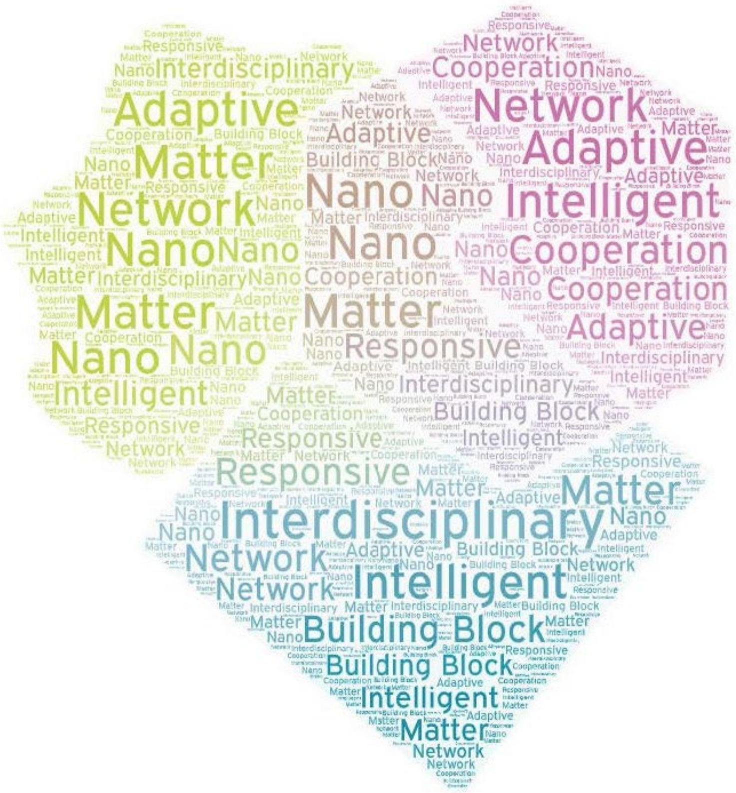
Universität
Münster

Center for Soft Nanoscience

CRC 1459
INTELLIGENT
MATTER

4th Münster Symposium on Intelligent Matter

June 25th, 2025
Münster, Germany



Book of Abstracts

4th Münster Symposium
on Intelligent Matter
June 25th, 2025

PROGRAM

9:50 am	*Welcome to MüSIM 2025!*	*Bart Jan Ravoo* *CRC 1459 Spokesperson*
10:00 am	**Silvia Vignolini** MPI of Colloids and Interfaces, Germany ***Bio - Inspired Responsive Optical Materials for Adaptive and Interactive Systems***	*Chair: Line Næsborg* *CRC 1459 Project Leader*
11:00 am	**Yoeri van de Burgt** Eindhoven University, The Netherlands ***On - Chip Learning with Organic Neuromorphic and Biohybrid Systems***	*Chair: Iris Niehues* *CRC 1459 Project Leader*
12:00 pm	Business Lunch	
1:00 pm	*Poster Sessions*	
2:40 pm	**MüSIM 2025 Young Researcher Award** **Alejandro Martínez Manjarres** University of Münster, Germany ***Photoregulated Supramolecular Polymerization through Halogen Bonding***	*Chair: Christina Kriegel* *CRC 1459 Managing Director*
3:00pm	**Martin Wegener** Karlsruhe Institute of Technology, Germany ***3D Metamaterials***	*Chair: Marcel Rey* *CRC 1459 Project Leader*
4:00 pm	**Andreas Walther** University of Mainz, Germany ***Hydrogels with a Pinch of Embodied Intelligence***	*Chair: Robert Hein* *CRC 1459 Project Leader*
5:00 pm	*Poster Prizes* Closing Remarks	*Nikos Doltsinis* *CRC 1459 Co-Spokesperson*
5:30 pm	MüSIM 2025 Networking Event	

MüSIM2025 Speakers

Prof. Dr. Yoeri van de Burgt

Eindhoven University
Department Microsystems
Institute for Complex Molecular Systems
Eindhoven, The Netherlands

Yoeri van de Burgt is associate professor at Eindhoven University of Technology leading the neuromorphic engineering group. He obtained his PhD degree in 2014 and briefly worked at a high-tech startup in Switzerland after which he worked as a postdoctoral fellow at the department of Materials Science and Engineering at Stanford University. He has been a visiting professor at the University of Cambridge in 2017 and Georgia Tech in 2022, and was awarded an ERC Starting Grant in 2018 and an ERC Consolidator Grant in 2023. He is one of the MIT Technology Review innovators under 35 Europe and Advanced Materials Rising Stars. Yoeri is a member of the scientific advisory board of the Centre for Cognitive Systems and Materials at the University of Groningen. He serves on the editorial boards of IOP Neuromorphic Computing and Engineering and Materials Science and Engineering R.

On - Chip Learning with Organic Neuromorphic and Biohybrid Systems

Yoeri van de Burgt, Eindhoven University, The Netherlands

Neuromorphic engineering takes inspiration from the efficiency of the brain and focusses on how to utilise its functionality in hardware. Organic electronic materials have shown promise in accelerating neural networks by performing multiply-accumulate operations in parallel, as well in the manipulation and the processing of biological signals, with applications ranging from neuromorphic accelerators and bioinformatics to smart sensors and robotics.

This talk describes state-of-the-art organic neuromorphic devices and provides an overview of the current challenges in the field and attempts to address them. I demonstrate a device concept based on novel organic mixed-ionic electronic materials and show how we can use these devices in trainable biosensors and smart autonomous robotics. I will present a novel implementation of backpropagation with gradient descent directly in hardware and highlight a route towards large-scale integration of organic neuromorphic arrays that are necessary for advanced intelligent computing systems.

Next to that, organic electronic materials have the potential to operate at the interface with biology. This can pave the way for novel architectures with bio-inspired features, offering promising solutions for the manipulation and the processing of biological signals and potential applications ranging from brain-computer-interfaces to bioinformatics and neurotransmitter-mediated adaptive sensing. I will highlight our recent efforts on hybrid biological memory devices and artificial neurons.

MüSIM2025 Speakers

Prof. Dr. Silvia Vignolini

MPI of Colloids and Interfaces
Director Sustainable and Bio-inspired Materials
Potsdam, Germany

Silvia Vignolini is the Director of the Sustainable and Bio-inspired Materials Department at the Max Plank of Colloids and Interfaces in Potsdam and a University Professor in Sustainability and Bio-inspired materials at the Chemistry Department in Cambridge. She studied Physics at the University of Florence, Italy. In 2009, she was awarded a PhD in Solid State Physics at the European Laboratory for non-Linear Spectroscopy and the Physics Department at the University of Florence. In 2010, she moved to Cambridge as a post-doctoral research associate working in the Cavendish Laboratory and the Plant Science Department. Her research interest lies at the interface of chemistry, soft-matter physics, optics, and biology. In particular, her research focuses on the study of how biopolymers are assembled into complex architectures within living organisms and how they can be exploited to fabricate sustainable functional materials.

Bio-Inspired Responsive Optical Materials for Adaptive and Interactive Systems

Silvia Vignolini, Max Planck Institute of Colloids and Interfaces, Germany

Nature is a great source of inspiration when it comes to materials that can change, react, and respond to their environment. This is particularly evident in optical systems, where living organisms must dynamically alter their appearance for communication, camouflage, and signaling.

By mimicking these biological strategies, engineered responsive optical materials are unlocking new possibilities in tunable transparency, structural coloration, and reconfigurable light modulation, providing new pathways for designing materials with self-regulation, real-time sensing, and autonomous feedback mechanisms.

In this talk, I will introduce some of the natural strategies that organisms develop to modulate optical appearance and show how we can mimic some of these strategies with biopolymers.

MüSIM2025 Speakers

Prof. Dr. Andreas Walther

Life-Like Materials and Systems
Department of Chemistry
University of Mainz
Mainz, Germany

Andreas Walther is a Professor for Macromolecular Materials and Systems at the Department of Chemistry at the Johannes Gutenberg University in Mainz (Germany), as well as a Max Planck Research Fellow at the MPI for Polymer Research. His research interests focus on developing life-like materials and systems that integrate dynamic processes and principles of chemical intelligence inspired from the basic principles of life. He was appointed to his present position in Mainz in 2020 with the prestigious support of the Gutenberg Research College. Andreas Walther is the recipient of an ERC Starting Grant and of an ERC Consolidator Grant. He was a co-founder of the DFG Cluster of Excellence on "Living, Adaptive and Energy-Autonomous Materials Systems" (livMatS).

Review 1: Walther, A.; “From Responsive to Adaptive and Interactive Materials and Materials Systems: A Roadmap” Adv. Mater. 1905111 (2020) (Invited View Point for a special issue on “Interactive Materials”).

Review 2: Merindol, R.; Walther, A. “Materials Learning from Life: Concepts for Active, Adaptive and Autonomous Molecular Systems” Chem. Soc. Rev. 46, 5588 (2017). (Invited Review for the Chem. Soc. Rev. special issue on “Chemical systems Out of Equilibrium”.)

Hydrogels with a Pinch of Embodied Intelligence

Andreas Walther, University of Mainz, Germany

Smart is good, but intelligent is better. The way towards intelligent matter involves designing material systems with embodied intelligence, featuring the sensor – processor – actuator paradigm. Such systems can be realized using physical or chemical information-processing routines that built, e.g., on metamaterial structures of chemical reaction networks to process information using logic procedures or feedback-regulated operation. In this talk, I will present different approaches towards hydrogels and soft robots that feature higher level of autonomous operation and decision-making capacity compared to traditional smart or responsive materials. The approaches combine elements of feedback-regulated enzymatic reaction networks, metamaterials, and other types of physical intelligence.

MüSIM2025 Speakers

Prof. Dr. Martin Wegener

Karlsruhe Institute of Technology
Institute of Applied Physics
Institute of Nanotechnology
Eggenstein-Leopoldshafen, Germany

After completing his Diploma and PhD in physics at Johann Wolfgang Goethe-Universität Frankfurt (Germany) in 1986 and 1987, respectively, he spent two years as a postdoc at AT&T Bell Laboratories in Holmdel (U.S.A.). From 1990-1995 he was professor (C3) at Universität Dortmund (Germany), since 1995 he is professor (C4, later W3) at Institute of Applied Physics of Karlsruhe Institute of Technology (KIT). Since 2001 he has a joint appointment as department head at Institute of Nanotechnology (INT) of KIT, from 2016-2022 he was one of three directors at INT. From 2001-2014 he was the coordinator of the DFG-Center for Functional Nanostructures (CFN) at KIT. Since 2018 he is spokesperson of the Cluster of Excellence 3D Matter Made to Order. His research interests comprise ultrafast optics, (extreme) nonlinear optics, optical laser lithography, photonic crystals, optical, mechanical, electronic, and thermodynamic metamaterials, as well as transformation physics.

