Brussels, 27 May 2022

COST 073/22

DECISION

Subject: Memorandum of Understanding for the implementation of the COST Action "Understanding interaction light - biological surfaces: possibility for new electronic materials and devices" (PhoBioS) CA21159

The COST Member Countries will find attached the Memorandum of Understanding for the COST Action Understanding interaction light - biological surfaces: possibility for new electronic materials and devices approved by the Committee of Senior Officials through written procedure on 27 May 2022.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA21159
UNDERSTANDING INTERACTION LIGHT - BIOLOGICAL SURFACES: POSSIBILITY FOR NEW ELECTRONIC MATERIALS AND DEVICES (PhoBioS)

The COST Members through the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action, referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any document amending or replacing them.

The main aim and objective of the Action is to bring together European scientists coming from distinct disciplines into this vibrant field of research, focusing on the photonic effects of nano- and micro-structures found in biological surfaces and their bionic applications. The project has great implementation potential, in the field of biological measurements and medicine. This will be achieved through the specific objectives detailed in the Technical Annex.

The present MoU enters into force on the date of the approval of the COST Action by the CSO.

OVERVIEW

Summary
Various biological surfaces are known to be covered by elaborated micro- and nano-structures, serving a number of functions (e.g. anti-reflective, structural coloration, anti-fouling, pro- or anti-adhesive, etc.) and inspiring numerous industrial applications. Recent years have witnessed a remarkable boost in research in this field. To a large extent, this boost owes to the increasing interdisciplinary of approaches being applied to the study of structured biosurfaces. Sciences as different as classical zoology and botany are inseminated with the advances in genetics and molecular biology; biologists collaborate more and more with nanotechnologists, materials scientists and engineers - all these contribute to the widening of the horizons of research on micro- and nano-structured biological surfaces, and to biomimetic and bioengineering applications of these surfaces in industry. We aim at 'riding the wave' of these developments with our proposal. The main goal of the COST Action “Understanding interaction light - biological surfaces: possibility for new electronic materials and devices” is to bring together scientists coming from distinct disciplines into this vibrant field of research, focusing on the photonic effects of nano- and micro-structuring of biological surfaces and their bionic applications. Our consortium will ensure cross-inspiration among the different participants coming from different research fields and will boost innovation in research and eventual industrial developments.

Areas of Expertise Relevant for the Action	Keywords
● Materials engineering: Biomaterials, metals, ceramics, polymers, composites ● Electrical engineering, electronic engineering, Information engineering: Micro-electronics, optoelectronics for electrical and electronic engineering	● photonics ● biological surfaces ● nanostructures ● microstructures ● biomimetics

Specific Objectives
To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination
● To broaden the scope of disciplines currently involved in specific projects in the field of biological photonic surfaces, bringing together geneticists, molecular biologists, entomologists (and zoologists in general), botanists, materials scientists, nanotechnologists, physicists, and engineers.
● To identify novel photonic surfaces in animals, plants, and microbes, analysing the biological and ecological needs mediated by these surfaces, to enable discoveries of fundamental molecular and materials principles underlying the development of photonic bio-surfaces.
● To uncover the relationship between form and structure in nature to rebuild/imitate them for real-world applications, analysing the structural/morphological build-up of these biological photonic surfaces to determine their physical properties in terms of anti-reflectivity, light scattering, etc.
● To design artificial bio-inspired photonic surfaces and characterize and model their photonic properties.
● To strengthen the International and European visibility of cross-disciplinary research on photonic biological and bio-inspired surfaces.
● To establish exchanges and collaborations within biomaterial and other communities.
● To promote the dissemination of expertise, methods and results, also with the industry.

Capacity Building

● To boost communication, collaboration and networking among European researchers with different backgrounds related to the fields of photonic bio-surfaces and biology-inspired artificial photonic surfaces and related fields (e.g., ophthalmology, nanotechnology, optical devices, coloration, photonics).

● To create a platform to share resources in this new R&D network. In particular, to spread across the consortium approaches and methodologies independently developed in different laboratories of the EU, as well as samples, specimens, instruments, and knowledge for comparative and collaborative analyses.

● To train the next generation researchers by cross-cutting exposure to all aspects of photonic surfaces and their industrial applications i.e., in biomedicine, displays, photovoltaics, structural coloration.

EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. SOUNDNESS OF THE CHALLENGE

1.1.1. DESCRIPTION OF THE STATE-OF-THE-ART

Photonic biological surfaces found across the phyla of the tree of life, but especially in insects, underlie multiple features of light manipulation for various purposes. These features and their examples are briefly overviewed below. Each subsection is concluded by a brief description of the current biomimetic applications.

Transparency and *Anti-reflective coatings* across species are used to decrease the visibility of organisms (protecting them against predators or, on the other side of the chain, hiding the predators from the prey), but also to maximize light reception by the visual organs. The large difference between the refractive index of the air (n=1) and that of solid biological media (n=1.5-1.8) forces significant portions of the incident light to be reflected. Such index mismatch is decreased by sub-wavelength structuring of the biological surfaces, e.g., with arrays of paraboloid protrusions (see Fig. 1) reducing reflectance essentially to zero. Technological applications exploiting the same principle of antireflective nanostructuring are numerous. They include antiglare coating for displays, lenses, and glasses and light harvest-maximizing solutions for solar cells (Fig. 1).

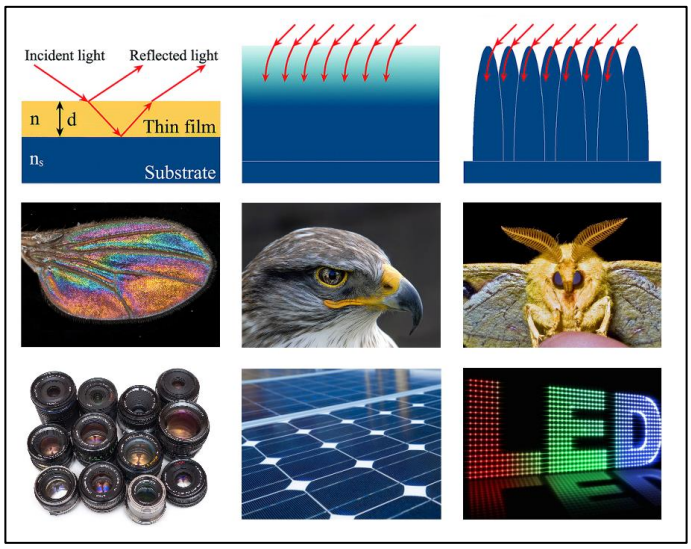

Fig. 1 Different principles of antireflective surfaces, their biological examples and technological applications.

