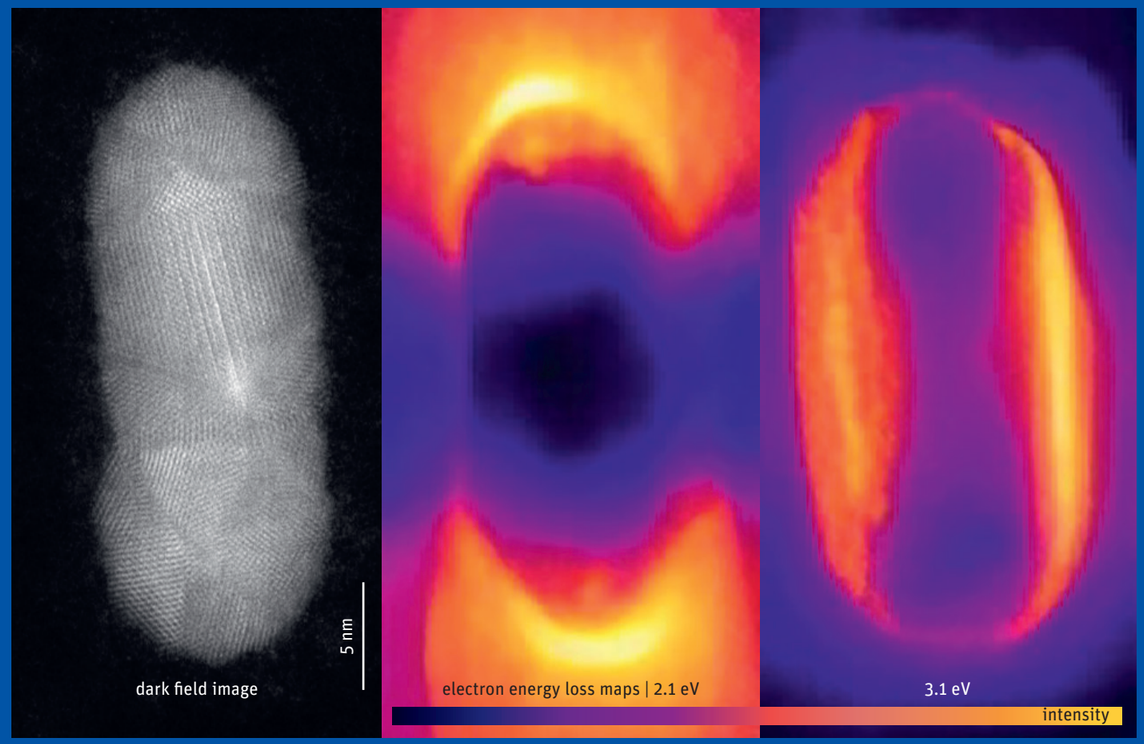
LLM REVIEW 2025

PROGRESS AND PERSPECTIVES FROM THE DEPARTMENT LIFE, LIGHT & MATTER OF THE INTERDISCIPLINARY FACULTY

The Department Life, Light & Matter

The Department of Life, Light & Matter (LLM) of the Interdisciplinary Faculty (INF) at the University of Rostock combines cutting-edge research at the interfaces of physics, chemistry, engineering and biomedicine. The focus is on processes at the atomic and molecular level – from light-matter interaction to functional materials and biohybrid systems. Scientists from five faculties of the University of Rostock and several non-university institutes are working together to understand complex systems and to develop new solutions for future issues in health, the environment and technology.

With its competence centres and modern large-scale facilities, the research building of the LLM department offers an excellent research infrastructure, initiates interdisciplinary cooperative research networks with national and international visibility and promotes young researchers in graduate programs.



LIGHT ON MATTER
MATTER AT THE NANOSCALE
CELLS IN CONTACT

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Universität Rostock Traditio et Innovatio

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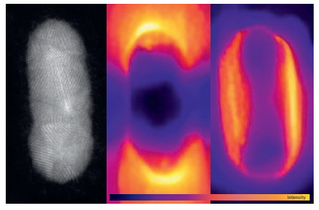
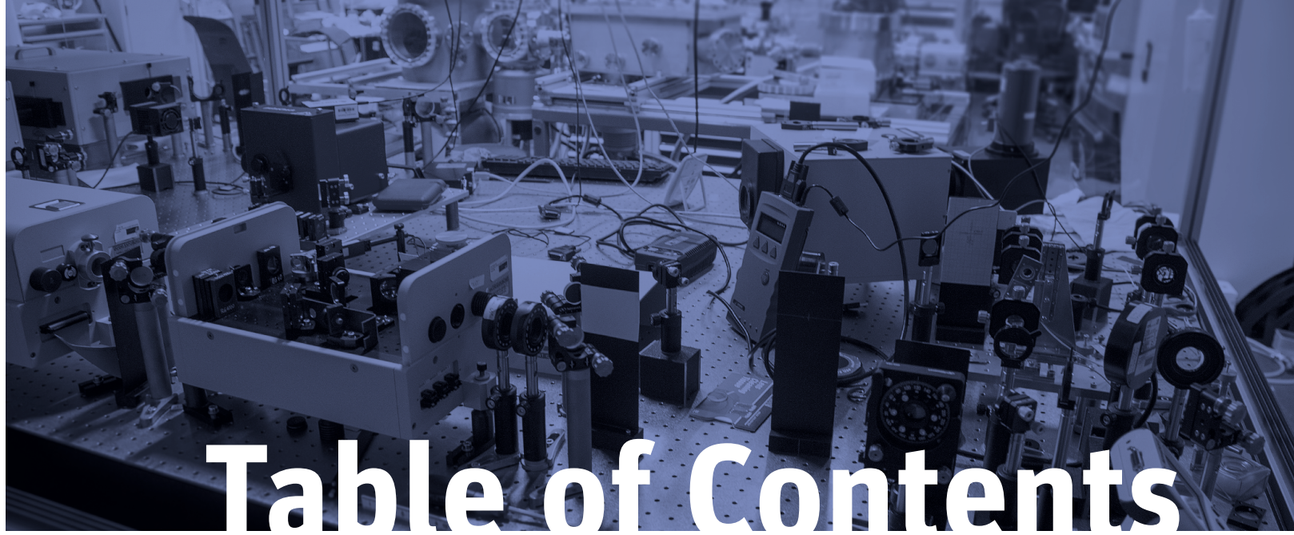


Cover image: The title image shows the investigation of a silver nanoparticle using electron energy loss spectroscopy (EELS). On the left is a dark-field image depicting the particle's shape and size. The color-coded maps in the middle and on the right visualize local energy losses at 2.1 eV and 3.5 eV - frequencies at which collective electron oscillations (plasmons) are excited. These resonances provide important information about the optical and electronic properties of the material. Such insights are particularly valuable for applications in sensing, catalysis, and nanophotonics - fields where light is deliberately made to interact with small structures.

The figure comes from the Meiwes-Broer research group (Institute of Physics) and exemplifies the capabilities of high-resolution electron microscopy within the framework of ELMI-MV.



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The Südstadt Campus brings together key research facilities in physics, chemistry, biology, and engineering, alongside LIKAT and Fraunhofer – forming the core environment for Life, Light & Matter.

Department Life, Light & Matter

Progress driven by research structures: 18 Years of concerted interdisciplinary collaboration

RALF ZIMMERMANN, SUSANNE RADLOFF

For decades, science policy speeches and publications have emphasized the importance of multi- and interdisciplinary research in addressing the pressing challenges of our time. Yet, the everyday experience of interdisciplinary researchers often contrasts with this recognition: funding structures and publication systems still tend to disadvantage interdisciplinary projects.

