EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Brussels, 13 April 2018

COST 034/18

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "Ultrafast opto-magneto-electronics for non-dissipative information technology" (MAGNETOFON) CA17123**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action Ultrafast opto-magneto-electronics for non-dissipative information technology approved by the Committee of Senior Officials through written procedure on 13 April 2018.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA17123
ULTRAFAST OPTO-MAGNETO-ELECTRONICS FOR NON-DISSIPATIVE INFORMATION TECHNOLOGY (MAGNETOFON)

The COST Member Countries and/or the COST Cooperating State, accepting 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 (the 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 new document amending or replacing them:

a. "Rules for Participation in and Implementation of COST Activities" (COST 132/14 REV2);
b. "COST Action Proposal Submission, Evaluation, Selection and Approval" (COST 133/14 REV);
c. "COST Action Management, Monitoring and Final Assessment" (COST 134/14 REV2);
d. "COST International Cooperation and Specific Organisations Participation" (COST 135/14 REV).

The main aim and objective of the Action is to drive and unite the research in the fields of ultrafast all-optical control of magnetic and transport properties of condensed matter systems in the emerging field of Ultrafast Opto-Magneto-Electronics, by filling the gap that exists between the communities of magnetism, photonics and electronic transport phenomena.. This will be achieved through the specific objectives detailed in the Technical Annex.

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 EUR 76 million in 2017.

The MoU will enter into force once at least seven (7) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14 REV2.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14 REV2.

TECHNICAL ANNEX

OVERVIEW

Summary

The explosive growth of digital data use and storage leads to an enormous rise in energy consumption, which is rapidly becoming unsustainable. Ultrafast opto-magneto-electronics is an emerging field that combines the ideas and concepts of opto-magnetism and spin transport with photonics for ultrafast low-dissipative manipulation and storage of information. Both light and spin currents can control magnetic order, but mechanisms as well as corresponding time scales and energy dissipation differ. The MAGNETOFON Action aims at the best of both worlds, combining short time scales and non-dissipative propagation of light with nanoscale selectivity and strong interactions of spin currents. The ultimate goal is to create and implement non-volatile, low-dissipative, and ultrafast functional elements for data technology.

The research objectives of the MAGNETOFON Action will be achieved by combining the existing expertise of the scientific communities dealing with ultrafast magnetism, spintronics, magnonics, photonics and advanced spectroscopy, and by sharing the new knowledge arising from the exchange between them. This Action will result in a considerable leap in the quality and effectiveness of research in Europe, by bridging the existing gaps between these areas.

The ambition of the Action is to initiate a breakthrough in the field of low-dissipative opto-magnetism and femtosecond spintronics with the help of a joint scientific program bringing together presently nearly non-overlapping scientific communities. By training a new generation of scientists at the interface of the involved disciplines, further development of the field will be ensured together with a successful translation of the scientific breakthroughs into innovative technological solutions.

Areas of Expertise Relevant for the Action	Keywords
● Physical Sciences: Nanophysics: nanoelectronics, nanophotonics, nanomagnetism or classify ● Nano-technology: Magnetism for nano-technology applications ● Nano-technology: Spintronics for nano-technology applications ● Nano-technology: Optics, non-linear optics for nano-technology applications ● Physical Sciences: Spintronics (theory)	● Opto-magneto-electronics ● All-optical magnetization switching ● Ultrafast magneto-transport

Specific Objectives

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

<u>Research Coordination</u>

- To develop the understanding of the processes that occur in magnetic solids and nanostructures, in response to a non-equilibrium excitation resulting in non-local transport.
- To learn to manipulate magnetic order with light pulses, direct as well as through the intermediate action of spin transport.
- To coordinate the experimental and theoretical efforts to develop concepts of spin-based information technology elements.
- To lead the development of novel experimental and theoretical tools.
- To develop concepts of novel approaches and devices for low-energy processing and storing of information.

<u>Capacity Building</u>

- To provide coordinated training and education in ultrafast opto-magneto-electronics to the European researchers, via workshops, workgroup meetings, short term scientific missions, etc.
- To advance the visibility and networking opportunities of Early Career European Investigators working in the area of ultrafast magnetism and spintronics, via the Action website, special sessions on major conferences, and participation in all Action workshops

● To advertise the Action in special sessions at international conferences, underlining the possibilities and advantages of participation
● To create a platform for fruitful collaboration between the researchers and industrial sectors related to magnetic memories, opto-magnetism, photonics and magnetic materials, via a coordinated dissemination plan
● To coordinate research groups in developing and sharing tools and equipment to avoid costly duplication and improve complementarities and synergism on the European scale
● To actively seek industrial involvement in the Workgroups, by setting specific valorisation-related deliverables
● To promote the full involvement of ITC representatives in all aspects of the Action's implementation
● To promote gender balance in all aspects of the Action's implementation, including in Action leadership positions

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. CHALLENGE

The explosive growth of digital data use and storage leads to an enormous rise in energy consumption, which is rapidly becoming unsustainable. Ultrafast opto-magneto-electronics is an emerging field that combines the ideas and concepts of opto-magnetism and spin transport with photonics for ultrafast low-dissipative manipulation and storage of information. Both light and spin currents can control magnetic order, but mechanisms as well as corresponding time scales and energy dissipation differ. The MAGNETOFON Action aims at the best of both worlds, combining short time scales and non-dissipative propagation of light with nanoscale selectivity and strong interactions of spin currents. The ultimate goal is to create and implement non-volatile, low-dissipative, and ultrafast functional elements for data technology. To reach this goal, the Action aims to coordinate and steer efforts from the communities of ultrafast magnetism, magneto-transport and photonics.

1.1.1. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

Already in 1820 it was observed by Ampere that the magnetic moment of a compass needle interacts with the electric current in the neighbouring wire. This observation has since developed into a very active area of magneto-transport, studying the interactions of magnetic order with electric currents, culminating in 2007 with the Nobel prize for giant magneto-resistance.

On the other hand, in 1845 Michael Faraday discovered the interaction of light with magnetized media, thus opening another area of fundamental research, that in our days is best reflected in the manipulation of magnetism with ultrashort optical pulses.

Despite apparent similarities, fundamental differences cause these two areas not to have much overlap with each other. Magneto-transport deals with electronic states near the Fermi energy E_F, in thermodynamic equilibrium and is intrinsically non-local. Magneto-optical interactions, on the other hand, deal with electrons far from E_F, therefore concerning non-equilibrium and non-thermodynamic processes, but are practically always considered to be local. In addition, the typical materials and structures are very different.

The ability to switch magnets between two stable states is the basis of modern data storage technology, and has a great potential to become the fastest information storage and processing technology. Since two metastable states of a magnet have equal entropies and energies, a switching between them can be realized with zero dissipation, according to thermodynamics. Unfortunately, this requires an indefinitely slow process. Therefore, thermodynamically, ultrafast and least dissipative processes seem to be mutually exclusive. Therefore, finding non-thermodynamic ways to control the magnetic state of media with the lowest possible dissipation and simultaneously at the fastest possible time scale is the ultimate challenge, to be solved by MAGNETOFON.

