning demonstrators. Projects could also address the validation of the novel user centric approaches.

**Exemplary use cases are:**

- Residential / Office: Creation of new user centric experiences based on light sources and luminaires.
- Medical / Industrial: High power and Hg-free devices for UV-B and UV-C with increased system performance and extended lifetime.
- Automotive: User centric light applications will play an increasing role as a differentiator between brands. Novel properties for both, interior and exterior lighting with regard to design (e.g. form factors, transparency and spatial flexibility) and performance/connectivity are considered.
- Agriculture: Besides technically optimizing the spectra of light sources (per species; intending higher crop quality and quantity) the integration of environment sensors and setting up of feedback loops will allow for a quantum step in this application field.

2. **What are the relevance and expected impact of this proposed action?**

- Extending & merging lighting technologies beyond classical illumination
- Unlocking new application domains (e.g. UV lighting for agriculture & medical,…)
- Allows tripling of global lighting need by 2050 while maintaining energy usage at the present level
- Increase human productivity by 4% caused by optimal lighting conditions
- Improved well-being in work and home environments
1. **What should be achieved by the funded projects under this proposed action?**

The aim of this research action is the integration of the lighting infrastructure with the Internet of Things including integration of new functionalities (e.g. VLC, indoor positioning ...) and unique form factors which clearly show the value beyond illumination and will offer new validated user centric value propositions.

**Key goals are:**
- Integration of lighting infrastructure with the Internet of Things including integration of new functionalities such as indoor position, VLC communication, asset tracking etc. The theoretical architectures developed for IoT communication (like for example the OpenAIS architecture) must be applied to field applications in real environments.
- Development and integration of new technologies as security, information and communication technologies to fulfill specific requirements as security, response time
- Integration of different vertical applications in different environments for indoor and outdoor
- Based on this integration development of new cross vertical use cases as productivity enhancement in offices.
- Development of specific new use cases such as high data information streaming based on Visible Light communication.
- Creating a full connected lighting infrastructure as THE key platform driving Internet of Things

**Exemplary use cases are:**
- Increase productivity and efficiency in offices and industries (e.g. better building management, floor space optimization) as office space optimization and productivity enhancement
- Improve energy management in offices, industries and cities
- Improve road safety by detection of traffic participants
- Connected lighting Platform will create new unprecedented applications that combine real-time, fine-grained data from various sources to further improve a building’s automation capabilities and occupants’ experiences
- VLC for indoor positioning and broadband data communication (e.g. video streaming and broadband download; indoor and/or outdoor)

2. **What are the relevance and expected impact of this proposed action?**

This research action will enable Europe to maintain and build on its leading position in innovative lighting solutions by; (a) the integration of the lighting infrastructure with the Internet of Things and with that (b) unlocking new application domains which not accessible for the lighting industry today (c) Creating THE IoT platform. These products are conservatively estimated to increase the global lighting market by 22% by 2020, equaling an 8 B€ annual turnover.
1. **What should be achieved by the funded projects under this proposed action?**

As for all photovoltaic technologies, all efforts for pushing OPV efficiency and lifetime to the limits are welcome. During the last few years, significant progress has been made by new concepts in certain fields of OPV, reaching 11% efficiency even in single stack devices. Further development of new organic materials for OPV is needed, to push the efficiency and lifetime to the limits. At the same time, these materials need to prove their scalability to production dimensions. This includes scalable synthesis routes up to the 100 gram scale, low-cost synthesis, different colors, superior to state of the art materials regarding performance and stability against temperature, light, or oxygen. To increase production yield, new materials should be more tolerant against processing window fluctuations or against moisture. Since OPVs comprise not only organic material, but also electrodes and barriers, also peripheral technologies need to be given consideration.

Dedicated material development for OPD is required in order to enable products with attractive performance. This requires materials with very low doping/defect concentration in order to surpass the leakage current and lag performance of amorphous Silicon. Materials with narrow absorption bands but high conversion efficiencies are needed in order to create unique product features of sensors, e.g. RGB sensors or visible-blind cameras without color filters would increase sensitivity. Materials with higher mobility and carrier lifetime are required in order to enable faster and more efficient sensors (e.g. for data transmission or medical imaging).

2. **What are the relevance and expected impact of this proposed action?**

This action has a manifold of aims:

- It will deliver materials which are urgently needed for improved OPV products to be used in the energy sector, mainly in building integrated photovoltaics, automotive applications, which aim for volume markets and high power supply. This, it has direct influence on the decarbonization of the European energy sector.

- It will deliver materials for a multitude of OPV niche markets, internet of things applications, energy supply of hybrid systems etc. Thus, it can cross-fertilize other European industries.

- It will deliver improved materials with better selectivity etc. for OPD applications, allowing new products for the diverse field of OPD producers, e.g. for medical and industrial imaging.

- New materials create growth along the value chain, from chemical industry as the first beneficiary to higher sales of all OPV and OPD stakeholders due to improved competitiveness.
1. **What should be achieved by the funded projects under this proposed action?**

   As the world’s largest exporter of agricultural and food products, Europe needs to solve two major problems: Food waste and food safety. More than 1.3 billion tons of food are wasted every year, and Europe is one of the most wasteful regions of the world; just in the United States about 48 million citizens get sick from foodborne illnesses every year (of which 128,000 are hospitalized and 3000 die). Both problems are addressed by the present research action, aiming at:

   - Conceiving and developing an innovative, simple-to-use, flexible VIS-NMIR-based photonic smart sensor solution (TRL 5-6) for the farm-to-fork food chain
   - Utilizing photonic sensing methods combined with advanced data processing techniques to develop and demonstrate sensor solutions that are highly flexible, i.e. that are easily adapted for usage on farms, in processing plants, by retailers and users
   - Demonstrating the realized solution with several stakeholders of the complete food chain, from farmers to consumers
   - Focusing on three main problems: (1) Production control adapted to small/medium-sized farms within the “precision farming” paradigm. (2) Development of novel types of production processes, including non-traditional combinations such as aquaponics, (3) On-site food processing and vending

2. **What are the relevance and expected impact of this proposed action?**

   We aim at providing key instruments for the global fight against food waste, occurring at each step of the complete farm-to-fork food chain. In particular, our goals include:

   - Contributing to the supply of the 500 million European consumers with healthy, nutritious and safe food at an affordable price
   - Helping to support and improve Europe’s status as the world’s largest exporter of agricultural and food products. This should be achieved by developing quality-assurance and analysis tools serving several links of the complete farm-to-fork food chain simultaneously
   - Providing Europe’s 12 million farmers (plus an additional 4 million people working in the food sector) with easy-to-use analysis and quality-assurance tools with which “precision farming” with less food waste, lower water and resource usage, higher yield and improved food quality is attained
   - Contributing to the preservation of our environment and stopping the rural depopulation by providing meaning analysis tools with which smaller-scale farming and local food processing can be done more cost-effectively and safely
   - Providing Europe’s 500 million consumers with simple but significant measurement tools with which the quality and the safety of processed food can be determined in every household, leading to less food waste and fewer cases of illnesses due to unhealthy or noxious food.
Work Group proposed action 2018-2020, extract

**Title:** Photonic Integrated Circuit Technology

1. **What should be achieved by the funded projects under this proposed action?**
   The project(s) should bring
   - Major advances in the capability and performance of photonic integrated circuit technology platforms.
   - Advanced building blocks in established integration platforms may include for example methods for phase noise reduction, modulator and polarization extinction ratio enhancement, high nonlinearity, polarization handling, non-reciprocal elements such as isolators, fast switching and high-performance single-photon sources and detectors. The activity accordingly encompasses forward-looking, higher-risk research up to experimental proof of concept (TRL3).
   - Maintain technological progress consistent with expected demands of communications systems, including internet, data centres and telecom systems.
   - Development of enhanced PIC building blocks in line with technology roadmaps, e.g. high sensitivity, high density, improved energy efficiency, higher speed.
   - A generic platform approach in order to separate circuit design from production methods, thereby facilitating exploitation in the widest possible range of applications for a volume production method.
   - Technology base established to serve new applications, e.g. LIDAR, microwave photonics, 3D imaging and display, quantum photonics, sensors and other fields
   - Actions should include a validation of results with fabricated PIC prototypes.

2. **What are the relevance and expected impact of this proposed action?**
   - Photonic integration technology, when made openly available through generic foundries, can lead to a dramatic reduction of the research and development costs of advanced photonic ICs (more than an order of magnitude). Europe is in a leading position in generic integration platforms and this approach is very readily applied across a wide range of new and fast developing business areas, including telecom and data communications but also quantum photonics, medical, sensing, metrology, displays and security applications.
   - The data centre networking market alone will reach $21.85 billion by 2018 with a CAGR of 11.8% (Infonetics). The bandwidth, cost and energy savings are essential to the continued development of the internet. Chip-level photonic interconnect is expected to generate $990M by 2020 (CIR) and the market for Ethernet optical interconnects is reaching $2.2 billion by 2018 (LightCounting).
   - Target markets include also a significant share of the optical sensor market ($15B 2020 worldwide, CAGR 16.9%, Allied Market Research) where integration is poised to deliver cost-effective solutions with orders of magnitude performance enhancement in imaging and point of care diagnostics through metrology for embedded structural monitoring.
   - The value of PIC markets are anticipated to scale to multi-billion dollar levels over the coming five years (see Integrated Optical Devices: Is Silicon Photonics a Disruptive Technology? http://www.lightcounting.com/reports.cfm, January 2016).
1. **What should be achieved by the funded projects under this proposed action?**
   The project(s) should bring
   - Major advances in the capability, performance and complexity of photonic system-on-chip and system-in-package through the intimate combination of photonic integrated circuit technology with other enabling circuits, devices and mother boards.
   - Create and develop advanced techniques for intimate integration of sub-systems incorporating multiple technologies such as high performance electronics, micro-optics, thermal management, micro-electro-mechanical systems (MEMS) and sensors.
   - Techniques should be generic, enabling application across multiple domains.
   - Demonstrable performance advantages in terms of e.g. sensitivity, speed, energy efficiency and robustness to extreme environments are targeted.
   - New concepts for integration may leverage wafer and chip stacking, hybrid and heterogeneous technologies, 2.5 and 3D integration, multi-level wiring and ultra-high bandwidth density connections.
   - A holistic approach to design through to test is envisaged to fully exploit new assembly techniques for high-performance systems-on-chip.

2. **What are the relevance and expected impact of this proposed action?**
   European research is in a world-leading position regarding photonic integrated circuits (PICs) and high performance electronics. These technologies are increasingly closely integrated and considerable performance advantage is anticipated as complementary technologies are integrated at the system on chip and system in package level. A step change in photonic system integration is achievable through the alignment of value chains including mechatronics, automation, electronics and photonics.

   European companies have world-leading capabilities in photonics, precision engineering, production tools and automation, thereby providing a comprehensive set of skills and resources to make this transition possible.

   The proposed action will secure European industrial leadership in a wide range of photonic applications and technologies, better connecting markets and technology and extending European leadership into photonic systems integration. We anticipate that the tighter integration between complementary technologies will be highly valuable for the penetration of new markets such as automotive, medical and consumer products, as well as for established telecom and datacom applications.
Work Group proposed action 2018-2020, extract

**Title:** Assembly and Packaging Technology

1. **What should be achieved by the funded projects under this proposed action?**
   The project(s) should bring
   - New concepts for assembly, packaging and module integration for photonic integrated circuits
   - Reduction in production costs by an order of magnitude or more, thereby facilitating the introduction of PIC technology into new markets such as automotive systems and consumer products
   - New concepts for optical connection to PICs
   - Automated assembly for low-cost, scalable production
   - Wafer-scale assembly techniques
   - Automated and high-throughput test approaches, including on-wafer testing
   - Non-hermetic chip environments
   - Massively parallel, low-cost, high speed electro optical connectivity solutions, targeting extremely high aggregate bandwidth, e.g. 40x100 GHz
   - Generic packaging solutions for high optical complexity PICs, thus lowering entry barrier into e.g. low volume sensor and medical markets
   - Techniques may include 3D assembly and chip/wafer stacking.

2. **What are the relevance and expected impact of this proposed action?**
   Europe is in a leading position regarding photonic integrated circuits (PICs), high performance electronics and semiconductor manufacturing equipment but much packaging and assembly is presently performed outside Europe. The costs and throughput for existing methods are limiting factors here and a new generation of assembly and packaging techniques is required to enable higher-volume, lower-cost products. European businesses active in the datacom/telecom industry have reached leading positions worldwide in their respective high-value applications. Considerable know-how also exists in related areas of robotics, mechatronics and semiconductor process equipment. A step change in package integration is achievable through the alignment of new value chains. Europe’s strength when compared to e.g. the USA is especially the collaboration between companies and research institutes with complementary skills.

   European companies have world-leading capabilities in photonics, precision engineering, production tools and automation, thereby providing a comprehensive set of skills and resources to make this transition possible. This proposed action can secure European industrial leadership in next generation assembly and package technologies for photonics and subsequent combinations of technologies. This enables European leadership in applications where assembly and packaging represents a major share in system performance and cost. The target is to keep the full value chain for high-value applications in Europe and to obviate migration to countries with lower labour costs through continuous innovation.
1. **What should be achieved by the funded projects under this proposed action?**

   In the ongoing quest for low-power, densely-integrated photonic technologies for communication and sensing, one of the key challenges relates to the need for efficient on-chip control of light flow. In free-space and fiber-optics these problems have been addressed through micro-opto-electro-mechanical systems (MOEMS). The key goal of this action is to bring the same solution to the nano-scale and to the world of Photonics Integrated Circuits. Indeed, novel opportunities in communication and sensing applications arise from the combination of nanophotonic circuits with downscaled electromechanical actuators, featuring at the same time much reduced drive voltage and increased bandwidth. Such novel nano-opto-electro-mechanical systems (NOEMS) capitalize on European leadership in the research fields of nanophotonics and optomechanics and provide a route towards integrated solutions for switching, tuning and reconfiguration at ultralow-power (nW-μW) levels.

   Funded projects should address the following key issues:
   - Reduce driving voltage and increase operating frequencies by developing efficient electromechanical actuation of nanophotonic devices;
   - Integrate NOEMS with waveguide circuits, lasers and detectors and develop scalable actuation/sensing geometries;
   - Develop a new generation of optical sensors combining the exquisite resolution of nano-opto-mechanical structures with integrated interrogation and read-out.

2. **What are the relevance and expected impact of this proposed action?**

   European photonics industry is already very strong. Complete supply chains for integrated photonics products are already in place, from foundries (III-V and silicon foundries), to brokering organizations (JePPIX, ePIXfab), design houses and end-users. At the same time, the market for MEMS and MOEMS is growing fast and industrial chains are being set up in Europe, in particular through the ENIAC-Lab4MEMS II public-private partnership, involving a pilot line based in STMicroelectronics. NOEMS represent the natural evolution of MOEMS and will impact all levels of the photonics value chain, by enabling higher integration densities, increased functionality and lower power consumption. It is expected that they will fit into future European MEMS and photonic integration pilot lines, increasing the competitiveness of European high-tech industry.

   On the point of view of addressing societal challenges, substantial impact is foreseen in at least two areas:
   1) Energy savings in optical circuits and networks; indeed, energy saving will be crucial with the growth of internet traffic that can be expected as a consequence of the digitization of European industry and society.
   2) Ubiquitous sensors: Integrated, low-cost optical sensors will mark a new era of the information society, enabling people to make informed choices in daily life, from purchasing food in a supermarket to driving a car. They will also have lasting impact in the area of personalised healthcare, by allowing continuous and non-invasive diagnostics.
1. **What should be achieved by the funded projects under this proposed action?**

The action should improve the reliability and reproducibility of 2D materials and explore the possibility of integrating them on 3D architectures so as to open completely new perspectives, and to allow full exploitation of the great potentials of 2D materials in a 3D context for augmented functionalities based on unprecedented optical, electronic and mechanical properties. The key goals of the action are:

- To assess and tailor the optical and conductivity characteristics of 2D materials, to address their integration on different material surfaces, and to study the phenomena taking place at the interface. In particular, (linear and nonlinear) optical properties of 2D materials should be deeply investigated in view of an optimal exploitation in device and microsystem design and fabrication.

- To achieve the possibility of using 2D materials as functional coatings for scaffolds, ridge waveguides, the internal walls of microchannels and microcavities, etc. The new physics that will emerge from the combination of the unique and already demonstrated properties of the 2D materials with novel 3D architectures and devices will open new application domains.

- To develop new fabrication techniques so as to ensure reliable and reproducible results, with potential for future low-cost mass production.

2. **What are the relevance and expected impact of this proposed action?**

European photonics and advanced manufacturing industry are already very strong. Complete supply chains are already present in both areas. Combining the expertise in 2D materials with that in 3D micro/nano-fabrication will enable the realization of new products with augmented functionalities exploiting photonic processes. Indeed, the combination of the unique properties of the 2D materials with novel 3D architectures and devices, will allow disruptive applications with a considerable impact on solving societal challenges. New markets will be addressed, thus ensuring the creation of new companies or the strengthening of the existing ones, and in the end an increase in employment together with an economical growth. A significant social impact can be foreseen in several crucial areas, as for example:

1) **Smart care.smart living:** The use of 2D materials integrated on different structures, mainly 3D but also 2D, allows the realization of any kind of sensors, from wearable devices for the monitoring of health-relevant parameters to the sensing infrastructure for smart buildings;

2) **Safety and security:** Coating with 2D materials can be widely exploited for example in food packaging for quality and toxicity detection but also in environmental sensing;

3) **Pharmaceutical testing:** the development of functionalized lab-on-chip, scaffolds for cell-growth and organs-on-chip will provide valuable low-cost platforms for testing of new drugs;

4) **Smart lighting and energy:** 2D materials are likely to revolutionize both the realization of efficient light sources and new generation photovoltaic cells.
1. **What should be achieved by the funded projects under this proposed action?**

The growth of Europe’s advanced manufacturing industry and successful digitization of its economy heavily relies on an efficient and effective optics and photonics innovation supply chain, of which free-form optics is an essential optical innovation technology driver. Cutting-edge pilot-lines play a crucial role in this innovation ecosystem because they bridge the gap between early prototype and commercial mass-production.

Key goals of the pilot line are:

- to offer solutions for a wide class of very demanding optical components and/or systems that are not commercially off-the shelf available and that are of strategic interest to the European industry. “Extreme” optical solutions will be addressed, mainly based on free-form optics, but not limited to, i.e. including e.g. aspheric optics, optical components combining and integrating diffractive, holographic, and/or refractive or reflective optics (including metasurfaces), and micro-, mini, and macro-optical components or systems in novel materials and/or with extreme specifications or disruptive functionalities;

- to cover all stages, from optical design, to prototyping, manufacturing, to optical quality control and testing. From technical as well as user perspective the pilot line will provide a low entry barrier access to low and medium production volumes, although the available processes will be suited also for scaling to high volume production;

- to give European SME’s the opportunity to enhance their products with the most competitive and manufacturable optical solutions by providing them fast access to the most-advanced expertise and cost-intensive prototyping and manufacturing infrastructures needed to manufacture new and innovative products, and to decrease their time-to-market.

