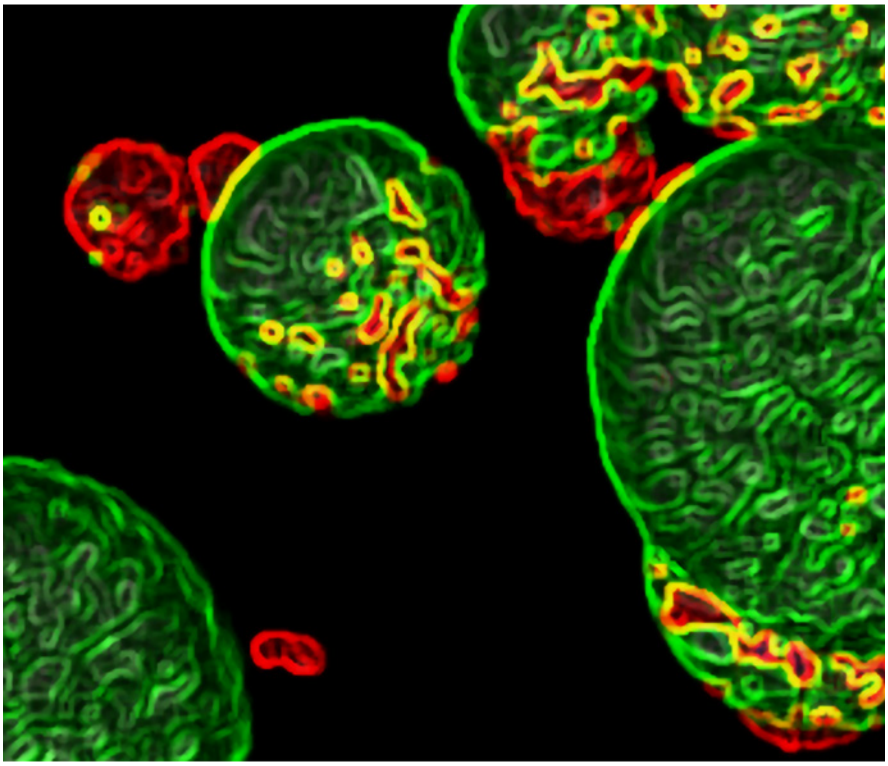
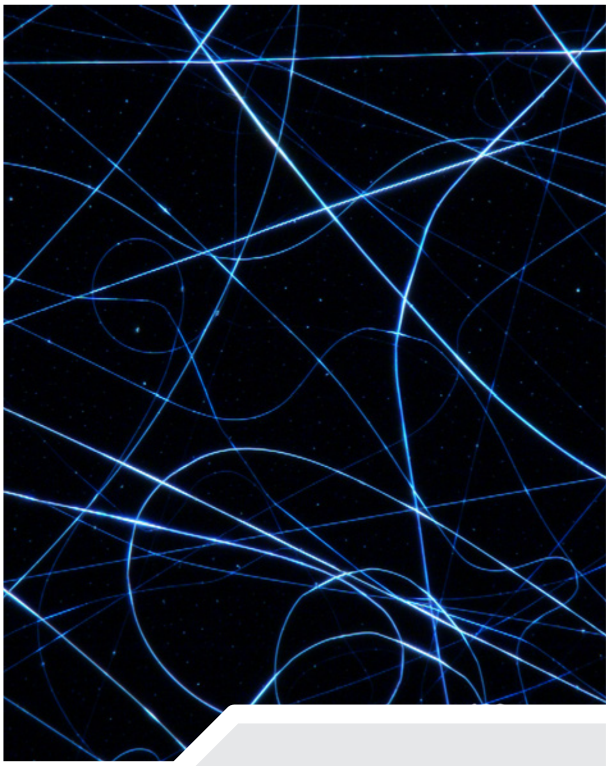
Neues Denken. Neue Materialien.





JAHRESBERICHT 2020
ANNUAL REPORT 2020

Leibniz Gemeinschaft

INM
Leibniz-Institut für Neue Materialien

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WILLKOMMEN ZUM JAHRESBERICHT DES INM, GESCHÄTZTE LESERINNEN UND LESER,

hinter uns liegt ein schwieriges Jahr, das mit seinen Einschränkungen die Arbeit an unserem Institut wesentlich beeinflusst hat. Umso mehr haben wir uns über das Verständnis, die Disziplin und die Resilienz unserer Mitarbeiterinnen und Mitarbeiter gefreut, die 2020 trotz allem zu einem erfolgreichen Jahr für das INM gemacht haben.

Eine besondere Premiere war für uns die Bewilligung des Leibniz-WissenschaftsCampus „Living Therapeutic Materials“, der zum 1. Juli seine Arbeit aufnahm. Mit ihm verstärken wir gezielt unsere Arbeiten im biologisch-medizinischen Bereich und vertiefen die Kooperation am Campus der Universität des Saarlandes.

Auch junge Forscherinnen und Forscher konnten in diesem Jahr wieder punkten. Der Dissertationspreis der Leibniz-Gemeinschaft ging erneut an das INM: Herr Dr. Pattarachai Srimuk wurde für seine Arbeit zur Wasserentsalzung ausgezeichnet, für die er außerdem den UMSICHT-Wissenschaftspreis erhielt. Den ersten Starting Grant des European Research Council für das INM konnte Frau Dr. Lola González-García einwerben. Sie leitet ab Januar 2021 eine neue Juniorforschungsgruppe *Elektrofluide*. Und schließlich belegen Humboldt-Stipendien an Frau Dr. Xuan Zhang und Frau Dr. Gülistan Kocer die ungebrochene Attraktivität des INM für hochqualifizierte internationale Kolleginnen und Kollegen.

Eine neue Juniorforschungsgruppe finden Sie bereits in diesem Bericht: Seit Januar 2020 verstärkt die Gruppe *Bioprogrammierbare Materialien* unter der Leitung von Herrn Dr. Shrikrishnan Sankaran unsere Forschung.

Wir wünschen Ihnen viel Spaß dabei, auf den folgenden Seiten noch mehr Neues und Spannendes zu entdecken, und freuen uns, wenn Sie uns auch in Zukunft gewogen bleiben.

WELCOME TO THE ANNUAL REPORT OF THE INM, VALUED READERS,

Behind us lies a difficult year, with restrictions that had a significant impact on the work at our institute. We were all the more pleased with the cooperation, discipline and resilience of our staff, which despite everything made 2020 a successful year for the INM.

A particularly special premiere for us was the approval of the Leibniz ScienceCampus "Living Therapeutic Materials", which was launched on July 1. It will specifically strengthen our efforts in the biological-medical field and deepen the cooperation at the Saarland University campus.

Young researchers were also able to score again this year. The dissertation award of the Leibniz Association went yet another time to the INM: Dr. Pattarachai Srimuk was honored for his work on water desalination, for which he also received the UMSICHT Science Prize. The first Starting Grant of the European Research Council for the INM was acquired by Dr. Lola González-García. She heads a new Junior Research Group *Electrofluids* starting in January 2021. Finally, Humboldt Fellowships awarded to Dr. Xuan Zhang and Dr. Gülistan Kocer demonstrate INM's continued attractiveness for highly qualified international colleagues.

You will meet a newly established Junior Research Group in this annual report: since January 2020, the group *Bioprogrammable Materials* headed by Dr. Shrikrishnan Sankaran strengthens our research portfolio.

We hope you will enjoy discovering even more new and exciting things on the following pages and appreciate your continued support.


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FluorChem Q
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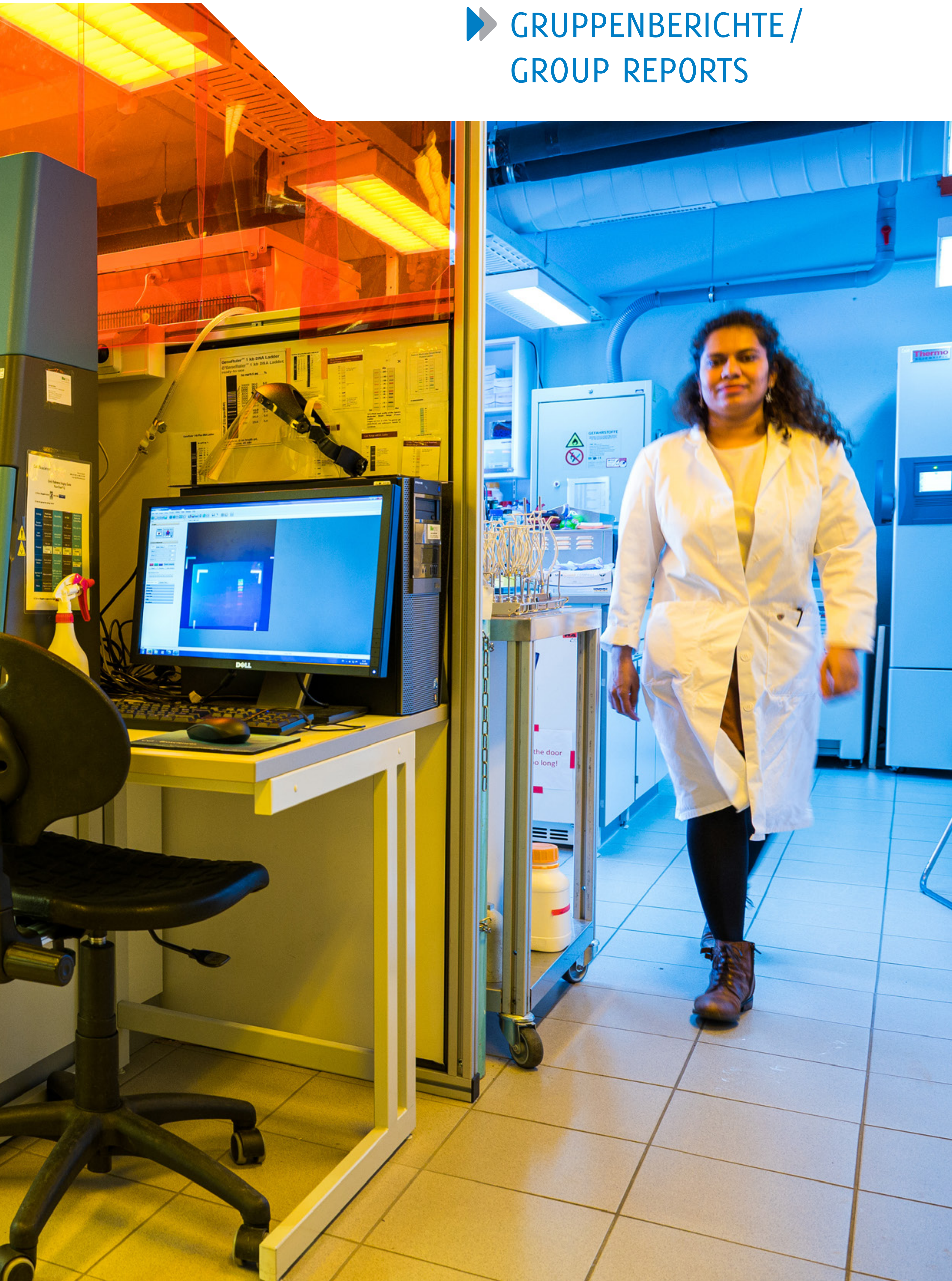
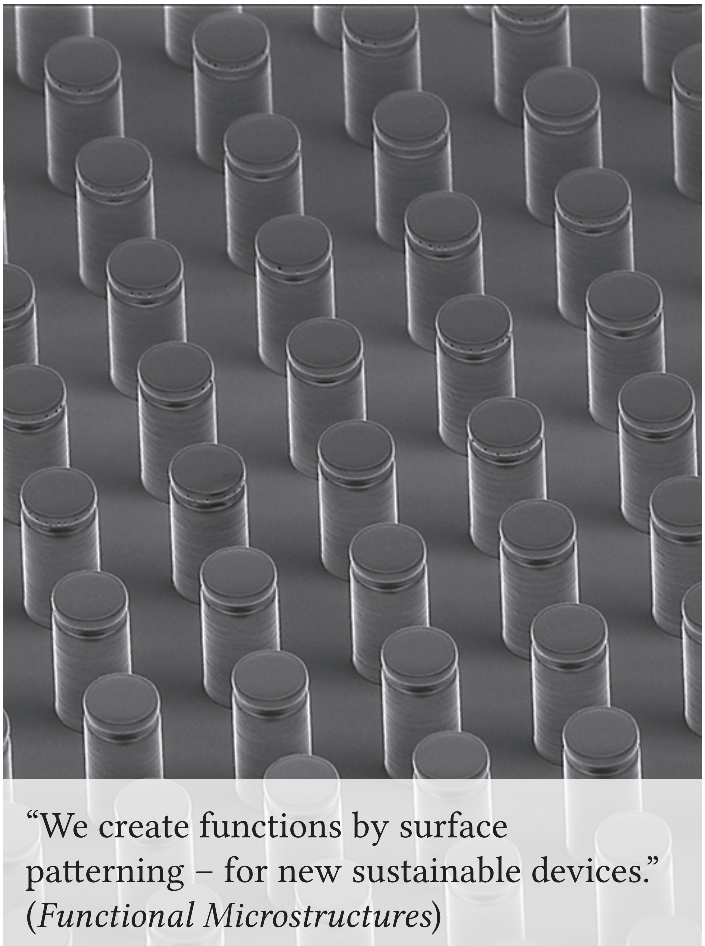
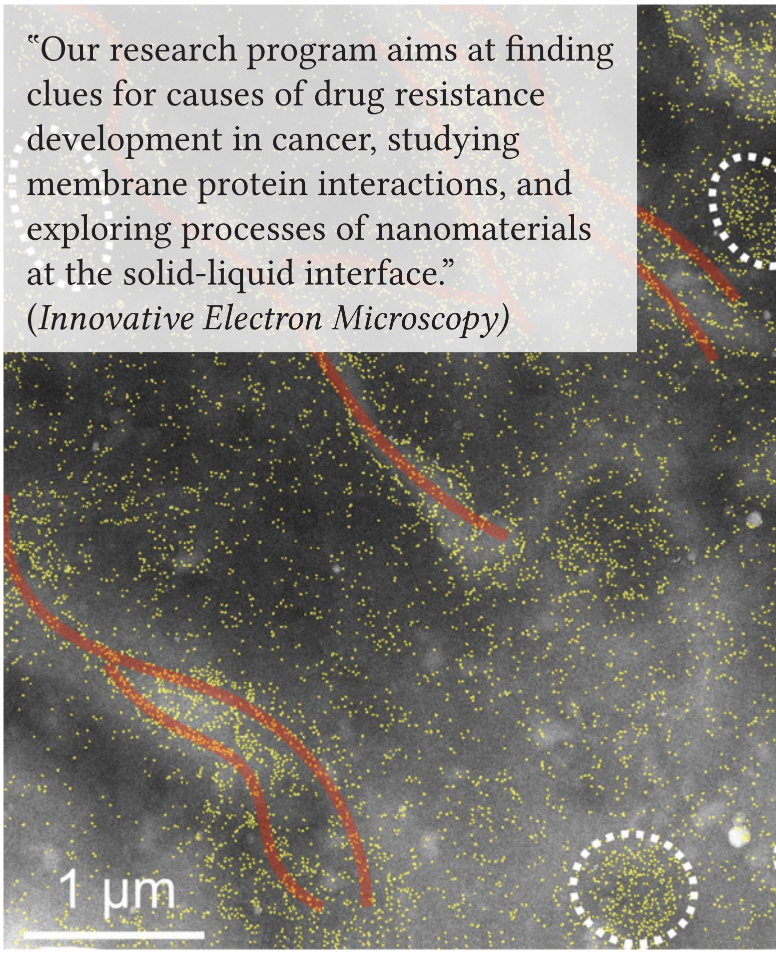
GRUPPENBERICHTE / GROUP REPORTS

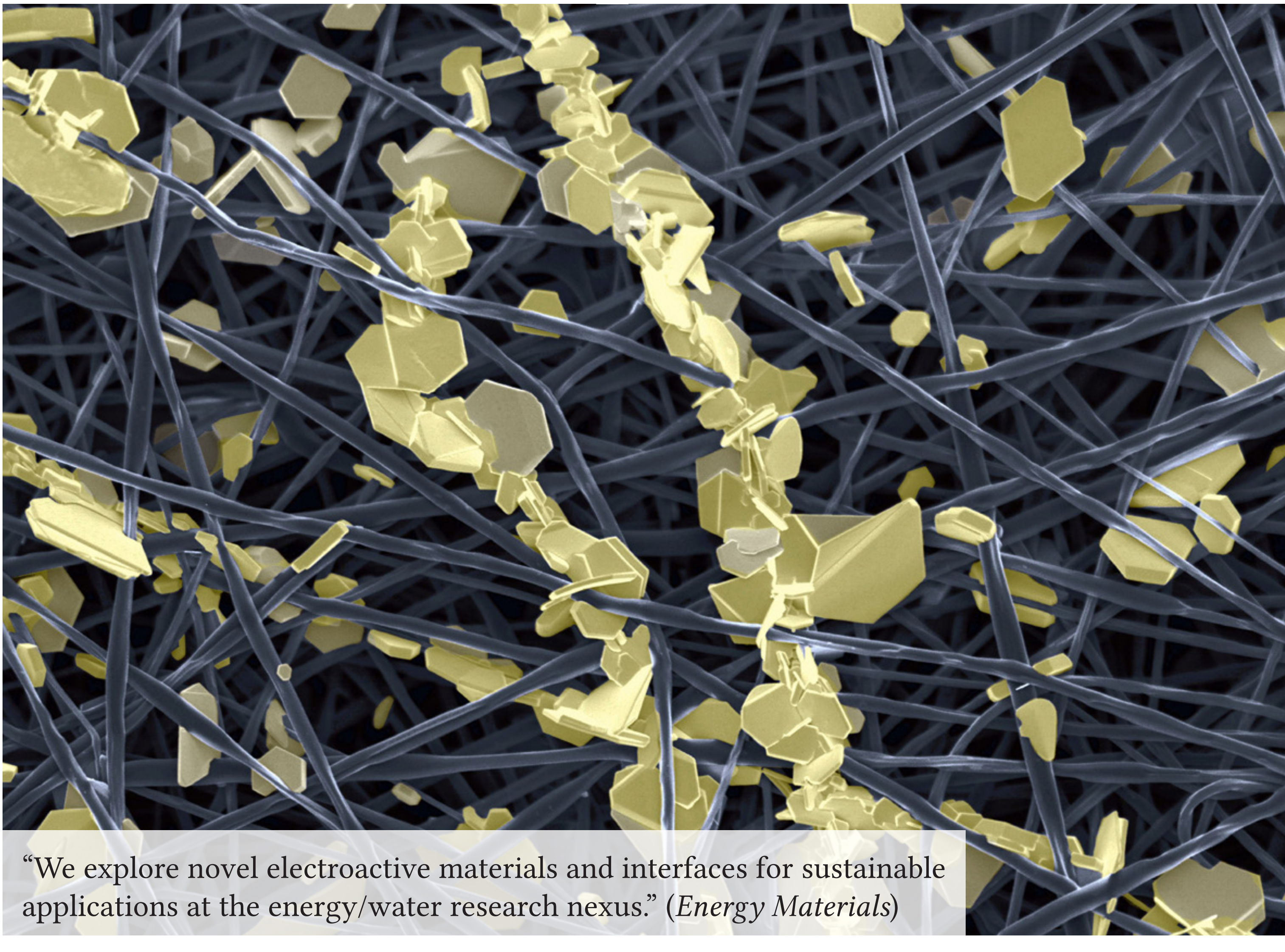




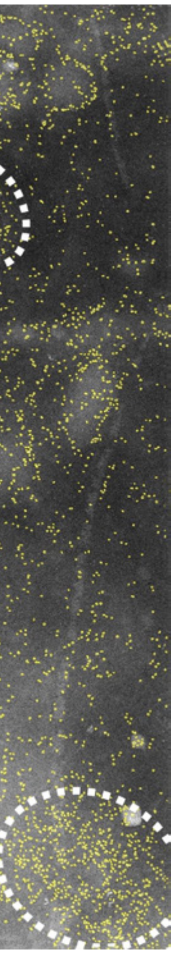
"We create functions by surface patterning – for new sustainable devices." (*Functional Microstructures*)

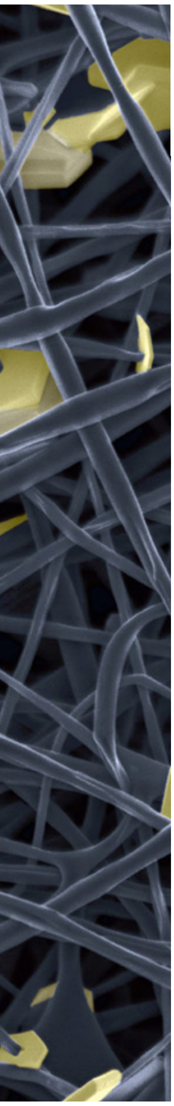


"Our research program aims at finding clues for causes of drug resistance development in cancer, studying membrane protein interactions, and exploring processes of nanomaterials at the solid-liquid interface." (*Innovative Electron Microscopy)*



"We explore novel electroactive materials and interfaces for sustainable applications at the energy/water research nexus." (*Energy Materials*)





“We measure and make use of interactions at surfaces – from atomic friction and molecular entanglement in hydrogels to the contact of skin with microstructured materials.” (*Nanotribology*)

GRENZFLÄCHENMATERIALIEN / *INTERFACE MATERIALS*

ENERGIE-MATERIALIEN / ENERGY MATERIALS

PROF. DR. VOLKER PRESSER

ZUSAMMENFASSUNG

Der Programmbereich *Energie-Materialien* erforscht elektrochemische Materialien zur Energiespeicherung und Wasseraufbereitung. Diese Anwendungen erfordern Materialien, welche auf der Nanoebene in Bezug auf Ionentransport und elektrische Leitfähigkeit optimiert werden. Wichtige Elektrodenmaterialien sind nanoporöse Kohlenstoffe, zweidimensionale Materialien (MXene), Oxide, Karbide und Sulfide. Diese Materialien und deren Kombination (Hybridisierung) ermöglichen leistungsstarke Lithium- und Natrium-Ionen-Batterien. Als Entsalzungsbatterien erlauben diese Materialien die Herstellung von Trinkwasser aus Meerwasser und die selektive Ionenentfernung, z. B. für die Lithium-Gewinnung. Für ein umfassendes System- und Materialverständnis elektrochemischer Prozesse und Materialien nutzen wir vielfältige Charakterisierungsmethoden, einschließlich In-situ-Verfahren. Wir nutzen verstärkt digitale Methoden zur prädiktiven Materialforschung. Unsere Kollaborationen umfassen sowohl die Grundlagenforschung als auch Industrieprojekte.

MISSION

The Program Division *Energy Materials* synthesizes, characterizes, and applies electrochemical materials for energy storage and water treatment. These applications require nano-designed materials with optimized electrical conductivity and ion transport. Important electrode materials are nanoporous carbons, two-dimensional materials (MXene), oxides, sulfides, and carbides. These materials, and their combination (hybridization), enable high-performance lithium- and sodium-ion batteries for next-generation energy storage devices. When used as a desalination battery, they store energy and allow the generation of drinking water from seawater.

Further, they allow ion-specific separation, for example, for lithium recovery. We employ an array of complementary characterization techniques, including advanced *in-situ* methods. Our research is more and more facilitated by predictive research based on digital material research and modeling. Collaborative activities range from basic research to industry projects.

CURRENT RESEARCH

Digital energy materials

Digital twinning allows not only to better understand processes and gives rise to unique ways for high-throughput analysis and predictive research. That is, we can first identify optimized materials before we synthesize them in the laboratory. We use such advanced tools within the BMBF-funded ProZell DigiBatMat project together with the Program Division *Structure Formation* and several other partners. Thereby, digital twinning will allow comprehensive virtualization of batteries and their fabrication. We also use predictive tools to simulate ion transport within nanoporous carbon to create advanced supercapacitors (collaboration with Institute of Physical Chemistry, Warsaw, Poland) and high-performance seawater desalination devices (collaboration with Huazhong University of Science and Technology, Wuhan, China). Fully understanding the pore size/ion size correlations and ion transport kinetics allows the controlled design of high-performance supercapacitors and ion-selective desalination devices.

Desalination batteries

We explore desalination batteries for triple-use, energy storage, elemental recovery, and water remediation. The ability to energy-efficiently desalinate saltwater is of high importance to the generation of potable water. Yet, the selective extraction of pollutants like lead or nitrate is equally essential. Desalination batteries can also be employed as seawater batteries where low-cost, abundantly available seawater serves as the electrolyte. This line of research allows the synergetic implementation of battery-technology, for example, related to high-performance sodium-alloying electrode materials and knowledge of ceramic ion-exchange membranes. We collaborate with several colleagues from IFAM Bremen, University of Manchester, Lancaster University, and University of Illinois at Urbana-Champaign. Within a project funded by the RAG Foundation, we explore Lithium recovery from regional mining water, but the technology can easily be extended to other water sources, such as hydrothermal water.