Therefore, the MAGNETOFON Action aims at creating a united area of opto-magneto-electronics that will use short optical pulses to drive the dynamics of magnetic order and magneto-transport, and study the arising non-equilibrium and non-thermodynamic states. This will be done via a dedicated involvement of research groups from ultrafast magnetism, magneto-transport and photonics. It will lead to fundamental breakthroughs in our understanding of the dynamics of non-thermodynamic systems

Funded by the Horizon 2020 Framework Programme
of the European Union

with the ultimate goal to find non-thermodynamic ways to control the magnetic state of media with the lowest possible dissipation and simultaneously at the fastest possible time scale.

1.1.2. RELEVANCE AND TIMELINESS

Half-a-century evolution of information technology has led to a billion-fold growth of the total volume of information that is being in constant movement across the globe. This is not only pushing our current technologies to their limits, but also that of our energy production: currently ICT consumes around 5% of the world electricity production and with an annual increase of 7%, this is rapidly becoming unsustainable. Strong efforts need to be directed to decrease the energy consumption by today's ICT. Therefore, we urgently need to find more efficient ways to generate and store data. Ideally, one would like to replace electron-based electronics with wave-based devices, as electron transport unavoidably leads to Joule losses. In contrast, waves such as light or spin/magnetization waves, move practically without dissipation and moreover offer unprecedented bandwidths. Therefore, photonics is firmly positioned in information technology as the global interconnecting system, whereas recently first steps are made to exploit spin waves. On the smaller device scale, though, the applications are still far away and photonics and magnonics have to build up all of the functional elements available in electronics step by step. The crucial questions are, how and where to find them?

Note that standard digital electronics rely on nonlinearity - that is, a large change in device output caused by a small variation of its input. This nonlinearity allows transistors to act as switches. Waves, unlike electrons, do not interact directly with each other, and thus the switching action is only possible through a significant nonlinearity in the medium with which they interact. However, optical nonlinearities are usually weak and therefore high intensity light is required, consuming again a lot of energy.

What is thus required are media that can control the waves passing through them, and that in turn can be controlled by waves, such as light, with little dissipation of energy and on a very short time scale. These requirements can actually be met by **combining light with magnetic materials**. The fact that magnetization is able to control the polarization and the intensity of light has been known since the 19th century experiments of Faraday and Kerr. That the magnetization itself can also be controlled by light, has recently been demonstrated: experiments showed that with short optical pulses one can rapidly reduce, increase or even create and switch magnetization and excite controlled precessional motion (spin waves). Unlike nonlinear optical processes, that are only small thermodynamic perturbations of optical media, magnetization switching by light works via a non-equilibrium and non-thermodynamic route. Furthermore, some of these processes rely on little or even no dissipation of optical energy, offering a pathway to energy-efficient control of magnetization by light and vice versa.

As a result, in recent years, the manipulation of magnetic order by ultrashort laser pulses has become a fundamentally challenging topic with a potentially high impact for future electronics, data storage and manipulation and quantum computation. Moreover, it has been shown that the laser excitation of magnetic media leads to the excitation of local spin-polarized currents but also nonlocal processes such as laser-induced spin transfer over tens of nanometers, thus linking the optical excitation with magneto-transport. Most excitingly, only over the past few years, combined high spatial- and time-resolved experimental approaches based on fs-X-ray scattering/spectroscopy have become available, potentially providing access to these non-local phenomena on the proper length and time scales.

Understanding the underlying mechanisms, that is, the interaction of photons with charges, spins, and lattice and the angular momentum transfer between them at the ultrafast time scale, is crucial for the further developments and applications in this area. However, a (non-adiabatic) description of magnetism and spin dynamics for non-thermodynamic systems is at present a monumental challenge.

In the research on **magneto-transport**, an important milestone was the discovery of giant magneto-resistance, which is a drastic dependence of electric current on the magnetic state of artificially prepared structures. While this rapidly found applications in magnetic sensors, hard disk read-heads, and created the basis for the first concept of magnetic RAM, even more intriguing was the discovery of various inverse effects. It was demonstrated that electric currents can become spin-polarized, and thus exert forces on the magnetization itself, driving precessional dynamics of spin-torque oscillators, switching magnetization in magnetic layers, and moving domain walls. Moreover, spin-orbit interaction leads to many even more intriguing effects, such as spin-Hall and Rashba effect. These are not only strong enough to switch magnetization without passing an electric current through the magnetic layer itself, but also can lead to magnetic effects in nonmagnetic materials, even without magnetic fields.

These electric- and spin currents are shown to couple to waves, such as THz radiation appearing from transient electric currents, and spin polarization leading to flows of spin-waves, or magnons. In a magnetic dielectric, the flow of magnons represent a pure spin current: transport of magnetization without electronic motion. Using laser pulses to drive transport makes all transients shorter, paving the way towards truly ultrafast 'wavetronics' based on non-equilibrium and non-thermodynamic behaviour.

These exciting discoveries has led to the growth in the number of research groups in both ultrafast dynamics and magneto-transport areas. The interaction between these two research areas has already started, and is driven by the necessities arising from the research itself. Stimulating these interactions by the coordinated efforts of a COST Action will drive the development of this fascinating area towards novel concepts for applications, as well as novel directions for fundamental research.

1.2. OBJECTIVES

1.2.1. RESEARCH COORDINATION OBJECTIVES

The primary goal of MAGNETOFON is to drive and unite the research in the fields of ultrafast all-optical control of magnetic and transport properties of condensed matter systems in the emerging field of Ultrafast Opto-Magneto-Electronics, by filling the gap that exists between the communities of magnetism, photonics and electronic transport phenomena. In particular, MAGNETOFON will

- develop the understanding of the processes that occur in magnetic solids and nanostructures, in response to a non-equilibrium excitation resulting in non-local transport. These processes are very complicated for comprehensive theoretical treatment and are subject of hot debates, that involve the interactions of various subsystems of a solid (electrons, phonons, magnons) with each other as well as with the electromagnetic field of the laser pulse.

- learn to manipulate magnetic order with light pulses, direct as well as through the intermediate action of spin transport. While direct manipulation has been demonstrated, coupling with spin currents opens up novel degrees of freedom for recording and detecting magnetic information.

- coordinate the experimental and theoretical efforts to develop concepts of spin-based information technology elements. Given the complexity of the problem, it is particularly important to promote progress in this area, to assure the success of the programme.

- lead to the development of novel experimental and theoretical tools.

- develop concepts of novel approaches and devices for low-energy processing and storing of information.