Highly reflective structures serve the opposite task: they increase the reflectivity of biological surfaces and, depending on the species, mediate the need to camouflage, communicate, generate light, or improve vision. A typical example of highly reflective biological structures are the scales of silvery fish. Normally, ca. 5% of the incident light is reflected at the tissue-air interface. However, multilayer reflectors, composed of stacks of alternating layers of high and low refractive index materials, can reflect up to 100% of the incoming light. The multilayer reflectors in fish scales are made of layers of guanine (refractive index of 1.83) alternated to tissue (refractive index of 1.4). Such broadband non-polarizing reflectors inspire dielectric mirrors with enormous technological importance.

Iridescent structural coloration can be obtained by several photonic structures. Such colours are found in several organisms like butterflies. In contrast to pigmented (or chemical) colours, which function through selective absorbance of parts of the spectrum of the incoming light, structural coloration is produced through the interaction of the incident light with the photonic nanostructures causing wavelength-selective light interference. Such photonic nanostructures are constituted by two or more materials with different refractive indices arranged periodically in space. Technological applications of structural coloration include non-chemical coloration in the clothing industry.

Light scattering by biological surfaces: whiteness in nature is optimized in some beetles and butterflies. The underlying mechanism to produce bright white in very small thicknesses is a fully disordered arrangement of randomly positioned nano-sized light scattering centres. Perfectly opaque white materials relying on broadband light scattering may find applications in paper production and design, heat reduction, the substitution of white pigments in food and cosmetics (Fig. 2). Other examples of light manipulation that can be observed in biological surfaces include broadband polarization management, waveguiding and lensing, as well as bioluminescence.

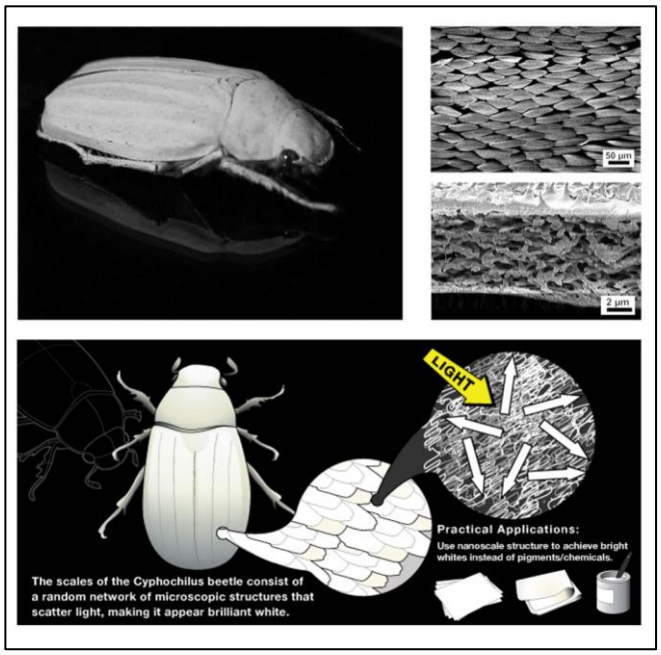

Fig. 2 White coloration by controlled light scattering in biological surfaces and its applications.

1.1.2. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

The study of photonic biological surfaces (PhoBioS) has been a developing field of research in the past decades. Numerous animals, plant, and microbial 'inventions' that appeared in the course of biological evolution have permitted light manipulation through the regulation of its absorption, scattering, reflection, interference, diffraction, waveguiding, transmission, lensing, and more. All these strategies for light management by biological surfaces, often coming in combinations of multiple mechanisms, lead to phenotypes such as pigmentary and structural coloration, transparency, anti- or pro-reflectivity, optimized light emission, polarization selectivity, and others. These phenotypes, in their turn, serve a multitude of biological functions, such as camouflaging, hunting, mating, feeding, and contribute to many more biological functions. Various micro- and nano-structuring of the biological surfaces mediate these photonic effects and have inspired and continue to inspire biomimetic technological applications in the fields of generation and harvesting of light and energy. Antiglare coatings, surfaces of solar panels, and light-emitting diodes are among the industrial examples of successful bionic inspirations of PhoBioS.

Recent years have witnessed a new wave of development in this field. This new drive, to a large extent, stems from the increasing cross-disciplinarity of approaches to understand the molecular and physical mechanisms of the photonic bio-surfaces and to transfer this knowledge to technological applications. Sciences as different as classical zoology and botany are inseminated with the advances in genetics and molecular biology; biologists collaborate more and more with nanotechnologists, materials scientists

and engineers – contributing to the widening of the horizons of research on micro- and nano-structured photonic bio-surfaces, and to bioengineering applications of these surfaces in industry. We aim at 'riding the wave' of these developments with our proposal.

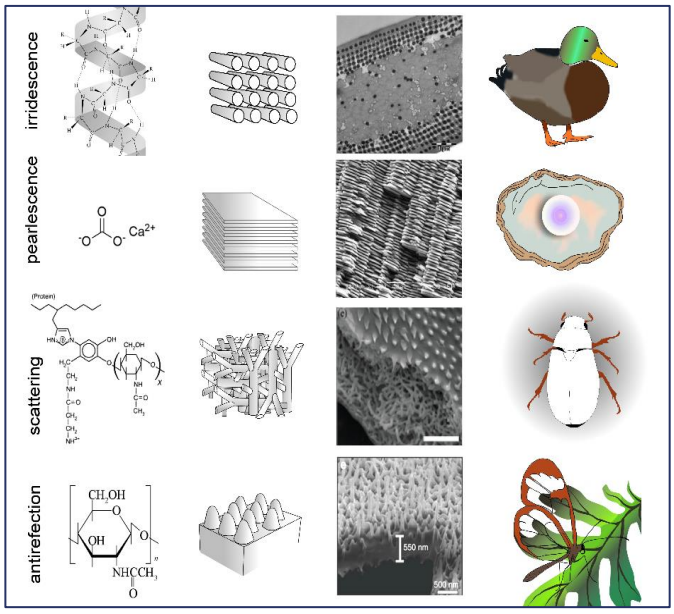

Fig. 3 Overview of the photonic effects of bio-surfaces at different levels (molecular-nanostructural-microstructural-organismal).