3D Metamaterials

Martin Wegener, University, Germany

Metamaterials are rationally designed composites that allow for effective material properties that go beyond (‘meta’) those of their ingredients. In this talk, I emphasize metamaterials in the sense of three-dimensional (3D) architectures. Such often complex architectures can be made by means of 3D laser nanoprinting, into which I also give a brief introduction. For the remainder, I emphasize recent examples from my group, including nonlocal metamaterials and stimulus-responsive metamaterial. The latter allow for drastically changing their effective properties upon illumination with light.

MüSIM2025 Young Researcher Awardee

Alejandro Martínez Manjarres, MSc

Organisch-Chemisches Institut
University of Münster
Münster, Germany

For his contribution

Photoregulated Supramolecular Polymerization through Halogen Bonding

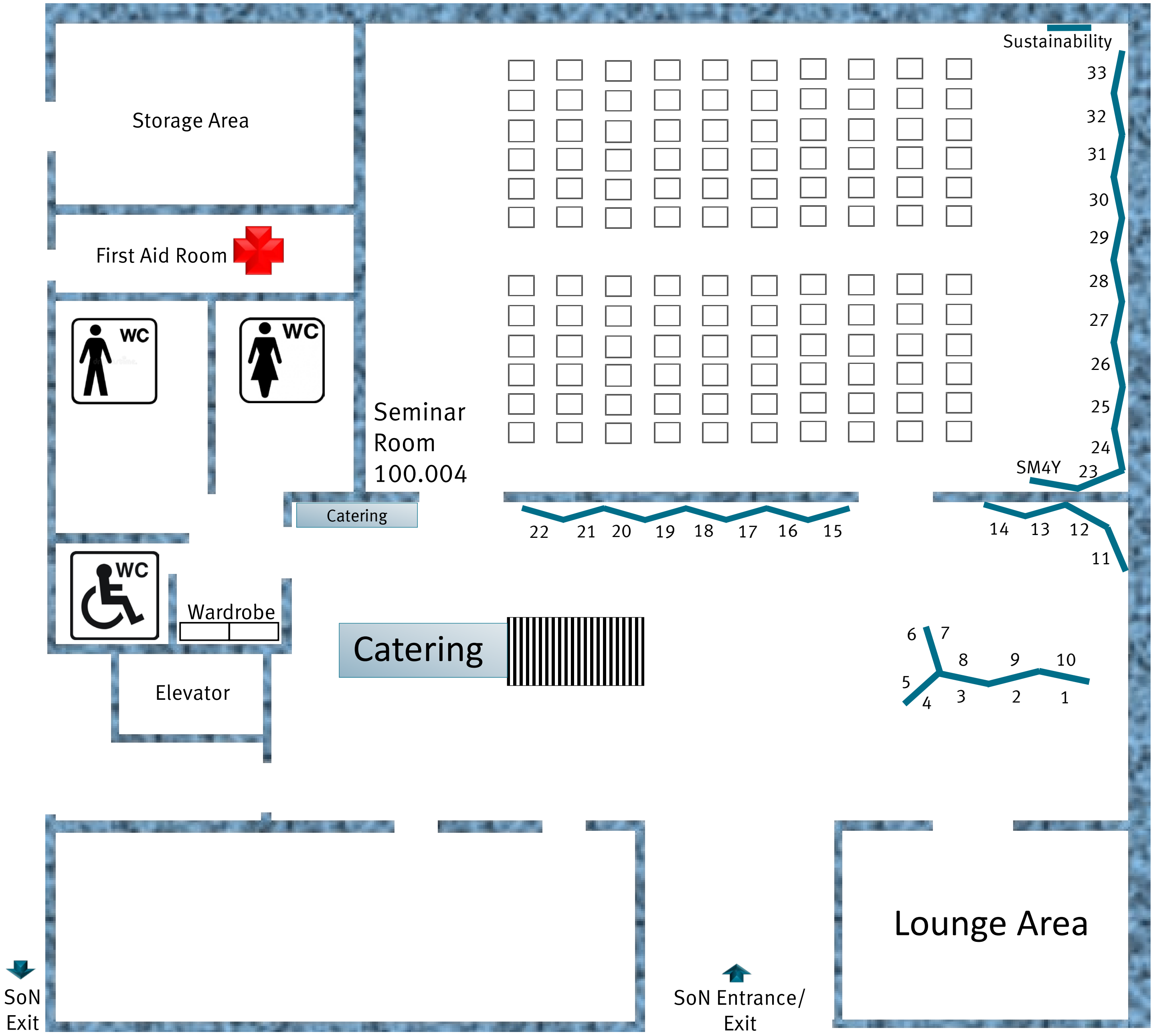
Alejandro Martínez Manjarres, Antonia Albers, and Gustavo Fernández
Angew. Chem. Int. Ed. 2025, 64, e20241972

Supramolecular polymers are able to change their structure, morphology and function in response to external stimuli. However, controlling the independence of stimuli-responses in these systems is challenging. Herein, we exploit halogen bonding (XB) as a reversible network element to regulate the photoresponsive and adaptive behavior of supramolecular polymers. To this end, we have designed a two-component system comprising an amphiphilic XB acceptor with the ability to self-assemble in aqueous media (OPE-Py) and a molecule with a dual photoresponsive and XB donor function [(E)-Azo-I]. OPE-Py self-assembles in aqueous media into supramolecular polymers, which transform into nanoparticle assemblies upon co-assembly with (E)-Azo-I. Interestingly, a third type of assembly (2D sheets) is obtained if OPE-Py is treated with (E)-Azo-I and exposed to photoirradiation. At ambient conditions, both nanoparticles and 2D sheets remain invariant over time. However, heating dissociates the XB interactions present in both assemblies, resulting in their trans-formation to the original fiber-like morphology of OPE- Py. Thus, breaking the communication between self- assembly and the stimuli-responses upon heating restores the original state of the system, drawing parallels to feedback loops in programming language. This work broadens the still limited scope of XB in solution assemblies and paves the way for multifunctional adaptive supramolecular systems.

4th Münster Symposium
on Intelligent Matter
25. June 2025

Poster Sessions Setup

Center for Soft Nanoscience Foyer, Seminar Room



Poster Session I (odd numbers): 1:00pm – 1:50pm
Poster Session II (even numbers): 1:50pm – 2:40pm

MüSIM2025 Poster Contributions

(alphabetical order, first author´s surname)

01. Dissipative Self-Assembly Synchronizes Neuromorphic Structural and Synaptic Plasticity
Vijay Basavaraj Banakar and Leonard Jan Prins
University of Padova

02. Unidirectional Molecular Adaptation by Coupled Stimuli
Sebastian Baumert, Torsten Dünnebacke, Sabine Käfer, Sebastian Hochstädt, Walter Robert Linke, Michael Ryan Hansen, Johannes Neugebauer, and Gustavo Fernández
University of Münster

03. Self-Assembly of Hybrid Nanostructures for Brain-Inspired Electronics
Marc Beuel[1,2], Jonas Mensing[2], Dominik Mählmann[2], Lisa Schlichter[2], Andreas Heuer[2], Bart Jan Ravoo[1,2], and Wilfred G. van der Wiel[1,2]
[1]University of Twente, [2]University of Münster

04. Developing Tunable Triplet Emitters towards Adaptive Electroluminescent Materials
Maria V. Cappellari, Carl Giard, Thaison Nguyen, Alex Oster, Dominik Schwab, Nikos Doltsinis, and Cristian A. Strassert
University of Münster

05. Single Step Preparation of Polymeric Structurally Coloured Glass through Polymerisation Induced Phase Separation
Chun Lam Clement Chan[1,2], Emily C. Davidson[2], and Michael M. Lerch[1]
[1]University of Groningen, [2]Princeton University

06. Combining Dopant Network Processing Units and Photonic Convolutional Processors for in-Sensor Computing
Reinier Cool[1,2], Ivonne Bente[2], Lorenzo Cassola[1], Wolfram H.P. Pernice[3], and W. G. van der Wiel[1,2]
[1]University of Twente, [2]University of Münster

07. Dynamic Redox Switching in Molecular Junctions Mediated by Self-Assembled Monolayers Of N-Heterocyclic Carbenes
Ankita Das[1], Alessandro Borrini[2], Christian Gutheil[1], Billura Shakhayeva[1], Björn Braunschweig[1], Robert Hein[1], Christian A. Nijhuis[1,2], and Frank Glorius[1]
[1]University of Münster, [2]University of Twente

08. Electrografted Molecular Thin Films: A Unique Platform for Dynamic Molecular Switching
Ritu Gupta[1] and Christian A. Nijhuis[1,2]
[1]University of Twente, [2]University of Münster

MüSIM2025 Poster Contributions

(alphabetical order, first author´s surname)

09. **Adaptive Air-Water Interfaces with Spiro-Pyran and Arylazopyrazole Photoswitches**
Michael Hardt, H.Gökberk Özcelik, Andreas Heuer, and Björn Braunschweig
University of Münster

10. **Towards a Scalable Fabrication of Biobased Photonic Pigments**
Marina Karsakova and Michael M. Lerch
University of Groningen

11. **Dynamic Covalent Bonds as a Tool for 3D Printing Recyclable and Self-Healing Materials**
Marvin Kollwitz and Michael Giese
University of Duisburg-Essen

12. **In-situ NMR for the Characterization of Micellar Systems for Photochemical Reactions**
Alisa Kondrateva, Gianna Pölderl, Julian C. G. Kürschner, Monika Schönhoff, and Line Næsborg
University of Münster

13. **Molecular Neuromorphic Devices for Energy Efficient Computing**
Harilal Kulangara[1] and Christian A. Nijhuis[1,2]
[1]University of Twente, [2]University of Münster

14. **Coherent Nanophotonic Neural Networks with Adaptive Molecular Systems**
Peter Lazarowicz, Jonas Konrad, Marlon Becker, Carsten Schuck, and Benjamin Risse
University of Münster

15. **Conducting Droplets as Neuron-like Oscillators for Computing**
Yi Li[1], Saurabh Soni[1], Arjan Vellema[1], Qianqi (Ivana) Lin[1], Mathieu Odijk[1], and Christian A. Nijhuis[1,2]
[1]University of Twente, [2]University of Münster

16. **Intelligent Molecules for Brain-like Devices**
Qi (Charlotte) Lin[1] and Christian A. Nijhuis[1,2]
[1]University of Twente, [2]University of Münster

