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

Brussels, 22 November 2013

COST 077/13

MEMORANDUM OF UNDERSTANDING

Subject : Memorandum of Understanding for the implementation of a European Concerted Research Action designated as COST Action MP1308: Towards Oxide-Based Electronics (TO-BE)

Delegations will find attached the Memorandum of Understanding for COST Action MP1308 as approved by the COST Committee of Senior Officials (CSO) at its 188th meeting on 14 November 2013.

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

COST Action MP1308
TOWARDS OXIDE-BASED ELECTRONICS (TO-BE)

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 4114/13 “COST Action Management” and document COST 4112/13 “Rules for Participation in and Implementation of COST Activities” , or in any new document amending or replacing them, the contents of which the Parties are fully aware of.

2. The main objective of the Action is to network active researches on the applications of transition metal oxides in the fields of nanolectronics, microactuation/microsensing and macroelectronics and to disseminate knowledge about their potential to external stakeholders.

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 EUR 68 million in 2013 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 4 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 section *2. Changes to a COST Action* in the document COST 4114/13.

A. ABSTRACT AND KEYWORDS

Transition-metal-oxide-based films and heterostructures are at the core next-generation nanoelectronic, microelectromechanical and macroelectronic devices expected to revolutionize fields of major social relevance as digital information and communication technologies, microactuation/microsensing and energy conversion. Such class of materials is characterized by an unprecedented wealth of functionalities, often being relevant to different fields of application, found in compounds that are extremely similar to each other in terms of chemistry, crystal structure and fundamental mechanisms. The necessity to handle the unprecedented complexity of these materials rescales efforts of solid state scientists to a higher level and poses challenges that no individual Institution or Nations can face.

The approach of the Action is based on the belief that fundamental and technological unsolved issues lie on grounds that are common to all transition metal oxides. The know-how progress should therefore not be addressed independently by separate communities concentrating on understanding single phenomena or exploiting single functionalities, but resorting, in view of the above mentioned similarities, to a thoroughly multidisciplinary approach.

The TO-BE Action will network nationally- and EU-funded researches active on synthesis, analysis, modelling and applications of transition metal oxides within the European Research Area (ERA), allowing to: define targets, strategies and methods; reduce fragmentation; aggregate communities with complementary know-how; attract and train a new generation of researchers; establish a regular know-how transfer with private corporations and other stakeholders; built the future oxide electronics community by fostering the participation of early stage researchers and tackling gender unbalance. The success of the Action will strengthen the innovative capacity of EU industry by making qualitatively new enabling technologies accessible for commercial exploitation.

Keywords: Multifunctional oxide materials, films and heterostructures,nanoelectronics, microelectromechanical systems, macroelectronics.

B. BACKGROUND

B.1 General background

The Action addresses the science and technology of transitions metal oxides (TMO), intended as core materials for next-generation nanoelectronic, microelectromechanical and macroelectronic devices, expected to revolutionize digital Information and Communication Technology (ICT), microactuation/microsensing and energy conversion.

The TO-BE Action is based on the belief that *this* is the timely moment for pushing the European TMO R&D community to shift from a purely bottom-up, curiosity-driven phase and to open a novel, scientifically and technologically mature phase of its activity, by increasing:

a) *at an Action internal level*: networking of expertise, coordination of research activities and the degree of attention to critical issues as gender balance and career development of ESRs.

b) *at an Action external level*: the visibility of the community towards the industrial sector (both SME and transnational corporations), public Entities, policy makers, mass and social media, the wider scientific community and the general public.

B.1.1: Transition metal oxides: complexity, differences and similarities

Mastering the complexity of TMO materials requires an unprecedented joint effort of theorists, experimentalists and materials scientists. These materials are in fact among the most complex in inorganic chemistry. The multiple interaction between lattice (strain, phonons, rotations of the perovskite octahedra) and electronic (charge, orbital, spin) degrees of freedom leads to intricate but unique phase diagrams. The community spontaneously self-assembled around this field of research, currently meeting only in dedicated conferences, is probably among **the most interdisciplinary communities** active in science today, since it includes scientists from **complementary fields** such as materials science, surface science, film and crystal synthesis, defect chemistry, ab-initio quantum chemistry, microscopic many-body theories , magnetism (intended in a broader sense), ferro/piezoelectricity, superconductivity, quantum transport, optics, synchrotron-light-based or free-electron-laser-based spectroscopies, nanofabrication, device design, device engineering and device testing, just to quote a few. Providing coordination at EU level to this community and extracting from its “collective knowledge” a global vision of the field and a roadmap to be pursued, both in terms of fundamental science and of application, is one of the aims of the TO-BE Action.

The activity of single research groups is often focussed on one single functional property, among the many that are shown within the TMO family and that are - partially - listed in section B2. Since the properties are highly diverse, and pertain to very different fields of science and to different applications, the individual groups typically have different backgrounds and little contact to each other. Nevertheless, the basic ingredients that are needed to address both fundamental and technological properties within this class of compounds are typically the same, whether the system is, e.g., a cuprate-based superconductor, a manganite-based half metal, a titanate-based ferroelectric, or other.

In terms for example of fundamental understanding, the ground state and the excitation spectra are typically determined by a number of **quite universal ingredients,** as electron correlation in narrow d-type bands, interaction of charge, spin and orbital degrees of freedom, point defects (e.g., oxygen vacancies), static or dynamic lattice deformations (induced e.g. by strain or phonons), deformation and rotations of the oxygen octahedra (in perovskite-related compounds). As a consequence, the theoretical approaches employed to address these systems, whether they are based on ab-initio on computations, microscopic many-body theories or phenomenological approaches, remains pretty similar for all systems.

The **similarity of the approaches** is even more striking when materials science, synthesis and technological aspects are considered. In particular, the main hurdles that hamper the implementation of commercial applications are universal to the whole class of compounds and their solution, due to the major physical/chemical/crystallographic similarities, will be universal as well. The hurdles to be overcome include: difficulties concerning the growth of epitaxial TMO films on Si or on other cheap industrial substrates; difficulties concerning the scalability of film growth techniques to large areas (the typical technique employed in research laboratories for oxide thin film growth, i.e. pulsed laser deposition, is almost unknown to industry); need for cost reduction of the synthesis process; difficulty in applying nanolithographic techniques typical of the micro/nano-electronic industry, limited stability of surfaces in ambient conditions; last but least, **"cultural mismatch"** between industry (that employs as personnel experts of Si-based technologies and is therefore intrinsically conservative towards totally novel concepts) and researchers of the TMO community (that are sometimes not fully aware of real industrial needs).

As shown above, the whole wide field of R&D addressed within the TO-BE project presents a number of global challenges that rescale the experimental, technological, theoretical and dissemination effort to a higher level that cannot be faced within individual research activities, or by individual Institutions. The presence of a network and of a global coordination support action directed by a wide and highly qualified experts group, flanking the wide number of individual researches based on National or EU funded projects and aiming at single scientific and technological objectives, will allow to pursue a number of targets that are of fundamental importance and could otherwise never be addressed.

B.1.2: Why a Cost Action

A COST Action is the only appropriate instrument to attain the above mentioned changing of paradigm and the above mentioned multidisciplinary approach. This will appear very clear in next sections, where the practical implementation of the Action is proposed. The breadth of the addressed field of research, the scale of the participants team (17 nations, over 30 institutions), the overall size of the involved research budget and the long-term nature of our targets make this Action unsuitable to be pursued under single research-funding programmes. The TO-BE Action will be complementary to the national and EU funded research programmes operating in this field as it will develop as an Umbrella Organization providing coordination and strategies for this field of research within the European Research Area (ERA).

