MRC

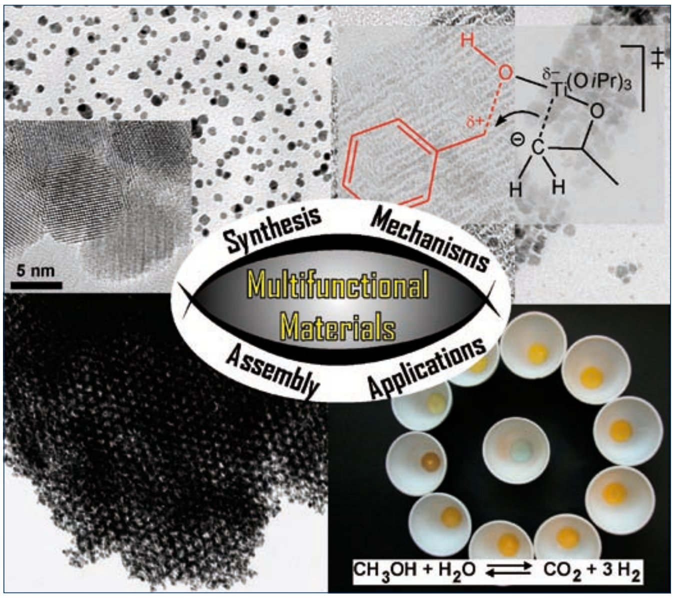
Materials Research Center

Multifunctional Materials

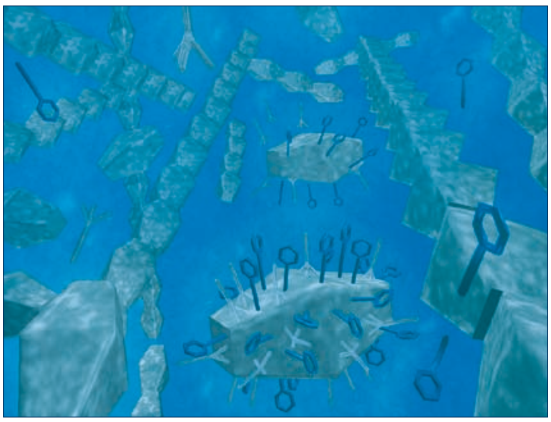
Research Profile

Nanoparticles play a crucial role in the development of advanced materials and devices. The reason lies in the fact that particles just a few nanometres in size exhibit different chemical and physical properties compared to the bulk material. However, to obtain inorganic functional materials in form of nanoparticles with well-defined shape, size and crystallinity, novel innovative synthesis strategies have to be developed. We focus our research on four topics:

- Development of generalized synthesis strategies to inorganic functional nanomaterials
- Investigation of formation and crystallization mechanisms
- Assembly of the nanoparticles into 1, 2 and 3D superstructures
- Processing of nanopowders



Research overview: Synthesis, formation mechanisms, assembly and applications of inorganic nanoparticles.



Anisotropically assembled titania nanoparticles.

Competences / Infrastructure

- Liquid-phase synthesis of inorganic nanoparticles
- Surface-functionalization and assembly of nanoparticles
- Characterization of inorganic nanoparticles
- Solvothermal processing and microwave chemistry
- Organic-inorganic nanocomposites

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Nanoparticles, Metal Oxides, Sol-Gel Synthesis, Nanocomposites, Self-assembly

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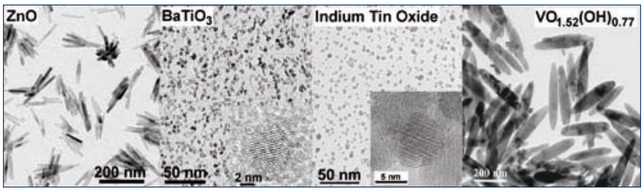
Nanoparticle Synthesis

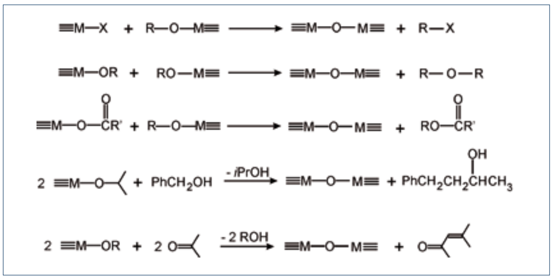
Our synthetis work is focused on the development of non-aqueous (or non-hydrolytic) sol-gel routes to metal oxide nanoparticles, i.e., the chemical transformation of molecular precursors into oxidic materials in organic solvents under exclusion of water. In comparison to the complex aqueous chemistry nonaqueous processes offer the possibility to better understand and to control the reaction pathways on a molecular level, enabling the synthesis of nanomaterials with high crystallinity and well-defined and uniform particle morphologies at moderate temperatures.



TEM images of selected metal oxides synthesized via nonaqueous sol-gel routes.

Formation Mechanism and Crystallization

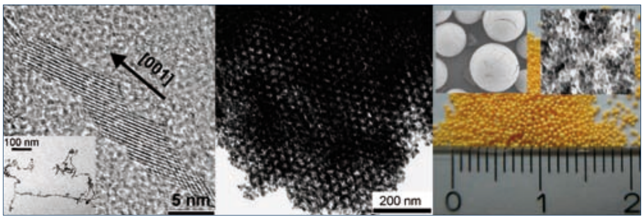
The formation of the inorganic nanoparticles is generally accompanied by processes involving basic organic chemistry principles. By retro-synthetical approaches one can correlate the processes leading to organic side-products to the growth mechanisms of the oxide particles. A careful study of the involved reaction mechanisms and the crystallization steps during nanoparticle formation will ultimately help in finding a relationship between a particular synthesis system and the final particle morphology.



Overview of the various condensation reactions found in non-aqueous sol-gel processes leading to the formation of a metal-oxygen-metal bond.

Nanoparticle Assembly

The arrangement of nanoparticles into well-defined ensembles can lead to novel and unique properties that are not found in the individual components. One strategy involves the use of nanoparticles with specifically functionalized crystal surfaces that self-assemble into organized arrays. The feasibility of this approach was proven by the self-assembly of functionalized anatase nanoparticles into pearl-necklace-like nanostructures. Other strategies are evaporation-induced self-assembly processes (mesoporous tin oxide as example), or nanocasting procedures, in which solid porous templates are filled with nanoparticles (ceria zirconia beads as example).



Assembled metal oxide nanoparticles (from left to right): Pearl-necklace-like titania nanostructures, mesoporous tin oxide, mesoporous ceria-zirconia beads.

Applications

The nanoparticles can directly be used in the form of nanopowders for applications in catalysis, photocatalysis, gas sensing, ceramics, or energy storage. For other applications, like thin film preparation or nanocomposites, the nanoparticles have to be dispersed in liquid medium. To avoid the formation of large agglomerates, the surface of the nanoparticles is functionalized by various organic ligands. One example along these lines is the preparation of UV-absorbing and transparent polymer-nanoparticle-composites consisting of PMMA and titania.

Photograph of a self-supporting and transparent polymethylmethacrylate film with 1 vol% titania nanoparticles.