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RESEARCH AT EUROPEAN LEVEL ON NANOSTRUCTURED MATERIALS

J.L. Vallés and I. Vergara*

Materials Unit. DG Research, European Commission, B-1049 Brussels, Belgium

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Abstract. Research on nanostructured materials has enjoyed a tremendous development in recent years, touching multiple areas of knowledge, and has produced innovative scientific and technological breakthroughs. The European Commission has already played an important role in the support of research on nanostructured materials at European level during the so-called Fifth Framework Programme and it will keep paying increased attention to this area under the current Sixth Framework Programme. The EC funded research projects and networks in this field are mainly focused on the development of novel nanostructured materials, in particular nano-composites and multifunctional thin-films, having radically new nanostructures and exhibiting chemical and physical properties that are significantly different from those of conventional materials, and thus potentially leading to promising technological applications.

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1. INTRODUCTION

Nanostructured materials, which have a unique microstructure tailored at the nano-level and exceptional nanosize-dependent behaviour, are a relatively new class of materials which can address many of today's industrial needs. Unlike traditional engineering materials, these materials contain grains or particles with an average size between 1 and 100 nm, or layers or filaments of that size. The combination of a composite-like nature and the nanoscale features results in exceptional properties that do not obey the simpler laws deduced for other bulk materials. An important reason for this is that nanostructured materials have a large number of atoms residing in grain boundaries and this fact strongly influences their properties. As an example, nanostructured coatings present improved mechanical performance, such as better lubricity, hardness, or corrosion resistance, that contributes to the overall quality of the component. The application of appropriate coating systems is also highly relevant for sustainable development, since it allows conserving scarce resources or substituting toxic materials.

The development of new nanostructured materials with customised properties and providing new functionalities is one of the challenges of nanotechnologies and it will have a major impact on many technological areas and industrial sectors. The use of this class of materials will increase as we improve our ability to tailor them, e.g. for novel catalytic, sensors, structural, electrical, magnetic, and biomaterials applications.

The European Union recognises the importance of Research and Technological Development in order to fulfil its ambitious objective, adopted at the Lisbon summit in 2000, of becoming the most dynamic and most competitive knowledge-based

Corresponding author: J.L. Vallés, e-mail: Jose-Lorenzo.Valles@cec.eu.int

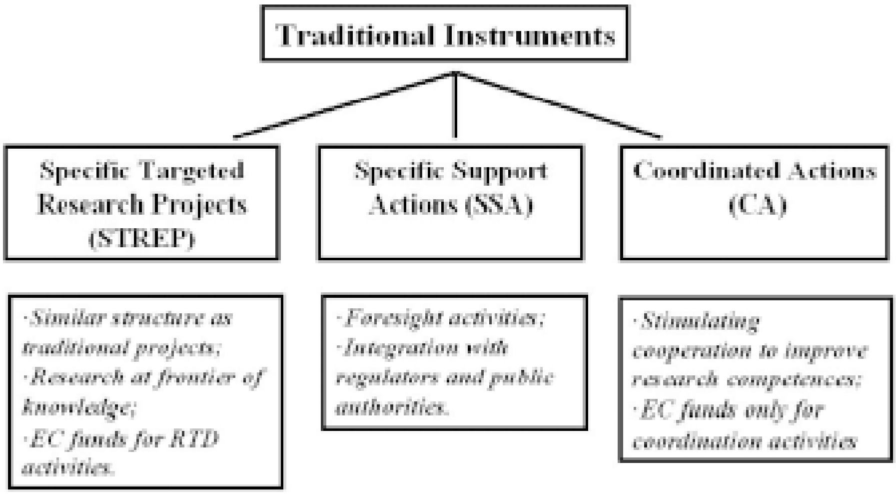

Fig. 1. Short description of the Traditional Instruments used in the implementation of the 6th Framework Programme.

economy in the world by 2010. The European Commission has supported research activities at European level for more than 20 years through multi-annual programmes under the so-called 'Framework Programme for Research, Technological Development and Demonstration'.

The current Sixth Framework Programme (FP6), covering the period 2002 to 2006, is a deliberate break with past FPs with regard to ambition, scope and the instruments to be used in its implementation. The aim is to achieve greater focus on questions of European importance (through Thematic Priorities) and a better integration of research efforts on the basis of an improved partnership between the various actors in the European Research Area, a new concept which was introduced by the European Commission with the aim of creating better overall framework conditions for research in Europe.