The University of Rostock recognized this need for change during its strategic realignment 20 years ago. True to its motto "Traditio et Innovatio", it created new structures to foster interdisciplinary research more effectively. As the first German university, Rostock established an Interdisciplinary Faculty (INF), which today unites four scientific departments. The INF aims to overcome boundaries between disciplines, methodological approaches, and between basic research and application.

Since its foundation in 2007, the Department of Life, Light & Matter (LLM) has promoted interdisciplinary collaboration across physics, chemistry, biology, engineering, and medicine. Research at LLM focuses on the microscopic perspective of atomic and molecular structures and processes. The department's current research vision, "Atomic and Molecular Scale Sensing" (Figure 1), illustrates this focus: the precise detection, control, and utilization of physical, chemical, and biological processes at the smallest scales. This vision forms the conceptual backbone of LLM's wide-ranging research – from light–matter interactions to functional nanostructures and interfaces between biological systems and materials.

In 2018, the department defined ambitious goals for its future development: expanding research infrastructure, fostering interdisciplinary cooperation, initiating new collaborative projects, and supporting early-career researchers. With this progress report, we reflect on the developments of recent years and look ahead. Many of these goals have been achieved or even surpassed. The number of acquired projects and consortia has grown significantly. Competence centers in Mass Spectrometry (MassSpec), Calorimetry and Thermal Analysis (°CALOR), Magnetic Resonance (MagRes), Optical Microscopy and Spectroscopy (MicroSpec), and Interfaces and Surfaces (InterSurf) have been further consolidated, complemented by the high-end Electron Microscopy Center (ELMI-MV).

The Department LLM is represented in two Collaborative Research Centres and several Research Training Groups. A strategic partnership has also been established with Kiel University, which has developed similar interdisciplinary structures. This collaboration has led to the joint Networked Matter Initiative, scientifically challenging in the field of materials science. A dedicated contribution in this report provides deeper insights into this initiative. LLM is thus not only well connected internally but also broadly visible within the national and the international research landscape. Alongside scientific excellence, the department emphasizes support for young researchers, the expansion of joint infrastructures, and close networking within and beyond the University of Rostock. Increasingly, cross-departmental research initiatives have emerged, demonstrating the long-term effectiveness of a shared interdisciplinary vision.

Looking ahead, the planned Helmholtz initiative HEDI (High Energy Density Institute) promises an exciting thematic expansion in the department's environment. Initial content-related parallels – for example in functionalized materials or nanoscale analytics – are already visible. Although HEDI will develop as an independent center, we look forward to the impulses and synergies that may emerge from future collaborations and intersections with LLM research.

Throughout the report, Spotlight on Research boxes illustrate how results are applied in cooperation with regional and national partners such as IBMT and SLV. A complete list of members and the Scientific Advisory Board is provided at the end of the report. We invite you to explore the diversity, dynamics, and depth of research at Life, Light & Matter in the following pages – and we hope you enjoy reading this report! ●

Research vision: Atomic and Molecular Scale Sensing

With its vision of Atomic and Molecular Scale Sensing, the Department of Life, Light & Matter aims to visualize, understand, and achieve targeted control of physical, chemical, and biological processes at the atomic and molecular level. Research focuses on three interconnected fields – light–matter interactions, nanoscale materials, and biological–technical interfaces. Methodologically, this work is supported by specialized competence centers for calorimetry (°CALOR), magnetic resonance (MagRes), mass spectrometry (MassSpec), interfacial analysis (Intersurf), and spectroscopy and microscopy (MicroSpec).

An example of the implementation of this vision is the contribution to AI-supported cell imaging (ChiSCAT): Here, high-resolution data from microscopy are used to analyze cell movements with the help of machine learning – an approach that makes molecular processes visible and opens up new perspectives for diagnostics and biomedical research. This broad foundation in physics, chemistry, engineering, and biomedicine enables interdisciplinary solutions and innovations at the interfaces.

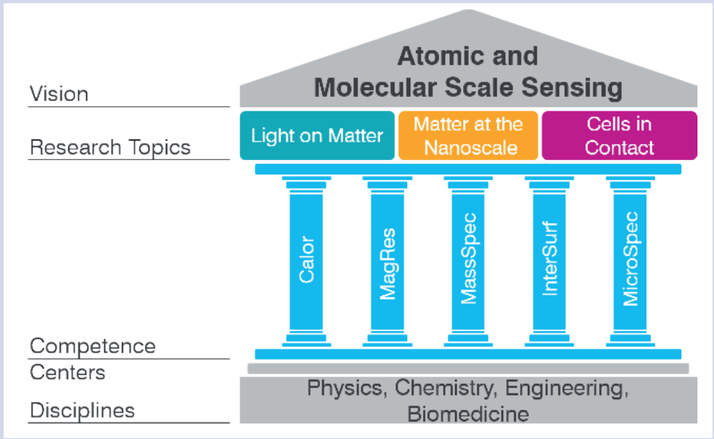

Figure 1: "Atomic and Molecular Scale Sensing" means making processes visible and controllable at the smallest scale, enabling new solutions in materials, medicine, and environmental technology.

The World of Hydrogels

Biocompatible Hydrogels from Carbohydrates – Promising Materials for Biomedical Applications

SINA LAMBRECHT, STEFAN JOPP, UDO KRAGL

Hydrogels, defined as hydrophilic, three-dimensional polymer networks, have been known since the 1960 [1]. They are well established in various disciplines, such as biotechnology (stent-coating), biomedicine (drug-delivery, tissue engineering), agriculture (water storage), and catalysis (immobilization matrix)[2–5]. Hydrogels are also used in daily life, e.g. as contact lens material or as superabsorbers in diapers[6,7]. Depending on their origin, polymer composition, charge, method and degree of crosslinking etc., hydrogels can have versatile properties, such as tuneable mechanical properties (from stiff to flexible), non-toxicity, biocompatibility, antimicrobial properties, and even self-healing capabilities [8–10].

When new biomaterials are produced, it is important to obtain a complete overview of their properties. This is necessary in order to understand the new material and adapt it for different applications.

Investigation of special properties of novel types of hydrogels

During our work at the department LLM we have produced novel semi-synthetic hydrogels. They are based on a sugar building block (glucose), which we have converted into a versatile building block in a short synthesis process. This building block is available as a crystal after production and we have determined its crystal structure. [11] Hydrogels based on naturally occurring polymers such as gelatine or alginate are well researched and are already widely used. In contrast, hydrogels based on natural monomers such as glucose are hardly known. Our work therefore opens up new possibilities as to how such simple building blocks from nature can be used in modern materials.

To characterize our new hydrogels, their gelation and polymerization was tracked via a new method combining a rheological measurement and an in situ Raman measurement at the same time [9]. We investigated the swelling behaviour of the hydrogels [12], as well as their antimicrobial activity and in vitro biocompatibility (see Figure 1) [13].
The biological tests were carried out in collaboration with the Institute of Technical Chemistry at Leibniz University Hannover. All hydrogels showed inhibitory effects against the fungus Candida auris. This is likely due to the positively charged imidazole groups in the hydrogels, which may interact with the negatively charged fungal cell membrane through electrostatic interactions.