17. **Synthesis of Functionalized Alternating Copolymers towards Responsive and Adaptive Materials**
Kirill Markelov and Armido Studer
University of Münster

18. **Tip-Enhanced Photoluminescence of Color Centres in hBN**
Dennis Mors[1,2], Christian A. Nijhuis[1,2], and Iris Niehues[1]
[1]University of Münster, [2]University of Twente

MüSIM2025 Poster Contributions

(alphabetical order, first author´s surname)

19. **Development of Intelligent Soft Actuators Based on Hybrid Materials**
    Christian A. Nijhuis[1,2] and Bart Jan Ravoo[1,2]
    [1]University of Twente, [2]University of Münster

20. **Second Harmonic Generation of Spin Waves in YIG Waveguides**
    Kirill O. Nikolaev[1], Jannis Bensmann[1], Dmitrii Raskhodchikov[1], Robert Schmidt[1], Wolfram H. P. Pernice[1,2], Steffen Michaelis de Vasconcellos[1], Rudolf Bratschitsch[1], Sergej O. Demokritov[1] and Vlasidlav E. Demidov[1]
    [1]University of Münster, [2]Heidelberg University

21. **Interface-Targeted Photoinduced Drug Release with Arylazopyrazole Photosurfactants**
    Ipsita Pani, Michael Hardt, Dana Glikman, and Björn Braunschweig
    University of Münster

22. **Strong Anisotropy Behaviour of the 2D Magnetic Semiconductor CrSBr**
    Pierre-Maurice Piel[1], Aleksandra Łopion[1], Jan-Hendrik Larusch[1], Nicolai-Leonid Bathen[1], Sebastian Schaper[1], Zdenek Sofer[2], and Ursula Wurstbauer[1]
    [1]University of Münster, [2]University of Chemistry and Technology Prague

23. **Electrochromic Dye-Doped Liquid Crystal PMMA Microcapsules**
    Yingqi Ren and Michael M. Lerch
    University of Groningen

24. **The Goldilocks Principle in Peptide Amphiphile Assembly**
    Mahdi Samapour[1], Sebastian B. Beil[2], Tobias Schnitzer[3], and Michael Lerch[1]
    [1]University of Groningen, [2]Max-Planck-Institute for Chemical Energy Conversion, [3]Albert-Ludwigs University Freiburg

25. **Dynamic Systems of Light-Propelled Microparticles with Intelligent Behaviour**
    Jesco Schönfelder[1], Marta Conti[1], Matthias Rüschenbaum[1], Elena Vinnemeier[1], Jörg Imbrock[1], Cornelia Denz[2], Raphael Wittkowski[3], and Marcel Rey[1]
    [1]University of Münster, [2] Physikalisch-Technische Bundesanstalt (PTB), [3] RWTH Aachen University

26. **Responsive Polymer Morphology Change Through Reversible Block Fragmentation Using Cucurbit[8]uril**
    Tim Silies[1], Dominik Mählmann[1], and Bart Jan Ravoo[1,2]
    [1]University of Münster, [2]University of Twente

MüSIM2025 Poster Contributions

(alphabetical order, first author´s surname)

27. **Structure-Property Relationship of CuSCN and Co-ligand Complexes**
    Jetnipat Songkerdthong[1,2], Pichaya Pattanasattayavong[2] and Christian A. Nijhuis[1,3]
    [1]University of Twente, [2]Vidyasirimedhi Institute of Science and Technology, [3]University of Münster

28. **New Photoswitches for Integration in Adaptive Nanosystems**
    Bastian Stövesand[1], Arne Nalop[1], Bart Jan Ravoo[1;2], and Frank Glorius[1]
    [1]University of Münster, [2]University of Twente

29. **Structure-Aided Chemical Signal Propagation in Hydrogel Metastructures**
    Foteini Trigka[1], Styliani-Theodosia Korfia Sara Bizzi[1], Hang Zhang[2], Bolei Deng[3], and Michael M. Lerch[1]
    [1]University of Groningen, [2]Aalto University, [3]Georgia Tech

30. **Mixed-Mode in-Memory Computing Using Adaptive Phase-Change Materials**
    Niklas Vollmar[1], Daniel Wendland[1], Akhil Varri[1], Anna Ovvyan[2], Sebastian Walfort[1], Zhongyu Tang[2], Wolfram H.P. Pernice[2], and Martin Salinga[1]
    [1]University of Münster, [2]Heidelberg University

31. **Supramolecular Light-Switchable Triazole-Hosts for Photoadaptive Anion Binding**
    Leonard Wyszynski, Yannik Steinberg, Leon Hoppmann, Marcus Böckmann, Nikos Doltsinis, Monika Schönhoff and Olga García Mancheño
    University of Münster

32. **Restoring Intracellular Homeostasis Disrupted by Synthetic Nanoassemblies**
    Xiaoran Zheng[1], Jiaqi Xing[2], Tanja Weil[2], Christopher V. Synatschke[2], and Seraphine V. Wegner[1]
    [1]University of Münster, [2]Max Planck Institute for Polymer Research

33. **Spectroscopic Imaging Ellipsometry at Cryogenic Temperatures: A Structural Phase Change in a 2D polar Metal**
    Jakob Henz[1], Siavash Rajabpour[2], Alexander Vera[2], Arpit Jain[2], Joshua A. Robinson[2], Su Ying Quek[3], Ursula Wurstbauer[1]
    [1]University of Münster, [2]PennState University, [3]National University of Singapore

Special MüSIM2025 Contributions

SmartMatters4You: Students Gain Insights into Research at the SFB 1459 "Intelligent Matter"

Julian Repke
University of Münster

Sustainability Starts with You!

Henning Klaasen
University of Münster

MüSIM2025 Poster Abstracts

1

Dissipative Self-Assembly Synchronizes Neuromorphic Structural and Synaptic Plasticity

Vijay Basavaraj Banakar and Leonard Jan Prins

University of Padova, Department of Chemical Sciences,
Via Marzolo, 1, 35131, Padova, Italy

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Dissipative self-assembly involves the emergence of supramolecular structures that reside in low-entropy states by dissipating energy to the environment, thereby increasing its entropy[1]. Actin polymerization is one such example of dissipative self-assembly. Actin remodeling in neurons involves morphological changes in dendritic spines (structural plasticity) that further influence synaptic plasticity (short-term plasticity and long-term potentiation)[2]. We describe a neuromorphic electrochemical device capable of emulating structural and synaptic plasticity in a synchronized manner. We achieved this by employing gold nanoparticles that form emergent semiconducting dissipative structures in response to low operating voltages. Supramolecular self-assembly of semiconducting dissipative material between synaptic electrodes reminisces actin remodeling of neurons. The device is capable of demonstrating hallmarks of habituation, including frequency sensitivity and intensity sensitivity. Systematic investigations revealed the memory effects and nonlinearity in the system. Additionally, the system was also capable of waveform recognition. We elaborate mechanism of memory formation in comparison with an appropriate control system that does not undergo self-assembly.

References

[1]. Ragazzon, G., Prins, L.J. Energy consumption in chemical fuel-driven self-assembly. *Nature Nanotech* **13**, 882–889 (2018).

[2]. Lamprecht, R., LeDoux, J. Structural plasticity and memory. *Nat Rev Neurosci* **5**, 45–54 (2004).

2

Unidirectional Molecular Adaptation by Coupled Stimuli

Sebastian Baumert[1], Torsten Dünnebacke[1], Sabine Käfer[1,2], Sebastian Hochstädt[3], Walter Robert Linke[3], Michael Ryan Hansen[3], Johannes Neugebauer[1,2], and Gustavo Fernández[1]

[1]*University of Münster, Institute of Organic Chemistry, Correnstraße 36, 48149 Münster, Germany*
[2]*University of Münster, Center for Multiscale Theory and Computation, Corrensstraße 36, 48149 Münster (Germany).*
[3]*University of Münster, Institute of Physical Chemistry, Correnstraße 28/30, 48149 Münster, Germany*

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Adaptation occurs at different scales in both natural and synthetic systems, but the underlying factors driving this process are not yet clearly understood. In this work, we investigate the molecular basis of adaptation and memory and their relationship with electronic communication. Our approach centers on p-conjugated molecular building blocks that incorporate light and pH-responsive units, enabling the independent or combined application of different stimuli. Combining experimental studies and quantum chemical calculations, we show that adaptive behaviour results from the coupled interaction of these stimuli. The system's response depends on the order in which the stimuli are applied. By precisely controlling the irradiation intensity and the amount of acid, we achieved one-point-return memory behaviour, highlighting the potential of our approach for advancing adaptive system design. These findings provide new insights into the design of (multi)stimuli-responsive systems and offer a framework for generally guiding the development of molecular-level adaptive behaviour.

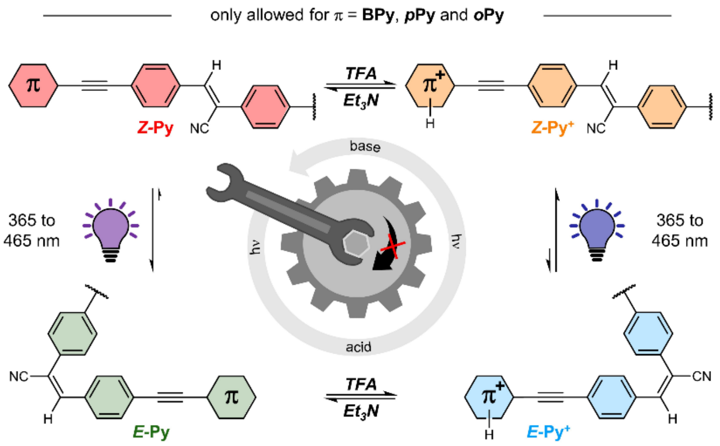

Fig. 1: Schematic representation of responsive behaviour of the system to independent pH and light stimuli.

