Symposium Hybrid Nanomaterials: From Novel Physics and Multi-Scale Self-Organization to Functional Diversity on the Device Scale (SYHN)

jointly organised by
the Chemical and Polymer Physics Division (CPP),
the Dynamics and Statistical Physics Division (DY),
the Crystalline Solids and their Microstructure Division (KFM), and
the Metal and Material Physics Division (MM)

Patrick Huber
Technische Universität Hamburg
and
Deutsches Elektronen-Synchrotron
DESY
patrick.huber@tuhh.de

Jörg Weißmüller
Technische Universität Hamburg
and Helmholtz-Zentrum Hereon
weissmueller@tuhh.de

Tobias Kraus
Leibniz-Institut für Neue
Materialien (INM)
and Universität des Saarlandes
tobias.kraus@leibniz-inm.de

The interplay of interfacial determinacy and geometric constraint leads to new, often surprising physicochemical behavior in many nanostructured materials. Particularly in the combination of soft and hard matter, this also results in special functionalities and mechanical properties that have the potential to completely rethink virtually all technological areas, especially energy generation, storage and conversion but also the bio-medical field.
However, the resulting hybrid systems are usually characterized by strong electro-mechanical, chemo-mechanical and thermo-photonic couplings that have so far eluded fundamental understanding. In recent years, nanoscience has also increasingly focused on the question to what extent the combination of soft and hard matter opens up the possibility of using multiscale self-assembly and phase transitions, similar to many biological systems, to transport nanoscale effects from the mesoscale to the macroscale in order to design hybrid structural materials with integrated multifunctionality for robust components.
This interdisciplinary symposium will focus on these issues at the interface between soft matter physics and chemistry and materials science. A special focus will be put on porous hybrid systems but also on multiscale assembly of nano-objects (nanoparticles) with respect to the interplay of mechanics and function. As application fields electro-mechanical sensors/actuators, fluidics and photonics will be in the center.

Overview of Invited Talks and Sessions

(Lecture hall Audimax 1)

Invited Talks

SYHN 1.1	Thu	10:00–10:30	Audimax 1	**Scaling behavior of stiffness and strength of hierarchical network nanomaterials** — •Shan Shi
SYHN 1.2	Thu	10:30–11:00	Audimax 1	**Functional and programmable DNA nanotechnology** — •Laura Na Liu
SYHN 1.3	Thu	11:15–11:45	Audimax 1	**Multivalent nanoparticles for targeted binding** — •Stefano Angioletti-Uberti
SYHN 1.4	Thu	11:45–12:15	Audimax 1	**Programming Nanoscale Self-Assembly** — •Oleg Gang
SYHN 1.5	Thu	12:15–12:45	Audimax 1	**Achieving Global Tunability via Local Programming of a Structure's Composition** — •Jochen Mueller

Sessions

SYHN 1.1–1.5	Thu	10:00–12:45	Audimax 1	**Hybrid Nanomaterials: From Novel Physics and Multi-Scale Self-Organization to Functional Diversity on the Device Scale**

SYHN 1: Hybrid Nanomaterials: From Novel Physics and Multi-Scale Self-Organization to Functional Diversity on the Device Scale

Time: Thursday 10:00–12:45 Location: Audimax 1

Invited Talk SYHN 1.1 Thu 10:00 Audimax 1
Scaling behavior of stiffness and strength of hierarchical network nanomaterials — •Shan Shi — Institut für Werkstoffmechanik, Helmholtz-Zentrum Hereon, Geesthacht — Institut für Werkstoffphysik und -technologie, Technische Universität Hamburg, Hamburg

Structural hierarchy is known to optimize mechanical behavior in deliberately designed structures and natural materials. The benefits of hierarchy implementing the high strength of nanoscale objects into hierarchical structures would lead to even more interesting mechanical characteristics. Yet, truly nanoscale structures with a prohibitive number of struts in any macroscopic bodies have not been demonstrated in load-bearing form that could be subjected to mechanical tests.

