European Cooperation
in the field of Scientific
and Technical Research
- COST -

Secretariat

Brussels, 30 November 2007

COST 264/07

MEMORANDUM OF UNDERSTANDING

Subject : Memorandum of Understanding (MoU) for the implementation of a European Concerted Research Action designated as COST Action MP0702: Towards functional sub-wavelength photonic structures

Delegations will find attached the Memorandum of Understanding for COST Action MP0702 as approved by the COST Committee of Senior Officials (CSO) at its 169th meeting on 15 - 16 November 2007.

MEMORANDUM OF UNDERSTANDING
for the implementation of a European Concerted Research Action
designated as

COST Action MP0702

TOWARDS FUNCTIONAL SUB-WAVELENGTH PHOTONIC STRUCTURES

The Parties to this Memorandum of Understanding, declaring their common intention to participate in the concerted Action referred to above and described in the Technical Annex to the Memorandum, have reached the following understanding:

1. The Action will be carried out in accordance with the provisions of document COST 299/06 "Rules and Procedures for Implementing COST Actions" (or in any new document amending or replacing it), the contents of which the Parties are fully aware of.

2. The main objective of the Action is to establish active links between European laboratories working in the field of artificial materials for photonics applications, where the structural dimensions are at or below the wavelength of light, to foster and accelerate long-term development of this field in Europe.

3. The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at 35 million EUR in 2007 prices.

4. The Memorandum of Understanding will take effect on being accepted by at least five Parties.

5. The Memorandum of Understanding will remain in force for a period of four years calculated from the date of the first meeting of the Management Committee, unless the duration of the Action is modified according to the provisions of Chapter V of the document referred to in Point 1 above.

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TECHNICAL ANNEX

A. ABSTRACT AND KEYWORDS

The objective of the Action is to establish active links between European laboratories working in the field of artificial materials for photonics applications, where the structural dimensions are at or below the wavelength of light. Fabrication of such structures has become possible due to the expertise delivered by nanotechnology, which opens the way to the study of new functional artificial materials and plasmonic structures, promising progress in miniaturisation - and which will allow exploration of new aspects of light-matter interaction. The goal is to increase knowledge about the basic mechanisms of the interaction of light with matter on a sub-wavelength scale. The scientific innovation concerns: the basic mechanisms of light-matter interaction in micro- and nanostructured materials - including metals (plasmonics), the trade-off between strong localization and propagation losses, photonic diagnostic instruments, and non-linear effects. The technological impact of the Action will lead to the implementation of advanced optical equipment and devices with high performance and low cost. The scientific transformation resulting from the Action will facilitate interconnection between topics that will produce new results in the field of photonics and pave the way to the forthcoming "era of nanophotonics".

Keywords: Nanophotonics, non-linear nanophotonics, hybrid material systems, plasmonics, metamaterials

B. BACKGROUND

B.1 General background

Computing and communication will dominate societal structures and individual lives in the approaching ubiquitous information society. Electronics is now approaching its speed limits - and Moore’s law may lose its validity. Photonics is potentially much faster and less energy consuming for signal processing than electronics and plasmonics, in particular, promises the practical advent of nanostructures in the field of information transfer.

The photon is the ultimate unit of information because it packages data in a signal of zero mass and has unmatched speed. The power of light is driving the photonic revolution - and information technologies that were formerly entirely electronic are increasingly employing light to communicate and provide intelligent control. Today’s society is at a crossroads in this technology. Recent advances in this emerging area now enable to launch a systematic approach toward the goal of full systems-level integration. The new emerging area of nano-scale optics or nanophotonics is aimed at integrating photonics with nanotechnology and developing novel photonic devices. Recent progress in the fabrication of photonic nano-materials and sub-wavelength optics provides the enabling science and technology for nano-scale optics. However, actual understanding of the interplay between light and nanostructures is still incomplete - and full integration of light with nano-scale devices and processes, as well as dynamic and all-optical control of such structures, will require fundamental advances in this research area.

The physics and technology of sub-wavelength structured optical materials such as photonic crystals, patterned metallic films and, more generally, artificial optical materials, such as metamaterials (i.e. structured materials with new characteristics obtained by combining materials properties and geometrically patterning), offer novel phenomena and applications over and above classical integrated optics - mainly because of their unique dispersion characteristics, which include photonic band-gap behaviour and slow propagation of light. The associated strong optical confinement has already led to much more compact devices and enhanced non-linear effects, implying the possible replacement of electronic functionality by all-optical operation at the highest speeds. There is an extensive worldwide effort, in both academic and industrial/commercial research labs, to address these challenges. Europe has shown that it can compete with the rest of the world provided that groups involved work collaboratively and resources are pooled.

Integration of electronic and photonic devices on the same chip will enable the systems urgently demanded by the ubiquitous information society – e.g. ultra-fast computers with optical intra-chip connections and photonic diagnostic instruments for single molecule and early cancer detection. Photonics that uses surface plasmon-polaritons (plasmonics) may solve the intrinsic electronics-photonics size-scale mismatch problem - and new self-organized electromagnetic materials may bring low cost solutions for industrial applications. The realisation of efficient coupling to and from plasmonic device structures, non-linear effects – in particular the trade-off between strong localization and propagation losses all require study.

The attraction and potential of confining photons are enhanced when controlled interaction between electrons and phonons is examined: the interplay of these quasi-excitations is likely to open the door to several technological innovations that need to have engineered thermal dissipation. Although it is clear that some of the major problems related to novel artificial materials are still technological in nature, the **physics of photonic structures at sub-wavelength** is a very open question. The aim of this Action is to shed light on several fundamental questions that remain open presently regarding the physics of the optical interaction caused by the dimensions of the structures being studied, and by the combination of different materials (hybrid structures) that modify critical properties such as the spatio-temporal response, the non-linear response and other effects. The Action research agenda will therefore be at the forefront of modern optics, and it aims to combine the fundamental concepts of non-linear photonics and plasmonics with nanotechnology, thereby developing novel photonic devices for manipulating light on the nano-scale, including sensing and imaging - and processing of information with unparalleled operating speeds.

One of the main advantages offered by COST networking is the provision of resources for a pan-European effort, so that smaller laboratories lacking facilities are able to collaborate with other groups to study, model, realise and characterise novel prototype devices. The flexibility of the COST Action, typically more that which applies for other instruments such as those supported by the EU (Framework Program) and ESF, gives a unique networking instrument as the necessary basis and forum of discussion, making it possible to enlarge and formulate new collaborations. This Action will therefore serve to spread the basic physics know-how produced to all participating areas in Europe and beyond.

