

Structure, Function, Systems

KIT NANOMICRO CENTER



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Nano and Microtechnologies

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Multidisciplinary:

Nano and microtechnologies aim at systems solutions with novel, functionally tailored materials. Science and engineering are advancing further into the microcosm. The objects studied and artificially produced structures often have dimensions in the nanometer or micrometer range (one nanometer corresponds to one millionth of a millimeter). Hence, their size is comparable with that of individual molecules or even individual cells. This results in new functionalities and properties that are used to improve existing or develop novel



products and applications. The fabrication, investigation, and application of structures, molecular materials, internal interfaces, and surfaces of less than 100 nm in dimension are therefore being pushed all over the world.

At Karlsruhe Institute of Technology (KIT), competences and resources are bundled by a worldwide outstanding science and engineering institution. Foundation of the KIT NanoMicro Center may well be considered the prerequisite for the development of a center of excellence in micro and nanotechnologies in Europe. Fundamental research of the KIT NanoMicro Center provides for a comprehensive knowledge base in nanotechnology and microsystems engineering. On this basis, the Center bridges the gap to technical implementation and marketable products. The focus is on nanobiology as well as on the setup of infrastructure facilities to support the work of internal and external users. For this purpose, the KIT NanoMicro Center links the expertise of scientists across disciplines. Further development of key technologies will contribute to securing sustainable economic growth in Germany and creating attractive jobs.

Work of the KIT NanoMicro Center is organized in eight topics:

- Nanoscale and Microscale Fabrication
- Electronic Properties
- Molecular Building Blocks
- Nanoscale Materials
- Systems
- Photonics
- Nanobiology
- Nanocharacterization

TOPIC 1:

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Big objectives:

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Fabrication of smallest components is the beginning only – it is headed towards the series production of nano and micromachines. Nano and microtechnical products have been used in everyday life for a long time already. Examples are self-cleaning or scratch-proof surfaces or smallest components of IT products. In the future, nanostructured surfaces, in combination with microcomponents, might have an even wider spectrum of functions. Minute chips might be used for rapid blood analysis. The KIT NanoMicro Center explores the basis of coming product generations.

Here, researchers are provided with excellent prerequisites to develop new nanoscale and microscale products. They can choose among a wide variety of fabrication and characterization methods, combine them, and, thus, create synergies.

Researchers employ both established and latest methods. Using the so-called

electron beam lithography, they fabricate components, whose details are smaller than 100 atoms in a continuous row, i.e. smaller than 10 nm. Filigree structures of nearly the same size are carved by ultrashort laser pulses into hard materials like ceramics or steel. Structural details of several 10 µm are produced by conventional methods optimized for smallest dimensions, such as micro injection molding, microcutting, or micro spark erosion.

The scientists inspect the quality of their hardly visible products with conventional means, for instance, with the electron microscope or with newly developed highly precise analysis methods based on e.g. the intensive X-rays of the ANKA synchrotron radiation source.

However, fabrication of individual smallest components is the first step



Grid points of less than 100 nm in size: Using parallel writing tips, several functional materials can be applied to the same surface at the same time.

only. To produce functioning micro and nanomachines in series some day, KIT researchers develop special grippers that assemble these minute components automatically and with highest precision.



Precise relocation: Using the ultrahigh-vacuum scanning force microscope, molecular electronic components can be fabricated.

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A billion minute electric switches, socalled transistors, are arranged on a modern computer chip having the size of a fingernail. These are ten times as many switches as in the year 2000. Miniaturization of electronic components makes computers quicker. In ten years' time, transistors will be as small as a molecule, i.e. their dimension will be in the range of a few nanometers only.

By means of a new method, the first atomic-scale transistor worldwide has been developed, the so-called single-atom transistor. By the specific relocation of a single (!) silver atom in a very small metal contact, an electric circuit can be opened and closed in a controlled manner. The component can be switched reproducibly at room temperature and gives rise to fascinating options for quantum electronics and logic circuits on the atomic scale. The nanostructures are not just smaller than conventional components. Quantum physics phenomena play a decisive role and electric characteristics are determined by quantum mechanics laws.