B.2 Current state of knowledge

B.2.1: From silicon to complex materials

Si-based technologies have driven the technological race during the last half-century. Si is synthesized and manufactured at reduced costs, is abundant in nature, well understood, simple and versatile. It possesses remarkable functional properties both in its pure elemental form (e.g. p-n-dopable semiconductor for metallic channels and junctions) and in oxide form (e.g. wide-bandgap barrier, piezoelectric). Its technology can benefit today of decades of previous improvements and investments. In spite of the extraordinary success of this material, international technology roadmaps point to qualitatively new concepts and functionalities that the ”simple” physics and chemistry of Si cannot support.

Transition-metal oxides (TMOs) form a vast and highly diverse family of compounds recognized for their stunningly rich physics and for their potential as next-generation nano-, micro, and macroelectronic materials. Research on TMOs was boosted in the last 25 years by a number of successive discoveries performed on materials that are members of this class. Such discoveries have attracted a wider and wider number of scientists gathering from a wide number of different disciplines, and include High Tc superconductivity, colossal magnetoresistance, half-metallic behaviour, record-high dielectric/ferroelectric/piezoelectric performances, multiferroic behaviour, resistive switching behaviour, giant thermoelectric and magnetocaloric effects, giant photoconductivity effects, giant ionic conduction, catalytic properties (including water splitting), field-induced Mott transitions, topologically nontrivial behaviour, and so on. Due to the intrinsic chemical and crystal similarities, TMOs can be stacked in multilayer heterostructures exhibiting an astonishing degree of epitaxial perfection. Such artificial systems not only allow to combine in a single device the functionalities of their individual layers, but often reveal an even wider range of emergent novel properties, like formation of high mobility 2D electron gases (or “liquids”) at the interface of insulating oxides, that can be surprisingly different from those of the single building blocks.

In spite of such huge potential, that was been also recently recognised in the 2011 and 2012 ITRS (International Technology Roadmap for Semiconductors) documents, a number of hurdles still obstruct the path towards the development of marketable applications. Trying addressing separately each of the above cited extraordinary properties is a limiting approach. The TO-BE Action will allow to address a global vision of the problem, identifying the fundamental challenges to be addresses for a long term development of the field and the initiatives to be taken in order to promote the commercial diffusion in the middle term of novel device concepts.

B.2.2: Current open challenges in fundamental understanding

The physics and chemistry of transition metal oxides is intimately connected to a number of fundamental common aspects, as strong electron-electron coupling, multiple interacting electronic and lattice degrees of freedom, metal to Mott-insulator transitions, tunable ordered-disordered phases, nanoscale inhomogeneities. Current present knowledge in this field it too vast to be summarized. A list of current and next-future trends in fundamental science relevant to the realm of the TMOs and TMO-based heterostructures would include:

a) Attempts to generate high critical temperature superconductivity, like that in the cuprates, by mimicking a strongly interacting single-band electronic system in proximity to an antiferromagnetic Mott insulator by synthesizing, for instance, layered nickelates or iridates.

b) Research in TMO materials where strong spin-orbit coupling occurs, as 4d and 5d systems. The coexistence with strong electron-electron interaction opens novel opportunities towards the achievement of correlated topological phases of matter.

c) Understanding the complex entanglement of the spin and orbital degrees of freedom and, more generally, the intrinsic multi-orbital nature of the electronic states controlling the low energy physical behaviour of oxides materials.

d) Understanding and exploiting the orbital degree of freedom, an interesting and peculiar ingredient of the TMO physics, opening the way of novel electronics concepts (orbitronic).

e) Understanding to address real systems, where defect chemistry plays a fundamental role, rather than perfect systems that, though simpler to model, might not reproduce the properties of real samples.

f) Understanding and exploiting the properties of heterostructures, where *all the above issues* are present at the same time and entangled. The reduction of the dimensionality, the explicit breaking of inversion symmetry, the epitaxial strain generated by lattice mismatch typically drives a interface spin, charge and/or orbital reconstructions that can lead in turn to new forms of orderings, metal-insulator transitions, unconventional superconductivity and multiferroicity, quantum-Hall and spin-Hall phenomena, novel electronic-thermal transport properties, and so on.

B.2.3: Current state of oxide-based technologies in electronics.

Transition metal oxides have a wide variety of applications in the electronic industry, together with the sister family of rare earth oxides, exhibiting a simpler physics. Several programmes of the 6th FP and some early programmes of the 7th FP have been focusing in fact on rare earth oxides, e.g. as high-k dielectrics, and on the simplest applications of TMO, typically piezoelectric sensors and transducers based on bulk sintered ceramics of lead zirconate-titanate, PZT, or similar compounds. Ferroelectric materials like PZT are also used in a non-volatile memory (ferroelectric RAM, FeRAM) offering lower power consumption and higher operation speed than flash memories, but a higher manufacturing cost and partially unsolved open compatibility issues with Si-based. Several ceramic TMOs with high oxygen-ion conductivity (such as Y-stabilized ZrO_2 or $LaGaO_3$) are also used as electrolytes in solid oxide fuel cells (SOFC). Ceramic $La_{1-x}Sr_xMnO_3$ is a common cathode material for SOFC. Binary and ternary TMOs have been introduced as ultrahigh-k gate oxides that can overcome downscaling limits of the Complementary metal–oxide–semiconductor (CMOS) technology, if thermodynamic stability issues with Si appearing in the materials processing phase can be solved. TMO thin film (WO_3, MoO_3) are used as optical coatings in electrochromic devices (such as “smart windows”) where they change their transmittance upon insertion or extraction of electrical charge. The market of these devices is still limited to niche applications (mainly in automotive technology) due to high manufacturing costs. Redox-based resistive switching in TMOs (as TiO_2, NiO, doped $SrTiO_3$, $Pr_{1-x}Ca_xMnO_3$), a is under the attention of industry for next-generation of non-volatile memories (resistive RAM) and for the implementation of a new electronic circuit element, the memristor. The whole separate field of cuprate supercondutors holds promise of a wide variety of low temperature applications, that are not the core of the technological efforts of this Action and are therefore omitted for brevity.

B.2.4: The TO-BE Action approach

The TO-BE Action proposes TMOs as future leading electronic materials. It aims at demonstrating their potential for the needs of the nano- micro and macroelectronic industry and, in the long term, for the satisfaction of social needs.

The approach fostered within the Action is based on the belief that fundamental and technological unsolved issues lie on grounds that are common to all transition metal oxides. The advancements of knowledge and know-how should therefore not be addressed independently by separate communities concentrating on understanding single phenomena or exploiting single functionalities, but resorting, in view of the similarities in the physical, chemical and materials science "bricks" at the base of this class of compounds, to a multidisciplinary global approach. The specific scientific and technological aspects that identify of our Action plan are reported in sections C and D.