Self-Assembly of Hybrid Nanostructures for Brain-Inspired Electronics

M. Beuel[1,2,3], J. Mensing[4], D. Mählmann[2], L. Schlichter[2], A. Heuer[4], B. J. Ravoo[2],
and W. G. van der Wiel[1,3]

[1]University of Twente, BRAINS Center for Brain-Inspired Nano Systems and MESA+ Institute for Nanotechnology, Drienerlolaan 5, 7522 NB Enschede, The Netherlands
[2]University of Münster, Center for Soft Nanoscience / Organisch-Chemisches Institut, Busso-Peus-Straße 10, 48149 Münster, Germany
[3]University of Münster, Physikalisches Institut, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany
[4]University of Münster, Institut für Physikalische Chemie, Corrensstraße 28-30, 48149 Münster, Germany

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Disordered hybrid nanomaterial networks exhibit complex energy landscapes[1] that can be tuned towards reconfigurable computational functionality, such as logic operations, feature extraction or other non-linear information processing. In this project, hybrid organic-inorganic nanostructures based on the assembly of nanoparticle networks connected by junctions composed of tailor-made organic ligands are constructed. Magnetite (MNP)[3] or gold nanoparticles (AuNP) act as single electron transistors while organic ligands act as tunable tunnel barriers introducing synaptic, tunable memory. Host-guest complexes with cyclodextrin and various guest molecules (e.g. semi-conductors and molecular switches like AAP) are explored as supramolecular junctions. By using dip pen nanolithography[2], the supramolecular are deposited on surfaces between nanoelectrodes. A genetic algorithm is used to find suitable configurations of control voltages to mimic the desired computations (for example by Evolution-in-materia). The theoretical underpinning of NP networks is investigated by developing a highly optimized physical model to simulate charge transport processes within the network stochastically [4] or by a mean-field approximation[6]. Besides, statistical and data-driven tools investigate requirements for computing and memory functionalities[4,5,6,7].

References

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[2] L. Schlichter, F. Bosse, B.J. Tyler, H. F. Arlinghaus, B.J. Ravoo, Small 2023, 19, 2208069.

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[4] J. Mensing, W. G. van der Wiel, A. Heuer, Frontiers in Nanotechnology, 2024, 6, fnano.2024.1364985.

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4

Developing Tunable Triplet Emitters towards Adaptive Electroluminescent Materials

M. V. Cappellari, C. Giard, T. Nguyen, A. Oster, D. Schwab, N. Doltsinis, and C. A. Strassert

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University of Münster, Institute of Inorganic and Analytical Chemistry,
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Transition metal complexes are well known for their efficient light-emission, allowing for a broad range of applications. We have synthesized metal organic compounds featuring tetradentate coordination patterns, which show drastic changes in their photophysical properties upon excimer formation facilitated by supramolecular self-assembly and metal-metal interactions. We demonstrate how the metal-metal distance can be precisely modulated by exerting pressure. Time-dependent density functional theory (TD-DFT) calculations attribute the observed wavelength shift to a reduction in the metal-metal distance and enhanced π-orbital overlap in the dimers.

Based on this effect, flexible and tunable polymers are being developed as luminescent materials. Azopolymers are promising candidates to control the material's density by light. Molecular dynamics (MD) simulations of a crosslinked azopolymer are performed at varying degrees of *cis*-azobenzene population to investigate the polymer's photoresponsive behaviour. Independent of the solvent, the polymer is found to strongly fold, even without photoswitching. The latter accelerates the folding process, which is however irreversible. Switching between an all-*trans* and all-*cis* state does not lead to major changes in the polymer density.

Donor-acceptor-based polymers offer an example for a pressure-responsive system. Absorption spectra for a polymer featuring a phenoxazine donor and a benzonitrile acceptor are calculated for pressures up to 8 GPa. The spectra are obtained using TD-DFT for structures taken from classical MD trajectories at constant pressure. No significant pressure-dependence is observed. Alternative donor-acceptor pairs, such as isophthalonitrile and tetraphenylethylene, are explored to achieve responsive behaviour.

5

Single Step Preparation of Polymeric Structurally Coloured Glass through Polymerisation Induced Phase Separation

Chun Lam Clement Chan[1,2], Emily C. Davidson[2], and Michael M. Lerch[1]

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Nature displays structural colour through a wide variety of nanostructures, leading to optical properties ranging from iridescence in photonic crystals and matte reflections in photonic glasses. One of these structures is the bicontinuous network morphology responsible for the blue colour in the feathers of some bluebirds. Despite an angular independent reflection advantageous for pigments, replication of this structure is challenging in synthetic systems. Most notably, the bicontinuous network morphology is not thermodynamically stable, and will gradually coarsen and lead to macrophase separation. In this study, we prepare polymeric structural coloured glass through spinodal decomposition triggered by polymerisation induced phase separation. This structure is preserved and prevented from further coarsening by introducing of a crosslinking and rapid photopolymerization. Furthermore, by tuning the ratio between a monofunctional monomer and a difunctional crosslinker, we can further tune the characteristic lengthscales of the phase-separated microstructure and thereby the reflected colour. This single-step approach results in the facile preparation of a photonic glass with angular independent properties, which can be potentially developed into pigments and incorporated into additive manufacturing systems.

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Combining Dopant Network Processing Units and Photonic Convolutional Processors for In-Sensor Computing

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Combining upcoming technologies for unconventional computing could enhance the individual technologies' strengths and suppress their weaknesses. Photonic convolutional processors (PCPs) are devices that are based on an integrated photonics platform that excel at performing ultra-fast matrix multiplication. Dopant network processing units (DNPUs) are silicon-based devices that utilize their tunable non-linearity to solve classification problems at low energy costs. We are amidst the process of combining the two platforms to realize in-sensor computing in a way that resembles a layer of a neural network. The PCP is used to reduce the dimensionality of incoming optical data at very low cost, reducing the cost of converting the data to the electrical domain. The data is then passed on to a layer of DNPUs that is trained to perform a complex non-linear operation. Based on these outputs, the final classification is performed. This combination could cut the time and energy costs required to classify incoming optical data.

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Dynamic Redox Switching in Molecular Junctions Mediated by Self-Assembled Monolayers Of N-Heterocyclic Carbenes

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Brain-inspired neuromorphic computing offers a promising low-power, high-efficiency alternative to classical architectures, but implementing stable and tunable artificial synapses remains a key challenge. We recently demonstrated molecular-level neuromorphic architectures using thiol-based self-assembled redox-active switches in conductance junctions. By coupling fast electron transfer with slow, diffusion-limited protonation, we enabled feedback pathways, negative differential resistance (NDR), and synaptic-like behaviour, including Pavlovian learning.[1] However, thiols suffer from oxidative instability and limited tunability. To overcome this, we employ N-heterocyclic carbenes (NHCs), which offer enhanced chemical stability and versatile backbone modification.[2] By incorporating a redox-active quinone unit into the NHC framework, we developed Redox-NHC molecules that form stable self-assembled monolayers in EGaIn junctions with gold electrodes. These systems show robust redox switching, high-voltage resistance, and reproducible NDR behaviour, enabling memory-like properties. To further expand functionality, we aim to integrate additional feedback mechanisms via tailored NHC backbones. We are exploring novel redox-switches which exhibit, for example, inherent hysteric behaviour, multi-redox or photoresponsive behaviour—traits ideal for next-generation intelligent conductance junctions.[3]

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Electrografted Molecular Thin Films: A Unique Platform for Dynamic Molecular Switching

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Brain-inspired computing has gained considerable attention in recent years due to its potential to emulate the dynamic characteristics of neurons and synapses, enabling faster computation and reduced power consumption over traditional Von Neumann architecture.[1] In this regard, dynamic molecular switches are quite appealing owing to their small size; suitable for faster memory operations, tunable chemical structures, easier synthesis process, low-operational voltage, less energy consumption, and responsiveness to temperature, pH, and solvent, which is practically unfeasible with traditional silicon-based electronics.[2–4] So far, reported studies have incorporated thiol-anchoring groups to self-assemble the active molecule on the gold (Au). However, interfacial defects formed during the self-assembly process, and their reactivity to oxygen and moisture limit the device's stability and performance. Here, we report a molecular switch with a configuration of Au/Phenz/EGaIn. Thanks to the electrochemical grafting technique, highly robust, well-ordered thin films of Phenz are covalently grown onto the thermally evaporated Au.[5,6] Based on proton-coupled electron transfer (PCET), Phenz switches from high to low conductance states with hysteric negative differential resistance (NDR). The switching dynamics are modulated by the number of scans and the bias scan rate. The observed temporal dynamics of the junctions illustrate their potential to emulate synaptic behaviour.

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Adaptive Air-Water Interfaces with Spiro-Pyran and Arylazopyrazole Photoswitches

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Interfaces that respond to stimuli like light or temperature are of significant interest in the field of dynamic materials.[1,2] Using molecular switches that react to different triggers enables the precondition of the properties of fluid interfaces and introducing a basic level of adaptivity, thereby extending the possibilities of soft matter interfaces beyond responsive functions. We explore the adaptive behaviour of air-water interfaces decorated by spiropyran (SP) and arylazopyrazole (AAP) photo-responsive surfactants. When exposed to UV light, the SP surfactants become more surface active, while the AAP surfactants undergo E/Z photoisomerization, significantly reducing their surface activity.

By adjusting the intensity and duration of the UV exposure, the interfacial properties can be shifted from a simple responsive state to a more complex, conditioned response, accompanied by a dramatic alteration in interfacial chemistry. Vibrational sum-frequency generation (SFG) and neutron reflectometry suggest that prolonged UV exposure induces SP and AAP surfactant aggregation at the air-water interface, driving the conditioned response where thick SP layers form in the presence of Z-AAP. These experiments are complemented with classical molecular dynamics simulations of the AAP and SP surfactants that visualize the occurrences at the air-water interface depending on the surface coverage.

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Towards a Scalable Fabrication of Biobased Photonic Pigments

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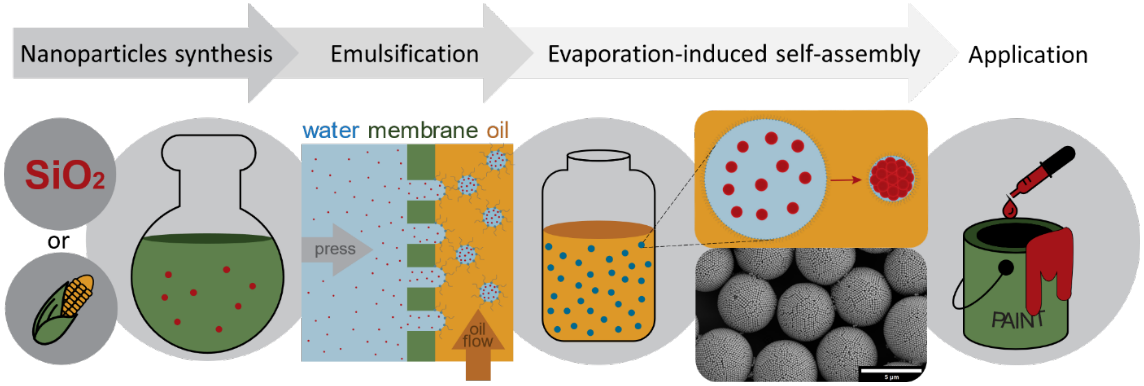
Structural colors are based on the physical interaction of light with nanostructures rather than on the absorption of light by pigment molecules. This makes structurally colored pigments highly resistant to fading and allows for the generation of vibrant colors, from blue to red, using a single, renewable, and cost-effective material.