Nanohybrid materials

High-performance electrochemical materials must combine electrical conductivity with an attractive charge storage capacity. To this end, we use two-dimensional materials, such as MXene, and we also develop nanoscaled hybrids of carbon, carbides, oxides, and sulfides to create high-performance Lithium-ion and Sodium-ion batteries. Such hybrids are obtained from various synthesis methods, including atomic layer deposition, electrospinning, hydrothermal and solvothermal processes, and chloroxidation. Two DFG grants currently support our hybrid material work. We also collaborate with colleagues from INP Greifswald, MPIE Düsseldorf, and TU Darmstadt.

OUTLOOK

Our work will develop electrochemical materials with tunable ion selectivity to serve as an innovative platform for a new generation of sensors, ion separation devices, and post-lithium battery technology. Modeling will transition from a tool to explain processes towards a powerful predictive method to enable high throughput screening and focused experimental work in the laboratory. More sustainable materials and processing methods will, over time, allow to not only enable novel electrochemical applications but also improve upon environmental friendliness.

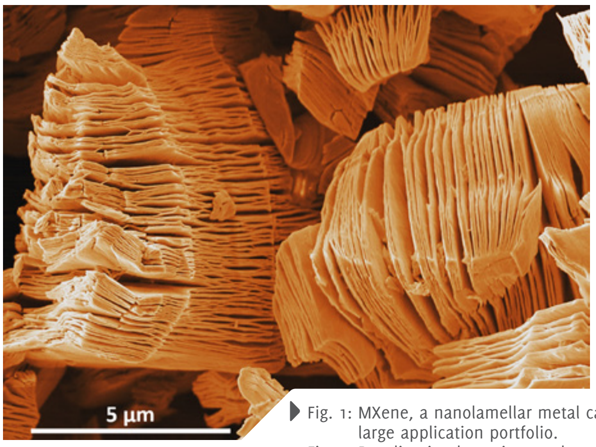


Fig. 1: MXene, a nanolamellar metal carbide with high electrical conductivity, tunable properties, and a large application portfolio.
Fig. 2: Desalination batteries can be used for energy-efficient ion separation, for example, for extraction of lithium-ions from mine water or hydrothermal water.

FUNKTIONELLE MIKROSTRUKTUREN / FUNCTIONAL MICROSTRUCTURES

PROF. DR. EDUARD ARZT, DR. RENÉ HENSEL

ZUSAMMENFASSUNG

Mikrostrukturierte Oberflächen erzeugen neue mechanische, optische und haptische Funktionalitäten ohne chemische Additive oder Modifikationen. Als bioinspiriertes Konzept, das Vorbildern u.a. von Geckos und Insekten folgt, gilt Strukturierung als ressourcenschonende und umweltgerechte Materialstrategie mit großer Zukunftsrelevanz. Der Fokus unserer laufenden Arbeiten liegt auf fibrillären Haftsystemen für die temporäre, reversible Adhäsion. Schwerpunkte sind das Verständnis auf der Ebene der Fibrillen und zunehmend auf der Ebene des gesamten Haftsystems anhand numerischer Modellierung und experimenteller Validierung, sowie das Design und die Prototyprealisierung von Haftstrukturen. Aktuelle Zielsetzungen sind Mikrostrukturen für Haftung unter Wasser und die modellmäßige Erfassung von Handhabungsmechanismen mit dem Ziel, auch „anspruchsvolle“ Objekte zuverlässig zu greifen. Eine weitere erfolgversprechende Richtung ist das Design von Wundpflastern, das in ersten Tierversuchen am Universitätsklinikum des Saarlandes validiert wurde. Unsere Arbeiten werden von der EU (inzwischen drei ERC Proof-of-Concept Projekte), einem Projekt der Leibniz-Gemeinschaft sowie durch Industriekooperationen gefördert.

MISSION

Micropatterned surfaces create new mechanical, optical, and haptic functionalities without chemical additives or modifications. As a bioinspired concept emulating i. a. geckos and insects, micropatterning is a future-oriented materials strategy with superior resource efficiency and environmental sustainability. The focus of our research lies on fibrillar systems for temporary and reversible adhesion. By numerical modeling and experimental verification, we create improved understanding on the single fibril level and increasingly on the array level and develop new designs and prototypes of adhesive microstructures. Current topics are microstructures for controlled underwater adhesion and the theoretical evaluation of pick-and-place mechanisms with the goal of reliable handling of “challenging” objects. Another promising direction is the design of wound adhesives for clinical application, which is now past the animal experiment stage with our partners at the Saarland University Medical Center in Homburg. Our research is funded by the EU (the third ERC Proof-of-Concept Grant), the Leibniz Association and industrial contracts.

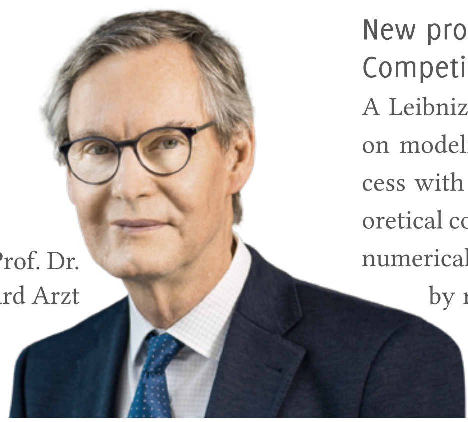
CURRENT RESEARCH

A comprehensive review article was recently written that critically discusses the state of the field (*Arzt et al., Progress in Materials Science, 2021*).

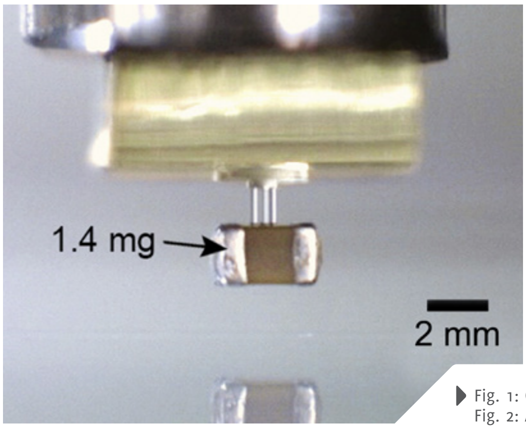
New project funded within the Leibniz Competition (“MUSIGAND”)

A Leibniz-funded project starting in 2020 focuses on modeling and simulation of the handing process with multifunctional fibrillar adhesives. Theoretical contact mechanics, instability analysis and numerical micropattern design are complemented by model-inspired experiments including *in situ* observation of the fibrillar contacts. Progress is made in understanding the accommodation of interfacial roughness

Dr. René Hensel



Prof. Dr. Eduard Arzt



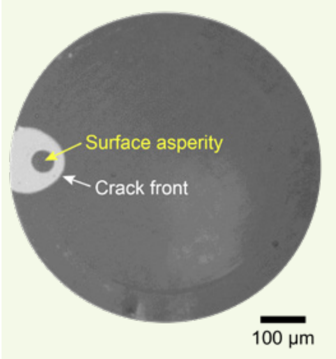


Fig. 1: Optimized microstructure for handling small objects.
Fig. 2: Adhesive contact observation for adhesion prediction.

and the controlled release of objects. The project is designed to lay the foundations for the next generation of advanced adhesive microstructures with increased handling reliability for complex objects. It is a multi-lateral cooperation with Saarland University, the University of California, Harvard University, Cambridge University and ESPCI Paris.

Switchable underwater adhesion

To gain strong adhesives that function under water, a cupped microstructure design has been introduced. In collaboration with Prof. Walter Federle (Univ. Cambridge, UK), switching of the adhesion strength was demonstrated to show potential for micromanipulation of objects in wet or submerged conditions (*Wang et al., Adv. Mater. Interfaces 2020*). Towards adhesion to rough surfaces, dewetting of thin liquid films confined between deformable adhesives and micropatterned substrates was studied in collaboration with Prof. Anton Darhuber (Eindhoven Univ. of Tech, NL) (*Chudak et al., Langmuir, 2020*).

Skin adhesives

Novel skin adhesives could potentially revolutionize surgical procedures and wound healing strategies. New silicone-based adhesives for the treatment of ear drum perforations were developed. In the ERC Proof-of-Concept grant (STICK2HEAL – *Innovative adhesives for ear drum healing*), the clinical potential of these materials was evaluated in cooperation with Prof. Bernhard Schick and Prof. Gentiana Wenzel (Saarland University Medical Center). Sufficient adhesion was found against explanted tympanic membranes of mice, using a custom-built mobile adhesion testing system. The microstructured adhesive also improves the hearing ability immediately following application.

Smart adhesives

INM's Gecomer Technology has been validated for numerous pick & place scenarios from micro to macroscale (Fig. 1). *In-situ* observations of individual contacts revealed that adhesion and related phenomena such as contact aging vary from fibril-to-fibril (*Thiemecke & Hensel, Adv. Func. Mater., 2020*). Such statistical variations of the adhesion strength complicate theoretical predictions for handling devices. In a new ERC Proof-of-Concept grant (STICK2SEE), we are pursuing an approach in which adhesion is predicted by *in situ* evaluation of the contact area and machine learning algorithms (Fig. 2). The concept of superimposing electroadhesion on fibrillar adhesion was successfully tested (*Chopra et al., ACS Appl. Mater. Interfaces, 2020*). Our microstructured adhesives were also successfully utilized in automated docking processes on board of the International Space Station, opening up another area of future application.

OUTLOOK

Micropatterned surfaces are a rich research field and continue to play a central role in INM's portfolio. Among the fundamental aspects to be explored are new designs including mechanical metamaterials to allow new functions and new strategies to switch adhesion. In addition, in situ observation of the real contact area will help to predict adhesion based on statistical learning algorithms. Recent results point to successful future applications in biomedicine and space.

NANOTRIBOLOGIE / NANOTRIBOLOGY

PROF. DR. ROLAND BENNEWITZ

ZUSAMMENFASSUNG

Der Programmbereich *Nanotribologie* forscht an der Entwicklung neuer Materialien mit besonderen adhäsiven und tribologischen Eigenschaften. Im Zentrum stehen dabei die Strukturierung und Funktionalisierung von Oberflächen und das Verständnis physikalisch-chemischer Mechanismen, die mechanische Eigenschaften wie Reibung, Verschleiß, Schmierung, Verformung und Adhäsion bestimmen. Die Systeme reichen von Graphen über Hydrogele bis hin zu mathematisch definierten Oberflächen aus dem 3D-Drucker. Die experimentellen Projekte basieren auf unserer Expertise in der hochauflösenden Rasterkraftmikroskopie. Auch auf größeren Längenskalen werden Experimente zu Reibung und Verschleiß durchgeführt, wobei vor allem die Rolle der Reibung mit Haut in der haptischen Wahrnehmung untersucht wird. Zu den wichtigsten Ergebnissen des Jahres 2020 gehören zwei Arbeiten, die aus dem letztgenannten Bereich stammen: eine Arbeit zur Reibung von Textilien auf dem Unterarm und eine zur visuellen und taktilen Wahrnehmung von Oberflächen, deren zufällige Rauigkeit bestimmte statistische Unterschiede aufweist.

MISSION

The Program Division *Nanotribology* explores new materials with specific adhesion and friction properties. We focus on surface functionalization and on understanding the physical chemistry of friction, wear, lubrication, deformation, and adhesion. Materials range from graphene over hydrogels to additively manufactured microstructures. The experimental projects rely on our expertise in the field of high-resolution force microscopy. Fundamental tribology experiments also address larger length scales, in particular in skin friction and its role in the haptic perception of materials. New projects employ single-molecule force spectroscopy in soft matter for biophysical applications.

CURRENT RESEARCH

Role of Hair Coverage and Sweating for Textile Friction on the Forearm

Friction of textiles on the human forearm is an important factor in comfort sensations of garments. We built an experiment to measure friction for textiles sliding on the forearm under loading conditions which are characteristic for wearing shirts or jackets. We quantified friction as function of hair coverage and sweating after physical activities. The study was initiated in a collaboration with industry and defines a benchmark for testing artificial skin models in studies of comfort sensations (*Lyu et al., Tribology Letters, 2020*).

Tactile perception of randomly rough surfaces

Most everyday surfaces are randomly rough and self-similar on sufficiently small scales. In collaboration with university colleagues in Materials Science and Computer Science, we investigated the tactile perception of randomly rough surfaces using 3D-printed samples, where the topographic structure and the statistical properties of scale-dependent roughness were varied independently. We found that the tactile perception of similarity between surfaces was dominated by the statistical micro-scale roughness rather than by their topographic resemblance. In contrast, the visual perception followed the topographic resemblance of surfaces. The results shed new light on the perception of materials through touch and vision (*Sahli et al., Scientific Reports, 2020*).

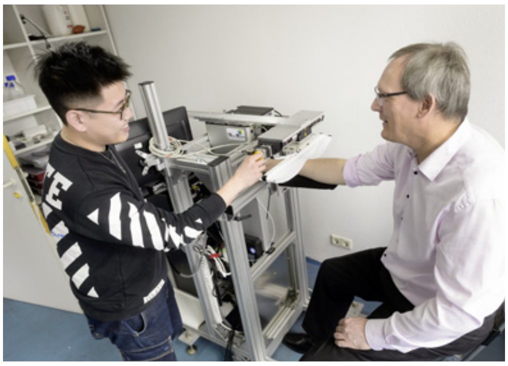


Fig. 1: As part of a psychophysical experiment, a study participant explores micro-structured samples with his fingertip. Friction forces are recorded and related to subjective judgements on the tactile experience.
Fig. 2: Experiment for measuring friction of textiles versus the skin of the forearm under condition which resemble the wearing of shirts or jackets.

Ongoing projects

In 2020, we started a project on frictional properties of stacked heterostructures of 2D materials, funded by a *Schwerpunktprogramm* of the DFG. We plan to reveal the effects of intermittent chemical bonds between 2D materials formed under high local pressure of a nano-scale tip. Other ongoing projects address the electrochemical control of friction on metallic glasses and the frictional interaction of single polymers with nanoporous membranes. We also started collaboration with the Junior Research Group *Bioprogrammable Materials* and search for nanomechanical signals from living bacteria enclosed in a hydrogel matrix.

OUTLOOK

We will continue to investigate the mechanisms which link structure and dynamics of surfaces to adhesion, friction, and wear in new materials. Our current projects include a friction and wear investigation of functional coatings containing MoS_2 flakes. In 2021, we will start the project "LightAct" in collaboration with the Program Division *Dynamic Biomaterials*. We will characterize the nanomechanical response of molecular motors which are driven by light and have the potential to deliver mechanical stimuli to cells. This project involving colleagues in Strasbourg and at the DWI Leibniz Institute for Interactive Materials in Aachen is supported in the framework of the Leibniz-Wettbewerb. The project is complemented by the development of novel DNA-based materials with force sensing functions for biophysical applications. Our research on haptic perception of materials, to paper as a disposable material – currently restricted by the Corona pandemic – will be further developed in collaboration with the Program Division *Functional Microstructures*, and the Departments of Materials Science, of Psychology, and of Computer Science at Saarland University, with the goal to reveal fundamental pathways of tactile perception through psychophysical experiments on micro-structured materials.

INNOVATIVE ELEKTRONENMIKROSKOPIE / INNOVATIVE ELECTRON MICROSCOPY

PROF. DR. DR. H. C. NIELS DE JONGE

ZUSAMMENFASSUNG

Eine nanometergenaue Materialcharakterisierung ist unabdingbar für die Weiterentwicklung der modernen Nanotechnologie und der Biologie. Der Programmbereich *Innovative Elektronenmikroskopie* (IEM) betreibt interdisziplinäre Forschung an der Schnittstelle der Physik der Elektronenmikroskopie (EM), Biophysik, Materialwissenschaft, Zellbiologie und Bildverarbeitung. Wir entwickeln modernste Techniken im Bereich in situ Transmissions-EM (TEM) und Raster-TEM (STEM) für die Forschung an funktionellen Materialien und biologischen Systemen unter realen Bedingungen. Auch untersuchen wir neue Wege für die dreidimensionale (3D) Datenaufnahme und verfügen über langjährige Erfahrung mit Bildverarbeitung sowie mit der Entwicklung von Protokollen für spezifische Proteinmarkierung mit Nanopartikeln. Dem Programmbereich steht ein hochmodernes Elektronenmikroskop (JEOL ARM200) zur Verfügung. Wir haben vielfältige Forschungskooperationen mit verschiedenen Universitäten und der Industrie.

MISSION

Nanoscale characterization is essential for the advancement of modern nanotechnology, energy science, biology, and biomedical sciences. The Program Division *Innovative Electron Microscopy* (IEM) conducts interdisciplinary research at the interface of physics of electron microscopy, biophysics, materials science, cell biology, and image processing. The division is world leading in the area of liquid-phase electron microscopy (LP-EM). We develop forefront *in situ* transmission electron microscopy (TEM) and scanning TEM (STEM) methods for the study of functional materials and biological systems under realistic conditions, mostly using a liquid flow system. We are also exploring new routes for three-dimensional (3D) data acquisition using intelligent STEM- and image reconstruction strategies. In addition, we have extensive experience with image processing, and with developing protocols for specific labeling of proteins with nanoparticles. The group houses a state-of-the-art electron microscope (ARM200, JEOL). Various research collaborations exist both with academia and industry.

CURRENT RESEARCH

Stoichiometry of calcium channels

LP-EM is being used to study the stoichiometry of Ca^{2+} channels formed by ORAI proteins in mammalian cells. The relative ratio of the different ORAI channels is highly relevant for cell function such as cell motility. This project is conducted together with Prof. Barbara Niemeyer, Saarland University, and is part of the SFB Collaborative Research Center 1027.

Growth factor receptors in cancer cells

We study the growth factor receptor HER2 at the single-molecule level within whole breast cancer cells in liquid, thereby analyzing differences in protein function between individual cancer cells (cancer cell heterogeneity). This research is done together with Prof. Stefan Wiemann of the German Cancer Research Center, Heidelberg, and Prof. Erich-Franz Solomayer of the Saarland University Hospital, Homburg. The project is funded the Else Kröner-Fresenius-Stiftung.

Examining patient biopsy samples with STEM

We have started examining long-term response in cell biopsies from patients with gastric- or gastroesophageal junction cancer treated with Trastuzumab. Investigations were done via molecular HER2 surface and pathway analyses in a project together with Prof. Timo Gaiser, University Medical Centre Mannheim, funded by the Deutsche Krebshilfe.

3D STEM

We are currently innovating in three-dimensional 3D STEM for obtaining nanometer resolution in micrometers-thick specimen. The project is a collaboration with Dr. Tim Dahmen, German Center for Artificial Intelligence, Saarbrücken. This research is funded by the DFG.

Studying the behavior of protein using graphene liquid cells

A graphene liquid enclosure capable of imaging proteins in liquid has been developed and has led to a project funded by an industrial partner. Dynamic processes at the solid-liquid interface were studied with STEM at the nanoscale. We have active research interactions with the Program Division *Structure Formation*.

Studying nanoparticles at the solid-liquid interface

Self-assembled structures and dynamic processes of nanoparticles at the solid-liquid interface were studied with STEM at the nanoscale. This research is funded by the DFG.

OUTLOOK

The IEM group is well situated to conduct research at the international forefront of electron microscopy both in the areas of biology/biophysics, and materials science. Future aims are to study processes of protein complexes, to develop a Liquid STEM into a standard characterization method for membrane proteins in cells, to study HER2 in patient biopsy samples, to improve the time-resolution of *in situ* STEM via artificial intelligence techniques, and to develop Liquid 3D STEM.

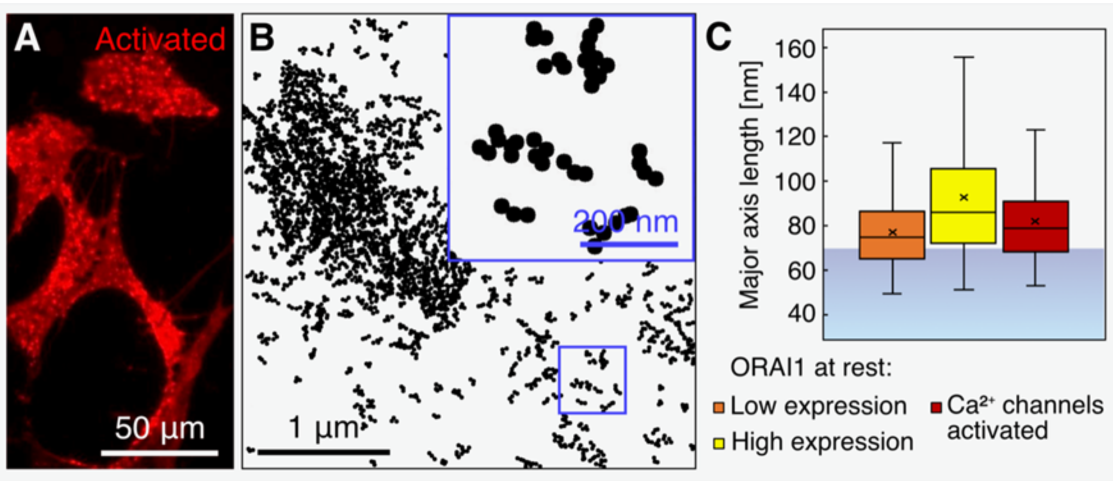
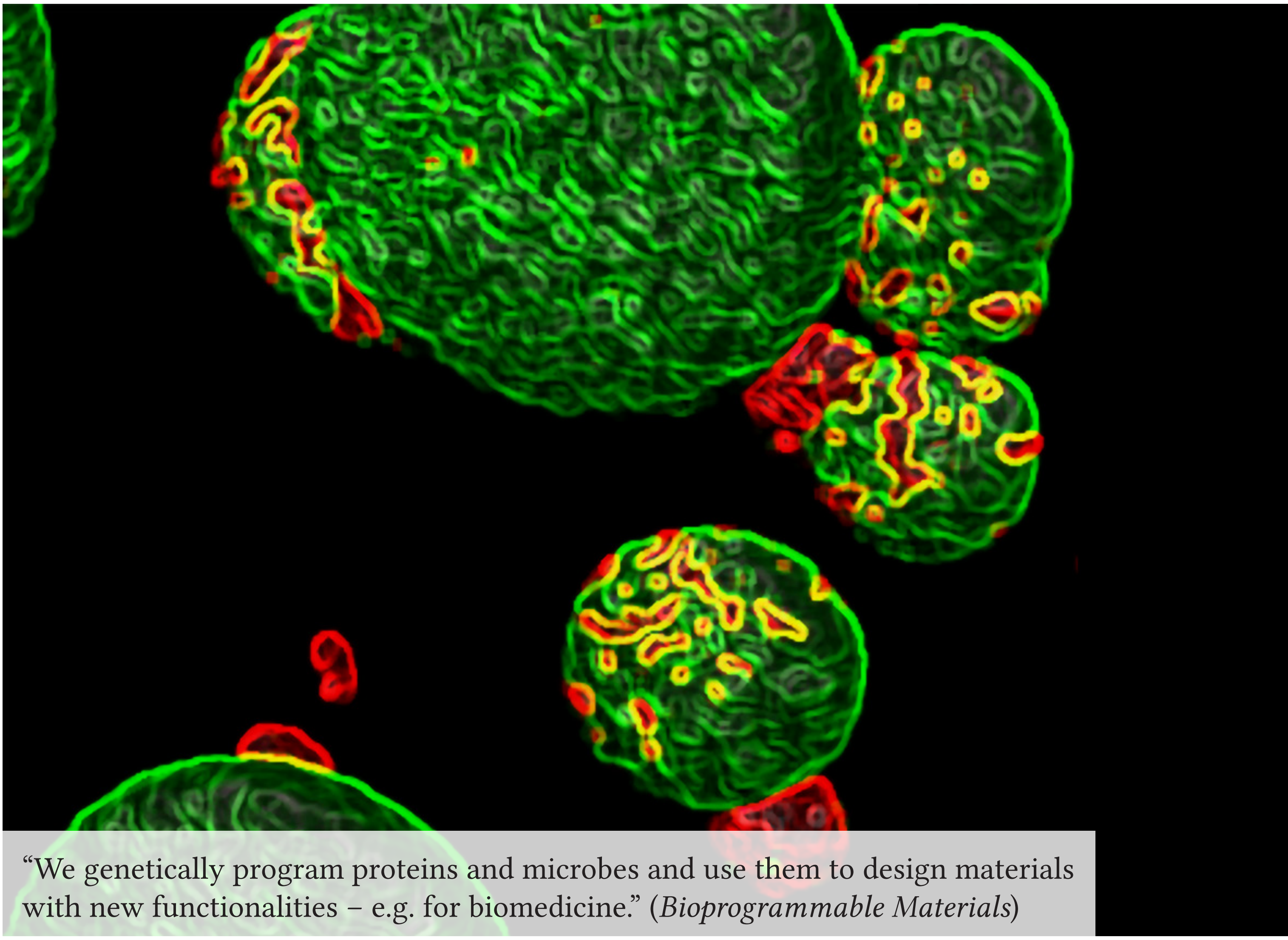
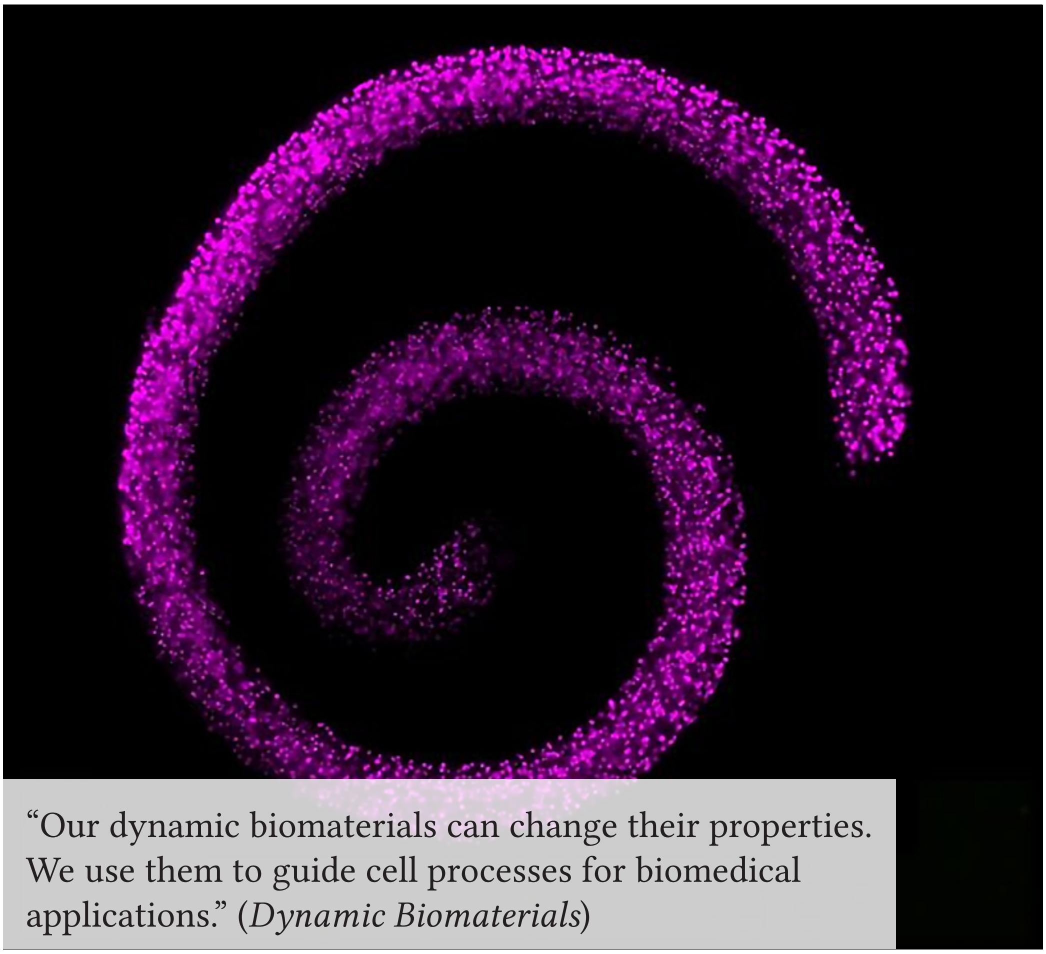