B.3 Reasons for the Action

B.3.1 Expected benefits for the formation of a Network of Experts

The approach to the advancement of knowledge and technology of TMO described in the former sections call, as a first step, for the formation of a wide diffused EU Network of Scientists sharing common knowledge about the fundamental features of TMOs but also complementary expertise on different fabrication methods, different characterization methods, different modelling methods, different functional properties, different fields of application and different device concepts. The TO-BE Action will coordinate this Network of Experts both acting within this community (i.e., giving targets to the research and assigning roles) and outside the community (i.e., dissemination information to external stakeholders). The benefits of the TO-BE Action should be searched in its capacity to foster in the short-medium term the EU scientific/technological advance.

The success of the Action will strengthen the innovative capacity of EU industry by making novel enabling technologies accessible for industrial exploitation and eventually changing the global industrial landscape in this area. An impact on the economic/societal needs is envisaged in the long term and can be seen as the ultimate aim of the project. Nevertheless, no evaluation of this second impact will be reasonably possible on the time scale of the project itself. The potential of the TO-BE Action should be assessed therefore in scientific/technological terms, on the base of the objectives, the methods and the organization plan proposed in next sections.

B.4 Complementarity with other research programmes

The burst of new research initiatives in the field of TMOs is clearly demonstrated by the current investments made in technologically advanced nations as EU countries, US and Japan. We briefly analyse below these programmes, and, in the case of EU programmes, the complementary aspects with respect to this Action.

B.4.1 Current EU Programmes

Two COST Actions are presently active on fields showing a minor overlap with TO-BE.

- COST Action MP0904 "*Single and Multiphase Ferroics and Multiferroics With Restricted Geometries*" (SIMUFER), 2010-2014
- COST Action MP1201 "*Nanoscale Superconductivity: Novel Functionalities through Optimized Confinement of Condensate and Fields*" (NanoSC)

The very partial similarities only regard the fundamental understanding aspects. They lie in the fact that, while no one of these COST Actions identifies TMOs as the class of investigated materials, both are based on addressing functionalities, as (multi) ferroicity and superconductivity, that are found (also) in TMOs and for which TMOs play an important role. There is no overlap in the approach to the problem, that is obviously complementary.

There are various EU research-funding programmes granted within FP7 that are related to the thematic area of the TMOs.

- FP7-ENERGY FET – "*Novel Composite Oxides by Combinatorial Material Synthesis for Next Generation All-Oxide-Photovoltaics*" ALLOXIDEPV
- FP7-NMP – "*Multiscale Modelling of Femtosecond Spin Dynamics*" FEMTOSPIN
- FP7-NMP Large-scale IP "*Interfacing Oxides*" IFOX
- ERC Sinergy Grant – "*Frontiers in Quantum Materials Control*" Q-MAC
- ERC Advanced Grants "*Perfectly interfaced nanomaterials for next generation oxide electronics*".

These programmes also focus on single aspects, as oxide-based photovoltaics, ultrafast spin dynamics, interfaces and high temperature superconductivity.

A slightly different case is given by the FP7 RegPot programme – "*Multifunctional advanced materials and nanoscale phenomena*" MAMA, that is partially centred on TMOs as part of the wider class of multifunctional advanced materials. MAMA mainly funds personnel, instrumentation and know-how exchange between experienced researchers. It also funds conferences and dissemination activities, and such experience acted as a nucleation centre for the formation of the present team. The MAMA programme ends in August 31st, 2013

The TO-BE Action is complementary to existing EU programmes and to the many national programmes and aims at acting as an Umbrella Organization for the whole research in the field.

B.4.2 Current Programmes in the US and Japan

US NATIONAL PROGRAMMES

- ARO/MURI Emergent Phenomena at Mott Interfaces, http://mottmuri.mrl.ucsb.edu/
- CAREER: Ferroic Coupling in Complex Oxide Heterostructures from First Principles http://www.nsf.gov/awardsearch/showAward?AWD_ID56441
- CAREER: Atomically-Engineered Complex Oxides and their Heterostructures for Novel Electronic Functionalities http://www.nsf.gov/awardsearch/showAward?AWD_ID45464 2009-2014
- Engineering Interface Magnetism via Defect Control in Complex Oxide Heterostructures http://www.nsf.gov/awardsearch/showAward?AWD_ID06278 2012-2015
- CAREER: Interface Engineered Multiferroics and Nanoscale Phase Modulation in Complex Oxide Heterostructures http://www.nsf.gov/awardsearch/showAward?AWD_ID48783 2012-2017
- FRG: Switchable Two-Dimensional Materials at Oxide Hetero-Interfaces http://www.nsf.gov/awardsearch/showAward?AWD_ID 06443 2009-2013
- NEB: Scalable Sensing, Storage and Computation with a Rewritable Oxide Nanoelectronics Platform http://www.nsf.gov/awardsearch/showAward?AWD_ID24131 2011-2015

MAJOR ACTIVE PROGRAMME IN JAPAN

- RIKEN Center for Emergent Matter Science, Yoshi Tokura http://www.riken.jp/en/research/labs/cems/

C. OBJECTIVES AND BENEFITS

C.1 Aim

The TO-BE Action will network nationally-funded and EU-funded researches on metal oxides within the ERA, allowing to: define targets, strategies and methods; reduce fragmentation; aggregate communities with complementary know-how; attract and train a new generation of researchers; establish a regular know-how transfer with corporations; disseminate knowledge on metal-oxide-based science and technology among national and EU Entities and the Public Society.

C.2 Objectives

The four primary wide Objectives, intended in a broader sense, to be pursued within this Action have different nature: one is relevant to *organization*, one to fundamental *science* and two to *technological applications*. A description in term of secondary specific objectives and some deliverables are reported for each of them

ORGANIZATION: To network scientists working on transition metal oxides (a) among themselves; (b) to the mainstream of solid-state technologies; (c) to Public Society

SCIENCE : To foster and coordinate a research aimed at advancing our present understanding about the way the multiple lattice and electronic degrees of freedom and of their mutual interactions determine the physical properties of TMOs

TECHNOLOGY (1) To foster the development of a technology for the growth of in-situ-quality-controlled, large-area epitaxial oxide films and heterostructures on different substrates including Si.

TECHNOLOGY (2) To single out the most promising applications of TMOs to nanoelectronics, microactiation/microsensing and energy conversion and to coordinate fabrication and testing of devices performed at a prototype level.

C.3 How networking within the Action will yield the objectives?

The Objectives of this Action are intrinsically based on networking, as reported below. The means, intended in terms of human resources, that are appropriate to implement the objectives of our Action are separate dedicated Work Groups (WGs) of Experts, as described in section D.

ORGANIZATION. Description: To create a network among scientists working on complementary aspects of TMO-based science and technology. To reduce fragmentation and optimize resources by avoiding duplication of multiplication of independent efforts. Highlight the similarity. To guarantee training and career opportunities to ESR in the field. To drastically reduce gender unbalance. Reduce the cultural mismatch with colleagues working in industry. To increasing the knowledge about the physics and the applications of transition metal oxides outside the present community, with special attention to: students and early stage researchers; scientists, engineers and officers working in private corporations; the wider solid-state scientific community; governmental and EU Entities; EU citizens and Public Society. **Main Deliverables**: Conferences and meetings; training schools for early stage researchers (ESRs); a web site about physics, applications and events related to TMOs, with special sections dedicated both to Action members and to external stakeholder; joint applications to H2020 programs with Industrial partners; signed agreements and know-how transfer actions with industrial partners; documented increase of female participation to scientific and management activities within this field of research.

