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Nanoscience and nanotechnology at the Institute of Materials Science of Barcelona (ICMAB)*

1. Introduction

The *Institut de Ciència de Materials de Barcelona* (ICMAB) is a research centre which depends on the *Consejo Superior de Investigaciones Científicas* (CSIC) which was set-up in 1987 and subsequently, in April 1991 the main building was inaugurated on the campus of the *Universitat Autònoma de Barcelona* (UAB) in Bellaterra. In 1998 the surface of the centre was increased by adding a new floor to the main building, and finally in 2009 it is scheduled that a new clean room facility of 190 m^2, presently under construction, will be fully implemented as a nanostructuring platform (Figure 1(a)). This platform, together with three additional services (Electron Microscopy, Proximity effect Microscopies and Thin film growth), are the heart of the ICMAB Nanotechnology unit (NTU) (Figure 1(b)). This Nanotechnology unit will be incorporated as a special facility to the Scientific and Technological Services (STS) of the ICMAB, which were created in 2004. Additionally to the NTU, the STS include the following laboratories: X-ray Diffraction, Low Temperatures and Magnetometry, Thermal Analysis, Molecular Beam Epitaxy and Spectroscopic Techniques. The STS have been strongly supporting the research and development activities deployed the ICMAB, based on an open access structure, for both the researchers of the Institute and for external users from academia or industry. Within the Institute Strategic Plan 2005-2009 it has been a priority to allocate funds and specialized technical personnel to them. They must be considered, therefore, as a key infrastructure for the success of ICMAB in its mission of creating internationally recognized research activity. The strategic decisions concerning the STS are being coordinated with the facilities available in the Nanocluster of Barcelona at Bellaterra (BNC-b, www.bnc-b.net), a cooperative partnership integrated in the UAB research park (PRUAB).

The aim of the ICMAB since its creation has been to generate new knowledge in Materials Science and transfer it to the society, particularly to industry. All aspects of materials science, from the discovery of new materials to the development of new processes of practical interest have been widely cultivated during the 20 years of life of the Institute. To accomplish these objectives the Institute carries out very diversified research activities, spanning a wide range of scientific and technological goals, with the mission of being at the forefront of international knowledge in this field.

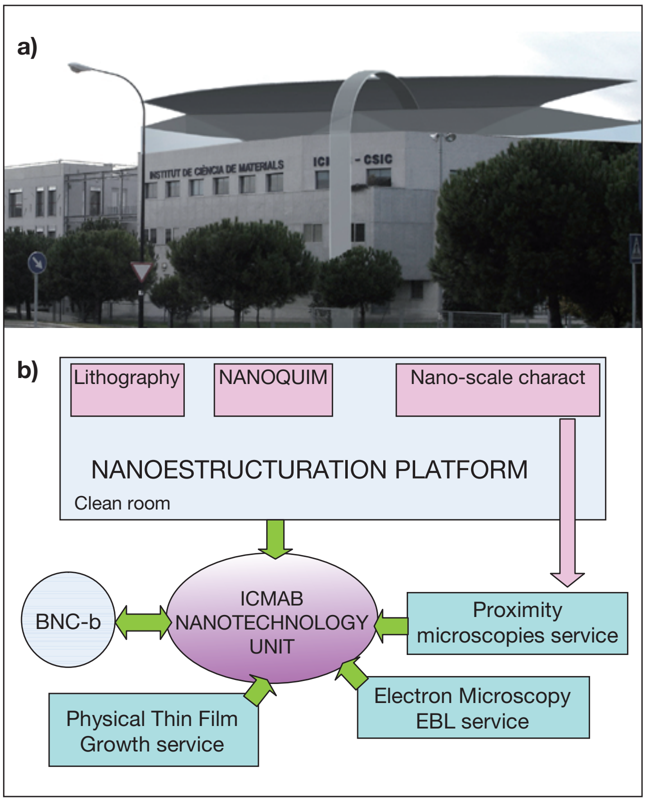

Figure 1. (a) General view of the ICMAB building, as it will be after building the Nanstructuration platform in 2009 and (b) general scheme of the organization of the Nanotechnology Unit at ICMAB.

2. Research activity

The character of the Institute is very interdisciplinary with a wide know-how base in several scientific areas including Chemistry (Inorganic, Organic, Solid State), Physics (Condensed Matter, Applied, Theory) and analytical studies including Crystallography, microscopy and spectroscopy. This interdisciplinary character must be considered a key aspect for the success of the Institute which has made possible that the research at ICMAB covers a broad range of activities, including synthesis of new materials, processing and crystallization, structural and microstructural studies, characterization of physical (magnetic, transport, superconducting, optical) and chemical (electrochemical, catalytic) properties, theoretical or

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simulation material studies, and finally, integration of materials into devices.