B.2 Current state of knowledge

At present, many Universities and industrial/commercial laboratories are conducting research in national or European projects such as IST projects. However, the fabrication and process technology for photonic crystals and more general artificial photonic structures, still requires a substantial basic research approach. The networking action developed in the framework of the COST P11 has oriented the activity toward to theoretical and experimental studies of: (i) the basic physics of 2D and 3D PhCs, (ii) active PhC light emitters and linear PhC structures for the manipulation and detection of light, (iii) non-linear optical interactions in 2D and 3D photonic crystals, taking into account both quadratic and cubic non-linear effects, the spatio-temporal response (e.g. solitonic effects) and saturation effects, (iv) the pulse propagation in photonic crystal fibres (PCFs), taking into account cubic non-linear effects and spatio-temporal effects, (v) experiments in microwave regimes as a tool for optimising the design of structures operating at optical frequencies, (vi) quantum aspects of propagation and the interaction of fields in PhCs (1D – 2D – 3D) for the generation of non-classical optical states and light-sources.

Functional sub-wavelength photonic structures fabricated from various materials with present-day nanotechnology offer previously unavailable possibilities. Metal/dielectric interfaces between bulk media and in double- multi-layer structures offer novel, previously unexplored dispersion and light-guiding properties. The seminal papers of Veselago and Pendry have initiated interest in flat lenses made of single (e.g. silver and gold) or double negative materials (split ring resonators and dipoles) that offer imaging with resolution well beyond the diffraction limit. Proper choice of the flat lens material structure will enable nanolithography with light sources the UV and visible ranges. Recently, methods for expanding the near-field to near-field imaging range of a flat lens to far-field to far-field operation have attracted particular interest. The need to measure the point spread function of metal and meta-material flat lenses is driving the interest in high resolution optical measurements using the scanning near-field optical microscopy (SNOM), surface-enhanced Raman spectroscopy (SERS) and tip-enhanced Raman spectroscopy (TERS) techniques.

The European Technology Platforms on Nanoelectronics (ENIAC) and in Photonics (PHOTONICS 21) have recognised the importance of basic research in the area of photonic and artificial materials for photonics. For example, for ENIAC photonics is a key knowledge area for the future development of heterogeneous integration and ‘More than Moore’ in the field of nanoelectronics. The impact areas of photonics have been addressed by “Photonics 21” - and the research activities in this Action will underpin the long-term research component of these platforms by gathering the scientific community in an interactive and coordinated manner. For those reasons, the Action will be more oriented towards the physics of nano- and micro-structured materials and their response to light. An important issue is the miniaturization and the possibility of tailoring the properties of the material structure/device of interest to obtain novel or enhanced functionality, e.g. wide tunability, low switching power, specific dispersion properties - and sensitivity to external factors (for sensing applications). More efficient (i.e. with complex functionality at low-cost) ultra-fast optical components for telecommunications, sensing, security, transportation and other areas of application, highly functional, low-cost devices for telecommunications and sensing (including bio-sensing) will be investigated and developed.

B.3 Reasons for the Action

The main reasons for the Action are the generation and dissemination of new scientific knowledge in the areas of photonics and nanophotonics - and the sharing of technical and human resources. The Action members will, at the same time, realise a number of high-value national and European projects – thus the Action will enable synergy and European scale added-value. This Action will operate within the frame of the specific themes recognized in the "Photonics 21" -Technology Platform, which has the responsibility for determining a strategic research agenda, in order to achieve a strong European leadership in Photonics in all areas, such as information and communication, lighting, manufacturing, security, the life sciences and health.

The benefits of the Action will consist of: (i) better understanding of light-matter interaction in artificially wavelength and sub-wavelength many-interface environments, using dielectrics or metals - or combinations of both, (ii) more efficient (i.e. with complex functionality at low-cost) ultra-fast optical components for telecommunications, sensing, security, transportation and other areas of application, (iii) networking with well known scientists in the field, exchange of knowledge, joint generation of new knowledge in the field of light-matter interaction. The expected results will include: (i) development of new nano-structured materials, diagnostic tools and methodologies for application in various areas, (ii) development of new numerical/simulation tools, (iii) development of new collaborations, and (iv) development of research exchanges, amongst others.

The Action will strengthen the rapid growth of achievements in this field on these topics by establishing wide-ranging international relationships within Europe, thereby stimulating and promoting collaborative research in a multi-disciplinary area. The cooperation, being the fuel necessary to start-up specific research projects involving partners in the Action, will favour the development of advanced apparatus for information and communications applications, lighting, manufacturing, security, the life sciences and health. The networking potential offered by the Action will promote the expected results thanks to the opportunity to access financial support for research at both national and European levels. The Action will largely profit from benefits that COST uniquely offers. In fact, even though the Action is well-focused on the development of concepts relevant to light-matter interaction, the activities include several cross-disciplinary topics that require very varied expertise. Therefore the best way to put together different specific projects is through a network and, among the possible network structures, the COST Action is the most suitable one, since: (i) it is wider in scope than a thematic network implemented through the Framework Programme, since it involves the participation of a large number of countries and different groups for each country and, furthermore, additional partners can join the Action during its life-time, (ii) it does not require a large amount of money to support a limited number of national delegates participating in the meetings and to support a program of Short-Term Scientific Missions, (iii) the specific research activities of the participating groups are supported in each country by other agencies.

B.4 Complementarity with other research programmes

Existing European networks deal with nanophotonics (Network of Excellence (NoE) PHOREMOST, COST 288, NoE ePIXnet), micro-structured fibres (COST 299 FIDES and NoE NEMO for telecom and sensor applications) - and with metamaterials (NoE METAMORPHOSE). The Action will, following the completion of COST P11, become a unique forum in Europe that unifies research in the physics, materials-science, technology and applications of ordered and non-ordered structures, metamaterials and plasmonics. The Action will establish interactions with the above and other consortia via liaisons, cross-action STSMs and joint events.

C. OBJECTIVES AND BENEFITS

C.1 Main/primary objectives

The main objective of the Action is to establish active links between European laboratories working in the field of artificial materials for photonics applications, where the structural dimensions are at or below the wavelength of light, and to foster and accelerate long-term development of this field in Europe.