2. **What are the relevance and expected impact of this proposed action?**

The pilot line for free-form (“extreme”) optics will:

- provide cost-effective innovative solutions for cutting-edge optical components and systems for European industry in a timely manner, in particular for SME’s that want to innovate their products with photonics;

- strengthen Europe’s position in the manufacture of high-end optical components and systems with the aim to maintain and further strengthen its pole-position in innovative photonics-enhanced products in a variety of industry sectors;

- be the starting point of a revival of optics manufacturing in Europe creating new employment in the high-tech European manufacturing and system integration industry.
3. **What should be achieved by the funded projects under this proposed action?**

   The project should make it possible, for researchers that experience difficulties in demonstrating their conceptual breakthroughs with state of the art technology, to access existing cutting edge technology platforms. Key goals are:

   - To create a European “Research-for-Innovation” Hub that operates as an open one-stop-shop center that provides access to a wide variety of photonics technology platforms and to a broad range of photonics services (design, measurement, packaging, etc...) for photonics and non-photonics researchers or research teams, both from academia and/or from industries.
   - To considerably lower the photonics research-to-innovation threshold through a more efficient and effective use of existing photonics expertise, facilities, and technology platforms in Europe, through intensified EU collaboration, and in an open science and open innovation spirit.
   - To enhance the alignment of (blue sky) photonics research with the industrial and societal innovation roadmaps, by creating or enhancing the “research-for-innovation” mindset of European researchers, by supporting proof-of-concept demonstrators based on novel and disruptive research concepts.
   - To stimulate awareness on intellectual property protection, freedom-to-operate analysis, and the route from research-to-innovation with European researchers.

4. **What are the relevance and expected impact of this proposed action?**

   One of the crucial challenges of the Industry 4.0 era is to feed the European innovation ecosystem with disruptive photonics research-and-technology inspired proof-of-concepts (TRL 1 to 4) so as to be able to find sustainable solutions to major societal challenges, to maintain and increase industrial competitiveness thus strengthening European economy and employment. The Photonics “Research for Innovation” Hub is expected to:

   - create a platform that inherently supports research-for-innovation, hence dramatically improving the alignment of cutting edge research activities with the innovation ecosystem;
   - considerably enhance the knowledge creation at the service of innovation with a demonstrable impact on EU industrial competitiveness;
   - better align fundamental research activities with the grand societal challenges;
   - stimulate cross-KET photonics research at the front edge of technology;
   - introduce photonics researchers to the European innovation ecosystem and pave the way for a new research-for innovation mindset that improves the links between research, innovation, and the societal challenges;
   - increase the number of non-photonics research professionals to approach and use photonic solutions.
5. **What should be achieved by the funded projects under this proposed action?**

The projects should demonstrate, at TRL level 5-6, *innovative photonic solar fuel devices* that efficiently convert solar energy into chemical energy, stored in fuels. Key goals are:

- Develop innovative architectures for photonic solar fuel devices with economic feasibility.
- Consolidate R&D in the field of catalyst development, and create room for disruptive materials and device concepts resulting in efficient chemical processes and high energy conversion efficiency.
- Demonstrate technical and economic feasibility with functioning demonstrators having a device efficiency of >5% and payback period of <10 years.
- Develop cost-efficient processes for mass production of the nanostructured materials required for efficient photon management in photonic solar fuel devices.
- Establish European research consortia and value chains that approach material / device / system development in an integrated fashion, comprising of universities, applied research organizations and industrial partners to ensure technical and commercial feasibility of large scale material and device production.
- Develop business cases around light-to-fuel conversion and stimulate industrial value chains to emerge in Europe.
- Familiarization of the general public with these developments to promote societal acceptance.

6. **What are the relevance and expected impact of this proposed action?**

One of Europe’s grand challenges is to guarantee a sustainable supply of energy. Solar and wind energy production both inherently fluctuate, not matched with fluctuating consumption. Affordable electricity storage systems to balance this are lacking. Storage of energy in the form of *fuels* is a very promising option, because of the high density (can be 100 times higher than in current Li-ion batteries). First generating electricity by PV and/or wind and then using electricity to generate fuels is inefficient and too costly. Photonic devices that use solar energy to directly convert e.g. water and carbon dioxide into fuels may bring the required breakthrough innovation. Presumably these devices will be large-area panels containing photonic structures, catalyst layers and flow channels. Globally there are no established positions yet and Europe has the opportunity to take the lead and create a multi-billion industry that will mass-manufacture these photonic devices and the systems around these. Moreover, devices that run on these fuels (such as home heating systems) represent another sizeable market for EU industry. Concepts are expected to be at TRL 3-4 by the end of 2018 and the impact of the proposed action is to bring the field to TRL 5-6, demonstrating approaches that can be scaled up industrially.
Annex – Full Proposals
WG 1 – Private Optical Networks for Vertical Markets

I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed
   - Application domains\(^4\): Optical Communications
   - Targeted application: Private Optical Networks for Vertical Markets

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+. What is the challenge (in Europe) in the respective area today?

   Digitising European industry is one of the key pillars to achieve a European Digital Single Market. Recent studies estimate that digitisation of products and services can add more than €110 billion of annual revenue in Europe in the next five years. The digitisation will challenge established business models and radically transform vertical markets such as healthcare, energy, financial services, automotive, manufacturing, media & entertainment, and public authorities. Transitioning to a data-driven economy, the amount of data to be processed and the dependability on that data is steadily growing while the required reaction time is continuously shrinking. Through parallelisation, the compute and storage infrastructure was able to keep pace with these fast developments, while the communication infrastructure was not. Virtual private 5G networks have been proposed as future solution for vertical industries (c.f. white paper “5G: Empowering Vertical Industries”). By enabling the execution of industrial processes to be observed, monitored, controlled and automated in the digital domain, private optical networks will deliver an important leap in productivity and trigger economic growth. Yet, the focus on public (i.e. operator-run) networks and wireless access allows to address only part of the market. When large network capacities, low latency, high security, ultra-high reliability, and full user-control are required, private optical networks are indispensable and have long been the solution of choice (e.g. in the financial services sector). Clearly, there are applications in other vertical markets also. As example, advanced technologies such as collaborative robots, and 3D machine vision will revolutionise factories of the future, but will create hundreds of Gb/s of data which need to be collected and processed in real time. Not only because of its bandwidth, security, reliability and control advantages, but also due to its immunity to EMI, a private optical network is the best choice for this application. Yet, little activity is noticeable in this and other vertical markets. The challenge in Europe is that too often new approaches are based on limiting communication capabilities of the past rather than a vision with unconstrained network connectivity in the future. As such the full potential of digitalisation is largely left untapped.

3. What needs to be done?

   A research activity covering the following steps is necessary:
   
   a) Enter into a dialogue with selected key players in a particular vertical market
   b) Develop a clear understanding of requirements, challenges and future opportunities
   c) Create awareness for optical communications as enabling technology
   d) Jointly research, develop and validate new approaches up to a prototype level
   e) Disseminate results and lessons learnt, contribute to standardization and industry forums

\(^4\) For horizontal work groups focus can be on generic technology domains
4. When should it be launched and how much funding is needed?

The area should be called as part of WP 2018. To cover multiple vertical markets, 5 small contributions with up to 4 M€ budget are foreseen (20M€ in total).

II. Proposal for Research Topic (2 page max) in Horizon2020 WP 2018-2020

Photonic Communication Solutions for Vertical Markets

1. The objective is to develop novel, purpose-built optical communication networks for vertical markets such as healthcare, energy, financial services, automotive, manufacturing, media & entertainment, and public authorities.

The network architecture can include several optical technologies from novel optical fibre systems to free space optics to aggregate information from sensors, robots and groups of dedicated machines for the local pre-processing and processing of time critical data. Rather than relying on a shared public network infrastructure, private networks (e.g. campus, production site, bank etc.), metro or regional networks are targeted, where the collected data can be aggregated by switches or routers and conveyed to a distributed processing. The architecture of the private network must be modular, scalable, energy-efficient, and easy to adapt to changes in processing needs. For these purposes, recent advances in photonic technologies have enabled the optical layer to become the ideal companion of the packet layer.

Whilst guaranteeing service quality, timing and security, private networks shall facilitate real-time processing of large data volumes over distributed network nodes. One example is the use of optical interconnection links and photonic switches to manage elephant flows (e.g. from monitoring video-streams) that can be set up at the rise of a corresponding service (e.g. activation of a robot in a manufacturing plant) by a facility management system.

Key performance indicators are: high network interface capacities (> 100 Gb/s), low latency (< 1 ms for time-critical services, bound by the latency of the transmission medium), high security (strong encryption), and ultra-high reliability (up to 99,999% availability)\(^5\). Projects should demonstrate an involvement of vertical market actors, develop technologies at least up to TRL 4, contribute to the relevant standardization in the field, and help to accelerate a subsequent product development. They must show how photonics is an enabler for the targeted application.

2. Relevant Research & Innovation present in Europe?

Europe has long been at the forefront of optical systems and network research, as exemplified by a multitude of world-class research papers at leading conferences such as OFC (Optical Fiber Communication Conference) and ECOC (European Conference on Optical Communications). A multitude of collaborative research projects in the past have created a strong link between industry and academia on which any future research can build. European optical network equipment vendors have >25% share of the $15 Billion optical equipment

\(^5\)It is understood, that not all KPIs necessarily have to be fulfilled at the same time. Relevance and fulfillment of the KPIs is dependent on the market(s) and application(s) being addressed by a particular proposal.
market and continue to invest in Europe, creating a solid basis for an exploitation of current and future project results in the EU. It is desirable, however, to improve technology transfer from academia to industry through an intensified cooperation.

3. Impact on European economy, employment

6 of the 20 largest optical equipment manufacturers have major R&D centres in Europe. By revenues, they represent more than 25% of the 15 Billion USD (2015) global optical equipment market which growths around 10% per year. Two of the top 3 component manufacturers have operations in Europe and more than hundred SMEs and universities provide complementary innovation on network, system, or component level. The build-up of private optical networks is on the rise, as can be seen from the inter-dater centre interconnect (DCI) market, which is growing at 45% CAGR and is forecasted to reach $4.7 Billion in 2019 (AGC Research). On basis of these numbers it is safe to assume that the direct impact of technologies targeted in this research topic relates to 100,000 jobs and several Billion USD across the whole value chain in Europe; the indirect effects are much bigger. According to the Photonics 21 Leverage Study, optical technologies leverage a telecommunication infrastructure market of 350 Billion EUR and impact more than 700,000 jobs in Europe (2010). The focus of the research activity is specialized high-value optical networking technology (as opposed to commodity products for mass market applications). Most of the European system OEMs as well as the component suppliers do not only have R&D functions but also a large part of the manufacturing in Europe and hence the research and innovation action will lead to further direct job growth in Europe. In summary, the objective of the proposed topic is twofold: 1) to further develop the optical market by fostering the development of purpose-built private optical networks; 2) to improve efficiency and market position of the EU industry, through early adoption of private optical network technology.

4. Impact on societal challenges

The digitisation to which this research topic acts as enabler will have a strong impact on a multitude of societal challenges, including but not limited to:

- Health, demographic change and wellbeing;
- Education, distance learning and media & entertainment;
- Manufacturing, development of automated manufacturing approaches
- Secure, clean and efficient energy;
- Smart, green and integrated transport;

5. EU added value

Relevant players and required expertise is distributed across Europe so that a European approach is required.
WG 1 – Photonics for intra data center and consumer applications

I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed
   - Application domain: Communication (photonic interconnect for digitalization of exascale ICT systems and subsystems including intra-data-centre and consumer applications)
   - Targeted application: Intra-data centre and consumer optical communication technologies

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+

Global IP traffic growth is expected to continue unabated, exceeding 10 zettabytes by the end of 2019 with over 75% of this traffic remaining within the data centre. This growth is driven by the population’s growing demand for online and Cloud services, which are constantly increasing in complexity and power. For example, Amazon Elastic Compute Cloud provides resizable compute capacity in the cloud, Apple’s Siri and Google uses servers in the cloud to interpret user requests and provide information, and IBM’s supercomputers are tackling medical diagnosis. European society now expects access to an exponentially growing amount of computing power and information. Exponential growth in performance requires exponential growth in the available bandwidth and to satisfy this demand, optical links must penetrate far deeper into the ICT infrastructure of data centres, migrating into corresponding consumer technologies to enable enhanced “digitization” of society. Europe holds vast research potential in this field, as proven repeatedly by world-leading results of its research centres and industrial labs and the establishment of a significant number of SMEs. However, translation of Europe’s research excellence into industrial leadership is hindered by the following challenges:
   - Integration of new technologies in the value chain often comes at high cost that negates the technology’s low-cost potential, e.g. the packaging of silicon nanophotonics and associated integrated optical technology to compensate for propagation loss in highly dense photonic switches
   - Europe lacks vertically integrated enterprises and relies on independent players who often occupy exclusive niches. Further consolidation across the value chain is necessary to steer research according to the requirements of the application.
   - Insufficient exploitation oversight by major end user organisations

Europe needs to tackle head-on the fierce competition coming from low-labour economies to ensure the full benefits of next generation photonic interconnect technology can be leveraged by European data centres at the heart of digitizing industry in Europe.

3. What needs to be done?
   a. Develop photonic technologies (components and subsystems) capable of a 10-fold reduction in cost and power consumption / Gb/s
   b. Scale optical interconnects for disaggregated exascale ICT and consumer environments
   c. Achieve full migration of optical interconnect into low level ICT and consumer subsystems

The purpose of this call should be to address the key challenge of how to throw open the market for optical interconnect from the current high margin, lower volume to low margin, high volume markets including consumer electronics, automotive and ICT systems. This requires a different approach to mere economies of scale, on which EU cannot compete with the Far East. It requires a fundamental rethink on the paradigms on active technologies, layout, packaging and system level integration. If this
paradigm can be developed and captured in the EU and properly protected, it would be enormously lucrative to EU interests and open up a global export market.

4. When should it be launched and how much funding is needed?
Should be launched in 2018 with EUR 35m funding
a. 5-8 small-scale projects, RIA, WP2018
b. 3 large-scale projects, RIA, WP2018

II. Proposal for Research or Innovation Topic(s) in Horizon2020 WP 2018-2020

Migration of photonic interconnect toward full digitization of ICT and consumer subsystems

1. Description of the topic, objective:

Achieve full migration of optical interconnect into ICT systems and sub-systems enabling enhanced digitization of ICT environments

The objective is to enable full disaggregation of data resources, which will ultimately transform data communication nodes into individual, optically interconnected network entities. This will be crucial to the digitization of ICT environments spanning not just intra-data centre networks, but migrating into consumer, automotive, aerospace and medical technology spaces, in which Europe is strong. To sustain digital data growth and keep up with surging traffic it is imperative to fully scale deployment of photonic interconnect by removing prevailing commercial barriers. This will necessitate the development of advanced concepts for design, layout, inter-communication, network architectures to enable and support exascale integrated photonics and photonic interconnect (Target TRL: 5-6)

Target specifications:
- **Sub-ToR and consumer interconnect target** - Ultra-low cost optical transceiver / switch terabit/s interconnect achieving over 10 fold reduction in cost/power consumption
- ICT systems and sub-systems with sub-ToR level, intra and inter-node, optical connectivity
- Agnostic, scalable, flexible switching architectures for inter-node communication within and between systems and racks including switchless or n-dimensional torus architectures
- Board and chip-level optical connection including electro-optical PCBs, optical waveguide coupling and connectors for board-to-board and fibre-to-board connectivity and optical coupling interfaces for chip-to-board interconnect – at least TRL 5 should be achieved

2. Relevant Research & Innovation present in Europe

Europe has proven scientific excellence in optical interconnects with world-leading research groups in relevant fields such as VCSELs, silicon photonics and optoelectronic PCBs. This is largely the result of sustained EC support through FP7 projects like PhoxTrot, RAPIDO, MIRAGE, FIREFLY, VISIT as well as H2020 projects NEPHELE, COSMICC, L3Matrix, STREAMS and ADDAPT. To sustain this momentum and reinforce the competitiveness of European R&D it is essential to ensure continuity of EC support in this field. European excellence has led to creation of innovative SMEs (e.g. Vertilas, Sicoya, Vario-optics, Polatis, Firecomms, XCeleprint, KAIAM) and has strengthened the leadership of large enterprises with investments on European soil (e.g. ST Microelectronics, Philips, IBM, Seagate, FCI/Amphenol, Bull, Finisar). With proper industrial leadership to ensure tighter protection of IP developed, exploitation of European research in optical interconnects will be assured within the EU. European players cover the entire value chain in the data centre ecosystem, whereas large-scale investments in new data centre facilities are planned for the next few years in Europe.
3. Impact on European economy, employment;
The data centre networking market alone will reach $21.85 billion by 2018 with a CAGR of 11.8% (Infonetics). This is driving growth in photonic interconnect sector, which represents an integral part of its ecosystem, with chip-level photonic interconnect expected to generate $990M by 2020 (CIR) and the market for Ethernet optical interconnects reaching $2.2 billion by 2018 (LightCounting).

4. Impact on societal challenges

**Digitization of Europe with data centres:** From value-added Cloud services to instant content delivery provided by edge computing, data centres enable digital goods and services with unprecedented empowerment for economic growth and access to knowledge. Optical interconnects are essential to remove current barriers in the access of online services and create an environment of equal opportunities, where digital networks and services can prosper. They will also substantially scale the performance of high performance computers, enabling breakthroughs in medicine, material design, climate modelling and more.

**Photonic interconnect for consumer applications:** The main goal of this priority will be to allow high volume, commoditised photonic interconnect for consumer applications, which includes computer/display interconnect (e.g. optical USB), automotive, medical, aerospace, sensors all forming part of and enabling rapid digitization of consumer technologies in society (Internet of Things)

**European data centres are vital to the on-going digitization of society and industry.** The greater sensitivity to where data is stored and processed in Europe provides a unique environment for the deployment of next generation optical interconnect technology, enabling the capture of the full value chain from component hardware to delivered services within Europe.

5. EU added value:

With soaring research and commercial interest in optical interconnects, the field is becoming exceptionally competitive. Global governmental and VC funding is reinforcing overseas efforts and posing fierce competition to European players. Japan, Korea and China are set to double their photonics research funding from €2.1 billion in 2014 to €4.2 billion in 2020, well in excess of H2020’s €0.6-18⁶, while the USA’s AIM initiative will provide $610m for integrated photonics. The disparate nature of Europe creates great potential for a broad and diverse resource pool, spanning many different technologies and design cultures and could be ideal for advanced photonics research. A pan-European approach is essential to pull these together and to:

- create critical mass combining excellence not available in a single European country;

⁶ http://optics.org/news/6/6/40
– foster collaborations across value chain to promote application and market-driven research
– promote emergence of disruptive approaches challenging limits of current state of the art
– consolidate market within Europe into more competitive schemes and supply chains

Enabling a European single data market where movement of data occurs freely across Europe

6. Funding:
The RIA action should be called in 2018 to ensure continuity of EC support, given that all ongoing projects on this topic will conclude by 2018. Given the larger funding levels in US and Asia, this gap can be expected to close rapidly if funding levels are not maintained. A funding level of EUR 35 million will be required to sustain this level of activity and allow globally competitive research.
WG 2 – Highly Productive Ultra-Short Pulse Laser Systems for Fast Material Processing

**Description of the area where Horizon2020 funding is requested**

1. **Area to be addressed**

   The research topics address the following areas:
   - Technology of short pulse (ns) and ultra short pulse laser systems (<10 ps) and related components and optical elements
   - Laser based industrial production with short and ultra short pulse lasers
   - Use of ultra short pulse lasers in industrial processes by leveraging the deployment costs

2. **Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+. What is the challenge (in Europe) in the respective area today?**

   The European Photonics industry and especially laser manufacturing for industrial applications has a leading position in the world. The market leaders in industrial lasers and machine equipment are located in Europe and many of the laser applications in the different fields can be found in European industry.