The speciality label of the Institute, however, is functional high-performance materials, which are very often the key factor for enabling, emerging new technologies in different sectors such as Information Science and Electronics, Energy, Environment and Healthcare.

Since its creation, a distinguishing characteristic of the Institute has been also its willingness to integrate the high performance materials being created into real demonstrators or prototypes, very often in collaboration with external engineering or industrial laboratories. This approach has been always very helpful to focus the research activities and to generate real technological breakthroughs. It has been also very appealing to raise industrial interest into the research activities being developed in the Institute with the help of the technology transfer unit, unique in CSIC institutes. Overall, the Institute has a balanced research effort on long term and mid term activities.

The research interests of the scientific groups of the institute are broad and dynamic: they have been changing with to the international advances in Materials Science during the last 20 years and, at present, a great deal of the scientific interests of the ICMAB is related to the field of nanoscience and nanotechnology, particularly in nanostructured materials. In Figure 2 we show a general scheme integrating the ICMAB´s scientific interests, with the material groups investigated and the relevant materials aspects and methodologies. All together, the know how in these areas has become the driving force for further development of the scientific disciplines indicated in the outer ring and the corresponding applicative areas where the Institute has influenced progress and innovations.

ICMAB researchers are very active in creating new knowledge in Nanoscience and nanotechnology, new nanostructured materials and devices with enhanced performances and also novel experimental methodologies and theoretical analysis and simulation tools. As the most active areas of research to date in nanoscience and nanotechnology we can mention the following:

- *Methodologies to create isolated functional nanoobjects*
  — Synthesis of nanoparticles, nanowires, nanotubes, nanorods, etc.
  — Soft-chemical methodologies for inorganic and organic material preparation
- *Self-assembly and self-organization of nanostructures*
  — Oxide epitaxial nanostructures by chemical solution deposition (CSD) and physical vapor deposition (PVD)
  — Organic molecular and supramolecular materials
  — Epitaxial semiconductor nanostructures
- *Complex nanostructured materials*
  — Nanocomposite aerogels and ceramics
  — Hybrid organic-inorganic materials
- *Thin films, multilayers and coatings*
  — Oxides by CSD and PVD
  — Solution processed materials: organic and hybrid materials
  — Coated textured metallic tapes
- *Structural and nanoscale materials properties characterization*
  — Crystal structure of materials: synchrotron X-ray and neutron diffraction
  — Surface crystal structures and mesoscopic organization
  — Electron microscopy: atomic and nanoscale structure, defects and strains
  — Scanning probe microscopies: nanostructure and physical properties
- *Theory and computer simulation of materials and properties*
  — Electronic structure and physical properties
  — Nanostructure formation and materials processing

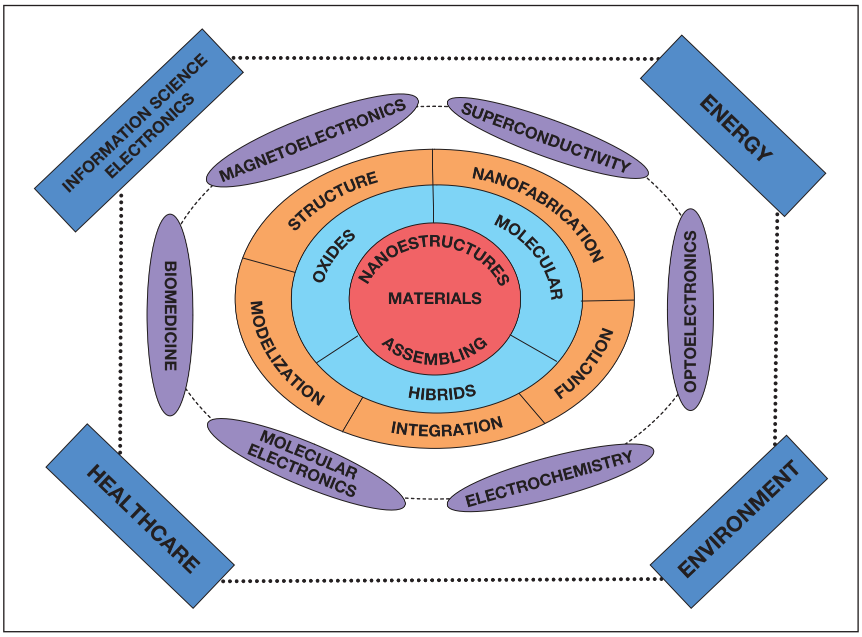

Figure 2. General layout of the present R+D activities and interests of ICMAB. From the scientific core of nanostructured materials and assembling to their functionality, scientific disciplines and technological application sectors