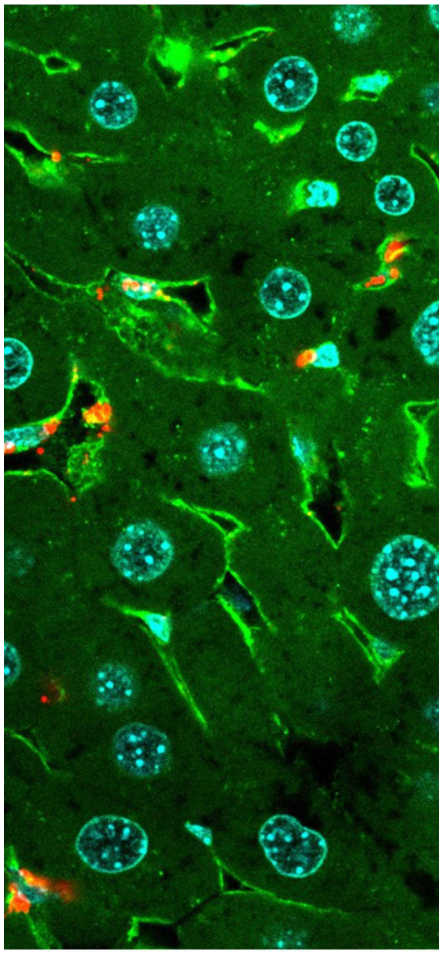
Fig.: ORAI1 calcium channel forming proteins in plasma membrane of activated HEK cells. (A) Fluorescence microscopic image of non-homogeneously distributed quantum dot labeled proteins. (B) Cluster analysis of electron microscopic image revealing protein positions. Inset shows newly discovered elongated clusters. (C) Length of clusters under various experimental conditions. *Int. J. Mol. Sci. 22, 799, 2021.*



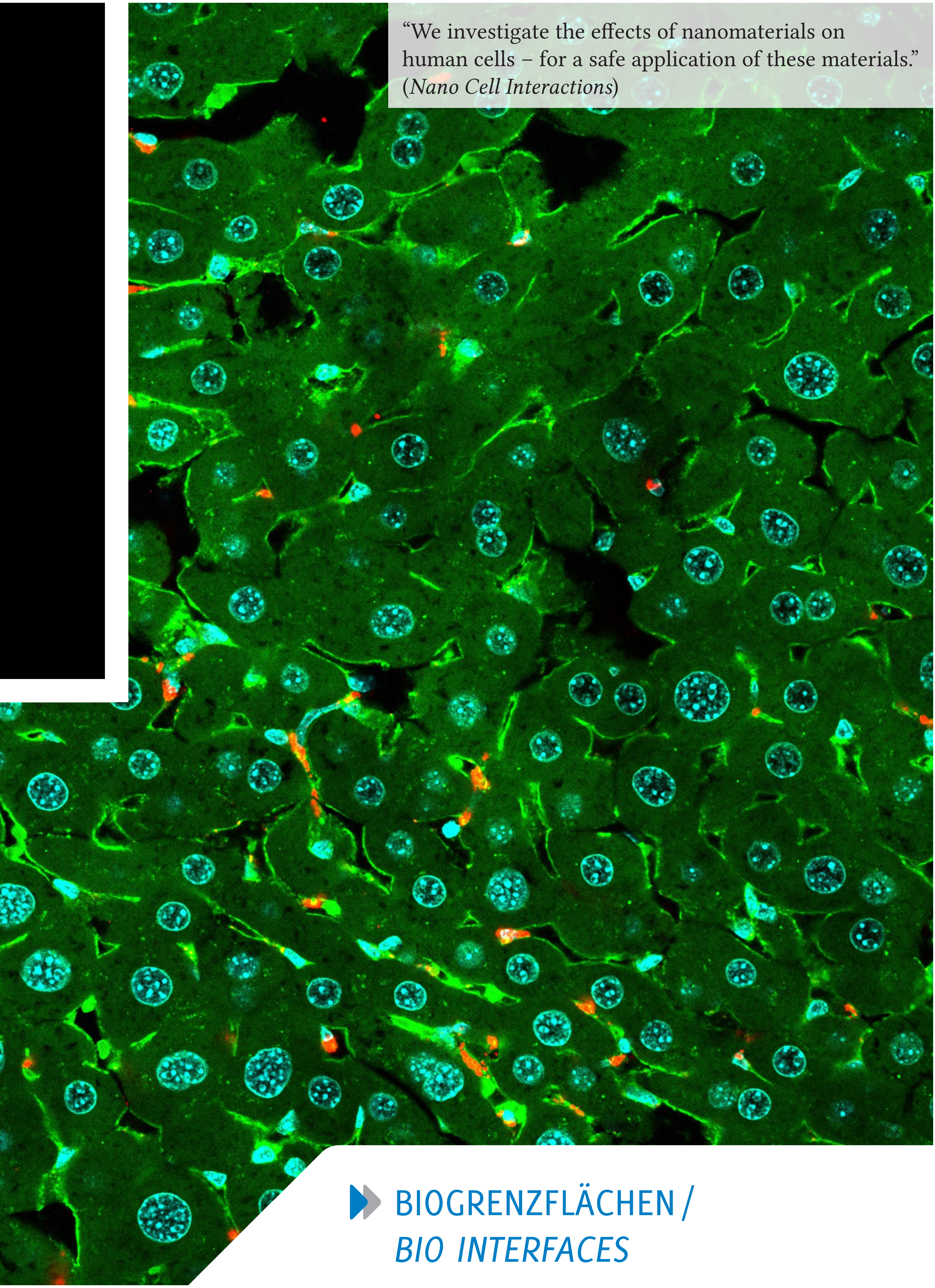
“We genetically program proteins and microbes and use them to design materials with new functionalities – e.g. for biomedicine.” (*Bioprogrammable Materials*)



“Our dynamic biomaterials can change their properties. We use them to guide cell processes for biomedical applications.” (*Dynamic Biomaterials*)



“We investigate the effects of nanomaterials on human cells – for a safe application of these materials.” (*Nano Cell Interactions*)



BIOGRENZFLÄCHEN / *BIO INTERFACES*

BIOPROGRAMMIERBARE MATERIALIEN / BIOPROGRAMMABLE MATERIALS

DR. SHRIKRISHNAN SANKARAN

ZUSAMMENFASSUNG

Die Juniorforschungsgruppe *Bioprogrammierbare Materialien* erforscht ein junges multidisziplinäres Feld, das die Gebiete der Synthetischen Biologie und der Biomaterialien kombiniert. Im Mittelpunkt steht die Entwicklung von Materialien mit genetisch programmierten Funktionalitäten, die für Biosensorik geeignet und in der Lage sind, auf Stimuli hin Medikamente langfristig freizusetzen und das Zellverhalten zu beeinflussen. Mit Werkzeugen der synthetischen Biologie werden Proteine und Mikroben so programmiert, dass sie intelligente und nützliche Funktionen erfüllen. Diese technisierten biologischen Gebilde werden dann in entsprechend entwickelte polymere Matrizen eingearbeitet. Das Ergebnis sind funktionell vielseitige Kompositmaterialien mit einer großen Bandbreite an Steuerbarkeit und In-situ-Kontrollmöglichkeiten.

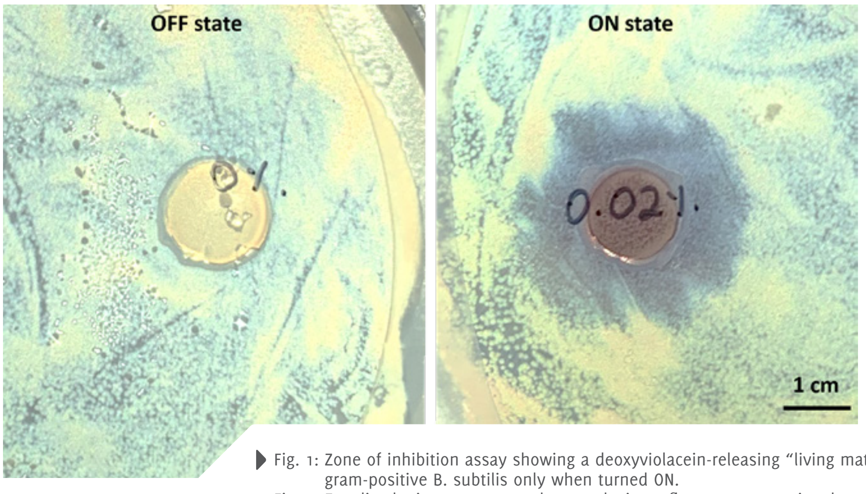
MISSION

The Junior Research Group *Bioprogrammable Materials* explores a young multidisciplinary field combining synthetic biology and biomaterials. It focusses on the development of materials with genetically programmed functionalities capable of biosensing, stimuli-responsive long-term drug release and manipulation of cell behavior. Synthetic biology tools are used to program proteins and microbes to perform smart and beneficial functions. These engineered biological entities are then incorporated in appropriately developed polymeric matrices, resulting in composite materials with highly versatile functionalities, a wide range of tunability and *in situ* controllability.

CURRENT WORK

Living therapeutic materials

We engineered bacteria to release therapeutic biomolecules in response to external stimuli. For instance, we used optogenetic modules to program an endotoxin-free version of E. coli (ClearColi) to light-responsively secrete either an angiogenesis-stimulating protein or an antimicrobial drug named, deoxyviolacein. We showed that bacterial hydrogels releasing deoxyviolacein were able to inhibit the growth of gram-positive bacteria (Fig. 1). We also established genetic circuits for activating protein production in bacteria in response to either aspirin or heating above 37 °C. Since the start of the Leibniz Science Campus *Living Therapeutic Materials* in July 2020, these genetic circuits are being applied in different cooperative projects with partners in Saarland University (UdS), Saarland University Medical Center (UKS), and HIPS. The greatest progress has been made with Prof. Rolf Müller (HIPS) in engineering E. coli to produce an antimicrobial agent, Darobactin, at fever temperatures i. e. above 37 °C (Fig. 2). With the Program Division *Dynamic Biomaterials*, these bacteria were encapsulated in



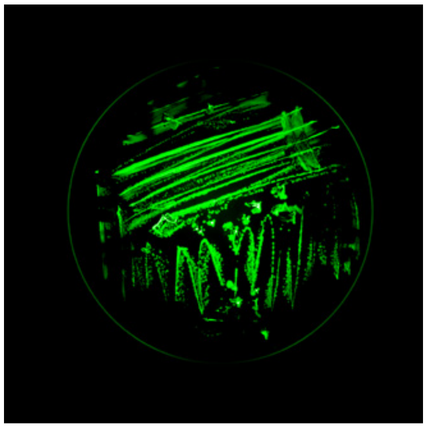


Fig. 1: Zone of inhibition assay showing a deoxyviolacein-releasing “living material” preventing growth of gram-positive B. subtilis only when turned ON.
Fig. 2: E. coli colonies on an agar plate producing a fluorescent protein when heated above 37°C.

Pluronic F127 based hydrogel constructs capable of sustaining long-term activity (months) while preventing bacterial escape. Preliminary results of *in vitro* immune response studies, done with INM fellow Dr. Bin Qu (UKS), promisingly indicate that both the bacterial strain we use (ClearColi) and hydrogel encapsulation prevent activation of unwanted endotoxic responses. The therapeutic functionality of these engineered bacteria in living material formats for antimicrobial and regenerative purposes is currently being tested *in vitro*.

Genetic engineering of light-responsive proteins targeting cellular functions

With *Dynamic Biomaterials*, we were previously involved in genetically engineering two photo-activatable (PA) proteins by introducing a non-natural photo-caged amino acid in their active sites. We demonstrated that one protein (PA-Hsp47) could stimulate collagen production in human cells (*Khan et al., BMC Mol. Cell Biol., 2020*) and the other (PA-ZH affibody) could induce mesenchymal transition in breast cancer cells. However, this strategy of engineering light-responsiveness presented limitations in terms of low production yields and irreversible activation. Subsequently, with *Dynamic Biomaterials*, we explored a different strategy by fusing a T cell-adhesion promoting protein (ICAM) to a light-responsive domain (LOV2-Jα) to achieve repeated activation of ICAM in blue light and inactivation in the dark. Computational modelling done by the group of Prof. Volkhard Helms (UdS) confirmed that the light-responsive domain blocks the active site of ICAM in the dark. Reversible activation of the light-responsive domain and adhesion of T-cells to the ICAM domain were experimentally verified. Further experiments are ongoing to verify the fusion protein’s ability to reversibly regulate T-cell adhesion.

OUTLOOK

To improve the applicability of living therapeutic materials, light, aspirin, and heat responsive genetic circuits, currently established in E. coli, will be adapted for human microbiome relevant bacteria such as Corynebacterium and Lactobacilli. Accordingly, a DFG-funded project for engineering light-responsive release of recombinant Nerve Growth Factor from Lactobacillus plantarum will commence in 2021. Secretion of different therapeutic biomolecules will be encoded in these genetic circuits for cooperative projects of the Leibniz Science Campus. These include ectoine or hyaluronic acid for dry eye disease (with Prof. Christoph Wittmann, UdS and Prof. Berthold Seitz, UKS), Interleukin 2 for cancer immunotherapy (with Dr. Bin Qu, UKS) and an inhibitor for Interleukin 6 receptor to prevent HPV-induced cancer (Prof. Sigrun Smola, UKS). In the topic of light-responsive proteins, to generate sufficient PA-Hsp47 for animal studies, strategies to increase production yields will be explored by using either solubility-enhancing genetic modifications or a different production host (e. g. yeast).

DYNAMISCHE BIOMATERIALIEN / DYNAMIC BIOMATERIALS

PROF. DR. ARÁNZAZU DEL CAMPO

ZUSAMMENFASSUNG

Der Programmbereich *Dynamische Biomaterialien* entwickelt instruktive synthetische Matrizen zur Einkapselung und Schnittstelle mit lebenden Zellen. Wir zielen darauf ab, funktionelle Gewebe und lebende Devices für medizinische und technische Anwendungen zu entwickeln. Im Zentrum unserer Forschung stehen lichtempfindliche Moleküle, Hydrogele und Zellen, die mit latenten Funktionsniveaus programmiert sind und bei Belichtung angeschaltet werden können, um Eigenschaftsänderungen und Reaktionskaskaden zu regulieren. Wir sind auch an der Kompatibilisierung von synthetischen Matrizen und lebenden Organismen mit Verarbeitungstechnologien wie 3D-Druck oder Mikrofluidik für zellbasierte Diagnostika und therapeutische Devices der nächsten Generation interessiert. Als längerfristige Perspektive beabsichtigen wir, Konzepte aus der Geweberekonstruktion auf die Synthese nachhaltiger und belastbarer technischer Materialien zu übertragen.

MISSION

The Program Division *Dynamic Biomaterials* develops instructive synthetic matrices to encapsulate and interface with living cells. We aim to bioengineer functional tissues and living devices for medical and technical applications. Central to our research are photoresponsive molecules, hydrogels and cells programmed with latent functional levels that can be unlocked upon light exposure to regulate property changes and response cascades. We are also interested in the compatibilization of synthetic matrices and living organisms with processing technologies like 3D printing or microfluidics towards next-generation cell-based diagnostics and therapeutic devices. As longer-term perspective we intend to transfer concepts from tissue reconstruction to the synthesis of sustainable and resilient technical materials.

CURRENT RESEARCH

Actuated interfaces that trigger cellular responses

The regulation of material properties using light is at the core of our research. We integrate light-triggers into hydrogels to regulate the presentation of bioactive components or the mechanics of the network (*Zheng et al., Materials Horizons, 2020*) and, by this means, guide the fate of embedded cells. We investigate the potential of these hydrogels to accelerate the formation of cardiac tissue by cultures of cells (Humboldt Postdoctoral Fellow G. Kocer), to mimic cell stratification in epithelial tissues (SPP 1782), or to regulate the activation of immune cells (SFB 1027). A recent highlight is the demonstration of mechanical stimulation of cell surface receptors by using light-driven synthetic molecular motors. Translation of these results into molecular technologies to stimulate mechanotransduction processes in 3D *in vitro* cell culture and *in vivo* is done in collaboration with the Program Division *Nanotribology*, the

DWI-Leibniz Institute for Interactive Materials and the University Strasbourg (SAW Project LightAct), and with GeorgiaTech (EU Project Mechanofibrosis).

Printed and implantable optical fibers for light-based cell therapies

To facilitate transfer of our technologies into medical devices, we develop biocompatible optical waveguides and integrate them into implantable living devices. Our technology is based on extrusion printing of hydrogel waveguides with core-cladding designs. These fibers are soft, hydrated, biocompatible, degradable and present adequate optical loss values (< 0.1 dB cm^{-1}) for the activation of biological processes using reasonable light sources for medical applications (*Feng et al., Adv Funct Mater, 2020*). Printing-based processing facilitates integration of the waveguide in implantable chips or cell therapy constructs.

Living therapeutic materials: encapsulation technologies for next-generation therapeutic modalities

We have consolidated the emerging field of Living Therapeutic Materials at INM and at our University Campus with the successful foundation of the Leibniz ScienceCampus *Living Therapeutic Materials* (see highlight article). We design matrices and processing technologies to safely encapsulate drug producing organisms and fabricate implantable drug eluting devices. Our material designs sustain cell viability during processing, control cell growth and maximize drug production at the application site. For this purpose, we use dynamic hydrogel networks and core-shell device designs. We specifically target drug delivery in the context of ophthalmology and by envisioned drug eluting living contact lenses for the treatment of chronic eye diseases.

Automatization of 3D culture models for high-throughput drug testing

Our group develops and patents hydrogels with adjustable crosslinking kinetics to facilitate automatized handling. These hydrogels allow mixing of polymeric precursors and cell suspensions under low shear forces and customized regulation of gelation times between a few seconds to a few minutes for comfortable processing (*J.I. Paez et al., ACS Appl. Mater. Interfaces 2020,* Patent application: *J. Paez et al., Priority 03.07.2019, filed under: DE102019117997.1*). Towards technology transfer, materials synthesis has been optimized and upscaled and the gel can allow automatized handling in high-throughput systems. As demonstrator, we are establishing 3D cell culture models of breast cancer spheroids (FET Mechanocontrol) and angiogenesis (cooperation with Experimental Surgery, Saarland University Medical Center UKS).

OUTLOOK

The development of cellular microenvironments to support and control cell growth and function remains a major topic in the group. The synthetic toolbox moves from organic synthesis to biochemical methods and from phototriggers to natural optical switches. The focus of the group is expanding from the development of biomaterials supporting tissue regeneration to the application of morphogenesis concepts to recreate biological materials *in vitro*, breaking the classical border between synthetic and bioengineering approaches in materials science.

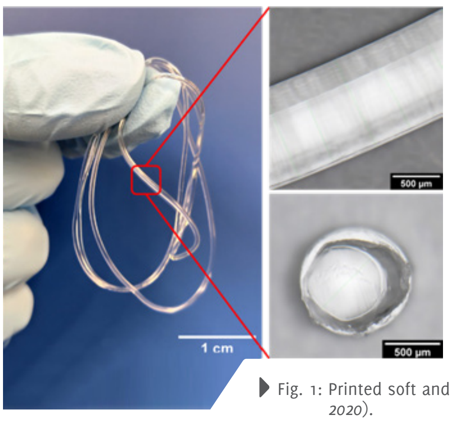


Fig. 1: Printed soft and degradable optical waveguides with core-shell structure (*Feng et al., Adv Funct Mater, 2020*).
Fig. 2: The new Leibniz ScienceCampus *Living Therapeutic Materials*, whose spokesperson is Prof. del Campo, started in July 2020 (www.lsclifemat.de).

NANO ZELL INTERAKTIONEN / NANO CELL INTERACTIONS

PD DR. ANNETTE KRAEGELOH

ZUSAMMENFASSUNG

Der Programmbereich *Nano Zell Interaktionen* beschäftigt sich mit den Auswirkungen technisch hergestellter Nanoobjekte auf menschliche Zellen, um zu einer sicheren Anwendung von Nanomaterialien in technischen und biomedizinischen Bereichen beizutragen. Ziel ist es zu verstehen, wie bestimmte Partikeleigenschaften die Struktur und Biochemie der Zellen beeinflussen, und aufzuklären, welche Mechanismen die Aufnahme und Lokalisation von Nanoobjekten beeinflussen. Als Untersuchungsobjekte werden anorganische Nanopartikel hergestellt und charakterisiert. Zur Lokalisation von Partikeln und Zellstrukturen werden vor allem lichtmikroskopische Techniken eingesetzt. Eine Besonderheit der Gruppe ist die Nutzung hochauflösender Stimulated Emission Depletion (STED)-Mikroskopie für diesen Zweck. Zur weiteren Analyse der Zellantwort werden darüber hinaus zellbiologische, biochemische und molekularbiologische Techniken eingesetzt.

MISSION

The Program Division *Nano Cell Interactions* explores the effects of engineered nano-objects on human cells to enable safe applications of nanomaterials in technical and biomedical fields. It strives to understand how particle properties influence structure and biochemistry of cells and to elucidate mechanisms that affect the uptake or location of nano-objects. Our purpose is to pave the way for the design of safer nanomaterials. For this reason, well-defined inorganic nanoparticles are prepared and characterized. Light microscopy techniques, for example Stimulated Emission Depletion (STED) microscopy, are used to localize particles and to analyze cellular structures. Further, cell-biological, biochemical, and biomolecular techniques are used for analysis of the cellular responses.

CURRENT RESEARCH

Structure of human native pulmonary mucus

The lung is one important target organ of nanomaterials that enter the human body via inhalation. Human respiratory mucus, lining the airway epithelium, forms a relevant barrier to nanomaterials inhaled unintentionally as well as to particulate inhalation therapeutics applied on purpose. Understanding the structure of mucus is essential for the prediction of interactions between nanomaterials and mucus and more specifically the potential transmucosal penetration of nanomaterials. Until now, the structure of bronchial mucus has been primarily investigated by electron microscopy techniques, operating under vacuum conditions. Such conditions are expected to alter the structure of mucus, which is a hydrogel. Mucus consists of water (95 % w/w), mucins (0.2-5.0 % w/v), non-mucin proteins, lipids, DNA, salts, cells, and cell debris. The glycosylated mucin glycoproteins make up the basic gel structure of mucus.