Under FP6, there is a wider range of instruments to implement the Thematic Priorities than was available in the past. Besides the 'traditional' instruments, described in Fig. 1, two new instruments called Networks of Excellence and Integrated Projects (see Fig. 2) have been made available. The two new instruments have a high level of management autonomy, including, where appropriate, the possibility to adapt the partnership and the content of the project or network. They are expected to have the capacity to mobilise the critical mass of expertise needed to achieve ambitious objectives, and to have strong structuring and integrating effects. The objective of the Networks of Excellence (NE) is to tackle fragmentation of existing research capacities in order to strengthen scientific and technological excellence on a particular research topic, by integrating at a European level the critical mass of resources and expertise needed to provide European leadership in that topic. The integration will be realized via a Joint Programme of Activities, by creating a progressive and enduring integration of the research capacities of the network while at the same time developing advanced knowledge.

An Integrated Project (IP) is instead designed to give increased impetus to industrial competitiveness or to address major societal needs by mobilising a critical mass of RTD resources and competencies. To achieve this, they should have ambitious and clearly defined S&T objectives, directed at obtaining specific results. As such, they go further than the clusters of projects in FP5 which, for example, did not have a large budget available for management and coordination and lacked the flexibility and the integrated activities available to IPs, such as training, technology transfer, or IPR issues.

2. RESEARCH ON NANOSTRUCTURED MATERIALS UNDER FP5

The Fifth Framework Programme covered the period 1998-2002. Under FP5, Industrial Technologies, and in particular Materials Research, were included within a Thematic Programme called 'Competitive

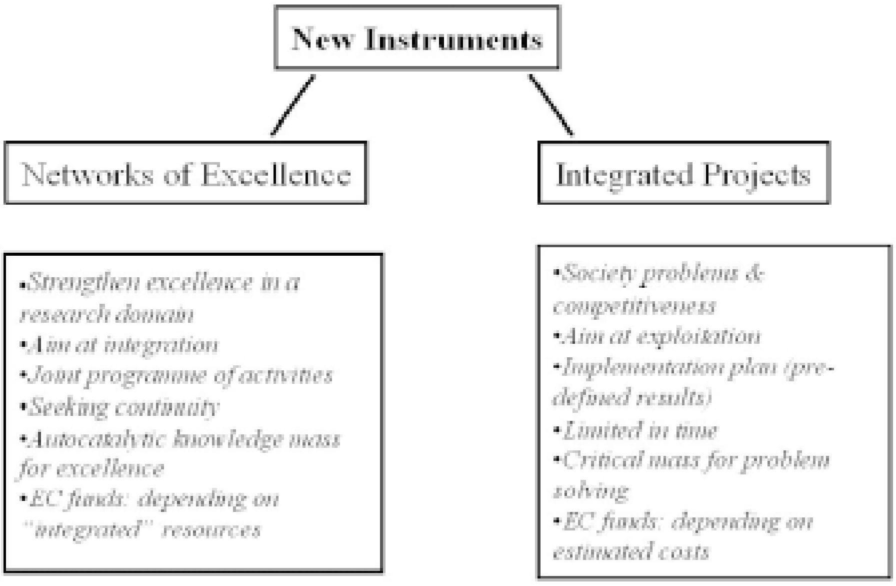

Fig. 2. Short description of the New Instruments used in the implementation of the 6th Framework Programme.

and Sustainable Growth' (GROWTH), which had a budget of € 2.705 million (or 19.7% of FP5).

The area of Nanostructured Materials was not specifically defined as such in FP5. Nevertheless, over 60 research projects in this research domain were funded under the GROWTH Programme, involving a total EC contribution of about 74 M€. The research topics in these projects covered a wide set of areas, such as tribology, magnetic storage, electronic, energy storage, catalysis, photonics, flame-retardant materials, and high-temperature coatings.

The 'Nanostructured tribological coatings' (NANOTRIB) cluster of projects (see Fig. 3) is a good example of the research on nanostructured materials carried out under FP5. Where areas of common interest clearly existed, consortia of individual research projects under FP5 were actively encouraged to co-operate in the framework a cluster of projects, in order to further enhance the coordination and the strategic impact of the projects and to build a critical mass. The NANOTRIB cluster established synergies between the consortia of six projects funded within the GROWTH Thematic Programme. These projects, called HIDUR, LUBRICOAT, MICLUB, NANOCOMP, SMART QUASICRYSTALS and TRIBO, all belonged to the field of nanoscale protective and lubrication films and low and high-friction surfaces. The combined effort involved a total of 60 partners from 16 European countries, including 24 SMEs. The total investment of the NANOTRIB cluster reached €16 millions, of which the European Commission provided half, and it clearly conformed to the criterion of reaching a critical mass from which significant results with wide-ranging applications could be expected. The cluster involved multidisciplinary teams addressing multisectoral applications, from metal forming and machine tools, to automotive engines, wind turbines and satellite mechanics. In addition, each of its constituent projects tried to provide a major contribution to sustainability: by minimising the use of materials through an enhancement of performance at the nano-scale, by optimising the use of renewable organic-based lubricants, or by seeking to extend product lifetimes and reduce energy consumption.