To investigate the in vitro biocompatibility, mural adipose cells (L929) were incubated with different concentrations of hydrogel eluates. [13] To obtain the eluate, the hydrogels were

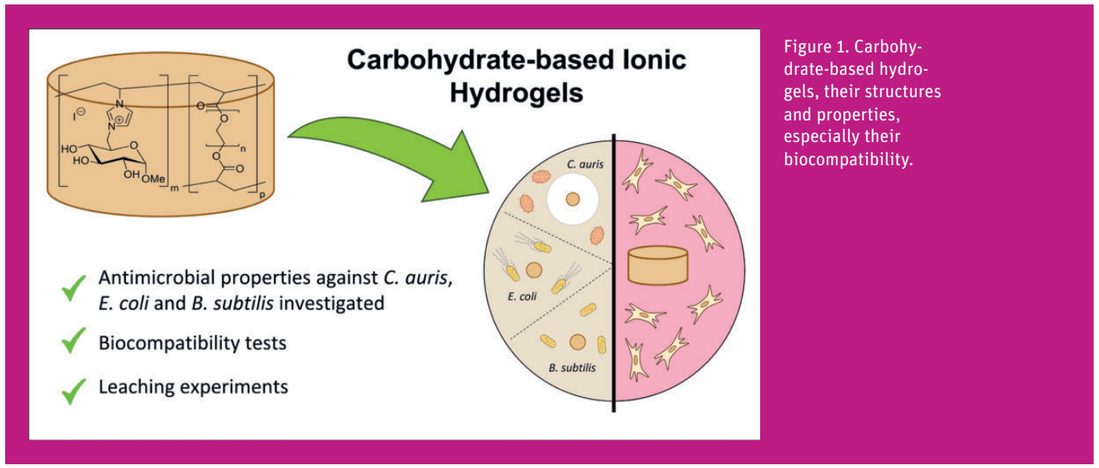

Figure 1. Carbohydrate-based hydrogels, their structures and properties, especially their biocompatibility.

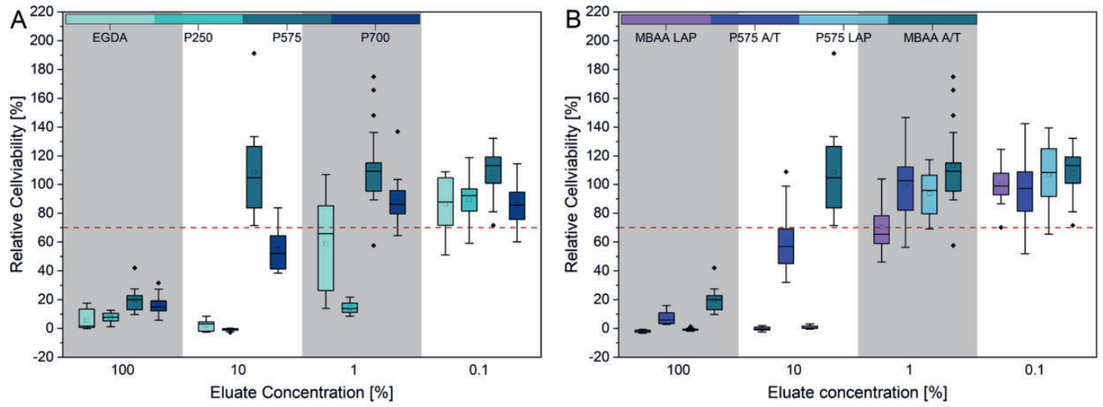

Figure 2. Cell viability after cultivation for 48 h of L929 cells in different concentrated hydrogel eluates: (A) different molar masses of (P) EGDA-crosslinkers and (B) comparison of MBAA and PEGDA 575 hydrogels with LAP and APS/TEMED as initiator system. (EGDA = ethylene glycol diacrylate, PEGDA = polyethylene glycol diacrylate, MBAA = N,N'-methylene bisacrylamide, APS = ammonium persulfate, TEMED = tetramethylethylenediamine)

incubated for 72 hours at 37 °C in the respective culture media The relative cell viability was then determined using CellTiter-Blue® (CTB)cell viability assay (Figure 2).

As shown in Figure 2A, all samples display cytotoxic effects at the highest eluate concentration (100%), which represents a worst-case scenario. A more realistic view is given by the diluted 10% eluate, where PEGDA 575 and PEGDA 700 show notably higher cell viability than EGDA and PEGDA 250. PEGDA 575 even meets the criteria for biocompatibility, with over 70% cell viability. In general, lower eluate concentrations result in less impact on cells.

Figure 2B highlights that the initiator system also affects cell viability. At 100% eluate, hydrogels made with the photo initiator lithium phenyl(2,4,6-trimethylbenzoyl)phosphinate (LAP) show slightly better cell compatibility than those made with APS/TEMED — this difference becomes more significant at 10%. For example, LAP-based MBAA hydrogels reach 60 ± 21% viability, compared to only −0.2 ± 2% for APS/TEMED. A similar trend is observed with PEGDA 575. Overall, the CTB assay suggests LAP is the better initiator for applications involving direct cell contact.

These results are just a small part of our characterization studies that we carried out for the hydrogels. We show that it is possible to create new, safe, and effective materials using basic building blocks from nature. With further development, these sugar-based hydrogels could open up new possibilities in biomedical applications—such as wound care, drug delivery, or even helping damaged tissues heal. ●

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Sustainable Biofilms for a Greener Future

The spin-off Cell2Green GmbH from the University of Rostock has developed an innovative process for producing biodegradable and recyclable biofilms. These materials, derived from renewable raw sources, offer a sustainable alternative to conventional PE plastic films. Their versatility ranges from transport wrapping to food packaging, where mechanical strength, flexibility, and environmental compatibility are key.

In collaboration with the Interdisciplinary Department Life, Light and Matter, Cell2Green is currently establishing a continuous production line that will enable scalable and energy-efficient manufacturing. The process integrates environmental friendly processing, and recycling strategies to ensure full circularity. With this technology, Cell2Green contributes to reducing plastic waste and advancing the transition toward a bio-based materials economy.

Transformation of Mechanical Energy as Internal Energy Source

for Electrically Active Implants

FRANZISKA GEIGER, RAINER BADER, DANIEL KLUESS

Diseases of the musculoskeletal system and the resulting limitations in mobility have a significant impact on patients' quality of life. Therefore, the central goal of the Collaborative Research Center (CRC) 1270 ELAINE (Electrically Active Implants) at the University of Rostock and Rostock University Medical Center is to develop and characterise electrically active implants with patient-specific feedback controlled stimulation and sensory functionality, for the regeneration of cartilage and bone defects as well as deep brain stimulation in case of M. Parkinson and Dystonia.

As part of this effort, one clinical application focus is total hip replacement (THR). In this context, THRs are among the most successful surgical interventions worldwide. In Germany alone, over 200,000 THRs were performed in 2023 and a trend expected to persist due to increasing life expectancy and global demographic growth [1,2]. As a result, the number of required revision surgeries is also projected to rise, with aseptic implant loosening or insufficient osseointegration remaining the most common cause for such follow-up procedures [1,2]. These follow-up procedures place a significant burden on both patients and the healthcare system. To address this, smart implant solutions for THR are expected to help reduce these burdens in the future. Therefore, the subproject B02 within the CRC 1270 ELAINE focuses on equipment of THR with internal energy supply and sensor-based diagnostic and therapeutic functions.

