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Research Road Mapping in Materials

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Directorate-General for Research
Directorate G — Industrial Technologies
Unit G.3 — Value-added Materials
Contact: Anne de Baas
European Commission
Office CDMA 4/066
B-1050 Brussels
Tel. (32-2) 29-63586
Fax (32-2) 29-60550
E-mail: anne.debaas@ec.europa.eu

EUROPEAN COMMISSION

Research Road Mapping in Materials

edited by Dr. Anne F. de Baas

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Contents

Introduction

Materials science and technology are advancing fast: they are of particular relevance for industry and society as materials create added value in most products. At the same time, costs must be minimised, sustainability improved, and products rendered more attractive, portable, or usable by making them smaller and lighter.

The Framework Programme (FP) for research and technological development is the European Union's main instrument for funding research in Europe, resulting from years of consultation with the scientific community, research and policy-making institutions, and other interested parties.

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FP6 and FP7 launched Cooperation Programmes with the following key Thematic Programmes (FP7):

- Theme 1 Health
- Theme 2 Food, agriculture and fisheries, and biotechnology
- Theme 3 Information and communications technologies (ICT)
- *Theme 4 Nanosciences, nanotechnologies, materials and new production technologies (NMP)*
- Theme 5 Energy
- Theme 6 Environment (including climate change)
- Theme 7 Transport (including aeronautics)
- Theme 8 Socio-economic sciences and the humanities
- Theme 9 Space
- Theme 10 Security

NMP underpins progress in virtually all other above mentioned Themes. The materials research done tries to find answers to questions such as:

- How can products and processes be improved?
- Are there better alternative materials and process?
- How can new materials reduce the number of components and production steps?
- What is the impact of materials on cost, quality, safety, consumer experience and regulatory compliance?
- How can maximum added value be derived from materials? Can we use fewer or local materials and suppliers?
- Which is the most sustainable material in terms of energy and primary resource consumption?

New materials can make crucial differences in many products. Multi-application materials form a generic, horizontal, cross-cutting field with actors in many different industrial sectors, The Nano Materials Production (NMP) Theme develops both multi-application materials, and materials for targeted applications in all FP7 Thematic Areas, notably Energy, Environment, Health, ICT and Transport.

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The dialogue between scientists and industries give rise to Research Road Maps (RRM). These offer great added value in guiding the activities undertaken by all stakeholders: scientists, industries, venture capitalists, research managers, etc. In addition, if based on economic and societal needs, they can be of great value in priority-setting interactions with public administrations at national and European level.

Addressing main challenges

In order to address the above questions in FP6, a number of the large instruments (Networks of Excellence and Integrated Projects) developed RRMs presenting their joint vision on future research in the Materials Science & Technology domain. As this brochure shows, some large projects also contributed.

Research road mapping involves identifying scientific and technological challenges related to the socio-economic and industrial trends expected for the coming decade(s). An analysis of existing RRMs shows that they are generally organised around three 'parameters':

- **Thematic areas/economic and societal challenges**, from which common drivers for materials innovation can be derived and which have cross-sector relevance such as the FP7 Themes: Energy, Environment,...
- **Horizontal and vertical classes:** horizontal classes are cross-cutting technologies e.g. modelling, metrology and standards, process technologies, manufacturing. Examples of vertical classes are structural, functional, multi-functional and bio-materials.
- **Market industry sectors** e.g. aerospace, transport, healthcare, packaging, textiles, construction.

RRMs consider these three parameters in different combinations: horizontal versus vertical technologies; technologies versus industry sectors; and industry sectors versus themes.

The RRMs of governmental agencies analyse 'society and market drivers' and establish **in a first step** 'Thematic Areas'. These RRMs contain choices in the form of prioritisation of 'FP7 Themes'.
In a **second step**, they identify intermediate challenges, in the form of 'applications/systems' to be realised. These are applications at a high level and usually require research in multiple fields. Examples of applications/systems are batteries, thermal/movement energy harvesting, de-pollution, CO_2 capture, protection of goods and buildings. This type of RRM does not normally continue to the **third step**, in which the technologies to be developed are identified.

The RRMs arising from laboratory experience usually discuss the parameters 'technologies' and 'industrial market sector', but do not identify new 'Themes', and hence do not typically include any prioritisation.

Strategies

The strategies followed by roadmap producers vary from closed to open.

In **closed strategies**, the desired end-result is chosen and means are defined to reach this goal. Such RRMs can easily be up-dated at regular

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intervals. Closed roadmaps tend to be highly predictive constructions that are adapted to the needs of markets and activities.

Open Strategies start from a good knowledge of the state-of-the-art in a specific field of activity, then extrapolate the developments of this activity over time. Open roadmaps may be fragile constructions, low on prediction and usually involving accompanying blue-sky research.

FP-funded activities have to support the European priorities, and hence benefit from RRMs. The formulation of each Work Programme and Call for Proposals for research in materials science and engineering within any Framework Programme requires thorough preparation and consultation. Timely and thorough cooperation between all main stakeholders and the Commission Services is thus of great value.

A workshop was organised by the European Commission in Brussels on 9 December 2008 to discuss the methodology for research roadmapping suited to the EC Research programmes. Here, the following lay-out for a **closed** RRM was agreed (actual action plans for research projects implementing the RRMs are excluded).