Components having the size of a molecule cannot be fabricated with conventional methods of microelectronics Consequently, new processes have to be developed for nanoelectronics. KIT scientists shift individual atoms with the modified type of a scanning force microscope or measure current flow through individual molecules. Among others, it is aimed at synthesizing molecules that function like electronic components. Fascinating electronic properties can also be observed in onedimensional nanostructures like carbon nanotubes. Scientists have already succeeded in individually contacting arrays of millions of tubes

KIT researchers intend to use nanostructures in the range of individual atoms and molecules for the safe exchange, more effective processing, or denser storage of data. But also sensors detecting individual atoms of a substance are feasible thanks to quantum physics. In this field, experimenters and theoreticians cooperate closely.



Signpost in quantum electronics: The single-atom transistor operating at room temperature.

TOPIC 3:









Theory and practice: To specifically develop nanoscaled systems, their properties have to be studied and understood. Apart from experiments, quantum chemistry calculations are needed e.g. to identify construction principles of metal clusters.

Molecules are multitalents: They shine, deflect, conduct electric current, and carry magnetic information. The KIT NanoMicro Center wants to use the capacities of these minute building blocks of matter. Feasible applications include magnetic storage media having a so far unreached storage density, transport means for nanoparticles, or computer chips with much smaller electronic components than those known today.

Apart from their

versatility, molecules have another advan-

tage that will be used

by KIT researchers to

produce functional

surfaces. They can

and regularly on a

is pre-structured

accordingly.

surface, if the latter

order autonomously



Carbon tubes for use in nanoelectronics: This experimental setup is highly efficient in sorting metallic semiconducting nanotubes.

The KIT Center studies the physical fundamentals of this self-organization process in order to control it. It is planned to produce areas of some square centimeters with rows of molecules or even three-dimensional molecule scaffolds. The latter might also serve as photonic crystals (see Topic 6).

Many applications of functional nanostructures require arrangement on and well-defined attachment to interfaces. Under variable ambient conditions, e.g. at fluctuating temperatures, the influences of surfaces and interfaces on the electronic and geometrical structure of the interacting molecules are studied experimentally and simulated with the help of computers.

TOPIC 4:

Nanoporous metal muscles: With this experimental setup, nanostructured switches, sensors or motion transducers can be produced.

Nanoscale Materials



Versatile in application: Development of nanostructured materials with specific properties.

Nanotechnology can give one and the same material several looks. The KIT NanoMicro Center develops nanostructured materials, whose mechanical, electric, magnetic, or optical properties can be modified by external impacts. Use of multi-layered composite particles may result in combined fluorescent and magnetic properties. KIT scientists develop nanostructured metals, whose properties can be adjusted specifically by electronic manipulation. In addition, these materials allow for the manipulation of the electronic properties of the components produced from them. For the cheaper production of the next generation of radio labels indicating the price and durability of goods at the supermarket, for example, nanoscale materials shall be dispersed onto plastic substrates like PET foils and indicate conducting, semiconducting, or insulating properties.

Moreover, the KIT NanoMicro Center uses nanotechnologies to make solar and fuel cells as well as energy stores more efficient. Nanoparticles and novel nanoscale carrier materials shall be developed for use in printable solar dye cells and for efficient oxygen reduction in electric energy conversion, respectively. Another objective consists in increasing the efficiency and stability of batteries for electromobility and stationary storage systems. Novel nanomaterials are developed for electrodes and electrolytes. To understand how materials are modified during use, the battery cells are characterized precisely during cycling. Hydrogen storage systems reach a high loading capacity when using nanoparticle composites, e.g. metal hydride amide and boronate systems, as a storage medium. Nanoscale catalysts on the basis of titanium clusters ensure short charging and discharge times. Safety studies focus on the behavior of these composites in case of hydrogen release.