1.2.2. CAPACITY-BUILDING OBJECTIVES

The research objectives of the MAGNETOFON Action can only be achieved by combining the existing expertise of the scientific communities dealing with ultrafast magnetism, spintronics, magnonics, photonics and advanced spectroscopy, and by sharing the new knowledge arising from the exchange between them. This Action will result in a considerable leap in the quality and effectiveness of research in Europe, by bridging the existing gaps between these areas. In addition, the Action will:

- provide coordinated training and education in ultrafast opto-magneto-electronics to the European researchers, via workshops, workgroup meetings, short term scientific missions, etc.
- advance the visibility and networking opportunities of Early Career European Investigators working in the area of ultrafast magnetism and spintronics, via the Action website, special sessions on major conferences, and participation in all Action workshops
- advertise the Action in special sessions at international conferences, underlining the possibilities and advantages of participation
- create a platform for fruitful collaboration between the researchers and industrial sectors related to magnetic memories, opto-magnetism, photonics and magnetic materials, via a coordinated dissemination plan
- coordinate research groups in developing and sharing tools and equipment to avoid costly duplication and improve complementarities and synergism on the European scale

- actively seek industrial involvement in the Workgroups, by setting specific valorisation-related deliverables

1.3. PROGRESS BEYOND THE STATE-OF-THE-ART AND INNOVATION POTENTIAL

1.3.1. DESCRIPTION OF THE STATE-OF-THE-ART

The ability to switch magnets between two stable bit states is the main principle of modern data storage technology. Due to many new ideas, originating from fundamental research during the last 50 years, this technology has developed in a breath-taking fashion. Although the move to wireless devices and the increase of cloud storage ensures that in the 21st century's digital economy the demands for denser, faster and more energy efficient data storage will keep growing, the heat produced by modern data centers is already a serious limitation to the increase of their performance. Finding a conceptually new way to control the magnetic state with the lowest possible dissipation and at the fastest time-scale is a new challenge in fundamental and applied magnetism.

Since two metastable states of a magnet have equal entropies and equal energies, according to (quasi-equilibrium) thermodynamics, a switching between these states can be realized with zero production of heat. However, in this case, the switching must be a reversible process which takes an infinitely long time. Hence within thermodynamics, ultrafast and least dissipative magnetic switching seem to be mutually exclusive. Thus, pushing the magnetization dynamics into a non-thermodynamic regime is the key to finding the required ultrafast and non-dissipative pathway.

- One of such pathways was discovered in the ferrimagnetic metallic alloy GdFeCo. It was shown that excitation of the alloy by a single femtosecond (fs) laser pulse brings this ferrimagnet into a strongly non-equilibrium state followed by magnetization reversal. The time-scale of the reversal is defined by the strength of the exchange interaction and is thus the fastest possible for magnetic systems. Such reversal is accompanied by a record low dissipation.
- Next, it has been shown that the impact of a fs laser pulse on a (magnetic) metal leads to the appearance of transient (spin-polarized) super-diffusive currents. These currents can change the magnetization of the material, can excite magnetic precession, and in turn, can generate outgoing waves such as photons in the THz range, or magnons. These phenomena directly indicate the possibilities to create nonlinear elements for wave-based information technologies.
- Most interesting, circularly polarized laser pulses were shown to act as instantaneous effective magnetic field pulses, driving magnetization dynamics and the associated magneto-transport.
- Spin-Hall effect, inverse spin-Hall effect and related effects, are relativistic spin-orbit coupling phenomena that can be used to generate or detect spin currents even in non-magnetic, as well as non-metallic systems. In a dielectric, a spin current is transported by magnons and is not accompanied by any electronic transport, thus cutting the dissipation by orders of magnitude.
- It has also been shown that magnon flows can be directly excited and manipulated with laser pulses. The character of the propagating waves was studied with an ultrafast spin-wave tomography technique, providing the full dispersive characteristics of these waves.
- There are first demonstrations that magneto-optics can be used at the nanoscale, much shorter than the wavelength of light. For such purposes, plasmonic structures are used.

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

Inspired by these results and opportunities MAGNETOFON aims to achieve the least dissipative and fastest possible magnetic switching as well as to spur the development of novel magnetic technologies beyond the limits of equilibrium thermodynamics. Theoretically, this requires solving the time-dependent Schrödinger equation, the complexity of which explodes for any realistic number of particles. As a result, further progress in magnetic technologies towards smaller sizes and shorter time-scales depends crucially on our ability to develop intermediate-level models that can bridge the gap between the failing conventional theories and the unsolvable full quantum mechanical approach. Towards these goals the Action formulates the following research questions at the boundary between ultrafast magnetism and magneto-transport:

- How to reduce the dissipations during femtosecond all-optical magnetic recording in metals? To stabilize a single magnetic bit at room temperature, a magnetic anisotropy energy barrier of 60 k_BT ~ 0.25 aJ (attoJoule, where k_B is the Boltzmann constant and T is the absolute temperature) is taken as by far sufficient. This value would then correspond to the energy which is required to switch the magnetic state. In practice, however, eight orders of magnitude higher energies are used and a lion share of it is subsequently lost via dissipation. Why? How can one improve this?
- Can one employ the principles of ultrafast switching via a strongly non-equilibrium state to control spins in magnetic dielectrics? Demonstrations of all-optical switching of magnetization were achieved almost exclusively in metals. However, switching in these materials is unavoidably accompanied by laser-induced heating of free electrons. If similar mechanisms were possible in magnetic dielectrics, it would drastically decrease the level of dissipation during all-optical magnetic recording. Is it possible to enhance the coupling between radiation and magnetization by employing intrinsic or induced magnetoelectric interactions in a medium?
- Can one invent methods in which all-optical magnetic recording will be assisted by electric fields or currents? Sizes of individual elements in competitive MRAM devices must be of the order of tens of nm. Switching these elements with light requires focusing light into a spot far below the diffraction limit. Alternatively, one can employ a combined action of electric field/current and light. By tuning parameters of the magnetic medium and laser excitation, regimes should be found where the fs laser excitation causes switching only in electrically addressed elements.
- Can the switching via a strongly non-equilibrium state be employed to improve the performance of existing memory devices? One of the main disadvantages of the present MRAM is the large heat dissipation in the device. Can one decrease the total heat dissipation if spin-torque or spin-orbit-torque act on the magnetic layer in a specially prepared strongly non-equilibrium state?
- How fast can magnetic information be read out after a magnet has been switched via a strongly non-equilibrium state? In MRAM devices read-out is mainly done electrically. How fast does the switching via a strongly non-equilibrium state affect transport or electric properties of a medium? What are the dynamics of the detected response?
- How do chiral spin textures in magnetic thin film systems as stabilized by Dzyaloshinskii-Moriya interactions behave when they are driven into a strongly non-equilibrium state by fs laser excitation? Huge spin torques may be anticipated in such non-collinearly aligned magnetic systems which may provide additional scenarios for ultrafast switching and data manipulation.
- Can one use subwavelength focusing of light to achieve a very localized excitation of either super-diffusive hot-electron spin-polarized currents in metals, or a wide-spectrum magnonic flow representing pure spin current in magnetic dielectrics? How to realize this in practice?