A RRM could consist of **4 layers and 11 supporting chapters**

First layer
FP Theme (Health, Energy, Environment, ICT,...) supported by the NMP Programme

Second layer
Applications/systems supporting the Theme and enabled by new materials

Third layer
Materials and/or processes enabling the applications/systems

Fourth layer
Research necessary to create the materials

participants expressed interest in publishing their RRMs.

Vision for the future

In the following pages, the activities taking place in EC projects are presented, in the hope they will serve the development of views on the future research still necessary to face challenges presented to economic and sustainable development. These RRMs should provide a clear vision on the systems to be put in place, the necessary materials, and the underpinning research still required in the various fields. We hope that they will bring advantages to all stakeholders involved: research partners, industrials, national funding agencies and the EC.

Acronyms

NoE	Network of Excellence
DIS	Durable Integrated Structure created by a NoE
IP	Integrated Project
DG RTD G3	Added-value Materials Unit of the Directorate General Research
RRM	Research Road Maps
EC	European Commission
FP6	6th Framework Programme
FP7	7th Framework Programme
NMP	Nanosciences, Nanotechnologies, Materials and New Production Technologies (Theme in FP6 and FP7)
WP	Work Programme

Fig 1 Main Layers of a RRM

The supporting chapters justify why scientists, industry or funding agencies should invest in these research areas.

Supporting chapters

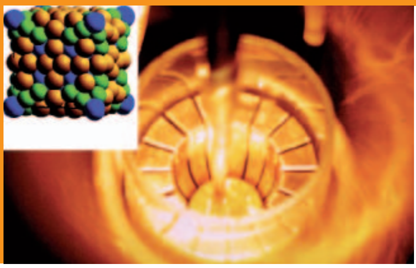
- Potential application domains/lead market sector for new material scientific and technological results.
- Context, including current bottlenecks.
- Motivation.
- Key performance figures (targets).
- Activity in- and dynamics of- the field, including the patent landscape.
- References.
- Time-line (for Research & Development and applications).
- Dependencies/conditions to be addressed (regulations, standardisation).
- Prioritisation for different (regional, national, European) funding schemes.
- Technology transfer possibilities and necessary education.
- Conclusions and recommendations.

The RRMs presented in this publication were created by projects funded by FP6 or FP7.
Note that the set of RRMs together do not cover the complete Materials Science &Technology domain.

Materials research is of a multi-disciplinary nature. Collaboration on cross-cutting issues would further the generic field of material science and hence be of benefit to all product applications serving many industrial sectors. Longer-term actions to strengthen horizontal cross-cutting industrial research should be undertaken to further the competitiveness of Europe in several sectors simultaneously. Such horizontal actions should involve the creation of both horizontal RRMs and/or horizontal infrastructures.

This publication is mostly (but not exclusively) based on the December 2008 Workshop, at which

CMA
Metallic alloys



Layer 1
Themes

- Energy
- Transport

Layer 2
Systems/applications

- Structures with reduced weight.
- Hydrogen production.
- Thermoelectric generators.
- Refrigeration.
- Protection for vehicles, aerospace, food processing machines, medical applications...

Layer 3
Materials enabling systems/applications

Metallic alloys and compounds in bulk and thin-film form with the following properties (or combinations of properties):
- High strength, light weight.
- Good thermoelectric properties with mechanical stability and environment-friendliness.
- Good magnetocaloric properties, low hysteresis losses.
- Good corrosion- and wear-resistance, low friction.
- Good corrosion-resistance, non-toxicity and/or bio-compatibility.
- etc.

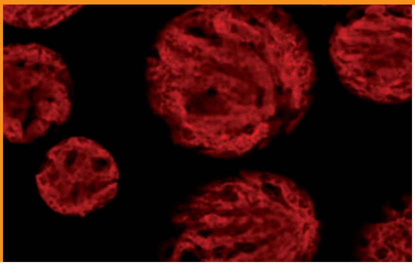
RRM Layer 4
Research issues to be addressed

- Fundamental research (experimental and theoretical) on thermodynamics and sample growth: phase diagrams, crystal growth, adsorption on clean surfaces, etc.
- Structural and electronic characterisation (bulk and surface).
- Understanding phase stability and chemical bonding.
- Modelling structural complexity.
- Mechanisms for stabilisation of complex or/ and a-periodic order.
- Role of complexity in the relationship between structure and physical properties.
- Role of complexity in surface properties (wetting, reactivity, friction...).
- Fundamental aspects of thin-film technologies production (modelling of reactors, modelling of chemical kinetics, system simulation, surface and gas phase in-situ diagnostics, identification of deposition mechanisms...).
- Understanding macroscopic deformation and modelling deformation processes.
- Basic research on thermoelectric cage compounds.
- Basic research on magnetocaloric materials.

More information
www.cma-ecnoe.org

DISC REGENERATION

Regeneration and repair of the degenerated intervertebral disc



Layer 1
Themes

- Health

Layer 2
Systems/applications

- Regeneration of intervertebral discs, bones, joints and blood vessels.

Layer 3
Materials enabling systems/applications

Biomaterials to repair and regenerate damaged intervertebral discs (IVD).