In spite of the fact that the six projects were conceived separately, the NANOTRIB cluster offered clear advantages to the members of the individual projects, such as a reduction of overlaps, synergy of ideas, networking for future collaborations, or a more efficient identification of the gaps in science or processing knowledge. Overall, the main results of this cluster of projects have been:

- The development of advanced high-performance Solid Lubricant Coatings with special applications on machinery and aerospace friction joints, with an improved performance that may be realised only by the increase of the allowable

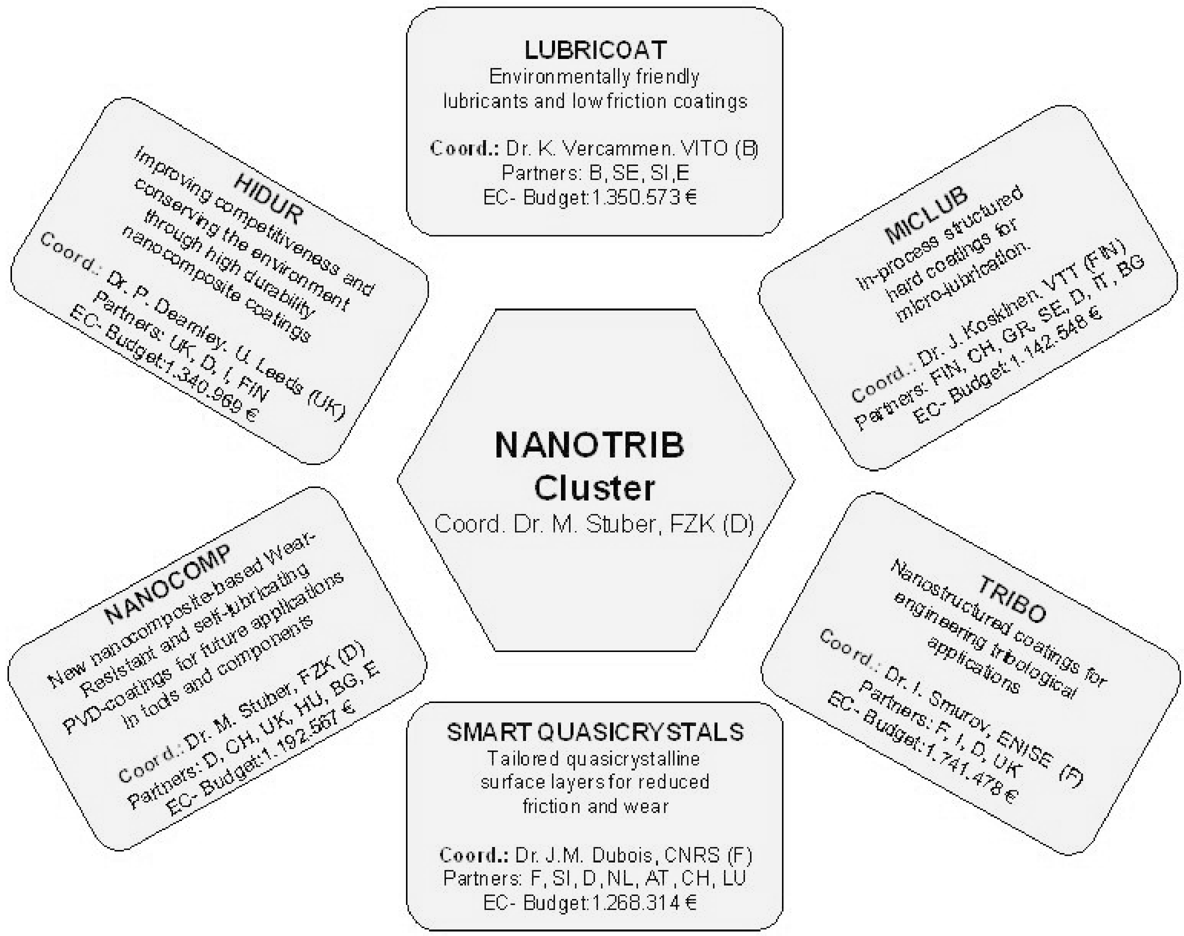

Fig. 3. Schematic information of the projects involved in the NANOTRIB cluster.

contact loads and operating temperatures. The coatings developed consist of Metal Matrix Composites produced by laser-assisted methods (Project TRIBO).