   Lasers and related processes and tools are key elements in production processes. One leading edge in this field are ultra short pulse lasers, which have gained acceptance in industry. First applications are the production of precise micro holes in metallic material or to cut brittle material like hardened glass for mobile devices. The main restriction for further industrial applications is the current limitation in available output power and productivity of these laser systems and related elements. This includes achieving technology that delivers high average power in combination with fast beam deflection or beam splitting for parallel processing.

3. **What needs to be done?**

   Photonics is a cross-sector technology and therefore cooperation along the entire value chain is essential to meet the new challenges. Fostering the development of new laser sources and optical elements is needed to extend their industrial applications. New lasers and processes will lead to a higher productivity of production processes and will give way to innovation in this field.

4. **When should it be launched and how much funding is needed?**

   WP2018, Research and Innovation Action (RIA)
   25 MEuro funding
   Average project size in terms of requested funding 3-4 MEuro
Proposal for Research or Innovation Topic in Horizon 2020 WP 2018-2020

Highly productive ultra-short pulse laser systems for fast material processing

1. Description of the topic and objectives

Short (ns) and ultra-short pulse lasers (<10ps) USPL have gained an important role in industrial laser manufacturing in the last years, although this technology is young and fast developing. Compared to existing laser systems with output powers of several kW used for cutting or welding, the average output power of current commercially available USPL is still only in the range of 100 W. First applications in production have been demonstrated like drilling precise micro holes in metallic material (injection nozzle, increasing the engine efficiency by >10%) or cutting brittle material (hardened glass for mobile devices, replacing mechanical processes which create huge amounts of fine dust emissions). In order to address industrial applications and to increase industrial relevance, future laser sources and further system elements have to reach and withstand higher average power levels of more than 1 kW in an industrial environment. The pulse energy depends on the application, for special surface applications high pulse energies in the order of Joules may be necessary, for others, moderate pulse energies at high repetition rates in the multi-MHz range and high speed and flexible pulse modulation and beam deflection systems may be necessary. Beside the laser source, developments in peripheral elements, such as beam transport, delivery fibres, beam shaping and optics are necessary for industrial implementation of future USPL. All these elements have to withstand the extreme intensities of short pulses in the area of nanoseconds, picoseconds and even femtoseconds. Not only usual near-IR wavelengths should be addressed, but also shorter wavelengths (down to UV) and longer wavelengths (up to mid-IR). Additionally, monitoring systems (components and process) and closed-loop control down to the work piece is essential for an enhanced product quality and supports the digitalisation aspects of “Industrie 4.0”.

For dedicated research actions (RA) with TRL<5, the emphasis should be on the laser source and all elements down to the work piece, including the necessary monitoring and closed-loop control. A relevant industrial application should be used as a demonstration example, but the process development itself should not be included in the RA. To limit the complexity of a project proposal the research area could be reduced to a combination of at least three connected work areas (between laser to work piece). Proposals should provide metrics and targets to measure the specific predicted impacts of the project.

2. Relevant Research & Innovation present in Europe?

Despite a strong competition from the US and East Asia, European research institutes and industry play a leading role in the research, development and manufacturing of laser devices, especially as a tool for manufacturing. In addition, the EC domestic market is one of the most important markets for laser materials processing systems. Thus, the exploitation of the R&D results by European industry is secured and will help to expand European industrial leadership in photonic applications and technologies, and safeguarded European capacity to manufacture innovative products. Strengthening of the European R&D network creates benefit for the less-developed EU countries, thus granting entrance to the Photonics market and enhancing the position of the European Photonics R&D market as a whole.
3. Impact on European economy, employment

The impact of the potential projects will be in an increase in the position of Europe in high value added manufacturing, thus strengthening the European Economy in general but especially in the field of laser machine tools and within all laser market and gives a strong relation to digitalisation concepts like “Industrie 4.0”. Beside laser equipment suppliers and end users, software and metrology providers will benefit from the envisaged solutions, creating advanced laser machine tools and higher penetration in the manufacturing sectors with positive effects on the complete production chain for industrial manufacturing.

Lasers and related processes and tools are key elements in production processes. One leading edge in this field are ultra-short pulse lasers, which are starting to gain relevance. The main restriction for further industrial applications is the current limitation in available output power and productivity of these laser systems and related elements. This includes achieving technology that delivers high average power in combination with fast beam deflection or beam splitting for parallel processing.

High power laser systems are needed to pave the way for a broad and totally new area of applications on industrial scale. European research institutes and technological leading companies in Europe are leading in the field of ultra-short pulse lasers. This gives the chance for Europe: projects in this field will lead to innovation on a fast track in order to enter and establish new applications in industrial scale.

4. Impact on societal challenges

Laser processes for manufacturing strongly contribute to the societal challenges in the field of Energy, sustainment of resources and a sustainable preservation of production in Europe. Major points for the use of laser technology for green manufacturing are that lasers reduce energy consumption and chemical waste. Sustainable (Green) Economy: e.g. light weight cars, batteries and fuel cells, high-efficiency photovoltaic modules require laser technology for their production to reach the needed high challenges of these products. From pace-makers to synthetic bones and from endoscopes to the micro-cameras used in in-vivo processes – laser based processes play a major role in addressing the needs of the ageing society in Europe.

5. EU added value

In line with the WG2 roadmap this call topic points out the ongoing relevance of ultra-short pulse lasers for industrial processes.
- Secured European industrial leadership in photonic applications and technologies, and safeguarded European capacity to manufacture innovative products.
- Consolidate KnowHow on an EU-Level rather than on a national level
- Increase the competitive level of EU-companies
- Avoid duplication in developments and better resource management

6. Funding

The funding in total is proposed to be 25 MEuro with an average project size in terms of requested funding of 3-4 MEuro.
Area to be addressed

The research topics address the following areas:

- Increased manufacturing productivity, by using precise and tailored deposition of laser energy, for well-controlled and efficient processes, with lot sizes beginning with one.

- Increased flexibility in manufacturing, enabling highly individualised products, in mass and specialised markets, across a wide range of consumer markets.

1. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+

The European Photonics industry and particularly laser manufacturing for industrial applications, has a leading position in the world. The market leaders in industrial lasers and laser machine tools are located in Europe and many current and various applications of lasers in materials processing can be found in European industry.

The vast majority of laser materials processing is currently undertaken using circularly symmetric energy distributions. Manipulation of laser light to produce exactly the required incident energy distribution has the potential to both increase the efficiency of the resulting process in current application areas such as micro-machining, welding and surface engineering and introduce new processes for new innovative applications.

2. What needs to be done?

Photonics is a cross-sector technology and therefore cooperation along the entire value chain is essential to meet the new challenges. In laser material processing, the systems between the beam source and the work piece, are a crucial element in the successful exploitation of the beam source. In achieving progress here, European leadership in this sector in industrial and research activities will be secured. Fostering the development of new laser beam forming elements and control systems is needed to both extend applications, in terms of efficiency and introduce new applications, in terms of applied energy distribution. Modelling of the interaction of tailored laser beams with the materials being processed will be needed as an aid to the iterative establishment of the optimum distributions. Partnerships are required to integrate the development and value chains in order for Europe to introduce this new form of laser materials processing.

3. When should it be launched and how much funding is needed?

WP2018:
Research and Innovation action.
4MEuro estimated average funding per project.
Number of proposals expected 10-15
Tailored laser beams (RA)

A laser beam has unique properties allowing ‘tailoring’ of the energy distribution incident on a material surface or indeed, within its volume. This research action focusses on the continuing necessity to explore new methods and schemes of beam shaping, for materials processing with today’s flexible and more powerful laser systems. The fundamental requirement is to provide the right distribution of photons at the right place and at the right time, producing a high resolution, temporal and spatial deposition of energy, thereby enhancing process efficiency over and above the use of a simple circularly symmetric focussed spot. This could be realised for example, using diffractive beam forming elements, advances in spatial light modulators, arrays of beams or laser sources, novel optical fibres or by distributions produced by rapid beam scanning. This call would seek collaborations that involve optics and beam delivery systems manufacturers, control systems engineers, laser systems suppliers and end users, as well as research organisations. It is also expected that mathematical modelling should be involved, to enhance the process of determining the correct energy distribution required for any particular application. Process development will be required in order to demonstrate and validate the benefits of applying a tailored laser beam. Application areas are wide but the results of the projects would be used in products addressing societal challenges in the areas of healthcare, transport, energy generation and the environment and impacts should focus on these areas. Proposals should provide metrics, the baseline and targets to measure specific predicted impacts.

1. Relevant Research & Innovation present in Europe?

Despite a strong competition from the US and East Asia, European research institutes and industry play a leading role in the research, development and manufacturing of laser devices, especially as a tool for manufacturing. In addition, the EC domestic market is one of the most important markets for laser materials processing systems. Thus, the exploitation of the R&D results by European industry is secured and will help to expand European industrial leadership in photonic applications and technologies, and safeguarded European capacity to manufacture innovative products. Strengthening of the European R&D network creates benefit for the less-developed EU countries, thus granting entrance to the Photonics market and enhancing the position of the European Photonics R&D market as a whole.

The research activities needed are aligned with the current advancements on digitalisation of production, aligning to Industry 4.0 and should enable straightforward mass customization of product in different sectors (aeronautics, automotive shipbuilding, metalmechanics, energy and electronics). Europe is a leading player in this digitalisation approach and with the results of the projects, Photonic solutions will become integral parts of a fully digital production systems, providing high quality components, even at small and medium lot sizes.

2. Impact on European economy, employment?

The impact of the proposed projects will be in an increase in the position of Europe in high value added and customised manufacturing, thus strengthening the European Economy in general but especially in the field of laser machine tools and within all laser markets. With full digital photonic
production “First time right” and customized products will be possible with a minimum of set up and production time, resulting in reduced manufacturing costs. Component manufacturers, laser equipment suppliers and end users will benefit from the envisaged solutions, creating advanced laser machine tools and higher penetration in the manufacturing sectors.

3. Impact on societal challenges?

The results of the projects will impact on several of the overreaching H2020 Societal Challenges, in particular in the areas of health, secure, clean and efficient energy, smart, green and integrated transport and the environment. For example, tailored energy distributions could be used to manufacture new medical and healthcare products, improve the efficiency of joining metals and non-metals, in equipment used to produce energy and to contribute to weight reduction and less CO2 emissions in the transport areas of rail, automotive and aerospace. Laser surface engineering, in a wide variety of applications, can benefit from optimization of the incident laser energy. Enhanced cutting capability should be available using tailored energy distributions and in laser based additive manufacturing processes, tailored beams should lead to faster processing with better usage of raw material.

4. EU added value?

Results of projects responding to this call should maintain and secure European industrial leadership in Photonic applications and technologies. They will also safeguard European capacity to manufacture innovative and efficient ways. Know How will be consolidated on an EU-Level rather than on a national level and this will contribute to an increase in the competitiveness of EU companies. In addition, added value will be found by avoiding duplication in developments and stimulating better resource management.
1. Areas to be addressed

- Laser-based manufacturing equipment and processes as a cross cutting topic for Mobility, Health Care, Machine Industry, Energy and others.
- Digital Innovation Hubs as an evolutionary approach for the support of SMEs in the development and integration of laser manufacturing processes with an emphasis on digital technologies in processes, equipment and business models providing process and system evaluation, business development support and industrial approval in end user conditions

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+. What is the challenge (in Europe) in the respective area today?

The European Photonics industry and especially laser manufacturing for industrial applications has a prime position in the world. The market leaders in industrial lasers and machine equipment are located in Europe and many of the laser applications in the different fields can be found in European industry.

For a large variety of laser processes, industrial installations have been implemented based on intense parameter evaluations and specialized technology developments with limited ICT integration. Long term knowledge build up and strong application specific business developments have led to economically beneficial transfer of efficient and flexible laser processes into industry. However, the gestation period for many new technical developments and processes is often too long to be transferred into effective production, even though clear technical benefits have been demonstrated. With this obstacle, a fast and effective technology transfer of new laser processes and equipment into a wider community of manufacturing is suppressed. The installation of Digital Innovation Hubs for laser based equipment and processes will help to speed up development, to foster new business and business models and to integrate highly productive laser processes into digital manufacturing solutions.

3. What needs to be done?

For a faster take up of innovative technologies for laser based manufacturing, a new approach in providing a connected set of services in combination with equipment assessment is needed to reduce development and implementation time cycles. For the transition from sequential development of processes and equipment towards a transparent digitization-ready manufacturing solution an integrated support of both system providers in the development of equipment and processes together with appropriate business models is needed as well as assistance and training for the implementation at the end users production.

Today, competence centers in Europe provide excellent services in the evaluation of laser equipment for industrial use, to move processes and equipment from TRL-Level 4-5 to TRL-Level 7-8. However, technical developments by themselves, are often not sufficient to allow rapid and consistent market penetration of new manufacturing solutions. Business models, financing,
training and education, as well as integration in the ever more digitized manufacturing and process chain, are often more important than the technical improvements. Due to this fact the transfer of innovative ideas into real industrial innovations is blocked by the lack of fast and effective support in all necessary areas of industrialization especially the required digitization which is still not at the level of concepts like Industry 4.0. There is a very strong need to develop instruments for the transfer of new laser equipment towards industry under the scope of driving Market Readiness Levels (MRL) from 4-5 to MRL 7-8.

With an integrated strategy of

- Identification of highly potential business cases behind new technical laser processes
- Development of business models for the anticipated solutions
- Provision of pre-competitive funding and post-validation support for access to venture capital
- Technical assessment of equipment, processes, digitization capability
- Provision of training and education modules for skilled workers
- Creation of attractive workplaces for EUROPE2020

major barriers for the implementation of new laser manufacturing equipment will be lowered and new laser processes will achieve a faster demonstration under industrial conditions.

4. When should it be launched and how much funding is needed?

The action should be launched at the beginning of WP2018 to make the best use out of cross links to the current I4MS initiative where APPOLO and LSHARE are successfully demonstrating the success of the basic concept of connected competence centers. The development of concepts for Digital Innovation Hubs is an essential evolution of this concept. In connection to smart specialization strategies and regional resources in infrastructure or funds, it is expected that a financial support at European level of about 20 Million Euros is needed to enable this development.

Proposal for Research or Innovation Topic in Horizon2020 WP 2018-2020

1. Description of the topic, objective

   Establishment of Digital Innovation Hubs (DIHs) for advanced laser manufacturing equipment and processes (RIA)

Digital Innovation Hubs for laser based manufacturing equipment, aim at a broad set of services that support fast evolution of innovative laser solutions for industrial production in Europe with the aim to achieve market readiness levels beyond eight within a minimum time frame. Based on specific sets of technologies, the services provided by a DIH need to span from business model development, support across technology assessment towards assistance in achieving capital investment for market entry and industrial uptake up to assistance in the end user driven industrial implementation of the new technologies. The business cases considered in the DIH can be market driven by manufacturing challenges at the end user site, from innovation ideas at equipment supplying SMEs but also bottom up, technology driven, from the scientific community. Each business case needs to be evaluated under industrial conditions with a significant benefit to the entire manufacturing chain. The business cases can include equipment manufacturing and also new
laser processing solutions but always must include an industrialization step to a technology and market readiness level of 7-8.

The services of a DIH should include actions that involve industrial users that represent a relevant market segment for laser based equipment and SME suppliers that are capable of providing robust and sustainable solutions for manufacturing companies. These services should address at least the following:

- Technology scouting
- Financing - from identifying regional funds to providing support in access to venture capital
- Mentoring in business development
- Brokerage between industrial users and SME suppliers
- Assessment of laser-based equipment
- Integration in digital manufacturing environments from design to production
- Implementation of test beds and validation therein
- Training for use and implementation of solutions in manufacturing environments with attractive work places for the young and ageing workforce

The resources of a DIH should provide the basis to implement the proposed business cases. To achieve this target, relevant equipment and infrastructure is needed to support the development of the embraced technology. This includes proven scientific background and a wide ranging set of complementing technological competencies in an existing network of competence centers.

The overall aims are to strengthen the equipment supplier base, predominantly SMEs, and manufacturing users, predominantly industrial companies, through a close cooperation with competence centers in an embracing set of services to improve manufacturing processes in relation to quality, speed, environmental and resource efficiency. Herein, the employment of ICT for the entire solution is key to achieve a degree of digitization at the level of Industry 4.0 concepts. The validation of innovative high-tech laser equipment shall be performed in in production-like environments that are very close to manufacturing conditions.

With the provision of scientific know how, comprehensive equipment for the evaluation of the business cases and financial as well as organizational support, a step in TRL from 4-5 to 7-8 shall be reached for the envisaged applications or solutions. The proposal should assign 25% of the budget for assessments to business cases as part of the proposal and provide a model on how to allocate the remaining 75% during the execution of the project.

2. Relevant Research & Innovation present in Europe?

Within the I4MS initiative, existing research organisations have teamed up to network competence centers around Europe. LSHARE and APPolo are two running projects that implement approaches to support SME focused innovation in manufacturing. Aside of these projects, regional laboratories in less developed areas of Europe receive tutoring and financial support to develop a profile that provides the basis for becoming a competence center. These research organisations
and independent laboratories provide a substantial foundation to implement digital innovation hubs (DIHs). Within the DIHs also financing aspects and new business models arising from e.g. implementation of additive manufacturing, will be covered to speed up the transfer from lab to industry. The success of the DIHs will be proven by successful transfer of new laser processes and equipment that has been evaluated and developed by the existing laser manufacturing community. Substantial research has created a set of solutions in the area of CPS and cloud computing which needs to be employed in laser based manufacturing with a clear focus on digitization beyond the Industry4.0 aspect. Digital Innovation Hubs therefore need to link to these areas where the focus of this action should cover manufacturing equipment from both sources to processes and application to integration in the work environment.

3. Impact on European economy, employment

The impact of the DIHs is multifold in the creation of an ecosystem that spans from a systematic stimulation and identification of innovative laser manufacturing ideas over feasibility studies for processes and equipment down to support frameworks that facilitate the creation of seamless market entry strategies.