- Porous scaffolds.
- Injectable acellular and cell-loaded bioactive polymer-based scaffolds.
- Biomimetic materials with appropriate mechanical and biological properties and enable the inclusion of the requisite cell signaling factors to produce a biohybrid structure which closely resembles the human tissue in all its essential attributes.
- Cell technology to control cell differentiation and permit successful injection into the body.

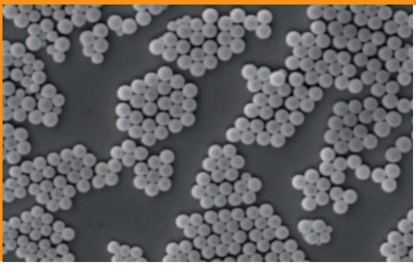
RRM Layer 4
Research issues to be addressed

- Regeneration of a healthy IVD and restoration of a physiological disc-vertebral system through appropriate biomimicking of the anatomy, physiology, cell biology and metabolism of the relative natural structures.
- Developing novel biomaterials capable of controlling angiogenesis such that it can proceed at different extents as required by the different regions of the disc structure.
- Definition of the appropriate cell sources, and identifying and evaluating suitable and more readily available alternative cells for incorporation in biohybrid substitutes.
- Angiogenesis: control over vascularisation via cell sources, materials functionalisation, over growth factor incorporation and delivery, to reach negligible vascularisation in the annulus and nucleus regions, and moderate vascularisation at the vertebral body level.
- Modeling studies to understanding of the physical aspects of the regeneration process.
- *In vivo* studies on animal models to ascertain the bio-functionality of substitutes.
- Enhanced integration of IVD tissue engineering with the adjacent vertebral body upon implantation.
- Less invasive surgery techniques.
- Surgical methodology and protocols to provide data for commercially implementable technologies.

More information

http://www.disc-regeneration.eu/

POLYSACCHARIDE and EPNOE
Bio-based polymers



Layer 1
Themes

- Health
- Food, Agriculture and Biotechnology
- Transport
- Environment

Layer 2
Systems/applications

- Medical applications (wound healing and drug delivery systems).
- Food products (e.g. controlled release of nutrients).
- Parts in cars, planes and trains.
- Fillers for concrete and parts for housing equipment.
- Sensors.

Layer 3
Materials enabling systems/applications

Novel polysaccharide-based materials (sustainable and CO_2–neutral plant biomass) from alternative sources (microorganisms, algae, crop residues, and new crops, etc)

- Feedstocks for new materials.
- Drug-delivery materials (hydrogels and functionalised polysaccharide-based materials).
- Wound-healing materials (e.g. high-water-content polysaccharide gels).
- Cosmetic products.
- Materials for diets (e.g. fat replacers) and functional food ingredients.
- Stimuli-responsive materials (e.g. changing structure, form, thickness, dependent on moisture, temperature, incorporated indicators).

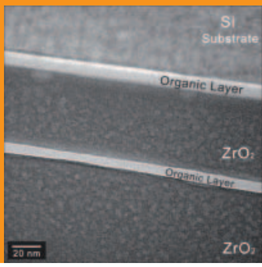
Layer 4
Research issues to be addressed

- Survey of available resources of plant polysaccharides in Europe, both marine and land based, with the aim of providing new sources of polysaccharides.
- Understanding genetic-physical-agronomic manipulations of bio-assemblies.
- Preparation of new strategies and routes for developing novel materials:
  - 3D shaping of solid polysaccharide materials from solutions;
  - thermoplastic cellulose processing;
  - enzymatic preparation of highly crystalline cellulose;
  - physical modification to provide new functionality;
  - new enzymology pathways to prepare biomass-based materials with tailored transport, surface and catalytic properties;
  - sequential extraction processes.

More information

www.epnoe.eu

EXCELL
Thin films



Layer 1
Themes

- Transport (incl. aeronautics)
- Energy
- Environment
- Health
- Safety

Layer 2
Systems/applications

- Coatings for wear-, oxidation- and corrosion-protection; low friction and self-lubrication..
- Environmentally adaptable nanocomposites for tools and machine parts.

Layer 3
Materials enabling systems/applications

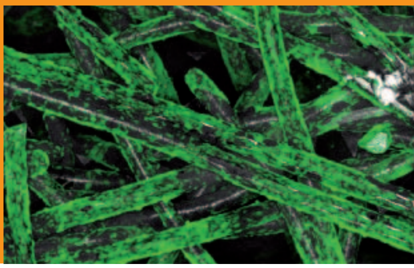
Ceramic nanocomposites:
- Hard, superhard and multifunctional ceramics.
- Difficult-to-cut materials with high oxidation- and corrosion-resistance for machines.
- Self-lubricating materials with low friction coatings to reduce energy consumption.
- Low-Cr nanocomposites with high hardness, while reducing environmentally hazardous elements.
- Strong, compact nanocomposites to eliminate the health risks associated with nanopowders.

Layer 4
Research issues to be addressed

- Development of advanced industrial nanocomposite coatings and coating technology for nanomaterials production that will provide better hard and superhard nanocomposites of higher hardness, thermal stability and oxidation resistance.
- Fundamental aspects of the development of new technologies transferable from laboratory to industrial scale at acceptable costs.
- Improving the presently available nanocomposite coatings by better control of the nanostructure formation and reduction of impurities.
- First-principles design of new nanocomposite coatings (combining ab initio DFT, non-linear FEM and thermodynamic modeling.
- Experimental verification of the results of new nanocomposite systems developed by first-principles design.