In this project, we focus on scaling up the production of photonic pigments by utilizing the evaporation-induced self-assembly of monodisperse nanoparticles within emulsion droplets, also incorporating bio-based building blocks. Using membrane emulsification, we can generate quasi-crystalline nanostructures in a scalable and reproducible way without cleanroom facilities or microfluidic systems. The nanoparticle building blocks used for these purposes require ultramonodispersity, colloidal stability and a high refractive index. Towards this end, we have successfully obtained starch- and polydopamine-based nanoparticles as bio-derived nanoparticle building blocks for structural color formation and explore their self-assembly behaviour.



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Dynamic Covalent Bonds as a Tool for 3D Printing Recyclable and Self-Healing Materials

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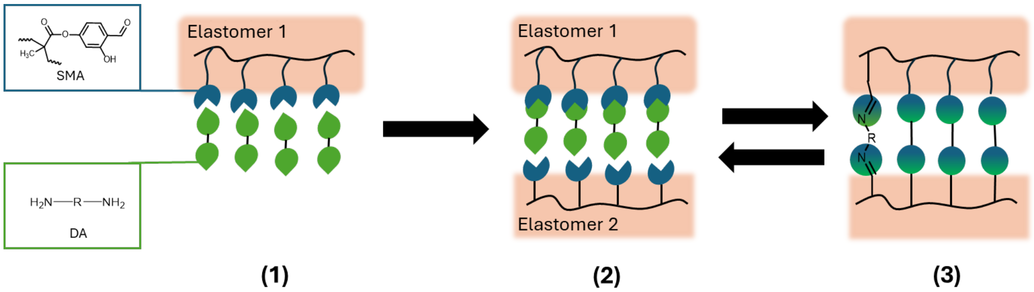
In today's world, sustainability and the efficient use of raw materials are becoming increasingly important. This is especially true in plastics production, because there is a strong emphasis on using materials as efficiently as possible, in the smallest quantities needed.[1] In this context, additive manufacturing (3D printing) proves to be highly effective, as material is typically applied only where it is required. This enables the rapid, simple, and cost-effective production of components.[2] In this study, we demonstrate a 3D-printed elastic material, featuring surface-active functional groups enabling the materials to form dynamic covalent imine bonds, which allows to post-functionalize the materials or provides the ability to self-healing. By employing resin-compatible amine acrylates the surface was amine functionalized. After photo-polymerisation in a commercially available SLA printer the materials properties could be subsequently functionalized by imine-condensation with salicylic aldehydes. The new materials can be varied in their emissive behaviour by chosing the corresponding salicyl aldehyde and may be employed as fluorescent sensors for metal ions in aqueous media. Using resin-compatible salicyl-aldehyde acrylates yielded after 3D-printing surfaces decorated with aldehyde functions. Variations in composition were explored to show tunability in mechanical and adhesive properties. The adhesion process was done in a two-step preparation. First, an aldehyde-containing polymer is activated with a bifunctional diamine (DA), which selectively reacts with the aldehyde groups to form imine bonds, as indicated by strong fluorescence[1]. A second sample with aldehyde functionalized surface is then attached, creating a stable dynamic covalent bond bridging the two materials samples[2]. Mechanical testing reveals that the crosslinked polymer exhibits high elasticity with adjustable stiffness. These material properties can be precisely controlled by varying the temperature. Moreover, the network is recyclable and reusable, thanks to the reversible nature of the dynamic covalent bonds.



Scheme 1: Grenal strategy of adhesion between elastomer surfaces through dynamic covalent bonds

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In-Situ NMR for the Characterization of Micellar Systems for Photochemical Reactions

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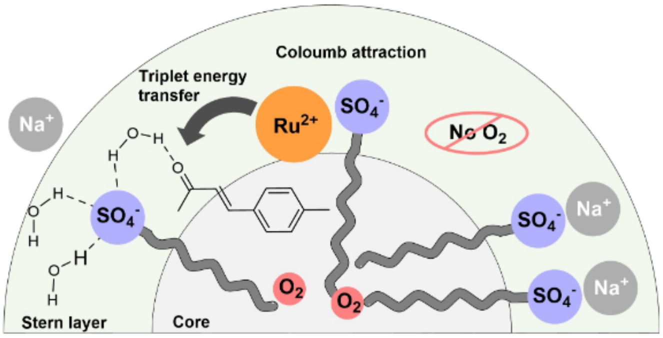
The development of self-regulating soft materials that rely on light-driven exothermic reactions and negative feedback through the optical properties of the sample is a promising strategy for creating stimuli-responsive systems. We investigate micellar photocatalysis of a [2+2] photocycloaddition via triplet-energy transfer. α,β-Unsaturated carbonyl compounds and activated alkenes are reacting in a mixture of sodium dodecyl sulfate, water, and photocatalyst $[Ru(bpy)_3](PF_6)_2$. Employing micellar reaction systems, oxygen remains within the hydrophobic core of the micelle, while the reaction takes place in the Stern layer, minimizing quenching[1].



The localization of molecular components, such as catalysts and substrates, in the micellar dispersion, as well as their influence on micelle structure are investigated by pulsed-field gradient NMR diffusion. For a range of substrates with varying polarity almost full micellar incorporation is observed, while the micellar size is only enhanced at very high substrate loading. Furthermore, the reaction progress and associated changes of molecular localization and micelle structure are monitored by in-situ NMR under irradiation. Here, significant changes in micelle characteristics are detected, likely related to reagent consumption and product formation during the reaction. These studies provide additional insights into the reaction mechanism and the localization of reactants and products within the system.

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Molecular Neuromorphic Devices for Energy Efficient Computing

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To develop energy-efficient computers for higher processing capacity and lower carbon footprint, our research aims to design intelligent molecules capable of emulating the computational processes of the human brain. Such a molecule has been recently reported that can learn based on proton-coupled electron transfer reaction. We aim to elucidate in detail the mechanism of charge transport and switching mechanisms, and how this knowledge can be used to optimize both electron transfer and proton coupling rates with the goal to optimize switching rates. We employ cleanroom-compatible, bottom-up fabrication approaches to achieve scalable and reproducible integration of these molecular junctions into device architectures. The molecule's intrinsic rectification behaviour reduces sneak path currents in the crossbar arrays, enabling more reliable large-scale integration. This work represents a critical step towards realizing scalable, low power molecular hardware for next-generation computing.

Coherent Nanophotonic Neural Networks with Adaptive Molecular Systems

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Optical Artificial Neural Networks (ONNs) have become increasingly important as candidates to overcome the limitations of Van Neumann-based Artificial Neural Networks. Current ONN implementations are typically electro-optical systems and so partially sacrifice the enhanced performance that ONNs provide. While all-optical linear operations within ONNs are already well implemented, the nonlinear elements (or Nonlinear Activation Functions) remain elusive. This work focuses on the development of ONN building blocks, exploiting nonlinear optical responses found in several adaptive molecular systems.

We build on our past work which used a solution-based photoswitchable azobenzene leading to a network capable of classifying the MNIST handwritten digits data set with an accuracy of 96 %[1]. Therefore, we extracted the nonlinearity from the saturable absorption effect exhibited by azobenzenes. Employing azobenzenes in polymer-based solutions allows for direct integration on-chip. This simplifies fabrication processes significantly and allows for the construction of components such as Mach-Zehnder Interferometers being instead on the nonlinear refractive index shift experienced by azobenzenes. We also further expand on saturable absorption-based neurons by considering alternative adaptive systems such as phthalocyanine. In combination with the development of Inverse Design algorithms for further footprint reduction[2,3], we lay the groundwork for chip-scale nonlinear activation behaviour.

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Conducting Droplets as Neuron-like Oscillators for Computing

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Biomimetic systems, emulating neuronal behaviour and bio-inspired computing, are important based on understanding of neuronal functions. Wherein oscillatory system is promising by producing rhythmic patterns (e.g., mimicking brain waves). Specifically, high-order complexity is essential to reach rich dynamics in neural behaviour (e.g., tonic, adapt and burst firing). Yet the system achieving such rich dynamics within one oscillator is rarely studied. The potential of soft materials and chemicals in mimicking natural oscillation is great but not fully appreciated. Here we report a self-driven oscillator based on liquid metal (alloy of Ga and In) droplet, driven by a continuous applied DC voltage, which are visually recorded in real time. The characteristics of this oscillator depends on the voltage, pH and viscosity of the medium in which the droplet oscillates. This oscillator exhibits high-order complexity, with its current output resembling the action potentials of various types of neurons. Furthermore, we demonstrate waveform classification and time series prediction using this oscillator.

Intelligent Molecules for Brain-like Devices

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To develop energy-efficient computers for higher processing capacity and lower carbon footprint, we aim to design intelligent molecules capable of emulating the computational processes of the human brain. Recently, we have identified the molecule 5,6,11,12,17,18-hexaazatrinaphthylene (HATNA) in tunneling junctions to exhibit synapse-like responses by coupling fast and slow processes via proton coupling electron transfer (PCET)[1]. The overarching goal of this research is to develop scalable devices based on cross-bar architectures, with HATNA monolayers serving as the functional layer. For the top electrodes, we utilize the microfluidic channels on PDMS to stabilized the EGaIn[2]. To enhance scalability and cleanroom compatibility in device fabrication, we propose a multifunctional layer incorporating the well-characterized conductive polymer PEDOT:PSS. The PEDOT:PSS layer serves dual purposes: it protects HATNA molecules from damage during the fabrication of the top electrode[3] and acts as a native proton source to initiate the PCET process within HATNA. PEDOT:PSS layer create a stable environment for HATNA PCET process which might accelerate the PCET. The addition of PEDOT:PSS layer is beneficial for manufacturing the device towards neuromorphic computing. In this poster, we give an overview of the electrical properties of PEDOT:PSS; crossbar device fabrication and its characterization.