A special focus lies on

- Support for a large number of SMEs (500+) to grow their markets and to provide solutions for industrial laser manufacturing in Europe.
- Creation of attractive work places for young and ageing workers through driving new production technologies towards the shop floor
- Increase in performance and reliability of manufacturing equipment by the use of highly productive laser process to lower manufacturing costs to keep production in Europe.
- Creation of business opportunities for equipment suppliers which again creates jobs and labor for local manufacturing companies.
- Foster the leading position of European laser manufacturing technology as solution providers worldwide.
- Offers on training and education from a prime source of knowledge providers and key stakeholders

4. Impact on societal challenges

Digital Innovation Hubs (DIH) in the context of laser based manufacturing provide a hotbed for fast evolution of unprecedented laser based manufacturing technologies. The consumption of energy and raw materials is reduced by the uptake of manufacturing technologies like 3D printing. The proposed innovation hubs support the development and uptake of such technologies. Within the entire eco system from idea to production, the digital innovation hubs create new jobs at equipment suppliers and producing companies, educate skilled workers and enhance cost efficient production at European plants. With these impacts,

- The digital innovation hubs secure European industrial leadership in photonic applications and technologies, and safeguard the European capacity to manufacture innovative products
- The digital innovation hubs enable a broader and faster take-up of photonics in digital manufacturing approaches in particular by:
  - SMEs.
o Change in work flow and labour practices with shorter and more effective set up times
o Less material consumption for process implementation

- The digital innovation hubs create solutions and educate to allow an ageing workforce an extended active involvement in manufacturing
- The digital innovation hubs provide technologies for green and resource preserving production and products lowering material and resource consumption
- The digital innovation hubs increase the employees’ involvement in the entire production chain through a new way of digital transparency

5. EU added value

Connection of relevant European competencies and regional competence centers that team up to support innovation on a consistent European service level with access to scientific and knowledge resources. With respect to digitizing laser-based equipment for the benefit of European industry, the platform needs to provide a pan European resource and connection point to create a transparent and standardized approach in using the best from “Usines de Future”, “Field Labs”, “Industry 4.0” and other initiatives. For the European Community, this provides the much needed link between regional manufacturing environments and international knowledge and resources.

With a strong link between smart specialization strategies and regional resources, the Digital Innovation Hubs connect activities across Europe that enable the use of shared resources, recollection of distributed knowledge and communication of best practices across all regions in Europe.

6. Funding

The action should be started at the beginning of WP2018 as Research and Innovation Action (RIA) to provide a continued support to SMEs, midcaps and industry in the advance and uptake of innovative manufacturing solutions. The action should complement regional activities such as smart specialization strategies (S3) and regional resources from infrastructure to structural funds. The networking of competencies and the access to distributed infrastructure on European level builds the basis for a wide support to research on innovative ideas.

It is expected that an indicative RIA budget of 20 MEuros at European level will enable the implementation of new sustainable and interconnected Digital Innovation Hubs that would provide support to more than 500 SMEs with corresponding 500+ innovations. This innovation support will multiply the impact by paving the market entry after the DIH support phase.

Supported SMEs in the role of equipment suppliers should match the received funding by additional personnel resources. This would assure commitment and support the success probability. Involved companies in the user role should be reimbursed their expenses for definition of the challenge. The refunding of the involvement should be matched by additional personnel resources committed to definition and validation activities to ensure substantial contribution and future uptake.
WG 3 – Next generation of biophotonic methods and tools to understand the cellular origin of diseases

WG 3 – Photonics enabled, more accurate quantified diagnosis during interventions and treatment – Research actions

I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed

The application domain is the health and life science area. The targeted application areas are

1. Photonics enabled, more accurate quantified diagnosis during interventions and treatment; diagnostics driven therapy (including, e.g., image guidance, medical laser systems etc.) or point-of-care diagnostic tools and instruments for minimally invasive as well as non-invasive longitudinal monitoring and/or companion diagnostics towards stratified medicine.

2. Pilot lines for advanced optical medical devices

3. Next generation of biophotonic methods and tools to understand the origin of diseases.

Generally, it is expected that the resulting tools and methods are clearly superior to earlier approaches/Goldstandards.

Additionally, the following specifications are expected (for 1. and 2.):
- High sensitivity, specificity and accuracy, with high reliability (in particular a minimal number of false positives) and speed
- Robustness
- Compliant with regulations
- Safe to operate, minimally invasive
- Low cost or leading to an overall cost reduction

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+

What is the challenge (in Europe) in the respective area today?

Photonics enabled therapy

While most of the projects in the area of biophotonics focus on either imaging or point-of-care equipment for the diagnosis of diseases, only very few projects concentrate on the advancement of therapy itself. Therapy can be improved in several ways. On the one hand, we need gentler and stronger focused therapeutic methods. In particular, we are looking for advanced photonic methods (from THz, visible light, X-ray to gamma frequencies) which support surgical procedures e.g. by helping to delineate tumor borders or areas with a perfusion deficit, to guide navigation of devices, to develop new surgical tools for navigation and treatment, or to locally apply drugs (note that further development of photodynamic therapy is generally excluded as it will usually be not possible to increase the TRL level substantially due to the need for FDA approval of the necessary drug except if approved photosensitizing agents are used and the development is focused on e.g. dosimetric planning and guidance tools). On the other hand, the challenge is to improve therapy
by longitudinally monitoring the therapeutic progress while administering a drug and/or by working towards stratified medicine, i.e. to include and measure individual dispositions, including genetic dispositions, with regard to the effectiveness of drugs using photonics (this also includes, e.g., methods to determine the resistance of bacteria against antibiotics). Another important issue for many diseases is the aftercare phase in order to prevent a relapse. The corresponding devices/methods should be more reliable and precise than current ‘gold standard’ methods allow, without substantially increasing the examination costs or duration. Even better than improving therapy, would be to build on strategies to avoid diseases right from the start or to detect first signs of changes in the health condition well before the symptomatic manifestation of a disease. Detection of the health status is facilitated by minimally or non-invasive longitudinal monitoring of biomarker panels in a decentralized manner employing photonics technologies.

_Pilot lines for advanced optical medical devices_

Europe’s photonics industry is facing fierce global market competition and has to cope with a very high speed of technological developments in the field. In particular, advanced optical photonic technologies for health applications is a very promising field, where Europe has produced during the past decades excellent R&D results. However, industrialization is still lagging behind. Europe is experiencing the existence of many fragmented and rather uncoordinated developments between many different national and regional players. Europe suffers also from a slow innovation process for turning many good R&D results into innovative products (‘Valley of Death’). This requires a joined-up approach, covering missing links in the value chain, such as assembly and packaging of photonics components.

_Next generation of biophotonic methods and tools to understand the origin of diseases_

A third topic that is in the focus consists of advanced instruments and methods to understand the cellular reasons for the origin of diseases to stop diseases even before their onset. This is a long-term challenge, which can be solved only by sustained effort.

3. **What needs to be done?**

1. In case of the photonics enabled, more accurate quantified diagnosis during interventions and treatment; diagnostics driven therapy, therapy monitoring, and decentralized health status monitoring we suggest both, a call for research projects to promote solutions to a TRL level where product development can pick up (1a) and a call for innovation projects to further develop prototypes close to the system level (1b).

2. The main objective will be to create interface and acceleration conditions to transform low TRL technologies to robust medical devices answering to clinician needs. Accordingly two calls for innovation projects are planned, one pilot line for _in-vitro_ diagnostics (2a) and a second pilot line for _in-vivo_ imaging (2b).

3. The further development for instruments to investigate further the origin of diseases should be supported by a call for research projects.
4. When should it be launched and how much funding is needed?

1a): WP2018, 20 million €
1b, 2a): WP2019, 20 million € each
2b), 3): WP2020, 20 million € each

II. Proposal for Research or Innovation Topic(s) (2 page max) in Horizon2020 WP 2018-2020

1. Description of the topic, objective:

For the topics described in the following we assume that a clear medical need stood in the beginning of the basic research and that already at that stage a clinician/physician or another end-user was directly involved.

*Photonics enabled therapy*

The objective concerning therapy is to further develop methods that provide the clinicians with photonics enabled tools to improve or to assess the successes of therapies, be it a surgery or the administration of a drug or a less traditional therapeutic approach (e.g. as in case of wearables/mobile health, tele-medicine etc.). In surgery it is often the case that e.g. the border of a tumor is not well-defined and/or not easily visible with the tools the surgeon has at hand. Usually tissue is therefore removed radically (i.e. generous). Another example is the administration of antibiotics, where it is often not known or yet not quickly determinable if the bacteria are resistant against the antibiotic. A third example is the radiation dose or the dose of a drug, e.g. a chemotherapeutic. Genetics may lead to the situation where a dose is already dangerous for one patient while the drug is dosed too low for another patient to be effective. For this topic we suggest both a call for research and a call for innovation projects. The research projects should start after TRL 3, which means that an experimental proof of concept had already been completed beforehand, and bring the instrument or tool to TRL 5 or 6 with a validation or demonstration in a clinical environment. For the innovation projects it is expected that TRL 5 has already been reached and that the instrument will have a completed TRL 7 after the corresponding project. The targeted diseases are restricted to the following major diseases: cancer, infectious diseases, cardiovascular diseases (skin cancer is explicitly excluded as a result of the market and portfolio analysis!) for both (research and innovation actions) since for these diseases the use of photonics methods and tools can make the biggest difference in comparison with conventional methods.

Accordingly, the difference between the research and innovation projects lies in the different technology readiness levels (TRL). Therefore, a corresponding research project must be carried out by teams that include, in addition to the physicians/clinicians, academic teams and companies that provide components, systems and methodologies and/or carry out further development activities on these. While the clinicians have defined the need earlier, they provide samples and finally carry out the evaluation concerning the usefulness of the instrument; the research and development is carried out by a team of academic institutions, research institutions and companies. There are various levels of company involvement...
possible. In one scenario, companies will mainly provide sub-systems and components, whereas academic institutions carry out assembling of the system and method development as well as e.g. the development of software and solutions for sample preparation. In another scenario, companies focus on system integration and method development in close collaboration with academic partners. In this context both system integration companies (mostly large OEMs) and SMEs collaborate with System and method development will need to include steps necessary to enabling clinical studies. For the innovation projects the project lead is expected to be conveyed to a company, but the evaluation of the instrument must still be carried out by the end-user. Also, for the innovation projects at least one medtech company (which is able to bring the product to the market proved by its market share or by an elaborated business case, which needs to show how to bring the product to the market) must be involved. Furthermore, a potential project proposal must include a part where the benefit of the outcome is demonstrated in a real environment – (preclinical studies, including pilot clinical studies when necessary) within the study. This demonstration needs also to assess the usability of the device and the ability to manufacture it.

**Pilot lines for advanced optical medical devices**

With regard to the pilot lines, the objective will be to create interface and acceleration conditions to transform low TRL technologies to robust medical devices answering to clinician needs. Activities will focus on the most promising photonics health technologies, on which Europe has heavily invested R&D wise these last decades, advanced optical technologies like, e.g. photoacoustic imaging or Raman spectroscopy etc. Such label free technologies present real competitive advantages in fields such as oncology, hematology, microbiology, endoscopy and dermatology, and show promising features in cellular therapy (characterization of tissues, biological fluids at cellular level, microbiological tests, label free *in-vivo* imaging, etc) The European photonics industry must pool investments for enabling the rapid development of new products and minimizing times to market. This speed to market approach needs to include the entire value chain, from advanced research through to technology take up, pilot lines, and manufacturing platforms, in close relation to end-users. Standardization must be addressed, in particular to answer to calibration and control issues, both at component and system level. The pilot cases will serve as models for the specifications of future optical based medical devices, with a focus on new components (laser sources, sensors) and system integration, answering to industrial requirements in reliability, robustness and replicability. Activities are expected to focus on Technology Readiness Levels 4 to 5, and target Technology Readiness Level 6 to 7. Potential projects could, e.g., be continuations of former, also EU, research projects with highly positive outcome.

**Next generation of biophotonic methods and tools to understand the origin of diseases**

With the third topic we want to further develop photonic tools to investigate the origin of diseases (i.e. the understanding of processes within the cell which lead to outbreak of diseases) from TRL 2 (technology concept formulated) to TRL 5 (technology validated in relevant environment). The goal is to provide the biochemical end-user and the medical doctors engaged in research with new tools towards a better understanding of the origin of diseases (DNA sequencing or other genomics, leading e.g. to personalized (or stratified)
medicine is not included, as the final goal is the development of photonic tools and not the research on the cellular processes itself).

For all three topics above, it is of less importance what kinds of photonic technologies and methods will be employed, what photonic component, subsystem or method will be combined or further developed as long as the final device is clearly superior to already available and established devices and has a definite added value for the physician/clinician and the patient in case of the first and second topic and for the biochemical end-user for the third topic. If photonic methods are combined with non-photonic methods, the further development of the latter is explicitly out of scope as long as it is not necessary for integration. The benefit of these newly to develop tools compared to existing one needs in any case to be obvious and proved in a final evaluation by the end-user in a realistic environment corresponding to the individual TRL level.

2. Relevant Research & Innovation present in Europe?

Point-of-care testing for the purpose of health status monitoring will play a pivotal role in the health care system and, thus, offers much room for photonics based solutions. There is a large number of European key players from academic and applied research institution as well companies, which can advance and exploit photonics technology in this field. The branches of photonics based diagnostics driven therapy (not always is therapy diagnostics driven; sometimes diagnostics is still not fast enough, like e.g. in case of sepsis) and in particular therapy monitoring is comparably new. Even in newer studies like the Yole report on Biophotonics (2013) these branches do not yet get special attention. However, the methods and instruments are comparable to those necessary for diagnostics in the first place like e.g. point-of-care equipment. Accordingly, European companies are able to supply the whole food chain from components over systems to complete solutions.

In the life science related market Europe is also well-positioned with larger companies like Zeiss, Leica and Tecan but also with a multitude of different SMEs. For medical imaging systems industries providing both hardware and software are e.g. Philips and Siemens Healthcare. Besides, there also exist several smaller companies who can be worldwide or European leaders on a particular specific domain related to equipment and/or components, as for example Thales for X-ray detectors and imaging solutions in cooperation with Trixell (a joint venture of Thales-Philips-Siemens). To fully exploit the potential of new photonics innovations it is also essential to optimize integration into the medical workflow and into existing hardware and software products and solutions.

3. Impact on European economy, employment;

The concrete business cases are the sales of systems and related components of

1) Biophotonics devices for health status monitoring, diagnostics guided therapy / therapy monitoring
2) Photonics enabled point-of-care and imaging tools.
3) Photonics based tools and instruments for Life Science applications.
Any decisive technological advantage will obviously improve competitiveness of the European companies and directly translate into higher sales. The explicit market figures for 1) is hard to determine as these markets are still developing and 1) is usually not detailed separately from the market for biophotonics imaging and point-of-care devices. For 2) we expect in particular:
- Strengthened industrial deployment of research results by promoting wide-scale cooperation and greater integration across the whole research and innovation value chain.
- New capacity to offer the medical community industrial quality solutions answering to their needs
- Early adoption of standards and specifications at research level allowing smooth technology transfer to the whole industrial value chain

Europe’s share of the biophotonics market currently amounts to about one third of which is predicted to be 85.5 billion € in 2020. The market for optical microscopes amounts to about 6.2 billion € in 2020 according a study of AT Kearney (2013). The market for optical in-vitro diagnostics amounts to 55.9 billion € according to the same study. This market study shows that Europe is (mainly thanks to Germany) in a leading position in these segments, which may, however, be threatened by the lack of innovation among the related products. If this does not change in the future, Asia is, according to the market study, in a strong position to take over the lead. Since the supply chains are comparably complex or highly diverse, statements about the parts of the value chains that are likely to be located in Europe and the number of potentially created jobs, would be impossible to make.

4. Impact on societal challenges

Most European countries will see a strong demographic change in the near future with drastic consequences for the health and well-being of the European citizens and for their healthcare systems. E.g. the number of new cancer cases and corresponding incidences will rise steeply every year as a consequence. The same is true for other age-related diseases such as cardiovascular, osteoarticular and cerebrovascular diseases and many others. Early detection, precise diagnostics is key to an appropriate and successful treatment. Of particular concern are the falling birth rates and the increasingly aged population. The latter is causing an increase of the number of people with degenerative diseases (Alzheimer’s, Parkinson’s etc) and the former decreases the ability of the working population to support retirees.

5. EU added value:

On the one hand, the addressed societal challenges are European wide, since disease knows no borders as would the impact in case of success. Therefore, combining the expertise across the EU to address these problems would generate a lot of synergies. In particular, since highly specialized knowledge is necessary in a number of different fields which is not available to a single country. This approach will exploit the EU’s substantial knowledge base in photonics and biomedical technologies and their clinical application. It will provide added value by investing in projects which allow complementary cross disciplinary skill sets to be combined from a number of different research groups.
6. **Funding:**

There are lots of barriers to the market entry of SMEs as medical device manufacturers due to regulations and other barriers as well as further risks. Also large companies face such issues. In order to ease these problems and accelerate the speed and effectiveness of R&D&I in Europe, higher levels of H2020 investments for both the academia and the industry would be useful. A concrete number/percentage is hard to provide. For applications in the area of the Life Sciences, environment and food quality the regulations are less serious, therefore the market barriers and the related risks are much lower, but, again, concrete figures are hard to provide.
WG 4 – 3D Light Field and Holographic Displays for Natural Visualization

Research and Innovation Action on “3D Light Field and Holographic Displays for Natural Visualization”

Objective of this call is the development of 3D light field or holographic systems for natural unaided visualization with non-intrusive, intuitive user-interaction. The primary application field is hereby automotive, healthcare, telecommunication and gaming. As the technology matures and costs are further reduced, it might replace conventional display technologies in the broader field of consumer electronics and entertainment as well. Main goals are to:

- Establish innovation consortia including industry and research along the entire value chain, from components and subsystems to end product and service providers.
- Development of components and systems featuring various photonics technologies and components to enable natural 3D impressions with a limitation-free user experience, namely: (i) 3D projection optics including natural depth-of-field view (multiple focus planes), (ii) high-speed/high-resolution microdisplays for light-field or holographic imaging, (iii) embedded SW and HW solutions for in-/outdoor localization, scene recognition, secure and ubiquitous connectivity, intuitive user-interaction, including human feature recognition, haptics.
- Creation of application scenarios for public, home and professional environments and verification in Living Labs including end-users.
- Development of service-focused business cases, e.g. for 3D Head-up-Displays for drivers and large-scale 3D control room applications for ground and air traffic control to enable safe and secure smart transportation, next-generation visualization solutions for education, health, Smart Home, entertainment, automotive, etc.

Relevant Research & Innovation present in Europe

In Europe, R&D on 3D light field and holographic displays is present along the whole value chain. There are multiple SMEs and research centers that develop 3D Display systems: (Holografika (HU), See Real (DE), imec(BE)), IRT b-com, Orange Labs, Université de Rennes (F), i2cat Foundation (SP). Researching novel 3D representations, 3D light field formats and content CIVIT/ Tampere Uni (FI), VUB-Iminds (BE), Mittunivesitetet (S).

Additionally, there are many research activities at human user interaction from 3D haptic feedback to gesture recognition (e.g. SoftKinetic (BE)).

System integrators in the field of Lifestyle & Health (medical imaging, remote doctor), Automotive suppliers (3D head-up displays) and Smart City & home (user interfaces) represent a significant innovation potential in Europe.

European stakeholders (Instituto Superior Técnico and Instituto de Telecomuniccoes (P), FET Poznan University of Technology (PL), etc.) are very active in standardization bodies: MPEG FTV Group, Light Field AhG, JPEG Pleno, forming future 3D TV standards.
Impact on European economy, employment

In the same way as the projected widespread use in the professional domains cited above, the targeted wider adoption of natural 3D light-field and holographic visualization with the related business models will impact a large number of higher volume application domains where Europe is already strong, e.g.:

- **Personal Health Care**: Typical applications are holographic medical imaging technologies (image-based diagnostics for early disease recognition), personal remote doctor, visual surgery assistance, medical education, surgical planning, robotic/remote surgery Holografika (HU), Siemens Med (DE)
- **Smart Transportation**: Typical applications are 3D Head-up-Displays for automotive industry (all known European car manufacturers and tier#1 suppliers) and large-scale 3D control room applications for ground and air traffic control where companies, like HungaroControl (HU) have a strong market position
- **Smart Cities, Smart Home, entertainment**, with companies like Siemens, Schneider, Barco, Greenpeak
- **Connectivity**: Telefonica, Vodafone, Telekom, 5G Lab Germany, etc., telepresence apps.