The main goal of the COST Action "Photonic effects of biological surfaces - PhoBioS" is to bring together European scientists coming from distinct disciplines into this vibrant field of research, focusing on the photonic effects of nano- and micro-structures found in biological surfaces and their bionic applications. Our consortium will ensure cross-inspiration among the different participants coming from different research fields and will boost innovation in research and potentially feed into industrial developments. The proposed project has great implementation potential, especially in the field of biological measurements and medicine, both dynamically developing and seeking innovative solutions.

Despite impressive progress, the field of photonic bio-surfaces and their technological applications has so far largely remained fragmented, as truly interdisciplinary projects are rarely funded. Therefore, entomologists admire the coloration of e.g., butterflies and analyse the underlying nano- and micro-structures – but lack the skill set to glimpse at their molecular and genetic build-up. Materials scientists may investigate the photonic properties of bio-inspired nanocoatings, but typically do so using non-biological materials and have difficulties in relating these coatings to the plethora of their biological origins. Geneticists track down macroscopic or behavioral phenotypes in model organisms to specific genotypes, yet rarely look closely at nanostructural perturbations and their physical consequences. Physicists analyse the properties of light manipulation as seen in various artificial photonic systems and surfaces, but they are limited in the understanding of the diversity of optical solutions to different tasks millions of biological species have developed in their evolution. Therefore, there is a strong need to create collaborative lines of research in the domain of photonic bio-surfaces, spanning across a broad spectrum of disciplines and stapling together approaches from genetics and molecular biology to nanotechnology and engineering.

The impressive advances in the study of the photonic natural structure are the basis where we build the PhoBioS consortium, which aims to bring together different expertise and skills to train a new generation of scientists capable to work in such a multidisciplinary field. Bio-inspired approaches and methodologies will then contribute to addressing the growing industrial needs for nano- and micro-structured photonic surfaces. The overall market of biophotonics was worth 28 billion Euros in 2015 and is predicted to reach 74 billion Euros by 2024. The technological applications of photonic bio-surfaces constitute a considerable share of this market.

Various industrial applications of photonic surfaces include photovoltaic cells, light-emitting diodes, the clothing industry, antiglare displays, etc. These needs are to be fed with breakthroughs in R&D activities

stemming from novel understandings of the mechanisms of biological photonic surfaces and novel translations of these understandings to technological applications. Thus, the pillars and ambitious goals of our **PhoBioS** consortium are as follows. First, through intensive cross-disciplinarity, we aim at decoding the molecular mechanisms of various photonic bio-surfaces. Second, we aim to translate this knowledge to novel biomimetic technologies attractive to the industry.

1.2. PROGRESS BEYOND THE STATE-OF-THE-ART

1.2.1. APPROACH TO THE CHALLENGE AND PROGRESS BEYOND THE STATE-OF-THE-ART

Continuous developments in the directions listed in the previous section lead to scientific discoveries and inspire novel industrial applications. However, these developments remain limited in their multidisciplinary, restricting the scope of the progress. Thus, aggressive multidisciplinary is a highly sought-after approach in the field of photonic surfaces, as it is for the field of biomaterials in general.

The main proposed innovation is the broadening of the scope of approaches and expertise that are required for the success of R&D projects in the field of photonic bio-surfaces. This goal will be achieved through cross-disciplinary training, catalysed by collaborations among the COST Action PhoBioS partners. As part of the COST Action activities, young scientists will receive direct hands-on experience and training in different disciplines through working within the consortium member laboratories. This multidisciplinary training will produce the next-generation leaders in R&D capable of and interested in applying a remarkably wide spectrum of approaches to individual R&D projects.

Our approach involves extensive interdisciplinarity: let us imagine a project concerned with a novel antireflective nanocoating discovered in an insect species. The traditional approach to this work would be a morphological examination of the structures (via electron and/or atomic force microscopy) and an investigation of their optical properties, i.e., anti-reflectivity, as a function of wavelengths and incidence. In parallel to this, if similar structures could be recreated using artificial materials, other researchers would independently aim to optimize the fabrication of such nanocoatings and re-investigate their optical properties. In contrast, within the PhoBioS framework, the project would be managed as follows. Firstly, zoologists/entomologists/ecologists would be involved to understand the biological role of nanocoatings. Secondly, genetics and proteomics specialists would be engaged to identify the candidate genes, proteins, and other molecules responsible for the formation of these nanostructures, and to genetically modify them. Thirdly, optics specialists would participate in the investigation of the physical properties, while zoologists would explore the biological and ecological consequences of these modifications. Fourthly, the recreation of these nanostructures *in vitro* through replica moulding or reconstruction of the nanostructures from the identified molecular constituents would be performed by materials scientists, again followed by the examination of the resulting optical properties.

This example illustrates the innovative approach to the challenge and progress that goes beyond current state-of-the-art: integration of expertise from traditionally divergent fields of science because of broadening of the scope of approaches to be applied to an individual R&D project, producing otherwise impossible scientific and technological – and ultimately industrial and societal – breakthroughs.

1.2.2. OBJECTIVES

1.2.2.1 Research Coordination Objectives

The PhoBioS consortium aims:

- To broaden the scope of disciplines currently involved in specific projects in the field of biological photonic surfaces, bringing together geneticists, molecular biologists, entomologists (and zoologists in general), botanists, materials scientists, nanotechnologists, physicists, and engineers.
- To identify novel photonic surfaces in animals, plants, and microbes, analysing the biological and ecological needs mediated by these surfaces, to enable discoveries of fundamental molecular and materials principles underlying the development of photonic bio-surfaces.

- To uncover the relationship between form and structure in nature to rebuild/imitate them for real-world applications, analysing the structural/morphological build-up of these biological photonic surfaces to determine their physical properties in terms of anti-reflectivity, light scattering, etc
- To design artificial bio-inspired photonic surfaces and characterize and model their photonic properties.
- To strengthen the International and European visibility of cross-disciplinary research on photonic biological and bio-inspired surfaces.
- To establish exchanges and collaborations within biomaterial and other communities.
- To promote the dissemination of expertise, methods and results, also with the industry.