More precisely, the project investigates how functionality and osseointegration status can be monitored in real time by means of dedicated sensors integrated into the THR, enabling early detection of implant loosening [3]. Once loosening is expected, electrodes embedded in the THR may deliver targeted electrical stimulation to the surrounding bone to promote tissue regeneration and restore implant fixation [4]. For these functions, a sufficient energy supply is beneficial, since external energy supply is uncomfortable for daily life. In work of Lange et al. [5], this has been explored through piezoelectric energy harvesting in cemented hip stems. Here, the energy generation relies on the piezoelectric effect. As the patient moves, mechanical deformations in the THR and thus in the embedded piezoelectric element induce electrical charges. So, the piezoelectric element converts mechanical energy into electrical energy. Our current study [6] extends this concept to an uncemented hip stem, in which the integrated electrodes for bone stimulation have direct contact with the adjacent bone stock. The accompanying study focuses on optimising the integration of piezoelectric elements so that energy output is maximized without compromising the mechanical stability of the implant.

In computer-based studies a number of designs were created by incorporating cavities of different sizes into the medial neck region of the hip stem, tailored to the dimensions of differently sized piezoelectric elements. The corresponding piezoelectric element, embedded in a polymethyl methacrylate (PMMA) housing, was inserted into this cavity, restoring the original outer contour of the stem (Fig. 1a). To analyse the different designs the finite element (FE) method was used. The FE method discretizes physical systems into small finite elements (e.g., tetrahedral) connected by nodes. Deformation is calculated from nodal displacements, allowing evaluation of stresses and strains within the material. To analyse the generated electrical power of the different designs, a FE model of the modified hip stem implanted into a femoral bone with physiological boundary conditions, i.e. maximum resultant hip joint contact force during gait, was used (Fig. 1a). The most promising hip stem design featured a piezoelectric element (outer diameter 5 mm, inner diameter 2.5 mm, height 10 mm) positioned at position 2 within the uncemented THR stem. For that design FE simulation predicted an average electrical power output of 439 µW during gait [6]. Accumulated throughout the day the harvested energy would be enough for electrically stimulating the bone stock within the recommended intermittent time of 45 minutes, three times a day. To examine the mechanical implant stability, the modified hip stem was experimentally tested under the boundary conditions according to ISO 7206-4 fatigue test (Fig. 1b). The stem successfully passed the fatigue test without failure.

In conclusion, the uncemented revision hip stem could be modified to integrate a piezoelectric element for energy supply while maintaining mechanical stability. The next step is to experimentally evaluate the electrical voltage and power during physiological activities of daily life. Additionally, further research into the location of the cables and the storage system into the hip implant is planned. ●

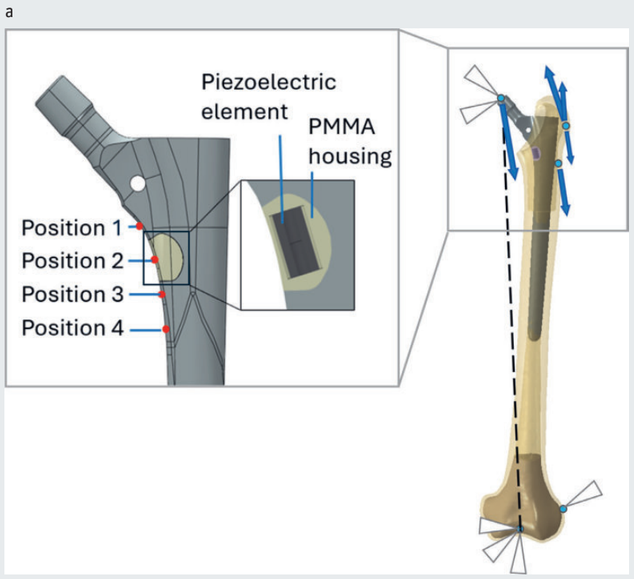

Figure 1: (a) FE model of revision hip stem with integrated piezoelectric element at various positions under boundary conditions at the time of the maximum hip joint resultant during gait; (b) Experimental test setup for fatigue testing of the modified revision hip stem.

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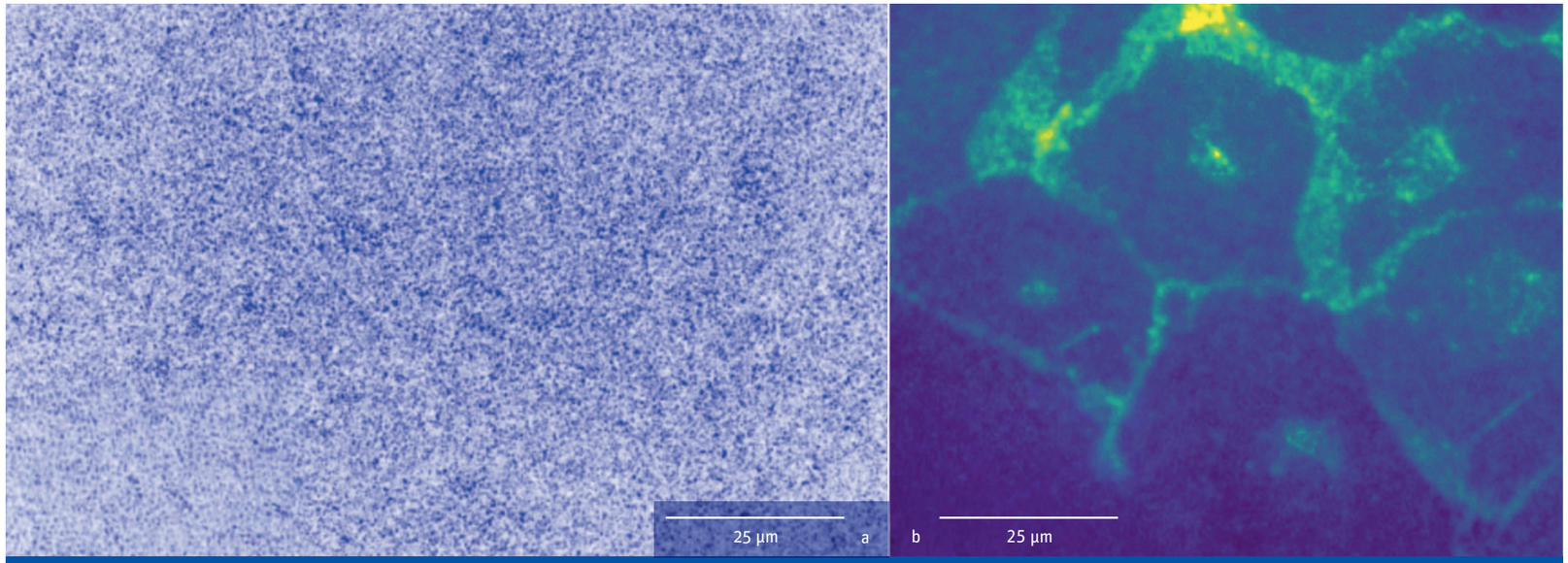


Figure 1: Microscopy images of cells (a) reflective speckle image of a set of iPSC-CM that was used for action potential detection. No structure is visible to the human eye; but the pattern is interferometrically sensitive to small motions in the cells; (b) fluorescence voltage signal of the same area. Cells and their nuclei are demarcated in green.

We can see you fire

detecting action potentials from cellular membrane fluctuations

FRIEDEMANN REINHARD, CHRISTIAN RIMMBACH, ROBERT DAVID

Cardiovascular disease (CVD) is responsible for 38% of all deaths and 46 billion euros of yearly healthcare costs in Germany. The human heart consists of three subtypes of cardiac muscle cells (CM): ventricular, atrial and pacemaker with distinct characteristics. One possible cellular source for the replacement of lost cardiomyocytes e.g. after an infarction is represented by induced pluripotent stem cell (iPSC-) derived cardiomyocytes.