C.2 Secondary objectives

The secondary scientific objectives of the research activities to be carried out in the frame of the Action are the following:

- Study and development of the physics of micro- and nano-structured materials, taking into account different methods of realizing structured materials and their characterization.
- Study and design of artificial optical materials, including metals and hybrid materials for the manipulation and detection of light, including bio-sensing and super-resolution behaviour.
- Study of non-linear optical interactions in artificial materials, taking into account both quadratic and cubic non-linear effects, the spatio-temporal response and saturation effects, and non-linear dynamics.
- Study of pulse propagation, taking account of cubic non-linear effects, and spatio-temporal effects in nanophotonic structures, including photonic crystal fibres.
- Study of the quantum aspects of propagation – and the interaction of optical fields in artificial materials for the generation of non-classical optical states and light sources.
- Development of novel numerical simulation tools.
- Development of new methods of diagnosis at the nano-scale to be applied in various areas.
- Develop innovative concepts of non-linear nano-scale photonics for applications in all-optical communication and information technologies.

This interdisciplinary program will involve innovative research in nano-scale optics and engineering, it will promote the new fields of nanophotonics and metamaterials.

C.3 How will the objectives be achieved?

The objectives will be achieved by:
- the implementation of tools for realization of artificial materials,
- the realization of software codes,
- the implementation of apparatus for real single-molecule detection,
- the implementation of advanced apparatus for large area nano-patterning.

The evaluation of the success of the Action can readily be made in relation to the scientific objectives by considering the number of peer reviewed publications, conference presentations and invited papers of the participating scientists on these subjects during the lifetime of the Action. Similar criteria can be used to evaluate the success in meeting the technological objectives, taking into account patents pending, new apparatus or prototypes realized, and new software developed.

The Action will be considered successful in terms of the achievement of the goals listed below.

Year 1: (i) 4 publications and conference presentations resulting from collaborative research efforts, (ii) 8 short-term scientific missions supported by the Action, (iii) 1-2 external experts from countries outside Europe - and from industry, present at the General Meeting.

Year 2: (i) 3 trans-national collaborative research proposals prepared, including groups participating in the Action, (ii) 10 publications and conference presentations resulting from collaborative research efforts, (iii) 10 Short-Term Scientific Missions supported by the Action, (iv) 1-2 external experts from Academia and from Industry present at the General Meeting, (v) 1 Training School (open to participants from industry/commerce) organised in accordance with the Timetable and the Dissemination Plan.

Year 3: (i) 2 trans-national collaborative research proposals prepared that include groups participating in the Action, (ii) 10 publications and conference presentations resulting from collaborative research efforts, (iii) 12 Short-Term Scientific Missions supported by the Action, (iv) 1-2 external experts from academia present at the General Meeting, (v) 1 Training School.

Year 4: (i) 2 trans-national collaborative research proposals prepared including groups participating in the Action, (ii) 10 publications and conference presentations resulting from collaborative research efforts, (iii) 10 Short-Term Scientific Missions supported by the Action, (iv) 1-2 external experts from industry present at the General Meeting, (v) 1 Training School.

Scientific and Technical achievements/year: (i) 25 publications in peer reviewed journals (total publications on the topics of the Action including both collaborative and non-collaborative research), (ii) 10 publications in conference proceedings, (iii) 2 new experimental achievements (apparatus/demonstrators/software/patents).

C.4 Benefits of the Action

The expected benefits of the Action will concern science, technology and, as a consequence - society. The aim is to create an efficient interlink among the European laboratories active in the field of artificial materials and nanophotonic devices. From a scientific point of view, the activities to be carried out in the framework of the Action will increase knowledge in basic physics and will lead to a better understanding of light-matter interaction in the presence of artificial structuring and nano-scale interfaces between materials. In particular a deeper insight into the mechanisms of light-matter interaction will be achieved by addressing problems linked to interaction on a small scale, and the non-linear optical response of materials (including new hybrid materials). Sub-wavelength photonics opens up both potentially novel devices and new physics associated with small structure dimensions. It allows for functional devices that are compact, lightweight, portable, low-powered, wearable, environmentally compatible, remotely controllable - and densely integrated. Miniaturization and interconnection of photonic devices can be addressed in a variety of media that includes photonic crystal fibres (PCF), light sources, detectors, couplers, connectors, switches, logic devices, amplifiers, sensors - and integrated photonic sub-systems. In fact, the approaches used will range from micro- to nano-scale, since the mechanisms change substantially, as do the experimental aspects (fabrication and characterization) along with them. New models will emerge.

The technological impact is clear when considering the different devices and instrumentation which will be implemented through the activities of the Action: there are technological traps of which are not known at the moment - and those will definitely require the development new knowledge. In particular, nano-sensing and nanophotonic devices will be strongly advanced through the successful accomplishment of the Action's objectives, since new tools will become available.

The expected impact through the Action is: (i) to establish international relationships in Europe within the field of artificial materials for nanophotonics, (ii) to stimulate and promote collaborative research, (iii) to implement an effective and sustained programme of Short-Term Scientific Missions, (iv) to strengthen linkage with companies interested in technological transfer of the scientific results obtained.

From a quantitative point of view the achievement of these specific objectives can be evaluated through the following parameters: (i) the number of trans-national collaborative research proposals prepared that include groups participating in the Action, (ii) the number of publications and conference presentations arising from the research activity, (iii) the number of Short-Term Scientific Missions supported by the Action, (iv) the number of participants from industry and commerce in the Action's meetings, (v) the number of Training Schools (open to participants from industry/commerce) organised in the dissemination plan.

In addition the expected outcome will be the development of: (i) new diagnostic tools and methodologies to be applied in various areas, (ii) new numerical simulation tools.

C.5 Target groups/end users

A number of companies have already expressed their vital interest in cooperating with the Action and in exploiting the results of Action's activities.