1.2.2.2 Capacity-building Objectives

The focus of the two leaders, USA and China, in the research on photonic bio-surfaces and artificial bio-inspired surfaces is mostly directed towards materials science- and nanotechnology-oriented research. Europe, somewhat lagging in these developments, provides a large diversity of organisms (plants/ animals/ microbial, marine/ terrestrial) under investigation in terms of photonic structures. Further, European scientists tackle the photonic bio-surfaces from different research angles (nanoscience, theoretical and applied optics, physical chemistry, zoology, botany, chemistry, engineering, material science, biophysics). This diversity represents a highly conducive environment for innovation in Europe, with huge potential for future implementation of scientific outcomes in the commercial sector. However, the many scientists and companies involved in research on photonic surfaces, and the diversity of end-users, remain poorly networked. In the absence of large, integrated, consortium projects, effective knowledge exchange and coordination of research/technical approaches are restricted to small subsets, hampering comparative studies and impeding identification of fundamental principles. Moreover, shared communication platforms and dedicated meetings for EU academics are scarce.

The Capacity-building Objectives of the COST Action PhoBioS are as follows:

- To boost communication, collaboration, and networking among European researchers with different backgrounds related to the fields of photonic bio-surfaces and biology-inspired artificial photonic surfaces and related fields (e.g., ophthalmology, nanotechnology, optical devices, coloration, photonics).
- To create a platform to share resources in this new R&D network. In particular, to spread across the consortium approaches and methodologies independently developed in different laboratories of the EU, as well as samples, specimens, instruments, and knowledge for comparative and collaborative analyses.
- To train the next generation researchers by cross-cutting exposure to all aspects of photonic surfaces and their industrial applications i.e., in biomedicine, displays, photovoltaics, and structural coloration.

From a quantitative point of view, the achievements of these research and capacity-building objectives can be evaluated by the following parameters:

- Number of presentations, publications and patents originating from collaborative research of the COST Action.
- Number of international collaborative research proposals prepared.
- Number of institutions (academic and industrial) participating actively in the network.
- Number of short-term scientific missions supported by the Action.
- Number and diversity of training activities, and number of people trained, to be measured e.g. with a dedicated LinkedIn group tracking the activities of the people trained.

2. NETWORKING EXCELLENCE

2.1. ADDED VALUE OF NETWORKING IN S&T EXCELLENCE

2.1.1. ADDED VALUE IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

At the EU level, significant integration in the broader field of biophotonics exists (reviewed in Tuchin et al., Front. Optoelectron. 2017). Among the existing EU platforms somewhat relevant to the proposed consortium PhoBioS, the COST Action MP1302 “NanoSpectroscopy” can be mentioned. This Action consolidated European expertise on all aspects of UV/visible/NIR nano spectroscopy (modelling, experiment, nanostructures, materials, equipment, and applications). The Action united more than 200 participating research groups from 35 countries. The interdisciplinary approach of nano spectroscopy encompasses the fields of physics, biochemistry, biology, medicine, nanotechnology, and materials science. Despite a limited complementarity with the proposed COST Action PhoBioS, MP1302 “NanoSpectroscopy” had a different and less focused spectrum of interests.

Another COST Action remotely associated with the PhoBioS was MP0901 “Designing novel materials for nanodevices - from Theory to Practice (NanoTP)”, having as its main objective the atomic-scale interface design, characterization, and engineering of surfaces and interfaces of nanostructures. As another example, the ITN PlaMatSu project united three European universities to provide a training network in the field of plant-inspired materials and surfaces.

The European Society for Biomaterials, whose goals are to encourage, foster, promote and develop research, progress and information concerning the science of biomaterials, is another existing EU platform with the interests partially overlapping with – yet much broader than – those of PhoBioS**.**

The present PhoBioS proposal is unique in its focus on a well-defined subfield of R&D – photonic surfaces in biology and their technological applications – in its aim to combine the broad scope of approaches across several disciplines to ‘attack’ this subfield from different angles, producing scientific and technological breakthroughs.

2.2. ADDED VALUE OF NETWORKING IN IMPACT

2.2.1. SECURING THE CRITICAL MASS AND EXPERTISE

Currently, education and training practices still largely follow the classic disciplinary curriculum with very limited cross-pollination. Given the variety of topics involved in the study of photonic bio-surfaces, a broad range of techniques and practical competencies are required. Such a variety of expertise often cannot be developed in a single institution, and therefore it is necessary to pool knowledge and infrastructure as well as technical diversity to reach scientific breakthroughs in the field of biophotonics and to convert them into biomimetic industrial applications. Through PhoBioS**,** the participating institutions and partners will be strongly interlinked and by profiting from the continuous flow of scientific and technological knowledge exchange, the partner organizations will incorporate data and methods from different research fields into their own studies and expand their core skills.

2.2.2. INVOLVEMENT OF STAKEHOLDERS

There is a growing need and urgent demand for skilled employees and trainees by European research institutions and companies working in the field of photonics and nanotechnology. Interdisciplinary projects involving industrial participation are indispensable to promote a timely knowledge transfer from academia to industry in order to make sure that Europe remains at the leading edge of innovation and technology. Inter-sectorial co-operation through new academic partnerships and STSMs between relevant partner organizations are the best way for young students to acquire analytical and advanced research expertise, combined with interdisciplinarity, integrating these into a highly active EU-wide research network, advantageous for career development and providing academic study with socioeconomic context.

2.2.3. MUTUAL BENEFITS OF THE INVOLVEMENT OF SECONDARY PROPOSERS FROM NEAR NEIGHBOUR OR INTERNATIONAL PARTNER COUNTRIES OR INTERNATIONAL ORGANISATIONS

The involvement of secondary proposers from a Near Neighbour or International Partner countries/organisations will bring many mutual benefits. The implementation of the project will strengthen the cooperation between proposing sides due to the creation of an interdisciplinary research team. Successful implementation of the project can bring numerous co-authored publications in scientific journals with high impact factors. The bilateral exchange can be proposed for the participating partners to open the door for working in modern laboratories with equipment unavailable in home institutions and to acquire practical knowledge and skills in the field of photonic biological and bioinspired surfaces, materials engineering, optoelectronics. Working in an international research team will allow its members to learn about the new research methodology and the way of implementing an interdisciplinary research project. Moreover, it will allow the development of the soft skills of the participants. Successful implementation of the project within a COST program will provide a strong basis for continuing the cooperation under new research ventures and preparing joint international grants proposals for future research projects.