- The development of a new deposition process (low-temperature, single-step physical vapour deposition) that enables to obtain hard coatings with pre-defined surface nanostructures on tools for minimum lubrication in metal forming (see Fig. 4). The new process produces topographical micro-pores, which can entrap microscopic quantities of lubricant and, during a forming cycle, subsequently expel the fluid into the critical contact areas of the tool/workpiece interface (Project MICLUB).
- New industrial deposition processes developed in order to produce new, wear-resistant and simultaneously self-lubricating coatings that meet, for example, demands of high temperature applications in drilling and milling tools and of low temperature applications in tribologically stressed components, using a novel combination of coating concept based on a hard metaestable ceramic matrix with nanocluster inclusions of a dry-lubricant phase of carbon or MoS_2. Multilayers of such coatings are also very promising in wear and friction behaviour (Project NANOCOMP).
- The development of an innovative tribological system consisting in a combination of vegetable or synthetic oil based biodegradable lubricants and low friction surface coatings, such as diamond-like carbon, with a positive impact in the environment (Project LUBRICOAT).
- The development of nanocomposite wear-resistant coatings on Aluminium alloys. The Al alloys combine good thermal properties with low density and are therefore ideal candidates for lightweight automotive disc brake rotors. The poor wear resistance of these alloys, however,

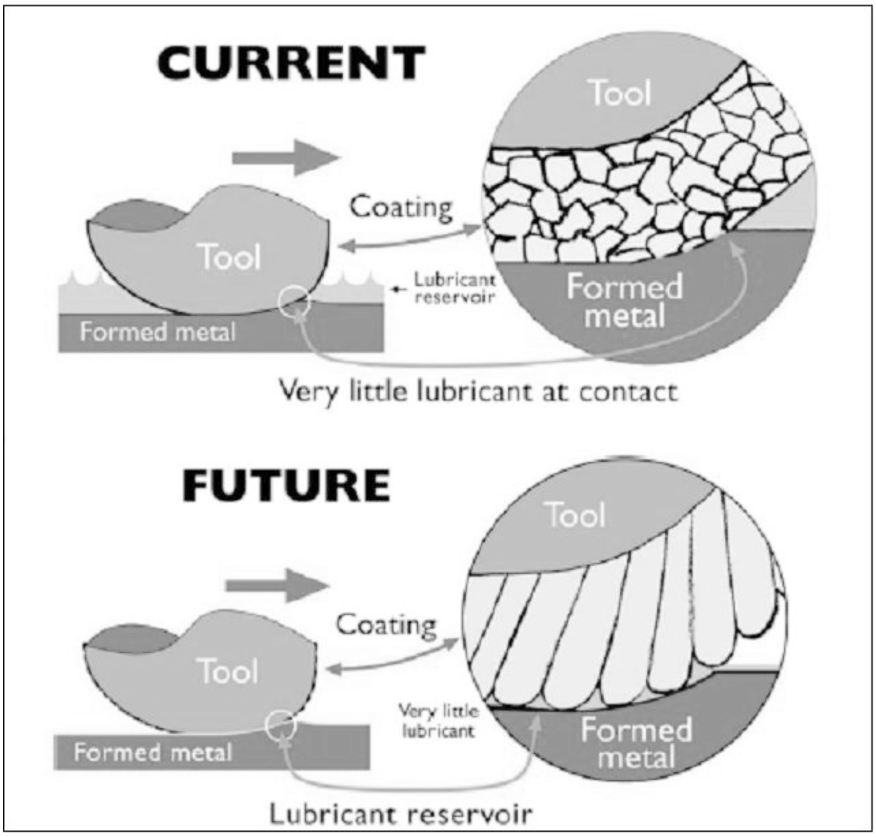

Fig. 4. Microlubrication process used in Project MICLUB, which has developed a nanostructured coating on the surface of tools for metal forming using physical vapour deposition.

necessitates the use of wear-resistant coatings on the rubbing surfaces. Investigations on the friction response of a titanium matrix nanocomposite-coated aluminium rotor are still currently undergoing (Project HIDUR).