More information
www.noe-excell.net
www.vinf.eu

EXPERTISSUES
Tissue engineering



Layer 1
Themes

- Health

Layer 2
Systems/applications

- Reconstruction and regeneration of bone and cartilage tissue defects resulting from a number of clinical scenarios such as trauma, pathological degeneration, or congenital deformation.

Layer 3
Materials enabling systems/applications

- Hybrid scaffolds.
- Optimised cells and stem-cell culture.

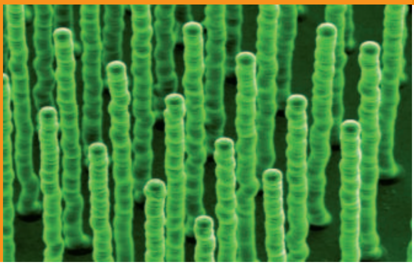
Layer 4
Research issues to be addressed

- New raw materials and scaffold development; standardisation of optimised cells; stem cell culture protocols.
- Study of bioactive surfaces and surface functionalisation; smart hybrid scaffolds with tissue-responsive properties; understanding biochemical and mechanical stimuli for the development of tissue with desired functionalities.
- Strategies for vascularisation of tissue during tissue growth and after implantation.
- Continuous research using proteomics/genomics tools, microarrays and cell-based tests to investigate the therapeutic value of novel biomolecules.
- Development of combined systems using growth factors or other bioactive molecules with carriers and release systems.
- State-of-the-art processing techniques such as microfabrication; rapid prototyping to produce tuned scaffolds with controlled topography and desired channel/porosity to provide tissue-specific response; design of *in vitro* culturing methodologies and related hardware equipment for the production of bone- and cartilage-like substitutes with enhanced *in vivo* functionality.
- Bioreactor technology for large-scale expansion of cells and 3D growth of tissues.
- Techniques for the storage, preservation and distribution of tissue engineering products; cryopreservation of stem cells, tissues and tissue-engineering constructs as a method to produce off-the-shelf products, available according to patients' needs.
- Bioinformatics to support tissue engineering; databases for tissue structure, function and biomaterial response.

More information
www.expertissues.org

FAME and EMMI
Hybrids and ceramics

RRM



Layer 1
Themes

- Energy
- Information Communication Technology
- Health
- Environment

Layer 2
Systems/applications

- **Energy** (conversion and storage):
  - Thermoelectrics – generators, refrigeration.
  - Delocalised energy production.
  - Sensors, transducers.
  - Heat pumps for building applications.
  - Solar cells, fuel cells, batteries.
  - Hydrogen generation by photocatalysis; hydrogen storage.
  - Solid-state lighting.

- **ICT:** Transistors, solid-state memory devices, nanoscale and molecular logic machines, metamaterial devices.

- **Health:** Tissue engineered organs and implants, magnetic contrast agents for magnetic resonance imagery (MRI), hyperthermia mediators, drug delivery and biosensors.

- **Environment:** Catalytic reduction of CO_2, gas sensors.

Layer 3
Materials enabling systems/applications

Inorganic materials, inorganic-organic hybrid materials and polymers:

- Eco-efficient, non-toxic materials; biocompatible and bioactive materials.
- Corrosion- and wear-resistant materials with mechanical stability.
- Bulk materials, thick films (micro-scale), thin films (nano-scale), nanostructured surfaces, nanostructured composites and nanocomposites, functionalised surfaces, mesoporous and nanoporous materials.
- Glasses, gel and hydrogel materials, hyperbranched polymers, foams, scaffold systems.
- Stimuli-responsive and phase-change materials for memories.

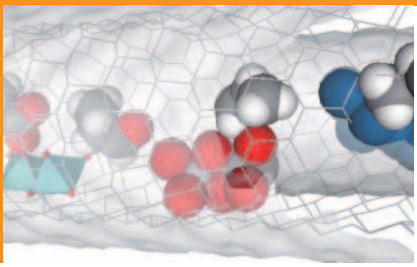
Layer 4
Research issues to be addressed

- Understanding and modelling of insulating/conducting interfaces between insulating and/or metallic oxides.
- Design of materials with specific parameters like conductivity, inductance, or dielectric, optical and magnetic properties.
- Deposition methods and self-assembly.
- *In-situ* nano-structuring of bulk materials, surface patterning
- Sintering of bulk materials (control of microstructure and nanostructure) and development of catalytic nanoreactors.
- Preparation of porous layers by chemical routes.
- Monitoring and control of the *in-situ* properties of thin films.
- *Ex-situ* measurements.

More information

www.famenoe.org
www.emmi-materials.eu

IDECAT and ERIC
Catalysis



Layer 1
Themes

- Energy
- Environment
- Transport

Layer 2
Systems/applications

- Sustainable chemicals production.
- Alternative fuel production processes.
- Efficient energy generation processes.