Yet, adult cardiomyocytes differ from iPSC-derived cardiomyocytes in terms of their electrophysiology and other cell signatures. This immature phenotype is characterised by a shortened action potential duration, a less negative resting membrane potential, and spontaneous beating.

To date, the gold standard of measuring action potentials of single cardiomyocytes is patch clamping. However, this is invasive and unsuitable for a three-dimensional organoid. Non-invasive, label-free methods are therefore highly desirable for organoid development. These could be used to determine subtypes and maturation stage of cardiomyocytes, as well as functional properties such as the contraction rates or action potentials.

This raises the question whether we could detect electric action potentials simply by looking at the cell surface? Indeed, numerous anecdotal evidence in the literature suggests this approach. While action potentials are mainly an electrical process, they slightly change the optical properties of cells and their membranes. This can be detected by interferometric microscopy, giving rise to “intrinsic optical signals” accompanying action potentials. The most established mechanism for intrinsic signals is a mechanical vibration of the cell membrane, induced by a change in mechanical stiffness upon electrical depolarisation. A technique to reliably detect these signals, could enable label-free imaging, no longer being limited by photo-bleaching and toxicity of voltage- and calcium-sensitive dyes employed today. It could even be implemented on the level of entire organs, paving the way to wireless brain- or heart-machine interfaces analysing organ activity by detecting scattered light signals.

However, this is a major challenge, due to the extremely small underlying dynamic deformations. The plasma membranes likely move only a few nanometers when firing action potentials. Detection thus requires interferometric optical techniques. Moreover, the most sensitive techniques, based on reflective illumination, do not produce a visually interpretable image but rather an apparently random speckle pattern. The small signal corresponding to the action potential has to be distinguished from signals of similar magnitude (diffusion and transport of cell organelles and proteins).

Recently, we studied a scheme to solve exactly this problem [1]. Rather than computing the exact shape of the speckle pattern corresponding to the action potential, our scheme merely exploits the a priori knowledge that action potentials are a repeating signal. We devised and studied an algorithm that can capture such repeating events. It is based on a first step of matched filtering in the time domain – a technique which is also employed for a very similar task in gravitational wave detection – and a second step of cross-correlation to identify repeating frames, a procedure similar to principal component analysis. We have demonstrated that this scheme can indeed recover action potentials in interferometric microscopic video recordings of Blebbistatin-paralyzed cardiomyocytes. In these cells, mechanical contraction is disabled or at least reduced, while action potentials are still preserved.

This first step opens the door to a large number of follow-up experiments. One exciting option is to extend the technique to neurons, where label-free detection of action potentials is more relevant but also more difficult than in cardiomyocytes, which might still contain traces of mechanical contraction yielding a strong intrinsic signal. Another direction is the development of more advanced algorithms, moving beyond simple correlation to identify repeating frames. Such advanced algorithms could for example be based on independent component analysis rather than principal component analysis. Finally, extending the technique to more advanced microscopy schemes is attractive. Here, interferometric microscopy combined with electrical or ultrasound modulation can directly probe electrical or mechanical properties of cells, so that repeating changes in these properties could be an even more powerful signature than mere motions of membranes. Full refractive index tomography could create a three-dimensional model of the refractive index of a cell and could hence predict the exact pattern corresponding to an action potential. Illumination with quantum light could further enhance the sensitivity of interferometry. Fortunately, all these directions can be explored in future collaborations within LLM. ●

Trelin, A. et al. ChiSCAT: Unsupervised Learning of Recurrent Cellular Micromotion Patterns from a Chaotic Speckle Pattern. Nano Lett. 24, 12374–12381 (2024).

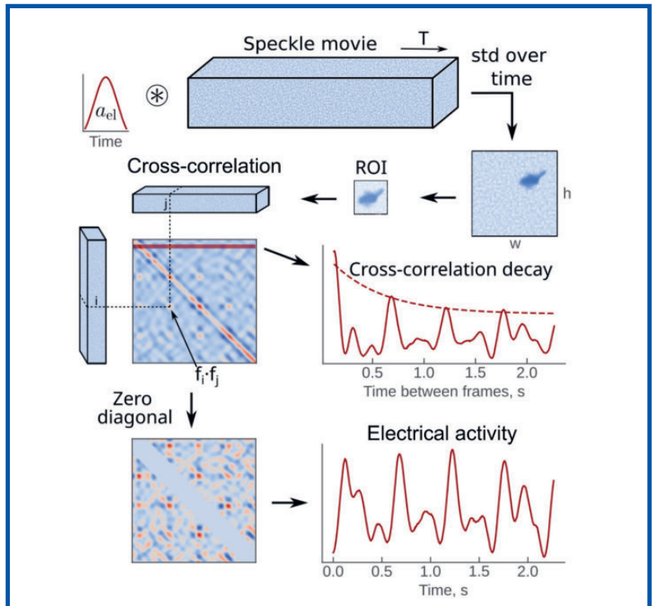
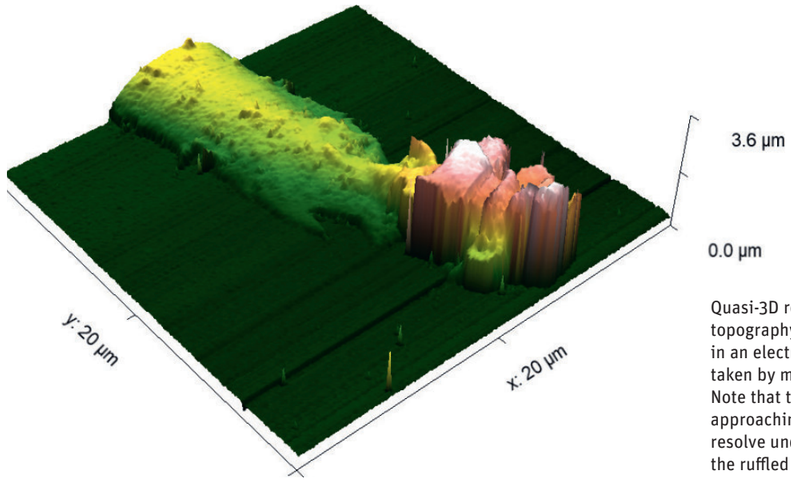


Figure 2 - Algorithm to detect a trace of action potentials (lower right plot, "Electrical activity") in a chaotic speckle pattern (Fig. 1a, "Speckle Movie" input in the upper plot). Temporal matched filtering is employed to highlight changes on the typical timescale of action potentials. Cross-correlation between frames identifies repeating patterns (off-diagonal peaks in the cross-correlation matrix). A diagonalisation akin to principal component analysis recovers the time trace of electrical activity. (ROI-region of interest)



Quasi-3D representation of a topography osteoblast adhered in an electric field landscape, taken by means of a nanopipette. Note that the pipette nanoprobe, approaching from above, cannot resolve undercut regions beneath the ruffled membrane protrusions

Molecular Structures

as electric field landscapes for osteoblast adhesion

INGO BARKE, SYLVIA SPELLER, HENRIKE REBL, SUSANNE STAEHLKE, CHRISTIANE HELM

The interaction between cells and material surfaces is a central aspect of biomedical research. In particular, the way cells sense and respond to physical and chemical surface cues determines whether implants or engineered tissues can successfully integrate into the body. Osteoblasts, the bone-forming cells responsible for growth and regeneration, are crucial for the successful integration of biomedical implants. Their ability to adhere and organise on material surfaces determines long-term implant stability. Within the Department Life, Light & Matter this links to the research foci Matter at the Nanoscale and Cells in Contact, where functionalised materials and cell–material interactions are studied.