- Understanding of the fundamental knowledge related with the mechanism of friction and the wear behaviour of quasicrystalline materials, and a demonstration of the usefulness of these materials in non-lubricated friction (Project SMART QUASICRYSTALS).

3. RESEARCH ON NANOSTRUCTURED MATERIALS UNDER FP6

The research area of Nanostructured Materials has reached an even higher relevance under the ongoing Sixth Framework Programme. It forms part of Thematic Priority 3, denominated ‘Nanotechnology and nanosciences, knowledge-based multifunctional materials, and new production processes and devices’, and it has become one of the most successful areas of research under the Materials sub-domain. The budget of Thematic Priority 3 was initially €1.300 million for the period 2002-2006, representing 10% of the funds devoted to the Thematic Priorities (see Fig. 5), and it was later increased in about 10% with additional funds. Three sets of Calls for proposals have already been launched since the start of FP6, in December of 2002, 2003 and 2004. In the first two sets of Calls, several areas were open in which proposals dealing with research on nanostructured materials were retained for funding:

– New materials by design (IP, NE, STREP, CA, SSA) -First Calls
– Expanding knowledge in size-dependent phenomena (NE, STREP, CA) - First Calls
– Self-organisation and self-assembling (IP, NE, STREP) - First Calls
– Understanding materials phenomena (NE, STREP, CA) - First Calls
– Development of nanostructured materials (IP) - Second Calls

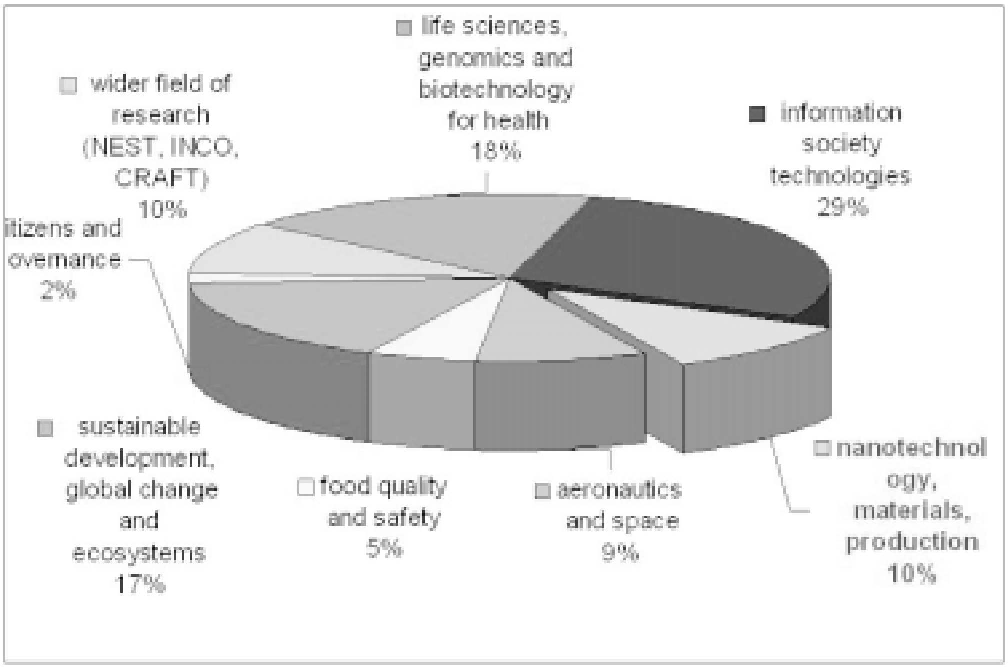

Fig. 5. Thematic Priorities in the 6th Framework Programme, according to budget.

- Tribology related surface engineering for multi-functional materials (IP) - Second Calls
- Bio-inspired materials & Organic/Inorganic Hybrid materials (STREP) - Second Calls
- Self-organisation and self-assembling (STREP) - Second Calls
- Nanostructured surfaces (IP) - Second Calls
- New production technologies for high added value products, exploiting and using nanoscale precision engineering techniques (IP) - Second Calls
- Hazard reduction in production plant and storage sites (IP) - Second Calls
- Mastering chemicals and creating new eco-efficient processes and synthesis routes (IP, NE) - Second Calls

The Integrated Projects specifically funded under 'Development of nanostructured materials' were required to have an industrial leadership and to be focused on the development of nanostructured materials, in particular nano-composites and multifunctional thin films, having radically new nanostructures and exhibiting radical innovation in the tribological behaviour and functionality.