Layer 3
Materials and processes enabling systems/applications

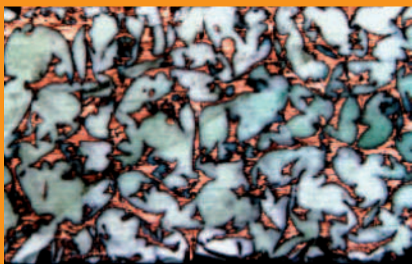
Catalysis routes to convert biomass and alternative raw materials into value-added products; sustainable processes that are energy- and eco-efficient, renewable, flexible, adaptive and carbon-efficient:
- Eco- and energy-efficient catalytic routes for the conversion of lignocellulosic biomass to biofuels and biomass-based chemicals.
- Novel electrocatalytic routes for the combined production of energy and chemicals using waste biomass resources.
- Oxygen-based catalytic processes for cleaner and energy-efficient chemical syntheses.
- Advanced catalytic methods for the reuse of CO_2.
- Tailor-made catalysts with specific properties: environment-friendly, recyclable, high selectivity, cost-effective and competitive.

Layer 4
Research issues to be addressed

- Effective multistep integration in catalytic processes (integration of several catalytic steps, combination of catalysis and innovative reaction and engineering concepts).
- Catalytic nanoreactors for process intensification and delocalised production.
- Solventless catalytic reactions (or using novel eco-friendly solvents).
- Smart catalysts integrating catalytic and sensor capabilities.
- Nano-architectured catalytic materials for energy storage and transformation.
- Selective activation of small molecules (N_2, CH_4, O_2) under mild conditions.
- Self-regenerating and adaptive catalysts.
- Predictive catalysis and synthesis of catalytic nano-designed materials.
- Complex, responsive and adaptive catalysts.
- Bio-mimicking catalysts for sustainable production of energy and chemicas.
- Understanding the interface between solid and biomolecules.
- Minimisation of waste and risk.

More information
www.idecat.org

KMM-VIN
Multi-component materials



Layer 1
Themes

- Transport
- Energy
- Health

Layer 2
Systems/applications

- **Transport:** elements of combustion engines – valve-trains, camshafts; elements of aero-engines – turbine blades, exhaust systems, sensors, actuators; devices for motion control, brakes.
- **Energy:** hydrogen storage; burning devices for high-sulphur coal; oil drilling components; coils in thermonuclear reactors, thermal management.
- **Health:** biomedical applications; substitution or repair of lost tissue function; sensors and actuators for control and support of many bodily functions.

Layer 3
Materials enabling systems/applications

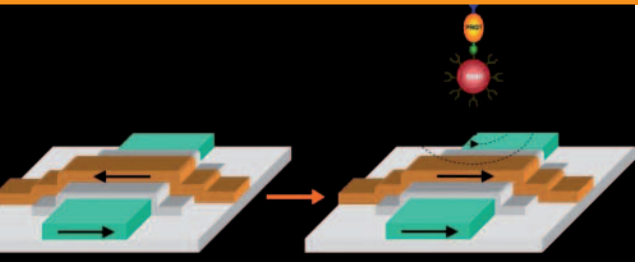
- Metal-ceramic composites (structural and multifunctional) and functionally graded metal-ceramic materials.
- Thermoelectric materials and composites.
- High-temperature, lightweight and porous ceramics.
- Matrix materials: smart intermetallics and magnetic glass-ceramic or polymer composites.
- Fibre-reinforced glasses and ceramic bioglass (resorbable) foams with polymer coatings.
- Bioactive materials and biofibres including anti-bacterial coatings.
- Phase-change materials (especially textiles) embedded in organic and metallic matrices
- Conducting polymers.
- Nanostructured and hybrid (inorganic/organic) materials and coatings.

Layer 4
Research issues to be addressed

- Modelling of the above materials.
- Modelling of sintering/microstructure development.
- Development of new metal-ceramic composites with high ductility, toughness and corrosion resistance.
- Development of reliable characterisation methods for advanced composites and functionally graded materials.
- Integrated closed-loop process-characterisation-modelling for nano/micro-structured biomaterials.
- Multilayer technology for new piezoceramics for high temperature applications.

More information
www.kmm-vin.eu

MAGISTER
Bio-inspired nanostructured oxides



Layer 1
Themes

- Health
- Environment
- Energy
- ICT
- Transport

Layer 2
Systems/applications

- Drug delivery, molecular analysis.
- Sensing (gasses, water quality).
- Energy conversion, Solar cells, batteries; and.
- Storage: ferroelectric random access memory; optical switching; photonic crystals; other optical; infrared and piezoelectric detectors; and flexible displays.
- Transport applications.

Layer 3
Materials enabling systems/applications

- SiO_2 (various forms of silica, bio-silica, salicylic acid).
- TiO_2, ZnO.
- Other metal oxides, hydroxides, phosphates and perovskites.
- New bio-inspired nanostructured oxides and nanocomposites.
- Biomineralisation.

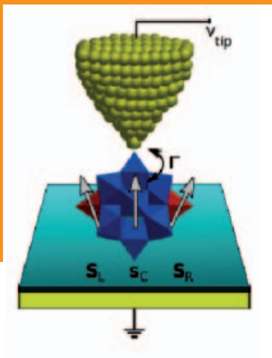
Layer 4
Research issues to be addressed

- Precursor materials: biological species selection (there are many thousands of diatom species, only one of which has its genome sequenced).
- Bio-inspired oxide materials growth and processing.
- Bio-inspired oxide materials characterisation (stoichiometry/composition, mechanical, electrical, optical).
- Exploration of the industrialisation of these bio-inspired materials for various applications.
- Bio-inspired oxide materials with ferroelectric and ferromagnetic properties for early diagnostics and drug delivery.