These questions call for a multidisciplinary approach of theoreticians, experimentalists and scientists/engineers specialized on the physics of devices. The problem, however, is that until very recently the fields of ultrafast magnetism and spintronics had no overlap and the ideas of strongly non-equilibrium magnetism have been extraneous in the physics of magnetic devices.

The MAGNETOFON Action proposes to address these problems. The ambition of the Action is to initiate a breakthrough in the field of low-dissipative opto-magnetism and femtosecond spintronics with the help of a joint scientific program which brings together presently nearly non-overlapping scientific communities. By training a new generation of scientists at the interface of the involved disciplines, further development of the field will be ensured together with a successful translation of the scientific breakthroughs into innovative solutions in technology.

The **main breakthroughs aimed in the Action** include

- The fastest ever generation and detection of magnetotransport properties will be developed. Efficiency of spintronic devices will be verified up to 10 THz.
- Demonstration of the fastest possible switching (<30 ps) with the lowest possible dissipation (<<10 fJ when normalized to $20 \times 20 \times 10$ nm^3 bit)
- Concepts of new femtosecond laser-assisted memory devices with orders of magnitude lower heat-dissipation than in state-of-the-art memory technologies

- Unique modelling scheme based on the multi-scale approach and incorporating both transport, temperature, laser pulse, current and electric field effects on magnetisation dynamics will be developed and tested on novel MRAM prototypes.
- World-unique experimental techniques to study laser-induced magnetization dynamics in a broad spectral range and high magnetic fields, that will include femtosecond time resolution, advanced spectroscopy from the THz to X-ray range, and thus also useful to study more complicated magnetic structures such as antiferromagnets, that offer intriguing possibilities to replace ferromagnetic materials in *so-called* antiferromagnetic spintronics.
- Precise control of pure spin currents (magnonic flows) in magnetic dielectrics; realization of magnetization control in magneto-electrics and multiferroics.

This is a rather challenging and therefore a high-risk Action which aims to push the borders of femtosecond opto-magnetism to its fundamental limits and demonstrate the proof-of-concept of novel opto-spintronic devices beyond the state-of the-art.

1.3.3. INNOVATION IN TACKLING THE CHALLENGE

The integration of photonics, spintronics and ultrafast magnetism is a long-sought, but still absent fusion. Low loss character of light propagation combined with the non-volatile character of magnetic order may bring revolutionary energy saving concepts. Spin currents generated with the help of laser pulses will serve as an intermediary to amplify the effects of light on magnetism.

Until recently, magneto-transport was well separated from magnetization dynamics. The correlation started with the demonstration of spin-torque effects inducing magnetic precession and switching, albeit in a quasi-equilibrium state. Later, it was shown that the laser-induced magnetization dynamics in metals is also accompanied by (super-diffusive) currents.

Non-thermodynamic processes are the key to the following novel concepts: manipulation of (i) exchange, (ii) spin-orbit and (iii) spin currents on time scales faster than thermodynamic equilibrium can be established, and find ways of fast and efficient control of magnetism.

This Action will create the research environment where two scientific directions will naturally merge, to create a novel area of fundamental research on non-thermodynamic processes in magnetic systems, leading to the development of a novel scientific community and energy-saving applications in ICT.

1.4. ADDED VALUE OF NETWORKING

1.4.1. IN RELATION TO THE CHALLENGE

The scientific challenges require a joint and multidisciplinary approach for the development of this advanced research area. Magneto-transport under non-thermodynamics conditions, and on the same time scale as ultrashort laser pulses, is a multi-parametric problem that cannot be solved in any single laboratory or even within a standard collaboration project. Theory involves multiscale and non-thermodynamic aspects, and thus requires a combination of several approaches, from the electronic structure, through atomistic, to the nano- and macro-scale of realistic devices. The experimental research requires the use of advanced and unique facilities, which can only be used and further developed by sharing and collaboration. Finally, there is a very large diversity in materials design and manufacturing, that affects the dynamics and efficiency. Therefore, the proposed set of technological and scientific goals will only be achieved via successful networking, the ultimate goal of this Action.

There are already large-scale efforts in both the photonics and magnetism communities, directed towards the understanding of ultrafast processes in optically excited non-equilibrium systems. To create truly ultrafast electronics with the lowest possible dissipation calls for a truly interdisciplinary approach and coordination of these efforts, to achieve breakthroughs in various directions. As such, COST Action is uniquely placed to provide support for networks on such scale. In particular, it will provide mobility of researchers, access to large facilities, intensive information exchange, and a whole educational programme for young researchers, that would be impossible under any other type of research networks. Moreover, the open nature of the Action will assure timely income of new partners and ideas, which will be also actively sought by the MAGNETOFON consortium.

1.4.2. IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

While there have been several successful European networks on magnetization dynamics in the past, such as DYNAMICS, ULTRASWITCH, ULTRAMAGNETRON, FANTOMAS, and others, there has never been a coordinated European effort for the development of non-equilibrium magnetism and spintronics, which will unify the research on laser-induced effects with that on magneto-transport.

There are also several conferences dedicated to either ultrafast magnetization dynamics (like Ultrafast Magnetism Conference - UMC), magneto-optics (MORIS), or spintronics (SPIE Spintronics, ICSQIT and many others) - however, they operate in a largely parallel and disconnected manner. The present Action intends to fill this gap by fostering research and organizing regular workshops and conferences in the joint area of non-equilibrium opto-magneto-electronics, using the COST Action instruments of Short Term Scientific Missions, Action Workshops, Training Schools and Focus Groups.

MAGNETOFON will serve to assure the excellence in European fundamental science and provide the concepts for novel energy-neutral approaches in information technology. Given the complexity of the problem, expanding and consolidating the research area is a must to achieve the goals of the Action.

In summary, the topics of MAGNETOFON are of great current interest and need, interactions are appearing but not coordinated. No comparable network or Action is known at this point.

2. IMPACT

2.1. EXPECTED IMPACT

2.1.1. SHORT-TERM AND LONG-TERM SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS

The quest for better, faster, more reliable, and most of all, less energy consuming information technology hardware is one of the most outstanding challenges of ultrafast magnetism and transport. On the short term, the MAGNETOFON Action aims at

- Substantial progress in non-thermodynamic physics achieved.
- Understanding and control of fundamental magnetic interactions demonstrated.
- Novel advanced experimental techniques for ultrafast processes developed.
- Novel theoretical approaches for non-equilibrium and non-thermodynamic behaviour developed.
- Visibility of European researchers improved.
- Education of highly-qualified personnel, having new professional interdisciplinary skills.
- Increased and improved international collaborations between interdisciplinary research groups.
- More rational and efficient use of facilities for experimental and computational research.
- Support development of knowledge-based, green, and competitive European industry.