SCIENCE. Description: to integrate in a collaborative network expertise and experimental activities from complementary fields of experimental and theoretical science such as: EXPERIMENT: thin film and crystal growth (including crystal/film heterostructures); real-time and in situ characterizations of growth; space-, time-, momentum- and energy-resolved probes both based on tabletop instrumentation or on large scale facilities; surface science; transport in applied external fields; nanofabrication. THEORY multi-scale methods integrating expertise and theoretical activities from complementary fields, such as ab initio computation, microscopic many-body theories and phenomenological approaches. **Main Deliverable:** scientific publications in top international reviews, invited/plenary talks in international conferences.

TECHNOLOGY (1) Description To foster the development of high throughput large area deposition of oxide thin films, heterostructures and coatings; To foster the complementary use of real-time techniques (electron-diffraction based techniques, optical techniques, X-ray based techniques, in situ AFM and others) to gain the maximum control during the film growth process; To foster activity on the fabrication of large area, low cost substrates such as perovskite-on-silicon or perovskite-on-sapphire substrates, to be employed for cost-efficient oxide based technologies. **Main Deliverable:** Editing and publishing of a technological roadmap for oxide-based technologies. Joint projects with private corporations. Filed patents.

TECHNOLOGY (2) Description To identify the TMO-based device concept with the highest potential for: a) memories and switchable logic devices; b) three terminal active devices; c) memristors; d) passive circuit elements; to identify the TMO-based device concepts with the highest potential in the fields of: epitaxial piezo-MEMS for micro-actuators (inkjet-printing, microfluidics); microsensors (pressure, chemical, accelerometers); bioMEMS, RF devices; to assess the potential of different applications in the field of energy conversion, as all-oxide, bandgap-engineered all-oxide PV cells; thermoelectric devices; magnetocaloric devices; energy harvesting. **Main Deliverable:** Editing and publishing of a technological roadmap for oxide-based technologies. Joint projects with private corporations. Filed patents.

C.4 Potential impact of the Action

The TO-BE Action will network the major nationally- and EU-funded researches on metal oxides within the ERA, allowing to:

- Define targets, strategies, roles and methods for the applications of TMO based technologies and for the realization of nanoelectronic, microelectromechanical and macroelectronic devices.
- Reduce fragmentation in the field, also aggregating independent communities following complementary approaches; attract and train a new generation of researchers;
- Provide links with Institutions operating outside EU;
- Realise a roadmap defining the development route of oxide-based technologies.
- Establish a regular know-how transfer with industrial corporations.
- Disseminate information about the potential of this class of materials to external stakeholders and to the public society.

The success of the Action will

- Strengthen the EU research on the fundamental properties of TMOs by fostering a global multidisciplinary approach where highly controlled samples fabrication, advanced characterizations (largely based on large scale facilities) and multiscale theoretical methods act in tight synergy to tackle some of the most intriguing problems of solid state science.
- Create the future, well trained, young and gender balanced community of Oxide Electronics.
- Tackle the main technological bottleneck that hampers the commercial diffusion of applications based on epitaxial TMO films, mostly based on piezoelectric materials, and is related to materials compatibility with Si technology.
- Focus on device prototypes based on more complex functionalities than piezoelectricity and select the device concepts that are more suitable for the admittance of oxide electronics into

the mainstream of solid state device technology.

- Strengthen the innovative capacity of EU industry by making novel enabling technologies accessible for industrial exploitation, in fields such as micro- and nanoelectronics, nanotechnology, advanced materials and meeting societal needs as ICT and clean energy and, more indirectly, security and health. This will help making the EU productive system more competitive and capable to tackle societal challenges, and eventually change the global industrial landscape in this area.

C.5 Target groups/end users

The end-users of the TO-BE Action are

1. Scientists participating in the Action and needing a network coordination.
2. ESRs and female researchers working in the field.
3. Students (at master and PhD level) willing to join the field.
4. Scientists, Engineers and Officers working in Corporations that may build future commercial applications based on concepts and technologies bolstered by the TO-BE Action.
5. The international research community working on transition metal oxides.
6. European scientists acting in neighbour fields and the general scientific community.
7. EU, governmental or regional Entities and policy makers
8. General public.

An effort has been made to join part of these classes of stakeholder to this Action since the proposal stage. The proponent team already includes therefore a relatively high percentage of women sitting in the MC, a high number of ESR and some SMEs. Inclusion of the other classes of stakeholder in the Action is one of the aims of our dissemination plan.

D. SCIENTIFIC PROGRAMME

D.1 Scientific focus

Research Tasks are formally identified into the structure of this Action as activities that are executed by group of participants. People participating to Tasks that are strongly synergic to each other are grouped into Work Groups (WG).**The Action identifies a WG for each of the primary Objectives defined in Section c.2**.

The structure of WGs is therefore as follows:

- **WG0 Management (MA)**
- **WG1 Fundamental Understanding (FU)**
- **WG2 Growth Control (GC)**
- **WG3 Towards Applications (TA)**

The activities to be held by WG0 (MA) will be described in the E Section. The activities to be held by WG1 (FU), WG2 (GC) and WG3 (TA) are briefly summarised below. The description of single research Tasks is reported in Section D.2.

WG1 (FU) *will be in charge of pursuing the SCIENCE Objective "To foster and coordinate a research aimed at advancing our present understanding about the way the multiple lattice and electronic degrees of freedom and of their mutual interactions determine the physical properties of TMOs"* . The members of WG1 will try to promote the global multidisciplinary approach briefly explained in section B and detailed in section D.2. WG1 will act in synergy with the Management WG in the organization of scientific meetings, and roundtables, that will be dedicated to the presentation of the groups and of their results, to the planning of activities and the presentation of joint applications in the field of fundamental understanding of TMO properties. The specific scientific activities fostered within this WG are described in two T1-"Experiment" and T2-"Theory", in section D.2.

WG2 (GC) *will be in charge of pursuing the first TECHNOLOGY Objective "To foster the development of a technology for the growth of in-situ-quality-controlled, large-area epitaxial oxide films and heterostructures on different substrates including Si"*. WG2 will act in synergy with the Management WG for the organization of technical meetings and roundtables and to join contacts with private corporations, also for the presentation of joint applications. In synergy with the Management WG and with WG3 it will publish a volume that is intended to serve as a technological roadmap for transition-oxide-based electronics. The specific scientific activities fostered within this WG are described by three tasks T1-"Large area growth", T2-"Perovskite-on-Si", T3-"Real-time monitoring" in section D.2.

WG3 (TA) *will be in charge of pursuing the second TECHNOLOGY Objective "To single out the* *most promising applications of TMOs to nanoelectronics, microactuation/microsensing and energy conversion and to coordinate fabrication and testing of devices performed at a prototype level"*. WG3 will benefit from the technological progresses in sample fabrication fostered WG2 and by the advancement of knowledge fostered by WG1. Furthermore, it will strongly interact with the Management WG and with WG2 for establishing a contact with EU corporations and for editing and publishing the technological roadmap of transition-oxide-based electronics. The specific scientific activities fostered within this WG are described three tasks "T1-Nanoelectronics", "T2-Microactuation and microsensing", "T3-Energy conversion" in section D.2.