More information

www.magister-project.eu

MAGMANET, MAGISTER and EIMM
Magnetic materials



Layer 1
Themes

- ICT
- Energy
- Environment
- Health
- Security

Layer 2
Systems/applications

- **Health:** smart magnetic scaffolds, remotely guided angiogenesis, remotely controlled drug delivery, magnetic lab-on-a-chip, magnetic resonance imaging, magnetic nanosensors for biodiagnostics, magnetic systems for theragnos-tics (the combination of diagnosis and therapy).
- **ICT and Security:** magnetic logic circuitry mediated by magnetic or electrical fields, or by pure spin control or anisotropy; low loss signal transmission; nano- and micro-scale magnetic memories; sensors and detectors (tagging); spintronic applications.
- **Environment:** chemical sensors based on magnetic materials; water purification technologies.
- **Energy:** magnetic OLEDs tuning the emitted light and its colour by the spin; low-temperature magnetic refrigeration.

Layer 3
Materials enabling systems/applications

- Magnetic nanostructured materials, magnetic nanocomposite materials and interfaces, small single and multidomain magnetic nanoparti-cles and magnetic metamaterials.
- Bio-compatible magnetic materials, including functionalised magnetic nanoparticles for biomedical applications.
- Molecule-based magnetic materials: low density, inexpensive, mechanical flexibility, low temperature processability, high strength.
- Multifunctional magnetic materials: hybrid materials integrating organic and inorganic characteristics, multiferroic materials; stimuli-responsive magnetic materials.

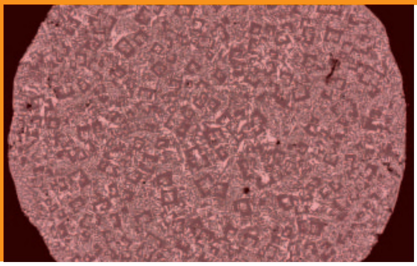
Layer 4
Research issues to be addressed

- Design of (molecular) magnetic materials with controllable structural/electronic features at the nanoscale (switching, photomagnetism, solubility, transparency, ...).
- Design of multifunctional magnetic materials (porosity, (super)conductivity, ferroelectricity, chirality, bistability, ...).
- Manufacturing via bottom-up fabrication (self-assembling and self-organisation), epitaxial growth, hybrid-material lithography and growth in a magnetic fields.
- Grafting and organisation of nanomagnets on surfaces and interfaces and engineering of interfaces.
- Relationship between processing techniques and material properties.
- Low-cost characterisation, metrology techniques and stardardisation (for single spins).
- Development of polarisation measurement techniques not dependent on spin-orbit coupling.

More information

www.magmanet-eu.net
www.magister-project.eu
www.eimm.eu

METAMORPHOSE and its VI
Nanostructured metamaterials



Layer 1
Themes

- Energy
- ICT
- Health
- Environment
- Transport
- Security

Layer 2
Systems/applications

- **Energy:** Low-loss electronic and optical components, advanced solar cells, intelligent control of power consumption and generation.
- **ICT:** Smart, adaptive integrated electronic and optical circuits and devices; sub-wavelength optical information processing systems, low-cost, low-power-consumption communication and control systems; magnetically and electrically controllable components.
- **Health:** Sensors, including biosensors; on-body communication systems; in-body drug delivery and control devices; implanted actuators.
- **Environment:** Monitoring and imaging devices
- Transport: Car radars, sensors, road safety monitoring systems, road monitoring and vehicle tracking.
- **Security:** Security control devices, sensors, imaging and monitoring devices.

Layer 3
Materials enabling systems/applications

Materials with superior and unusual electromagnetic properties:

- Negative-valued permittivity and permeability.
- Near-zero values of permittivity and/or permeability.
- Extreme anisotropy (e.g., permittivity along one direction is close to zero but permittivity in the orthogonal direction is very high).
- Strong and anisotropic spatial dispersion (material parameters strongly depend on the wave vector).
- Extremely strong chirality and other bi-anisotropy coefficients.
- Externally tunable parameters.
- Designed-for-purpose nonlinearity.

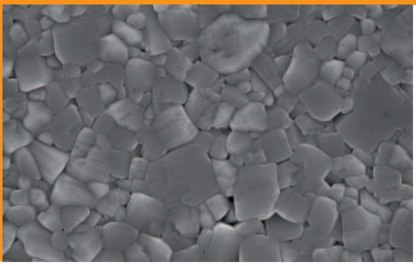
Layer 4
Research issues to be addressed

- Theoretical modelling and design of artificial materials – providing design control over material parameters, losses, spatial dispersion and non-linearity.
- Conceptually novel architectures for electrical, magnetic, and optical control of the properties of engineered materials.
- Active optical materials with compensated loss.
- Nano-structured light- and microwave-energy harvesting materials.
- Research on field-transforming metamaterials (cloaks, concentrators, dividers).
- Targeted synthesis of electromagnetic materials.
- *In-situ* and non-destructive characterisation of artificial electromagnetic materials.

