

## Short Version

# EMPA Research Program „NANO 2“ (2004-2007)

## Mission

Our goal is the understanding of relevant phenomena in nano science and their application in adequate technologies.

- Within four thematic modules we develop novel materials, processes and devices based on nanoscale features and interactions
- We perform experimental R&D as well as theoretical modelling in highly promising areas
- We operate a dedicated, world class nano infrastructure and have direct access to partner facilities; furthermore, we develop/improve advanced tools for nano characterization/manipulation
- Within a scientific network of partners we work on the leading edge of nanotechnology aiming at international reputation and providing innovation to industry

## General Outline

Issue of nanotechnology is the invention and application, as well as the understanding and characterization of structures, molecular materials, surfaces and interfaces with critical dimensions in the 10 to 100 nm range and manufacturing tolerances that might be even well below. Structures with these dimensions provide new opportunities in materials science and engineering and offer novel functionalities in advanced devices.

Within our first initiative “**NANO 1**” (2000-2003) we successfully built up a “**EMPA Center of Competence in Nanotechnology**”, covering the fields of nanostructured inorganic coatings, organic nanosystems, nanoparticle ceramics and composites, reliability of nanostructured materials and devices. In this context we have established pilot plants for manufacturing nanoparticles as well as sophisticated instrumental infrastructure, including FIB/TEM, experimental SEM/ESEM, VT/LT-STM, synchrotron based X-ray tomography (XTM). Two specifically designed **new EMPA laboratories “Nanotech@Surfaces” and “Surfaces, Coatings, Magnetism”** represent the organisational expression of our efforts. At the same time we have strengthened our links to the Universities of Basel and Geneva (with their NCCR’s “Nanoscience” and “MANEP”) as well as to the CSEM.

“NANO 2” covers an ambitious follow-up program of “NANO 1”, still giving much attention to materials oriented questions but setting new priorities in the field of instrumentation and tooling, nano electronics and photonics as well as highly functional surfaces. More and more emphasis will be devoted to the bottom-up approach in nanotechnology. The specific objectives of EMPA’s four modules are summarized below. More detailed coverage is given in an extended module description of “NANO 2”.

## Module 1: Instruments and Tools for Nanoscience and Nanotechnology

“NANO 2” will devote considerable efforts to the **construction, installation and operation of advanced scanning force microscopes (SFM)**, namely a unique UHV low temperature SFM (LT-SFM) set-up in combination with a field ion microscope system. This new instrument is based on technology that has been developed within the TOP NANO 21 at the University of Basel. The new features allow for example the measurement of lateral forces during the controlled manipulation of

a single atom or molecule on a surface. EMPA has, furthermore, direct access to the laboratories of the **University Basel**, including its UHV high resolution magnetic force microscope (hrMFM), a UHV versatile LT-SFM, and in the near future, a SFM capable of measurements in liquid environments with ultras small cantilevers.

Many important phenomena (biocompatibility, corrosion/inhibition mechanisms, etc.) are controlled or initiated by nanometer level interaction at a metal (oxide) – solution interface. In order to investigate these local phenomena in the presence of an electrochemical component, it is necessary to develop **new electrochemical measurement strategies**. Among these are Scanning Kelvin Probe Methods (SKPM) and a scanning tapping nanocapillary electrochemical setup (STMES). Advanced capillary methods, furthermore, will allow full electrochemical control with a lateral resolution in the 100 nm range.

The bridging of the presently existing gap between nanoscience and nanotechnology can only be closed by the development of new methods for device fabrication and in-situ material characterization, thus leading to “**nanofactory tools**”. Scanning probe instruments can be used for the prototyping of nanometer-sized devices. An alternative approach to manipulate matter on the nanoscale arises from the combination of scanning probe instruments with beam methods. The SEM with its mm down to nm resolution is the ideal imaging platform for a nano-workbench; EMPA will progressively strengthen its focus on the development of microinstruments operating inside an advanced analytical SEM. On the other hand, we systematically upgrade our FIB, TEM as well as (TOF)SIMS equipment, providing so additional **nanoscale analytical capabilities**.

## Module 2: Nano Electronics and Photonics

Subject of EMPA activities in this field are electronic, optic, magnetic, and sensory materials resp. functional structures smaller than about 100 nm, including integration in micro- and nano-devices, furthermore, physical modelling and simulation. For devices with nanometer sized functional elements, one has to take into account **fundamental principles** of thermal fluctuations, quantum statistics and finally Heisenberg’s uncertainty relation.

CMOS technology with logic gate lengths below 100 nm using gate dielectrics in the 1 nm range in thickness is already in industrial production. Further reduction to 40 nm is demonstrated in laboratory set-ups; physical limits lead to a restricting gate length in the order of 10 nm. EMPA’s involvement in **solid state nanoelectronics** includes the physical understanding of the phenomena below about 5 nm. Specific research topics will cover modelling and experimental characterization of failures, reliability and degradation of ultra-thin dielectrics.

In order to continue the miniaturization of electronic devices, entirely new nanoelectronic device structures and computational paradigms are required. Since molecules are the smallest units that will ever have completely engineered electronic and optical properties, scientists have pursued the idea to build circuits by molecular structures, called **molecular electronics**. Single molecule devices are highly promising, since their functionality can be chemically tailored. We aim at developing efficient strategies for molecular self-assembly on surfaces permitting so the controlled fabrication of functional molecular superstructures in view of next generation storage, sensor and responder applications.

In recent years carbon has attracted much interest as a post-silicon electronic material, due to the variety of stable forms and electronic properties. In particular, the discovery and evolution of **carbon nanotubes (CNT)** leads to first technological devices using micrometer sized electron emitting structures with CNT’s. Especially field emission flat panel displays (FED) seem to be very promising for commercialization. EMPA can base on a long experience in the catalytic growth process of CNT tips and is a world leading laboratory in field emission characterization of CNT nanostructures.