An appropriate training plan for young academic researchers and those from industry/commerce, realised through a programme of Short Term Scientific Missions linked to Training Schools organised in the framework of the Action, will strengthen the academic research and its connections with the key technological issues. This will reinforce the linkage between academic and industrial/commercial institutions, thereby improving the European position in this field.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

Micro- and nano-structured materials can guide light in novel ways, resulting in devices that exploit strong confinement, e.g. photonic wires and photonic crystal channel waveguides, providing both compactness and enhanced functionality. An important issue is miniaturization and the possibility of tailoring the properties of the material structure/device to obtain novel or enhanced functionality, e.g. wide tunability, low switching power, specific dispersion properties - and sensitivity to external factors (for sensors). The scientific programme of the Action will be concentrated along several main lines, where the "core" activity will target a 'better understanding of light-matter interaction in artificially wavelength- and sub-wavelength scale structured materials'. Highly functional, low-cost devices for telecommunications and sensing (including bio-sensing) will be investigated and developed, e.g.:

- high-speed components for all-optical communications networks and low-power super-continuum generators,
- sensors,
- atomic spectroscopy,
- frequency/wavelength converters for communications, spectroscopy and microscopy,
- quantum information technology,
- photonic-crystal fibre light sources of optical and terahertz radiation,
- nano-structured materials for energy conversion.

The scientific programme of the Action will provide an open and flexible framework to make it possible for any other interested country to join the Action.

D.2 Scientific work plan – methods and means

The Action will stimulate the research in the following areas which correspond to the Working Group objectives:

Working Group 1 - Plasmonics, Metamaterials, and Non-reciprocity

This Working Group will undertake the following research activities:

Plasmonics

The use of surface plasmonic fields will lead to a novel generation of photonic devices that are much more compact than those available with current optical technologies, as well as it will bridge the gap between the photonic and electronic technologies. The research in this Working Group will include:

- Study of periodic and non-periodic nano-scale metallic systems (collections of shaped metallic nano-particles or holes in metal films), their dispersion properties, transmission characteristics, field distributions, surface/interface wave phenomena. The aim is to search for and achieve behaviour such as backward-waves (bulk and surface), extraordinary transmission and beaming effects - and strong, sub-wavelength optical field generation.

- Study of guiding using chain-like arrays of nano-particles - and examination of the possibilities for backward-wave propagation and enhanced propagation distances.

- Investigation of 2D and 3D nano-structured metal/dielectric interfaces for applications in telecommunications and sensing.

The aim is to investigate the possibility of development of all-optical switching devices based on periodically modulated metal surfaces and organic adsorbates exhibiting non-linear properties. Periodic modulation of the metal surface generates photonic bandgaps (BG) for propagating surface plasmons. The propagation characteristics of plasmons are very sensitive at the stop-band edge. The idea is to obtain all-optical switching by tuning the BG properties of the metal surface via adsorption of non-linear adsorbates that exhibit 2nd or 3rd order non-linearities, for example conjugated molecules or composite media consisting of metal nano-particles functionalized with proper non-linear layers. This class of devices can, in principle, take advantage of: i) the enhancing properties of metal nanostructures, related to the strong fluctuations of local electromagnetic fields that amplify the physico-chemical properties of molecular adsorbates and ii) of the large and ultrafast non-linear response of conjugated materials.

Metal/dielectric nanostructures, for example metal nano-particles with different shapes (spheres, rods, stars) capped with organic adsorbates, have a strong potential impact on the development of biosensors or biomedicine (in vivo imaging, drug-delivery, diagnosis, local anti-cancer therapy). For this purpose, direct laser ablation methods can provide an interesting approach because of the purity and biocompatibility of the final products. The stability of nano-structured systems also deserves careful investigation. Among these structures, those including capping fluorophores are of great interest for bio-sensing and bio-imaging.

However, the interaction of metals and fluorophores still represents an open problem, resulting in an enhancement or a quenching of the fluorescent emission, depending on different factors that range from the geometry of the system to the physico-chemical properties of the interacting materials**.**

- Nonlinear plasmonics

The interest in this area was recently sparked with the discovery of enhanced light transmission through nano-holes in a periodic array or by surrounding nano-holes with surface corrugations (‘nano-antennas’). Even with holes that are far below the cut-off frequency, the resonant excitation of surface plasmons caused the amount of light transmitted through the holes to be several times larger than expected for an isolated sub-wavelength hole. To achieve complete understanding of such effects, it is necessary to characterize both the amplitude and phase evolution of plasmonic wave propagation, which is still a largely unexplored area of research. It has, however, recently been understood that the unique features of surface plasmon waves could lead to photonic devices that are much more compact than those achievable with current optical refraction technologies. The Action aims to develop the fundamental concepts of optical propagation in nano-scale plasmonic waveguides and suggest novel concepts for optical control and manipulation in non-linear nano-scale structures. In particular, the properties of non-adiabatic couplers between high-contrast conventional dielectric waveguides and metal-dielectric-metal sub-wavelength plasmonic waveguides will be investigated, as well as different ways of engineering compact nano-plasmonic circuits. The Action will investigate the transmission of light through sub-wavelength apertures surrounded by groove structures and determine the groove parameters that optimize transmission. In particular, nonlinear optical transmission through periodically nanostructured metal films (surface-plasmon polaritonic crystals) coated with a nonlinear polymer or polymer-disperse liquid crystal will be analyzed, and studied experimentally. It is expected that the optical transmission of such nanostructures will depend on the control-light illumination conditions that produce bistable resonant transmission.

- Intense sub-wavelength "superfocusing" of light

Superfocusing can be achieved by using noble-metal nano-particles that interact strongly with light at the frequency of a coherent electron oscillation or localized surface plasmons (SP) in the particles. The existence of "hot spots" on nano-particles, where local fields are highly concentrated, makes possible the giant enhancement of both the linear and non-linear optical responses of molecules and atoms placed at such hot-spots, thus showing promise for the realization of efficient lab-on-a-chip sensing platforms and super-resolution imaging devices - and also for modification (e.g. strong enhancement) of spontaneous emission of atoms or quantum dots that are in resonance with SP modes. However, localized SP resonances on nanoparticles have so far only demonstrated low Q-factors.

<u>Metamaterials</u>

This activity direction will include:

- Design and fabrication of novel or optimized metamaterials in order to achieve deep sub-wavelength operation, low propagation-losses, good impedance matching with free space, isotropic designs, wide-band operation, robust negative-index behaviour. These characteristics will lead to metamaterials that are more appropriate for superlensing and/or cloaking applications. Novel negative-index optical metamaterials could lead to the development of revolutionary concepts in imaging and sensing.

- Design of “active” metamaterials, by incorporating active, photoconductive or non-linear media into the current metamaterial designs.
- Study of non-linear metamaterials.