Table 1 provides information on the total number of proposals received in the First and Second Calls, and of those retained for funding, in which research on nanostructured materials was a core part of the proposal. Table 2 lists the successful IP and NE proposals among those considered in Table 1. The average European Commission grant to the NEs included in Table 2 is around € 7,3 million and the average total budget of the IPs is about € 14,5 million, from which the EC is funding on average € 9,5 million (or 65,5%). The main topics covered among the IP, NE and STREP proposals retained for funding in this field are the following:

- fire-retardant polymer nanocomposites
- nanostructured materials for energy production
- nanostructured coatings for self-cleaning glasses
- super-hard nanocomposite films
- corrosion protection
- nanostructured coating conductors
- catalytic nanomaterials
- ceramic nanocomposites for multiple applications

The third and last Calls for proposals of Thematic Priority 3 were launched in December 2004. The deadline for receiving the 'traditional' instrument proposals and the second-stage proposals of the IPs is 15 September 2005. Among the domains open in these Calls, proposals related to nanostructured materials could be expected, for instance, in the following research areas:

- Development of nanostructured porous materials (IP)
- Advanced materials processing (CA)
- Interfacial phenomena in materials (STREP)

Table 1. Summary of the proposals received and retained for funding in which research on nanostructured materials was a core part of the project. Traditional Instruments (TI) are: STREP, SSA, and CA (see Fig. 1). New Instruments (NI) are: IP and NE (see Fig. 2).

	Nanostructured Materials – proposals received	Percentage of total proposals	Nanostructured Materials – proposals retained
1st Calls - TI	73 185 M€ requested	20%	16 STREP 40 M€ requested
1st Calls - NI	23 IP + 31 NE 600 M€ requested	13%	0 IP + 4 NE 50 M€ requested
2nd Calls - TI	70 280 M€ requested	17%	10 STREP 34 M€ requested
2nd Calls - NI	29 IP + 4 NE 380 M€ requested	21%	7 IP + 1 NE 142 M€ requested

– Multifunctional ceramic thin films with radically new properties (STREP)
– Materials by design: multifunctional organic materials (STREP)
– Materials for solid state ionics (STREP)

The project IP-NANOKER (see Table 2), starting in Spring 2005, is a good example of the IPs funded in the field of nanostructured materials. Its objective is to develop and industrialize knowledge-based nanoceramics and nanocomposites for top-end functional and structural applications (see Fig. 6) that are beyond reach with only incremental materials development. In fact, many new technological advances in ceramics are limited by the impossibility to combine high mechanical performances of actually known ceramic materials with critical functional or structural material properties. The industrial applications of nanocomposites with ceramic and metallic nanoscale particles or nanoscale phases rely on the successful consolidation of these materials into bulk-sized components while preserving their nanostructures. Traditional consolidation techniques have the strong limitation of not being able to retain the nanoscale grain size. The multisectoral and cross-cutting approach of this IP is essential in order to assemble the critical mass needed fulfil its ambitious objectives. The specific technological objectives and expected breakthroughs of IP NANOKER are:

– New multifunctional materials with hardness, fracture resistance and fracture toughness properties up to 2 or 3 times higher than the best state-of-the-art materials that operate in chemical-physically aggressive environments.
– New multifunctional materials processed into knowledge-based, industrially applicable nanoceramics and nanocomposites with added multifunctionality, e.g. biocompatible functions and very long lifetime, optical properties and biocompatible functions, tribochemical functions and excellent electrical conductivity, and nanocoatings with tribological and barrier functions.

NANOFUN-POLY is a good example of the Networks of Excellence funded in this field. The main objective of NANOFUN-POLY is to become, before the end of the funding period, the European reference point on Multifunctional Nanostructured Polymers and Nanocomposite Materials, and to later continue operating in a self-sustained way. This objective will be reached through a trans-disciplinary partnership of initially 12 core partner institutions and 17 satellite partners in 18 different countries, including associate countries outside the EU and other countries outside Europe such as the United States, China and Argentina. The partnership of the Network combines excellence in different scientific areas, and the synergy of international excellence and multidisciplinary approaches will lead to develop and spread knowledge in innovative functional and structural polymer-based nanomaterials and their sustainable technologies. Applications that will benefit from NANOFUN-POLY concern strategic industrial sectors which can be competitive only by using advanced technologies: optoelectronics

Table 2. Integrated Projects and Networks of Excellence in the area of Nanostructured Materials funded within the First and Second Calls in FP6. The first four proposals correspond to the First Calls.