In a study conducted in frame of a joined doctoral project between the *Nano Cell Interactions* group and the Biopharmaceutics and Pharmaceutical Technology group at Saarland University (Prof. Marc Schneider), also involving INM's Service Group *Physical Analysis*, mucus structure was investigated using various microscopy techniques. First, the impact of dehydration on mucus was analyzed. Scanning electron microscopy analyses revealed that during sublimation the non-porous structure of hydrated mucus was transformed into a porous sponge-like structure. This result was confirmed using conventional confocal laser scanning microscopy (Fig. 1). In addition, the structural organization of the major gel forming mucin MUC5B in its hydrated state was visualized using superresolution STED microscopy. This analysis revealed the nano-scale granular patterns of mucin macromolecules and their agglomerates within an essentially pore-free mucus structure (Fig. 2). The results provide novel insights into the native structure of mucus and will advance the understanding of nanomaterial penetration as well as the development of particulate drugs. The results of this study have been accepted for publication *(Meziu et al., Int. J. Pharm., 2021)*.

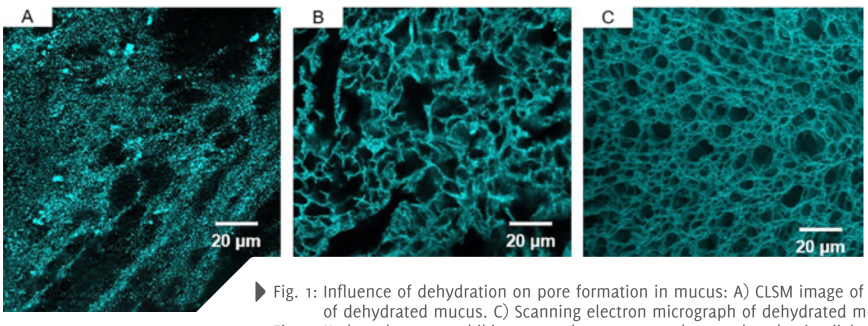
Further ongoing investigations aim at investigating the structure and barrier properties of mucus produced *in vitro* by cells derived from the human bronchial region cultivated at the air liquid interface. Here, the structure of mucus is analyzed using confocal laser scanning microscopy. Furthermore, the penetration of model particles of various sizes is investigated using 3D-time lapse confocal imaging. Application of the particles is achieved by their controlled nebulization using the Vitrocell® Cloud 6 exposure system.

Nanosafety 2020

In the frame of the Leibniz Research Alliance Nanosafety, the international conference Nanosafety was organized. Originally planned to be held in Zaragoza, the conference was held virtually due to the Covid19 pandemic. A detailed report is given in form of a highlight article.

OUTLOOK

Future research activities will focus on the further development of silicon dioxide nanoparticles and the evaluation of their potential applications in the biomedical field, more specifically for therapeutic purposes. One aim will be to use the particles as delivery agents to enhance the performance of endovascular catheters. In this context, the durability of the particles will be analysed. Further studies will focus on the identification of the hazard potential of a new group of 2D nanomaterials, the MXenes developed in the Program Division *Energy Materials*. The results will be used to propose Safe-by-Design concepts for future applications of these materials. Together with external partners, the group aims at further contributing to the enhancement of research data management in the field of materials safety (for further information see the website of the InnoMatSafety consortium https://nfdi4nanosafety.de).



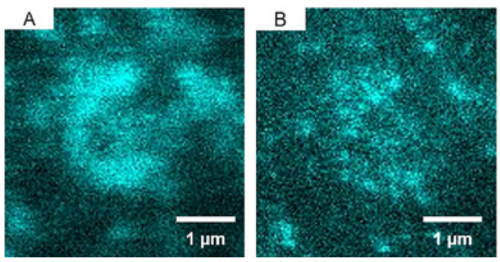
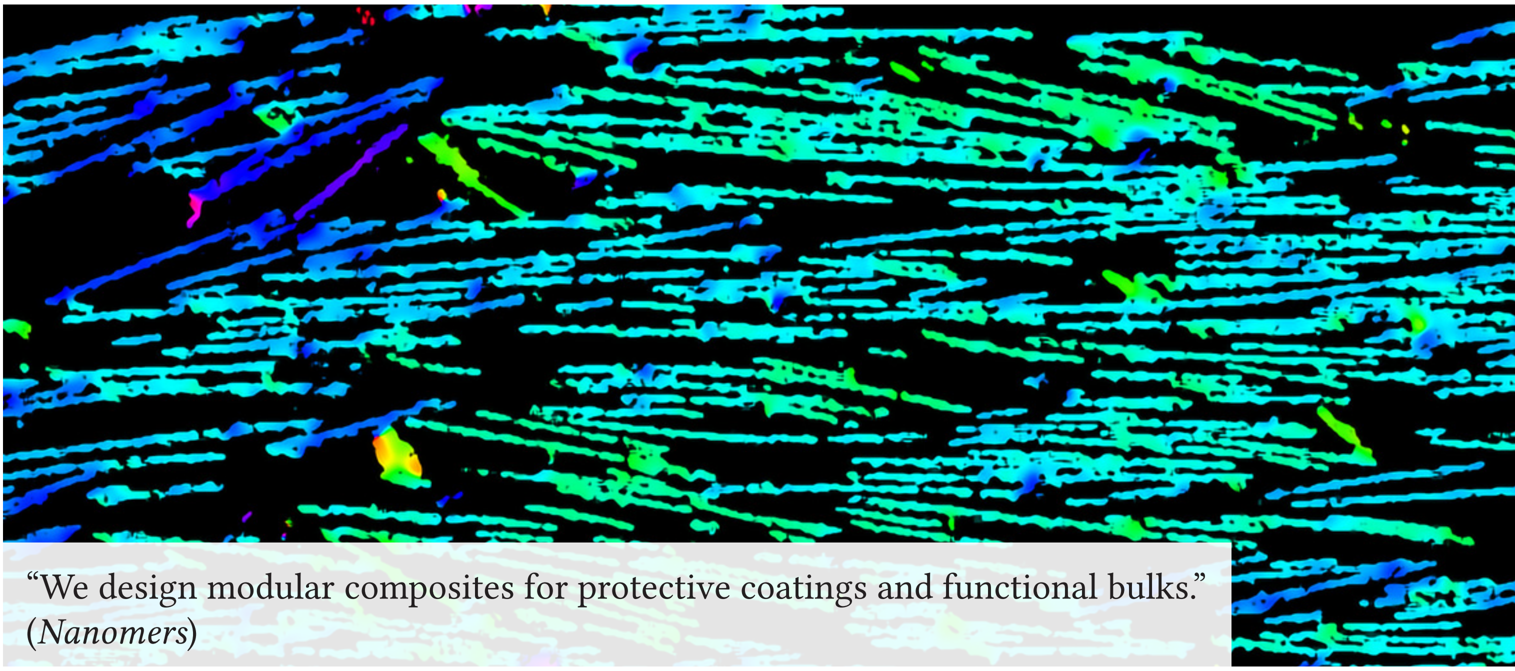
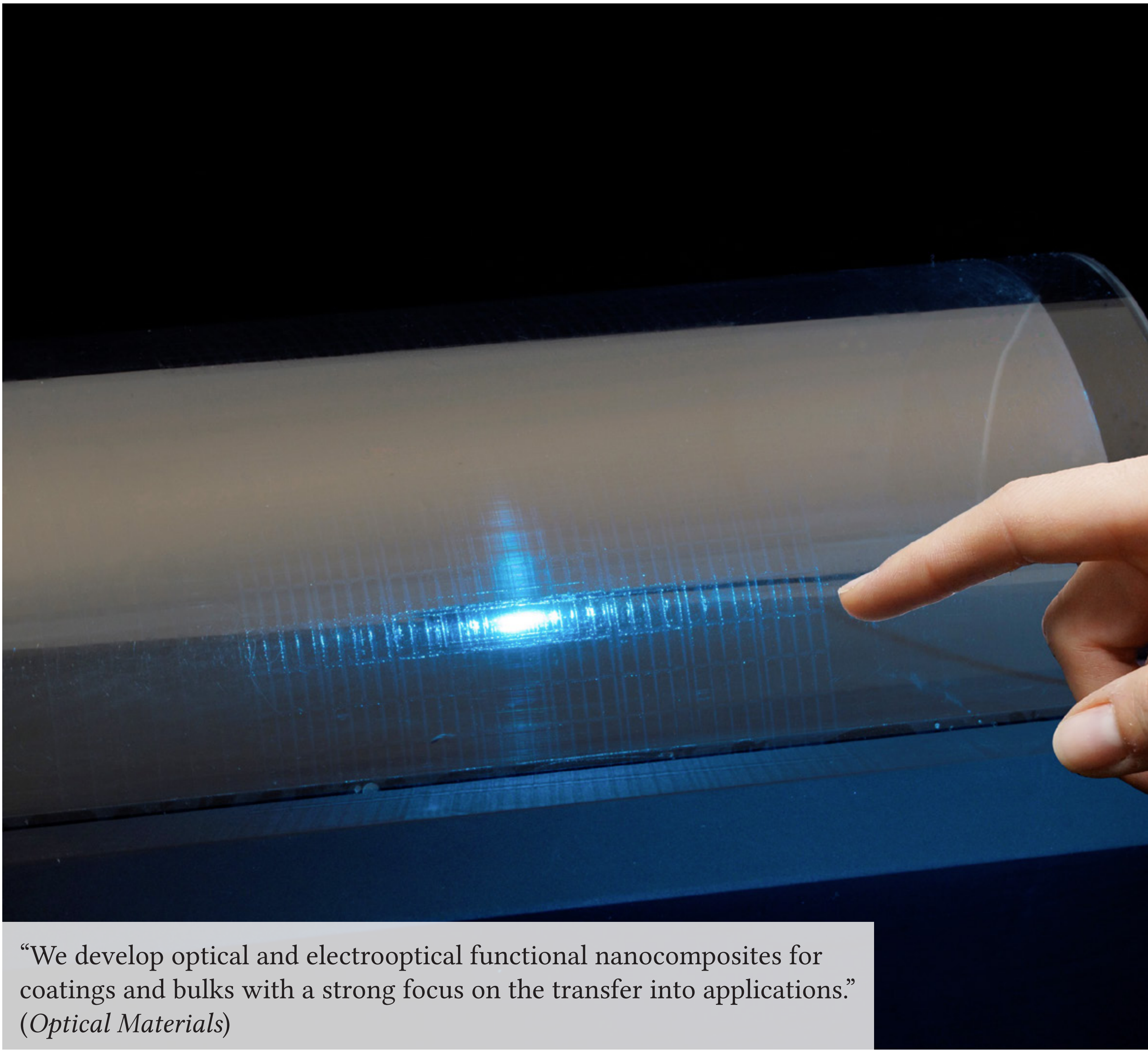


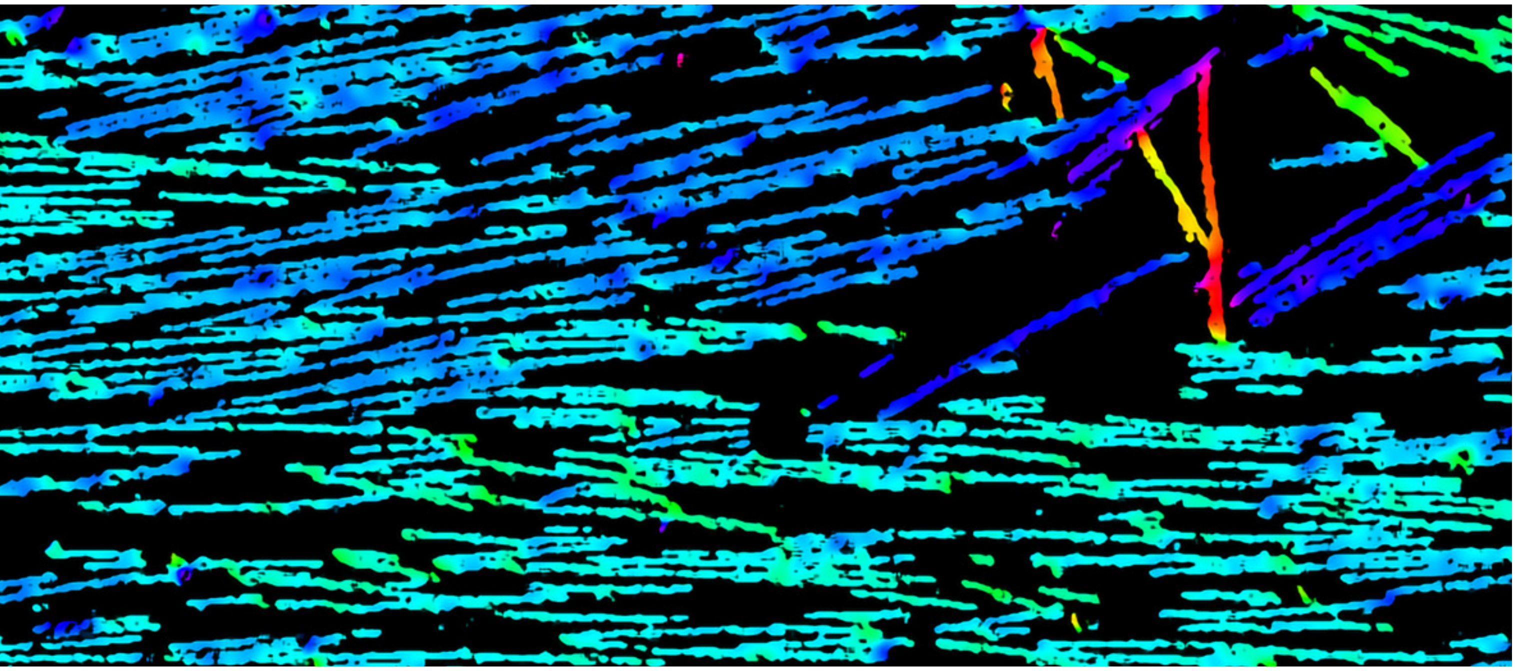
Fig. 1: Influence of dehydration on pore formation in mucus: A) CLSM image of hydrated mucus. B) CLSM image of dehydrated mucus. C) Scanning electron micrograph of dehydrated mucus.
Fig. 2: Hydrated mucus exhibits a granular structure when analyzed using light microscopy. A) CLSM image of mucin agglomerates. B) Superresolution STED microscopy reveals small spots corresponding to mucin MUC5B mono- or multimers. MUC5B was stained using AntiMUC5B antibody.



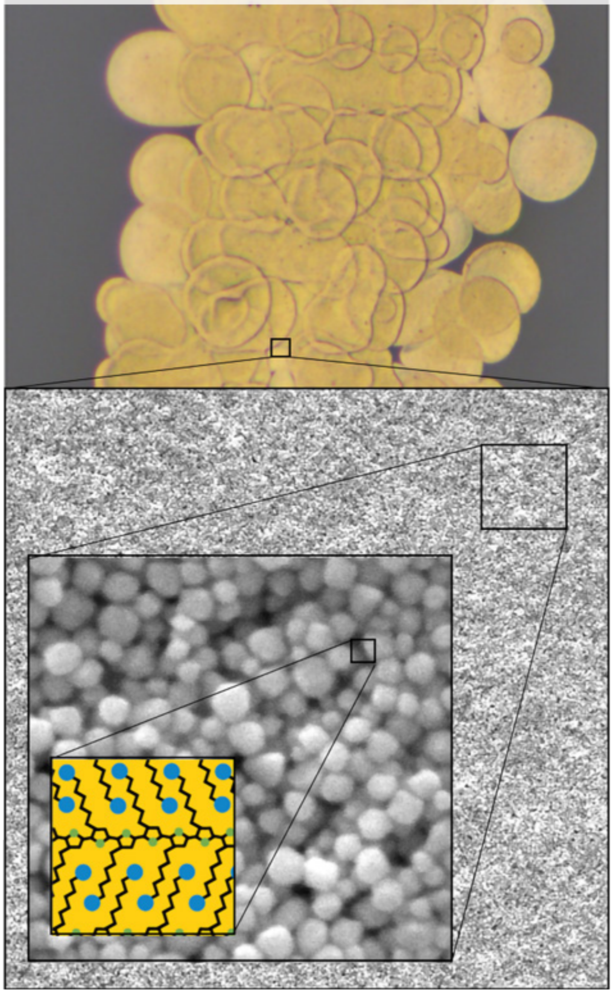
“We design modular composites for protective coatings and functional bulks.” (*Nanomers*)



“We develop optical and electrooptical functional nanocomposites for coatings and bulks with a strong focus on the transfer into applications.” (*Optical Materials*)



“We study how molecules, polymers and colloidal particles join to form materials.” (*Structure Formation*)



NANOKOMPOSIT-TECHNOLOGIE / *NANOCOMPOSITE TECHNOLOGY*

NANOMERE / NANOMERS

DR.-ING. CARSTEN BECKER-WILLINGER

ZUSAMMENFASSUNG

Der Programmbereich *Nanomere* entwickelt multifunktionelle Schutzschichten, Kompaktwerkstoffe und Materialien für additive Fertigungsverfahren auf Basis von Kompositen mit polymeren und hybriden Matrizes sowie nano- und mikroskaligen, funktionellen Additiven. Die funktionellen Additive können halbleitend sowie keramischer oder metallischer Natur sein. Neben kugelförmigen Partikeln werden auch solche mit plättchenförmiger Morphologie eingesetzt. Mit einer maßgeschneiderten Oberfläche versehen, erlauben die Partikel den Übertrag festkörperphysikalischer Eigenschaften anorganischer Materialien in Polymere und Beschichtungen. Bei der Erzielung neuer Werkstoffeigenschaften steht der Anwendungsbezug im Vordergrund. Schwerpunkt der Entwicklungsaktivitäten sind schwermetallfreie, aktive Korrosionsschutzsysteme für Stahl und Aluminiumlegierungen, temperaturbeständige, feuerfeste Bindemittel für Naturfaserkomposite, transparente, selbstheilende Beschichtungen und Polymerkomposit-basierte Materialien für die additive Fertigung.

MISSION

Activities of the Program Division *Nanomers* comprise the development of functional coatings and bulk materials based on a polymer matrix composite concept. A strong focus is put on application-oriented projects for industrial materials. Functions of interest are heavy metal free corrosion protection, fire resistant polymer matrix composites, temperature stable inorganic binders and transparent self-healing surfaces. Applications are in electronics, medicine, optics, automotive, construction, engineering and additive manufacturing.

CURRENT RESEARCH

Hybrid nanocomposites for corrosion protection coatings for light metal alloys / AluResist

The project AluResist supported by the state of Saarland is focused on corrosion protection coatings for fasteners made of a new high strength aluminum alloy. Now, in its last phase the coating materials are to be adjusted to application processes having potential for mass production. Functional nanoparticles embedded in a Nanomer-hybrid matrix are used as additives to provide active corrosion protection to coatings by releasing passivating agents. The last project steps will be finished during the first half of 2021 so that the industry partner can then start the planning of production steps.

Polymer composite coatings for corrosion protection of mild steel / HORUS

The concept for heavy metal free corrosion protection for low alloyed and mild steel is based on polymer composite coatings using a combination of passive diffusion and barrier effect of inorganic platelets (tortuous path for corrosive molecules). In addition it utilizesactive flake-type micro- and nanoparticles based on metal phosphates to repassivate the surface in case of a damage in the coating that reaches the substrate. The results on the combined effect were studied on Nanomer powder coatings using Electrochemical Impedance Spectroscopy, potentiometry and standard corrosion tests and were presented at *EUROCORR 2020*. The polymer composite coating approach is also used in the ZIM-project HORUS to protect low alloyed construction steel against corrosive gases produced in refuse incineration plants.

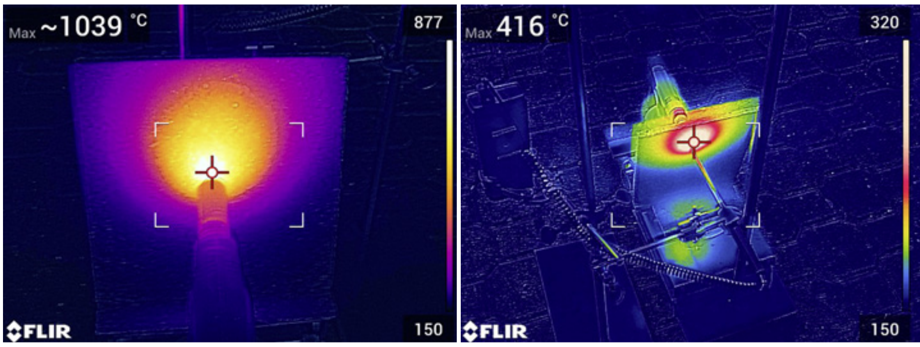


Fig. 1: Production of acacia shreds used for production of NaMiComp fiberboards in the field (Okombahe / Namibia).
Fig. 2: Temperature distribution on acacia fiberboard with Namibinder in flame test after 1 h, left: frontside, right: backside.

At INM, the material development work in HORUS is performed in cooperation with the Program Division *Optical Materials*. The developed Nanomer coatings show significant stability in corrosive test such as hydrochloric acid vapor test and so called green death test. The project currently reached the technology phase including tests in real environment.

Fire resistant fibreboards from bush biomass / NaMiComp III

The project phase NaMiComp III, supported by BMZ-GIZ and Saarland in cooperation with the University of Namibia (UNAM) started as the last phase of the NaMiComp project in 2020. This phase is dedicated to the transfer of the research results on the fabrication of a fiberboard plate derived from bush biomass towards the Namibian economy. The inorganic Namibinder developed so far and the acacia fiberboards are fabricated exclusively from Namibian precursors. The mechanical and thermal properties of fiberboards are determined at the lab scale to derive a materials data sheet in order to enable the preparation of a marketing initiative to integrate the activity of the local industry in Namibia. The first application in focus of this framework is the use of the fire resistant fiberboards as construction materials for “low-cost-housing” in Namibia and other sub-Saharan African countries. The project is in line with the *Leibniz in Africa* initiative.

In addition, an industry project on tribological modification of bulk polyurethane elastomers used in safety equipment started at the beginning of 2020.

OUTLOOK

Material development within the group will be based on the polymer composite approach. The synthesis of polyrotaxanes developed in 2019 for self-healing hard coatings will be upscaled for transfer to industry projects. Reactive materials will be derived therefrom as well as transparent hybrid materials that will be used for direct 3D-printing and stereolithography of optical elements. Polymer nanocomposites with specific mechanical and electrical properties will be developed as filaments to enable multi-material additive manufacturing.

OPTISCHE MATERIALIEN / OPTICAL MATERIALS

DR. PETER W. DE OLIVEIRA

ZUSAMMENFASSUNG

Der Programmbereich *Optische Materialien* entwickelt optische und elektrooptische Verbundwerkstoffe als wertschöpfende Bestandteile in Bulk- und Beschichtungsmaterialien. Die Kompetenzen in der Modellierung von nasschemischen Prozessen zur Synthese organisch-anorganischer Matrices und bei der Herstellung von Nanopartikeln mit spezifischen chemischen Modifikationen, ermöglichen die Entwicklung neuer Werkstoffe mit anpassten physikalischen Eigenschaften wie Brechungsindex oder Leitfähigkeit. 2020 wurden u. a. glasartige Barriereschichten für flexible Solarzellen, Polymer-Verbundmaterialien mit Nano-Luftblasen zur Erniedrigung des Brechungsindexes sowie brechungsangepasste Polymerharze zur Herstellung transparenter Glasfaserverstärkter Kunststoffe (GFK) entwickelt. Diese Themen stehen für unsere Patentstrategie aus der Nutzung bestehender und der Schaffung neuer Patente in industrie- und produktrelevanten Bereichen. Mit einer angepassten Strategie von digitalen Präsenzen will die Gruppe zudem ihre Resultate für Gesellschaft und Industrie sichtbarer machen.

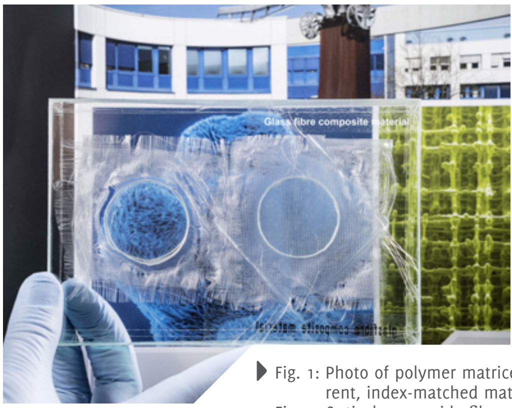
MISSION

The Program Division *Optical Materials* has the mission to design new optical and electro-optical composite materials as value-adding functionalization agents for bulk materials and coatings on glass, ceramic, and polymeric substrates. Core competences of the group are in modeling of wet chemical processes to synthesize organic-inorganic matrices and in the production of nanoparticles with specific chemical modifications. The combination of these competences allows the development of new classes of optical materials for bulks and coatings. Therefor it links the chemistry with the requested physical properties such as refractive index, conductivity, absorption, or light sensitivity. This is accompanied by a focus on the needs of society and industry for new solutions to answer present and future material, process, and product demands.

CURRENT RESEARCH

Glass-like coatings for flexible Copper-Indium-Galium-Selenide (CIGS) solar cells

A cost-efficient, environmentally sound, and electrical insulating glass-like sealing was developed for metal foils as a basis for flexible CIGS cells. The sealing is applied by slot-coating on AISI 304 steel foil and sintered to a glass-like material at 450 °C. This flexible transparent coating protects the foil from corrosion, improves the scratch-resistance, and can be rolled to a coil. Further layers to complete the solar cell are added by our partner. Due to the combination of steel and glass, temperatures of 600 °C higher than standard can be used for selenization, which leads to higher photo-voltaic efficiency. This research is a co-operation of INM and a European industrial partner.