The work plan must be kept flexible enough to permit the inclusion, at the implementation stage, of disciplinary perspectives and activities not foreseen during the preparation of the proposal. The addition of new Tasks is seen as the most straightforward approach to update the Action structure to modified external conditions, such as scientific/technological innovations, introduction of new hot topic and addition to the Action of new partners active on other aspects of TMO science and technology. Just to quote an example, the creation of new Tasks dedicated to catalysis at oxide surfaces, to optics/photonics applications or to solid oxide fuel cells (now part of WG3-T3) might be envisaged in next future in WG3. The creation of a totally new WG might also be considered, under the conditions reported in Section E.

D.2 Scientific work plan methods and means

In this section the single Tasks foreseen in the Work Groups are described; WG1 Fundamental Understanding (FU); WG2 Growth Control (GC); WG3 Towards Applications (TA).

WG1(FU)–T1 "Experiments" The present participating institutions gathers together many of the leading groups in EU that are most active in a research area of Transition Metal Oxide (TMO) based materials. The synthesis and characterization of these materials requires a variety of different experimental techniques, which are available to this Action. These oxides are fabricated using different techniques such as pulsed laser deposition in the form of thin films, i.e. epitaxial or heterostructures, and in form of single crystals in image furnaces. To-BE also includes groups having regular access to large scale facilities, both as users and as beamline responsible on synchrotron light (for techniques including X-ray diffraction, X-ray absorption spectroscopy with linear and circular dichroism, angle –resolved or angle-integrated photoemission spectroscopy, resonant inelastic X-ray scattering, photoemission electron microscopy) and neutron (neutron scattering, polarised neutron reflectometry) facilities and, in the future, to free electron lasers. Small scale facilities which are also available to the Action include: high resolution electron microscopy, electron energy loss microscopy; optical spectroscopy experiments also based on ultrafast lasers; nanofabrication facilities (including electron beam lithography and focus ion beam etching); surface science facilities; magnetic characterization facilities including scanning SQUID microscopy; transport characterizations in external applied magnetic and electric fields down to the mK range.

WG1(FU)–T2 "Theory" The interplay of ordered phases, strong-correlations and quantum topology is a timely and crucial issue in bulk oxides and heterostructures. There are many energy scales involved in the physics of oxide materials that, to be disentangled, call for the use of advanced probing techniques, as time-, space-, momentum- or energy-resolved, photon based spectroscopies. In order to understand experimental data deriving from such techniques it is central to combine methods which traditionally come from different sides of research, ranging from the first-principles methods, based on density functional theory (DFT), to advanced many-body techniques, as well as to approaches and theories able to capture the dynamics, the character of the excitations, as well as the transport properties. The aim of this WG is to support the coordination of the know-how concerning the different approaches both for the analysis of the emergent phenomena in some of its major manifestations in the oxide materials and the comparison of the methodologies used to address the specific aspects related to the nature of the ground state and of its elementary excitations.

WG2(GC)-T1 "Large area growth". High throughout, large area growth of oxide thin films is today a largely unsolved problem which needs to be addressed. The technique that proved to be by far the most successful in oxide film growth, i.e. pulsed laser deposition, has is generally considered unsuitable to large area deposition, due to the limited dimension of the plume and to the reduced deposition rate. Typical large area deposition techniques employed in industry, as chemical vapour deposition, have not achieved so far the very high level of crystalline quality that is needed for TMO samples. Nevertheless the joint use of high power excimer lasers, laser beam rastering on target and sample movement during growth appears as a promising solution allowing to rescale the highly successful PLD growth from laboratory to industrial level. The task "Large area growth" will coordinate the groups acting within the TO-BE Action on this topic.

WG2(GC)-T2 "Perovskite-on-Si". Oxide thin films and heterostructures of peroskite-related materials are deposited often in research laboratories on single crystal oxide substrates, such as $SrTiO_3$. The use of such substrates is not cost effective, not compatible with industrial manufacturing techniques and therefore does not allow the direct integration of oxide-based films with conventional technologies. High quality epitaxial growth of complex oxides on silicon or on other microelectronic substrates (as Al_2O_3 sapphire) is needed. The growth of very high quality epitaxial $SrTiO_3$ films on Si has been recently demonstrated, mostly by molecular beam epitaxy. Rescaling such technology to an industrial level would make commercially available high quality “Perovskite-on-Si” (or “Perovskite-on-sapphire”) substrate, replicating the well established SOI (silicon on insulator) or SOS (silicon on sapphire) technologies, to be used both in research and in industry applications. The task “Perovskite-on-Si” will ensure that this topic will be coordinated between the groups acting within the TO-BE Action.

WG2(GC)-T3 “Real-time monitoring”. Transition metal oxides are highly sensitive to small amounts of crystallographic defects and completely lose their electronic properties when crystal order is lost. TMO-based technologies require therefore an unprecedented degree of control of the growth process to guarantee that the complex crystal structure is reproduced in thin film form with the highest degree of perfection. This task will coordinate a team of laboratories interested in increasing the real time control of thin film growth. One of the tasks of this group will be analysing novel techniques that can be applied in the specific growth conditions of oxides. This includes modified RHEED concepts, fast imaging and spectroscopy of the laser plume, surface second harmonic generation, 2D Curvature and Stress Monitoring, real time AFM, real time X-ray diffraction. Furthermore, typical surface science techniques that require UHV and might not be compatible with the TMO growth conditions (as LEED, XPS) will be applied through direct UHV transfer of the sample from the deposition chamber.

WG3(TA)-T1 “Nanoelectronics”. The goal of this Task is to foster and coordinate the European research on unconventional nanoelectronic devices based on Transition Metal Oxides. This WG activity will be focused three main topics, namely: (a) development of novel nanopatterning and nanomanipulation techniques or optimization of existing techniques for oxide nanodevices; (b) design and realization of devices with new functionalities on nanometric scale; (c) design and realization of nanometric devices for non-charge based electronics.

As a target of the present Task, the Action aims to compare the potential of different approaches and to identify the most promising solution offered by TMO technology with the same family of devices, e.g: Memories – compare the potential, at a prototype level, of redox based resistive switching devices, tunnel electroresistance devices, all-oxide magnetic tunnel junctions.

Three terminal field effect devices - compare the potential, at a prototype level, of Mott-transition based filed effect transistors, MOSFETs with ultrahigh-k dieletric barrier, FETs acting on oxide 2DEGS, reconfigurable nanodevices (sketchFETS) based on oxide 2DEGs, oxide-based Datta Das transistors.

WG3(TA)-T2 "Microactuation and microsensing"

The aim of this Task is to foster and coordinate the research on piezoelectric micro-electronic-mechanical-systems for microactuation (e.g. inkjet-printing, microfluidics), and microsensing (e.g. pressure sensors, chemical sensors, acceleration sensors). The peculiarity of our approach lie in the fact that all devices will be based on epitaxial $Pb(Zr,Ti)O_3$ (abbreviated as **epi-PZT**) thin films. The use of such films will result in the desired stable functionality, necessary for device applications, without PZT film preconditioning. In order to explore the novel functionalities of epi-piezo-MEMS, an unprecedented control on crystallinity and defect structure of epi-PZT films is needed. In tight synergy with the Tasks of the WG2, the Action will push towards the growth of 1) suitable buffer layers for epitaxial growth and optimized piezo properties and 2) epitaxial piezoelectric films on commercial substrates (Si and Silicon-on-Insulator (SOI)) with a quality comparable to state-of-the-art epitaxial films grown on single crystalline oxide substrates. Next steps are to establish patterning and processing conditions within and beyond the constraints of current fabrication technologies, and to characterize the structural and piezoelectric properties, as a prerequisite for delivering novel device concepts for actuation and sensing applications.