On the long term, one can expect the development of ultrafast non-thermodynamic and non-equilibrium area of physics, that will lead to new directions of technology, such as ultralow-energy information processing and storage, computation and communication tools that run on the energy that is directly harvested from the environment, etc. As a consequence, many jobs will be created in the high-tech industry, assuring European leadership.

Scientific, industrial, economic and social benefits are thus expected as a result of Action activities. From a scientific point of view, advances on all topics in Section 1.3 will be achieved, whereas a strong positive impact on European research is expected. For industrial applications, the physical concepts, control schemes, algorithms and material database for engineering will be available.

2.2. MEASURES TO MAXIMISE IMPACT

2.2.1. PLAN FOR INVOLVING THE MOST RELEVANT STAKEHOLDERS

The most relevant stakeholders are the scientific communities working on opto-magnetism, photonics and spintronics and all industries connected to ICT; the Action will involve them in a common and coherent programme of research directed towards the development of novel concepts, that includes:

- Training schools

- Short Term Scientific Missions
- General Action workshops
- Specialized sessions at magnetic conferences
- Creation of Focus Groups on specific subjects

To enhance the participation of industries in the Action, their representatives will be involved in the definition of the magnetic systems suitable for their application domain. They will be invited to the conferences and workshops organized by the Action. When defining the plans for the coming period, industry will consult on the possibilities of implementation of the involved processes and techniques.

2.2.2. DISSEMINATION AND/OR EXPLOITATION PLAN

Results of the Action will be disseminated as widely as possible by the following ways:

- **Publications** in peer review scientific journals and on national and international conferences.
- **Intellectual property:** attention will be paid to any potential IP that could emerge from the Action. Any IP issue will be discussed at the MC meetings. Communication among partners and good trust will be the key for successful and efficient handling of IP rights matters.
- **Tutorial review articles** and teaching material on the different aspects of opto-magneto-electronics. This material will be organized into a coherent perspective, intended to help students and researchers entering the field, so that they can more easily join ongoing research. All material will be made available in the Action public website and posted in web servers (such as the ArXiv) for free and Open Access download.
- Posting of working documents, technical and financial reports for the Action Members on the private part of the web site, to facilitate the exchange of information about work in progress.
- Establishment of an e-mail network and a discussion forum for all researchers interested in the activities of the Action. This forum will also help the Action to single out potential new partners.
- **Social networks**, such as a Twitter account dedicated to advertising the on-going activities of the Action. Local funding councils and institutes will be encouraged to follow and re-tweet.
- Publication of information on the Action **website** as well as on the websites of participating organizations. The Action website will contain a common scientific information database, and information on the activities (conferences, schools, workshops, etc.) and the management of the Action. Downloadable materials on Action conferences will be available. Links to related projects and institutions, in a way such that the general public can build a larger view of the opto-magneto-electronics and put it in perspective will be available as well.
- **Annual conferences, workshops and training schools**. Researchers from industrial laboratories will be regularly invited to contribute to these events.
- The Action will organize regular events at **industrial partners** site, that will serve a double purpose: 1) to make industry aware of scientific progress; 2) to make researchers aware of the industry problems - both will help to generate more contacts of academia with industry.
- Annual progress reports, final report, state of the art reports, case study reports.
- Press releases concerning the most important scientific results will be made widely available.

2.3. POTENTIAL FOR INNOVATION VERSUS RISK LEVEL

2.3.1. POTENTIAL FOR SCIENTIFIC, TECHNOLOGICAL AND/OR SOCIOECONOMIC INNOVATION BREAKTHROUGHS

The MAGNETOFON Action will join and coordinate a large number of active and high level research groups which are leaders in one or more fields of the Action. These teams have access to state of the art experimental and computational facilities which will guarantee the research impact of the Action. These platforms will be accessible to all the participants of the Action through the planned interactions. Some teams have highly interdisciplinary know-how and skills which are needed for the success of the targeted applications. The main risk is the dispersion of the participant teams on studies of too many research directions and systems. To counteract, the Action will set several milestones, at least one per Workgroup, to monitor the progress of the Action and to select the most promising and profitable directions. As the result, important steps towards the creation of an innovative, knowledge-based and competitive European industry are made. Moreover, the high added-value of opto-magnetic elements and concepts means that the related industry requires highly qualified people to run the corresponding facilities, with the creation of new professional skills for working within interdisciplinary teams.

3. IMPLEMENTATION

3.1. DESCRIPTION OF THE WORK PLAN

3.1.1. DESCRIPTION OF WORKING GROUPS

The Action duration is 4 years, a period adequate to achieve research results and create solid links among partners. The Action activities will be organized in four Working Groups (WGs). This section outlines the scientific programme of the Action having in mind that other tasks will be defined upon constitution of the WGs and in the time span of the Action.

WG1. All-optical switching/manipulation of magnetization

From the very beginning of research on laser-induced magnetization dynamics, magnetization reversal by light pulses was considered as a holy grail of this research area. However, only recently such all-optical switching of magnetization was reliably demonstrated and understood, in ferrimagnetic metallic alloys and multilayers. It appeared that the specific electronic and magnetic structure of these materials assures a rapid switching of the magnetization by each laser pulse. In contrast, the recent indications of all-optical switching in thin ferromagnetic multilayers, including the industrially relevant FePt and CoPt structures, indicate that a different and not yet understood mechanism must be active.

In each case, the reversal requires a transfer of angular momentum. In ferrimagnets, this appears to be the exchange of the angular momentum between sublattices, possibly assisted by super-diffusive spin transport over nanometer distances. It is of great interest to investigate if one could amplify and shape this transport, for example, in artificial multilayered ferrimagnets, for more efficient switching.

Furthermore, it was suggested that in the process of all-optical switching the optical pulse serves as an ultrafast heat supply only. This raises the question if short current pulses can be used to drive the ultrafast switching as well. Thus, both optically- and electrically-driven dynamics in such multilayers is of high interest. In particular, what is the limit for the optical pulse duration ensuring the magnetization reversal? What is the dynamical response of magnetization to short current pulses, how short should the latter be? The experimental reports on this subject are incomplete and controversial. This WG will consider the generation of ultrafast electrical pump pulses generated optically using photo-electric switches in combination with time-resolved MCD probe pulse measurements.

It has also been shown that polarised laser pulses can be equivalent to short pulses of effective magnetic field, due to inverse opto-magnetic effects. The origin, mechanism, and amplitude of this field are not well understood, particularly in metals, where circular currents can thereby be excited, as shown by early work on plasmas. If one could understand and control these currents, this can also be used for the direct ultrafast control of magnetization.