Acronym	Instrument	Title	Coordinator
SANDiE	NE	Self-Assembled semiconductor Nanostructures for new Devices in photonics and Electronics	Prof. Marius Grundmann Universität Leipzig, Germany
NANOQUANTA	NE	Nanoscale Quantum Simulations for Nanostructures and Advanced Materials	Prof. Rex Godby University of York, United Kingdom
NANOFUN-POLY	NE	Nanostructured and Functional Polymer-Based Materials and Nanocomposites	Prof. Jose Maria Kenny Consorzio Interuniversitario Nazionale per la Scienza e la Tecnologia dei Materiali, Italy
SOFTCOMP	NE	Soft Matter Composites - An approach to nanoscale functional materials	Prof. Dieter Richter Forschungszentrum Jülich, Germany
NAPOLYDE	IP	Nano-structured polymer deposition processes for mass production of advanced product functionalities enabling innovative energy production & integration	Dr. Patrick Choquet Recherche et Développement Cockerill Sambre groupe Arcelor, Belgium
MULTIPROTECT	IP	Advanced environmentally friendly multifunctional corrosion protection by nanotechnology	Dr. Helmut Schmidt Institut für Neue Materialien gem. GmbH, Germany
AMBIO	IP	Advanced nanostructured surfaces for the control of biofouling	Prof. James Callow University of Birmingham, United Kingdom
NAPOLEON	IP	Nanostructured waterborne polymer films with outstanding Properties	Dr. Steven van Es Surface Specialties S.A., Belgium
IP NANOKER	IP	Structural Ceramic Nanocomposites for top-end Functional Applications	Dr. Ramón Torrecillas Consejo Superior de Investigaciones Científicas, Spain
NANOSAFE2	IP	Safe production and use of nanomaterials	Dr. Frederic Schuster Commissariat à l'énergie atomique, France
INNOVATIAL	IP	Innovative processes and materials to synthesise knowledge-based ultra-performance nanostructured PVD thin films on gamma titanium aluminides	Dr. Christoph Leyens Deutsches Zentrum für Luft-und Raumfahrt e.V., Germany
IDECAT	NE	Integrated Design of Catalytic Nanomaterials for a Sustainable Production	Prof. Gabriele Centi Consorzio Interuniversitario per la Scienza e Tecnologia dei Materiali, Italy

and telecommunications, packaging, agriculture, building construction, automotive and aerospace, etc. The integrated approach of this NE will range from macromolecular and supramolecular chemistry to tailored design and advanced processing methods for polymer-based nanostructured polymers and nanocomposites. Training, communication, dissemination and transfer of knowledge and

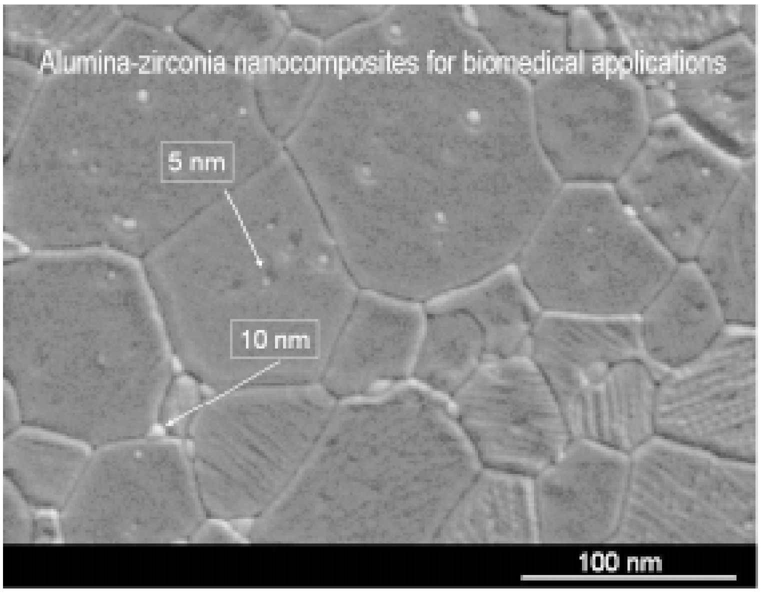

Fig. 6. Alumina-zirconia nanocomposite for biomedical applications which are among the materials studied by IP-NANOKER.

technologies developed inside the Network will also be essential components of the Joint Programme of Activities.