WG3(TA)-T3 "Energy conversion"

The goal of this WG is to initiate new strategic direction in the area of materials-by-design of functional nanostructures, where engineering of the interfaces is the key to novel applications within energy conversion. We are now once more in the midst of a revolution, this time arising from interfaces and heterostructures of oxide materials. Such materials exhibit a wide range of phenomena, including magnetism, superconductivity, ionic conduction and ferroelectricity, and they find use in a large number of renewable energy applications such as photovoltaics, water-splitting, batteries, fuel cells, information storage and LEDs. Common to all these popular high-tech devices, that have created lots of jobs and had a major impact on our society, is that the fundamental understanding of the heterostructures and the properties of the material interfaces is essential for the capability to engineer, convert and apply them in devices. The goal is to unravel the underlying physics of interfaces and heterostructures, to model, design and realize new ones, and to develop their potential into novel nanoscale devices for energy conversion. This will be the major topic of this work plan.

E. ORGANISATION

E.1 Coordination and organisation

The COST TO-BE Action is chaired by an Action Chair and a Vice Action Chair. It is represented by the **Management Committee** according to the Rules and Procedures for Implementing COST Actions. As for the milestones of the Action, we refer to the timetable in section F.

A Management (MA) WG will complement the three scientific and technological WGs. The activity of such WG will be also divided in tasks, as listed below and later described in section E.2:

WG0 – T1: Internal meetings, conferences, workshops, joint projects

WG0 – T2: Dissemination and website managements

WG0 – T3: ERS careers and training; short term scientific missions (STSM)

WG0 – T4: Editing the roadmap book/volume.

A **Steering Group (SG)** will be defined within the MC. This team is built in such a way to represent all the Management. Scientific and Technological activities of the Action, with a special weight on Management. It includes the WG and Task leaders of Management and the leaders of the other WGs. The full list of SG members is reported for clarity below

- MC Chair.
- MC vice Chair, with a special assignment on gender balance issues
- WG0 (MA) – T#1 leader
- WG0 (MA) – T#2 leader
- WG0 (MA) – T#3 leader
- WG0 (MA) – T#4 leader
- WG (FU) leader
- WG (GC) leader
- WG (TA) leader

In case decisions within the SG need to be taken by votation, the four WG0 Task leader (that have been named by the Action Chair and not directly by the MC) will not participate to the vote.

The **Management Committee** will meet at the beginning of each year plus once at the end of the Action, reporting annually to the COST office. In the course of the first MC meeting, the MC will vote the WG1,2,3 leaders. In the course of each annual meeting, the MC will focus on decisions regarding the overall structure of the TO-BE Action. This will include: approving the access of new participants; confirming or redefining the WG1,2,3 leaders; confirming or redefining the Tasks structure of WG1,2,3. The creation of new WG Tasks during the annual MC meetings is seen as the most straightforward approach to update the Action structure to the upcoming scientific/technological innovations and to the addition of new partners to the Action. Furthermore, under request of a group of at least 1/4 of the MC members, the creation of a new WGs will be considered for approval by the MC. In case of approval by voting, a new WG leader will be elected and will join the SG.

The **SG** will meet yearly. It will keep a regular internal exchange of information via e-mail and web conferences and prepare the agenda of the MC meetings. The SG will be in charge of monitoring all the activities pursued by the Action within the four WGs. The leaders of the four WG0 tasks will be named by the Action Chair and might be confirmed or changed at the 3rd year. In case votation is needed to take decisions within the SG, the WG0 Task leaders will not participate to the vote.
The milestones and deliverables of the TO-BE Action are reported in the table in Section F, together with the principal planned events.

E.2 Working Groups

The WG leaders of WG1,2,3 will elected during the first MC meeting, while WG0 will be directly lead by the Action Chair and Vice-Chair. Task leaders within each WG will be named by the WG leaders. Every participant to the Action will be assigned to a WG and to a Task.
The assignments of WG1,2,3 leaders include:

1. Participating and voting in the SG meetings;
2. Naming the Task leaders within their WG.
3. Fostering collaborations and network activities within the WG, included the organization of topical WG meetings, also with the support of the WG0-T1 Task leader.
4. Supporting the WG0-T1 Task leader in all the Action network activities.
5. Monitoring the timeliness of the WG activities vs. the foreseen milestones schedule and scientific objectives and report to the SG.
6. Providing scientific/technological contents for the website
7. Collaborating with the WG0-T3 leader in the choice of the STSM

The structure of WG1,2,3 has been reported in section D and will not be repeated in this section. The structure of WG0 is reported below.

The Management WG is lead by the Chair and Vice-Chair with the help of four Task leaders named by the Action Chair. Tasks leaders will work in tight synergy since their activities are interconnected. Task leaders will report on the advancements of their respective activities in the SG meetings.

WG0(MA)–T1: Internal meetings, conferences, workshops, joint projects.

This task will be in charge of most of the scientific/technological networking aspects within the Action and will need Coordination with T#2 especially for the website, with T#3 especially for the STSM. It will be in charge of providing the maximum integration of the partners belonging to the private sector with research institutions, fostering a fruitful know-how exchange. It will provide a coordination to single national researchers and to researchers focusing on different functionalities of similar materials. It will organize an annual conference and support the single WGs for the preparation of topical meetings. It will spread information about calls within H2020 programmes and stimulate the formation of teams submitting joint applications.

WG0(MA)-T2: Dissemination towards external stakeholders and website managements.

This task will be principally in charge of the communication with external stakeholders, but, as being responsible for the website management, it will also strongly interact with T#1 and T#3 providing a platform for the communication within the participants, including job posting. T#2 will be in charge of organising round tables and establishing durable links with external stakeholders (including corporations), EU and national Entities, the EU Public Society, major scientist working in the same field outside EU. T#2 will also be in charge of expanding the TO-BE network by fostering the participation of new partners. Further details about the dissemination plan and about the website are reported in the dedicated H section.

WG0(MA)-T3: ERS careers and training; short term scientific missions (STSM).

This task will be in charge of attracting ERS, providing them a training both in terms of education (training schools) and practical working experiences within the participant institutions (STSM) and by keeping a database of job opportunities and of ESR CVs that will be hosted on the website managed within T#2. STSM of experienced researchers will be also managed within this Task. The attention to gender balance issues, that is a priority of our Action, will be maximum within this Task. STMS will be agreed with WG leaders. The Vice-chair, having a special assignment on gender balance issues, is entitled to require regular information on this specific aspect and to report timely any problem to the SG.

WG0(MA)-T4 Editing of the roadmap book/volume.

This task will be in charge of monitoring the activity that will lead to the publication of a dedicated volume named "Roadmap of oxide-based technologies" (the title might be revised in the course of the years). The editorial board will include the Action Chair, the WG0 – T#4 leader and the WG2 and WG3 leaders. Other editors might be added. Authors of the volume will typically be part of the Action Working Groups, but contributions by non-EU authors will also be solicited. Some abstract of the Roadmap will be freely available on the Action website. The editorial board will define a timeline for the Roadmap preparation and publication. The leader of this Task will be in charge of contacting the authors and monitoring the timeliness of the activity vs the timeline.