The COST Action PhoBioS will involve up to a hundred of participants from a dozen participating laboratories from countries across Europe. These laboratories will bring mutually complementing expertise to the Action required for its success. Using the dedicated website, PhoBioS will spread information internationally, informing and inviting researchers and companies to join and use the available infrastructure/funding. Furthermore, with the websites, PhoBioS also aims to give locals, schoolchildren, and the general public the possibility to be informed about the topics regarding photonic surfaces in biology and their technological potential through bio-inspiration and biomimetics. Additionally, PhoBioS will invite international researchers and companies working in the field of photonic bio-surfaces to attend in PhoBioS meetings and conferences, contribute to the Training Schools, and participate in the technological set-up and implementation. Their experience and knowledge will be hugely beneficial to enhance European progress in the research on photonic biological and bio-inspired surfaces, understanding, and reproducing the basic bio-photonics mechanisms and principals involved.

3. IMPACT

3.1. IMPACT TO SCIENCE, SOCIETY AND COMPETITIVENESS, AND POTENTIAL FOR INNOVATION/BREAK-THROUGHS

3.1.1. SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS (INCLUDING POTENTIAL INNOVATIONS AND/OR BREAKTHROUGHS)

The present COST ACTION will continue to unite the widespread European expertise and activities in the many disciplines associated with photonic bio-surfaces and their technological applications, streamlining and pooling knowledge, approaches, methods and techniques as well as fostering close alliances with other research sectors and industries, in which photonic surfaces could provide technological alternatives and facilitate new possibilities.

Scientific impacts

short-term, within the COST Action period

PhoBioS will be truly multidisciplinary, welcoming researchers and industrial partners from different fields, sectors, and backgrounds to identify and characterize novel, previously uncharted structures and materials using a holistic approach. The involvement of different research fields with their diverse methods will not only provide a world-leading scientific and technological resource for the consortium members, but it will also bring benefit to external researchers through the results and realized technological innovations. Furthermore, with the planned website, PhoBioS will provide the interested members of the public, industry, and policymakers with an information hub showcasing the potential of

biologic and bio-inspired photonic surfaces. Finally, the database of photonic structures in the living world of Europe, open to the general public, will also contribute to these goals.

long-term, beyond the COST Action period

In the long term, PhoBioS will enhance in many ways the existing cooperations and research in this field. The network will strengthen the position of researchers and companies alike for future implementation of product ideas and foster the implementation of a wealth of novel materials spanning from the photonic industry to biomedicine. With detailed knowledge of the molecular mechanisms of the development of photonic bio-surfaces and the translation of these mechanisms into technological applications, the scientific and industrial community will have an invaluable resource to draw upon.

Scientific breakthroughs

The potential for scientific innovations within PhoBioS is high (indicating a low risk level) since each single photonic biological surface characterized will represent a stand-alone contribution to a deeper understanding. There are millions of insect species only, each potentially presenting a valuable source of inspiration. The same applies to every bio-inspired photonic surface to be analysed. The impact of such contributions will be compound, with every piece of information adding to the greater picture. In the long term, every finding that will emerge from the network through collaboration and information sharing will improve the understanding of structures and biomolecules involved and, thus, the likelihood of impact. As an example of scientific breakthroughs we anticipate, we can mention genetic modifications to generate bio-surfaces with the desired novel photonic properties, as well as engineering of artificial photonic surfaces with the help of biotechnological production of the constituents found in the biological surfaces.

Technological impacts

Development, adaptation, and standardization of new and existing methods (e.g., microscopy, molecular biology, biochemistry, genetics, proteomics, lithography, etc.) for research on photonic surfaces will be extremely useful for other research areas dealing with the identification of substances (i.e., biomaterials, toxins, proteins, etc.) and structures (i.e., robotics, fastening systems), as well as for photonics and nanotechnology. The technological impact in terms of understanding photonic surfaces will provide the basis for the development of new bio-inspired technological photonic surfaces and their industrial applications. Moreover, by generating awareness on the biological system we expect to boost the use of biomaterials and biopolymers in industry, catalysing the production of more sustainable products.

Technological breakthroughs

The design and testing of bio-inspired models in WG2 (see below) will demonstrate our understanding of the photonic surfaces and our ability to implement this knowledge. Although we acknowledge that some attempts may fail, these will still contribute to our technological understanding and appreciation of the knowledge deficiencies. Artificial models which correspond functionally and/or technologically to the biological original will constitute breakthroughs to inspire new innovations. As an example of technological breakthroughs, we may anticipate, we can mention application of bio-surfaces for individualized document protection.

Socioeconomic impacts

The achievements of PhoBioS will certainly provide in the long-term novel biomimetic solutions with broad social, environmental, and economic impacts. Stakeholders such as a) photonics and nanotechnology industries will profit through the development and production of environmentally- and eco-friendly photonic surfaces; b) biotechnology and bioproduct companies (as well as companies working in cosmetics, analytics, sensor technology, art, and more) could implement novel biomaterial and composites with photonic properties; c) companies and research institutions would benefit from the input of the young scientist trained by the consortium; d) the whole society would benefit from the advance in the technology and efficiency of environmentally-friendly materials, reducing our current dependence on non-sustainable products.

Socioeconomic breakthroughs

Novel products and materials based on biological photonic surfaces could provide socio-economic advantages; the progress in this direction will raise awareness of environment-friendly alternatives to current technologies. Nevertheless, the R&D of any biomimetic products, may it be photonic surfaces or other, is still to some extent risky in view of the regulatory aspects and its potential limitations in

practical industrial implementations. These issues will be among those to be addressed through the activities of the COST Action PhoBioS, contributing to the growth of the public and regulatory bodies' awareness of the scope and power of bio-inspired photonic surfaces and biomaterials in general. As an example of potential societal breakthroughs, we can mention contributions to species and habitat conservation through investigation of importance of biological surfaces for survival in environment.