4. FUTURE CHALLENGES UNDER FP7

In June 2004, the European Commission presented its views on the 'Future of the European research policy', in which it clearly indicated the way forward, putting emphasis on: consolidating support for collaborative transnational research, the reinforcement of EU support to basic research, the strengthening of the support to industrial research and innovation oriented technological development, including longer term public-private partnerships, actions to raise human potential, developing research infrastructures of European interest, and improving the co-ordination of national research programmes.

The newly proposed 7th Framework Programme is expected to be the central Community action to support the development of Europe's knowledge economy. The European Commission aims at doubling the yearly budget in comparison with the currently active FP6, within the context of the ambitious objective of the Barcelona summit of radically increasing the investment in European R&D in order to approach 3% of GDP by 2010. FP7, as proposed in April 2005 by the European Commission, has a simplified and user-friendly structure with four main objectives, each supported by its own specific programme:

– Cooperation: To gain leadership in key scientific and technology areas by supporting cooperation between universities, industry, research centres and public authorities across the European Union as well as with the rest of the world.
– Ideas: To stimulate the creativity and excellence of European research through the funding of 'frontier research' carried out by individual teams competing at European level.
– People: To develop and strengthen the human potential of European research through support to training, mobility and the development of European research careers.
– Capacities: To enhance research and innovation capacity throughout Europe.

The programme on Cooperation will be organised into sub-programmes or themes, each of which will be operationally autonomous as far as possible, while at the same time demonstrating coherence and consistency and allowing for joint, cross-thematic approaches to research subjects of common interest. The nine themes identified for the 'Cooperation' part are:

– Health;
– Food, Agriculture and Biotechnology;
– Information and Communication Technologies;

– Nanosciences, Nanotechnologies, Materials and new Production Technologies;
– Energy;
– Environment (including Climate Change);
– Transport (including Aeronautics);
– Socio-economic Sciences and the Humanities;
– Security and Space.

Theme 4, which has the title ‘Nanosciences, Nanotechnologies, Materials and new Production Technologies’ has been designed with the objective to improve the competitiveness of the European industry and ensure its transformation from a resource-intensive to a knowledge-intensive industry, and it covers the following subareas:

– Nanoscience and Nanotechnologies. The objective is to increase and support the take up of knowledge generated in this revolutionary field for all industrial sectors. Topics may include: interface and size dependent phenomena; materials properties at nano-scale; self assembly; metrology; new concepts and approaches; impacts on health and safety; convergence of emerging technologies.
– Materials. The objective is to generate new knowledge to enable new industrial products and processes to be achieved, exploiting the potential of interdisciplinary approaches in materials research. Topics may include: high performance, sustainable and knowledge-based materials; design and simulation; nano-, bio- and hybrid materials and their processing; chemical technologies and materials processing industries.
– New Production Technologies. The objective is to create continuously innovating production capabilities to achieve leadership in industrial products & processes in the global marketplace. Topics may include: Knowledge-intensive production; new paradigms for emerging industrial needs; adaptive, networked and knowledge-based production; convergence of technologies for next generation of high value-added products (nano, bio, info, cognitive...).
– Integration of technologies for industrial applications. The objective is to accelerate the rate of industrial transformation by exploiting the application potential and integration of new technologies. Topics may include: Integration of nano, materials and production technologies in sectoral and cross-sectoral applications (e.g. health, construction, transport, energy, chemistry, environment, textiles & clothing, pulp & paper, mechanical engineering).

Research on nanostructured materials is expected to continue being a key area under Theme 4 of FP7, and in particular within the above-mentioned Materials sub-domain.

The European Commission’s proposal for FP7 will be further elaborated and detailed in the so-called specific programmes, the Commission’s version of which is expected to be ready in September 2005. Commission proposals are only finally adopted if they are approved by the European Parliament and the Council, and the final approval of FP7 could take place in Spring of 2006. If that is the case, the first Calls for Proposals under FP7 would likely be launched around November 2006.

REFERENCES AND BIBLIOGRAPHY

- More information on the Framework Programmes is available at http://www.cordis.lu.
- More information on the NANOTRIB cluster of projects can be found at http://www.vito.be/nanotrib.
- For more information on Project IP-NANOKER, please contact its coordinator Dr. Ramón Torrecillas (rtorre@incar.csic.es).
- More information on NANOFUN-POLY is available at http://www.nanofun-poly.com.