E.3 Liaison and interaction with other research programmes

The TO-BE Action will have different opportunities of interaction with other COST Actions and in particular with those which are thematically closer to the field of TMOs, such as the MP0904 "Single and Multiphase Ferroics and Multiferroics With Restricted Geometries" (SIMUFER), 2010-2014, and the MP1201 "Nanoscale Superconductivity: Novel Functionalities through Optimized Confinement of Condensate and Fields" (NanoSC) .

Similarly, there will be tight liaisons with most of the research programmes funded within the FP7 that address different issues related to the synthesis, the advanced analysis and the modelling of TMOs.

Due to the strong thematic overlap, a fruitful interaction with the FP7-ENERGY FET – "Novel Composite Oxides by Combinatorial Material Synthesis for Next Generation All-Oxide-Photovoltaics" ALLOXIDEPV, the FP7-NMP – "Multiscale Modelling of Femtosecond Spin Dynamics "FEMTOSPIN, the FP7-NMP Large-scale IP "Interfacing Oxides" IFOX, ERC Sinergy Grant – "Frontiers in Quantum Materials Control" Q-MAC, the FP7 RegPot – "Multifunctional advanced materials and nanoscale phenomena" MAMA, and the ERC Advanced Grant "Perfectly interfaced nanomaterials for next generation oxide electronics" is foreseen.

The exchange of information is naturally guaranteed by the fact that participants of TO-BE are principal investigators or partners in most of the above mentioned projects. The direct exchange of information via email or skype conferences will be the first mean for developing a close interaction between the main players in the TMOs field. The interaction is then further strengthened by inviting the project scientific coordinators to attend the Workshops/Conferences planned within TO-BE. During that occasion a round table will be organized to specifically discuss some of the main projects

results and the strategies to improve the European competitiveness in the TMOs area.
The interaction with the other international research programmes will be organized by means of seminars. The main representatives of the research programme in US and Japan will be invited to attend one of the event scheduled in TO-BE and to give also seminars at some of the TO-BE partnering institutions.

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 considerably involve early-stage researchers. This item will also be placed as a standard item on all MC agendas.

Gender balance

TO-BE will promote diversity and equal opportunities, ensuring gender balance in accordance with the principles of equal opportunities and non-discrimination (minimum of 1/3 representation of either gender according to the EU Treaty). All participating members will be asked to specifically involve female (or male) researchers in their country for participating to the Action if there are less than 30 % female (or male) researchers involved.
Moreover, in line with the European Research Area objective, the Action will address the specific issue of gender imbalances in the decision making processes by ensuring at least 1/3 representation of either gender in the MC and the SG. All necessary measures will be taken to ensure the same 1/3 representation of either gender in all initiatives that will be implemented in favour of ESRs, reported below.
Gender balance will be closely monitored by the vice chair of the MC vice chair that will be appointed Gender Balance Coordinator under WG 0. The gender balance coordinator will be selected by the MC among the researchers from the less represented gender. She (or he) will monitor the compliance with the gender balance objectives stated above, will conduct impact assessment / audits of procedures and practices to identify gender bias and suggest and implement innovative strategies to correct any bias. Such audits will be a milestone of the project and the results and measures to be taken will be included in the yearly report.

Early Stage Researchers (ESRs)

The TO-BE Action will implement specific actions to foster the active involvement of ESRs and contribute to the development of their career in science. The following means will be adopted to achieve this objectives:

1. "Training-through research": by supporting Short Term Scientific Mission, ESRs will interact with experienced researchers from partner institutions and other ESRs and increase their independence in research.
2. Improving decision-making skills: early stag researchers will be involved at all levels, including management tasks (such as outreach activities and the organization of the scientific programme of the TO-BE events).
3. TO-BE Training Schools: Two training schools on first and third year will take place under this Action. The participation of 20-30 ESRs will be supported. Open calls dedicated to ESRs also outside the Action will be issued to apply to the participation grant. During the Training School specific sessions on soft skills (communication skills, Intellectual Property Rights, etc) will be organized.
4. Conference grants: TO-BE will support the participation of ESRs to the main conferences in the field (e.g., Workshop of Oxide Electronics: an annual workshop that is held in Europe every three years, next time in 2015). In this context, ESRs will be encouraged to submit abstracts for poster or oral communications. Selection of the grants will be done via an open call be advertised on the main relevant websites and on the Euraxess and/or similar portals.
5. STSMs: The MC will encourage the ESRs to use the STSMs, as they provide an excellent platform for broadening the scientific horizon, learning new technical aspects, creating new collaborations and experiencing different working environments. At least 3 STSMs will be reserved for the ESRs.
6. ESRs Think Tank: In all TO-BE meetings a specific session dedicated to the ESRs will take place,. This will be completely organized by the ESRs and will have the aim of sharing knowledge and experiences among the ESRs involved in the Action.

In order to obtain a picture of the situation with respect to the involvement of ESRs and to monitor the effect of the measures described above, TO-BE MC shall provide statistical data on the age distribution of the participants in the Action on a yearly base and suggest improvements, if needed.

F. TIMETABLE

The Milestones **[M],** Deliverables **[D]** and Events **[E]** of this Action are reported in the Table Below.

The Acronyms employed in the table are defined below:

- **MC:** Management Committee
- **SG:** Steering Group
- **T1:** First Task of the Management WG: “Internal meetings, conferences, workshops, joint projects”
- **T2:** Second Task of the Management WG: “ Dissemination and website managements”
- **T3:** Third Task of the Management WG: named:” ERS careers and training; short term scientific missions (STSM)”
- **T4:** Fourth Task of the Management WG: “Editing the Roadmap book/volume”

		I Trimester	II Trimester	III Trimester	IV Trimester
Year 1	**MC**	KO meeting, definition/confirmation of WG/Tasks structure and chairs **[E]**	GB and ESRs involvement policy established **[M]**		
	SG	Appointment of members **[M]**		Web conferencing **[E]**	
	T1	Appointment of members **[M]**	KO meeting of WG1,2,3 **[E]**	Web conference WG1,2,3 meetings **[E]**	Semestral meetings of WG1,2,3 **[E]**
	T2	Appointment of chair, Website open **[M]**	Announcement 1st biennial conference online **[M]**	Announcement 1st Training School online **[M]**	Report on dissemination and outreach activities **[D]**
	T3	Appointment of chair **[M]**	STSM plan Y1 SEM2 ready **[M]**		STMS plan Y2 SEM1 ready **[M]**
	T4	Appointment of chair **[M]**			Chapter structure of the Roadmap approved **[M]**
Year 2	**MC**	Annual meeting, GB and ESR check point **[M] [E]**			
	SG	Annual meeting **[E]**		Web conferencing **[E]**	
	T1	1st Biennial Conference, WG1,2,3 meetings **[E]**	Semestral meetings of WG1,2,3 **[E]**	Web conference WG1,2,3 meetings **[E]**	Semestral meetings of WG1,2,3 **[E]**
	T2		Checkpoint on website activity **[M]**		Report on dissemination and outreach activities **[D]**
	T3	1st Training School, Start STSM **[E]**	STMS plan Y2 SEM2 ready **[M]**		STMS plan Y3 SEM1 ready **[M]**
	T4		Structure of the Roadmap ready, including chapters **[M]**		Authors of the Roadmap defined **[M]**