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Synthesis of Functionalized Alternating Copolymers towards Responsive and Adaptive Materials

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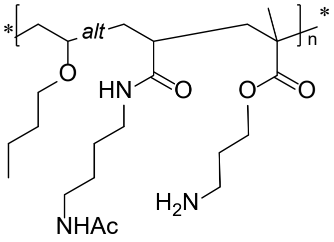
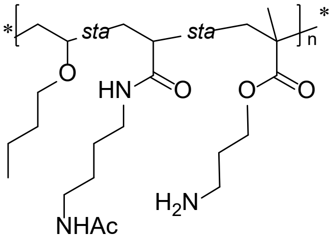
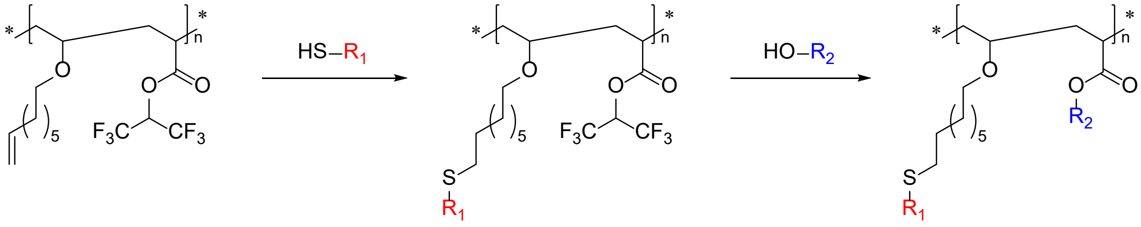
The control over the primary structure of the polymer is crucial for designing responsive and adaptive soft materials. So far, only few examples of alternating copolymers showing responsive behaviour are demonstrated in the literature. Consequently, novel alternating copolymer systems are highly demanded in terms of responsive soft materials. By means of postmodification methods, properties of a copolymer can be altered by introducing functionalized entities. In addition, orthogonal postmodification methods such as thiol-ene-click, amidation/esterification and azide-alkyne-cyclocaddition approaches allow selective and multiple tuning of the properties of the polymer towards responsive and adaptive behaviour. Recently, Prof. Herrmann and coworkers showed that coacervates of sodium dodecylbenzene sulfonate (SDBS) and their genetically engineered proteins which have a high content of lysine, exhibit adhesive properties. Our idea is based on exchange of proteins by our functionalized terpolymers due to broader variety of functionalities. By modification of our alternating terpolymer with H-bond donor and acceptors the terpolymers were obtained. The adhesive properties were analyzed by our collaboration partner at RWTH Aachen.





In the second project, the alternating copolymers are functionalized with donor and acceptor molecules to access luminescent polymers. After the synthesis, UV-/vis and fluorescence of the functionalized copolymers were measured to evaluate spectroscopical properties.



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Tip-Enhanced Photoluminescence of Colour Centers in hBN

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Color centers (CCs) in hexagonal boron nitride (hBN) are promising candidates for stable and bright quantum light sources even though their origin is still unknown. We use a scattering-type scanning near-field optical microscope (s-SNOM) to study the photoluminescence (PL) emission characteristics of such quantum emitters in metalorganic vapor phase epitaxy grown hBN[1]. Here, a sharp metallic tip is used to convert the illuminating field into a strongly concentrated near field at the very tip apex the so called nanofocus. We use this technique to measure the CCs with a nanoscale resolution beyond the diffraction limit (Fig.1). On the one hand we prove direct interaction of the nanofocus with the CC leading to tip-enhanced PL (TEPL). Additionally, we observe constructive interference between direct beams to/from the CC and those scattered from the AFM tip, resulting in an arc around the CC (Fig.1). With this tip-assisted PL (TAPL), we determine the in-plane dipole orientation of CCs.

In future works exfoliated hBN can be used to link crystallographic axis to the dipole orientation, thereby revealing possible origins of the CC in hBN.

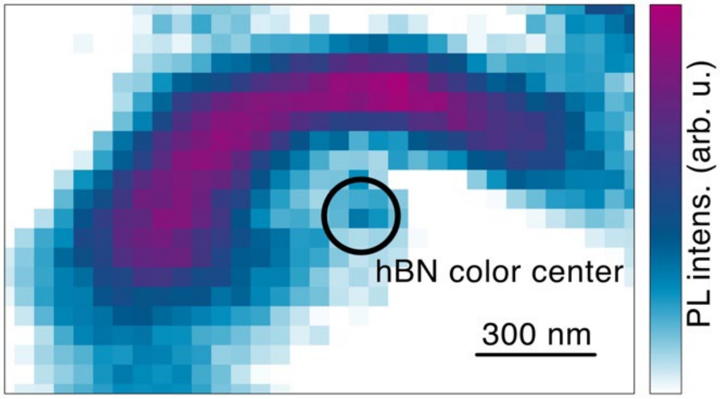

Fig. 1 PL map of a CC with the corresponding arc from TAPL. [1]

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Development of intelligent soft actuators based on hybrid materials

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Intelligent soft matter systems can make a profound impact on various applications such as wearable devices, sensors, and the emerging area of soft robotics. In this project, we aim to develop electrically powered soft actuators, incorporating hybrid materials that enable an internal feedback mechanism for adaptivity and learning. We envision soft actuators where the electrode material is a malleable metal polymer composite and the filler material (which is typically water or air) is a gel or block copolymer composite. The hybrid material is compatible with 2/3D printing techniques suitable for soft actuator fabrication. Once feedback-controlled actuation has been realized, we will demonstrate a self-learning soft gripper.

Second harmonic generation of spin waves in YIG waveguides

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Spintronics has emerged as a promising candidate for building computational systems and boosting the performance of information technology.[1] For computing purposes, spin waves offer several advantages, such as low energy losses, broad bandwidth (GHz up to THz), and nanometer-scale wavelengths.[2] A key requirement for complex computing applications is the realization of nonlinear processes, such as second harmonic generation (SHG).
Here, we present SHG in nanoscopic spin waveguides.[3,4] The waveguides are made of the insulating material Yttrium Iron Garnet (YIG), which exhibits exceptionally low spin-wave damping. The waveguides are 500 nm wide and 80 nm thick. Spin waves are excited via a gold microstrip antenna in two configurations, governed by the orientation of the external magnetic field. Surface spin waves are generated with the magnetic field in plane and perpendicular to the waveguide[3], while so-called backward volume spin waves are generated when the field is along the waveguide[4]. We engineer the dispersion of the spin-wave modes to achieve resonance conditions for efficient SHG. Interestingly, in backward volume configuration, the second harmonic spin waves propagate in the opposite direction of the fundamental wave.
Our results open up new possibilities for nonlinear spin-wave devices for signal processing.

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Interface-Targeted Photoinduced Drug Release with Arylazopyrazole Photosurfactants

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Smart responsive materials have significantly advanced high-precision drug delivery. While drug release in bulk aqueous solutions has been well-characterized, the aqueous–hydrophobic interfaces play a crucial role in biological systems, serving as entry points into cells. These interfaces are involved in many essential biomolecular interactions. The specific role aqueous-hydrophobic interfaces in drug release has been largely underexplored. In this study, we conduct a fundamental investigation into the release of encapsulated drugs at the air–water interface, which serves as a model for the organic/aqueous interface of cells. By combining light as an external stimulus with the superior properties of arylazopyrazoles (AAP) over conventional azobenzene photoswitches, we introduce a micellar nanocarrier for the capture and release of the chemotherapeutic drug doxorubicin (Dox). Using a powerful combination of interface-sensitive techniques such as surface tensiometry and interface-specific vibrational sum-frequency generation spectroscopy, we demonstrate the photoresponsive release of Dox encapsulated in AAP photosurfactant micelles to the air–water interface. To enhance the biocompatibility of the nanocarrier, we further investigate the complexes formed between the AAP photosurfactant and the positively charged biopolymer poly-L-lysine. The encapsulation of Dox in the colloidally stable surfactant-polyelectrolyte complex improves the efficiency of photoisomerization-induced Dox release to the air-water interface.

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Strong Anisotropy Behaviour of the 2D Magnetic Semiconductor CrSBr

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Chromium sulfide bromide (CrSBr) is a two-dimensional magnetic semiconductor combining optical properties with magnetic ordering. Between different layers of the crystal, spins couple antiferromagnetically, yielding an A-type antiferromagnet below the Néel temperature ($T_N = 132$ K).[1] CrSBr has a direct bandgap of approximately 1.3 eV, independent of layer count. Its strongly anisotropic electronic band structure yields quasi-one-dimensional[2] electronic and excitonic states and a triaxial dielectric tensor with excitonic features in the crystal plane as we identified from spectroscopic imaging ellipsometry (SIE).

Excitonic transitions are highly sensitive to collective spin order. Below the critical temperature, a magnetic field applied along hard axes drives the system from antiferromagnetic into ferromagnetic order, causing a quadratic redshift of exciton energies.[3] This effect is theoretically explained by spin-allowed charge transfer changing the composition and nature of excitons.[4] For higher-energy excitonic states, this coupling is even stronger[4] and can be studied by optical magneto-spectroscopies of CrSBr.

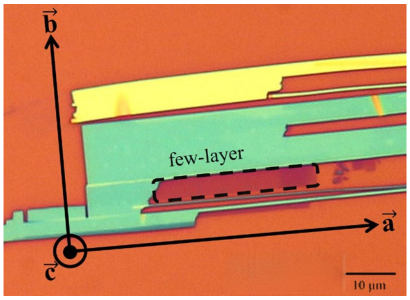

Fig.1. Optical microscope image of a CrSBr bulk flake with the few-layer region marked with the dotted line. Strong anisotropy of the crystal lattice impacts optical and magnetic properties of the material.

We combine complementary approaches to study the magnetic, optical and vibrational degrees of freedom in CrSBr as well as their coupled collective excitations. Therefore, we employed SIE, photoluminescence, reflectance and Raman scattering spectroscopies in dependence of external magnetic fields applied along the three crystal axes.

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Electrochromic Dye-Doped Liquid Crystal PMMA Microcapsules

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Soft displays are gaining traction as a key component in next-generation wearable technology, offering the potential for flexible and conformable interfaces. However, current technologies face limitations regarding wearability and functionality due to the mechanical incompatibility between conventional rigid, planar electronics and soft, dynamic surfaces.[1]

In this project, we aim to fabricate red, green, and blue (RGB) dye-doped liquid crystal (LC) PMMA microcapsules with a core-shell structure. This core-shell design protects the LCs and prevents dye contamination between different colors, which is crucial for vibrant color representation. The transparency, flexibility, and biocompatibility of PMMA make it suitable for soft display applications.[2] By doping LCs with RGB dyes, each microcapsule achieves distinct voltage-dependent color transitions, enabling high-resolution pixelation. This approach holds promise for creating full-color, dynamically controllable soft displays with potential applications in wearable electronics, smart textiles, and flexible signage.[3] By leveraging the voltage-dependent optical properties of the dye-doped LCs within the PMMA microcapsules, high-resolution and energy-efficient soft displays, advancing flexible display technology can be achieved.