The Action aims to develop innovative concepts in nonlinear photonics, nano-photonics and the physics of negative-index metamaterials. This relates to both theoretical and experimental studies of photonic-crystal physics and engineering, slow-light photonic structures, nonlinear optical switching devices, tuneable nonlinear plasmonic structures, and optical metamaterials that have a negative index of refraction. In particular, the possibility of reducing the speed of light is essential for the creation of compact photonic chips for all-optical signal processing, the goal pursued by many leading international research centres. Flexible and dynamic manipulation of slow light will open up new possibilities for parallel switching of pulses, all-optical sensing and monitoring - and optical computation.

Almost all studies of the properties of left-handed metamaterials so far have been restricted to the effects produced by their linear response. Moreover, both the magnetic permeability and the dielectric permittivity of the metamaterial were assumed to be independent of external parameters and optical field strength. However, an earlier analysis of nonlinear properties of left-handed materials has revealed a number of unusual intensity-dependent effects that can occur in such resonant media, including a hysteresis-type dependence of the magnetic permeability on the magnetic field intensity. The nonlinear properties of left-handed composite materials can readily be enhanced in the microwave regime by placing diodes in the slots of magnetic resonators in the composite structure. This effect has recently been demonstrated at microwave frequencies -and the Action aims to demonstrate the world-first voltage-tuneable metamaterials, operating at microwave frequencies, that have parameters controlled by an applied bias, together with enhancement of the amplitude of the propagating electromagnetic field.

The Action will coordinate studies of a variety of nonlinear effects in optical metamaterials, including (i) the fundamental nonlinear response of left-handed media and composite structures, (ii) amplitude-induced control of the wave propagation and negative refraction effects in such structures, (iii) defect-induced tuneable transmission, (iv) nonlinear effects in stop-band structures and waveguide geometries, (v) parametric effects and frequency mixing in nonlinear structures based on left-handed metamaterials, etc. The Action will track closely technological developments in this promising area - and identify novel possibilities for spatio-temporal control in metamaterials. This interdisciplinary research program will involve innovative research in nano-scale science and engineering, promote new fields of nanophotonics and metamaterials research - and will provide linkages between leading-edge science and industry/commerce in important emerging technologies.

Non-reciprocity

Magnetophotonic crystals (MOPhC) have become the subject of intense worldwide research activity. It was realised only recently that periodic nano-structuring of a bulk MO material could produce strong optical localization because of the intrinsic interference properties of photonic crystals, leading to giant enhancement of the intrinsic strength of all MO effects, such as Faraday rotation and Kerr non-reciprocity. The area of MOPhC research began when, in 2003, Inoue observed experimentally, for the first time, enhancement of the Faraday rotation by two orders of magnitude in a 1-dimensionally (1D) periodic multilayer stack consisting of a periodic alternation of magnetized iron garnet MO layers and isotropic dielectric layers. The key target has now become to observe the same enhanced non-reciprocal MO effects in a truly integrated waveguide format, using 2-dimensional (2D) MOPhC structures. Such a development holds the promise of realising the important non-reciprocal optical functionalities of an optical isolator and an optical circulator available in an efficient and competitive integrated version. The enhancement of the non-reciprocity in MOPhC devices opens up the possibility of a whole new scale of miniaturized and improved non-reciprocal devices, such as non-reciprocal directional PhC couplers, non-reciprocal Mach-Zehnder PhC interferometers, non-reciprocal circulating PhC cavities – and so on. A scientific goal of this part of the Action research agenda is to develop a fast and efficient modelling framework for the theoretical study of 2D MOPhCs. The tools that will be developed will then be used to design and optimize novel integrated non-reciprocal MO circuits based on PhC waveguide structures. Finally, the models developed will be validated by characterization of fabricated prototypes of novel non-reciprocal PhC circuits.

Working Group 2 - Hybrid and planar sub-wavelength scale materials and components

In order to use established, low-cost passive materials and technologies such as silica glass and the corresponding technologies, hybridization of the passive host structure with active ingredients is required, e.g. for amplification, switching and tunability. Such hybrid material systems may be produced by various techniques, e.g. liquid-crystal infiltration, incorporation of optically active nano-particles and non-linear polymers. On the micro- and nano-scale, the topic is challenging in both physics and technology respects and not yet sufficiently well explored. Therefore, fabrication techniques with resolutions beyond the diffraction limit of light are needed. As a consequence, characterisation techniques and instruments with increased accuracy become a must in order to understand and operate these structures. Interference effects at the nano-scale become even more important in the functionality of lightwave devices than at a larger scale, so that small variations in geometry can yield huge effects on the light propagation.

For nanophotonic interconnection at high data rates, compact photonic crystal or micro-disc lasers, operating electrically with close-to-ideal quantum efficiency and sub-100 µW cw output power levels, will be required. Use of high index semiconductor substrates is unavoidable and must be built into the device design. Hybrid integration techniques are also likely to be required here, as also for non-reciprocal or non-linear functionality.

The massive investment of the micro-electronics industry in lithographic tools provides an extremely useful set of techniques for constructing sub-wavelength scale planar photonic components, such as ultra-violet photolithographic patterning or direct write techniques using electron-beam or ion-beam writing. Many planar sub-wavelength structures are presently produced through electron-beam lithography (EBL), which is highly demanding in regards of fabrication steps and operators' skills. An easier alternative is the focused-ion-beam milling (FIB-M), which requires no photoresist and highly flexible structures can be directly fabricated. Nanoscale processing can be also performed using masks made of materials susceptible of self-assembling, like for instance nano-beads, porous alumina membrane, block copolymer with dry etch selectivity. These latter techniques are less costly and time consuming than any lithography process because expensive exposure steps are not required.

The optical properties of a component – its refractive index, gain/loss coefficients and non-linear coefficients – can be altered (e.g. in a periodic or quasi-periodic manner) in one or two dimensions in planar devices. Moreover, several fabrication processes make it possible to transfer, deep into the bulk of a material, a pattern that is defined on its planar top surface. These fabrication processes make it possible to design and construct many useful elements – passive, amplifying and lasing waveguide devices, structured non-linear optical devices for quasi-phase-matched interactions – and so on. The available fabrication technologies make it possible to combine several different functions in compact devices that have characteristic lengths as short as 1-10 µm, thereby enabling sophisticated processing of optical signals for applications in areas such as optical communications and bio-photonics.