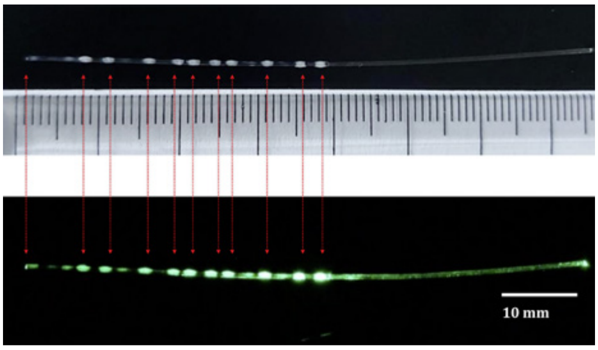


Fig. 1: Photo of polymer matrices with embedded glass fiber mesh. Left circle: Embedded mesh, clear transparent, index-matched matrix polymer. Right circle: Embedded mesh, opaque, standard matrix polymer.
Fig. 2: Optical waveguide fiber with Poly(hydroxyethyl)methacrylate (PHEMA) coating. Top: Light scattering indicates positions of laser-induced nano-bubble formation. Bottom: Out-coupling of green light from fiber due to reduced refractive index of PHEMA-nano-bubble-composite.

Nano Bubbles

Stable dispersions of nano- and sub-micron-scaled air bubbles in polymers lead to a locally and gradually targeted decrease of the refractive index of this nanocomposite compared to the basic polymer. The target was to develop materials with high transparency, meaning isolated bubbles with sizes of less than 50 nm. The materials are based on selected acrylic monomers; the free radical polymerization was started by Azo-initiators, the resulting N_2 worked as a blowing agent forming the gas-bubbles. These materials can find applications for light out-coupling or as security marks. The research was part of a doctoral thesis finished in 2020 in cooperation with the *InnovationCenter INM*.

Refractive index matching coatings

Plastics are ideal material candidates for lightweight constructions, but lacking the mechanical strength of for example steel, so they need to be reinforced by fibers such as glass. Composites of glass and for example special polymers – both transparent materials – lose transparency due to the mismatch of refractive indices of both materials. Thus, this work targeted transparent composites by selecting polymers/monomers, fillers, and a tailored adjustment of the dispersion curve of a matrix to that of glass. The adjustment of the polymer's dispersion curve by combining selected monomers with inorganic nanoparticles resulted in an adjustment of the refractive index on 4 digits over a wide wavelength range. The low-temperature process enabled the stacking of 10 layers of glass mesh per mm height while still resulting in a transmission higher than 90 % with a haze below 0.9 %. In the automotive industry, this material permits the design of transparent A-, B- and C-pillars connecting the car body and its roof. This research is a co-operation of INM and an industrial partner.

OUTLOOK

The focus of the research and development tasks of *Optical Materials* lies on novel materials with tailored optical properties. Upcoming research topics include the combination of electrospinning and nanowires or photochemical metallization for large touch circuits for use in whiteboards or the further development of the glass-like coatings technology for improved corrosion and abrasionprotection for injection molding of high-tech polymer composites. Such topics represent the group's patent strategy, which aims to exploit existing patent bases and the expansion to include new patents in industry-relevant and product-oriented research fields. This is accompanied by an improved digital presence of *Optical Materials* and its adapted acquisition strategy to make it visible to the industry, especially in application fields such as display technology, energy conversion, and active optics; thereby not neglecting cooperation with German and international universities and research institutes.

STRUKTURBILDUNG / STRUCTURE FORMATION

PROF. DR. TOBIAS KRAUS

ZUSAMMENFASSUNG

Der Programmbereich *Strukturbildung* erforscht die Bildung, Struktur und Eigenschaften von Hybridmaterialien aus heterogenen Flüssigkeiten. Wir untersuchen, wie sich Metalle, Polymere, Keramiken und Biomoleküle zu Partikeln oder Kolloiden verbinden und auf Längenskalen zwischen Nanometern und Millimetern gezielt strukturieren lassen. Mittels Inkjet- und 3D-Druck können wir so Funktionsmaterialien nahe Raumtemperatur und an Luft verarbeiten. Das Verhalten der heterogenen Vorstufen ist komplex und die Materialeigenschaften sind nichtlineare Kombinationen der Eigenschaften ihrer Komponenten. Deshalb untersuchen wir die Wechselwirkungen der Komponenten bei der Verarbeitung und erforschen, wie komplexe Hybridmaterialien sich während ihrer Lebensdauer (absichtlich oder unbeabsichtigt) verändern und wie sie am Ende ihres Lebens wieder in ihre Komponenten zerlegt werden können. Der Programmbereich stellt neue Hybridmaterialien für Elektronik, Optik und Sensoren her und untersucht weitere Materialien in Kooperation mit Forschungsinstitutionen und Unternehmen.

MISSION

The Program Division *Structure Formation* investigates the formation, structure, and properties of hybrid materials from heterogeneous liquids. We study how metals, polymers, ceramics, and biomolecules join as particles or colloids and how they can be rationally structured at length scales between nanometers and millimeters. This allows us to process functional materials via inkjet and 3D printing close to room temperature and in air. The behaviour of the heterogeneous precursors is complex and the resulting material properties are non-linear combinations of properties of their initial components. We study interactions between the components during processing. We investigate how complex hybrid materials change (intentionally or inadvertently) during their lifetimes, and how they can be disassembled into the initial components. The Program Division synthesizes new hybrid materials for electronics, optics, and sensors and studies further materials in cooperation with scientists and companies.

CURRENT RESEARCH

Reversible inkjet printing

Inkjet printing of functional materials, for example for the fabrication of electrical circuits, has been a research topic of the group for several years. Sustainability is an increasingly important aspect of this work. A key result of 2020 indicated that the “hybrid ink concept”, we developed in the Program Division in order to create sinter-free inks, could lead to a future circular use of electronic materials.

A project in collaboration with the “Papiertechnische Stiftung” is focused on the printing of RFID antennae directly on cardboard. Our consortium succeeded in finding a combination of cardboard, specifically developed coating, and hybrid ink that provides acceptable conductivity (*Kang et al., Small, 2020*). But the team went one step further: Hybrid particles do not require sintering and could potentially be moved to repair damages or removed from the cardboard for recycling. In 2020, we demonstrated the feasibility of such steps: cracks in the conductive traces were repaired by adding liquid. Intense agitation in water removed a large part of the hybrid ink and re-dispersed them like in the original ink (Fig.). This "reversibility" suggests that we can recover and reuse our conductive inks in a circular manner.

Organic shells on nanoparticles: unexpected turns

Nanoparticles with inorganic cores and organic shells are common material components; they are increasingly used in inks for digital printing, too. It is important to understand whether such inks are stable. One important question pertains to the length of the organic molecules on top of the inorganic core: the longer, the better, one may think.

Research from 2020 shows that while "long" molecules dominate the stability of particles (*Monego et al., Langmuir, 2020*), it depends on the solvent whether the particles stay finely distributed. Sometimes, particles in a solvent that is very similar to their own shell are less stable than others. Explaining this deviation from the classical "like prefers like" rule required Molecular Dynamics simulations in a cooperation with Asaph Widmer Cooper and his group in Sydney, Australia.

Observing particle assembly live in the electron microscope

Innovations in INM's Program Division *Innovative Electron Microscopy* have made it possible to image nanoparticles directly in liquid. We teamed up with this group in order to observe how non-polar particles arrange in organic solvents.

First results, published in *Cepeda-Perez et al., Science Advances, 2020*, include detailed images of particle arrangements at the wall holding the liquid. Current research is aimed at understanding the formation mechanism of the unexpectedly complex arrangements we observed.

OUTLOOK

Functional inkjet printing is rapidly growing, but conventional "analog" screen printing is still much more commonly used for the production of electrical leads in products. Screen printing pastes contain microparticles and have fluid properties that strongly differ from nanoparticle-based inkjet inks. Projects started in 2020 are aimed at understanding the dynamics of microparticle pastes, the formation of materials through the interaction of their components, and the origin of the electrical properties of screen-printed electronics.

Hybrid combinations of different materials are in the focus of other starting projects, too. The EU-funded project "iSeed" aims at artificial "seeds" that can optically transmit environmental data. Sensing and conversion into light signals will be performed by a hybrid "sensor material". An entirely different application of such combinations of inorganic particles and "soft" matrices will be explored in the Leibniz Science Campus *Living Therapeutic Materials*: metal nanoparticles in hydrogels will enable the material to change its temperature and stimulate encapsulated bacteria to produce drugs.

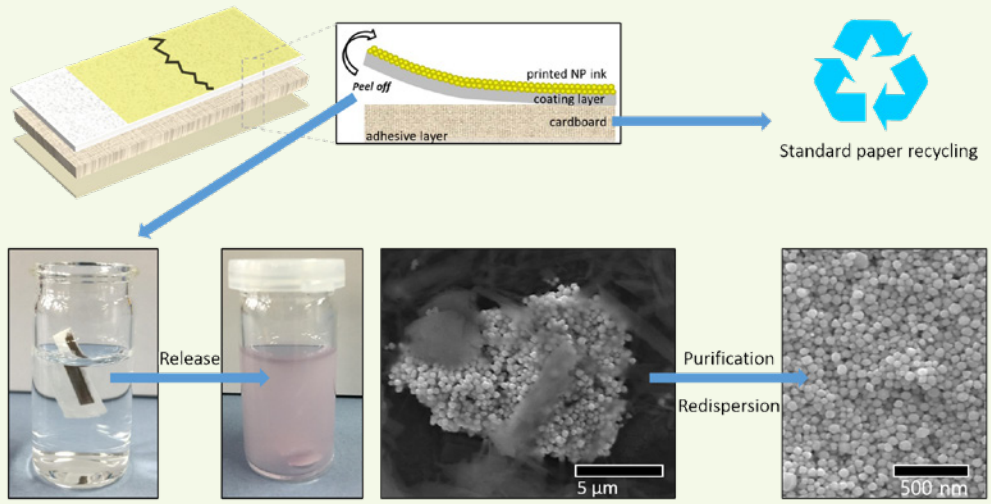


Fig.: Reversible conductive printing: an inkjet-printed, damaged circuit (left) is recycled by splitting it and re-dispersing the conductive hybrid particles in water via ultrasonication.

INNOVATIONSZENTRUM INM / INNOVATIONCENTER INM

DR. KARSTEN MOH, DR. PETER W. DE OLIVEIRA

INM InnovationCenter

ZUSAMMENFASSUNG

Das *InnovationsZentrum INM* ist die Schnittstelle zwischen den Wissensplattformen des INM und der Industrie. Seine wichtigste Aufgabe ist die frühzeitige Wahrnehmung und Verwertung disruptiver Erkenntnisse aus der Grundlagenforschung. Auf administrativer Seite unterstützt es die Programmbereiche des INM durch die Anbahnung und Koordination von Kooperationsvorhaben. Auf operativer Seite werden insbesondere Industrieprojekte durchgeführt und unterstützt; aufgrund der besonderen Lage im Jahr 2020 eine große Herausforderung. Zusammen mit den Servicebereichen des INM werden darüber hinaus Dienstleistungen im Bereich der chemischen und physikalischen Analytik sowie Langzeittests angeboten. Eine Validierung und Optimierung der Produktionsprozesse, die die Materialentwicklung begleitet, ermöglicht eine umfassende und effiziente Umsetzung neuer Ideen vor dem Hintergrund starken Wettbewerbs und zunehmend verkürzter Produktzyklen bei High-Tech-Produkten. Der Fokus im Berichtszeitraum lag auf dem Transfer ökologisch und ökonomisch nachhaltiger Technologien des INM in die Anwendung.

MISSION

The *InnovationCenter INM* is the interface between the knowledge-platforms of INM and the industry. Its most important task is the early recognition and exploitation of disruptive findings from basic research. On the administrative side, it supports the program divisions of INM in the initiation and coordination of cooperation projects. On the operational side, industrial projects are executed and supported. Regarding the special situation during 2020, this turned out to be challenging. Together with the service groups of INM, services in the field of chemical and physical analysis as well as long-term tests are offered. Validation and optimization of production processes accompanying the development of materials enables a comprehensive and efficient implementation of new ideas against the background of strong competition and increasingly shorter product cycles for high-tech products. The focus within the reporting period was on the transfer of ecologically and economically sustainable technologies of the INM into applications.

Dr. Peter W. de Oliveira

Dr. Karsten Moh

CURRENT RESEARCH & DEVELOPMENT

Energy Materials

In 2020, the *InnovationCenter INM* focused on establishing an energy research laboratory together with the Program Division *Energy Materials*. The idea is to bring disruptive results regarding battery materials, battery recycling, (selective) water deionization and hydrogen technology to an application relevant level. A first project named "Merlin" on lithium extraction from mining

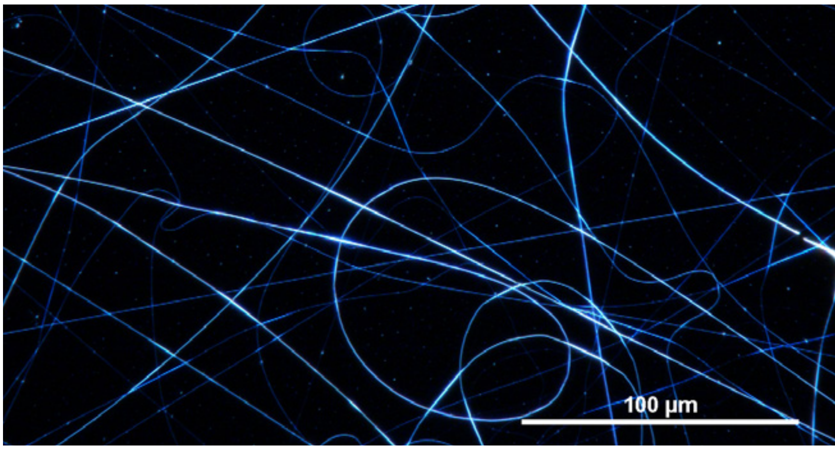


Fig. 1: Preparation of electrodes with eco-friendly polymer binder for electrochemical energy storage.
Fig. 2: High aspect ratio silver fibers (350 nm of diameter x 50 mm long) for Touch Sensor technology.

water started in October 2020 in cooperation with and headed by the Program Division *Energy Materials*. An industry funded feasibility study analyzed the economic impact of electrochemical lithium recovery from end-of-life lithium-ion-batteries. Further project proposals (public and industry funded) are in the pipeline with an envisaged start in 2021.

Materials for the digital environment

A second focus of the *InnovationCenter INM* was to prepare for the future INM initiative "materials for the digital environment". The aim is to provide the infrastructure for application oriented activities regarding printable electronics, soft electronics, and intelligent handling. This includes a laboratory for the scale-up of nanoparticle syntheses and ink formulations, as well as electrospinning. A project (ERC Proof of Concept, PI: Prof. Arzt) in collaboration with the Program Divisions *Functional Microstructures* and *Optical Materials*, validates the market for intelligent gripping systems including microoptical elements for vision and sensing.

Electrospinning (Large Touch-Sensors)

The market demands for touch sensors with 100" increases rapidly. For example, the digitalization of schools and universities based on "Blended learning" process requires such display size. The commercial production of large touch sensors in a reasonable cost-frame depends on the implemented technology for the transparent and conductive coating. The candidates for this emerging field are metal mesh and nanowire technologies. Both technologies until now suffer from the high costs for upscaling. To fulfill all the market requirements, INM has developed a process based on electrospinning to produce metal fibers of submicron size with a very high aspect ratio of up to 10^4. This allows to produce a large touch sensor with a high light transmission combined with low sheet resistance and low haze.

Besides executing industry and public funded projects, the *InnovationCenter* offers a wide range of INM's analytical services for our industry customers. The available facilities allow companies to improve the quality and competitiveness of their products.

OUTLOOK

Over the last years, joint research at INM together with the supporting activities of the *InnovationCenter INM* has brought remarkable progress towards commercial use in emerging areas like printed electronics, optical applications, and new handling systems. Our commitment for the future is to early identify promising research results within INM's program divisions and to enable the transfer into application by making use of our innovation-network. Besides the aforementioned areas and the newly established energy research, we will start to expand our activities into the second large INM initiative on "biomedical materials", especially for health applications.

SERVICEBEREICHE / SERVICE GROUPS

CHEMISCHE ANALYTIK / CHEMICAL ANALYTICS

DR. CLAUDIA FINK-STRAUBE

Die Servicegruppe *Chemische Analytik* nutzt moderne element-analytische, chromatographische und massenspektrometrische Verfahren zur Materialcharakterisierung. Diese werden als Servicedienstleistungen für das INM, die Universität sowie Externe angeboten. Die Elementanalytik führt routinemäßig die quantitative Bestimmung nahezu aller stabilen Elemente mit ICP-OES, FL- und GF-AAS durch. Elementverteilungen im Ultraspurenbereich können mit HR-SF ICP-MS analysiert werden. Zur Identifizierung organischer Moleküle durch akkurate Massebestimmung, Größenbestimmung und Strukturaufklärung kommen GC-MS, GPC, LC-ESI-MS und LC-ESI HR-Q-TOF zum Einsatz. Im Rahmen von Praktika erhalten Schüler, Azubis und Studierende einen Einblick in die Methodik chemisch-analytischer Verfahren am INM.

PHYSIKALISCHE ANALYTIK / PHYSICAL ANALYTICS

DR. MARCUS KOCH

Hauptaufgabe der Servicegruppe *Physikalische Analytik* sind elektronenmikroskopische Untersuchungen von Proben aus dem INM, dem universitären Umfeld und von Firmen im Rahmen von Servicedienstleistungen. Hierbei gilt es, die notwendigen Präparationsschritte gezielt anzuwenden, um Einblicke in die Form, den Aufbau und die Zusammensetzung der Probe gewinnen zu können. Abbildungen mit bis zu sub-Nanometer-Auflösungen können mit einem „Umgebungs-Rasterelektronenmikroskop" (ESEM), einem Zweistrahlgerät (FIB) und einem Transmissionselektronenmikroskop (TEM) gewonnen werden. Personen, die ihre Proben selbständig untersuchen möchten, werden in die entsprechenden Geräte eingewiesen. Im Rahmen von Online-Vorlesungen und Praktika bekommen Studierende einen Einblick in die Elektronenmikroskopie am INM.

WERKSTATT / WORKSHOP

DIPL.-ING. KARL-PETER SCHMITT

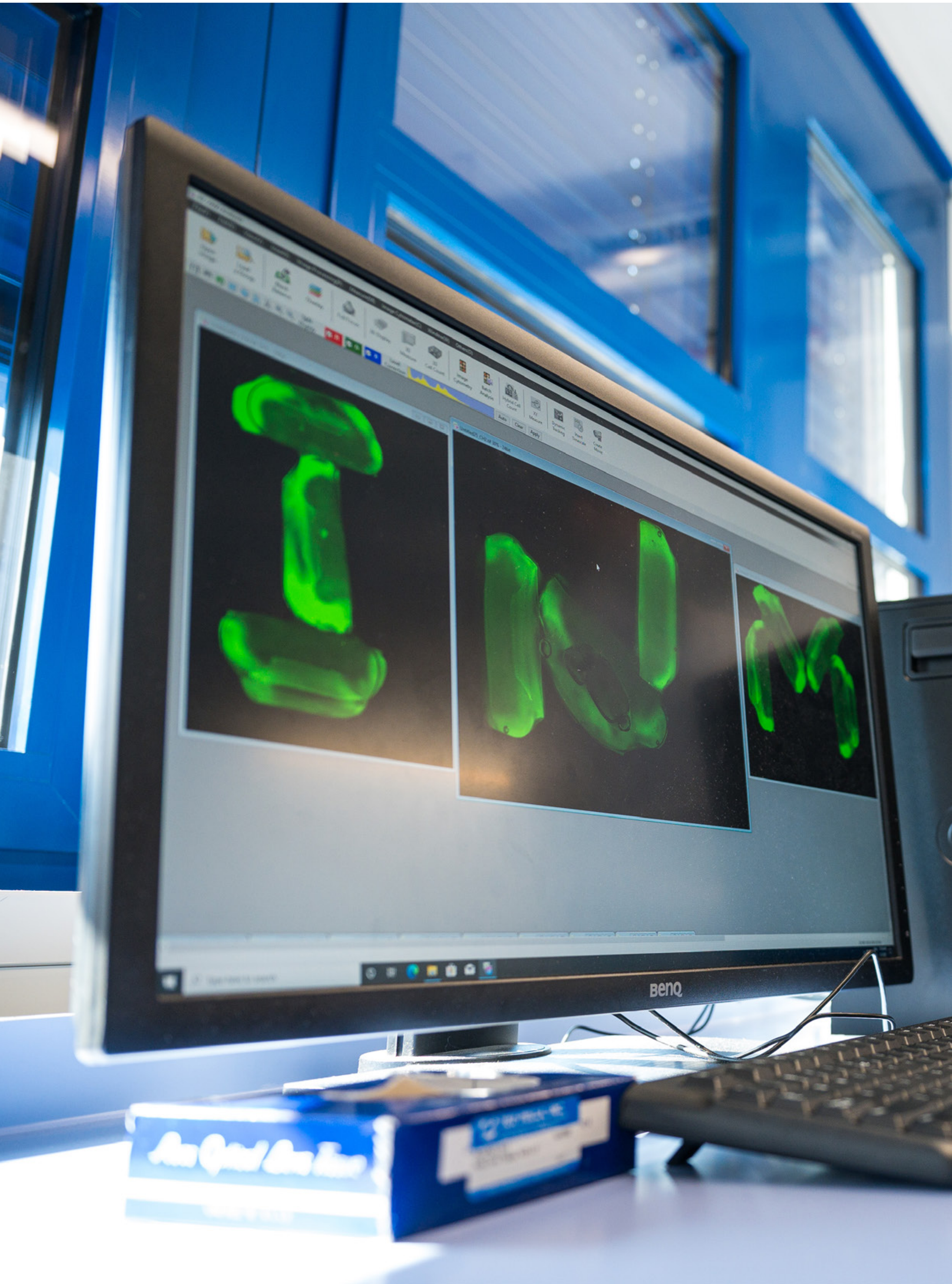
Der Servicebereich *Werkstatt* unterstützt die am INM durchgeführten Forschungs- und Entwicklungsprojekte in der Entwicklung und Herstellung nichtkommerzieller Anlagen und Komponenten. Neben der Planung und Konstruktion werden Geräte und Maschinen zudem gewartet, repariert oder nach Nutzervorgaben modifiziert. Neben klassischen Fertigungsarten ist die Fertigung von Werkstücken auch durch automatisierte Fertigungsprozesse möglich. Wir bieten jedes Jahr Ausbildungsstellen als Industriemechaniker*in und Elektroniker*in für Betriebstechnik an und führen Praktika für Schüler*innen durch. Im Rahmen von Umbauarbeiten am INM hat die Werkstatt 2020 aktiv am Rückbau der bestehenden Infrastruktur mitgewirkt.

NTNM-BIBLIOTHEK / NTNM LIBRARY

DIPL.-BIBL. MA ELKE BUBEL

NTNM CAMPUS-BIBLIOTHEK

Die NTNM-Bibliothek ist die gemeinsame Bibliothek für Naturwissenschaft und Technik des INM und der Fakultät NT der Universität des Saarlandes. Für Wissenschaftler*innen des INM erbringt die NTNM-Bibliothek unterstützende Serviceleistungen beim Publikationsprozess. So wurde 2020 das Angebot an Publish & Read Vereinbarungen mit wissenschaftlichen Verlagen weiter ausgebaut. Korrespondenzautor*innen des INM haben unter diesen Vereinbarungen die Möglichkeit, Publikationen in subskriptionsbasierten Zeitschriften dieser Verlage ohne weitere Kosten open-access zu veröffentlichen. Der Anteil der Open Access-Publikationen des INM bei Artikeln in referierten Zeitschriften konnte von 34 % (2019) auf 46 % (2020) erhöht werden.


BenQ

TACTILE PERCEPTION OF RANDOMLY ROUGH SURFACES

RIAD SAHLI[A], AUBIN PROT[A], ANLE WANG[B], MARTIN H. MÜSER[B], MICHAL PIOVARČI[C], PIOTR DIDYK[C], ROLAND BENNEWITZ[A]
[A]NANOTRIBOLOGY [B]SAARLAND UNIVERSITY [C]UNIVERSITA DELLA SVIZZERÀ ITALIANA, LUGANO

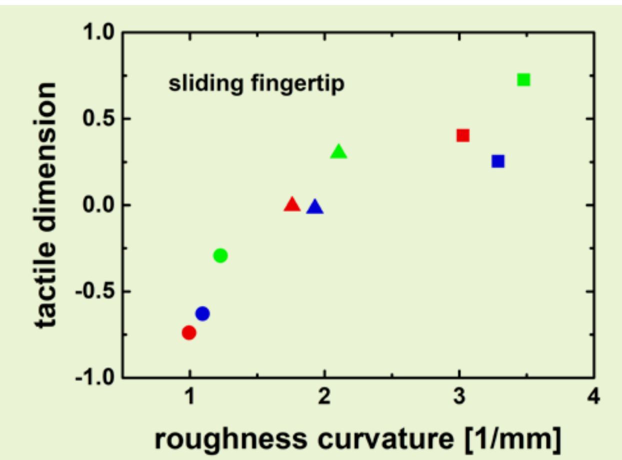


Fig. 1: Shape or roughness, which dominates the tactile perception of similarity?
Fig. 2: The average tactile classification of samples by participants depends strongly on surface roughness.