More information

www.metamorphose-eu.org
www.metamaterials-eu.org

MIND and the PIEZO-INSTITUTE
Piezoelectric materials



Layer 1
Themes

- Health
- Transport
- ICT (Telecommunications)
- Energy
- Security

Layer 2
Systems/applications

- Sensors.
- Transducers.
- Active devices (including actuators, micro-pumps, micro-motors, noise reduction, energy transformers and harvesters).

Layer 3
Materials enabling systems/applications

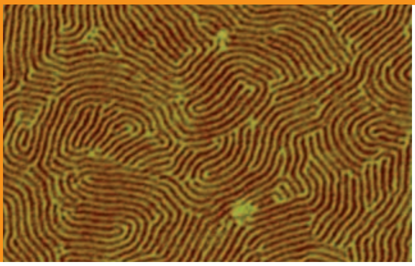
- Lead-free ceramics: KNN (potassium-sodium-niobate) family.
- Novel lead-based ternary ceramics.
- Thin and thick films of lead-based and lead-free compositions.
- 3D micro- and nano-structures, including high aspect ratio elements and nanowires.
- Integrated structures, including piezo/passive, piezo/semiconducting.

Layer 4
Research issues to be addressed

- Piezo-electric materials with better electro-mechanical performance (doping, nanoparticles, phase instabilities, interfaces, defects, tunability).
- Piezo-electric materials with better extreme-environment behaviour and biocompatibility (stability, lifetime, bio-mimetics via hybrid-piezo-electric materials).
- Multifunctionality (piezo and magnetism/strain).
- Lead-free materials and processes (ceramics and flexo-electric composites).
- Manufacturing processes (low temperature, composites, spark plasma sintering).
- Characterisation, modelling and design (extreme conditions, across length scales, composites, industrial versions).

More information
www.piezoinstitute.com

NANOFUN-POLY and ECNP
Multifunctional nanostructured polymers and nanocomposites



- Semiconductors.
- Protonic exchange membranes.
- advanced polymeric coatings and filters.
- Biopolymers and polymeric scaffolds.
- Polymeric materials with nanomarkers for traceability.
- Agriculture plastic films.
- Cellulose in polymers.

Layer 1
Themes

- ICT
- Energy
- Health
- Environment
- Transport (inc, aerospace)
- Security
- Food and agriculture

Layer 2
Systems/applications

- **ICT:** flexible electronics; low-loss electronic and optical components; sensors, including biosensors.
- **Energy:** photovoltaic devices, energy storage, fuel cells, thermal insulation.
- **Health:** *in-vivo* and *in-vitro* tissue engineering and orthopaedic devices;
- theranostics, cosmetic products.
- **Environment:** advanced recycling processes for polymeric materials; multifunctional food packaging; drug delivery for agricultural applications; soil remediation; water desalination.
- **Transport:** structural parts, functional (corrosion protection) coatings and interior materials for road vehicles, trains, naval applications, aeronautics and aerospace.

Layer 3
Materials enabling systems/applications

- Polymer composites and nanocomposites, nanostructured polymers and block copolymers.
- Hyperbranched polymers with multifunctional properties.

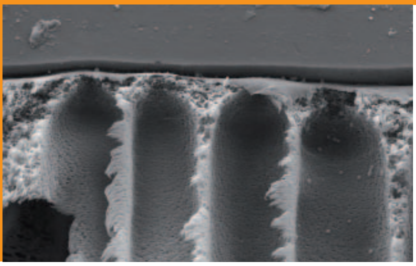
Layer 4
Research issues to be addressed

- Functionalised fibres, films, composites and 3D objects with complex shapes through hierarchical design at all length scales (macro-, meso-, micro- and nano-).
- Multifunctional nanostructured and organic-based nanocomposite coatings for protection and decoration, with improved properties (toughness, transparency, scratch resistance, barrier).
- Multifunctional materials for flexible organic electronics and : energy-conversion.
- Multifunctional materials for protonic exchange membranes with high mechanical properties, thermal stability and functional life for fuel cells.
- Polymer nanocomposites with purpose-designed barrier properties.
- Iintrinsically flame-retardant nanostructured polymers and nanocomposites.
- Inclusion of nanoparticle toxicity in life cycle assessment (LCA) methodology.
- Development of bio-based polymer nanotechnologies.
- Polymer scaffolds with controlled porosity and nanoparticle, distribution, plus surface and bulk properties customised for protein and cell attachment in tissue engineering.
- Layer-by-layer production technologies for nanostructured polymers and nanocomposites including *in-situ* nanostructuration.

More information

www.nanofun-poly.org
www.ecnp.eu.org

NANOMEMPRO and European Membrane House
Membrane materials



Layer 1
Themes

- Energy
- Environment
- Health
- Food

Layer 2
Systems/applications

- **Environment:** membrane bioreactors; effluent processing; enhanced drinking water treatment; water desalination; CO_2 capture.
- **Energy:** H_2 separation; methane removal from natural gas and biogas; fuel cells (particularly high temperature); new processes for energy production (reverse electro-dialysis; pressure-retarded osmosis); energy saving (ammonia separation, dehydration…).
- **Health:** Artificial and bio-artificial organs, sensors and actuators; repair surgery.
- **Food:** Membrane contactors, membrane emulsification and encapsulation; biological reactors.