Year 3	**MC**	Annual meeting, GB and ESR check point **[M]**			
	SG	Annual meeting **[E]**		Web conferencing **[E]**	
	T1	WG1,2,3 meetings **[E]**	Semestral meeting WG1,2,3 **[E]**	Web conference WG1,2,3 meetings **[E]**	Semestral meeting WG1,2,3 **[E]**
	T2	Announcement 2nd Training School online	Checkpoint on website activity, announcement of 2nd biennal conference online **[M]**		Report on dissemination and outreach activities **[D]**
	T3		STMS plan Y3 SEM2 ready **[M]**	2nd Training School **[E]**	STMS plan Y4 SEM1 ready **[M]**
	T4		Preliminary draft of the Roadmap with Eds.		**[D]** Final fraft of the Roadmap with editors
Year 4	**MC**	Annual meeting, GB and ESR check point **[M]**			
	SG	Annual meeting **[E]**		Web conferencing **[E]**	Final report **[D]**
	T1	WG1,2,3 meetings **[E]**	Semestral meeting WG1,2,3 **[E]**	2nd Biennial Conference, WG1,2,3 meetings, **[E]**	
	T2		Checkpoint on website activity **[M]**		Report on dissemination and outreach activities **[D]**
	T3		STMS plan Y2 SEM2 ready **[M]**		Final report on ESR activity **[D]**
	T4		Roadmap ready for publication **[M]**		Roadmap published **[M]**

G. ECONOMIC DIMENSION

The following COST countries have actively participated in the preparation of the Action or otherwise indicated their interest: AT, BE, CH, DE, DK, EL, ES, FR, IE, IL, IT, NL, NO, PL, RS, SE, UK. On the basis of national estimates, the economic dimension of the activities to be carried out under the Action has been estimated at 68 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?

All the target audiences of our dissemination activities and all the stakeholder of the TO-BE Action, are addressed in our dissemination plan within one or more Tasks of the Management WG: this includes:

- Experienced researchers and ESRs working in the field (WG0-T3)
- Undergraduates, Master students and PhDs willing to begin a career in science (WG0-T3).
- The international research community working on transition metal oxides (WG0-T1, T2, T4) and the wider community active on solid state science and devices.
- European-level and regional-level Research Policy decision-makers
- Industry (in particular SMEs and start-ups in the field of nanoelectronics, microactuation/microsensing and energy conversion)
- General public

H.2 What?

In order to increase the visibility, The Action will resort to the following means:

- **TO-BE website** (WG0-T2). Main target: ALL
- **Social media channels** (WG0-T2) Main targets: general public and policy makers
- **TO-BE Biennial training schools** (WG0-T3)**.** Main Target: ESRs
- **TO-BE scientific events** (WG0-T1). A biennial conference on the physics and applications of transition metal oxides. Main target, the international TMO community.

- **Meeting stakeholders** (WG0-T2) Main targets: general public, industries and policy makers
- **Open access:** (WG0-T2). Main targets: general public, industries and policy makers
- **TO-BE Roadmap** (WG0-T4). Main target: and the wider community active on solid state science and devices.
- **Yearly report,** (SG) including a plain language summary (Targets: All)
- **Articles in peer reviewed journals** (WG1, 2, 3). Main target, the international TMO community.
- **TO-BE brochure** (WG0-T2). Main targets: general public, industries and policy makers
- **Press releases**, (WG0-T2). Main targets: general public, industries and policy makers

H.3 How?

Details about a number of initiatives mentioned in section H.2 (excluding those that are self-explaining) are provided below.

TO BE Website: A public access website including multimedia communication (podcasts, webinars, etc)will be established, maintained and run . The website will be designed to facilitate intra-participant communication as well as external communication (to all other targets) based on specific sections and dedicated paths. The participants' "restricted access area" will contain web conference facilities, Action calendar and updatable blog / discussion board. The open access section will aim to become a reference for the whole international community working on transition metal oxides, hosting the announcements to international workshops and conferences in the field, job posting for this specific field of research, links to homepages of the major groups working on transition metal oxides, links to major publications by the participants groups.

Social media channels (e.g., Wikipedia pages, Youtube channels, professional Linkedin network, etc,). In order to ensure optimal circulation, access to and transfer of scientific knowledge both to the scientific community, the relevant stakeholders and the public in general dissemination and information via the main social media will be adopted.

TO-BE Biennial training schools. The International TO-BE training school will aim at gathering PhD students, post-docs, young scientists and acknowledged senior researchers working on transition metal oxides for a period of about two weeks, to build up the future Oxide Electronics scientific community. Basic notions of solid-state physics (superconductivity, ferroelectricity, magnetism, correlations, etc) will be recalled, but the school will also give an extended overview of the field, covering topics such as multiferroics, oxide interfaces or manganese, nickel and cobalt perovskites. Oxide-based devices (tunnel junctions, field-effect devices, memristors) will also be presented in detail, as well as key advanced characterization and computational techniques.

TO-BE scientific events: The events will be key dissemination points to other research groups. Particular attention will be paid to organization of such events in conjunction with other international activities to enable dissemination to broader audiences. Two Conferences will be organized with a biennial schedule. The first biennial Conference, entitled “Emergent phenomena and quantum complexity in functional oxides and heterostructures”, will aim to provide an interdisciplinary forum for researchers working on synthesis, theory, modeling, and analysis of functional complex oxides, bridging fundamental aspects of materials research and applications. The TO-BE Conference will gather scientists with common scientific interests in oxide materials in a friendly and stimulating atmosphere to share both recent developments and new ideas about the most promising materials with new physical behaviours and functionalities. A participation of about 200 researchers will be foreseen. The second biennial Conference “Multifunctional oxides and heterostructures: novel trends for applications in nanoelectronics, energy and information and communication technologies” will aim to gather scientists and other stakeholders from the area of oxides materials and heterostructures in order to discuss the most relevant materials solution for applications in nanoelectronics, energy and ICT. A participation of about 200 researchers will be foreseen.

Stakeholders meetings All the participants of this Action will collaborate to gather a database of external stakeholders that are potentially interested in getting information about our Action, with special emphasis on SMEs. The wide participants team should guarantee the collection of a considerable amount of initial addresses, and this database will be constantly updated by the action of the WG0-T2 team. Various initiatives will bring this team of stakeholders closer to the Action: direct inclusion into the Action, inclusion in the mailing list, access to the restricted area of the web-site, organization of actual or virtual round tables in which all WGs 2 and 3 will be strongly involved.

Open access policy: In order to ensure optimal circulation, access to and transfer of scientific knowledge both to the scientific community, the relevant stakeholders and the public in general, TO-BE will adopt an open access publication policy. Whenever possible in agreement with parties involved and respecting intellectual property rights, free internet access to and use of publicly-funded scientific publications and data will be preferred. Subject to copyright and licensing arrangements, a copy of publications arising from and supported by this COST Action (including journal articles, books and conference and workshop proceedings) will be deposited in the e-print repository of the COST Office.

TO-BE Roadmap: this initiative aims to assimilate the approach of the yearly International Technology Roadmap for Semiconductors in a book that will be dedicated to the future development of transition-oxide-based technologies. The first part of the roadmap will be dedicated to fabrication technologies (with special emphasis on film growth issues) while the second half will be dedicated to novel device concepts. The roadmap will be edited by the Action chair, the Wg0-T4 chair and the WG2,3 chairs, authored by many authors within and outside the Action and published in a dedicated book. This initiative will both contribute to a more mature approach of the TMO community towards technological applications and disseminate the knowledge on the potential of TMO based technology in Industry and in the wider solid state scientific community.