Is it the shape or the roughness that dominates our perception when we touch an object? For a systematic investigation of this question, the two characteristics need to be varied independently. This approach was realized in cooperation with colleagues from Saarland University by designing randomly rough surfaces using a computer algorithm. Study participants evaluated our samples and gave an unambiguous response: Human touch recognizes roughness statistics over shape.

For the study, a matrix of nine samples with three different topographies and three different roughness statistics was produced by 3D printing. Study participants evaluated the perceived similarity between samples by touch. Friction forces between fingertip and surfaces were recorded while the participants explored the samples. We discovered that the tactile perception of similarity can be predicted based on the difference in friction. Participants noticed differences in the friction coefficient as small as 0.035 for samples with friction coefficients between 0.34 and 0.45.

Most materials are randomly rough at sufficiently small scales. The dominance of roughness in tactile perception is balanced by visual perception, which was found to follow topographic resemblance. We plan to continue our activities in understanding the tactile perception of materials with studies on micro-fibrillar surfaces and on samples with switchable friction for tactile communication.

Our project was carried out together with the *Chair of Computational Materials Science* led by INM Fellow Martin Müser contributing expertise in the design and contact mechanics of randomly rough surfaces and the *Perception, Display, and Fabrication Group* of Piotr Didyk, formerly Department of Informatics at Saarland University, providing conceptual support and statistical analysis.

R. Sahli, A. Prot, A. Wang, M.H. Müser, M. Piovarči, P. Didyk, R. Bennewitz, Scientific Reports (2020) 10:15800

CUPPED MICROSTRUCTURES FOR STRONG AND SWITCHABLE UNDERWATER ADHESION

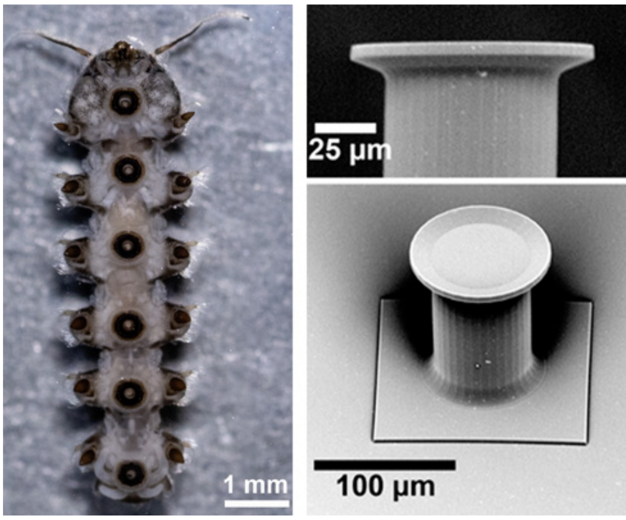
YUE WANG, RENÉ HENSEL, EDUARD ARZT
FUNCTIONAL MICROSTRUCTURES

Underwater and wet adhesion is highly desirable for numerous applications such as pick-and-place robotics or medical treatments. In contrast to dry adhesive contacts, liquids potentially counteract intimate contact formation and weaken intermolecular attraction.

Our group has now introduced a novel microstructure design that can generate reversible adhesion enhanced by the presence of a residual liquid film. Such cupped microstructures resemble common mushroom-shaped fibrils, but exhibit tilted flanges that form a cup. This design is inspired by suction organs of aquatic animals (Fig. 1). The comparably small structural modification has the effect to change the adhesion mechanism from pure van der Waals interactions under dry conditions to suction under wet conditions. As a result, high adhesion strengths of 1 MPa and more were obtained in dry and wet states. This alteration offers great potential, since cupped microstructures combine best of both worlds.

To improve the applicability of the mechanism, the adhesion under wet conditions can be switched between high (~1 MPa) and low (<0.2 MPa) adhesive states by adjusting the retraction velocity. This switchability can be explained by the self-sealing property of cupped microstructures: during pulling, a competition arises between the generation of a pressure difference by sealing of the contact perimeter (enhancing adhesion) and transmission of tensile stresses to the interface (favoring detachment). Faster and stronger pulls lead to an improvement of the seal, further increasing adhesion. The transition velocity depends on the cup design and the fluid used. The switching action was demonstrated in an underwater pick-and-place process as illustrated in Fig. 2. The suction mechanism is not limited to fully submerged conditions but works also for objects partially wetted by water or oil.

Y. Wang, V. Kang, E. Arzt, W. Federle, R. Hensel, ACS Appl. Mater. Interfaces (2019), 11 (29), 26483
Y. Wang, V. Kang, W. Federle, E. Arzt, R. Hensel, Adv. Mater. Interfaces (2020), 7 (23), 2001269



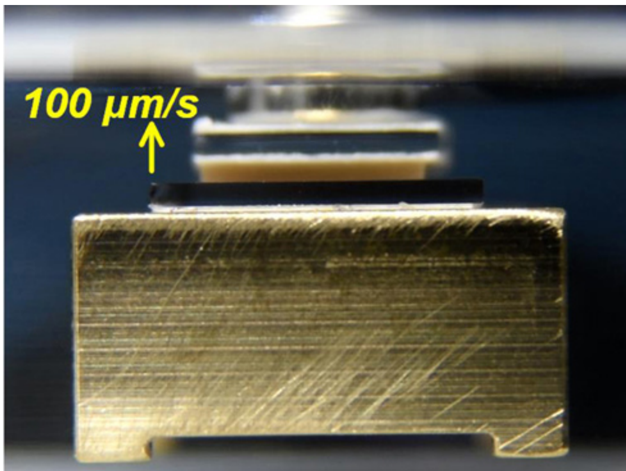
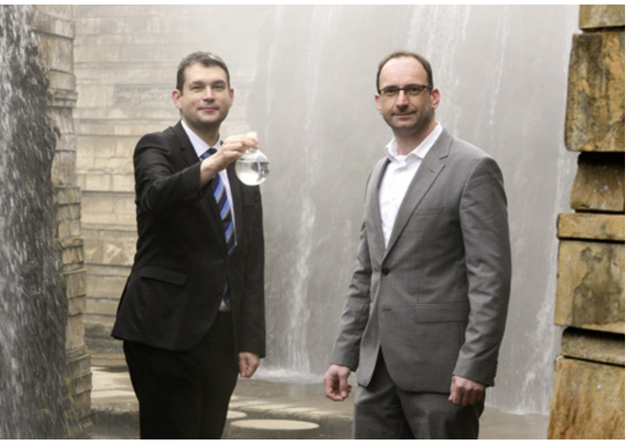


Fig. 1: Cupped microstructures (right) inspired by net-winged midge larvae (left, courtesy of W. Federle).
Fig. 2: Demonstration of underwater pick-and-place handling.

MERLIN: MINE WATER LITHIUM RECOVERY

SARAH SALEEM, KARSTEN MOH, VOLKER PRESSER
ENERGY MATERIALS, INNOVATIONCENTER INM



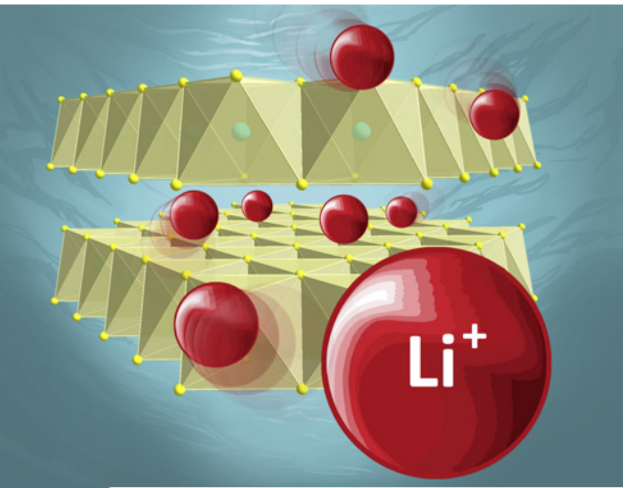


Fig. 1: Prof. Volker Presser and Dr. Karsten Moh explore electrochemical ways to efficient lithium extraction from regional mine water.
Fig. 2: Crystalline electrode materials, known from Lithium-ion batteries, can serve as Li-selective materials for the MERLIN process.

Lithium is a critical enabling element for advancing our fleet of internal combustion cars to electric drive. Most available lithium at present originates from conventional hard-rock mining (like in Australia or China) or solar-evaporation related to brine pools (like in Chile, Bolivia or Argentina). The global energy storage market greatly expands, thus increasing the demand for lithium. With growing environmental awareness and social responsibility, it is crucial to explore more regional and more sustainable ways of extracting and utilizing lithium. Invisible to the eye, there is a large source for lithium that has remained fully unutilized so far, namely, water coming from former coal mines. Effluent mine water in the Saar region carries hundreds of tons of dissolved lithium ions each year.

The RAG-Stiftung supports a joint exploratory study of the Program Division *Energy Materials* and the *InnovationCenter INM* to use energy-efficient electrochemical methods for lithium extraction. The core technology of this approach is the use of lithium-selective electrodes. Upon charging, these electrodes selectively immobilize lithium via ion intercalation and release it upon discharge. This process's beneficial features are utilizing existing electrode materials known from state-of-the-art lithium-ion batteries and recovering most of the energy invested while charging during the discharging process. Iterative cycling between charge and discharge steps gradually increases lithium concentration exiting the electrochemical cell and can be used as a precious resource for subsequent processing towards metallic lithium. We foresee the great potential of this technology for other lithium sources, such as hydrothermal brines, salt lakes, or within the context of lithium-ion battery recycling.

DIGIBATMAT: DIGITAL MATERIAL RESEARCH FOR ADVANCED BATTERIES

TOBIAS KRAUS, VOLKER PRESSER

STRUCTURE FORMATION, ENERGY MATERIALS

Batteries are key components of electromobility and mobile communication. Battery development today relies on traditional, largely experimental methods that provide crucial but often incremental advancements. Larger steps away from established technology are hampered by the complexity of the involved materials and the resulting risks. The BMBF-funded project *DigiBatMat* aims at a more holistic and data-driven approach that unifies experimental and simulated data. A comprehensive ontology integrates data from material synthesis, characterization, processing, electrochemical benchmarking, and "postmortem" analysis into a single digital platform. This platform provides convenient linear and non-linear data analysis for both academic and industrial research partners. Our vision is to expand this approach towards developing digital services for predictive battery development and prediction of failure modes.

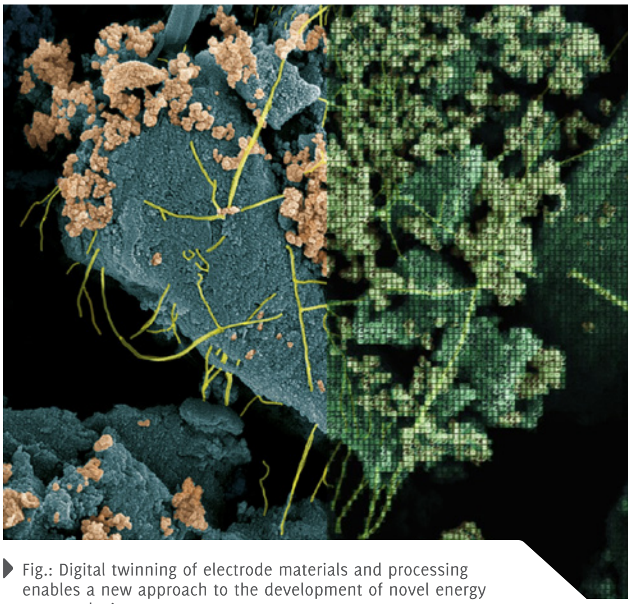


Fig.: Digital twinning of electrode materials and processing enables a new approach to the development of novel energy storage devices.

Our project integrates "knowledge" (abstract models as results of extensive research), "reference data" (from precise and systematic measurements of isolated aspects on highly defined materials), and "real data" (e. g., from production processes). This challenge is aggravated by varying degrees of confidentiality of the data. We will address the question using a combination of formal logic that can represent "knowledge" in ontologies, databases of reference data connected to these ontologies, and analysis tools that connect them to "real data". Machine learning can "mask" confidential data and integrate them into black-box models that others can use without full access.

The project is part of the national ProZell Cluster. It involves several partners, namely the Karlsruhe Institute of Technology, Technical University Braunschweig, AWS Institute for Digital Products and Processes, and Aalen University.

LIGHT-DRIVEN MOLECULAR MACHINES FOR ACTIVE MATERIALS

ARÁNZAZU DEL CAMPO[A], ROLAND BENNEWITZ[B], STEFAN HECHT[C], NICOLAS GIUSEPPONE[D]
[A]DYNAMIC BIOMATERIALS [B]NANOTRIBOLOGY [C]DWI – LEIBNIZ INSTITUTE FOR INTERACTIVE MATERIALS
[D]UNIVERSITY OF STRASBOURG

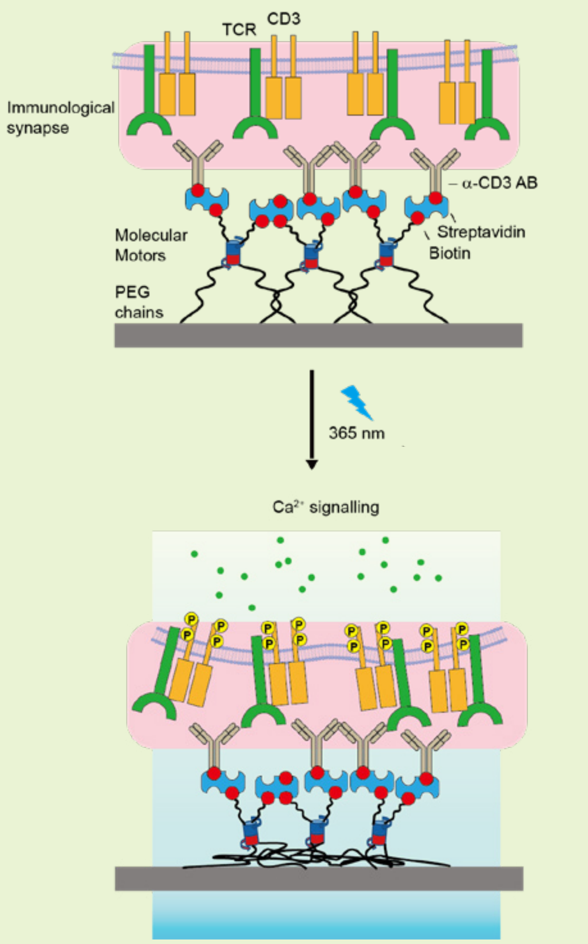


Fig.: T cell activation by means of molecular forces.

Molecular motors are the smallest machines invented by mankind. Driven by light or chemical energy they switch their conformation irreversibly, push or pull on attached linker molecules, and exert mechanical force. In the next three years, INM will collaborate with the DWI – Leibniz Institute for Interactive Materials and the University of Strasbourg in a project to optimize active materials which are equipped with light-driven molecular motors. The context of the project are dynamic biomaterials which can stimulate the mechanosensing of enclosed living cells.

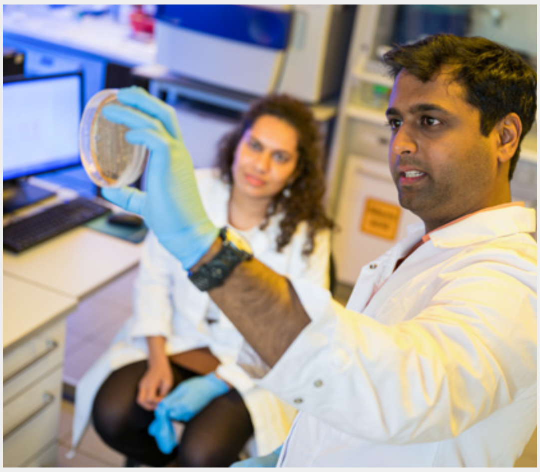
In a first study which demonstrates this novel tool of biophysics, we have applied opto-regulated forces to cellular receptors using the molecular motors. They were embedded in a hydrogel and connected to an adhering cell via polymeric linkers. When activating the rotary motors by light, the linkers twist and pull on the cells' receptors, thus starting a chain of mechano-sensitive biochemical processes in the cell. The force of the motors was quantified by their ability to pull small beads against the flow in a microfluidic cell. Cell experiments were implemented in a large collaboration with the Medical School of Saarland University.

The aim of the new project, which gained financial support from the Leibniz Competition, is an optimization of the molecular motors: revolutions per second, delivered power, and acceptance of green light as fuel which does not harm the living cells. The expected results will not only facilitate biomaterials for cell stimulation in unprecedented temporal and spatial resolution, but also deliver design rules for active light-driven materials for applications beyond cell biology.

Y. Zheng, M.K.L. Han, R. Zhao, J. Blass, J. Zhang, D.W. Zhou, J.-R. Colard-Itté, D. Dattler, A. Çolak, M. Hoth, A.J. García, B. Qu, R. Bennewitz, N. Giuseppone, A. del Campo, Nat Comm (2021), accepted

THREE QUESTIONS TO SHRIKRISHNAN SANKARAN

Shrikrishnan Sankaran is a bioengineer trained in India and the Netherlands who works at the interface of materials science, engineering, and the life sciences. Since January 2020, he has been the appointed head of the Junior Research Group *Bioprogrammable Materials* at INM.



CAN YOU GIVE US AN IDEA OF WHAT BIOPROGRAMMABLE MATERIALS ARE?

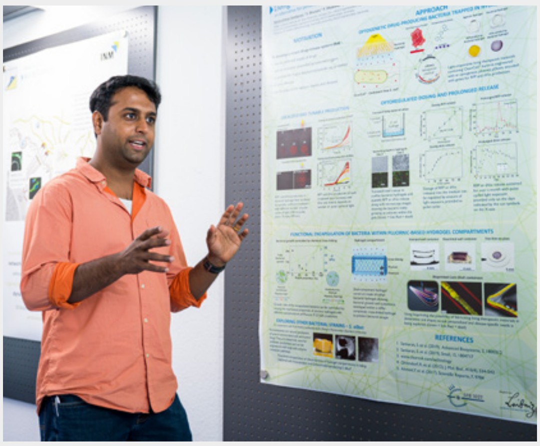
Bioprogrammable materials are materials augmented with biological components that have been programmed to sense input signals, process them, and generate a desired responses as output. For instance, we are making smart therapeutic gels containing programmed bacteria. They are able to sense external inputs like light, heat or disease conditions and respond by releasing drugs at doses corresponding to the intensity and duration of the inputs.

WHAT FASCINATES YOU ABOUT THIS RESEARCH FIELD?

My academic upbringing was in multiple fields – Electronics, Biotechnology, Chemical Engineering – and now I'm working in a materials science institute. My research field also involves this disciplinary diversity that I enjoy. It's a unique combination of materials science and synthetic biology with concepts borrowed from a broad range of allied fields. Creativity plays a big role and it is even entertaining to learn about what others in the community are inventing. In a nutshell, it is a very vibrant and exciting field to be in at the moment.

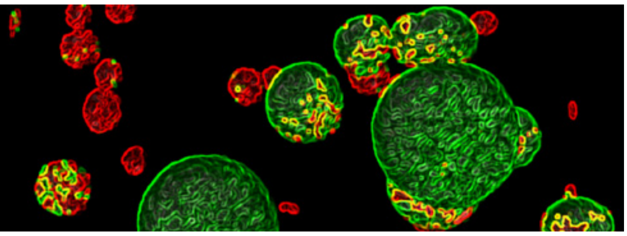
YOUR RESEARCH FIELD IS STILL YOUNG. LET'S TAKE A LOOK INTO THE FUTURE: WHAT DO YOU WISH COULD BECOME REALITY IN TEN YEARS' TIME BASED ON YOUR RESEARCH?

My dream is that our work will contribute to developing a bioeconomy for a sustainable future. In ten years, my vision is that we are able to create smarter, cheaper and greener biomedical devices capable of performing tunable, autonomous, multiplexed and logic functions for long-term sensing and therapeutic applications. Realistically, regulatory issues might slow down the path to clinical applicability, but I expect that the considerable benefits of this technology will be clearly demonstrated by then.



NEW LEIBNIZ SCIENCE CAMPUS: "LIVING THERAPEUTIC MATERIALS" TAKE OFF

MARIO QUILITZ, SHRIKRISHNAN SANKARAN, ARÁNZAZU DEL CAMPO
DYNAMIC BIOMATERIALS, BIOPROGRAMMABLE MATERIALS



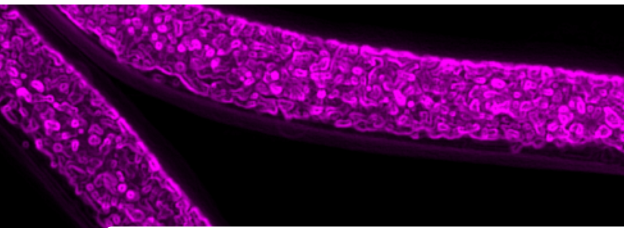


Fig. 1: Hydrogel-encapsulated bacterial colonies whose size and shape are controlled by material mechanical properties.
Fig. 2: 3D printed living therapeutic fiber containing bacteria producing a violet colored antimicrobial drug in response to light.

The Leibniz Science Campus (LSC) "Living Therapeutic Materials" took off on July 1st 2020. The LSC is a collaborative platform for interdisciplinary research between INM, Saarland University and the Helmholtz Institute for Pharmaceutical Research (HIPS) at Saarland Campus. 20 PhD students in the LSC work on disruptive concepts and devices for affordable and personalized delivery of biopharmaceuticals.

Living Therapeutic Materials are porous matrices containing living, generally-regarded-as-safe (GRAS) organisms that sustain their metabolic function. These organisms are natural producers of relevant therapeutic molecules. When inserted in a nurturing medium, like the human body, such encapsulated biofactories can produce and deliver the drug directly at the therapeutic site. This strategy is expected to alleviate costs of drug production and enable long-term and combined therapies with innovative biopharmaceuticals. Researchers in the LSC envision implantable, next-generation devices for drug delivery in various clinical scenarios, and work on their design and translation to the clinic.

This aim requires unique competences and interdisciplinary expertise. In the LSC the biomaterials expertise from INM, the generic engineering knowledge from HIPS and the expertise in medicine, biotechnology and bioinformatics from Saarland University are integrated in cooperative projects.

The Leibniz Science Campus is organized in the form of a graduate school in which more than 20 young scientists work on bi- or multilateral projects across institutions and disciplines. They also take part in a structured program for interdisciplinary training with topical workshops, seminars, and lectures to complement their skills in science and technology transfer.

The LSC is funded by the Leibniz Association after a competitive application process. It is co-funded by the Federal State of Saarland and the partner institutions.

FIRST CONFERENCE ON LIVING MATERIALS: LIVING COMPONENTS IN NOVEL MATERIALS

CHRISTINE HARTMANN, SHRIKRISHNAN SANKARAN, ARÁNZAZU DEL CAMPO
DYNAMIC BIOMATERIALS, BIOPROGRAMMABLE MATERIALS

Living cells are capable of synthesizing a staggering number of complex molecules from simple precursors. Such processes in natural materials allow for continuous, efficient, and autonomous (re)generation and adaptation in response to external factors. These properties are desirable in many medical and technical materials, but they are not yet realizable with non-living matter. A new paradigm in material synthesis is emerging, in which living cells like bacteria or yeast are used as active components in man-made materials to augment non-living matter with life-like capabilities. Living Materials are a new class of materials that incorporate living organisms into synthetic matrices to achieve advanced programmable functionalities.

INM organized the first international Living Materials Conference which took place on February 12 to 13, 2020 in Saarbrucken. Around 100 materials scientists, synthetic biologists, and application engineers from all around the world gathered to discuss the general scientific basis and application perspectives of the field. The sessions dealt with the questions of how to compatibilize living bacteria with non-living matrices, at both material design and processing level, and how to incorporate synthetic biology to enable functionality.

Initial application scenarios of living materials were presented, i. e., self-healing concrete and adhesives, self-renewing bioremediation membranes and catalysis materials, self-powering lighting solutions, or self-replenishable drug delivery depots. A special session on risk assessment and regulatory issues related to living materials, with contributions from regulatory agencies and industry, highlighted relevant considerations for technology transfer in this budding field. This session was organized in cooperation with the Leibniz Research Alliance Health Technologies.

The conference was chaired by Aránzazu del Campo and Shrikrishnan Sankaran and supported by DFG (German Research Foundation). A follow-up event will take place in May 2021.

Fig. 1: Participants of the Living Materials Conference engage in lively discussion during the poster session.
Fig. 2: 3D printed living therapeutic fiber with drug-releasing live bacteria (green) encapsulated in a core-shell hydrogel construct.

GORDON RESEARCH CONFERENCE ON LIQUID PHASE ELECTRON MICROSCOPY

NIELS DE JONGE
INNOVATIVE ELECTRON MICROSCOPY

Fig. 1: View of the Lucca (Barga) valley, Italy, on January 27, 2020.
Fig. 2: Attendees of the conference.