Apart from these 'external' impacts on magnetic systems, an intriguing possibility is to use light to control the intrinsic magnetic parameters, such as exchange or anisotropy, to achieve switching. The anisotropy barrier makes magnetic bits stable, preventing them from spontaneous switching. This barrier is only ~ 0.25 aJ, which is then also the energy sufficient to switch a bit. In practice, however, eight orders of magnitude more energy is used and the lion share of it is lost via dissipation. To switch a magnetic bit close to the theoretical energy limit is one of the grand challenges of the Action. Moreover, as the exchange interaction is the strongest force in magnetism, direct manipulation of exchange may provide a route to the fastest magnetization switching ever. The Action will thoroughly investigate the possibilities of such a route.

Along these lines, the Workgroup 1 is structured into the following four tasks:

T1.1. All-optical switching in ferrimagnetic alloys and multilayers: To investigate the roles of local exchange-driven angular momentum transfer versus non-local one by super-diffusive currents, and to optimize this transfer for optimal switching
T1.2. All-optical switching based on inverse opto-magnetic effects: To investigate the efficiency of the inverse opto-magnetic effects in thin films and multilayers, and the feasibility of single-pulse switching.

T1.3. Feasibility of switching via the modification of magnetic anisotropy or exchange interaction: To study the possibility to modify the intrinsic magnetic parameters with a laser pulse, and to evaluate the feasibility of magnetic switching via this modification
T1.4. Magnetization reversal in thin film and multilayer ferrimagnets driven by current pulses: To investigate the possibility to use short electric pulses to switch the magnetization

Major deliverables:

D1.1. Report on optimized multi-layered structure for switching, acceptable by industrial standards
D1.2. Report on switching feasibility via the inverse Faraday effect in metals
D1.3. Report on possibilities of switching via the modification of exchange or anisotropy in metals
D1.4. Introductory course on all-optical switching of magnetization
D1.5 Report on knowledge transfer to industry and industrial feasibility of all-optical switching in metals

Milestone MS1: Feasibility of single-shot switching based on inverse opto-magnetic effects

WG2. Optics of spin currents

Recent developments in fundamental research and technological applications led to the concept of Spin Transfer Torque MRAM (STT-MRAM). In such devices, the magnetization of the ferromagnetic storage layer is switched using nanosecond spin-polarized electron pulses only. The electron spin exerts a torque on the magnetic storage layer and leads to a switching time of nanoseconds (i.e MHz frequencies). The ever-increasing amount of data exchange requires a further acceleration of the switching. A promising route is provided by ultra-short femtosecond pulses of spin-polarized electrons. Indeed, optically generated spin currents may serve as a direct stimulus to manipulate the magnetic order; recent research has shown the generation of such non-equilibrium spin currents upon the excitation of magnetic media with fs laser pulses. The challenges to efficiently generate such spin currents and to detect them can be solved with THz techniques. Moreover, pioneering works have shown signatures of ultrafast STT on ferromagnetic layers by optically generated pulsed spin currents. Tuning and optimizing the properties of the magnetic storage layer could accelerate the magnetization dynamics to the 100 GHz-THz range, by using for instance rare-earth / transition metal alloys.

In addition to the STT effects, driven by the exchange interaction between the injected spins and the magnetic host, spin-orbit effects could excite spin currents in dielectric materials, create spin polarization in a nonmagnetic metal, or detect spin currents electronically. Moreover, they also lead to very specific effects in THz radiation, directly coupling the outgoing wave with the transient currents.

Along these lines, the Workgroup 2 is structured into the following four tasks:

T2.1. Generation of controlled hot electrons using fast laser excitation in engineered multilayers: To study the conversion efficiency of photons to hot electrons as well as the energy, the density and the polarisation of hot electrons generated by short laser pulses
T2.2. Magnetization switching with hot electrons: To study the feasibility and efficiency of single-pulse switching via hot-electron transport, exploring different structures to increase switching frequencies
T2.3. Laser-driven spin-orbitronics: To study the spin-orbit interaction induced effects on laser-driven ballistic and superdiffusive currents.
T2.4. THz control and detection of spin currents: To develop techniques and study the spin current behaviour at THz frequencies

Major deliverables:

D2.1 Report on optimized generation and transport of hot electrons in multilayers
D2.2 Report on the laser-driven spin-orbit effects
D2.3 Report on feasibility of switching via hot electrons, via both STT and spin-orbit effects
D2.4 Course on THz radiation techniques
D2.5 Report on knowledge transfer to industry and industrial feasibility of switching by spin currents

Milestone MS2: Demonstration of switching with super-diffusive hot electron currents

WG3. Ultrafast magneto-electrics

In laser-induced magnetization dynamics in metals, a major part of the pulse energy is transferred, via the conduction electrons, to the thermal bath. Though in some cases this thermal energy is essential to trigger the dynamics or switching, it is unavoidably lost via dissipation. To significantly reduce these losses, transparent magnetic dielectrics are a viable approach. Without thermal 'screening' by the free electrons, other, non-thermal, effects become important, such as modification of magneto-crystalline anisotropy by charge transfer, magnetic dynamics triggered via the inverse Faraday effect, or direct manipulation of magnetic exchange interactions. While some of these effects, such as photomagnetic anisotropy, do require moderate absorption, this does not result in a direct increase of thermal energy.

Therefore, transparent magnetic dielectrics represent the most viable materials for low-dissipation magnetic switching. This was recently confirmed by single-pulse switching in magnetic garnets with a record low energy loss. This WG will investigate various mechanisms of laser control of magnetization in magnetic dielectrics. Along with conventional magnetically-ordered media, the Action will also attempt to realize the optical switching in multiferroics, where multiple types of ordering coexist, and particularly those where magnetism and ferroelectricity are strongly coupled to each other.

In the optical and near IR spectral range the interaction of ultrashort laser pulses with a medium is governed by the electric-dipole transitions, while the magnetic field of the electromagnetic wave remains “silent”. The natural idea to employ multiferroics as media in which coupling of the electric field to the magnetization is built in, has not yet resulted in optically-driven switching of magnetization. Thus, it is still unclear if the magneto-electric interactions could effectively enhance coupling of magnetization to light and facilitate the all-optical control of a magnetic state.

The situation changes drastically, when one employs pulses in the THz range. Here both resonant and off-resonant interaction of the magnetic field component of the pulse with a medium becomes efficient, which has already been used for driving magnetization dynamics in various media. Recently it was also shown that the electric field of a THz pulse can trigger magnetization dynamics as well via modification of the magnetic anisotropy. This Action will take advantage of both the electric and magnetic fields of the picosecond THz pulses to manipulate the magnetization.

There are two basic approaches to enhance the response of the magnetization to picosecond THz pulses. First, the Action will focus on media with low symmetry that allow for linear magneto-electric coupling, as well as composite magneto-electrics, and those supporting electromagnons, i.e. coupled electric- and magnetic-dipole excitations.