3.2. MEASURES TO MAXIMISE IMPACT

3.2.1. KNOWLEDGE CREATION, TRANSFER OF KNOWLEDGE AND CAREER DEVELOPMENT

Stakeholder	*PhoBioS* outcome	Expected impact
Research community		
All EU scientists and institutes working in the field of photonic biological or bio-inspired surfaces	Characterization of the molecular mechanisms of formation of photonic bio-surfaces and use of these mechanisms for bioengineering and biomimetics	✓ Cross-disciplinary investigation of photonic bio-surfaces ✓ New knowledge about the molecular mechanisms of photonic bio-surfaces ✓ New inspiration for material science and applied research institutes ✓ Fundamental and technological progress stimulating new developments across biological and engineering disciplines ✓ Increase in scientific publications, grants, and patents in the field
All interested researchers/ persons/ companies	Web platform on photonic bio- and bioinspired surfaces	✓ Exchange of data and publications ✓ Showcase for the EU contribution ✓ Public communication and engagement ✓ Networking of national researchers and knowledge exchange
General public, Consumers & Policy makers		
All persons interested in biological phenomena and their translation to technological applications	Popularization of the beauty and impact of biological strategies, and explaining their use as the source of inspiration for exciting technological applications, with emphasis on their eco-friendliness	✓ Increase in the general public interest in the study of biological phenomena ✓ Public awareness of the concepts of bionics and bio-inspiration ✓ Better biological and technological education of the younger generations ✓ Increased awareness of the opportunities for the eco-friendly bio-inspired technological developments
Biophotonics and Surface science societies; national and EU agencies	Research and networking in the fields of photonic biological and bioinspired surfaces	✓ Awareness of the necessity to promote, support, and publicize research on photonic biological and bioinspired surfaces ✓ Representation of the European *PhoBioS* community
Regulatory agencies	Bio-inspired products and prototypes and their technological applications, especially in the human- and environment-sensitive domains, as case studies for the development of general regulatory practices for biomaterials	✓ Awareness of the scope of biomimetic applications, especially in the human- and environment-sensitive domains ✓ Generalization and implementation of the regulatory practices towards biomaterials
SMEs & Industry		
Private-public partnerships and spin-offs	Innovative concepts for biomimetic applications	✓ Strengthening of the collaboration with the industrial sector

Applied research institutes; SMEs	Web platform on photonic bio- and bioinspired surfaces	✓ Inspiration for new applications in the industrial sector ✓ Information about the progress and activities of the European *PhoBioS*community

3.2.2. PLAN FOR DISSEMINATION AND/OR EXPLOITATION AND DIALOGUE WITH THE GENERAL PUBLIC OR POLICY

Dissemination and exploitation of the project results (WG3, see below) are an integral part of PhoBioS and will be the particular responsibility of the Dissemination & Exploitation Board (DEB), consisting of three nominated MC members. The dissemination activities of DEB include:

- ✓ Set-up and maintain continuous performance throughout the COST Action, enabling efficient communication between the Action members
- ✓ Coordinate, evaluate and disseminate all National, European and International D&E activities on the scientific, technological and public outreaches within the network and towards external stakeholders
- ✓ Organize Pan-European dissemination activities, i.e., proposing a European "*Photonic Bio-Structures Day*" and support local and national dissemination and exploitations campaigns
- ✓ Participate at international meetings (World Biomaterials Congress – annual, the 2020 meeting to take place in Glasgow; Society for Experimental Biology – annual, the 2019 meeting to take place in Seville; CIMTEC – International Conferences on Modern Materials and Technologies, bi-annual, the 2020 meeting to take place in Perugia; International Congress of Entomology – bi-annual, the 2020 meeting to take place in Helsinki; Living Light conference – bi-annual conference on photonic structures in nature, the 2020 meeting taking place in Queensland; multiple symposia on bioinspired materials by the Materials Research Society and Gordon Research Conferences
- ✓ Set-up and run websites such as *www.PhoBioSurf4.eu* and *www. PhoBioSurf4eu.com*
- ✓ Set-up of LinkedIn, Facebook and Tweeter group pages on the project
- ✓ Pursue contact and cooperation with relevant thematic COST Actions, EU and national projects, researchers and companies
- ✓ Prepare press releases and public relations material for all PhoBioS members for effective promotion during national public outreach activities
- ✓ Create a corporate identity within the Network (e.g., logo and PhoBioS poster) presenting the COST Action aims and outcomes at the different conferences and symposia
- ✓ Database of photonic structures in the living world of Europe, available to the general public
- ✓ Best photo competitions; artistic competitions involving structural colours

In addition to these dedicated Pan-European activities, all MC and Action members will be encouraged to stimulate local and national activities, publicity campaigns and, by this, promote PhoBioS as well as its thematic outreach. The members, whether academic, private, RTD, SME or industrial partners, will be encouraged to use their business and scientific networks, to participate in research societies and to publish in industrial journals and magazines, promoting PhoBioS and informing not only stakeholders, customers and the general public but also national biophotonics and nanocoatings manufacturers about PhoBioS and its objectives. All Action members should take part and refer to the COST Action in:

- ➢ Lectures and laboratory courses within the academia and for public
- ➢ Science correspondence in national and international newspapers and magazines (e.g. Universum, Geo, National Geographic, Scientific American)
- ➢ Popular media (radio, newspaper and TV interviews) and social networks (Twitter, Facebook, ScienceBlogs, LinkedIn, Youtube) to make the project more accessible for different audiences
- ➢ Different national activities such as high school science fairs, student's and children's universities, "university meets public", "long night of science", exhibitions, etc.

- At conferences, meetings and in publications

Exploitation activities

The PhoBioS will take an integrative overview of the exploitation of PhoBioS results and technologies across the whole project and will take care of:

- Identifying funds, grants, and other useful resources suitable to support research in the COST Action and, in particular, the more resource-intensive WGs 1 and 2 (see below)
- Identifying knowledge that could be subject matter for protection through patents or publications
- Developing and distributing standardized methods and successful protocols within the Network

General guidelines with regard to intellectual property and confidentiality (also in view of publication authorship and patent applications) are subject to the consortium agreement between the MC members and these will be set up at the outset of the COST Action, containing arrangements about the management of foreground and background knowledge, Intellectual Property Rights during and beyond the project.

4. IMPLEMENTATION

4.1. COHERENCE AND EFFECTIVENESS OF THE WORK PLAN

4.1.1. DESCRIPTION OF WORKING GROUPS, TASKS AND ACTIVITIES

PhoBioS will be managed by the Management Committee (MC). The MC will be responsible:

- To implement and set the strategic direction of the Action.
- To elect the Core Group (CG), Grant Awarding Coordinator, the WGs Leaders, and D&E Board (DEB).
- To supervise, monitor, and give recommendations to the boards and coordinators.
- To coordinate the scientific, technical, and financial progress of the Action.
- To address and document all issues raised by external regulatory and other bodies relevant to the objectives of the project.
- To coordinate and perform with the DEB all national COST Action activities, scientific, and public outreach.