TOPIC 5:

Fabrication of micro process engineering components requires specialists in the fields of microstructuring, assembly technology, and surface modification. In addition, numerous test facilities have to be operated to verify the system design and optimize the processes taking place in the microstructures. In the systems, various conditions exist, for example, temperatures from -250 °C to 750 °C. For novel industrial production processes, the KIT NanoMicro Center develops systems with microscopically small structures. They are referred to as micro process engineering systems. With them, production processes can be controlled much more precisely than in conventional process engineering, because substances in small volumes respond more rapidly to external impacts, e.g. temperature variation.

Consequently, micro process engineering often increases the safety, economic efficiency, and environmental compatibility of production processes. Use of thousands of parallel microchannels in a system ensures the high throughputs required for industrial mass production. However, gases, liquids, and solids in the microcosm behave differently, because they have a very large surface area in relation to their volume. The materials strongly interact with the



Interior of a micro process engineering system: Flow channels with a catalyst coating for the acceleration of chemical reactions. The catalyst (enlarged section) is a nanostructured system with fine pores.

walls of the microscopically thin tubes or microchannels. Engineers at the KIT NanoMicro Center take these special conditions of the microworld into account when designing the micro process engineering systems already. Expensive failures are avoided.

The KIT NanoMicro Center develops a design methodology to guarantee functional safety of micro process engineering systems. It also facilitates the design of hierarchic systems, in which nanostructures, microparts, and macrocomponents cooperate. The methodology includes processes to test nano and microstructured components.

TOPIC 6:

It is all about light: Scientists in the field of nanophotonics focus on the design, fabrication, and characterization of nanostructured materials with novel optical properties, including the generation of circularly polarized light. The KIT NanoMicro Center applies nanotechnologies to use light for information technology in a way that has been unknown so far.

The keys to this process are so-called photonic crystals and meta materials, in which nanometer-sized functional units or "optical atoms" form a regular artificial crystal. This crystal has optical properties natural crystals do not have. Certain photonic crystals reflect light of a selected wavelength range perfectly in all directions.

These crystals might be used as optical resonators for a new generation of microscopically small lasers. The KIT Center is experienced in the production of three-dimensional photonic crystals made of silicon. The next objectives are first applications, such as an optical diode that lets light pass in a single direction only and, hence, might be used for optical data communication.



It works with light: Scanning electron image of a photonic quasi crystal.

Optical atoms of the meta materials mostly are loops and rods of gold or silver. Together, they refract light in a way desired by optics engineers, but not existing in nature. The KIT Center produces and investigates two-dimensional meta materials. It also has developed a method to produce three-dimensional meta materials. These materials may be applied in lenses for imaging with perfect sharpness or for a cloak of invisibility at certain wavelengths of light.

It is the long-term objective of the KIT Center to integrate various photonic crystals and meta materials in systems for e.g. fast and broad-band data communication with light.

TOPIC 7:

Cultivation of cells: With the cell chips that are carrier structures provided with microcontainers, three-dimensional cell cultures can be cultivated.

Nanobiology bridges the gap between nanotechnology and life sciences. Interdisciplinary teams develop new methods to study the differentiation of cells and the communication of cells with each other.

This knowledge is used to develop fast and highly sensitive analysis methods for medical diagnosis or for the optimization of stent or prosthesis surfaces to ensure good tissue growth and, at the same time, to avoid the formation of biofilms and. hence, inflammations. Cell growth in cell cultures shall be controlled specifically for the production of substitute tissue and organs. For this purpose, surfaces are structured on the nanometer scale and modified chemically, such that they simulate the "chemistry" of the cell membrane and are recognized by the cell. Nanometer-sized biomolecules, such as proteins or genes, are the wheels and

actuators driving the cell mechanism. To manipulate them and to observe them in action, the KIT Center develops technologies that set these wheels and actuators with highest precision and image individual biomolecules. Such an imaging project is the virtual embryo D.A.V.E. (Digital Animated Virtual Embryo), by means of which cell processes can be monitored in real time with highest resolution.

The development of the cell does not only depend on the biochemical processes taking place inside, but also on the physical properties of its surroundings. KIT researchers build three-dimensional artificial environments for the cells, whose structural details are in the nanometer range. By varying the characteristics of these scaffolds, for example, their elasticity, the scientists identify influencing factors. These findings are used to produce miniaturized bioreactors, so-called cell chips.