Second, even in media with high symmetry a number of phenomena are allowed, which can be driven concommittantly by the electric and magnetic fields of the THz pulses. In other words, the symmetry in this case is broken dynamically. This also includes inverse magneto-optical effects, the manifestation of which in the THz range is yet to be found.

This WP will include the following four tasks:

T3.1 Inverse opto-magnetic effects and crystal symmetry: To study the symmetry properties of opto-magnetic effects, their polarization and spectroscopic dependencies, including light-induced modifications of the symmetry
*T3.2 Modification of key magnetic parameters: exchange and magneto-crystalline anisotrop*y: To search for the microscopic mechanisms that allow such manipulation
T3.3 All-optical switching in magnetic and multiferroic dielectrics: To investigate and summarize various mechanisms that may lead to a single optical pulse magnetic recording in dielectrics
T3.4 Dynamics in magneto-electrics and multiferroics driven by short THz pulses: To separate the effects of electric and magnetic fields of intense THz radiation on the magnetization in dielectrics

Major deliverables:

D3.1 Classification of inverse opto-magnetic effects for different symmetry classes
D3.2 Report on ultrafast magneto-electric coupling in multiferroics and magneto-electric media
D3.3 Report on feasibility and mechanisms of switching in magnetic and multiferroic dielectrics
D3.4 Material for summer school on multiferroics
D3.5 Report on knowledge transfer to industry and industrial feasibility of multiferroics

Milestone MS3: Demonstration of switching with single-cycle THz pulses

WG4. Ultrafast opto-magnonics

Spin-polarized currents in metals are not the only way for magnetic transport. As a proof, spin currents exist in dielectrics as well, where the angular momentum is transported by spin waves, or magnons. Analogous to electric currents, magnonic currents can be used to encode, transport and process information. A magnonic current has advantages over the conventional (spin-polarized) electronic current as it does not involve the motion of electrons and thus it is free from Joule heat dissipation.

Present research in ‘magnonics’ focuses on electronically driven GHz functionality in lateral micro- and nanostructures. An entirely new area will open up if spin-waves and other quasiparticles can be generated and manipulated using fs optical pulses. In short, this will include most of the opto-magnonics, magneto-plasmonics, and magneto-acoustics, plus various magneto-acoustic and magneto-plasmonic resonances. Opto-magnetism provides great flexibility to excite spin waves and tune their parameters. By combining various opto- and photo-magnetic phenomena one can control amplitude, initial phase and, possibly, frequency of the excited spin precession. Furthermore, proper spatial shaping of the laser spot allows to control the emission of the spin waves.

As magnons are waves, magnon logic circuits, similar to those developed in nanophotonics, can be envisaged, but based on waves with completely different dispersion behaviour. This may thus result in different functionalities. Magnonic currents can be generated and detected optically, both in a coherent way in stroboscopic pump-probe schemes, and incoherently using inelastic light scattering techniques. By fs optical excitation, magnonics can be pushed to the THz domain. Implementation in multilayered magnetic devices provides a unique way towards 3-dimensional reconfigurable magnonics.

The workgroup will be organized along the following four tasks:

T4.1 Optical shaping of magnonic currents: To realize optical control of wave vectors and wave fronts of excited magnons; to investigate options for sub-wavelength magnonics
T4.2 Electric excitation and detection of optically-driven magnonic currents: To study short time scale behaviour of spin-torque transfer, spin-Hall effect, etc., via electric pulses.
T4.3 Magnonic crystals and reconfigurable magnonic devices: To use engineered structures for optimization of magnon excitation, propagation and focusing.
T4.4 Magnonic currents generated in metals via all-optical switching: To study the interaction of magnonic currents with the electronic system in metals at the ultrashort time scale.

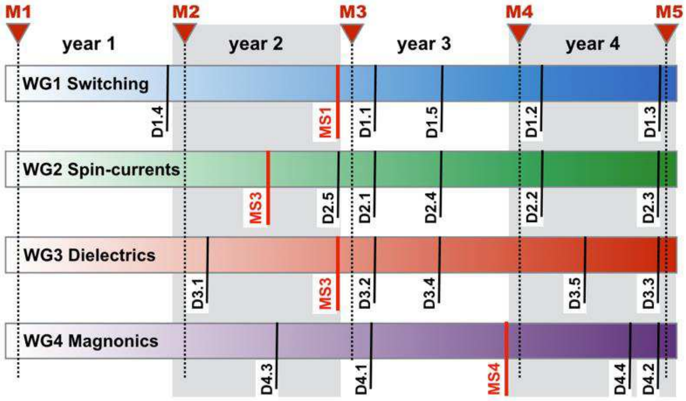
Major deliverables:

D4.1 Report on focusing limits of magnonic spin currents
D4.2 Report on proposed magnonic applications and on their industrial feasibilities
D4.3 Summer school on magnonics
D4.4 Report on knowledge transfer to industry and industrial feasibility of magnonics

Milestone MS4: Demonstration of and a feasibility report on ultrafast magnonic logic

3.1.2. GANTT DIAGRAM

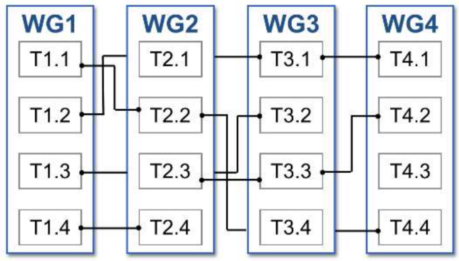
The GANTT diagram, including Action Workshops with MC meetings (M1-M5), determining the flow, deliverables and milestones of the Action, begins with the Kick-off meeting (M1), followed by other meetings every six months, where management and technical issues will be discussed. When required, additional technical and Core Group meetings will be organized as video-conferences.



All research tasks will be carried out in parallel and many participants will participate in several WGs. The Action work plan will ensure the maximum exchange of information between the research groups developing the different tasks. The Action will also actively seek new partners, therefore the work plan will also be flexible in order to allow the inclusion of new participants and unforeseen activities.

3.1.3. PERT CHART (OPTIONAL)

The strength of the MAGNETOFON organization is that while the Workgroups have well-defined topics, there is still a substantive overlap between various tasks defined within the Workgroups. This creates an ideal condition for interactions between the involved research groups and organizations and assures better coordination of research tasks.



3.1.4. RISK AND CONTINGENCY PLANS

MAGNETOFON is a highly synergetic and multidisciplinary Action, and successful completion of its overall vision, i.e., bringing the fields of photonics, spintronics, and ultrafast magnetism together to form a common research field with the final aim to develop novel, energy efficient ways to create and store data, will depend crucially on forming bridges between these research fields and simultaneously overcoming all research challenges. If successful this will lead to ground-breaking new and green ICT technology. This makes MAGNETOFON a high-risk, high-gain effort. Inherent risk mitigation is achieved by the low to medium risk levels of the separate Tasks, as defined in the Workplan.