The Core Group (CG) will be elected from the MC members at the Kick-off meeting. It will be comprised of the Action Chair, Action vice-Chair, the WG Leaders, the Grant Awarding Coordinator, the Science Communication coordinator as well as one DEB member. The CG will support the MC in the management and coordination of all initiatives such as MC and WG meetings, STSMs, Training Schools and other matters that may arise during the term of the Action. The CG will form a central core of the Action relevant for all requests, concerns, and issues raised by various parties from within and outside of this network.

Short term scientific missions (STSM) will be actively used to enhance information exchange, for research trips for use of special instrumentation or know-how, and to enable young researchers and senior experts to participate in inter-group programs. STSM applications must be related to one or more of the five tasks (1.1-1.3 & 2.1-2.2) and require approval by the relevant working group coordinator. The Grant Awarding Coordinator, elected at the first MC meeting, will then further evaluate the value of the STSM prior to approval by the CG. This procedure will be completed by email to avoid delays.

Working groups 1&2 and their tasks will be coordinated by an expert member, elected through the first MC Meeting, while WG3 will comprise a board of three voted MC members (one of these participates also in the CG). The leaders of each task will be elected during the first WG Meeting. The task meetings will be chaired by the respective WG coordinator and regularly:

- review progress and timeliness of all tasks and outreaches

- ensure effective coordination and implementation of each task and D&E activity
- verify and adjust the scientific and technical progress of the tasks
- proactively suggest improvements of the COST Action strategy
- participate at Dissemination & Exploitation activities
- communicate with the task members, invite foreign researchers and specialists relevant to their task and guarantee with the DEB an effective dissemination of each task/working group.

The MC will meet at least once per year in person and the CG will meet twice a year or more often, in case of extraordinary issues. They may also reach consensus by electronic communication. To ensure the simplest and yet effective and decision-making management, the CG will meet during this time as well and report to the MC about the Action's progress. Regular meetings of the three WGs and their tasks will be organised on request and will take place virtually (i.e., by TelCo, VidCo) or during Training School and conference meetings.

WG1: Learning from nature – photonic surfaces in biological objects

Objectives

- ✓ To identify novel photonic surfaces in animals, plants, and microbes
- ✓ To analyse the biological and ecological needs mediated by these surfaces
- ✓ To determine their physical properties in terms of anti-reflectivity, light scattering, etc
- ✓ To analyse the structural/morphological build-up of these biological photonic surfaces
- ✓ To understand the genetic makeup of these structures and, more broadly, of the molecular mechanisms of their formation
- ✓ To develop a platform for sharing knowledge, procedures, specimens and instrument analyses

Task 1.1: Biology and ecology

Millions of species of animals (especially insects), plants, and microbial communities remain understudied with respect to the photonic surfaces that they build and utilize for various needs. This first task of WG1 will be to 'hunt' for novel photonic surfaces in nature and to understand the roles these surfaces play in e.g., prey-predator interactions, mating, camouflage, etc. We will also aim at creating a database of photonic structures in the living world of Europe, which will be constantly updated. Being available to the general public, it will also contribute to the WG3.

Task 1.2: Morphology and physical characterization

High-throughput and collaborative characterization of the morphological build-up of biological photonic surfaces will be aimed at understanding the structures involved and will rely on various microscopy methods such as scanning electron microscopy, transmission electron microscopy, atomic force microscopy. In parallel, physical characterization of the light manipulation capacities (light scattering, polarization, absorption/reflection, lensing effects, etc.) of these surfaces will be performed, again collaboratively.

Task 1.3: Genetics and molecular mechanisms of formation of the photonic bio-surfaces

The molecular mechanisms governing the formation of photonic biological surfaces are still largely unexplored. Unravelling these mechanisms will provide not only scientific breakthroughs but will also direct the development of the bio-inspired photonic surfaces of WG2 within PhoBioS and other researchers. We will exploit the *omics* analytical techniques (proteomics, lipidomics, glycomics, metabolomics) in order to reveal the composition of the surface materials building up the photonic structures. We will combine these *omics* approaches with genetics and synthetic biology, e.g. to manipulate the genes encoding protein components of the photonic structures and enzymes enabling synthesis of the non-protein components of the structures, as well as to bio-engineer novel structures encoding modified proteins/ enzymes as well as foreign proteins/enzymes (i.e. proteins important for the build-up of photonic structures from one organism will be expressed in another organism). While established model genetic organisms will be heavily used for these experiments, the advance of genetic methods nowadays enables genetic manipulations even in the organisms previously considered genetically non-tractable, further expanding the window of opportunity for this type of investigation.

Activities: Research projects, Lectures, Publications, Conference Proceedings, Short-term scientific missions (STSMs), Training Schools

Milestones:

M1.1: Launch of the open database of photonic surfaces in Europe (Month 30).
M1.2: New state of the art book of "Photonic surfaces in biology" (Month 40).
M1.3: Final Report (M48).
M1.4: A number of collaborative publications in leading biological and biophysics journals (throughout the duration of the project).

Major deliverables:

D1.1: Report from the Training Schools organised, including the list of participants, training materials and other outputs (annually).
D1.2: Report of the dissemination and public relation activities (biennially).
D1.3: Progress report comprising the number of STSMs and publications for each task (annually).

WG2: Artificial models – bio-inspired photonic surfaces

Objectives

- ✓ To design artificial bio-inspired photonic surfaces
- ✓ To characterize and model the photonic properties of the artificial surfaces
- ✓ To disseminate data among engineering science and industry

Task 2.1: Design and generation of lab prototypes of bio-inspired photonic surfaces

We will rely on the prior art in the field as well as on the novel biological surfaces to be discovered and characterized in WG1 to design and produce bio-inspired photonic surfaces through a variety of approaches, including replica moulding, lithography, chemical synthesis, 3D printing, electrospinning, in vitro admixing of the constituents of the biological photonic surfaces, etc. These design/production endeavours will go hand in hand with the physical characterization of the light manipulating capacities of the surfaces. The results of the physical characterization will feedback to modify the design and production step in a reiterative manner, to reach the optimization of the surfaces.

Task 2.2: Dissemination of the new designs and lab prototypes among material scientists and engineers of academia and businesses, for further development.