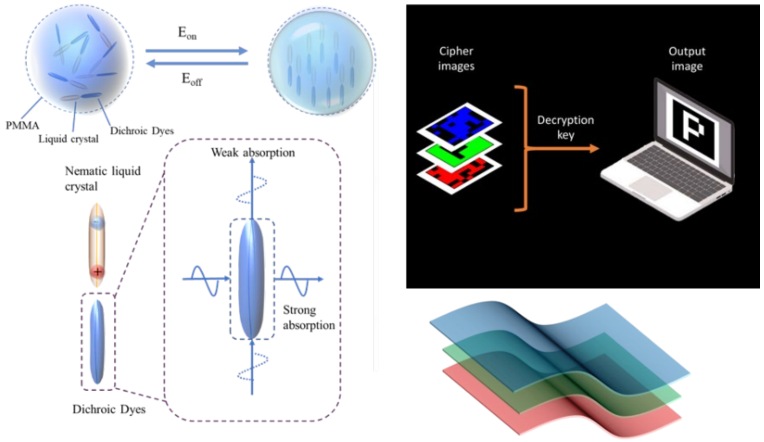

Fig. 1 The mechanism diagram of the dye-doped liquid crystals and conceptual design of the soft device in encryption [4].

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The Goldilocks Principle in Peptide Amphiphile Assembly

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Achieving hierarchical microscale architectures from peptide amphiphiles (PAs) requires a finely tuned balance between molecular rigidity and flexibility-a "Goldilocks Principle" of dynamicity. Using the diphenylalanine (FF) motif, we systematically varied N- and C-terminal chemistry and chain flexibility in model PAs.[1-4] Circular dichroism and electron microscopy reveal that only the PA with balanced dynamicity undergoes a multi-step assembly: nanoscale helical ribbons bundle into rope-like intermediates, which further merge into complex, sea urchin-like microscale structures. In contrast, a more rigid analogue forms only simple star-shaped microstructures, while a more flexible siloxane-based PA yields only nanospheres. These findings establish that optimal molecular dynamicity is essential for enabling hierarchical bundling and complex biomimetic architectures, providing a general design rule for programming peptide-based materials from the molecular to the microscale.

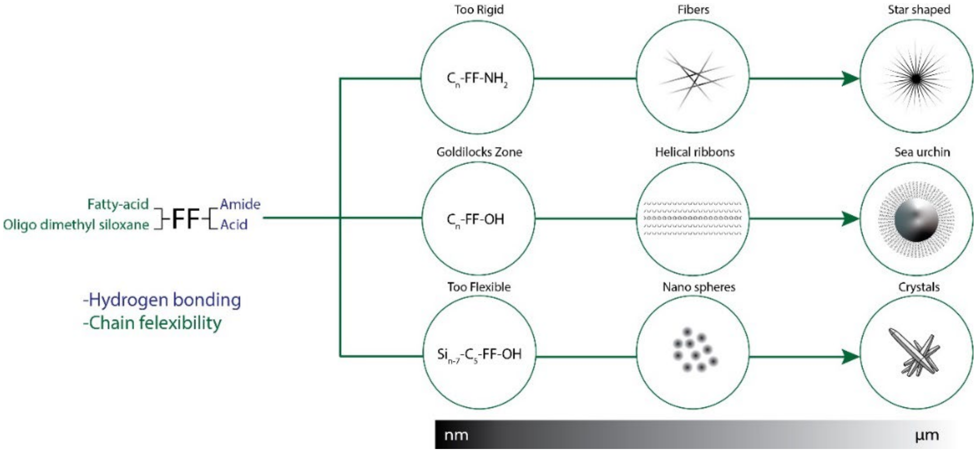

Figure 2 Goldilocks principle in peptide amphiphile assembly: optimal rigidity-flexibility produces distinctive structures across multiple size scales.

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Dynamic Systems of Light-Propelled Microparticles with Intelligent Behaviour

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Active particle systems have attracted broad interdisciplinary interest due to their complex collective dynamics. Potential applications range from simulating collective behaviours in biological systems to enabling reservoir computing for physical information processing. Given its widespread availability, ease of control, and broad biocompatibility, light serves as an ideal means to propel microscopic particles. In our project, we design and fabricate light-propelled active microparticles as key elements of collective particle systems. By tailoring particle geometry and metasurface patterns, and functionalizing surfaces with temperature-responsive polymers, we aim to precisely control individual particle mobility. The project investigates collective behaviour of both active particles with identical design and mixtures of active particles with either different shapes or motion behaviours. Ultimately, the project aims to implement a proof-of-concept physical reservoir computing setup, utilizing the acquired understanding of both individual dynamics of each particle and emergent collective behaviours.

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Responsive Polymer Morphology Change Through Reversible Block Fragmentation Using Cucurbit[8]uril

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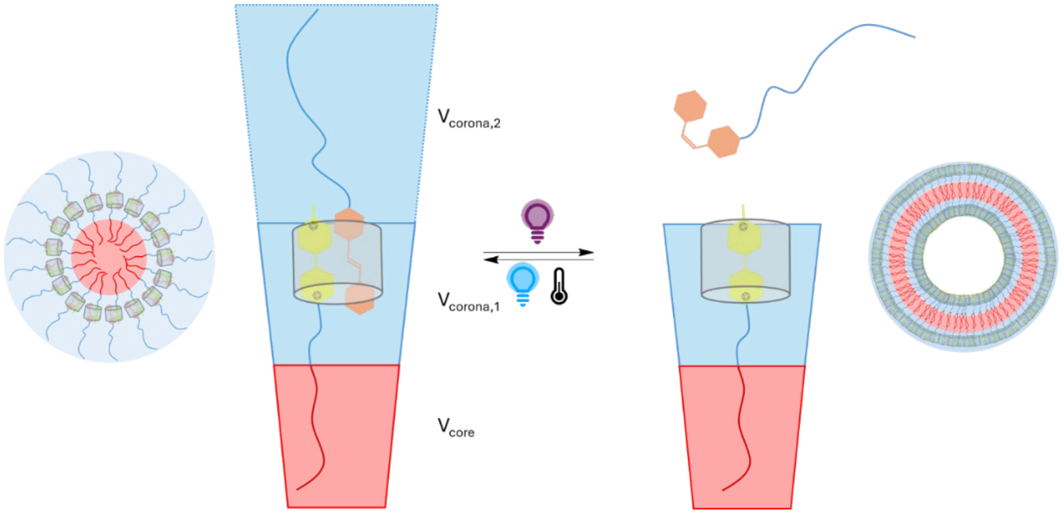
Controlling the shape of supramolecular structures is an important aspect of the development of intelligent matter.[1] Block copolymers offer a good foundation to create stimuli responsive systems via block fragmentation. The length of the hydrophobic and hydrophilic blocks determines the aggregation behavior and can be steered by the introduction of host-guest chemistry. A promising candidate as host is cucurbit[8]uril. This macrocycle possesses the ability to form a heteroternary system, which enables the use of two orthogonal addressable guests. This multistimuli responsive system can be set up by azobenzene, which is isomerized by irradiation with different wavelengths and by viologen as a redox active species.[2]

Using these molecules as head group for the water-soluble polymers, it is possible to change the packing parameter and therefore the morphology of the supramolecular structures between micelles and vesicles with simple to use orthogonal stimuli with good spatial and temporal control.



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Structure-Property Relationship of CuSCN and Co-ligand Complexes

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Copper(I) thiocyanate (CuSCN) is a well-known 3D coordination polymer with promising hole-transporting semiconductor properties, making it suitable for various optical and electronic applications. CuSCN can be transformed from its native 3D structure into 2D or 1D coordination polymers through functionalization with pyridyl-based ligands.[1] In this work, we report a synthetic approach for producing phase-pure $[Cu(SCN)(3\text{-}XPy)]_n$ complexes (where X = OMe, H, Br, Cl). These complexes form stable 2D layered structures, as confirmed by the single-crystal structure of $[Cu(SCN)(3\text{-}OMePy)]_n$. The electronic nature of the substituents enables systematic tuning of the energy levels and band gaps, resulting in visible-range optical absorption and emission. Furthermore, We recrystallized 1D zigzag chain structure of $[Cu(SCN)(3\text{-}ClPy)_2]_n$.[2] A thermally non-invasive method for metal electrode deposition using patterned eutectic gallium–indium (EGaIn) as soft contacts on single crystals was prepared. This setup enables length and temperature-dependent electrical conductivity measurements and provides a platform for future investigations into charge transport mechanisms. The electrical conductivity exhibits a linear relationship with the measuring distance. An activation energy of 180 meV was extracted from temperature-dependent measurements. Moreover, this material demonstrates reversible potentiation and depression of electrical conductivity under light illumination. These properties highlight its potential for future applications in optoelectronic neuromorphic devices.

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New Photoswitches for Integration in Adaptive Nanosystems

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Molecular photoswitches are versatile sensors and actuators for the development of intelligent matter. In this project we develop new photoswitches as building blocks for the assembly of adaptive molecular nanosystems with inherent feedback by optical and chemical signals. The project will focus on the development of molecular photoswitches that enable out-of-equilibrium light-induced supramolecular materials based on the self-assembly diazocines which form supramolecular assemblies as well as adaptive supramolecular materials that can be stimulated with visible light using disequilibration by sensitization under confinement of arylazopyrazoles. Furthermore, we will advance photo-responsive *N*-heterocyclic carbenes as surface ligands towards the development of adaptive solid state systems. We will prepare photoswitches conjugated to NHCs and investigate their self-assembly as ligands for nanoparticles and surfaces. Our photoswitches will be integrated in adaptive molecular systems and soft materials such as adaptive supramolecular polymers, active colloids, adaptive polymer complexes and micelles, self-regulating vesicles and hydrogel actuators.

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Structure-Aided Chemical Signal Propagation in Hydrogel Metastructures

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The propagation of chemical signals provides the basis for vital processes in nature, from pattern formation to endocrine signalling and movement, that typically rely on reaction diffusion mechanisms.[1-2] Recently, efforts have focused on creating synthetic material analogues by embedding reaction networks in structured media for signal processing, pattern formation,and programming movement.[3-6] Yet, chemical signal propagation still appears challenging.[7] Expanding their potential for soft robotics, adaptive structures, and life-like materials requires more refined control over spatio-temporal dynamics and ability to steer signalling along arbitrary trajectories for functional outputs.[8-9] Multistable mechanical metamaterials[10] can switch between multiple stable folding states with distinct properties[11] and have recently emerged as useful tools to structure distribution of external stresses, propagation of mechanical signals (so-called solitons[12]), and programmable shape changes.