Detailed Risk and Contingency plans

R1 (WG1-4) A main risk in the Action is the dispersion of the efforts of the many teams involved, due to the large number of possible research directions and systems. To avoid this, few systems will be defined during the kick-off meeting and Deliverables and Milestones are set for the individual WG's.

R2 (WG1) Failure to achieve low-power switching is assessed as a 'medium' risk. All-optical switching has been shown already in ferrimagnetic alloys but needs to be demonstrated in more industrially relevant metallic multi-layer structures. This is obviously more challenging. The risk mitigation is to use higher laser power and to vary the laser wavelength, to find the most efficient light-matter conditions.

R3 (WG2) Failure to achieve switching by super-diffusive currents is assessed as 'low'. The existence of these currents, generated by fs laser excitation of metallic multilayers, has been demonstrated, as has the switching of magnetization by spin-polarized currents. The combination of these effects is expected to work, though not yet demonstrated. The overall risk mitigation includes the further exploration of photonics-assisted switching, using a combination of laser and magnetic field.

R4 (WG3) Failure of observing switching of multiferroics by THz pulses is seen as a medium to low risk, as all-optical switching by near infrared pulses has already been observed in dielectrics. The risk mitigation is straightforward, shift the excitation wavelength to shorter, thus higher energy, photons. In addition, the Action will look for optimized material combinations.

R5 (WG4) Failure to demonstrate magnetic logic, that is, the manipulation/switching of one spin signal by another is not likely, as first steps in this direction look promising. However, besides individual components as generation and detection of magnonic signals, real logic still has to be demonstrated. The risk mitigation is via the optimization of the materials and laser pulse parameters.

R6 (WG1-4) No agreement between theory/modeling and experiments (high). While parameters and models for photonics and electronics are well-known, the magnetic components will be based on novel materials for which the physics of light-matter interaction is largely unknown, therefore the high risk. The risk mitigation strategy is to rely on experimental data and use empirical approaches.

R7 (WG1-4) The last risk is related to the transfer of the accumulated knowledge to industries (medium). Depending on the complexity of the involved processes and their cost, this transfer may not be as easy as expected. This is why, when it will be possible, the Management Committee will associate, as much as possible, the industry representatives with the choice of the systems.

3.2. MANAGEMENT STRUCTURES AND PROCEDURES

The MAGNETOFON Action will be coordinated by a Management Committee (MC) as described in the Rules and Procedures for Action Management of COST Actions. The Action will organize a kick-off meeting to which all members will be invited. The Chair and the Vice-Chair will be elected at the kick-off. Also, Scientific Coordinators for the WGs, the Short Term Scientific Missions (STSM) Manager and the web site team will be appointed. Chair, Vice-Chair, Scientific Coordinators and STMS Manager will constitute the Core Group of the Action, assuring efficient, flexible coordination. Strategic evolution of the Action will be discussed in the Core Group and then proposed for validation to the MC. The Core Group will prepare the various documents (scientific, financial etc.) for the MC meetings. At the MC meetings, the Tasks described in the WGs will be discussed and updated, if necessary.

The Action will develop and implement a dedicated plan to promote the full involvement of ITC representatives in all aspects of the Action's implementation, also including them in the Action leadership positions, such as Scientific Coordinators and co-Coordinators of the WGs. A special attention will be put on the level of involvement of Early Career Investigators. To comply with the COST Excellence and Inclusiveness Policy with respect to ECIs, the Action will develop and implement a plan to promote the full involvement of ECIs in all aspects of the Action's implementation (including in Action leadership positions).

Because the gender balance is rather poor in the scientific areas covered by the Action, a dedicated plan will be developed and implemented to promote gender balance in all aspects of the Action's implementation, including in Action leadership positions. The issues related to gender balance will be discussed at each MC meeting, and a special position of gender balance coordinator will be created to keep track of both progress and problems in this important area.

Meetings of the MC will be included in the annual Action conferences. These meetings will tackle all strategic issues and opportunities for the Action, such as supervising and coordinating the efforts of the WGs, suggesting and approving new WGs, as well as changing directions or closing down existing WGs depending on new opportunities for the Action. A major issue will be the organization of the next Action conferences. Organizational details of approved STSMs will be fixed. Ways to improve the tools for internal communication and external contacts will continuously be discussed.

The Action tools to implement coordination of research comprise STMSs, Annual Conferences, Workshops, Summer Schools and the Action website. At the Annual Conferences and associated MC meetings, the Action progress will be thoroughly reviewed and plans for the coming period adjusted.

The website team will create and maintain a website in accordance with COST office requirements. This interactive web site will contain information about partner groups (topics of research and skills) research activities (Highlight section, presenting major scientific breakthroughs), conferences and workshops, list of potential host groups for short visits or training, forthcoming activities, device or sample exchange. It will provide the agenda and minutes of each MC meeting, and include annual, cumulative and final reports.

Budget will be allocated for STSMs between the participating research groups. A motivation and a simple plan should be submitted to the STSM Manager, who will present the current applications of the highest quality to the MC. Depending on the available budget, the MC will decide which applications should be granted. The MC is responsible for gender- and geographical balance in the distribution of travel reimbursements. Priority to the applications of ECIs and those coming from ITCs will be given in the STSM selection process.

The organization of Training Schools and Workshops will be coordinated by the MC with the help of the WG coordinators. These will be widely announced in order to reach the largest possible panel of scientists from different disciplines.

Although successful collaborations do require face-to-face meetings and imply a great deal of travelling, the MC will undertake all possible initiatives to limit the environmental impact of the Action. This will include the intensive use of video or web conferences, as well as careful adjustments to collocate meetings with other scientific events related to the field of research of the Action. In that respect, the ratio of productivity over environmental impact is particularly favourable to the STSMs.

Scientific reports will be compiled annually by the WG coordinators. On this basis, the Chair will compile the annual Action Progress Reports and present some of the highlights to the MC during its annual meeting. This report will form the basis for the evaluation of achieved objectives and possible reevaluation of future targets proposed at the MC meeting. The website will be used to inform the scientific community about the progress of the Action internally and externally.

3.3. NETWORK AS A WHOLE

At the time of the proposal of this Action the network of the MAGNETOFON included 19 COST Countries, of which 8 are Inclusiveness Target Countries, and 3 Near Neighbour Countries (NNC) with total 33 institutions representing a wide international interest in the issues dealt by MAGNETOFON. This includes 3 industrial partners and 30% Early Career Investigators. The proposers were selected to guarantee a long-lasting impact on not only European research, but also world-wide. The proposers have authored a significant number of books, journal and conference papers and combine expertise in ultrafast photonics, nano-magnetism, and magneto-transport. The proposers are also in close cooperation with other industrial partners. Using these relations, the impact of MAGNETOFON outside the academic area will be guaranteed. Partners from NNCs will support the Action by providing valuable scientific contributions and being active in dissemination of the Action results within their countries.