The first Gordon Research Conference on the topic of Liquid Phase Electron Microscopy (LP-EM) took place at the venue Renaissance Tuscany Il Ciocco, Lucca (Barga), Italy, on January 26 to 31 2020. This conference presents a milestone in the development of the LP-EM research field. LP-EM refers to a class of methods for imaging specimens in liquid with nanometer spatial resolution using electron microscopy. The fact that electron optics requires a high vacuum, and thus the sample must be stable in a vacuum environment is a major limitation for conventional electron microscopy: many types of specimens – in particular liquids – relevant to biology, materials science, chemistry, geology, and physics, change their properties when placed in a vacuum. LP-EM now overcomes this key limitation of electron microscopy.

This Gordon Research Conference discussed the latest research results, advances in method, and future directions of LP-EM. It presented an international forum for scientists from multiple disciplines and at different stages in their career. Oral and poster presentations focused on the usage and development of this new *in situ* technology to study fundamental aspects involving the structure and dynamics of organic and inorganic materials, and biological specimens.

Both theoretical and experimental aspects were discussed:
- innovation in liquid cells and holder designs; microscopy and spectroscopy,
- beam-sample interactions and the use of low dose LP-EM,
- nucleation and growth of nanoparticles and crystals,
- electrochemistry,
- imaging in ionic liquids,
- the self-assembly and structure of soft matter,
- studying biological samples, for example, protein function,
- advanced image acquisition, analysis and data interpretation.

The conference was chaired by Niels de Jonge (INM) and Nico Sommerdijk (Radboud University Medical Center, Nijmegen, The Netherlands). Keynote speaker was Armand Alivisatos (University of California, Berkeley, USA).

Website:
https://www.grc.org/liquid-phase-electron-microscopy-conference/2020

NANOSAFETY 2020 – THREE-DAY VIRTUAL CONFERENCE ORGANIZED AT INM

CHRISTIANE PETZOLD, ANNETTE KRAEGELOH
NANO CELL INTERACTIONS, LEIBNIZ RESEARCH ALLIANCE NANOSAFETY

The international conference *Nanosafety 2020* was the 3rd of the *Nanosafety-conference* series and was originally supposed to be held in Zaragoza… until the COVID-19 pandemic hit. So instead, we organized the event in a virtual form together with partners from the Leibniz Research Alliance Nanosafety, the research group Nanostructured Films & Particles at the University of Zaragoza in Spain, and INM.

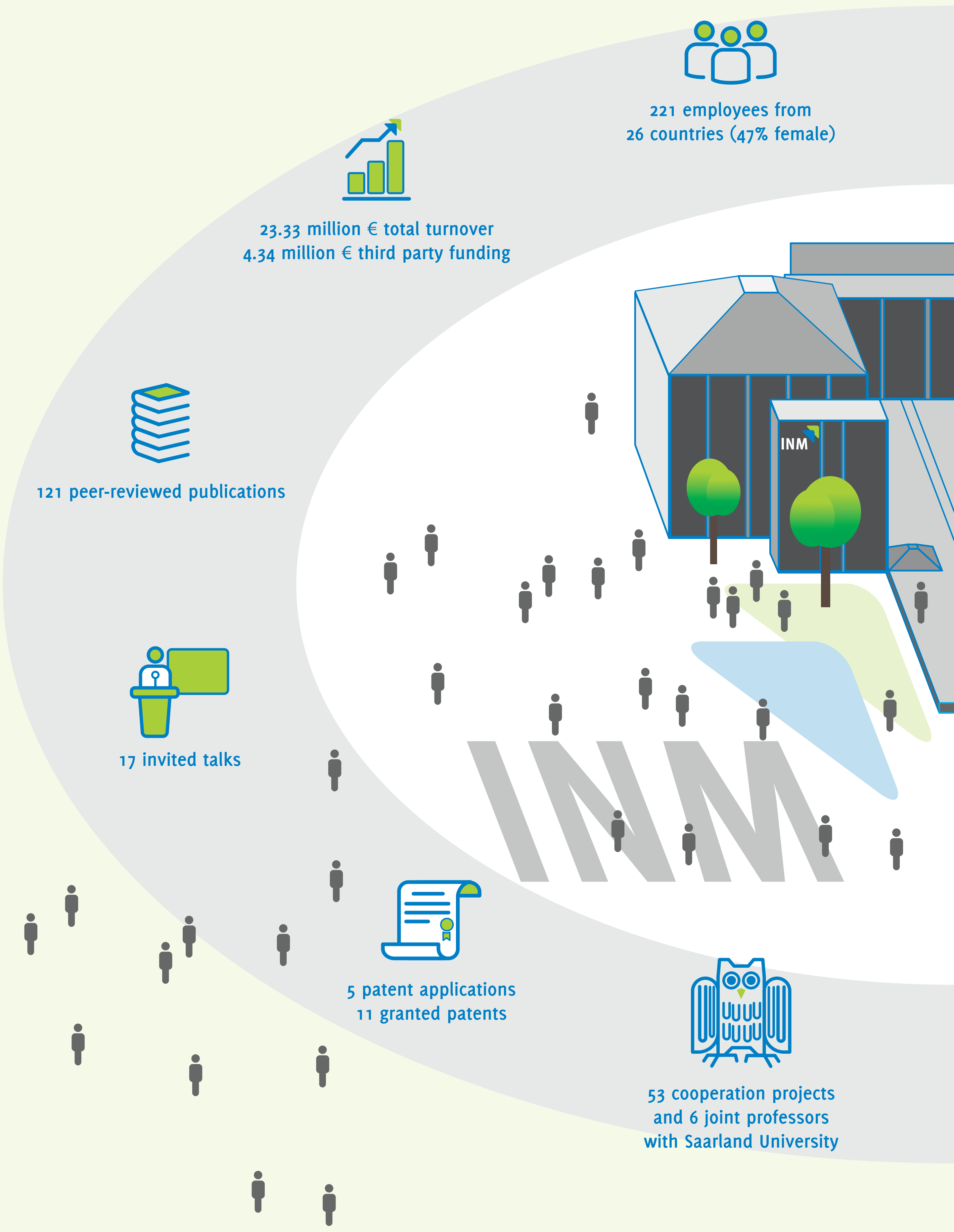
Running from 5th to 7th October, *Nanosafety 2020* had all components of a physical conference: sessions with invited and contributing speakers, discussions, workshops, and a poster session. Speakers and participants joined from 33 countries on 5 continents and included representatives from research institutions and industry.

As the effect of particles on health and the environment is a heavily discussed and up-to-date research topic, microplastics in the environment and the cardiovascular effects of airborne nanoparticles were one of the key aspects of this year's conference. Top ranking experts, among others Christian Laforsch, Anne Kahru and Mark Miller, shared insights of their research.

Another highlight was the workshop on the challenges and needs for the digitisation in nanosafety research to reach a continuous digital workflow. Experts shared their experiences with standard operating procedures and the use of electronic lab notebooks and gave an overview on the current status of databases in the field.

While the nanosafety-community has always been an international one, the virtual format of the conference enabled participants and speakers from all over world to easily join talks and lively discussions with speakers and participants – without restrictions in time, money or entrance visa. Most talks and the poster presentations had been made available online after the event, opening for all attendants the possibility to watch them at a later time.

Fig. 1: During the Nanosafety 2020 online conference, about 160 participants from 33 countries came together.
Fig. 2: Enkeleda Meziu from the *Nano Cell Interactions* group presented her results on barrier properties of mucus lining the airways.


221 employees from
26 countries (47% female)
23.33 million € total turnover
4.34 million € third party funding
121 peer-reviewed publications
17 invited talks
5 patent applications
11 granted patents
53 cooperation projects
and 6 joint professors
with Saarland University
INM
INM

FAKTEN UND ZAHLEN 2020 / FACTS AND FIGURES 2020

97 scientists (40 % female)
thereof: 39 doctoral students (46 % female)

9 doctoral theses
11 master theses
8 bachelor theses

Teaching 48,2 weekly hours per semester

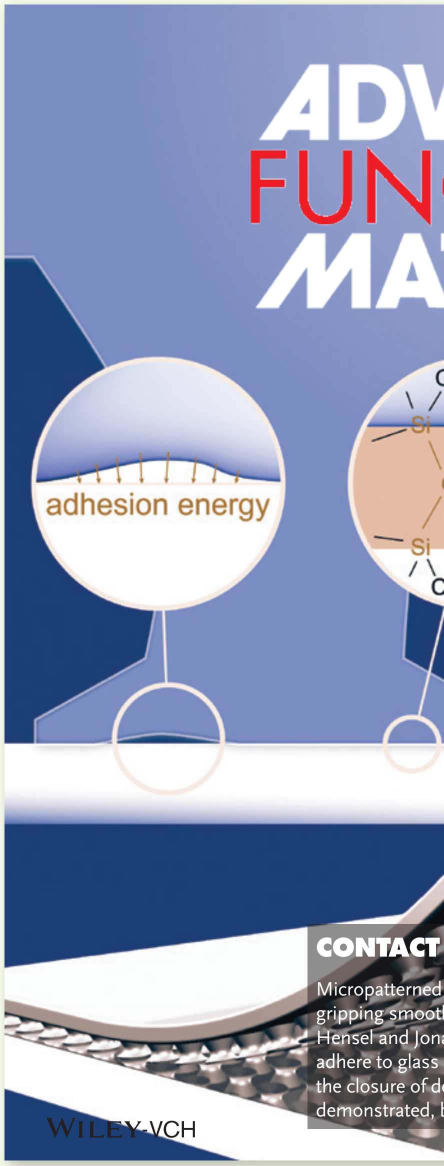
20 symposia, colloquia and other events

Cooperations with 49 institutions in Germany

International cooperations with 58 institutions from 21 countries

AUSGEWÄHLTE PUBLIKATIONEN / SELECTED PUBLICATIONS

Y. Zheng, M. Kim Liong Han, Q. Jiang, B. Li, J. Feng, A. del Campo
4D hydrogel for dynamic cell culture with orthogonal, wavelength-dependent mechanical and biochemical cues
Materials Horizons (2020) 7, 111



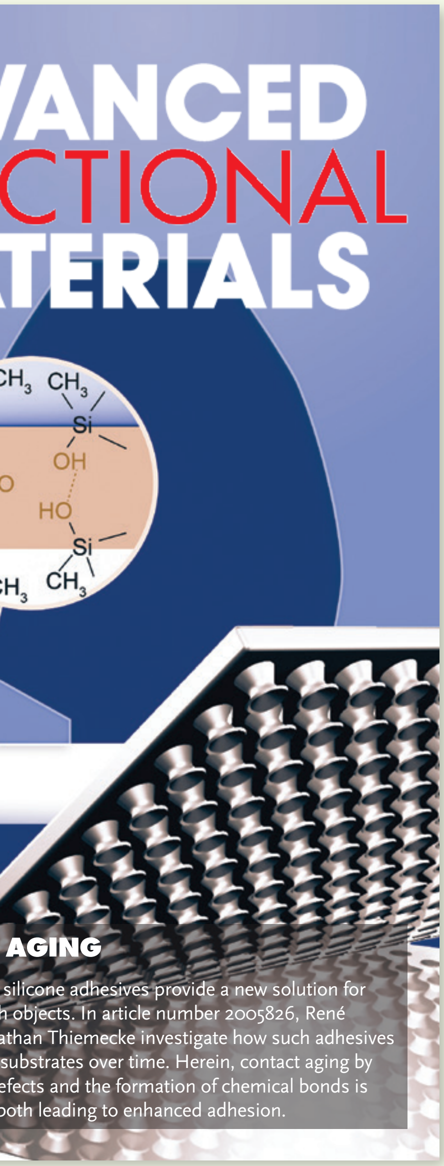
P. Srimuk, X. Su, J. Yoon, D. Aurbach, V. Presser
Charge-transfer materials for electrochemical water desalination, ion separation and the recovery of elements
Nature Reviews Materials (2020) 5, 7, 517

I. K. Backes, L. Gonzalez-Garcia, A. Holtsch, F. Müller, K. Jacobs, T. Kraus
Molecular Origin of Electrical Conductivity in Gold–Polythiophene Hybrid Particle Films
Journal of Physical Chemistry Letters (2020) 11, 24, 10538

E. Cepeda-Perez, D. Doblas, T. Kraus, N. de Jonge
Electron microscopy of nanoparticle superlattice formation at a solid-liquid interface in nonpolar liquids
Science Advances (2020) 6, 1404-1-5

D. J. Kang, Y. Jüttke, L. González-García, A. Escudero, M. Haft, T. Kraus
Reversible Conductive Inkjet Printing of Healable and Recyclable Electrodes on Cardboard and Paper
Small (2020) 16, 2000928

J. Feng, Y. Zheng, S. Bhusari, M. Villiou, S. Pearson, A. del Campo
Printed degradable optical waveguides for guiding light into tissue
Advanced Functional Materials (2020) 30, 45, 2004327



R. Sahli, A. Prot, A. Wang, M. H. Müser, M. Piovarči, P. Didyk, R. Bennewitz
Tactile perception of randomly rough surfaces
Nature Scientific Reports (2020) 10, 15800

Y. Wang, V. Kang, W. Federle, E. Arzt, R. Hensel
Switchable Underwater Adhesion by Deformable Cupped Microstructures
Advanced Materials Interfaces (2020) 2001269

H. Wu, H. Friedrich, J. P. Patterson, N. A. J. M. Sommerdijk, N. de Jonge
Liquid-phase electron microscopy for soft matter science and biology
Advanced Materials (2020) 32, 2001582-1-21

S. Fleischmann, J. B. Mitchell, R. Wang, C. Zhan, D. E. Jiang, V. Presser, V. Augustyn
Pseudocapacitance: From fundamental understanding to high power energy storage materials
Chemical Reviews (2020) 120,14, 6738

DAS INM IN ZAHLEN / INM IN FIGURES

DAS INM IN ZAHLEN

Im Jahr 2020 betrug der **Gesamtumsatz** des INM 23,33 Mio. Euro.

Erlöse aus der gemeinsamen Finanzierung durch den Bund und die Länder (**institutionelle Förderung**): 18,74 Mio. €,
- davon Personal- und Sachaufwendungen: 15,09 Mio. €,
- und für Investitionen: 3,65 Mio. €

Erlöse aus Drittmittelvorhaben: 4,34 Mio. €
- davon 3,14 Mio. € aus öffentlichen Projektförderungen,
- und 1,20 Mio. € aus Vereinbarungen mit Industrieunternehmen.

Sonstige betriebliche Erträge: 0,25 Mio. €

Das INM hatte Ende 2020 **221 Beschäftigte** (117 m, 104 w), davon

- 58 Wissenschaftler/innen (37 m, 21 w),
- 39 Promovierende (21 m, 18 w),
- 50 Beschäftigte (26 m, 24 w) in den Bereichen Labor, Technik und Service,
- 33 Beschäftigte (9 m, 24 w) in der Verwaltung und den Sekretariaten,
- 36 studentische / wissenschaftliche Hilfskräfte (22 m, 14 w) und 5 Auszubildende (2 m, 3 w).

INM IN FIGURES

In 2020, the **total turnover** of INM added up to 23.33 million euro.

Proceeds from the **joint financial support** by the federal government and the federal states (institutional funding): 18.74 million €,
- including expenses for personnel and materials: 15.09 million €,
- and for investments: 3.65 million €.

Proceeds from **third party funding:** 4.34 million €
- including 3.14 million € from public grants,
- and 1.20 million € from industrial contacts.

Other operating income: 0.25 million €

At the end of 2020, **221 employees** (117 m, 104 f) worked at INM including:

- 58 scientists (37 m, 21 f),
- 39 doctoral students (26 m, 24 f),
- 50 employees (26 m, 24 f) in laboratories and technical services,
- 33 employees (9 m, 24 f) in administration and secretarial offices,
- 36 graduate assistants (22 m, 14 f) and 5 apprentices (2 m, 3 f).

m = männlich, w = weiblich / m = male, f = female

KURATORIUM & WISSENSCHAFTLICHER BEIRAT / BOARD OF TRUSTEES & SCIENTIFIC ADVISORY BOARD

Stand / As of: 31.12.2020

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Universität des Saarlandes, Saarbrücken

HABILITATION UND DISSERTATIONEN / HABILITATION AND DOCTORAL THESES

HABILITATION / HABILITATION

Annette Kraegloh
Nanomaterial Zell Wechselwirkungen
Zelluläre Biochemie
Universität des Saarlandes, Saarbrücken

DISSERTATIONEN / DOCTORAL THESES

Vaishali Chopra
Adhesion Modulation in Bio-inspired Micropatterned Adhesives by Electrical Fields
Universität des Saarlandes, Saarbrücken
Prof. Dr. E. Arzt

Jun Feng
Printed Soft Optical Waveguides for Delivering Light into Deep Tissue
Universität des Saarlandes, Saarbrücken
Prof. Dr. A. del Campo

Seongjun Kim
Nanoporous Materials for Optical Applications
Universität des Saarlandes, Saarbrücken
Prof. Dr. E. Arzt, Dr. P. W. de Oliveira

Peter Kunnas
Liquid-Phase Electron Microscopy: Toward Direct Imaging of Self-Assembly Processes in Low-Atomic Number Colloidal Suspensions
Universität des Saarlandes, Saarbrücken
Prof. Dr. N. de Jonge

Hwirim Shim
Nano-Design of Metal Oxide Electrodes for Li- and Na-ion Hybrid Energy Storage
Universität des Saarlandes, Saarbrücken
Prof. Dr. V. Presser

Jana Staudt
Synthese, Charakterisierung und optoelektronische Anwendungen von $Nb:TiO_2$
Universität des Saarlandes, Saarbrücken
Prof. Dr. E. Arzt, Dr. P. W. de Oliveira

Lulu Xue
Guiding Synthetic Dynamic Soft Materials to grow like Living Organisms
Universität des Saarlandes, Saarbrücken
Prof. Dr. A. del Campo, Dr. J. Cui

Jingnan Zhang
Engineered Antigen-Presenting Hydrogels: Model Platforms for Studies of T Cell Mechanotransduction
Universität des Saarlandes, Saarbrücken
Prof. Dr. A. del Campo

Xiaozhuang Zhou
Dynamic Polydimethylsiloxane based Polymer Composites for Functional Materials
Universität des Saarlandes, Saarbrücken
Prof. Dr. A. del Campo, Dr. J. Cui

ABSCHLUSSARBEITEN / THESES

MASTERARBEITEN / MASTER THESES

Lucas Huppert
Monodisperse Goldpartikel für leitfähige Tinten
Universität des Saarlandes, Saarbrücken
Prof. Dr. T. Kraus

Kevin Kaub
Alteration of the Polymerization Dynamics of Cortical Actin in Different Adhesive States
Universität des Saarlandes, Saarbrücken
Prof. Dr. F. Lautenschläger

Michael Klos
Electrically Conductive Hybrids of Gold Nanoparticles and Hydrogels Fabricated by 3D-printing
Universität des Saarlandes, Saarbrücken
Prof. Dr. T. Kraus

Lorena Jimena Llontop Alzamora
Metabolic Engineering of Deoxyviolacein Producing Enzymes in E.coli to Improve Applicability of the Living Therapeutic Materials
Technische Universität Kaiserslautern
Prof. Dr. N. Frankenberg-Dinkel, Dr. S. Sankaran, Prof. Dr. A. del Campo

Niloofar Nekoonam
Development of a New Resin for Two-photon Printing of Adhesive Microstructures
Universität des Saarlandes, Saarbrücken
Prof. Dr. E. Arzt, Dr. R. Hensel

Gabriela Prada
Nanoparticle-based Dielectric Layers by Inkjet Printing
Universität des Saarlandes, Saarbrücken
Prof. Dr. T. Kraus

Lorena Ramirez
Prussian Blue Analogue Derivatives for Electrochemical Energy Storage
Universität des Saarlandes, Saarbrücken
Prof. Dr. V. Presser

Fabian Rundel
Neuartige adhäsive Mikrostrukturen mit kontrolliertem Knickverhalten
Universität des Saarlandes, Saarbrücken
Prof. Dr. E. Arzt, Dr. R. Hensel

Kordula Schellnhuber
AFM-Kraftspektroskopie von einzelnen DNA-Strängen
Universität des Saarlandes, Saarbrücken
Prof. Dr. R. Bennewitz

Dominik Schmidt
Electrical Conductivity of High-volume Fraction Carbon Black Suspensions under Shear Load
Universität des Saarlandes, Saarbrücken
Prof. Dr. T. Kraus

Bixian Ying
Mixed Metal Oxides Derived from Thermal Oxidation of MXene (Ti_xNb_{1-x})$_2$C for Lithium-ion Battery Application
Universität des Saarlandes, Saarbrücken
Prof. Dr. V. Presser

BACHELORARBEITEN / BACHELOR THESES

Christoph Anton
Mikrorheologische AFM- Untersuchungen der Viskoelastizität adhärenter und suspendierter Zellen unter der Veränderung des zellulären Kortex
Universität des Saarlandes, Saarbrücken
Prof. Dr. F. Lautenschläger

Enno Carstensen
Nanotribology of MoS_2 Layers on HOPG
Universität des Saarlandes, Saarbrücken
Prof. Dr. R. Bennewitz

Aylin Feuerstein
Stability Studies of Gold Nanorod Suspensions
Universität des Saarlandes, Saarbrücken
Prof. Dr. T. Kraus

David-John Kondziela
Textile Skin Friction: Simulation in Computer Modelling and Artificial Materials
Universität des Saarlandes, Saarbrücken
Prof. Dr. R. Bennewitz

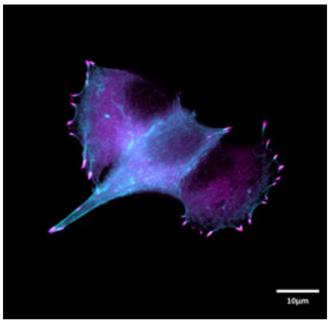
Jamir Priesner
Manipulation of Particles at the Micro and Nano Scale at Nafion® Surfaces
Universität des Saarlandes, Saarbrücken
Prof. Dr. N. de Jonge

Sahra Slet
3D-Druck mittels viskosen Hybrid-Reaktivmaterialien
Universität des Saarlandes, Saarbrücken
Prof. Dr. M. Gallei, Dr. C. Becker-Willinger

Peter Spies
Untersuchungen zur Stabilität von Halbleiter-Nanodrähten
Universität des Saarlandes, Saarbrücken
Prof. Dr. T. Kraus

Marius Weiler
Entwicklung einer transparenten Elektrode zur Messung von Körpersignalen
Universität des Saarlandes, Saarbrücken
Prof. Dr. E. Arzt, Dr. K. Kruttwig

AUSZEICHNUNGEN / AWARDS



Eduard Arzt
International Member of the United States National Academy of Engineering (NAE)
United States National Academy of Engineering

Eduard Arzt
Morris Cohen Award
TMS – The Minerals, Metals & Materials Society, USA

Shardul Bhusari
3rd prize, SFB 1027 Photo Competition 2020
Collaborative Research Center SFB 1027

Shardul Bhusari
Miniproposal Grant 2020
Collaborative Research Center SFB 1027

Indra Navina Dahmke
Sponsorship award for young scientists 2019
DORUCON – Dr. Rupp Consulting

Lola González-García
ERC Starting Grant
European Research Council

Mitchell Han
Young Scientist Award – Best Poster
11th Annual Symposium Physics of Cancer and German Society for Cell Biology (DGZ), 23.09.2020

Gülistan Kocer
Research Fellowship for Postdoctoral Researchers
Alexander von Humboldt Foundation

Franziska Lautenschläger
Offer of a professorship (accepted)
Saarland University, Saarbrücken

Franziska Lautenschläger
One of 175 inspiring people of the DPG
DPG – German Physical Society

Enkeleda Meziu
Poster prize
Nanosafety 2020, 05. – 07.10.2020

Pattarachai Srimuk
Selection for 70th Lindau Nobel Laureate Meeting
Lindau Nobel Laureate Meetings

Pattarachai Srimuk
UMSICHT Science Award
Fraunhofer Institute for Environmental, Safety, and Energy Technology UMSICHT

Pattarachai Srimuk
Leibniz Dissertation Award 2020
Leibniz Association

Divyendu Goud Thalla
1st prize, SFB 1027 Photo Competition 2020
Collaborative Research Center SFB1027

Malgorzata Wlodarcyk-Biegun
Innovational Research Incentives Grant (VENI)
Dutch Research Council (NWO)

Xuan Zhang
Research Fellowship for Postdoctoral Researchers
Alexander von Humboldt Foundation

REFERIERTE PUBLIKATIONEN / PEER-REVIEWED PUBLICATIONS

143 Publikationen
publications
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121 Publikationen in referierten Zeitschriften
publications in peer-reviewed journals

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GRENZFLÄCHENMATERIALIEN / INTERFACE MATERIALS

Energie-Materalien / Energy Materials

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Nano Zell Interaktionen / Nano Cell Interactions

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Schaltbare Mikrofluidik / Switchable Microfluidics

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Zellskeletale Fasern / Cytoskeletal Fibers

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167 Publikationen
Publications
davon / *including*