Herein, we investigate how autocatalytic chemical waves propagate across metamaterial structures prepared from double network hydrogels with different geometry, hydrogel composition, and signalling chemistry. As folding states change, so do the signalling patterns. We illustrate how dynamically flipping between folding states allows for on-demand modulation of chemical signal propagation, including structure-aided transport in which chemical signals hop across large distances aided by cycles of flipping through the folding states. Structuring chemical signal transport through foldable geometries, instead of propagation through the bulk, opens up unprecedented possibilities for user-defined control over spatiotemporal signal distribution in life-like materials.

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Mixed-Mode in-Memory Computing Using Adaptive Phase-Change Materials

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The recent developments in generative AI have made the need for fast and efficient computing more evident than ever. As improvements of conventional electronic computer chips based on the von Neumann architecture are failing to keep up with the steep rise in computational demand, alternative and novel computing paradigms are heavily researched. One promising candidate is photonic in-memory computing.

In this project, we study photonic integrated circuits using adaptive phase-change materials (PCMs) as non-volatile and scalable photonic memory elements. Switching these elements electrically enables us to implement opto-electronic feedback for so called mixed-mode computing. However, mixed-mode circuits require the integration of algorithms and various hardware components into one system. On the algorithm level, we explore new paradigms for efficient neural network calculations in mixed-mode circuits. On the hardware level, we work on each of these components including mixed-mode PCM synapses, novel PCMs for photonic computing, waveguide crossbar arrays with trimmed directional couplers and resonators, as well as efficient, large-bandwidth electrical and optical packaging.

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Supramolecular Light-Switchable Triazole-Hosts for Photoadaptive Anion Binding

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In order to develop adaptive materials with controllable anion binding, photo-responsive tetra triazole host structures containing azobenzene, arylazopyrazole or diazocine as molecular switching unit are developed. These allow Z-selective anion binding based on a larger anion-binding constant as compared to the E-form, and thus induce photo-reversible anion availability. Here we present a study on the role of different functional units of the hosts: On the one hand the structure (cyclohexyl versus phenyl) of linkers, the positioning of triazole binding units and the addition of solubility tags is explored to identify optimal binding motifs. Host structures providing sufficient binding, as well as large contrast of the binding constant of each isomeric form are identified. Ab initio DFT calculations demonstrate the conformational arrangement of the host-anion complex, which aids the structural design.

Towards adaptive behaviour, the influence of the anion binding state on isomerization efficiency is investigated. For both, photoisomerization and thermal isomerization a stabilization of the Z form is found to be induced by anion binding. Thus, the Z isomer with a bound anion forms a trapped state with enhanced lifetime, which will be further exploited in developing adaptive materials.

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Restoring Intracellular Homeostasis Disrupted by Synthetic Nanoassemblies

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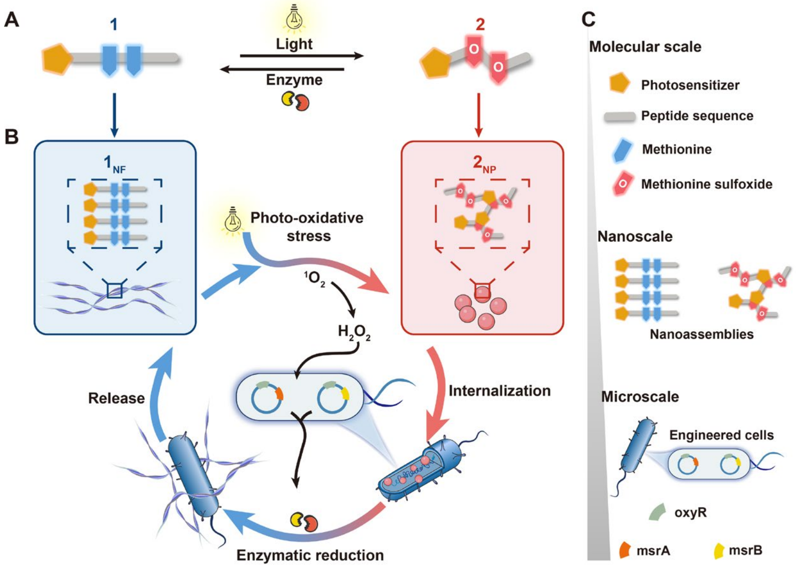
Cells have evolved to defend against perturbations by maintaining their intrinsic homeostasis to survive. However, no intrinsic pathway exists for them to expel new-to-biology synthetic nanostructures. Here, we establish programmable influx-efflux cycles of synthetic nanoassemblies in living cells that expel invasive nanostructures and restore intracellular homeostasis. Specifically, a model photosensitizer-peptide conjugate undergoes multiple redox cycles between methionine (Met) and methionine sulfoxide (MetO), resulting in reversible morphological transformations between nanofibers (NFs) and nanoparticles (NPs). Upon irradiation, the oxidized peptide NPs are internalized into bacteria, causing perturbations. To counteract these perturbations, engineered bacteria activate the expression of MetO reductases in response to photo-oxidative stress. The internalized NPs are intracellularly enzymatically reduced such that they are expelled as reduced NFs, setting the stage for subsequent cycles. The concept of engineering cells to expel intracellular NPs and restore homeostasis paves the way for the generation of cross-talk between supramolecular assemblies and genetic networks in living cells.



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Spectroscopic Imaging Ellipsometry at Cryogenic Temperatures: A Structural Phase Change in a 2D polar Metal

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2D polar metals are a novel class of atomically thin 2D materials, realized by intercalating metal atoms between graphene and a silicon carbide substrate.[1] This results in large area, stable, 2D metals with a strong bonding gradient in z-direction within only a few atomic layers.[2] These materials feature interesting properties such as a large plasmonic response in the visible range.[3]

To uncover the relation between light-matter interaction, temperature and structural changes, 2D gallium is studied by temperature dependent spectroscopic ellipsometry and transport measurements down to 1 K.

Spectroscopic Imaging Ellipsometry (SIE) combines the ability of an ellipsometer to determine optical properties of thin film samples with the lateral resolution of a microscope. This enables the investigation of the homogeneity of the dielectric response on the micrometer scale in various systems.[3-5]

Combining SIE with a cryostat with optical access, we explore the temperature-dependence of 2D gallium from room temperature down to 1 K. We show a change in the dielectric response of the material from homogeneous behavior at room temperature to a heterogenous regime at low temperatures.[6] We interpret this change to indicate a structural phase transition in the material.

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SM4Y

SmartMatters4You: Students gain insights into research at the CRC 1459 Intelligent Matter"

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Since 2019, the number of first-year students in STEM courses has been falling. Aside from the fact that a general recruitment of STEM students is very important for Germany as a technology location, it is particularly important to recruit women for STEM courses. In 2021 only 35% of STEM students in Germany were female[1].

SmartMatter4You empowers scientifically interested female upper school students to pursue a career in science. Through the cooperation from the research in the CRC 1459 "Intelligent Matter" and the know-how of the school laboratory MExLab Physik the students can experience unique access to highly topical research in interdisciplinary workshops and take part in hands-on excursions to science-related companies.

SmartMatters4You helps to bridge the gender gap by raising awareness of gender equality and using empirically proven strategies for success[2]. A major goal of the project is to arouse fascination and convey the importance of basic research in order to attract the female scientists of tomorrow. In a scientific accompanying study, the mechanisms of the career choice decisions of high school students and the role of social barriers are examined from an interdisciplinary perspective using methods of empirical social research. In 2025, the project will be carried out for the fourth time, so that extensive data from the accompanying scientific research, findings and experiences about the project are available.

[1] Statistisches Bundesamt: Pressemitteilung Nr. N004 vom 23. Januar 2023; https://www.destatis.de/DE/Presse/Pressemitteilungen/2023/01/PD23_N004_213.html

[2] Augustin-Dittmann, S., Gotzmann, H. (2015): MINT gewinnt Schülerinnen: Erfolgsfaktoren von Schülerinnen-Projekten in MINT, Wiesbaden: Springer VS.

Sustainability

Sustainability Starts with You!

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Sustainability is undoubtedly of paramount importance in preserving this planet for future generations – but sustainability also starts with each individual. However, *green* chemical methods are usually developed using methods that are just as harmful to the environment as those that are not labelled green. Table 1 shows the energy consumption of the University of Muenster and the Center for Soft Nanoscience (SoN) in 2023.[1] Further, plastic waste, chemicals, water consumption, building maintenance, business travel etc. contribute to the carbon footprint of researchers.[2]

Table 1: Consumption data of University of Muenster and SoN.

Type of Energy	University of Muenster /kWh	Center for Soft Nanoscience /kWh
Electricity	44 600 000	1 780 000 (4.0%)
Heating	42 800 000	1 130 000 (2.6%
Cooling	10 500 000	1 010 000 (9.6%)

'Sustainability Starts with You' wishes to report on additional consumption data from the Department of Chemistry and Pharmacy in Muenster. This data was used to design a three-hour interactive seminar on sustainability. The aim now is to test and evaluate the seminar with chemists at different levels of training, with a view to making it available to all universities through publication.

Your group could be next, so together we can create change (Fig. 1).

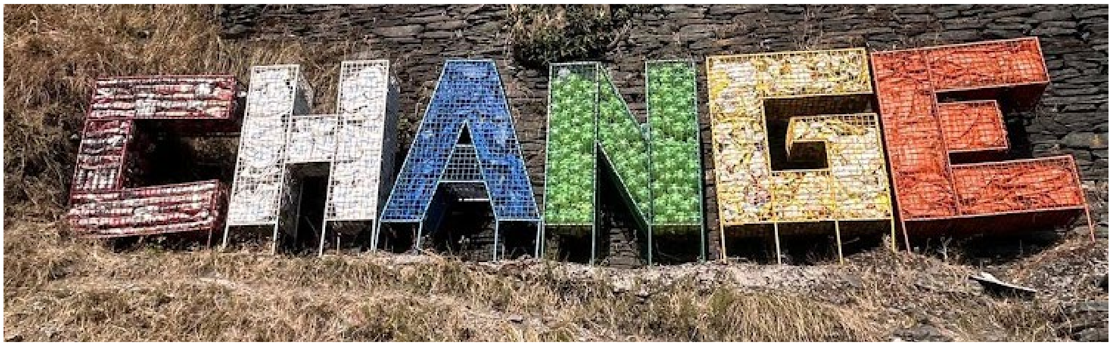

Figure 1: Much like an organization in northern India that turns litter into art, individuals can take action to make their labs greener.

[1] Internal data from University of Muenster available on https://uni.ms/54by2 (accessed 8 May 2025, 06:20 pm).

[2] T. Freese, N. Elzinga, M. Heinemann, M. M. Lerch, B. L. Feringa, *RSC Sustainability*, **2024**, *2*, 1300-1336.

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