The materials which are investigated are strongly linked to their nanostructure and functionality and hence the focus is in searching for improved performances of materials and devices at reduced cost to promote its applicability in several technological sectors (Figure 2). The main technological areas which are covered are the following:

- *Materials for energy and environment*
  - Superconducting materials and systems
  - Materials for energy storage: batteries, supercapacitors
  - Hydrogen vector materials: fuel cells, H generation and storage
  - Organic based devices: OLEDS, photovoltaic cells
  - Chemical sensors and catalytic materials
- *Materials for electronics*
  - Oxide magnetoelectronics and devices
  - Organic electronics materials and devices
  - Nanomagnetic materials and devices
  - Optoelectronic semiconducting materials
- *Materials for healthcare*
  - Electroactive and drug delivery materials
  - Biosensors and materials for diagnosis and tissue engineering

In summary, the type of materials which are being investigated cover from ceramics and molecular compounds (inorganic and organic) to hybrid materials, and most of them are fabricated in different shapes and dimensions: nanoparticles, thin films, single crystals, bulk materials, etc. The achievement of controlled nanostructures is a key issue to achieve enhanced performances and, hence, a big effort is devoted to correlate the observed nanostructures with processing issues and the achieved properties. The investigated properties are also very broad, but with special focus on magnetic, superconducting, electronic and optical properties. Finally, theoretical analysis of materials and processes have become invaluable support tools to achieve in depth understanding of the properties and to advance in the materials preparation and processing. Figure 3 displays a few examples of nanostructured materials recently developed in the ICMAB.

It's also worth to emphasize that final use of materials require integration into devices or systems and for this purpose ICMAB researchers strongly cooperative with polytechnical universities, technological centers, hospitals or industrial companies.

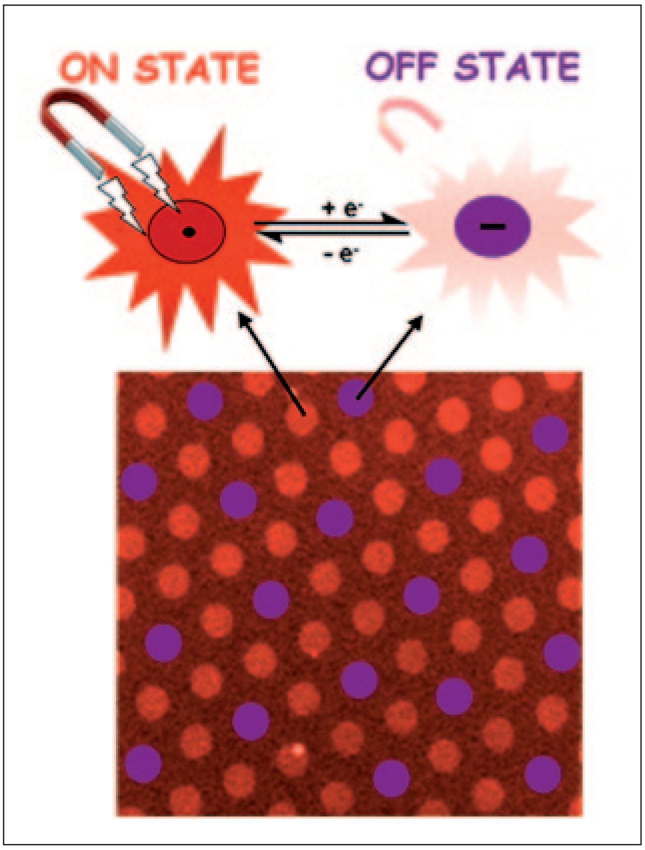

Figure 3b. Confocal microscope image of a self-assembled monolayer of a polychlorotriphenylmethyl organic radical patterned on a quartz surface. This multifunctional molecule behaves as an electroactive switch with optical and magnetic response.

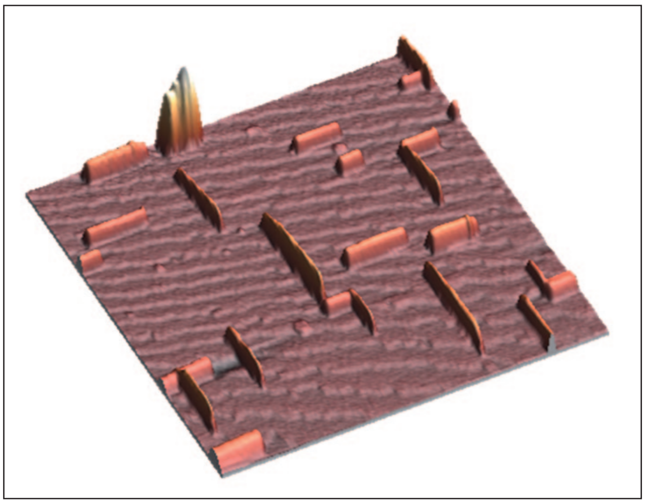

Figure 3a. AFM image of CeO2 nanostructures grown on a LaAlO3 substrate by chemical solution deposition.