Activities: Research, Lectures, Publications, Conference Proceedings, STSMs, Training Schools.

Milestones:

M2.1: Interim report (Month 24).
M2.2: Final report (Month 48).
M2.3: A number of collaborative publications in leading material science and nanotechnology journals (throughout the duration of the project).
M2.4: Patent application(s) (throughout the duration of the project).

Major deliverables:

D2.1: Report from the Training Schools organised, including the list of participants, training materials and other outputs (annually).
D2.2: Report of the dissemination and public relation activities (biennially).
D2.3: Progress report comprising the number of STSMs and publications for each task (annually).

WG3: Dissemination & Exploitation

Objectives

- ✓ To strengthen the International and European visibility of cross-disciplinary research on photonic biological and bio-inspired surfaces.
- ✓ To establish exchanges and collaborations within biomaterial and other communities.
- ✓ To promote the dissemination of expertise, methods and results.

Tasks:

WG3 is dedicated to coordinating, monitoring and by this guaranteeing optimal visibility of **PhoBioS** at academic, industrial, and public levels. The Dissemination & Exploitation Board (**DEB**) will be responsible for organizing, performing and evaluating pan-European activities and ensuring efficient

communication both internally and externally. Further details about the planned D&E activities and strategies can be found in section 2.2.2.

Activities: Press releases, Electronic newsletters, Roadshow participation, Conference organization, Campaigns, Activity Days.

Milestones:

M3.1: Project website (6-monthly).
M3.2: Conference for WG1 and WG2 (Annual).
M3.3: Launch of the open database of photonic surfaces in Europe (Month 30).
M3.4: Final Report (M48).

Major deliverables:

D3.1: Report on the MC (Management Committee) & CG (Core Group) Meetings.
D3.2: Release of an Electronic newsletter (biennially).
D3.3: Action Progress report (annually).
D3.4: Report of Activity Days/Happy Hours Meetings (annually).

Note: milestones M1.4, M2.3, and M2.4 are distributed throughout the duration of the COST Action.

4.1.2. DESCRIPTION OF DELIVERABLES AND TIMEFRAME

The main Action deliverables are:

- D1: Report from the Training Schools organised, including the list of participants, training materials and other outputs (M12, 24, 36, 48).
- D2: Report of the dissemination and public relation activities (M6,12,18,24,30,36,42,48).
- D3: Progress report comprising the number of STSMs and publications for each task (M12, 24, 36, 48).
- D4: Report on the MC (Management Committee) & CG (Core Group) Meetings (M6,12,18,24,30,36,42,48).
- D5: Release of an Electronic newsletter (M6,12,18,24,30,36,42,48).
- D6: Action Progress report (M12, 24, 36, 48).
- D7: Report of Activity Days/Happy Hours Meetings (M12, 24, 36, 48).

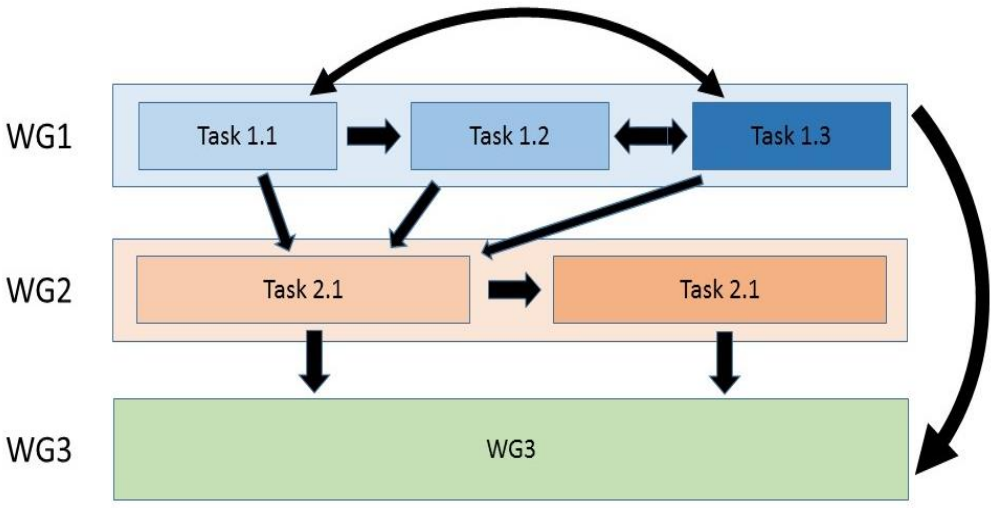

Fig. 4 PERT Chart

Task 1.1 (Biology and ecology) feeds to Task 1.2 (Morphology and physical characterization), the latter feed forth to and back from Task 1.3 (Genetics and molecular mechanisms); Task 1.3 further cross-feeds Task 1.1. All three Tasks of WG1 feed to Task 2.1 (Design and generation of bio-inspired photonic surfaces) of WG2, which in its turn is the source for Task 2.2 (Upscaling of bio-inspired photonic

surfaces). Both Tasks of WG2, as well as WG1 as a whole, provide material for the Dissemination & Exploitation of WG3.

4.1.3. RISK ANALYSIS AND CONTINGENCY PLANS

Risk relevant for WG1: Failure to identify the molecular and genetic mechanisms underlying the formation of photonic biological surfaces.

Contingency plan: The consortium members are aware of these difficulties. Noteworthy, for several organisms' preliminary results and data are already available for further study within WG1. Following the same success lines in other organisms is likely to mitigate this risk.

Risk relevant for WG2: Difficulties in the design of bio-inspired surfaces; difficulties or delays in the production of prototypes of the surfaces.

Contingency plan: To minimize this risk, several network partners will work in parallel and in collaboration on these tasks to find the optimal designs and set-ups. In addition, external and international researchers will be invited to join WG2 and participate in the technological implementation and optimization. Further, industrial partners (SME and larger) will be approached to cooperate on this task.

Risk relevant for all three WGs: One or more Action members show weak commitment to the network progress, task participation and dissemination activity or leave the consortium.

Contingency plan: The MC and EB will supervise effective communication at all management levels to avoid misunderstanding and ensure an optimal internal and external outreach. In the event of a major partner loss, the remaining Action partners will look for alternatives and discuss alternative management structures to compensate and substitute the member lost in the relevant tasks

4.1.4. GANTT DIAGRAM