128 Publikationen in referierten Zeitschriften
publications in peer-reviewed journals

39 sonstige Publikationen
other publications

50 Publikationen im Open Access veröffentlicht
publications published in Open Access
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Schaltbare Mikrofluidik / Switchable Microfluidics

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EINGELADENE VORTRÄGE / INVITED TALKS

203 Vorträge
talks
davon / *including*

17 eingeladene Vorträge
invited talks

186 sonstige Vorträge
other talks

(Stand/As of 15.03.2021)

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GRENZFLÄCHENMATERIALIEN / INTERFACE MATERIALS

Energie-Materialien / Energy Materials

V. Presser
Redox-enabling the electrical double-layer: redox-electrolytes vs. redox-materials
71th Annual Meeting of the International Society of Electrochemistry (ISE)
Belgrade <SRB>; August 30 – September 4, 2020

V. Presser
Electrochemical desalination
1st German-French Summer Workshop on High Power Devices
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Funktionelle Mikrostrukturen / Functional Microstructures

E. Arzt
New materials: from bioinspiration to innovation robotics
Les Entretiens Franco-Allemands de Nancy
Nancy <FRA>; February 13, 2020

Innovative Elektronenmikroskopie / Innovative Electron Microscopy

N. de Jonge
Liquid phase electron microscopy, fundamentals, application to study membrane proteins in whole cells, and future outlook
Webinar at DENSolutions, Netherlands
virtuell; October 20, 2020

Nanotribologie / Nanotribology

R. Bennewitz
Molecular mechanisms in the control of friction
K-TRIB 2020 – 2nd Korea-Tribology International Symposium
virtuell; November 29 – December 2, 2020

R. Bennewitz
Molecular mechanisms of lubrication
International Symposium on “Friction beyond scale, materials and interfaces”
Symposium, Annual Meeting of the Japan Society of Vacuum and Surface Science, Tokyo <JAP>
virtuell; November 19, 2020

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Force microscopy experiments on molecular mechanisms in lubrication
CECAM Workshop on Molecular Mechanisms of Tribo-chemistry and Lubrication
Lausanne <CHE>; January 27 – 29, 2020

BIOGRENZFLÄCHEN / BIO INTERFACES

Bioprogrammierbare Materialien / Bioprogrammable Materials

S. Sankaran
Shielded living therapeutics: hydrogel confined bacteria for smar drug delivery
Living Materials 2020
Saarbruecken <GER>;
February 12 – 14, 2020

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Living therapeutic materials -hydrogel-confined bacteria for smart drug deliver
BMT2020 – 54th DGBMT Annual Conference on Biomedical Engineering
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Dynamische Biomaterialien / Dynamic Biomaterials

A. del Campo
New platforms for living therapeutics: Engineered biofilms as self-regulated and self-replenishable drug delivery devices
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NANOKOMPOSIT-TECHNOLOGIE / NANOCOMPOSITE TECHNOLOGY

Optische Materialien / Optical Materials

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Strukturbildung / Structure Formation

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5 Patentanmeldungen
patent applications

11 erteilte Patente
granted patents

6 europäische
european

5 internationale
international

51 Patentfamilien
patent families

ERTEILTE EUROPÄISCHE PATENTE / PATENTS GRANTED IN EUROPE

Europäisches Patent Nr. 2460035 INM-329
Titel: *„Verfahren zur Herstellung von Beschichtungen mit Antireflexionseigenschaften“*
Erfinder: Michael Veith, Peter William de Oliveira, Mohammad Jilavi, Sakthivel Shanmugasundaram

Europäisches Patent Nr. 3030345 INM-358
Titel: *„Oberflächenmodifizierte Metallkolloide und ihre Herstellung“*
Erfinder: Budiman Ali, Carsten Becker-Willinger, Mirko Bukowski, Marlon Jochum

Europäisches Patent Nr. 2835402 INM-359
Titel: *„Formation of Surface Modified Metal Colloids“*
Erfinder: Carsten Becker-Willinger, Budiman Ali, Mirko Bukowski, Marlon Jochum, Alan Taylor, Géraldine Durand

Europäisches Patent Nr. 3117448 INM-360
Titel: *„Vorrichtung für die korrelative Raster-Transmissionselektronenmikroskopie (STEM) und Lichtmikroskopie “*
Erfinder: Niels de Jonge

Europäisches Patent Nr. 3350267 INM-378
Titel: *„Leitfähige Nanokomposite“*
Erfinder: Beate Reiser, Tobias Kraus, Lola González-García, Johannes Maurer, Ioannis Kanelidis

Europäisches Patent Nr. 3490625 INM-386
Titel: *„Vorrichtung mit einer strukturierten Beschichtung zur Verwendung als Implantat zur Behandlung von Trommelfellperforationen und zur Zellkultivierung“*
Erfinder: Eduard Arzt, Sarah Fischer, Klaus Kruttwig, René Hensel, Bernhard Schick, Gentiana Wenzel

ERTEILTE INTERNATIONALE PATENTE / PATENTS GRANTED INTERNATIONALLY

KR Patent Nr. 10-1958511 INM-335/KR
Titel: *„Verfahren zur Herstellung von metallischen Strukturen“*
Erfinder: Karsten Moh, Peter William de Oliveira, Sarah Schumacher, Eduard Arzt

US Patent Nr. 10,822,697 INM-340/US
Titel: *„Method for Producing Metal Structures“*
Erfinder: Peter William de Oliveira, Karsten Moh, Eduard Arzt

US Patent Nr. 10,774,223 INM-374/US
Titel: *„Method for Producing Anisotropic Zinc Phosphate Particles“*
Erfinder: Sener Albayrak, Casten Becker-Willinger, Dirk Bentz, Emilie Marie Perre

CN Patent Nr. 107532045 INM-376/CN
Titel: *„Komposit-Pillarstrukturen“*
Erfinder: René Hensel, Sarah Fischer, Eduard Arzt

AU Patent Nr. 2016321811 INM-378/AU
Titel: *„Conductive Nanocomposites“*
Erfinder: Beate Reiser, Tobias Kraus, Lola González-García, Johannes Maurer, Ioannis Kanelidis

LEHRVERANSTALTUNGEN / TEACHING

WINTERSEMESTER / WINTER SEMESTER 2019/2020

Eduard Arzt und Mitarbeiter*innen
NanoBioMaterialien 1
Universität des Saarlandes, Vorlesung und Übung, 2 SWS

Eduard Arzt und Aránzazu del Campo
INM-Kolloquium
Universität des Saarlandes, Kolloquium, 2 SWS

Eduard Arzt und Mitarbeiter*innen
Einführung in die Materialwissenschaft für (Studierende der) Mikrotechnologie und Nanostrukturen
Universität des Saarlandes, Vorlesung und Übung, 4 SWS

Carsten Becker-Willinger
MC07: Technologie der Polymere und Komposite
Universität des Saarlandes, Vorlesung, 2 SWS

Carsten Becker-Willinger
Non Destructive Testing: Polymer Materials Part 1
DIU – Dresden International University, Blockvorlesung, 1 SWS

Roland Bennewitz
Experimentalphysik IV a (Festkörperphysik I)
Universität des Saarlandes, Vorlesung, Übung, 3 SWS

Roland Bennewitz (mit J. Kluempers, Bonn)
Good Scientific Practice and Communication
Universität des Saarlandes, 1 SWS

Aránzazu del Campo und Mitarbeiter*innen
Biomedizinische Polymere
Universität des Saarlandes, Vorlesung, 2 SWS

Marcus Koch (mit F. Breinig, Univ. des Saarlandes)
Zellbiologie
Universität des Saarlandes, Vorlesung, 4 SWS

Tobias Kraus
Kolloquium der Gesellschaft Deutscher Chemiker (GDCh)
Universität des Saarlandes, Kolloquium, 1 SWS

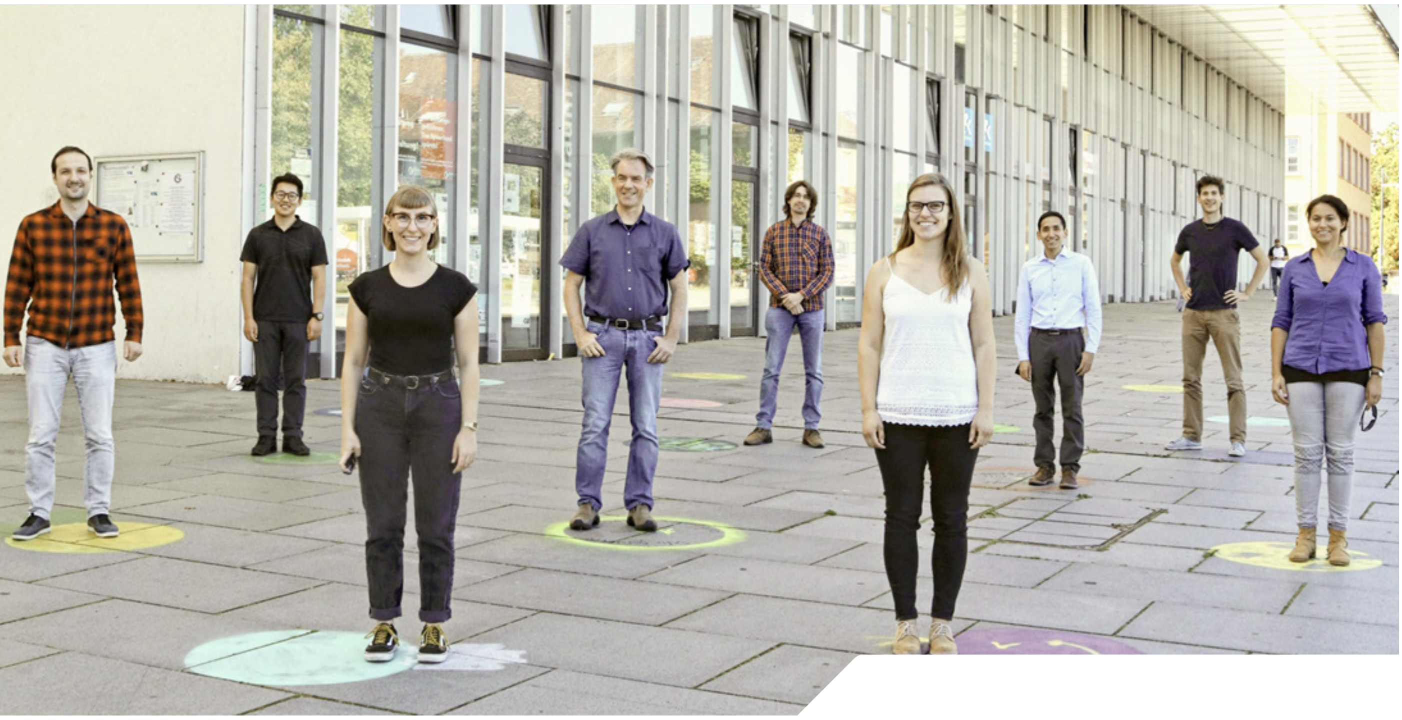
Tobias Kraus (mit G. Jung, C. Kay, H. Natter, M. Springborg, Univ. des Saarlandes)
Masterpraktikum Physikalische Chemie
Universität des Saarlandes, Praktikum, 2 SWS

Tobias Kraus (mit G. Jung, C. Kay, H. Natter, M. Springborg, Univ. des Saarlandes)
Physikalische Chemie V (PCV)
Universität des Saarlandes, Vorlesung, 4 SWS

Tobias Kraus
Functional Coatings (Beschichtungen)
Universität des Saarlandes, Vorlesung, 4 SWS

Franziska Lautenschläger
Einführung in die Biologie I
Universität des Saarlandes, Vorlesung, 2 SWS

Volker Presser (mit R. Hempelmann, R. Chen, D. Scheschkewitz, Univ. des Saarlandes)
Materials for Efficient Energy Use (EnTV)
Universität des Saarlandes, Vorlesung und Praktikum, 6 SWS



SOMMERSEMESTER / SUMMER SEMESTER 2020

Eduard Arzt und Aránzazu del Campo
INM-Kolloquium
Universität des Saarlandes, Kolloquium, 2 SWS

Annette Kraegeloh, Eduard Arzt und Mitarbeiter*innen
NanoBioMaterialien-2
Universität des Saarlandes, Vorlesung, 2 SWS

Annette Kraegeloh, Eduard Arzt und Mitarbeiter*innen
NanoBioMaterialien-P
Universität des Saarlandes, Praktikum, 4 SWS

Aránzazu del Campo, Julieta Paez und Shrikrishnan Sankaran
Biopolymere & Bioinspirierte Polymere (BioPol)
Universität des Saarlandes, Vorlesung, 2 SWS

Tobias Kraus
Praktikum Kolloide und Grenzflächen
Universität des Saarlandes, Praktikum, 3 SWS

Tobias Kraus
Kolloquium der Gesellschaft Deutscher Chemiker (GDCh)
Universität des Saarlandes, Kolloquium, 1 SWS

Tobias Kraus
Vertiefungspraktikum Werkstoffchemie (WCV)
Universität des Saarlandes, Praktikum, 2 SWS

Volker Presser (mit M. Gallei, R. Gianluca, Univ. des Saarlandes)
Smart Materials and Polymers (MC06)
Universität des Saarlandes, Blockvorlesung, 2 SWS

Volker Presser
Grundlagen der Thermodynamik
Universität des Saarlandes, Vorlesung und Übung, 4 SWS

WINTERSEMESTER / WINTER SEMESTER 2020/2021

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Universität des Saarlandes, Vorlesung, 2 SWS

Eduard Arzt und Aránzazu del Campo
INM-Kolloquium
Universität des Saarlandes, Kolloquium, 2 SWS

Eduard Arzt und Mitarbeiter*innen
Einführung in die Materialwissenschaft für (Studierende der) Mikrotechnologie und Nanostrukturen
Universität des Saarlandes, Vorlesung und Übung, (virtuell), 4 SWS

Eduard Arzt, Annette Kraegeloh und Mitarbeiter*innen
NanoBioMaterialien-P
Universität des Saarlandes, Praktikum, 4 SWS

Carsten Becker-Willinger
MC07: Technologie der Polymere und Komposite
Universität des Saarlandes, Vorlesung, 2 SWS

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Experimentalphysik IV a (Festkörperphysik I)
Universität des Saarlandes, Vorlesung und Übung, 3 SWS

Roland Bennewitz (mit I. Weyand, Saarbrücken)
Gute wissenschaftliche Praxis und Kommunikation
Universität des Saarlandes (GradUS), Blockseminar, 1 SWS

Aránzazu del Campo, Shrikrishnan Sankaran und Mitarbeiter*innen
Biomedizinische Polymere
Universität des Saarlandes, Vorlesung, 2 SWS

Marcus Koch (mit F. Breinig, Univ. des Saarlandes)
Zellbiologie
Universität des Saarlandes, Vorlesung, 2 SWS

Tobias Kraus
Kolloquium der Gesellschaft Deutscher Chemiker (GDCh)
Universität des Saarlandes, Kolloquium, 1 SWS

Tobias Kraus (mit G. Jung, C. Kay, M. Springborg, Univ. des Saarlandes)
Advanced Topics in Physical Chemistry (PC 06)
Universität des Saarlandes, Vorlesung, 4 SWS

Tobias Kraus
Functional Coatings (Beschichtungen)
Universität des Saarlandes, Vorlesung und Übung, 4 SWS

Tobias Kraus (mit G. Jung, C. Kay, M. Springborg, Univ. des Saarlandes)
Masterpraktikum Physikalische Chemie
Universität des Saarlandes, Praktikum, 2 SWS

Tobias Kraus
Vertiefungspraktikum Werkstoffchemie (WCV)
Universität des Saarlandes, Praktikum, 2 SWS

Volker Presser (mit R. Hempelmann, D. Scheschkewitz, Univ. des Saarlandes)
Materials for Efficient Energy Use (EnTV)
Universität des Saarlandes, Vorlesung, 2 SWS

VERANSTALTUNGEN / EVENTS

JANUAR – FEBRUAR

Schülerpraktikum
B. Ali, L. Barnefske, D. Beckelmann, A. Colbus, J. Dollmann, R. Drumm, Z. Fu, A. Haettich, H. Heintz, R. Hensel, M. Horst, A. Jung, P. Kalmes, S. Kiefer, A. May, C. Muth, R. Muth, M. Quilitz, H. Rimbach, B. Schäfer, K. Schellnhuber, S. Selzer, S. Siegrist, E. Terriac, T. Trampert, L. Weber, A. Weyand
Saarbrücken,
20.01. – 07.02.2020

Gordon Research Conference on Liquid Phase Electron Microscopy
N. de Jonge, C. Hartmann (mit Gordon Research Conferences)
Lucca (Barga), Italy,
26. – 31.01.2020

JANUAR – FEBRUAR

nano tech 2020
P. W. de Oliveira, M. Amlung
Tokyo, Japan,
29. – 31.01.2020

Post-Doc Day 2020
I. N. Dahmke, E. Ortega, F. Weinberg, M. Han, I. Tavernaro
Saarbrücken, 06.02.2020

Living Materials 2020
A. del Campo, C. Hartmann, S. Sankaran (mit Leibniz-Forschungsverbund Gesundheitstechnologien)
Saarbrücken,
12. – 14.02.2020

APRIL – JUNI

Kick-off-Meeting MUSIGAND
E. Arzt, R. Bennewitz, R. Hensel, C. Müller, M. Samri, X. Zhang, L. Barnefske
virtuell, 28.04.2020

Mini-Symposium „Materials for the Digital Environment“ 1
A. del Campo, E. Arzt, R. Bennewitz, C. Hartmann, T. Kraus
virtuell, 16. – 24.06.2020

NanoS-QM Expert Workshop
A. Kraegeloh, C. Petzold (mit M. Razum, FIZ KA, und Projektpartnern)
virtuell, 17.06.2020

AUGUST

Book a Scientist der Leibniz Gemeinschaft
V. Presser, T. Kraus
virtuell, 18.08.2020

Besuch von Studierenden aus dem Programm AMASE (EUSMAT) der Univ. des Saarlandes
M. Koch, M. Quilitz
virtuell, 27.08.2020

FEBRUAR

Roland Dr. Thünauer, Centre for Structural Systems Biology (CSSB), Hamburg, Germany
The Pseudomonas aeruginosa Lectin LECB Differentially Facilitates Bacterial Infection at the Apical and Basolateral Side of Epithelia
27.02.2020, Host: Prof. Dr. Aranzazu del Campo

JUNI

Prof. Dr. George Malliaras, University of Cambridge, United Kingdom
Electronics on the Brain
16.06.2020

Dr. Ferruccio Pisanello, IIT – Center for Biomolecular Nanotechnologies, Arnesano, Italy
Tapered Optical Fibers Technology for Multifunctional Neural Interfaces
17.06.2020

JUNI

Prof. Dr. Itzhaq Cohen-Karni, Carnegie Mellon University, Pittsburgh PA, USA
Bioelectronics with Nanocarbons – Bridging the Gap between the Digital World and the Soft and Squishy World
18.06.2020

JUNI

Prof. Dr. Christopher Bettinger, Carnegie Mellon University, Pittsburgh PA, USA
Hydrogel-based Electronics: Ultracompliant Electrodes for Neural Interfaces and beyond
23.06.2020

Prof. Dr. Philipp Gutruf, The University of Arizona, Tucson, USA
Highly Miniaturized Soft, Wireless and Battery-Free Bio Interfaces
24.06.2020

VORTRÄGE IM INM-KOLLOQUIUM / INM COLLOQUIUM TALKS

SEPTEMBER

MSE-Digital-Konferenz: P09: Wet Processing of Nanostructured Materials
L. Gonzáles-García, T. Kraus (mit G. Lozano, H. Wolf)
virtuell, 22. – 23.09.2020

MSE-Digital-Konferenz: B04: Cell culture substrates: new surfaces for stem cell proliferation
D. Doblas-Jimenez, T. Kraus (mit C. Grandfils, F. Hautekeer, C. Müller-Renno, E. Olmos)
virtuell, 24.09.2020

MSE-Digital-Konferenz: C01: Advanced Particle Characterization for Material Analysis and Synthesis
L. Gonzáles-García, T. Kraus (mit H. Cölfen, W. Peukert, G. Salazar-Alvarez)
virtuell, 24. – 25.09.2020

SEPTEMBER

PostDoc Talks. EU funding: Programs, proposal Dos and Don'ts & a short introduction to Horizon Europe
E. Ortega, F. Weinberg, J. Fleddermann, M. Han, I. N. Dahmke
virtuell, 24.09.2020

Besuch von Teilnehmerinnen des MentoMINT-Programmes der Univ. des Saarlandes
P. Blach, G. Moreira Lana, M. Quilitz, C. Sauer-Hormann, A. Zimmermann (mit Univ. des Saarlandes)
virtuell, 30.09.2020

Mini-Symposium „Materials for the Digital Environment" 2
A. del Campo, E. Arzt, R. Bennewitz, C. Hartmann, T. Kraus, V. Presser
virtuell, 30.09. – 06.10.2020

OKTOBER

Nanosafety 2020
C. Hartmann, A. Kraegeloh, C. Petzold (mit Leibniz-Forschungsverbund Nanosicherheit, J. Santamaria, Univ. Saragossa)
virtuell, 05. – 07.10.2020

Besuch von Studierenden aus den Programmen Atlantis und I.de.Ar der Universität des Saarlandes
M. Koch, M. Quilitz (mit EUSMAT, Univ. des Saarlandes)
virtuell, 09.10.2020

OKTOBER

Mini-Symposium "Bioprocessed and Bioinspired Materials"
A. del Campo, C. Hartmann
virtuell, 21. – 23.10.2020

Particle-Based Materials Symposium 2020
C. Hartmann, T. Kraus (mit G. Garnweitner, TU Braunschweig, R. Klupp Taylor, FAU Erlangen-Nürnberg, A. Kühne, Ulm University, K. Mandel, FAU Erlangen-Nürnberg, D. Segets, University Duisburg-Essen, N. Vogel, FAU Erlangen-Nürnberg)
virtuell, 22.10.2020

SEPTEMBER

Prof. Dr. Kaspar Althoefer, Queen Mary University of London, United Kingdom
Soft Robots Interacting with the Real World
30.09.2020

OKTOBER

Prof. Dr. Bas Overvelde, AMOLF, Amsterdam, The Netherlands
Rational Design of Reconfigurable and Multistable Metamaterials
01.10.2020

Prof. Dr. Janos Vörös, ETH Zurich, Switzerland
Conductive Elastomers for Stretchable Bioelectronics
01.10.2020

Prof. Dr. Matteo Cianchetti, Sant'Anna School of Advanced Studies, Pisa, Italy
Soft Mechatronics for the Phygital Environment
06.10.2020

OKTOBER

Prof. Dr. André R. Studart, ETH Zurich, Switzerland
3D Printing of Bioinspired Materials
21.10.2020

Prof. Dr. Wilfried Weber, University of Freiburg, Germany
Synthetic Biological Strategies to Design Functional Materials
22.10.2020

Prof. Dr. Amar Mohanty, University of Guelph, Canada
Sustainable Materials Potentials through Circular Economy – Why We Need Them Now in Mitigating Climate Change!
23.10.2020

DAS INM IN DEN MEDIEN / INM IN THE MEDIA


Forschungsallianz für biomedizinisch-pharmazeutische Wirkstoff-Forschung
Wirtschaft A7
Wie sich Lack aus dem Saarland von Kratzern heilt
Self-healing coating
Wie Immunzellen Krankheitserreger jagen
Wie kommen Immunzellen an ihr Ziel?
Wasser effizienter entsalzen
Na+
wird
Saarland erfolgreich auf Automobilmesse DIFA in Südkorea
saaris
DAEGU INTERNATIONAL FUTURE AUTO EXPO 2019
Leben
78,6°C
96,4°C
INM
Kaum beschädigt, schon repariert
erc
Second round winners in 2020 - Proof of Concept call
Gecko inspired grippers for micro assembly
4,3 Millionen Euro Budget
Neuer Leibniz-Wissenschaftscampus startet in Saarbrücken
Meldungen
Hohe Ehrung für Eduard Arzt

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Leibniz Research Alliance for Nanosafety
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As of: 31.12.2020
PD: Program Division
JRG: Junior Research Group

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RAG Stiftung / RAG Foundation (S. / *p.* 40 oben / *top*)
Privat / Private (S. / *p.* 56, Bild / *image* 4)

Titelseite / *Front page*:

oben / *top*: Außenansicht des INM / *Exterior view of INM.*

Mitte links / *Middle left*: In Hydrogel eingekapselte Bakterienkolonien, deren Größe und Form durch die mechanischen Eigenschaften des Materials kontrolliert werden. / *Hydrogel-encapsulated bacterial colonies whose size and shape are controlled by material mechanical properties.* (Juniorforschungsgruppe Bioprogrammierbare Materialien / *Junior Research Group Bioprogrammable Materials*)

Mitte rechts / *Middle right*: Silberfasern mit hohem Aspektverhältnis (350 nm Durchmesser x 50 mm Länge) für die Touch Sensor-Technologie. / *High aspect ratio silver fibers (350 nm of diameter x 50 mm long) for Touch Sensor technology.*
(InnovationsZentrum INM / *InnovationCenter INM*)

SAARLAND
Großes entsteht immer im Kleinen.

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Prof. Dr. Aránzazu del Campo, Günter Weber

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