We expect the outcome of the innovation actions to enable **European system manufacturers** to bring to market **highly competitive products** by integrating 3D light field and holographic visualization solutions for **systems and user-centric services** in the business cases listed above, and to build a **Europe-centered value chain** by strengthening domestic manufacturing of **optical & semiconductor components, and software** up to the already strong system integrators and end users, e.g. from telecom, medical, or transportation industry.

The global 3D display market is to reach **113 B-EUR by 2020** (Allied Market Research) with the chance of European companies capturing a market share beyond 20% based on the strength of the European industry in the application field of Automotive and Healthcare. Next-generation **3D light-field and holographic systems** represent a complex area with cross-connections strengthening components and subsystems manufacturing, developing systems and system integration. This is therefore **not a simple Asian flat panel display topic** and EU still leads thinking. 3D light field and holographic systems require complex optical solutions where players like VUB, Zeiss, Philips, Barco have demonstrated technological leadership. Many of the proposed approaches for 3D light field and holographic displays rely on customization of advanced CMOS platforms in Europe (ST(FR), Intel (IRL), Globalfoundries (DE), CEA (FR), Imec (BE), X-fab (DE)).

There is a competitive advantage for the hub of EU companies in the **3D technology field** (gaming, TV, 3D content, entertainment, software apps, system integrators, etc.). Establishing a 3D light field, holographic display and computational imaging platform offers an additional opportunity for the creative industry, 3D content supply and 3D eco-system stakeholder companies, a good chance in particular for SMEs here. Furthermore, integrated system manufacturing on the EU industrial basis, especially in the field of Health and Automotive is strong in Europe.

EU-level funding will ensure European companies to compete with US and Asia in the emerging **next-generation 3D visualization markets**, create **high-end jobs** and cultivate a skill base in Europe. This will contribute to further foster Europe’s world-wide credibility to gain a leading position.
Impact on societal challenges

Providing natural, freely-viewable 3D visualization over a wide field-of-view (FOV) and field-of-depth (FOD), neither requiring headgears, nor limiting the number or position of users, avoiding eye and brain-strain, or any discomfort, even on longer use, going beyond the limitations of current 3D systems will have a huge impact on several social and industrial challenges. Namely for personal health (image-based diagnostics, personal remote doctor, visual surgery assistance, robotic/remote surgery), for mobility (smart transportation integrated at vehicle and control level), or for prevention of climate change (analysis and interpretation of large 3D metrological datasets and 3D simulation). In a more general manner, it will enhance social interaction in real world spaces empowered by virtual information presentation (education, gaming), without suffering limitations in user experience or comfort.

EU added value: There are already several strong industrial key actors in EU (automotive, telecom, medical, microelectronics, optical industry). A RIA on 3D light field and holographic visualization systems would give momentum of yet less developed industries with potential (data spaces, digital services, system integration, component suppliers). There are living European-wide cooperations between companies and institutions with strong networks. The EU funding would be essential to keep current competitive advantage over recently initiated major Asian and US programs.

Funding
Research & Innovation Action (RIA) 2018: 3D Light Field and Holographic Systems, 18M€
WG 4 – Connected Lighting

WG 4 – Beyond Classical Lighting

I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed

Connected Lighting:
- human centric lighting (as defined by Lighting Europe\(^7\))
- integration of the lighting infrastructure with the Internet of Things (IoT),
  connected lighting
- integration of new functionality by e.g. sensors, controls, both on device and
  on system level

Application domains includes (but not limited to):
- Residential
- Automotive
- Medical
- City
- Offices
- Industry

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+

What is the challenge (in Europe) in the respective area today? (e.g. The excellent results obtained by European research centers and industrial labs in the field did not give birth to any product up to now; the reason is 3-fold:
- Some materials involved and process steps do not exist in current foundries.
- Large investment are needed to produce this new technology in European foundries
- Tier 2 suppliers in this field are quite weak in Europe; European Tier 1 suppliers currently implement Asian products in their commercial equipment.)

Europe is the leading region in the lighting domain, creating 150.000 jobs mainly within SME’s and being the home of the #1 and #2 global lighting companies. The LED lighting market is still dominated by Europe\(^8\) but without continued research and technology development this position of European strength could be lost. The global lighting market is estimated to reach 130 B€ by 2020\(^9\), with LED-based lighting accounting for around 84% of the market value at that time\(^10\).

Since the prices of LED lighting dropped significantly during the last years, LED/OLED lighting is now becoming the dominant lighting technology and the market focus is shifting from energy efficiency to additional smart features (VLC, indoor positioning, human centric

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\(^8\) Spectaris Spotlight Photonics 2014


\(^10\) [http://de.slideshare.net/FrostandSullivan/2015-to-the-point-trend-7-led-lighting](http://de.slideshare.net/FrostandSullivan/2015-to-the-point-trend-7-led-lighting)
lighting,...). This creates the problem that new players from the consumer electronics market are trying to enter the lighting market and create an entirely new competition. Intensive R&D on connected lighting and beyond classical lighting is needed to ensure Europe keeps its leading role in the new lighting market and does not lose it to Asian (and other) players; as it happens to us with the electronics developments some time ago. Furthermore, the novel technologies require huge acceptance with the end-users and the luminaire manufacturers, to make application easier and support a buying decision for the novel technologies.

3. What needs to be done?
   a. Consolidate R&D in the field, especially regarding the validation of the technology by Tier 1 suppliers and automobile manufacturers (Research activity).
   b. Set-up a pilot production line involving the technology providers as well as the potential European customers; they should be provided a free access to the products of the pilot line and integrate them in equipment pre-series (Innovation activity).
   c. Explore the other potential fields of valorisation, including niche markets, where cost constraints can be relaxed (Innovation activity).

A research action on connected Lighting would be needed, which should be implemented in three steps (the first in 2018, the last in 2020) which focus on the different aspects of connected lighting. First the focus should be on the connectivity aspect, then in the following year the focus should be on research beyond classical lighting, where early results from the connectivity projects could already be used and in the final year the focus should be on measuring the quality and impact of this research:

- Research and innovation action on connected lighting: the integration of the lighting infrastructure with the Internet of Things, including integration of new functionalities (e.g. VLC, indoor positioning, ...) and unique form factors which clearly show the value beyond illumination and will offer new validated user centric value propositions. Based on the architecture developed in the currently running OpenAIS European project or a similar architecture, the connected lighting RIA develops new technologies for integrating the lighting infrastructure with the Internet of Things by implementing the security features despite limited resources (slow microprocessors, small memories, limited battery power), ensure the real-time requirements could be fulfilled (if the light switch is pressed, the light has to react within 100ms) and that the additional features (optical wireless communication (OWC) including VLC, ...) don’t compromise the system integrity. Application domains could be lighting in the building environment (such as offices and industries with OWC for indoor positioning and broadband data communication, home with OWC for video streaming and broadband download, smart cities with OWC and connected lighting (wireless and wire based) for traffic management systems) and/or industrial lighting (such as automotive using the better OLED form factors and design flexibility,)
- Research and innovation action (RIA) which is going beyond the classical lighting applications/classical technologies and beyond spectral ranges (e.g. UVB/UVC). The aim of this call is to extend the knowledge on human centric lighting including...
neighboring domains like horticulture by developing of exceptional user centric experiences. Solutions are based on lighting solutions that could, beside the visible part of the spectrum, also include other spectral ranges and investigate what could be done if not just the visible part of the spectrum is investigated but also neighboring spectral ranges (UVB/UVC, IR,...) were used additionally. It has to be investigated how this can be used to improve the user experience and whether this can for example be used for better chronobiologic synchronization or to more selectively influence the different growth phases of plants. This could include research on new materials and emerging lighting technologies that will create new possibilities in this area and include all types of light sources (such as laser, LED, OLED etc.). Furthermore the impact of this human centric lighting system has to be validated.

4. When should it be launched and how much funding is needed?

a,c WP2018
b. WP2019

**WP2018:** Research action/Innovation action on connected lighting (integration of lighting with the IoT) (30M€)

**WP2019:** Research action on beyond classical lighting application (30M€)

II. Proposal for Research or Innovation Topic(s) (2 page max) in Horizon2020 WP 2018-2020

**Proposal for Research Topic “Connected Lighting”**

**Description of the topic, objective:**

- At present the main advantage of solid state lighting technologies (LED/OLED/Laser) is still their energy efficiency. Lighting installations with connected lighting and advanced light management systems are still an exception.
- Research on connected lighting; the integration of lighting with the Internet of Things is needed, including the integration of new functionalities which clearly shows the value beyond illumination and will offer a new validated user centric value proposition for lighting in the built environment (such as offices, industries, home, smart cities), industrial lighting (such as automotive, horticulture, healthcare) and outdoor applications.
- The theoretical architectures developed for IoT communication (like for example the OpenAIS architecture developed in a current EU project) must be applied to real world field applications and the security aspects have to be investigated (for example: it has to be investigated which information has to be sent electronically and for which information could optical wireless communication (OWC) be used etc.).
Integration of different vertical applications in different environments as home, offices, industry and outdoors.

Based on this integration development of new cross vertical use cases as productivity enhancement in offices.

Development of specific new use cases such as high data information streaming based on Visible Light communication.

**Relevant Research & Innovation present in Europe?**

- The #1 and #2 global lighting companies have their home in the EU and there are more than a thousand innovative SME’s in this domain.
- An excellent High Tech R&D infrastructure is found within Europe. Well-known clusters are established around Grenoble, Espoo, Munich, Regensburg and Eindhoven.

**Impact on European economy, employment:**

- Europe has to further build on its strength as innovation leader with new applications and markets for the lighting industry. This research action will enable Europe to maintain and build on its leading position in innovative LED/OLED/Laser solutions by; (a) extending lighting technologies to the IoT and positioning itself in new markets like indoor positioning or broadband communication within the building via the lighting system, (b) unlocking new application domains not accessible for the lighting industry today (like building usage analysis, broadband communication,...) by introducing new technologies, (c) enable new smart city (safety and security where lighting infrastructure is used for monitoring and signaling etc.) and smart building functionality (indoor positioning, VLC,...) by creating a cost-effective smart lighting platform.
- These products are conservatively estimated to increase the global lighting market by 22% by 2020, equaling a 8 B€ annual turnover.  

**Impact on societal challenges:**

- Secure, clean and efficient energy: LED/OLED/Laser technology will enable tripling of the global lighting need by 2050 while maintaining energy usage at the present level. Further energy savings potential can be achieved through intelligent lighting systems enabled by smart lighting systems.
- Climate action, environment, resource efficiency and raw materials: compared to the classical lighting technologies LED/OLED/Laser lighting uses significantly less raw materials and reduce thereby the impact on the environment. In particular the reduction of (toxic) metals going into waste streams is a significant goal.
- Additional to the energy saving of the light source itself the connected lighting system can save an additional 70% of energy while simultaneously increasing the comfort of the user.

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11 [http://www.marketsandmarkets.com/Market-Reports/smart-lighting-market-985.html?gclid=CIL1kv7nqc4CFSSsq0wodWgMP5Q](http://www.marketsandmarkets.com/Market-Reports/smart-lighting-market-985.html?gclid=CIL1kv7nqc4CFSSsq0wodWgMP5Q)
EU added value:

- All relevant knowledge is, with a few exceptions, not available on a regional or national level.
- Combining all expertise available on a European level is the only way to guarantee a fast and successful realization of the project results.
- Apart from a few big players, the European lighting industry consists mainly of SMEs. Bringing their innovative power together requires a European approach.

Funding:
100%
Proposal for Research Topic “Beyond Classical Lighting”

Description of the topic, objective:

- At present the main advantage of solid state lighting technologies (LED/OLED/Laser) is still their energy efficiency. Human centric lighting accounts currently only for a marginal part of the market and even the most basic features like tunable white are not widely used. On the “smart” side there is usually not much more than simple dimming implemented.
- Research/innovation on human centric lighting is needed, including the integration of new functionalities which clearly shows the value beyond illumination and will offer a new validated user centric value proposition for lighting in the built environment (such as offices, industries, home, smart cities) and/or industrial lighting (such as automotive, horticulture, healthcare).
- To enable this new functionalities research on UVB and UVC for applications like human health, disinfection, functional agriculture, automotive etc. is needed.
- Integration of the different parts (light sources, sensors, optical systems,...) into a lighting system that allows human centric lighting for applications like automotive (interior lighting in cars), medical (hospital rooms with additional options for disinfection), residential (ambient assisted living) and even horticulture (selectively influence the different growth phases of plants).
- Validation of the effects which this lighting system has on the human body and other application fields (e.g.: growth of plants etc.)

Relevant Research & Innovation present in Europe?

- The #1 and #2 global lighting companies have their home in the EU and there are more than a thousand innovative SME’s in this domain.
- An excellent High Tech R&D infrastructure is found within Europe. Well-known clusters are established around Grenoble, Espoo, Munich, Regensburg and Eindhoven.

Impact on European economy, employment:

- Europe has to further build on its strength as innovation leader with new applications and markets for the lighting industry. This research action will enable Europe to position itself as a leading player which could become one of the most important sectors in healthcare by (a) going from classical lighting to human centric lighting , (b) unlocking new application domains not accessible for the lighting industry today by introducing new technologies (extended spectrum), (c) enable new smart city (enhanced safety by optimized light spectra) by creating a cost-effective human centric lighting platform.
- Increase crop production per m2
- Reduce the need for pesticides in vertical farming.
These products are conservatively estimated to increase the global lighting market by 22% by 2020, equaling a 8 B€ annual turnover[^12] and have the potential to open up a new human centric lighting market.

**Impact on societal challenges:**
- Secure, clean and efficient energy: LED/OLED/Laser technology will enable tripling of the global lighting need by 2050 while maintaining energy usage at the present level. Further energy savings potential can be achieved through intelligent lighting systems enabled which are part of the human centric lighting systems.
- Increase human productivity by 4% caused by optimal lighting conditions.
- Climate action, environment, resource efficiency and raw materials: compared to the classical lighting technologies LED/OLED/Laser lighting uses significantly less raw materials and reduce thereby the impact on the environment. In particular the reduction of (toxic) metals going into waste streams is a significant goal.

**EU added value:**
- All relevant knowledge is, with a few exceptions, not available on a regional or national level.
- Combining all expertise available on a European level is the only way to guarantee a fast and successful realization of the project results.
- Apart from a few big players, the European lighting industry consists mainly of SMEs. Bringing their innovative power together requires a European approach.

**Funding:**
100%

[^12]: [http://www.marketsandmarkets.com/Market-Reports/smart-lighting-market-985.html?gclid=CIL1kv7nqc4CFSsq0wodWgMP5Q](http://www.marketsandmarkets.com/Market-Reports/smart-lighting-market-985.html?gclid=CIL1kv7nqc4CFSsq0wodWgMP5Q)
WG 4 – Robust materials for OPV and OPD performance

I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed

Organic photovoltaics (OPV) and organic photodetectors (OPD) for large-volume applications

- Application domains
  - Building-integration of OPV
  - OPV for automotive
  - OPD for flat panel X-ray detectors
  - OPV and OPD for portable electronics and wearables

- Targeted applications
  - Semitransparent OPV glass façades and shadings
  - Standardized building elements with OPV
  - Energy harvesting in car glass and car interior (e.g. dashboard)
  - Self-powered electronic devices and wearables containing OPV or OPDs
  - (curved) X-ray detectors for medical imaging using OPD
  - OPDs for industrial security and safety systems

We suggest joining forces between OPV and OPD to use synergies between both topics regarding materials and processing technology, although both are at different TRL and aim for different markets.

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+ What is the challenge (in Europe) in the respective area today?

- Europe holds the leading position for OPV manufacturing in terms of technology and production facilities at SMEs like Belectric, Heliatek, and InfinityPV. In the long run, labor costs will not be the cost-limiting factor for OPV production. Thus, Europe needs to maintain and strengthen its world-leading position in the module development and commercialization of OPV. The full OPV value chain is available in Europe and should be kept here.

- Very good results have been obtained in lab-scale OPV research and OPV test installations. Next, this must be translated into reliable products and production technologies. Selection is required to only support technical solutions with very good potential for upscaling at preferably low losses in efficiency and lifetime as compared to lab samples.

- Products must be developed that exploit the unique properties of OPV: semitransparency, low weight, on flexible or shaped substrates. OPV is non-toxic, has a low energy payback time of only a few months, and is free of rare earth or heavy metal materials. Thus, it is the greenest PV technology at all. However, its large-scale deployment requires significant investments in production technology and production tools, as well as further development of materials.

- In the field of OPD, European companies together with research institutes have demonstrated world-first product prototypes. European companies are at the forefront of imaging technology and application. Players are e.g. Philips, Siemens and Teledyne Dalsa, medium companies like Trixell and start-ups as Jenetric and Isorg. Organic photodetectors promise to become a game-changer in this application field. They promise cost reduction of flat panel detectors and enable new products such as curved light detectors, interactive displays or advanced industrial security.

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13 For horizontal work groups focus can be on generic technology domains
and safety systems. In particular the geometrical form factor (free definable photoactive area with only structuration of one electrode) and the large photoactive areas (e.g. lens free) play an important role for the industrial sensing applications.

3. What needs to be done?

- Funding is needed to set up pan-European collaboration in the field of OPV and OPD, to surpass the notorious valley-of-death. For OPD it is important to find integrators which make use of the unique benefits such as low cost processing on large area and flexible substrates in order to generate unique product features. Development of dedicated OPD materials will boost the performance of the devices to benchmark or surpass a-Si which is mandatory to replace the solid state detectors used today.
- Funding is needed to develop and showcase large area pilot installations that prove the market-readiness of OPV in end products, in order to convince early-adaptor customers (opinion leaders in building industry and automotive). Joint developments with these customer industries should be fostered.
- Ongoing research for OPV materials is required to improve the triangle of efficiency, stability and cost. To stay a truly green technology, only manufacturing processes which use abundant, and non-toxic materials (non-halogenated solvents, no heavy metals, no rare earths) should be developed. OPD materials are presently by-products of the OPV research (which is mostly tailored for broad spectral response and stability). Dedicated OPD materials are needed in order to minimize leakage current for high sensitivity, maximize speed for fast sensors or tailor spectral sensitivity in order to create a differentiator to Silicon (e.g. vis-blind sensors, RGB sensors without color filters). The involvement of European chemical companies is important.
- A number of pilot lines for organic electronic (OE) products like OPV and OPD exist at several places in the EU, both owned by public institutions and by private companies. Upgrading such existing pilot lines will be required to stay at the forefront of technology, and to prepare volume production of OPV.
- Integrations with 2D or 3D substrates need to be improved based on high throughput processes in order to reduce the cost of final products that will be available for different type of applications.