In this Working Group, the goal will be to develop theoretical and numerical models, fabrication tools, devices and characterization techniques for sub-wavelength planar photonic components. The research directions will include:

<u>Theoretical & experimental studies of the fundamental properties of tuneable coupled-cavity structures</u>

The last decades have seen tremendous progress in the design and fabrication of dielectric and semiconductor microcavities, which trap light in compact volumes by the mechanisms of total internal reflection or distributed Bragg reflection and can support optical modes with extremely high Q-factors. Such resonators have demonstrated the potential for development of high-performance, ultra-compact optical components such as semiconductor microlasers, wavelength-selective filters, coupled-cavity optical waveguides, and slow-wave structures amongst others. Modern manufacturing techniques make possible the fabrication of coupled-cavity structures in various configurations – and the possibility of tailoring the properties of such structures by tuning their configuration paves the way for their use both in already-demonstrated and in emerging optoelectronic and quantum-optical devices. Furthermore, high-Q optical cavities are ideal candidates for compact dynamic components in all-optical WDM networks, since the strong confinement and long photon lifetimes obtainable in such cavities enable significant enhancement of the effect of changes in the cavity refractive index - thus making it possible to realize the optical bistability functions in very compact integrated structures at relatively low power levels. Manipulation of optical bistability adds new functionalities to coupled-cavity optical components, including signal modulation, switching, and memory functions.

<u>Hybrid photonic-plasmonic structures for light focusing, near-field enhancement and bio-sensing</u>

Among other exciting applications in photonics, optical microcavities have demonstrated potential in the development of inexpensive, ultra-compact, highly sensitive and robust biochemical sensors for both mass and fluorescence sensing. Such sensors detect resonant frequency shifts caused by the changes in their environment through the interaction of the evanescent field of the waveguide-mode outside the microcavity with analyte or with nano-particles and macromolecules. High values for the Q-factor of the waveguide modes used for detection are crucial for efficient and robust detection, since the resonance linewidth and the fluorescence enhancement effects are directly related to the Q-factor value. However, only the evanescent portion of the waveguide-mode field extends into the outer medium, whereas high optical intensity is essential for many important applications in biotechnology and biosensing. High field intensity translates into giant amplification of the Raman scattering process and to increased sensitivity in fluorescent detection.

Another target will be to explore the strong sub-wavelength optical confinement offered by plasmonic nano-particles, with record Q-factors being achieved in optical microcavities. There is clear experimental evidence that microcavity effects yield a further increase in the SP-enhanced fluorescence intensity. As one of the possible applications of hybrid photonic-plasmonic structures, clusters of SP nano-particles such as optical-microcavity-coupled end-structures for focusing optical energy into sub-wavelength spots will be investigated. Such end-structures can potentially be used for focusing and channelling of optical energy into nano-scale detectors such as single atoms, molecules and quantum dots. This avenue of research will result in the development of new classes of novel nano-scale photonic devices, as well as biosensing platforms for both mass and fluorescence detection and rapid genome sequencing.

Working Group 3 - New functionalities

<u>Non-linear dynamics of photonic systems</u>

Most of the current applications of active photonic systems, in particular of light sources, rely on the Action’s understanding of how the output of such systems evolves in time and how their rich dynamical behaviour can, in turn, be made useful. Pulses of light with intensities sharpened by mode-locking or shaped by amplitude-phase device, all-optical generation with dynamics beyond the GHz frequency range, mode switching dynamics, possibilities for quasi-periodic and chaotic optical behaviour are some examples of current activities in this field that have significant potential for industrial/commercial applications. Interesting innovative light sources in the context of non-linear dynamics and control of laser properties include lasers based on quantum dot active regions, microcavities and photonic crystal lasers. These and several other sub-wavelength photonic structures that will be developed in the frame of this COST Action will be analyzed in terms of their non-linear dynamical properties, making use of appropriate modelling, systematic analysis based on bifurcation and non-linear dynamical theories, and of state-of-the-art experimental facilities (with fast scanning and high spectral resolution). This study will directly contribute to the development of novel concepts for light sources and ultra-fast and femtosecond and picosecond pulsating light output.

Non-linear light propagation phenomena

There has been a strong interest recently towards the theoretical and experimental study of light localization, spatial solitons, soliton interactions, pattern formation, filamentation and sub-diffractive propagation, and non-linear parametric processes in extended photonic structures. Examples include cavity non-linear optics and work related to dissipative solitons and localized structures, photonic crystal waveguides and bandgap solitons, the inclusion of photonic crystals and metamaterials into optical cavities for the control of diffraction and modulation instabilities - leading to patterns, photonic lattices and their use for pattern control and the enhancement of parametric photon generation. The novel sub-wavelength-featured waveguide structures that will be investigated in the frame of the Action will open the path towards fundamentally new research activity in the modelling and experimental observation of non-linear light propagation. The possibility of forming easily reconfigurable waveguides with controllable properties in photonic systems is of great interest for optical interconnection and optical routing applications.

Photonic-crystal fibres (PCFs)

PCFs offer an unprecedented control over waveguide dispersion. Combined with a high optical non-linearity, provided by PCFs with very small, often sub-wavelength cores and high core-cladding index steps, this enables a radical enhancement of non-linear-optical transformation for laser fields with broadly varying parameters from continuous-wave radiation to few-cycle laser pulses. Some existing and emerging successes include PCF-based supercontinuum radiation sources and frequency converters, non-linear spectrographs and microscopes based on coherent anti-Stokes Raman scattering (CARS), the creation of all-fibre pulse compressors for high-peak-power pulses within a broad range of wavelengths and advanced laser sources of few-cycle light pulses, as detailed in Part 2. PCFs designed for single-mode waveguiding with large-mode-area are giving a new momentum to the development of high-power fibre laser systems, allowing the creation of high-power fibre lasers, amplification of a short-pulse fibre laser output, compression of sub-megawatt, sub-picosecond laser pulses, and efficient supercontinuum generation for high-energy nanosecond and femtosecond laser pulses.

Fibre structure engineering with a sub-wavelength precision is expected to provide very highly non-linear fibre structures and to allow a unique accuracy of dispersion compensation in PCF laser and frequency-conversion systems. As a part research agenda of the Action, a conveniently formalized algorithm for the design of PCF dispersion in fibre laser and frequency-conversion systems through a sub-wavelength-precision engineering of PCF structures will be developed and evaluated. Another goal of this project is to use a unique combination of properties of these fibres for the demonstration of novel fibre-optic light sources for a broad range of applications, including spectroscopy, photochemistry, and sensing. This will include the design of a variety of structure-nano-managed PCFs with special dispersion profiles optimized for phase-matched four-wave mixing, soliton self-frequency shift, supercontinuum generation, as well as parametric generation of spectral sidebands through self- and cross-phase modulation-induced instabilities. Experiments will be performed to demonstrate efficient spectral transformation and frequency shifting of ultra-short laser pulses through the above-specified non-linear processes. The results of these studies will be used to develop optimal strategies for the creation of novel compact sources of frequency-tuneable ultra-short pulses with a controlled chirp for non-linear spectroscopy and time-resolved measurements.