Magnetic thin films and devices are used in many industrial applications, especially in magnetic storage industry. By advanced sputter technologies **new ordered magnetization structures** will be studied; particular distributions of domain sizes can be created in specific thin films. Another

promising theme will be **polymer based electronics/ photonics**, focussing on functional nano-composites for advanced devices like OLED's, OFET's or solar cells.

Generally there is an urgent need from industry for various kinds of sensors which are continuously shrinking in size. We will investigate methods and processes to fabricate, modify, and characterize **sensors based on micro- / nano electromechanical structures** (MEMS/NEMS). In this context, reliable **micro- and nanointegration** is a big engineering challenge, since miniaturization comes to its limit, due to physical constraints. On the other hand, packaging and interconnects to the macro-world are important for any nanodevices. The integration of hybrid structures into flexible electronic circuits will steadily increase and thus match the required high integration level.

### Module 3: Nanostructured Materials and Coatings

EMPA's **nanopowder pilot production** will be pushed in three directions, namely for higher manufacturing rates, more complex powder systems, and adequate monitoring as well as modeling competences. **TiO<sub>2</sub> particle production and implementation in functional coatings** will be of specific interest. In a new approach we want to embed the TiO<sub>2</sub> nanoparticles in a metallic matrix profiting of its enhanced chemical and mechanical stability. Other projects aim at introducing TiO<sub>2</sub> particles into special physical/chemical coating processes or at integrating them in textile fibers.

In **metal/ceramic composites**, we mostly followed the route of liquid infiltration until now using ceramic preforms. A new approach implements powder metallurgy profiting from our nanopowder manufacturing capabilities. The aim is to achieve an isotropic dispersion of nanoparticles in different matrices to improve specific materials properties. This implies the development of advanced process technologies, e. g. microwave sintering. With activated infiltration, nano-precipitation of hard phases can be realized in a specific way. A similar route leads to 3-dimensional interconnecting networks (foams), the activation being carried out by a nanoparticle route. The performance of these composite systems is most often controlled by the **interfacial nanostructure** of the materials involved. In the field of **nanostructured ceramics**, EMPA concentrates on specific functionalities, such as thermal shock tolerant ceramics, high temperature sensors, TiO<sub>2</sub> based nanostructured bioceramics, and high efficient electrodes for "solid oxide fuel cells" (SOFC).

**Polymer/ceramic nanocomposites** with tailored nanoparticles provide added values like higher strength, tailored thermal properties or electronic/photonic functionalities; furthermore, polymer nanocomposite materials are of specific interest for high density magnetic storage. Microcapsules filled with active agents, ranging from <1 up to 1000 μm diameter, bring even more opportunities (e.g. controlled release systems). Within its **biomimetic initiative**, EMPA has succeeded in elaborating procedures to isolate cellulose nanofibrils out of wood. Taking adequate fibrils dispersions and using selected polymers, we shall develop highly promising polymer nanocomposites with application in the medical and automotive industry.

EMPA has built up substantial competence in surface technologies in the last years, expanding the performance of coatings to new limits, be it by modifying the manufacturing processes or by introducing novel precursor material systems. **Nanostructured coatings by PVD/CVD technology** promise applications in many industrial fields, including for example magnetic storage, thermoelectrical energy conversion or piezoelectric actuators. Nanocomposite coatings containing nanocrystalline metal nitrides, carbides or oxides in combination with an amorphous binder phase provide a new approach to superhardness combined with excellent oxidation resistance. Flexible substrates, e. g. textiles, are becoming multifunctional thanks to nanotechnology, offering a whole set of specific properties. They can be made water-repellent, antibacterial and fungicidal, in addition, they can be electrically conductive or heat resistant. **Thermal spraying using nanopowders** provides an even higher flexibility in composition and structure, including not only metallic/ceramic materials but also mixtures with polymers. Opportunities are foreseen in energy conversion (for example thermal barrier coatings), **biomedical applications** (Ti implants), etc.

## Module 4: (Bio) Organic Nanostructured Surfaces

It is our goal to create **functional systems based on the rational assemblage of molecules, supramolecular systems and biological matter** in order to realize nanostructured systems with specific properties that find their applications for instance in the medical including biomolecule sensors. One of the most significant advantages of organic nanostructured materials is the synthetic flexibility of organic molecules. A major goal will be to gain knowledge in the field of micro- and nanomanipulation of chemical entities, including molecular and bio-recognition, bio surfaces and materials.

**Biological surfaces** are surfaces that contain biomolecules. The biological surface research includes bulk material development, prototype development of biomaterials and surface development. Biological surfaces can be obtained among others by self-assembly, the key molecular ordering principle in nature. With this technique nanoscale devices can be constructed being able to mimic some of the functions of living systems such as sensing, transportation, information storage or light harvesting. Interesting applications are in addition the investigation of the interaction of proteins with solid surfaces and the design of sophisticated devices to detect specific proteins or conformations of proteins in solutions.

The deposition of thin **macromolecular (polymeric)** films is a powerful way to alter the properties of surfaces. The functionality associated with the film is usually either located within a pendant chemical group, or the consequence of the multilayer assembly, e.g. in polyelectrolytes and hydrogels. The understanding of fundamental relationships between macroscopic properties and the microscopic chemical and physical interaction forces is an important prerequisite for successful interface engineering. New, very effective and application targeted adhesive systems based on natural products from e. g. algae have already been developed. Thin films of other promising candidates for advanced product design such as mussel glue, tribologically active slippery hag fish proteins and biodegradable polyhydroxyalkanoate polymers have been identified and will be evaluated with respect to their potential.

Duebendorf, February 26, 2004 / W. Muster