Moreover, the KIT NanoMicro Center studies potential biological effects of nanostructured materials and nanoparticulate systems.



Analysis of biofilms: By means of MALDI-ToF mass spectroscopy, maturation of biofilms and the resulting variation of the biochemical composition of the cell can be studied.

TOPIC 8:



High luminance: The actine filaments recorded by fluorescence microscopy are some ten nanometers wide.

Research into new effects based on the nanoscale, the development and optimization of components, and the understanding of molecular processes in biological systems require characterization techniques meeting special needs. Methods of highest spatial resolution are applied to study the structure as well as chemical, mechanical, magnetic, optical, and electronic properties.

Many developments at KIT focus on nanoparticles which, due to their small dimensions, have properties that differ from those of macroscopic solids. Nanoparticles are the basis of materials and products with improved properties, they serve as shining markers or containers of active substances in biological systems, and they are used in catalysis to accelerate chemical reactions. The sizes of nanoparticles range from molecular structures down to about 100 nm. Characterization is aimed at analyzing the atomic structure, chemistry, and optoelectronic properties of individual particles in order to derive clear correlations. For this purpose, aberration-corrected transmission electron microscopes equipped with spectroscopes and



View into the smallest detail: Individual platinum atoms, molecular platinum structures, and crystalline platinum nanoparticles recorded with a transmission electron microscope.

monochromators are applied. In life sciences, novel light optical microscopy methods are developed and used. With a resolution of up to 20 nm, biomolecular functional processes in living cells can be analyzed with highest sensitivity. For these methods, special nanoscale probes are produced and optimized.

Various experimental facilities are available at the ANKA synchrotron radiation source.



Structure of the KIT NanoMicro Center

More than 800 employees are working at the KIT NanoMicro Center. The annual budget of the Center exceeds 80 million Euros. Hence, the Center's size is unique in the field of nano and microtechnologies in Germany. Fourteen joint professorships and the associated research groups on Campus North and Campus South of Karlsruhe Institute of Technology



cooperate in the KIT NanoMicro Center. In addition, the Center pools the excellence of several outstanding research programs, projects, and facilities in this field. These are:

- The programs "Nano and Micro Systems Technologies" and "BioInterfaces" of the Helmholtz Association of National Research Centers,
- the excellence cluster "DFG Center for Functional Nanostructures" (CFN),
- the graduate school "Karlsruhe School of Optics and Photonics" (KSOP),
- the DFG Collaborative Research Center "Design, Production, and Quality Assurance of Molded Microcomponents Made of Metallic and Ceramic Materials",
- the DFG graduate college "Analysis, Simulation, and Design of Nanotechnological Processes",

- the laboratory for electron microscopy (LEM),
- the Functional Nanostructures
 Competence Network (Baden-Wuerttemberg State Foundation),
- and the Karlsruhe Nano Micro Facility (KNMF), a cost-free user platform for cooperation partners from research and industry. The platform offers unique high technologies to structure and characterize functional materials on the nanometer and micrometer scales. These are pooled at the laboratories for micro and nanostructurization, for microscopy and spectroscopy as well as for synchrotron characterization. Detailed information is available at www.kit.edu/knmf.

Karlsruhe Institute of Technology (KIT)

Karlsruhe Institute of Technology (KIT) is the merger of Forschungszentrum Karlsruhe, member of the Helmholtz Association, and Universität Karlsruhe (TH). KIT has a total of 9000 employees and an annual budget of EUR 730 million.

The merger into KIT gave rise to one of the biggest research and teaching institutions worldwide, which has the potential to assume a top position in selected research areas. It is aimed at establishing an institution of internationally excellent research in natural and engineering sciences, outstanding education, promotion of young scientists, and advanced training. KIT closely cooperates with industry as an innovation partner. It is a leading European energy research center and plays a visible role in nanosciences worldwide. KIT focuses on the knowledge triangle of research, teaching, and innovation.



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