Electric currents and potential gradients play critical roles in tissues and cells. They are key in tissue development, wound healing, as dynamic transmembrane potentials in the nervous system, brain and heart, and by converse piezoelectric / electrokinetic effects in bone formation and remodelling.

These endogenous electric fields and currents arise from modulation of transmembrane ion currents via ion channels with hydrated ions as charge carriers. Even though the abundance of ions in physiologic media, the electric double layer does not fully screen the surface potentials. The reason is that metabolically and thermally driven membrane fluctuations partially disrupt the screening layer, retaining a residual potential at the hydrodynamic distance, known as the zeta(ζ) -potential.

Most native surfaces exhibit a negative surface potential due to electron spill-out. E.g., the ζ potential of glass is about -60 mV while that cell of surfaces is around -20 mV. Surface potentials can shift towards more positive values by molecule attachment (amine groups attract protons) or become more negative via carboxylic acid groups donating protons.

Osteoblasts, essential for bone healing, regeneration, and implant integration, respond better to slightly positive surfaces, such as amine-coated glass, by adhering and spreading faster than on negatively charged surfaces [gruening2020]. Also, electric fields promise to enhance osseointegration by accelerating adhesion and proliferation on implant surfaces.

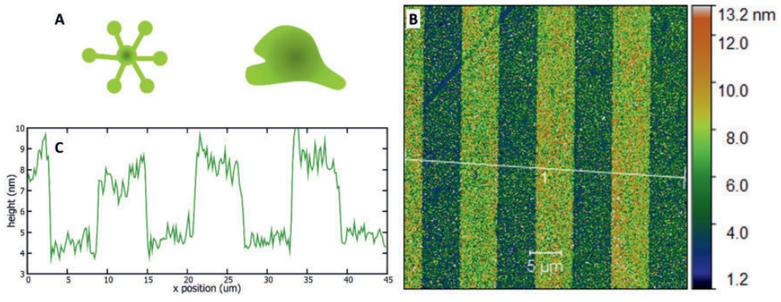


Figure 1: (A) Schematic illustration of molecular species used for micro-contact printing: amine-terminated dendrimer (generation 1, left) and the outer shape (envelope) of albumin (right); (B) AFM determined topography of printed albumin stripes (in air) with an apparent height of ~ 4 nm as shown in the line profile in (C).

Lateral amine-containing structures can generate electric field landscapes on substrates without electrodes. A rough estimate of the lateral field strength at the boundary between a molecular monolayer and glass is ~10^6 V/m, assuming sharp transitions over 1–2 monomer widths, oriented perpendicular to the boundary with bare glass. The electric field is directed in-plane and perpendicular to the transition line, towards the bare glass.

Preparation and Characterisation

To prevent confounding effects from topographical or biochemical cues, the molecular layers, albumin and amine-terminated dendrimers, were patterned as monolayer-high stripes via micro-contact printing with periodicities of 12 µm and 40 µm, corresponding to stripe widths of 6 µm and 20 µm, respectively. Stripe luminescence and heights were assessed by fluorescence microscopy and atomic force microscopy (AFM) (figure 1). In physiological medium (DMEM), scanning ion conductance microscopy (SICM) was used to evaluate the topographical pattern and to image cell membranes/surfaces. The albumin, dendrimer molecules, and osteoblasts themselves are appreciably autofluorescent in the UV range.

Cellular Responses

Three main responses were observed [voelkner2022]: (1) cells adopted a spindle-like morphology; (2) they preferred glass regions over albumin or dendrimer-coated stripes—despite protein coatings usually supporting adhesion—and migrated only along the stripe direction (Figure 2); (3) prominent membrane ruffling appeared at cell poles (Figure 3), aiding rapid shape changes [voelkner2021].

Possible Mechanism

Cells were cultured in a medium with 1.8 M calcium ions (Ca^{2+}), closely matching physiological plasma concentration. Intracellular Ca^{2+} concentration remains ~100 nM—four orders of magnitude lower—maintained by transmembrane ion channels and pumps. As a second messenger, Ca^{2+} triggers various cellular responses.

Low-frequency and DC electric fields generally do not penetrate cells but instead modulate the transmembrane potential depending on field orientation [weaver2005, schwan1992]. Osteoblasts tend to migrate towards negative potentials [monsees2006], driven by cytoskeleton remodelling: actin polymerisation in high extracellular Ca2+ and depolymerisation by Ca2+ depletion. Thus, cell adhesion decreases at anodes and increases at cathodes [djamgoz2004], suggesting Ca2+ currents and an internal counteracting field during electrostimulation. In our study, osteoblasts on amine-containing stripes are compatible with a field-modulated Ca^{2+} flux across the membrane. Without an external electrode/cathode, cells retract from both sides of the stripes and align into spindle-like morphology along the stripe direction with an aspect ratio ~ 1:5 on 20 µm-wide stripes. This behaviour resembles localized, two-sided frustrated electrotaxis. An additional mechanism may involve electro-kinetically triggered redistribution of ion channels within the cell membrane [allen2013]. Indirect effects due to localized changes to the medium by the electric field may participate.

Conclusion and Perspective

Molecule patterns generating surface potential landscapes can electrically stimulate cells without electrodes, avoiding corrosion and unwanted electrochemical reactions. Next, we will explore how substrate-induced electric fields affect stem cell differentiation. ●

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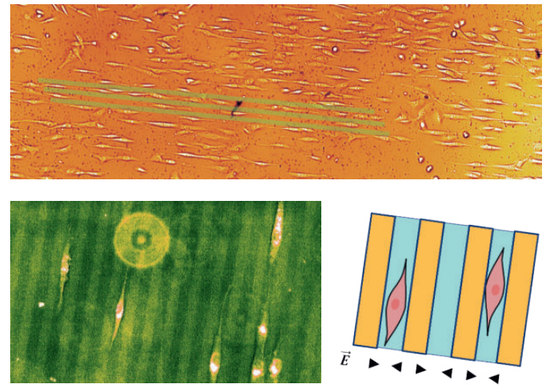


Figure 2: Bright field image of osteoblasts (stripe's direction is indicated by transparent lines). Autofluorescence image of osteoblasts (after 24 h) on molecule landscape. Scheme of adhesion geometry

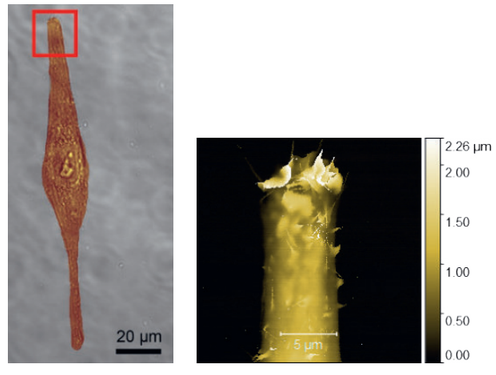


Figure 3: Brightfield optical image of a spindle-shaped osteoblast, with false colour enhancement for improved visibility. The red frame indicates the location of a cell pole. SICM of spindle cell poles reveals pronounced peripheral membrane ruffling.