4. When should it be launched and how much funding is needed?

a) WP 2018: (IA) Large volume OPV applications like Building Elements; 30M€ (maybe jointly with EEB)
b) WP 2019: (RIA) Robust materials for OPV and OPD performance; 25M€ (maybe jointly with NMPB)
c) WP 2020: (RIA) OPD integration into large area imagers for medical and non-medical imaging applications; 15M€
RIA Topic “Robust materials for OPV and OPD performance”

Description of the topic, objective

As for all photovoltaic technologies, all efforts for pushing OPV efficiency and lifetime to the limits, i.e. towards 17% power conversion efficiency and 25 years lifetime, are welcome. Projects need to be industry driven, with new inputs from academia. New organic materials for OPV need to prove their scalability to production dimensions. This includes scalable synthesis up to >100 gram scale, low-cost, different colors, superior to state of the art materials regarding performance (higher efficiency and lower dark leakage) and stability against temperature, moisture, light, oxygen. To increase production yield, new materials should be more robust, e.g. against processing window fluctuations or against moisture. Since OPVs comprise not only organic material, but also electrodes and barriers, also peripheral technologies need to be given consideration. Dedicated material development for OPD is required in order to enable products with attractive performance. This requires materials with very low doping/defect concentration in order to surpass the leakage current and lag performance of amorphous Silicon. Materials with narrow absorption bands but high conversion efficiencies are needed in order to create unique product features of sensors, e.g. RGB sensors or visible-blind cameras without color filters would increase sensitivity. Materials with higher mobility and carrier lifetime are required in order to enable faster and more efficient sensors (e.g. for data transmission or medical imaging).

Relevant Research & Innovation present in Europe?

Europe is world-wide leading in OPV/OPD research with respect to public research institutions, as well as most of the top OPV and OPD companies operate in Europe. This includes material suppliers and other companies along the full value-chain. EU investment into Research & Innovation can become a key driver in the establishment of European production of OPVs and OPDs.

Impact on European economy, employment

Research for better performing and cheaper OPV/OPD materials will create revenues and employment along the full value chain. First, materials suppliers such as Merck (DE), BASF (DE), Ossilia (UK) or lolitec (DE) may offer their products to the world market, followed by technology developers (e.g. independent engineering firms selling technology prescripts). Manufacturers of semi-finished products (Heliatek and Belectric (both DE), Arkema (FR), InfinityPV (DK) or Eight19 (UK)), and manufacturers of components, like automotive component suppliers (e.g. Webasto, DE), building material industry (AGC (BE), Pilkington (UK), Saint Gobain (FR)) or medical instrumentation (e.g. Trixell (F), Philips (NL), Siemens (DE)), and last but not least manufacturers of final products, like e.g. from automotive or building industry. Existing and new roll-to-roll production lines with low labor need will allow production in the EU.

Impact on societal challenges

OPV is an enabling technology that will help achieving Europe’s climate targets by local energy harvesting in many places where conventional PV is unsuitable, e.g. for reasons of weight, aesthetic concerns or shape. It can be used e.g. in

- energy efficient buildings,
- smart and integrated transport,
- internet of things (IoT), wearables and mobile applications

OPV is a truly green photovoltaic technology that uses no toxic materials (no heavy metals). Instead it employs mostly easy-to-recycle hydrocarbons. For importance of OPDs, see Topic 3.

**EU added value**

OPV has enormous potential in reducing the energy imports from other regions. Besides supporting EUs climate action, OPV will also save critical raw materials such as rare earth elements. OPV and OPD are different industries, but use similar materials and academic background knowledge. Thus, they may cross-fertilize each other and create new chances for industry, SMEs and academic players within Europe. This will strengthen the European position as world-leading region for the development and commercialisation of OPV and OPD.

**Funding**

100% funding as RIA
I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed: Smart broadband sensing solutions where it matters for Europe: Agriculture, Smart Manufacturing and IoT

Sensing of the future will need to explore at once more than one single part of the photonic spectrum in order to achieve disrupting sensing solutions: from the UV range, where hidden deterioration in organic samples can be detected, to the visible spectrum in which fluorescence phenomena reside, over the broadband spectrum containing unique fingerprint absorption spectra, making use of recent developments in sensitivity-boosting laser-based spectroscopy, up to the THz frequencies where dielectrics become transparent and concealed objects can be revealed. In addition, the possibility to perform high-specificity Raman spectroscopy in the VISNIR spectral range is of high practical interest. For the past decade, the rate of data generation was twice as large compared to the expansion of communication bandwidth, and 90% of the created data was never analyzed. It is obvious, therefore, what is urgently needed: Not only must better, cheaper broadband sensors be developed, acquired data must also be analyzed, and this analysis must eventually occur at the sensor site: Sensors must get smart! Also, for highest value creation we must not only develop smart sensors but also novel smart-sensor-based business models, i.e. smart broadband sensing solutions, which is perfectly in line with the upcoming developments in Industry 4.0.

We propose to accomplish and demonstrate this in three industrial areas of vital importance for Europe: Agriculture & Food, Smart Manufacturing, and the forthcoming Internet of Things (IoT).

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+ What is the challenge (in Europe) in the respective area today?

Agriculture & Food: In 2013 Europe became the world’s largest exporter of agricultural and food products. However, a lot needs to be done to improve the world’s food production industry. According to a widely cited report, getting food from the farm to our fork in the USA eats up 10% of their total energy budget, swallows 80% of their freshwater consumed, and nevertheless America is losing about 40% of its food to landfill. Smart and flexible broadband sensor solutions will help to reduce this dreadful waste of food and resources.

Smart Manufacturing: Europe is the world’s largest manufacturer of machine tools and the industry’s technology leader. As a key enabling capability for manufacturing, machine tooling is of vital importance for Europe, and “smarter” machine tools are at the basis of more efficient, lower cost, higher quality and more competitive production. Smart sensor solutions will help to achieve this goal, by increasing the speed and accuracy of high-precision European machine tooling.

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16 D. Gunders, “Wasted: How America is Losing Up to 40% of Its Food from Farm to Fork to Landfill”, NRDC Issue Paper, August 2012
Internet of Things (IoT): The forthcoming Internet of Things (IoT) revolution promises ubiquitous sensing with huge business opportunities: A total IoT market size of about $400b is predicted for 2024, of which $46b is the size of the device market\textsuperscript{18}. Such a huge market is of great interest to European industry, and it is of essential importance that European companies aim for complete smart sensor solutions right from the beginning.

3. What needs to be done?

Although all three considered relevant industrial domains make use of various parts of the wide photonic spectrum, the physical properties of the required components, subsystems and solutions vary widely and are complementary:

**Agriculture & Food:** The reasons for the occurrence of food waste are very different for the various types of food and the step in the supply chain from farm to fork. As an example, in fruits and vegetables, 20% of losses occur during production at the farm, and 28% are due to waste by consumers\textsuperscript{3}. The challenge, therefore, is to create highly flexible yet affordable broadband sensing solutions that can be adapted to all the critical steps in the food production supply chain, providing information about the microbiological and chemical contamination along the entire chain. In particular, user-friendly and portable devices in the hands of the farmers up to the final users will enable them to obtain information about the quality of soil, used irrigation water and therefore of the final crop.

**Smart Manufacturing:** The primary reason for using a broad spectral range for novel metrology systems in machine tooling is the significantly reduced requirements of the eye-safety regulations, allowing the use of longer wavelengths and significantly increased light power levels. This leads to much faster and more precise sensor solutions, which can be employed in many more places in the complete manufacturing process.

**IoT:** The dominating factor of IoT sensing solutions is their price. For this reason, significant compromises in the selectivity of the employed sensors must be made, and this must be compensated by extensive data processing and multi-sensor data fusion of the various sensor modalities. Once it is known how to interpret sensor data “to make meaning” out of them, this processing will be carried out at the sensor site, i.e. “at the edge”. Until then, sensor data has to be transmitted to the Cloud, where sufficient data processing and interpretation resources are available.

4. When should it be launched and how much funding is needed?

Research Action (F3S): WP2018
Innovation Actions (SensOPro, myCloudSense): WP2019

\textsuperscript{18} G. Girardin et al., “Technologies and Sensors for the Internet of Things”, YOLE Development, June 2014
II. Proposal for Research or Innovation Topic(s) (2 page max) in Horizon2020 WP 2018-2020

Research Action: F3S – Flexible Farm-to-Fork Sensing

1. Description of the topic, objective:
   The problems which photonics could solve are twofold: (1) Agriculture: Up to now, the global trend in agriculture was to increase the farm size, go toward more intensive farming methods, and, as a consequence of the scale factor, to offer lower prices to the consumer. Such a model has reached its limits both from the environmental and social perspectives; example: the increasing malaise of many farmers with small farms, who are no more able to live from their activity, despite their hard work. (2) Consumption: European consumers want food that is not only safe and wholesome, but also traceable and conform to their ethics, especially regarding its origin and the way it is produced. Currently, an increasing share of EU consumers is not able to find food products that fully comply with their expectations.
   At each stage of the production process “from farm to fork” there is a need for quality/hygiene/ process control and data transmission, from the analysis of raw materials to packaging tests. Many sectors are concerned: agriculture, livestock/fish/shellfish/seaweed farming, food processing etc.
   Specific emphasis should be laid on the domains where photonics technology will directly contribute to solve the above mentioned problems, in some cases associated with robots:
   - Production control adapted to small/medium size farms, including also “precision farming”
   - Development of novel types of production, including also combinations such as aquaponics
   - On-site food processing and vending, for example in “farmers markets”

Photonic solutions are very well suited to provide highly advanced sensors capable of extracting and measuring data in complex solid, liquid and gaseous mixtures, as well as organic matter. As a consequence, agrofood, agriculture, fish and shellfish farming as a whole are potentially a very big market for photonics. However, it is split up in tiny niches. Each product and each step of the production process need an application-specific sensor. For example, each sort of apple shows a specific color when the apple is ripe; apples will produce different and specific scents at every stage of their ripening. This indicator fractionalization is a barrier for the development of new advanced sensors as each market niche is too small and cannot justify the investment in a complete new sensor that will satisfy its specific needs. Also, farmers, especially in small/ medium-size farms, are in need of very simple and user-friendly devices allowing them to save time and to increase their competitiveness.

In order to fulfil these needs, the envisaged F3S research action proposes to develop; (1) photonic sensors that are very flexible, i.e. one photonic “nose” for all kinds of apples that can be easily tuned to one specific type; (2) methods that can be implemented in the sensing set-up to facilitate the use in-field, at-line or in-line (e.g. self-learning, statistics etc.).

2. Relevant Research & Innovation present in Europe?
   Numerous studies were done in Europe and elsewhere to close the gaps between production, storage and consumers. It was discovered that a prime reason for hospitalization in developed
countries is foodborne illnesses\(^\text{19}\). It is estimated that each year roughly 48 million Americans (1 in 6 persons in the USA) get sick, 128,000 are hospitalized, and 3,000 die of foodborne diseases. In particular, vegetables with big green leaves are affected with various kinds of cross-contamination (e.g. chemicals such as PCB, dioxin, or microbiological contaminations). According to the literature, the classical chemical/physical/microbiological sensing techniques are unable to cover adequately the whole chain. In addition, classical techniques are still rather time consuming, expensive and user-unfriendly. Europe has already undertaken important steps to increase the safety of food, for example in the framework of the SAFOODNET project\(^\text{20}\) but the lack of low-cost, easy-to-use and reliable sensors has hampered the widespread employment of sensor solutions outside the food processing plants.

3. **Impact on European economy, employment**;

“The EU has 500 million consumers and they all need a reliable supply of healthy and nutritious food at an affordable price. The economic environment is set to remain uncertain and unpredictable. [...] Farming is not just about food. It is about rural communities and the people who live in them. It is about our countryside and its precious natural resources. In all EU Member States, farmers keep the countryside alive and maintain the rural way of life. If there were no farms or farmers, our hamlets, villages and market towns would be profoundly affected — for the worse. [...] All in all, farming and food production are essential elements of our economy and society. With its 28 Member States, the EU has some 12 million farmers with a further 4 million people working in the food sector. The farming and food sectors together provide 7% of all jobs and generate 6% of European gross domestic product”\(^\text{21}\).

The use of cost-effective photonics-based sensors and related technologies (robots, IoT) will impact on the EU economy by:
- Increasing the competitiveness of EU agriculture and food products;
- Strengthening the EU industry position in agriculture equipment and food processing.

4. **Impact on societal challenges**

The above mentioned photonics technologies will impact on EU major societal challenges by:
- improving the health of all EU citizen: contributions to a better control of the food chain processes to decrease food-borne illnesses;
- saving energy: contributions to (1) the reduction of waste of agricultural products and processed food, (2) the development of local food processing, thus avoiding unreasonable long-distance transportation of agricultural products;
- preserving our environment: provide control equipment for (1) reducing the environmental impact of production methods, (2) allowing cost-efficient smaller-scale production and crop diversification;


\(^\text{20}\) SAFOODNET - Food Safety and Hygiene Networking within New Member States and Associated Candidate Countries, European Project No. FP6-022808, URL: http://safoodnet.vtt.fi

\(^\text{21}\) European Commission, “The EU’s common agricultural policy (CAP): For our food, for our countryside, for our environment”, EU publication, 2014.
- stopping rural depopulation: transformation of farmers’ daily activities through the use of sensors and associate technologies (robotics, IoT etc.), thus, making related jobs more attractive to young people, and making small/medium-size farms more competitive;
- improving the quality of life of all European citizens: thanks to renewed small/medium-sized farm production methods, the EU citizen consumption patterns will evolve in line with their expectations: more locally traceable and labeled products (e.g. with ‘Protected Designation of Origin’ or ‘Protected Geographical Indication’ labels).

5. **EU added value:**
Agriculture is one of the most important industrial sectors of Europe. Launched in 1962, the EU’s common agricultural policy (CAP) is a partnership between agriculture and society and between the EU and its farmers. Its purpose is to set the conditions that will allow farmers to fulfil their multiple functions in society, the first of which is to produce food.

To be efficiently implemented, targeted development of innovating ICT technology – as proposed in the present F3S Research Action should be closely coordinated with the CAP and can therefore be addressed only at a European level.

6. **Funding:**
WP 2018: €30m

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22 From the above mentioned publication: “The EU recognises that the age structure of farmers has become a matter of concern. Helping young farmers get started is a policy ‘must’ if Europe’s rural areas are successfully to meet the many challenges that face them.”
I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed

- **Application domains**
  - Photonic Components and Photonic Integrated Circuits, providing capabilities for products in a wide variety of application domains.

- **Targeted applications**
  - Data communication and telecommunications from short reach to long reach; next generation supercomputers and data centres;
  - Sensing, metrology and control, e.g. for medical applications, instrumentation and industrial equipment, structural health monitoring, bio-sensing and safety systems, automotive, aerospace and consumer products.

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+. **What is the challenge (in Europe) in the respective area today?**

European research is in a worldwide leading position regarding photonic integrated circuits (PICs) at the chip level. PICs are already widely deployed by European manufacturers in telecom and data networks and the generic foundry model developed in Europe is making this technology available to a wider applications community. There is however massive upside potential for PICs in industry, particularly in sensing, metrology, control and other applications. Furthermore it is vital that the performance and capability of European PIC manufacturers continues to be developed in order to meet competition from other countries. In particular:

- Some core optical functionalities not yet available in PICs
- Performance levels need to be continually enhanced in order to provide compatibility with next-generation telecom, data communications and sensor requirements, including systems based on quantum optical concepts
- Technologies for higher-density, lower-power components and circuits for next-generation PICs still have to be developed
- Techniques for combining photonic and electronic functionality in order to provide optimum performance and cost-efficiency are still at an early stage; advanced electronic/photonic integration schemes are not yet in production
- Packaging has a major impact on product performance and typically accounts for a large part of the costs. Action is required to develop high performance, lower cost solutions that are scalable in manufacture
- Photonic software design and simulation tools and Process Design Kits need significant improvement in order to support advanced PIC designs effectively
- European pilot-line activities for generic PIC technologies are presently limited to a single dielectric PIC technology. There is an urgent need for this capability to be available for other key PIC technologies (InP and silicon photonics incorporating lasers), as well as for packaged

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23 For horizontal work groups focus can be on generic technology domains
components using automated assembly approaches that are scalable to high volumes with low unit costs.

As the European strength in photonics often lies in the mid-sized companies, reducing entry barriers by pooled research and pilot line efforts is especially important.

We note that while the European position is strong, major investments presently underway in other regions, notably in the USA and in Asia, will lead to a highly competitive scenario in the next few years. The emergence of the AIM Photonics programme in the USA, together with investments in China, Japan and other countries, underlines the need to consolidate and build on European strengths and bring these capabilities to market-readiness in a very timely manner.

The developments detailed in this document are fully in line with the strategic roadmap established by Photonics21 at the beginning of the Horizon 2020 programme.

3. **What needs to be done?**

a. Development of enhanced PIC building blocks in line with technology roadmap, e.g. high sensitivity, high density, lower power, higher speed; explore technology developments offering radical enhancement of performance and functionality, enabling existing and new applications, including quantum photonics (Research activity)

b. Integration of PICs with other technologies, including hybrid/heterogeneous electronic/photonic integration and electronic-photonic co-design, towards ‘photonic systems in package’ (Research activity)

c. New packaging technologies for scalable manufacturing, providing high performance and functionality (e.g. RF, EMC, thermal ...), while providing a breakthrough in cost (Research activity)

d. Establish pilot production lines providing low entry barrier access to PICs based on InP and/or silicon photonics including lasers, supporting low to medium volumes and capable of being scaled up to high volumes, and including appropriate measures to stimulate demand and uptake (Innovation activity)

e. Support and develop pilot production capabilities for automated low cost packaging of PIC-based components (Innovation activity).

4. **When should it be launched and how much funding is needed?**

a. WP2020, 30M€ (supporting multiple research projects)

b. WP2019, 20M€ (supporting multiple research projects)

c. WP2018, 20M€ (supporting multiple research projects)

d. WP2018, 20M€ (supporting one or more innovation activities)

e. (in collaboration with WG1): WP2019, 20M€ (supporting one or more innovation activities).
Photonic Integrated Circuit Technology

1. Description of the topic, objective

The objective is to achieve major advances in the capability and performance of photonic integrated circuit technology platforms. A generic approach is sought, thereby facilitating exploitation in the widest possible range of applications.

Anticipated technology advances include the use of new semiconductor and other materials and their combination with existing technologies, along with new approaches to avalanche photodetectors and lasers, supported by advances in modelling and simulation. Heterogeneous and fully monolithic integration approaches are both in scope. Desired circuit capabilities include improved energy efficiency, coherence, sensitivity, density and incorporation of advanced functions such as high nonlinearity, polarization handling, fast switching and sensing. Integration of new functionalities should facilitate existing or new applications, e.g. LiDAR, microwave photonics, particle and molecular sensing, 3D imaging and display, quantum communication, quantum computing and quantum sensing. Actions should include a validation of results with fabricated PIC prototypes.

In addition to roadmap-based developments, we seek radical approaches that can achieve major improvements in performance and functionality, such as will be required for new application areas including photonic quantum information processing, as well as enabling the continual enhancement of present-day systems. These improvements include but are not limited to laser coherence (phase noise reduction), modulator and polarization extinction ratio, polarization handling, non-reciprocal elements such as isolators and high-performance single-photon sources and detectors. The activity accordingly encompasses forward-looking, higher-risk research up to experimental proof of concept (TRL3).