The main areas of applications of these novel light sources will include laser spectroscopy and optical diagnostics, multiplexed frequency conversion of ultra-short low-energy light pulses, information technologies and data transmission, biomedical applications, including optical coherence tomography, gas- and condensed-phase sensing, biosensing - and ultra-short-pulse metrology.

The work on this program will thus cover the following research topics. (i) Development of PCF dispersion nano-management concept and demonstration of structure-nano-managed PCFs for dispersion compensation in fibre laser systems, (ii) development of PCFs with dispersion profiles optimized for efficient supercontinuum generation, soliton frequency shifting, and parametric frequency conversion for applications in non-linear Raman microspectroscopy, bioimaging, and optical metrology, (iii) development of highly non-linear sub-wavelength-core PCFs for efficient supercontinuum generation and frequency conversion of low-energy laser pulses. The approaches to accomplishing these tasks will include: (i) a detailed analysis of PCF dispersion as a function of the PCF design, investigation of fabrication tolerances, a detailed comparison of numerical simulations and experimental measurements, (ii) experimental and theoretical analysis of pulse propagation dynamics, including the measurement of the spectral intensity, as well as spectral phase and temporal envelope characterization by means of cross-correlation frequency-resolved optical gating, and (iii) optimization of the fibre design, including implementation of the fibre dispersion nano-management approach for the generation of optimally shaped frequency shifted PCF output suitable for coherent anti-Stokes Raman scattering (CARS) microspectroscopy, including single-beam CARS.

Photon-phonon interaction, photon-electron interaction

The potential effects of photon-confinement are enhanced when controlled interaction with electrons and phonons is implemented - and the interplay of these quasi-excitations is likely to open the door to several technological innovations. Careful analysis and study of interactions in structures with small dimensions will produce new paradigms and novel functionalities.

Slow-light structures and devices

Through fundamental studies, the Action aims to establish and demonstrate highly innovative concepts for controlling, steering and slowing light in micro- and nano-photonics structures. By making use of non-linear optical effects, the performance offered by other, essentially linear approaches with the aim of generating delays many times the length of the optical pulse will be exceeded. In particular, that research direction will enable to design photonic structures that change radically the behaviour of optical waves, opening novel possibilities for the control of slow light. Periodic refractive index modulation introduces unique features in the dispersion dependence, such as the appearance of distinct spectral transmission and stop-bands. The light is slowed down at the band edges, and becomes localized inside the gaps, allowing for new ways for directing the flow of light. The Action will develop original approaches for the design of structures with multiple-scale modulation, where dispersion is optimized for the control of slow light propagation.

This activity will explore the possibility of engineering the diffraction behaviour of in-band slow light – and the Working Group shall seek to design photonic structures that simultaneously support slow light modes with distinct amplitude and phase states. This particular regime has not been considered previously - and will allow for signal multiplexing within the same optical system, with the potential for flexible all-optical control using tuneable material properties.

E. ORGANISATION

E.1 Coordination and organisation

The organisation of the Action conforms to the "Rules and Procedures for Implementing COST Actions" (doc. COST 299/06).

The Action will realise its goals via Management Committee meetings, Working Group meetings, Kick-off Workshop, Annual Conferences including Strategic Conference, a Final Conference, Training Schools, STSMs, joint papers and reports.

A minimum of two MC meetings per year will be organised in signatory countries, co-located with WG meetings, with additional WG meetings where appropriate. WG leaders will report on progress to the MC.

The MC will supervise progress and stimulate necessary action. It will report on progress to the COST Office on a yearly basis - and will appoint an Editorial Board for the Final Report - as a book produced by a recognised publisher.

A dedicated web page will be established and maintained to facilitate the Action’s management and to enhance Action visibility. A password-protected ftp site will be maintained to facilitate the internal exchange of working documents.

STSMs especially will be encouraged. Applications will be selected by the MC - and will initiate or strengthen bilateral cooperation, thereby completing Action goals.

In the Kick-off Meeting, after the election of the Chairperson and Vice-Chairperson, the Management Committee of the Action will address the basic issues for the organisation of the Action concerning:

1) the establishment of Working Groups (WG) and appointment of WG leaders (Chair and Co-Chair),

2) the selection of projects to be accepted as activities of the Action,

3) the introducing of collaboration and communication tools and

4) the election of a person responsible for the Short-Term Scientific Missions programme.

The Kick-off Workshop of the Action will be organised no later than six months after the Action starts, with participation of Action’s members and also open to external participants. This will facilitate the starting of efficient networking between participating labs, help Action’s community to identify themselves and their research areas, make the Action visible to the outer world, and also attract new parties to participate actively to the Action.

E.2 Working Groups

Initially the Action will be organized in three Working Groups (WGs):

- WG1 - Plasmonics, Metamaterials, and Non-reciprocity
- WG2 - Hybrid and planar sub-wavelength scale materials and components
- WG3 – New functionalities

The operation of the scheme will be checked after its first year and will be modified according to the actual number of active participants in each WG - and the number of new participants that join the Action. All the participating groups will be invited to provide basic information on their current research projects (title, abstract, WG preference, scientific workers involved – and so on) – and a list of projects will be prepared. The function of the WGs will be coordinated by WG leaders, whose tasks will include informing the MC about the progress of projects, stimulating STSMs, initiating special workshops and maintaining close cooperation with other WG leaders.

As a basic communication tool between partners - and between the Action and other parties - a website will be planned and set-up, shortly after the kick-off meeting. The MC will elect a person to be responsible for the website management. The website will include a “static” section that covers: (i) general information on the Action's programme and objectives; (ii) basic information on participating groups with a link to the group websites; (iii) information and forms to be used for STSM applications; (iv) information for scientists willing to join the Action. The “dynamic” section of the website will provide information on: (i) up-dated timetables of Action activities (planned Conferences, meetings, etc.); (ii) recent scientific and technical achievements and related links; (iii) filed reporting of past activities and achievements.