Light on Matter

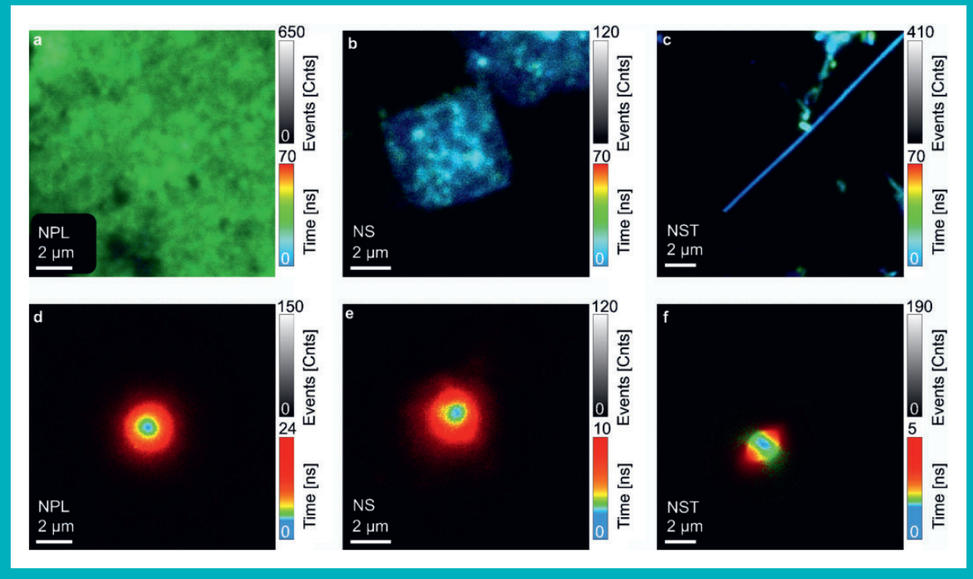


Figure 1: FLIM lifetime and diffusion maps – The upper row shows spatially resolved images of the carrier lifetime weight by intensity of a nanoplatelet film (a), a nanosheet (b), and a nanostripe (c). The corresponding diffusion maps are in the lower row, showing the same field of view. The timescale indicates the carrier diffusion time from the fixed excitation spot (blue) to its recombination spot. A nearly isotropic diffusion can be seen for the nanoplatelet film (d) and the nanosheet (e). The nanostripe shows the diffusion along its shape (f).

Charge Dynamics in Materials

Tracking charges in advanced optical materials: Excitons in perovskite nanocrystals

CHRISTIAN KLINKE, RONJA MARIA PIEHLER,

Metal halide perovskites are promising materials for the next generation of optoelectronic applications, such as light-harvesting devices, light-emitting diodes, and photodetectors. Compared to other optical materials they show excellent tunable optical properties which pave the way for exciting advancements in optoelectronic perovskite applications like solar panels, LEDs, and light sensors because they absorb and reemit light exceptionally well and can be produced relatively easily.

The chemical method of colloidal synthesis is a versatile approach to produce tailored nanocrystals. We used colloidally prepared zero-dimensional perovskites nanoplatelets, one-dimensional nanostripes, and two-dimensional nanosheets to investigate the diffusion behavior of optically excited excitons – electron-hole pairs – and their recombination mechanics. The goal of this work was to understand how the outer and inner structure of colloidal nanocrystals affect the motion of charge carriers.

The internal structure of such crystals can be "layered" like a stack of thin sheets. In perovskites with thinner layers the band gap is larger, and energy tends to be tightly bound as excitons. In thicker, "bulk-like" regions with a smaller band gap, charges tend to separate and move more freely. When different layers coexist, energy can "funnel" from high-energy regions (thin, few-layer zones) into lower-energy regions (thicker, many-layer or bulk-like zones). This funneling can be helpful for collecting light efficiently, but it can also limit how far energy travels if the pathways act like bottlenecks.

To watch charges – and with this energy – move in time, we used a specialized microscope that measures both where and when light is emitted after the crystals are excited by a brief laser pulse. This technique, called fluorescence lifetime imaging microscopy (FLIM), allowed to map how the cloud of excited charges spreads out from the spot where the laser hits. By separating the paths of the laser (excitation) and the detector (collection), we could fix the excitation at one point and then scan the surrounding area for photoluminescence to create "diffusion maps" of charge motion over time which are shown in Figure 1.

The images and time-resolved maps revealed clear differences between the three shapes. In nanoplatelet films and individual nanosheets, the diffusion pattern was nearly circular, indicating that charges could move in all in-plane directions similarly. In nanostripes, the pattern was elongated, reflecting that charges primarily moved along the length of the stripe and were limited by the narrow width. Visually, this already hinted that nanostripes might support longer-range charge movement along their primary axis, while nanoplatelets and nanosheets were more confined.

To interpret these patterns, we combined the imaging with structural and optical measurements. X-ray diffraction confirmed that nanoplatelets and nanosheets contain multiple, distinct layer types (a "mixed-n" structure), while nanostripes are more bulk-like. Optical measurements of absorption and emission supported this picture: nanoplatelets and nanosheets displayed features associated with excitons in layered regions, while the main emission peak was consistent with recombination in bulk-like regions. In other words, charges excited in thin-layer domains tend to migrate and eventually emit light in thicker, lower-energy regions – a hallmark of energy funneling.

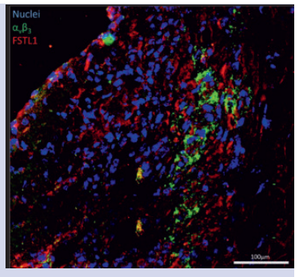
These findings suggest a design trade-off: Layered architectures with energy funnels can be excellent for directing energy into low-loss regions, which is beneficial for bright emission and potentially for efficient light collection. But the same funnels and interfaces can limit how far energy travels laterally, which matters for devices that rely on moving charges across distances, such as certain photodetectors or solar cell architectures. Bulk-like structures, exemplified by nanostripes in this study, permit faster, longer-range charge motion but may sacrifice some of the stability and emission benefits associated with layered designs.

In conclusion, both shape and internal structure control how energy travels in perovskite nanocrystals. The research offers a grounded, visual, and quantitative understanding of charge diffusion in three forms of perovskites. Nanostripes support freer, faster charge motion; nanosheets sit in the middle; nanoplatelet films face the biggest hurdles due to layering and interparticle hopping. The work shows how layered mixed-n designs create powerful energy funneling but also introduce quasi-traps that slow lateral diffusion. It confirms that bulk-like regions promote free-charge transport and higher diffusivity. And it underscores that optimizing perovskite devices is not about a single "best" structure, but about balancing stability, emission efficiency, and transport speed for the task at hand. If the goal is to move energy quickly and far, bulk-like architectures have a head start. If the goal is to gather and emit light efficiently, layered structures offer valuable tools – so long as we tame the traps that come with them. ●

Discussed publication

Ronja Maria Piehler, Eugen Klein, Francisco M. Gomez-Campos, Oliver Kühn, Rostyslav Lesyuk, Christian Klinke: Chasing Charge Carriers: Diffusion Dynamics in Mixed-n Quasi-Two-Dimensional Colloidal MAPbBr3 Perovskites, Adv. Funct. Mater. (2025) 2500097. https://doi.org/10.1 002/adfm.202500097

How to track a healing heart?