2. Relevant Research & Innovation present in Europe?

As a result of significant investments in a number of FP6, FP7, H2020 and regional projects, Europe has established a lead in generic photonic integration technologies in InP, silicon and low-loss dielectric waveguide circuits. This has allowed an ecosystem of coordinating bodies, optical and CMOS foundries, optical chip design and simulation services, and photonic testing and packaging companies to develop and flourish. H2020 projects should connect to and build on the results of those projects in other to strengthen Europe’s lead in this field. We strongly encourage cooperation between this activity and national, regional and European projects targeting specific application areas including communications, sensing and quantum photonics.

3. Impact on European economy, employment

Generic integration technology, when made available through open access foundries, can lead to a dramatic reduction of the research and development costs of advanced photonic ICs (more than an order of magnitude), which brings them within reach for smaller companies. We expect that the introduction of advanced photonic integration technologies in novel or improved products by SMEs will provide these SMEs with a strong competitive edge over
competitors inside and outside Europe. Such a development will clearly lead to a strong increase of highly-skilled employment in Europe. Because of its generic character, the technology will be applied in a wide range of business areas, including telecom and datacom as well as quantum photonics, medical, sensing, metrology, displays and security applications. Applications engineers and PIC designers need to be actively engaged with PIC foundries to ensure that flexibility and close coordination exists in the European Value Chains for product innovation in these markets.

PIC performance enhancements and compatibility with new markets are of clear value both for new entrants using generic foundry technologies and for vertically integrated players creating products for specific markets such as telecommunications, data communications and high performance computing.

The data centre networking market alone will reach $21.85 billion by 2018 with a CAGR of 11.8% (Infonetics). This is driving growth in photonic interconnect sector, which represents an integral part of its ecosystem, with chip-level photonic interconnect expected to generate $990M by 2020 (CIR) and the market for Ethernet optical interconnects reaching $2.2 billion by 2018 (LightCounting). Target markets include also a significant share of the optical sensor market ($15B 2020 worldwide, CAGR 16.9%, Allied Market Research). The value of InP and Silicon Photonics PIC markets are anticipated to scale to multi-billion dollar levels over the coming five years (see Integrated Optical Devices: Is Silicon Photonics a Disruptive Technology? http://www.lightcounting.com/reports.cfm, January 2016).

4. Impact on societal challenges

Photonic integration will contribute to a significant reduction of the power consumption of the internet and supports a further growth of the internet, which is of crucial importance for the sustainability of our modern information society as it extends to objects contributing to the so-called Internet of Things. From value-added services offered by the cloud to instant content delivery provided by edge computing, data center technologies offer unlimited opportunities affecting economic growth and access to knowledge. Optical interconnects are also essential for scaling the performance of high-performance computing (HPC) systems, with significant impact in a broad variety of societal challenges, giving rise to breakthroughs in medicine, material design, climate modelling and more. Improved photonic sensors with greater functionality and addressing wide-ranging applications have the chance to bring advanced medical technology much nearer to the patient, resulting in better, quicker and more cost-effective diagnostics. Development of advanced technologies that can be applied in numerous product domains will support the establishment of European Value Chains (EVCs) and ensure that product innovation thrives in Europe, benefitting European society through employment and early access to new technologies.

5. EU added value

The technological infrastructure for PIC design, development and manufacturing are too large and complex to be supported by a single company or a single country. Europe has gained its present leading position through a strong cooperation of the key players in the field, both industrial and academic, in European R&D projects.
Public authorities in other regions of the world have recognised manufacturing of integrated photonic components as a key domain and are heavily investing in R&D to enable large scale manufacturing. For example, the US initiative AIM Photonics will be supported by more than 610 M$ in public and private funds. In Japan, the PETRA consortium will receive about 250M€ of total public funding until 2021, whilst in China, a new PIC initiative based in Shanghai has recently been announced. EU investment is required to reach a critical mass at European level and to maintain European technology at the forefront of developments and applications.

6. **Funding**

EC funding available for this topic should be sufficient to support a combination of large and small projects with a total EC contribution in the region of €30M.
Photonic System on Chip/System in Package

1. **Description of the topic, objective:**
   The objective is to achieve major advances in the capability, performance and complexity of photonic system-on-chip and system-in-package through the intimate combination of photonic integrated circuit technology with other enabling circuits, devices, motherboards and housings. Photonic circuits are typically employed in combination with high performance electronics, micro-optics and thermal management and the efficient integration of these technologies is accordingly of major importance. Micro-Electro-Mechanical Systems (MEMS) and sensor ICs are also often advantageously combined with photonics. The focus of this call is to create and develop advanced techniques for intimate integration of sub-systems incorporating multiple technologies. Demonstrable performance advantages in terms of e.g. sensitivity, speed, energy efficiency and robustness to extreme environments are targeted. Techniques should be generic, enabling application across multiple domains. New concepts for integration may leverage wafer and chip stacking, hybrid and heterogeneous technologies, 2.5 and 3D integration, multi-level wiring and ultrahigh bandwidth density connections. Converged solutions for electronic IC and photonic IC are in scope. A holistic approach to design through to test is envisaged to fully exploit new assembly techniques for high-performance systems-on-chip.

2. **Relevant Research & Innovation present in Europe?**
   European research is in a world-leading position regarding photonic integrated circuits (PICs), high performance electronics, package technologies and the associated assembly techniques. Its strength when compared to e.g. the USA is especially the collaboration between companies and research institutes with complementary skills. European SMEs and larger companies active in the datacom/telecom industry have reached leading positions worldwide in their respective high-value applications. A step change in package integration is achievable through the alignment of value chains including mechatronics, automation, electronics and photonics. Whilst the final assembly of many photonic products presently takes place in countries with lower labour costs, the proposed R&I targets highly integrated solutions which can be manufactured using wafer-scale techniques and highly automated assembly approaches, thus making European production cost-effective. European companies have world-leading capabilities in photonics, precision engineering, production tools and automation, thereby providing a comprehensive set of skills and resources to make this transition possible.

3. **Impact on European economy, employment**
   The proposed action will secure European industrial leadership in photonic applications and technologies, and extend European leadership into applications where assembly and packaging represents a major share in system performance and cost. We anticipate that the developments proposed here will be highly valuable for the penetration of new markets such as automotive, medical and consumer products, as well as for established telecom and datacom applications. The target is to keep the full value chain for high-value applications in Europe and to obviate migration to countries with lower labour costs through continuous innovation.
The data centre networking market alone will reach $21.85 billion by 2018 with a CAGR of 11.8% (Infonetics). This is driving growth in photonic interconnect sector, which represents an integral part of its ecosystem, with chip-level photonic interconnect expected to generate $990M by 2020 (CIR) and the market for Ethernet optical interconnects reaching $2.2 billion by 2018 (LightCounting). Target markets include also a significant share of the optical sensor market ($15B worldwide, CAGR 16.9%, Allied Market Research). The value of InP and Silicon Photonics PIC markets are anticipated to scale to multi-billion dollar levels over the coming five years (see Integrated Optical Devices: Is Silicon Photonics a Disruptive Technology? http://www.lightcounting.com/reports.cfm, January 2016).

4. Impact on societal challenges
Photonic integration will contribute to a significant reduction of the power consumption of the internet and supports a further growth of the internet, which is of crucial importance for the sustainability of our modern information society as it extends to objects contributing to the so-called Internet of Things. From value-added services offered by the cloud to instant content delivery provided by edge computing, data center technologies offer unlimited opportunities affecting economic growth and access to knowledge. Optical interconnects are also essential for scaling the performance of high-performance computing (HPC) systems, with significant impact in a broad variety of societal challenges, giving rise to breakthroughs in medicine, material design, climate modelling and more. Improved photonic sensors with greater functionality and addressing wide-ranging applications have the chance to bring advanced medical technology much nearer to the patient, resulting in better, quicker and more cost-effective diagnostics. Strengthening multi-functional integration activities will support the establishment of European Value Chains (EVCs) and ensure that product innovation thrives in Europe, benefitting European society through employment and early access to new technologies.

5. EU added value:
The technological infrastructure for PIC-based component design, development and manufacturing are too large and complex to be supported by a single company or a single country. Europe has gained its present leading position through a strong cooperation of the key players in the field, both industrial and academic, in European R&D projects. Public authorities in other regions of the world have recognised manufacturing of integrated photonic components as a key domain and are heavily investing in R&D to enable large scale manufacturing. For example, the US initiative AIM Photonics will be supported by more than 610 M$ in public and private funds. In Japan, the PETRA consortium will receive about 250M€ of total public funding until 2021, whilst in China, a new PIC initiative based in Shanghai has recently been announced. EU investment is required to reach a critical mass at European level and to maintain European technology at the forefront of developments and applications.

6. Funding:
EC funding available for this topic should be sufficient to support a combination of large and small projects with a total EC contribution in the region of €20M.
WG 6 – Assembly and Packaging Technology

1. Description of the topic, objective:

   New concepts are sought for assembly, packaging and module integration for photonic integrated circuits, compatible with a range of applications and capable of achieving radical reduction in production costs. Approaches must be scalable to high volume production.

   Whilst PIC chip technology has advanced greatly in the last decade and interfacing requirements have grown in complexity, owing to the higher data rates and greater functionality now required, assembly techniques are still mainly based on technology which was developed at a time when products were simpler and costs could be substantially higher. There is accordingly an urgent need for new approaches to packaging and assembly which can achieve lower costs and higher functionality. Such approaches are required in order to maintain the projected growth of internet and data centre performance, as well as high-speed user connections and high-performance computing. Furthermore it will be vital to reduce production costs by an order of magnitude or more in order to facilitate the introduction of PIC technology into new markets such as automotive systems and consumer products.

   Appropriate tasks within this action may include any of the following:

   - New concepts for optical connection to PICs
   - Automated assembly for scalable, low cost production
   - Wafer-scale assembly techniques
   - Automated test approaches, including on-wafer testing
   - Non-hermetic chip environments
   - Massively parallel, low-cost, high speed electro optical connectivity solutions, targeting extremely high aggregate bandwidth, e.g. 40x100 GHz
   - Generic packaging solutions for high optical complexity PICs, thus lowering entry barrier into low volume sensor and medical markets

   We anticipate that it may be valuable to adapt knowledge and techniques from the silicon IC world to photonics, introducing, for example, optical interposers, 3D vias, 3D assembly, chip/wafer stacking.

2. Relevant Research & Innovation present in Europe?

   European research is in a world-leading position regarding photonic integrated circuits (PICs). Its strength towards e.g. the USA is especially the collaboration between companies and research institutes with complementary skills. European SMEs and larger companies active in the datacom/ telecom industry have reached leading positions worldwide in their respective high-value applications.

   Migration of production to countries with lower labour costs is presently unavoidable in electronics and high volume photonics, given existing technology. The proposed R&I targets automation and elimination of the labour intensive part, thus making European production cost-effective. European companies have world-leading capabilities in photonics, precision engineering, production tools and automation, thereby providing a comprehensive set of skills and resources to make this transition possible.
3. **Impact on European economy, employment**

The proposed action will secure European industrial leadership in photonic applications and technologies, and extend European leadership into applications where assembly and packaging represents a major share in system performance and cost. The target is to keep the full value chain for high-value applications in Europe and to obviate migration to countries with lower labour costs through continuous innovation.

The data centre networking market alone will reach $21.85 billion by 2018 with a CAGR of 11.8% (Infonetics). This is driving growth in photonic interconnect sector, which represents an integral part of its ecosystem, with chip-level photonic interconnect expected to generate $990M by 2020 (CIR) and the market for Ethernet optical interconnects reaching $2.2 billion by 2018 (LightCounting). Target markets include also a significant share of the optical sensor market ($15B 2020 worldwide, CAGR 16.9%, Allied Market Research). The value of InP and Silicon Photonics PIC markets are anticipated to scale to multi-billion dollar levels over the coming five years (see *Integrated Optical Devices: Is Silicon Photonics a Disruptive Technology?* [http://www.lightcounting.com/reports.cfm](http://www.lightcounting.com/reports.cfm), January 2016).

4. **Impact on societal challenges**

The internet is an essential ingredient of everyday work and life. Our research will make the internet faster and more reliable and help to ensure that the ever-increasing demand for bandwidth and capacity can be met. EU-based manufacturing will also help to avoid potential security issues related to dependency on countries outside the EU. Improved datacom optics will help to build faster computers, thus enabling new medical and environmental research. Improved photonic sensors with greater functionality and addressing wide-ranging applications offer opportunities to bring advanced medical technology much nearer to the patient, resulting in better, quicker and more cost-effective diagnostics. Strengthening assembly and packaging activities will support the establishment of European Value Chains (EVCs) and ensure that product innovation thrives in Europe, benefitting European society through employment and early access to new technologies.

5. **EU added value:**

The technological infrastructure for PIC-based component design, development and manufacturing are too large and complex to be supported by a single company or a single country. Europe has gained its present leading position through a strong cooperation of the key players in the field, both industrial and academic, in European R&D projects. Public authorities in other regions of the world have recognised manufacturing of integrated photonic components as a key domain and are heavily investing in R&D to enable large scale manufacturing. For example, the US initiative AIM Photonics will be supported by more than 610 M$ in public and private funds. In Japan, the PETRA consortium will receive about 250M€ of total public funding until 2021, whilst in China, a new PIC initiative based in Shanghai has recently been announced. EU investment is required to reach a critical mass at European level and to maintain European technology at the forefront of developments and applications.

6. **Funding:**

EC funding available for this topic should be sufficient to support a combination of large and small projects with a total EC contribution in the region of €20M.
WG 7 – Nano-opto-electro-mechanical systems

I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed
Optics is increasingly pervading computing systems and data centers, as it provides the fastest and potentially lowest-energy way of transferring information. However, present photonic technologies operate at energy/bit levels which are incompatible with the expected scaling of data rates and the well-known limits of on-chip power dissipation. In the ongoing quest for low-power, densely-integrated photonic technologies, one of the key challenges relates to the need for efficient on-chip control of light flow, e.g. in large-scale switching matrices and in reconfigurable circuits. In free-space and fiber-optics these problems have been addressed through the use of optical micro-electromechanical systems (MEMS), which enable ultralow-power light steering and are widely employed in optical switching networks and projection devices. While the combination of MEMS with standard, μm-scale waveguides requires high driving voltages and is therefore impractical, novel opportunities arise from the combination of nanophotonic circuits with downscaled electromechanical actuators, featuring at the same time much reduced drive voltage and increased bandwidth. Such novel nano-opto-electro-mechanical systems (NOEMS) capitalize on European leadership in the research fields of nanophotonics and optomechanics and provide a route towards integrated solutions for switching, tuning and reconfiguration at ultralow-power (nW-μW) levels.

Besides their application in optical interconnects, the strong coupling between light and mechanics in NOEMS can also be used to achieve exquisite sensitivity to displacement, acceleration and force in a new generation of optical sensors. While MEMS already power acceleration sensors in smartphones and airbags, nano-optomechanical structures have been shown to provide much increased resolution and bandwidth with an ultrasmall footprint, with potential applications in e.g. navigation systems, acoustic wave imaging and chemical sensing. Their implementation however relies on the ability to integrate the sensing part with an active interrogation circuit, which can be achieved only in the framework of an integrated nanophotonic circuit.

2. What is the challenge?
In order to exploit the full potential of NOEMS in communication and sensing applications, the main challenge is to translate research concepts into working devices which can be integrated into functional photonic integrated circuits. This can be done by addressing the following issues:

- Reduce driving voltage and increase operating frequencies by developing efficient electromechanical actuation of nanophotonic devices.
- Integrate NOEMS with waveguide circuits, lasers and detectors and develop scalable actuation/sensing geometries
- Develop a new generation of optical sensors combining the exquisite resolution of nano-opto-mechanical structures with integrated interrogation and read-out.

3. What needs to be done?
   a. Research into nano-opto-electro-mechanical systems providing novel paradigms for sensing and light control. These systems should take full advantage of light confinement at the sub-μm
scale to offer a performance, scalability and/or functionality well beyond existing optical MEMS solutions
b. Integrate functional NOEMS into established or new integration platforms, such as silicon or III-V membrane photonics

4. **When should it be launched and how much funding is needed?**
a. WP2018. Funding needed: 8-10 M€

II. **Proposal for Research or Innovation Topic(s) (2 page max) in Horizon2020 WP 2018-2020**

1. **Description of the topic, objective:** Research projects should aim at the development of ultrasmall (light confinement at the sub-μm scale) and ultralow-power (sub-μW) nano-opto-electro-mechanical systems offering novel functionalities or breakthrough performance improvements for optical sensing and/or light control (e.g. switching, modulation, tuning, steering). The investigated devices should target clearly-identified applications, and have the potential for scalability and/or integration in a technology platform for dense photonic integration.

2. **Relevant Research & Innovation present in Europe**
   EU research is very strong in the fields of nanophotonics and optomechanics. Additionally, strong industrial chains have been created for the manufacturing of photonic integrated circuits on InP and Si platforms and of optical MEMS. The implementation of novel nano-opto-electro-mechanical devices into photonic integration platforms will provide Europe industrial leadership in the field of optical interconnects and highly-integrated, low-cost optical sensors.

3. **Impact on European economy, employment**
   European photonics industry is already very strong. Complete supply chains for integrated photonics products are already in place, from foundries (III-V and silicon foundries), to brokering organizations (JePPIX, ePIXfab), design houses and end-users. At the same time, the market for MEMS and optical MEMS is growing fast and industrial chains are being set up in Europe, in particular through the ENIAC-Lab4MEMS II public-private partnership, involving a pilot line based in STMicroelectronics. NOEMS represent the natural evolution of optical MEMS and will impact all levels of the photonics value chain, by enabling higher integration densities, increased functionality and lower power consumption. It is expected that they will fit into future European MEMS and photonic integration pilot lines, increasing the competitiveness of European high-tech industry.

4. **Impact on societal challenges**

   Substantial impact is foreseen in at least two areas:
   **1) Energy savings in optical circuits and networks:** The energy used to exchange information in data centers, supercomputers and even personal computers is already a dominant part of the energy spent for information processing, and is projected to grow exponentially together with the growth of internet traffic. This poses a threat to the digitization of European industry and society.
Photonic circuits can dramatically lower the energy needed for interconnects but only if novel components operating at much reduced power levels are developed. Nano-opto-electro-mechanical systems can substantially reduce the power dissipation of photonic integrated circuits and thereby contribute to the sustainable development of the information society.

2) Ubiquitous sensors: Integrated, low-cost optical sensors will mark a new era of the information society, enabling people to make informed choices in daily life, from purchasing food in a supermarket to driving a car. They will also have lasting impact in the area of personalised healthcare, by allowing continuous and non-invasive diagnostics.

5. EU added value:
   The required competences in nanophotonic devices, optomechanical sensing and photonic integration are only available at the European scale.

6. Funding:
   Funding needed under Horizon 2020: 8-10 M€
WG 7 – 2D materials on 3D structures for new device architectures

I. Description of the area where Horizon2020 funding is requested (1 page max)

1. Area to be addressed
   - Application domains: New architectures for innovative optical and microfluidic components and devices
   - Targeted application: Sensing, life science

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+ What is the challenge (in Europe) in the respective area today?

Two dimensional materials have been proposed and are being explored to realize compact and energy-saving components and devices with increased functionalities and better performances. Starting from graphene, object of a large European flagship investment, other options are now being investigated (phosphorene, silicene, etc.), as well as different technologies such as atomic layer deposition. However, despite 2D materials have great potential and excellent performances as compared to bulk, extensive application is still far away due to several technical limitations:
- For most of these materials the reliable realization of large area sheets is still to be achieved;
- In many applications they need to be placed on a substrate to give sufficient robustness to the device, but they tend to detach;
- Interconnection with the external world, which is intrinsically 3D, and coupling-decoupling signals is still a problem, resulting in significant losses.