Attention will be paid to enhancement of collaborative activity by encouraging the formation of consortia able to prepare proposals for submission under specific calls launched within the Seventh Framework Programme (FP7) of the European Community - or launched by other national and international agencies. With this aim in mind, information on new calls of possible interest for Action participants will be given through the website - and invitations to participate in the Action may be circulated.

A plan will be made for the organisation of Training Schools, with the aim of organising three Schools during the lifetime of the Action. The Schools will be open to participants from industry/commerce and will provide basic information and understanding on optical manipulation methods, devices and applications. For PhD students the Schools will be implemented through the STSM programme: a number of missions will be planned as final stages following a specific School for students from laboratories participating in the Action.

E.3 Liaison and interaction with other research programmes

The Action will interact with other consortia and international organisations active in the field of the Action in view to enable mutual exchange of knowledge and results, facilitated by STSM exchange and organization of workshop. Examples of consortia include, but are not limited to, the following: NoE PHOREMOST, COST 288 and the follow-up Action, NoE ePIXnet), micro-structured fibres (COST 299 FIDES and NoE NEMO for telecom and sensor applications) and metamaterials (NoE METAMORPHOSE).

These interactions will be organised via appointing liaisons and via co-organising Strategic Conference, joint events and meetings, and mutual information on planned events.

E.4 Gender balance and involvement of early-stage researchers

This COST Action will respect an appropriate gender balance in all its activities and the Management Committee will place this as a standard item on all its MC agendas. The Action will also be committed to considerately involve early-stage researchers. This item will also be placed as a standard item on all MC agendas.

The Action will especially encourage young researchers to contribute actively in the activities of the Action. Short-Term Scientific Missions will be an important means towards capacity building for early-stage researchers.

This Action will continue with the action "Women in Photonics" that is currently undertaken by two NoEs: Metamorphose and Phoremost - and the school on Photonic Metamaterials, for PhD students, postdocs and young researchers.

F. TIMETABLE

The Action will run for a total of **four years**.

The Action will start with a Kick-off Management Committee meeting - with presentations by all partners and fixing of the organisation issues. Regular MC Meetings will be organised at the end of each General Meeting (MC&WG). The General Meeting at the end of each year will be considered as a Milestone of the Action when the progress will be evaluated and a necessary action will be taken.

1	0	Kick–off MC meeting	
	6	Kick-off Workshop, MC&WG Meeting	
	9		
	12	MC&WG Meeting	Milestone # 1
2	3	Training School	
	6	MC&WG Meeting	
	9	Annual Conference	

	12	MC&WG Meeting	Milestone # 2
3	3 6 9 12	Training School MC&WG Meeting Strategic Conference MC&WG Meeting	 Milestone # 3
4	3 6 9 12	Training School MC&WG Meeting Annual Conference MC&WG Meeting	 Milestone # 4
	3 6	Final Conference Final Report	

The timetable includes the Kick-off meeting of the Management Committee. During year two, three and four Annual Conferences will be organised. With respect to that, invitations will be extended to other COST Actions or European projects active in the Action's field of interest. Those will be intended to assure an efficient means of dissemination of the results.

Short-Term Scientific Missions will be encouraged and conducted in a permanent basis. Careful evaluation of the applications will be the responsibility of the Working Group leaders and members.

The Final Conference will be organised at the end of the Action.

After the completion of the Action, the Final Report will be edited and published in cooperation with a recognised international publisher.

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, BE, BG, CY, CZ, DK, FI, FR, DE, GR, HU, IE, IL, IT, LT, NL, NO, PL, PT, RO, SK, ES, SE, CH, TR, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 35 Million € for the total duration of the Action. This estimate is valid under the assumption that all the countries mentioned above but no other countries will participate in the Action. Any departure from this will change the total cost accordingly.

H. DISSEMINATION PLAN

H.1 Who?

The target audience for the dissemination of the results of the Action includes: (i) other researchers working in the field with special attention to the early-stage researchers as Ph.D. students, (ii) other COST Actions as COST 299 FIDES, COST 288 on Ultrafast Nanophotonics and the follow-up Action, (iii) Networks of Excellence such as PHOREMOST, METAMORPHOSE, NEMO, (iv) European project consortia, (v) industrial organisations and networks, (vi) International Standard Bodies (International Electrotechnical Commission), and other interested parties.

H.2 What?

The dissemination methods will include: (i) posting of general information on a public website, (ii) posting of working documents on a password protected ftp site, (iii) establishing an e-mail network, (iv) publications, including Annual Progress Reports and case-study reports, Conference Proceedings, Final Reports, (v) Annual Conferences, the Strategic Conference and the Final Conference, (vi) contributions to other national and international conferences and symposia, (vii) Training Schools, (viii) articles in peer-reviewed scientific and technical Journals.

H.3 How?

The Action’s website will contain information on Action’s research agenda, activities - especially meetings, past and coming events with special attention to Conferences and Training Schools, Reports and publications. This will be permanently updated during the Action’s lifetime.

A password-protected ftp site will contain the working documents. This site will be made available also to external parties upon registration.

E-mail networks will be established for the Working Groups and for the Action. This will facilitate the exchange of information.

The Action’s Annual Progress Reports will be made available through the web site, as well as selected publications and case study reports. The Final Report will be published by a recognised international publisher.

The Action will organise two Annual Conferences co-located with recognised international events in order to assure a wide audience and impact, and one Strategic Conference with another COST Action or research consortium. The Final Conference will be organised within three months after the completion of the Action. The Proceedings of those events will be edited and published in a cooperation with a recognised international research organisation in the field of photonics, and will be available via a generally accessible electronic database.

The Working Groups of the Action will organise special topical sessions at main events, with a large participation of the Action's members.

An important part of the dissemination activity will be targeted at young researchers. With this aim in mind, three Training Schools will be organised during the lifetime of the Action. The schools will deal with both basic and applied topics, providing information on methods of optical manipulation, devices and applications. The Schools will be open to industrial participants and, in order to address properly the needs of industry, the programme of the School will be discussed and decided in agreement with representatives of companies interested in sending members of their staff as students. On the other hand, for students coming from participating institutions, the programme of the School will be completed by means of a short visit to one of the participating laboratories. Such visits will be supported through the STSM programme.

The Action will promote and support the publication of joint technical papers containing the results obtained in the framework of the Action authored by members of the Action in peer-reviewed scientific and technical Journals. If necessary, financial support may be granted to the authors by the Management Committee in justified cases.