Here, we prepared macroscopic, crack-free nested network nanomaterials "hierarchical nanoporous gold" by two-stage self-organization processes of dealloying, which processes allow for large samples contained over trillions of struts to be synthesized. Macro-compression tests indicate the hierarchical architecture affords enhanced strength and stiffness. The experiments are well supported by our proposed scaling laws for the stiffness and strength for nested network with different numbers of hierarchy levels and by atomistic simulations. Therefore, this work for the first time demonstrated that structural hierarchy brings enhanced mechanics for truly nanoscale network materials.

Invited Talk SYHN 1.2 Thu 10:30 Audimax 1
Functional and programmable DNA nanotechnology — •Laura Na Liu — 2. Physics Institute, University of Stuttgart, Stuttgart, Germany

A fundamental design rule that nature has developed for biological machines is the intimate correlation between motion and function. One class of biological machines is molecular motors in living cells, which directly convert chemical energy into mechanical work. They coexist in every eukaryotic cell, but differ in their types of motion, the filaments they bind to, the cargos they carry, as well as the work they perform. Such natural structures offer inspiration and blueprints for constructing DNA-assembled artificial systems, which mimic their functionality. In this talk, I will discuss a variety of DNA-assembled architectures with different motion and functions. I will also outline ongoing research directions and conclude that DNA nanotechnology has a bright future ahead.

15 min. break

Invited Talk SYHN 1.3 Thu 11:15 Audimax 1
Multivalent nanoparticles for targeted binding — •Stefano Angioletti-Uberti — Department of Materials, Imperial College London, United Kingdom

Ligand-coated nanoparticles are a leading candidate for various applications where targeted binding is necessary, e.g. drug-delivery or biosensing, to name just two.

In this system, the main idea is that binding to the target occurs via the formation of ligand-receptor bonds. In fact, typically many of such bonds will form and in various competing patterns that vary not only depending on the bond strength but also on features such as grafting densities, or the geometry of binding. This results in highly tuneable binding affinities and more generally peculiar (and not yet fully exploited) novel binding properties that arise from the statistical nature of the binding, properties that could be exploited to achieve new functionalities.

In this talk, I will present some of our recent work to understand these so-called multivalent nanoparticles, showing how theory and simulations have been used to both rationalise and predict the behaviour of experiments and point the consequences of our findings for the development of nanomedicine applications based on multivalent binding.

Invited Talk SYHN 1.4 Thu 11:45 Audimax 1
Programming Nanoscale Self-Assembly — •Oleg Gang — Columbia University, New York, NY, USA — Brookhaven National Lab, Upton, NY, USA

The ability to organize rationally functional nanoscale components into the targeted architectures promises to enable a broad range of nanotechnological applications, from designed biomaterials to photonic devices and information processing systems. However, we are currently lacking a broadly applicable methodology for the bottom-up nano-fabrication with ability to prescribe a structure and to integrate different types of components. The talk will discuss our progress on uncovering guiding principles and establishing a practical platform for assembly of designed large-scale and finite-size nano-architectures from diverse nanocomponents through the DNA-programmable assembly. The recent advances in creating periodic and hierarchical organizations from inorganic nanoparticles and proteins will be presented. The use of the developed assembly approaches for generating nanomaterials with nano-optical, electrical, and biochemical functions will be demonstrated.

Invited Talk SYHN 1.5 Thu 12:15 Audimax 1
Achieving Global Tunability via Local Programming of a Structure's Composition — •Jochen Mueller — Johns Hopkins University, Baltimore, MD, United States

Once fabricated, structures and devices typically maintain their properties throughout their lifetime. In recent years, various stimuli, including temperature, pressure, and magnetic fields, have been implemented to actively change the mechanical and other physical properties after fabrication. Yet, most such approaches are limited to individual properties, specific geometries, or require high structural complexity. Inspired by this work – and by these challenges – we propose a framework for programmable and thermally reconfigurable multi-material systems. The initial structure is monolithically fabricated via 3D printing and programmed by integrating active materials that can change their mechanical properties from virtually identical to over two orders of magnitude in difference with respect to a passive base material. By varying the temperature, the programmed structure can actively adapt a wide range of mechanical properties and deformation behaviors, including the deformation mode, Poisson's ratio, and effective relative density. We anticipate the proposed framework to enable significant progress in numerous technological fields, such as aerospace, biomedical, and robotics.