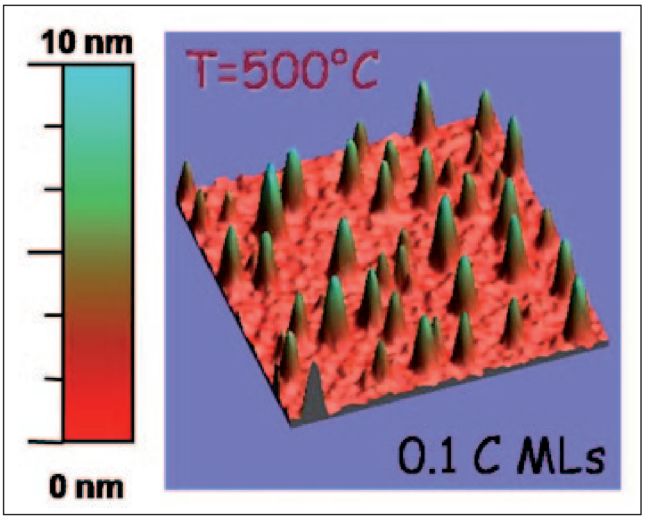

Figure 3c. AFM image of carbon-induced self-assembled Ge quantum dots grown on Si(001) by molecular beam epitaxy (MBE).

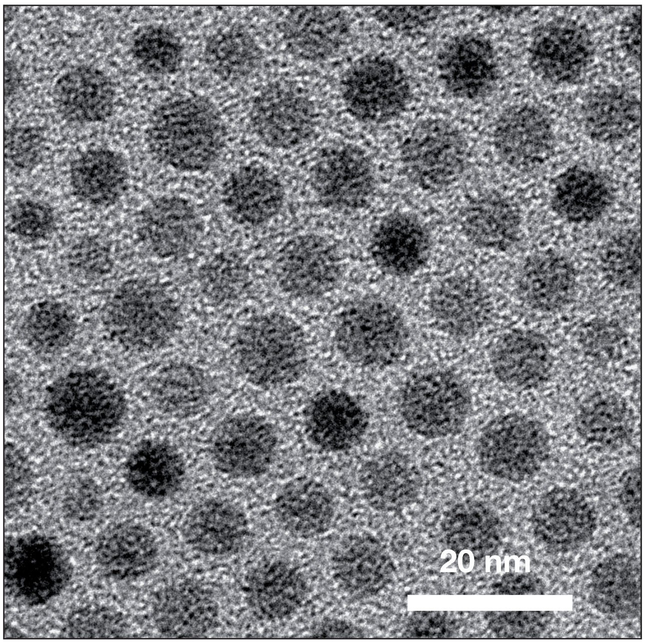

Figure 3d. TEM micrograph of stabilized g-Fe2O3 nanoparticles.

3 Indicators

At the end of 2007 the ICMAB was composed of 44 permanent scientific staff, 38 contracted post-doc, 68 pre-doc (40% of them non-Spanish citizens) and a total of 45 permanent or contracted technical and administrative staff, leading to a total of about 200 people.

The staff personnel is distributed at present in 9 Departments, the Scientific and Technological Services and one general service organization including management, library, Technology transfer unit, informatics and maintenance. The names of the Departments are the following:

- Molecular and Supramolecular Materials
- Materials Simulation and Theory
- Crystallography
- Solid State Chemistry
- Magnetic Materials and Functional Oxides
- Superconducting Materials and large scale nanostructuration
- Optical and Surface Properties of Nanostructured Materials
- Molecular Nanoscience and Organic Materials

The research activities are nearly exclusively developed in the scope of competitive research projects funded by public institutions (CICYT, European Union, Generalitat de Catalunya, CSIC) or funded through industrial research projects.

The annual budget of the ICMAB approaches 9 M€ at present and from this, about 55 % corresponds to salaries and about 35 % were obtained in competitive funds (public and private).

The leadership of ICMAB researchers has been recognized with the allowance of several honours such as the National Physics and Materials Prize, Novare Prize from Endesa, DuPont Prize, Duran Farell Prize from Gas Natural, the “Esteban Terreros” Prize from FECYT and Spanish Royal Society of Chemistry Prizes.

The personnel of ICMAB publishes at present more than 200 articles included in ISI per year.