On the other hand, in many applications 3D architectures are needed, as for example in the case of microfluidic-based lab-on-chips, scaffolds for cell-growth, organ-on-chips, optical microcavities, etc. The possibility of integrating 2D materials on 3D architectures would open completely new perspectives, allowing full exploitation of the great potentials of 2D materials in a 3D context for augmented functionalities.

The action opens new fields as compared with simple 2D and 3D structuring of conventional materials since it explores novel 2D materials and combines them with 3D architectures. Thus it takes advantage both from new functionalities allowed by novel materials and from innovative system architectures.

3. What needs to be done?

Research programs targeting 2D materials to explore the possibility of using them to “functionalize” the surface of 3D architectures should be set in place. The key points to be considered are on one side the optical and conductivity characteristics of the material, on the other side the capability of integrating it on different material surfaces, and the phenomena taking place at the interface. In particular, (linear and nonlinear) optical properties of 2D materials should be deeply investigated, since up to now focus was mainly limited to electronic and mechanical properties. Ideally, one should achieve the possibility of using 2D materials as functional coatings for scaffolds, ridge waveguides, the internal walls of microchannels and microcavities, etc. The emphasis should be on the new device physics that emerges from the combination of the unique and already demonstrated properties of the 2D materials with novel 3D architectures and devices. New fabrication techniques should be explored

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24 For horizontal work groups focus can be on generic technology domains
to ensure reliable and reproducible results, with potential for future low-cost mass production. Atomic layer deposition could also be explored as an alternative technique.

4. **When should it be launched and how much funding is needed?**

   a. WP2018. Funding needed: 5-7 M€

II. **Proposal for Research or Innovation Topic(s) (2 page max) in Horizon2020 WP 2018-2020**

1. **Description of the topic, objective:** Research projects should aim at the study and optimization of presently available and possible new 2D-materials targeting not only the best optical and conductivity performances, but also robustness, reproducibility and reliability of the fabrication process and the capability of achieving a good adhesiveness on 3D structures at the micro and nanoscale. Concerning 3D-manufacturing, despite much progress has been achieved in this emerging field, the capability of realizing high-quality micro and nanostructures is still to be reached. The targeted components and devices, combining 2D features on 3D architectures, should allow new functionalities, better performances and low energy consumption. Cost effectiveness and scalability to mass-productions should be considered.

2. **Relevant Research & Innovation present in Europe?**

   EU research landscape shows an excellent competitiveness in the field of 2D materials and in advanced micro-manufacturing. Indeed, thanks to the huge investment in the graphene flagship, very strong competences have been created, which can be easily transferred to other even more promising 2D-materials, such as silicene, phosphorene, etc. Also concerning advanced manufacturing, EU leadership is well established in several emerging fields and in particular in 3D-printing. The combination of both competences will pave the way towards new application domains.

3. **Impact on European economy, employment**

   European photonics and advanced manufacturing industry are already very strong. Complete supply chains are already present in both areas. Combining the expertise in 2D materials with that in 3D micro/nano-fabrication will enable the realization of new products with augmented functionalities exploiting photonic processes. Indeed, the combination of the unique properties of the 2D materials with novel 3D architectures and devices, will allow disruptive applications with a considerable impact on solving societal challenges. New markets will be addressed, thus ensuring the creation of new companies or the strengthening of the existing ones, and in the end an increase in employment together with an economical growth.

4. **Impact on societal challenges**

   A significant impact can be foreseen in several areas, as for example:

   **1) Smart care/smart living:** The use of 2D materials integrated on different structures, mainly 3D but also 2D, allows the realization of any kind of sensors, from wearable devices for the monitoring of health-relevant parameters to the sensing infrastructure for smart buildings
2) Safety and security: Coating with 2D materials can be widely exploited for example in food packaging for quality and toxicity detection but also in environmental sensing

3) Pharmaceutical testing: the development of functionalized lab-on-chip, scaffolds for cell-growth and organs-on-chip will provide valuable low-cost platforms for testing of new drugs;

4) Smart lighting and energy: 2D materials are likely to revolutionize both the realization of efficient light sources and new generation photovoltaic cells

5. EU added value:
The required competences in 2D materials, 3D advanced micro/nano-manufacturing and integration expertise are only available at the European scale. Combining the excellences present in the different areas will be beneficial for the overall European competitiveness
WG 7 – Pilot Line for Free-form Optics

1. Area to be addressed

Classical optical components, such as lenses and mirrors, play a crucial role in photonic systems, photonic instruments, photonic light sources, and in photonics-enhanced products. They are the interface between the optical or photonic signal handling and processing devices and the outside world. As such, imaging optics is key in high-end information capturing devices (e.g. digital cameras, optical readers, advanced optical microscopes, and medical diagnostic instrumentation) whereas collection optics is essential in light and optical energy capturing systems (e.g. in photonic sensors, optical data communication receivers and photonic interconnects, in optical spectrum analysers, in lab-on-chip optical diagnostics, and in solar energy). Also light projection and beam shaping optics are crucial elements in e.g. LED-based lighting and illumination systems, in digital light projectors and displays, in virtual reality eyewear and head-up displays, and in laser-based advanced manufacturing systems. Recent advances in high-precision manufacturing technologies (such as 3-D optical nanoprinting, and ultraprecision diamond tooling and polishing) and the availability of on-machine optical metrology are currently enabling unprecedented optical free-form shapes with exceptional surface finish. Seminal breakthroughs in novel optical materials (such as optical polymers, infrared and UV glasses, and optical ceramics) considerably extend the optical spectral ranges, optical power-handling capacity, or manufacturability at low cost of optical components and systems, while novel optical design methods such as transformation optics enable the creation of unparalleled optical functionalities. These revolutions in optics, combined with the advances in mass-manufacturing technologies (e.g. DUV lithography, micro- and nano-injection moulding, wafer-scale hot-embossing, and roll-to-roll printing) and surface coating technologies are currently pushing the performances of the “classical optics” into the realm of “extreme optics” and are paradigm-shifting optical and photonic innovation of existing and future products in a variety of industry sectors. As such “extreme optics”, whose main pillar can be considered free-form optics, will play a prominent position in facilitating and accelerating the uptake of photonics innovation in Europe.

2. What is the challenge?

The growth of Europe’s advanced manufacturing industry and successful digitization of its economy heavily relies on an efficient and effective optics and photonics innovation supply chain, of which free-form optics is an essential optical innovation technology driver. Cutting-edge pilot-lines play a crucial role in this innovation ecosystem because they bridge the gap between early prototype and commercial mass-production. Four European pilot-lines (MIRPHAB on infrared sources and sensors, PIX4Life on SiN photonic integrated circuits for health applications, PI-SCALE for flexible OLEDs, and ... for packaging and integration) have recently been created to accelerate product innovation from lab to market. These pilot lines should be complemented by a free-form optics (“extreme optics”) – pilot line to give European SME’s the opportunity to enhance their products with the most competitive and manufacturable optical solutions by providing them fast access to the most-advanced expertise and cost-intensive prototyping and manufacturing infrastructures needed to manufacture new and innovative products, and to decrease their time-to-market.
3. **What needs to be reached/done?**

The objective is to set-up a pilot line for extreme optics. Extreme optics is strongly based on free-form optics at large, i.e. including e.g. aspheric optics, optical components combining and integrating diffractive, holographic, and/or refractive or reflective optics (including metasurfaces), and micro-, mini, and macro-optical components or systems in novel materials and/or with extreme specifications or disruptive functionalities. The pilot line should offer solutions for a wide class of very demanding optical components and/or systems that are not commercially off-the shelf available and that are of strategic interest to the European industry. It should cover all stages from optical design, to prototyping, manufacturing, to optical quality control and testing. From technical as well as user perspective it should provide a low entry barrier access to low and medium production volumes, although the available processes should be suited also for scaling to high volume production. The action may include process and equipment optimisation and qualification, and should include a validation of the pilot line offer with the involvement of external users through pre-commercial pilot runs. A credible strategy to future full-scale manufacturing in Europe should be elaborated. The pilot line should be staffed by experts in the field, and should be driven by the key-stakeholders able to set-up and run such pilot lines, and cover the value chain as appropriate.

4. **Expected impact on European economy, employment, societal challenges?**

The pilot line for free-form (extreme) optics should

- provide cost-effective innovative solutions for cutting-edge optical components and systems for European industry in a timely manner, in particular for SME’s that want to innovate their products with photonics
- strengthen Europe’s position in the manufacture of high-end optical components and systems with the aim to maintain and further strengthen its pole-position in innovative photonics-enhanced products in a variety of industry sectors
- be the starting point of a revival of optics manufacturing in Europe creating new employment in the high-tech European manufacturing and system integration industry

5. **EU added value: why should it be funded at EU level rather than national or local level?**

A pilot line for extreme optics necessitates a variety of cutting-edge technology infrastructure and optical manufacturing platforms as well as a critical mass of very skilled experts. The most efficient and effective way to create this open access facility is to combine forces at the European level and to leverage the different facilities through transnational and transregional collaborations. This will lead to an efficient use of the limited financial resources and to an open innovation ecosystem to support a large network of European companies and suppliers.

**Requested funding? When 2018/2019/2020?**

2018: between 8 to 14 M€

Despite being a call for a pilot line, due to the disruptive technologies to be developed, it should be a RIA rather than an IA.
Cross Cutting Task Force – Photonics Research-for-Innovation Hub (PR4I Hub)

1. Area to be addressed

Cutting-edge photonics research is one of the main innovation and digitization drivers in the Industry 4.0 era. Photonics research and technology is currently widely recognized as a continuous supplier of original concepts, novel functionalities, and highly advanced fabrication methods to leverage the productivity and competitiveness of a growing variety of photonics and non-photonics well-established industrial sectors. At the same time photonics research and technology is in the driving seat to support a multitude of pioneering companies with disruptive ideas that will form the basis of our digital economy in the decennia to come. Photonics research in Europe is widely recognized for its excellence and its world-class researchers. At the same time these researchers experience difficulties in demonstrating their conceptual breakthroughs with state of the art technology because of a lack of access to existing cutting edge technology platforms. This causes a severe discontinuity in the European innovation ecosystem, limiting the uptake of top-notch research results and restricting their economic impact.

To overcome this hurdle and feed the European innovation ecosystem with disruptive photonics research-and-technology inspired proof-of-concepts (TRL 1 to 4) it is crucial to provide European researchers and research teams (both photonics and non-photonics researchers, both from academia and from industries, and from all research disciplines or industry sectors) with access or services to the best European photonics facilities and technology platforms through the creation of a “Photonics Research-for-Innovation Hub”

2. What is the challenge?

To create a European “Research-for-Innovation” Hub that operates as an open one-stop-shop center that provides access to a wide variety of photonics technology platforms and to a broad range of photonics services (design, measurement, packaging, etc…) for photonics and non-photonics researchers or research teams, both from academia or from industries.

To considerably lower the photonics research-to-innovation threshold through a more efficient and effective use of existing photonics expertise, facilities, and technology platforms in Europe, through intensified EU collaboration, and in an open science and open innovation spirit.

To enhance the alignment of (blue sky) photonics research with the industrial and societal innovation roadmaps, by creating or enhancing the “research-for-innovation” mindset of European researchers, by supporting proof-of-concept demonstrators based on novel and disruptive research concepts.
To stimulate awareness on intellectual property protection, freedom-to-operate analysis, and the route from research-to-innovation with European researchers.

3. What needs to be reached/done?

A network of competence centres that operates through a single entry gate should be created to support European researchers who develop new technological approaches or new proof-of-principle demonstrators with a clear path to innovation, based on novel optical/photonic materials, architectures and process concepts and.
Researchers should get fast and easy access to the most advanced services, know-how, or technology support at the European level. Competences on non-standard technological solutions (from design to realization and characterization) will be made available. Both individuals, teams, and collaborative consortia should be considered to receive this support through short-term projects (up to 6 or maximum 12 months for the most ambitious ones). Targeted R&D projects must concern novel photonics-based components/devices/systems and/or the integration of enabling photonics components/technologies in non-photonic systems and/or the development of innovative photonic technologies. Criteria for accepting the project proposals need to take into account their impact in terms of innovation potential.

Impact on the research and innovation ecosystem should be measured and optimized.

4. **Expected impact on European economy, employment, societal challenges?**

The Photonics “Research for Innovation” Hub is expected to:

- create a platform that inherently supports research-for-innovation, hence targeting a dramatic improvement of aligning existing research activities with the innovation ecosystem;
- considerably enhance the knowledge creation at the service of innovation with a demonstrable impact on EU industrial competitiveness;
- better align fundamental research activities with the grand societal challenges;
- stimulate cross-KET photonics research at the front edge of technology;
- introduce photonics researchers to the European innovation ecosystem and pave the way for a new research-for innovation mindset that improves the links between research, innovation, and the societal challenges;
- increase the number of non-photonic research professionals to approach and use photonic solutions.

The action will foster the impact of research institution in supporting disruptive innovation, which is at present strongly limited by the lack of internal design-fabrication-characterization facilities. The same problem is faced by highly ambitious SMEs. As a result of the action many more innovative ideas will find a way towards realisation and exploitation at the European level, with a consequent increase of European competitiveness on the medium to long-term.

5. **EU added value: why should it be funded at EU level rather than national or local level?**

In view of the limited financial resources and the expensive research and technology platforms, infrastructures and competences need to be shared in Europe through transnational and transregional collaborations. This will lead faster results, more efficient use of resources, and the establishment of a complete ecosystem “from lab to fab”. Non-commercially existing photonic technologies will be made available (or tailored/developed when needed) throughout Europe so as to target medium to long-term disruptive innovation.

2018: 8-10 M€

The type of action should be a large-scale RIA, the aim being to create a network of facilities acting as centres of competences targeting photonics research and technology support for medium to long-term innovation. Research institutions and/or companies involved in advanced R&D programs and developing new technologies should be part of the core of the action.

The model (and organisation) should resemble that of ACTPHAST but beneficiary institutions would mainly be research institutions and possibly highly innovative SMEs. The evaluation of the projects to be supported by the action will be done by a Committee including representatives from high-tech companies so as to ensure their potential for innovation. Of course confidentiality issues will be guaranteed during the evaluation process.

The proposal is cross-cutting since it addresses all possible application domains of photonics and is planned to exploit different technological solutions. It is also somehow halfway between WG6 (targeting industrial development) and WG7 (targeting disruptive research).
Cross Cutting Task Force – LIGHT TO FUEL; photonic devices for the production of solar fuels

1. Area to be addressed

One of the grand challenges for Europe in the coming decades will be to guarantee a sustainable supply of energy, whilst keeping the energy system reliable and affordable. Based on the forecasted increase in Europe’s energy demand and decrease in fossil energy, Europe is urged to increase the share of renewables in the overall energy system. To cover the forecasted energy demand in 2050, the total amount of energy from renewables needs to increase by at least a factor 4. An important source of renewable energy is solar energy, which is currently mostly harvested by photovoltaic (PV) modules that convert sunlight into electricity. Another source is electricity generation by wind turbines. Since the supply of both solar and wind energy inherently fluctuate and efficient and affordable electricity storage systems are not available, owners of distributed systems such as PV modules and wind turbines remain dependent on the electricity grid for selling and buying electricity and grid owners are left with the increasingly difficult task of continuously balancing electricity generation and consumption.

Suitable technically and economically feasible technologies for energy storage would allow the build-up of an energy buffer that enables consumers to cope with the fluctuation in supply of solar and wind energy. Storage of energy in the form of fuels is a very promising option, because of its high storage density – e.g. hydrogen has a gravimetric storage density of 120 MJ/kg, which is roughly 100 times higher than the storage density of current Li-ion batteries – and the ability to directly use these fuels, e.g. for heating, in transportation or to generate electricity. Rather than a two-step process with inherent losses and complexities (first generating electricity by PV and/or wind, then using electricity to generate fuels), photonic devices that directly convert solar energy to fuels may bring the required breakthrough innovation for securing Europe’s future energy supply. Examples of promising energy storage molecules/fuels are hydrogen, methane, liquid hydrocarbons, ethanol and methanol.

2. Position of Europe in the application domain (research, industry), foreseen evolution from now to 2020+ What is the challenge (in Europe) in the respective area today?

To efficiently convert and store solar energy in form of fuels, the development of photonic devices that enable the production of fuels with sunlight as energy source is required. Such devices should be optimized for efficient harvesting of sunlight – using e.g. photon management strategies similar to the ones used in PV modules – and efficient conversion of chemical precursors to fuels. Latter requires efficient photocatalysts, which can be organic molecules, transition metal complexes or nano- or sub-micron particles or structures consisting of semi-conductors and/or metal. Most suited chemical precursors for the production of solar fuels are carbon dioxide and hydrogen or water, which can e.g. be converted to methane or methanol. Methane can be used for domestic heating or electricity generation, methanol is of direct use as fuel in internal combustion engines, or can be dimerized to dimethyl ether, which is a clean alternative for diesel or liquefied petrol gas. The use of carbon dioxide as carbon source would result in a decrease of the level of carbon dioxide in the atmosphere, which is an important additional advantage of this technology.

Currently, photonic materials and devices for the production of solar fuels are mainly developed by university research groups in a non-integrated fashion. Groups with a background in chemistry focus
on the design, synthesis and validation of suited catalysts, device physics groups focus on the development of photochemical or photo-electrochemical cells. To facilitate market introduction of such technologies in the next 10 years, it is important to rank potential applications through performing techno-economic evaluations. Outcome of such studies may guide both the development of devices and catalysts. For most applications, the performance of the catalysts materials and the design of the photonic devices require significant improvements. Furthermore, academic groups working on materials and equipment should join forces, and co-develop complete solutions in consortia with applied research organizations and industry stakeholders for scale up of technologies, whilst ensuring the technical and economic feasibility on an industrial scale (materials producers, chemical companies, module manufacturers, energy companies etc.). Furthermore, business cases should be developed, and efforts should be made to familiarize the general public with these developments to facilitate societal acceptance.

3. What needs to be done?

*Necessary steps to overcome the problem described, including the type of activity (research, innovation, other)?*

- Consolidate R&D in the field of catalyst development, and create room for disruptive materials and device concepts resulting in efficient chemical processes and high energy conversion efficiency.
- Develop cost-efficient processes suitable for large scale and large area production of the catalyst.
- Develop cost-efficient processes suitable for large scale and large area production of the nanostructured materials required for efficient photon management in photonic solar fuel devices.
- Develop innovative photonic devices for the efficient conversion of solar energy to chemical energy and storage in form of fuels.
- Establish research consortia that enable material and device development in an integrated fashion.
- Establish research consortia comprising universities, applied research organizations and industrial partners to ensure technical and commercial feasibility of large scale material and device production.
- Development of business cases.
- Familiarization of the general public with these developments to promote societal acceptance.

4. When should it be launched and how much funding is needed?

*In which year should the area be called: as part of WP 2018, WP 2019 or WP 2020?*

Preferably in 2018, large international consortium projects with a duration of 3 to 4 years should be funded. Suitable project budget is 8-10 Mio € per consortium project. Given the diversity of promising technological concepts, preferably several projects should be funded in parallel.