Layer 3
Materials enabling systems/applications

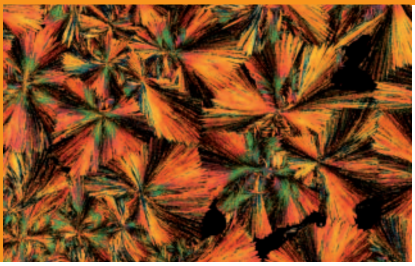
- Inorganic membranes.
- Organic/polymeric membranes.
- Mixed matrix membranes.
- Biocompatible materials.
- Membranes for tissue engineering.
- Membrane materials for packaging.
- Affinity membranes.

Layer 4
Research issues to be addressed

- Modelling and simulation for improved material design:
  - reconstruction in 3D materials for identification of internal morphology;
  - stronger predictive model for membrane degradation;
  - investigation of the role of membrane properties as regards performance;
  - new progress in simulation of pore blocking and fouling.
- Integration-based processes:
  - for new membrane manufacturing (from lab to industrial scale);
  - as a privileged way for process intensification (separation, reaction, phase contacting purposes….);
  - use of more friendly solvent media in membrane processes;
  - monitoring and control of membrane technologies for improved safety and increased efficiency (energy, end-product quality…).

More information
www.nanomempro.com
www.euromemhouse.com

ONE-P
Organic multifunctional materials for sensors and biomedical applications



Layer 1
Themes

- ICT
- Health

Layer 2
Systems/applications

- **ICT:** Specific, biocompatible, stable, reliable, sensitive biosensors based on organic/plastic electronics, scalability to mass production.
- **Health:** Remote diagnosis; continuous monitoring of biophysical signalling (temperature, stress, pressure) outputs; minimal invasive endoscope/catheter for diagnostics and therapy; diagnostics devices for telemedicine; integrated systems for detection by cell, DNA, protein and enzyme analysis.

Layer 3
Materials enabling systems/applications

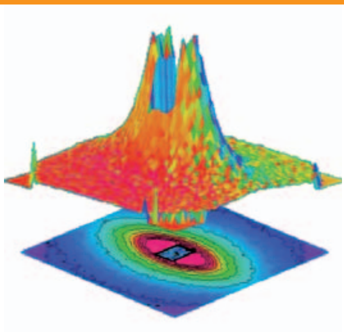
- Multifunctional materials that combine charge transport and/or fluorescence with biocompatibility, specific biorecognition and biostability.
- Nanostructured surfaces as *in-vivo* and *in-vitro* biosensors for molecular markers related to various diseases (cancer, cardiovascular, diabetes, inflammatory, neurodegenerative, infectious).

Layer 4
Research issues to be addressed

- Fundamental research on organic and polymer semiconductors.
- Fundamental understanding of biocompatibility and specific biorecognition.
- Theoretical modelling of charge transport, fluorescence, exciton diffusion and specific bio-recognition to reach predictive design rules for new materials.
- Synthesis of novel multifunctional biocompatible materials through covalent and supramolecular interactions.
- Characterisation of material properties, structures and functions.
- Integration of functions into materials or sets of compatible materials; role of surfaces and interfaces on biosensor performance.
- Encapsulating materials protecting the electronic functionality against bodily fluids and/or undesired contact with the body.
- Materials and inherent fabrication methods adapted to scalable mass production.

More information
www.one-p.eu

SOFTCOMP
Soft matter composites



Layer 1
Themes

- Energy
- Food, agriculture and biotechnology
- Health

Layer 2
Systems/applications

- Coatings and paints.
- Resins.
- Oil recovery.
- Processing systems for polymers, gels and pastes.
- Cosmetics.
- Body and skin care products.
- Drug delivery.

Layer 3
Materials enabling systems/applications

- Composite materials.
- Surfactants, colloids and polymers.
- Proteins.
- Materials with controlled porosity.
- Emulsions.
- Membranes and cells.
- Block copolymers with additives.
- Complex composite glasses and gels.
- Environment-friendly cleaning agents.
- Biomineralisation.
- Cleaning agents for printers.

Layer 4
Research issues to be addressed

- Molecular engineering and flow rheology:
  - flow behaviour and structure formation;
  - flow behaviour of self-assembled structures;
  - molecular rheology of polymers and blends.
- Self-assembly and structure formation:
  - phase behaviour and pattern formation in external fields;
  - biomimetic systems for cell biology;
  - self-assembly in complex amphiphilic systems;
  - tailoring polymer/nanofiller composites.
- Slow dynamics:
  - glass and gel formation in complex mixtures;
  - polymer dynamics in increasingly complex environments.

More information
http://www.eu-softcomp.net

European Commission

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Materials science and technology are advancing fast: they are of particular relevance for industry and society as materials create added value in most products. It is generally recognised that new materials can make crucial differences in many products: helping to increase the functionality, minimise costs and render products more attractive, portable, or usable by making them smaller and lighter.

The Nano Materials Production (NMP) Theme develops both multi-application materials, and materials for targeted applications, mostly in the FP7 Thematic Areas: Energy, Environment, Health, ICT and Transport.

In this brochure we present the activities taking place in EC projects to develop views on future research still necessary to face challenges in Materials Science & Technology related to economic and sustainable development. These research roadmaps (RRMs) should provide a clear vision on the systems to be put in place, the necessary materials, and the underpinning research still required in the various fields. We hope that they will bring advantages to all stakeholders involved: research partners, industrials, national funding agencies and the EC.

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