In PET/CT imaging, [68Ga]Ga-NODAGA-RGD is considered a standard tracer to visualize angiogenesis after myocardial infarction. Mechanistically, this tracer binds to αvβ3-integrin surface receptors, assumed to mark sprouting vessel tips. However, cardiac healing is a complex process, involving various cell types like macrophages and fibroblasts that also display αvβ3 integrin expression. In our recent study, activated fibroblasts emerged as the dominant source of αvβ3 expression in the infarcted heart. Immunofluorescence imaging on tissue sections showed highest αvβ3 levels in the infarct zone that predominantly co-localized with Fstl1, a marker of activated fibroblasts. Hence, [68Ga]Ga-NODAGA-RGD seems to report scar remodeling more than pure angiogenesis, so its signals should be interpreted critically when used as an "angiogenesis tracer." doi10.1007/s00259-025-07489-4

Characterization of Aerosols

Laser desorption and ionization of molecules on nanoparticles

JOHANNES PASSIG, CHRISTIAN PELTZ AND HASEEB HAKKIM, RALF ZIMMERMANN

Atmospheric aerosol particles have major effects on both Earth's climate system and human health. Among these particles, organic aerosols represent one of the most complex and least understood fractions [1]. They contribute to climate forcing through multiple pathways: by scattering and absorbing solar radiation, by modifying cloud properties, and by altering surface albedo when deposited on snow or ice.

Quantifying these effects remains challenging due to the immense chemical diversity of organic aerosols, their dynamic aging processes, and the internal mixing states they exhibit in the atmosphere. These transformations modify critical properties such as hygroscopicity, volatility, and optical characteristics, ultimately affecting their atmospheric lifetime and climatic role. Consequently, predictive models of aerosol–climate interactions still carry substantial uncertainties.

A deeper understanding of these effects requires information at the single-particle level. For instance, the number of activated cloud condensation nuclei depends not only on the overall mass fraction of water-soluble organics but also on their distribution within the particle population [2]. As a further example, an equal distribution of toxic compounds in inhaled aerosols may be less harmful, while their concentration in a few heavily loaded particles can overwhelm pulmonary clearance mechanisms and trigger inflammatory responses.

To meet these challenges, the research aims to provide real-time insights into the composition and properties of individual aerosol particles.

Innovative Approaches and Key Techniques

In the LL&M department, resonant laser excitation schemes were designed to probe individual particles and reveal their chemical signatures through single-particle mass spectrometry (SPMS). These schemes target the resonant excitation of atomic states of transition metals [3]. Such metals are of dual relevance: as air pollutants, they can trigger acute cardiovascular effects, while as essential micronutrients, their scarcity in large parts of the Southern Ocean limits marine productivity and carbon sequestration [4]. To address this, the novel SPMS technique was recently deployed on the research vessel Sonne during a cruise across the Indian Ocean, where it analyzed the sources of Fe-containing particles in the remote atmosphere. Beyond metals, a new method has been developed to detect traces of aromatic molecules [5]. This approach enables the identification of sources and carriers of toxic aromatics in background air with unprecedented sensitivity [6]. Their resonant ionization opens new possibilities by using the aromatic species as molecular tracers to identify pollution sources and atmospheric processes, see Fig. 1 for an example on wildfires. Moreover, the method is sensitive enough to determine the type of fuel used by ships from distances of many kilometers [7].

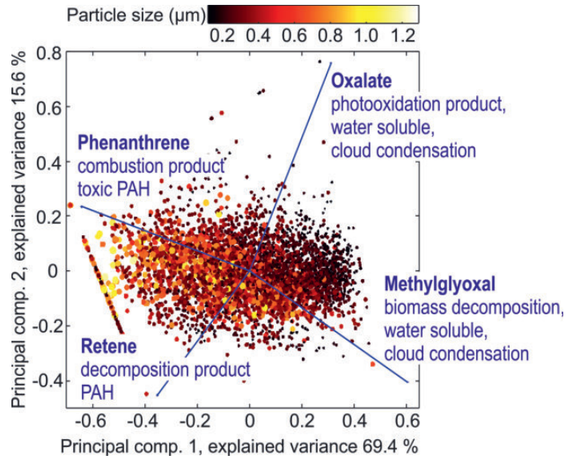


Fig. 1: Principal component analysis of 3,000 particles from a wildfire ageing experiment. The position of each dot represents the chemical composition of a single particle based on four selected key components. The data illustrate the early transformation of the aerosol population: while smaller particles already carry strong signatures of hygroscopic oxidation products, many larger particles still contain substantial amounts of insoluble, toxic aromatics.

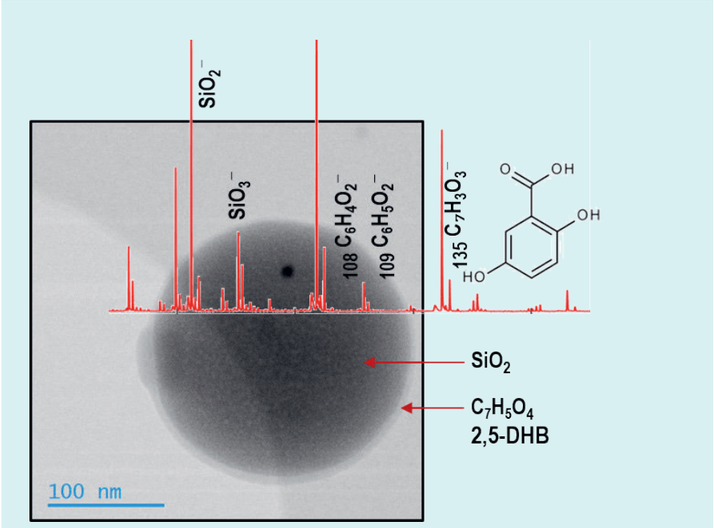


Fig. 2: TEM image of a SiO_2 particle coated in-flight with a thin 2,5-dihydroxybenzoic acid layer. The anion mass spectrum, obtained with a single 50 fs laser pulse, exhibits signals from both the core and the coating. TEM image by Kevin Oldenburg, LL&M.

Key Challenges

Despite advances in chemical analysis, the complex impacts of organic aerosols on health and climate remain poorly understood. One challenge are dynamic changes within a variety of compounds. Another is the particles' morphology: oxidized surface layers form rapidly in the atmosphere and strongly influence their optical properties, cloud condensation activity and surface chemistry. The associated increase in viscosity suppresses the diffusion of radicals into the particle, thereby shielding the enclosed pollutants from photooxidation. Such processes are thought to underlie the detection of polycyclic aromatic hydrocarbons in the Arctic, despite their lifetimes of only a few hours in laboratory experiments [8].

Research Strategy and Perspectives

These challenges–the sensitive detection of a broader diversity of particle compounds and the distinction between surface and bulk composition–are at the core of the project "Interface-assisted laser desorption and ionization of molecules on nanoparticles", conducted within the Collaborative Research Center 1477 LIMATI. In close collaboration with the strong-field nanophysics group, the project aims to deliver a mechanistic picture of controlled laser desorption and ionization under ultrashort pulses — a key prerequisite to translate advanced laser desorption protocols into practical applications. A pilot study indicated a transition in material ejection mechanisms — from thermal vaporization to Coulomb-driven and bubble-bursting ejection — as the laser pulse duration decreased from the nanosecond to the femtosecond range. [9]. This transition was accompanied by a substantial sensitivity enhancement, holding promise for a wide range of applications, such as mass spectrometry imaging of single-cell metabolomics, where sample material is inherently limited.

The project focuses on depth-resolved analysis of particle surface layers, leveraging size- and wavelength-dependent near-field enhancements that are expected to confine energy dissipation and laser-driven material ejection to the surface [10]. To create realistic proxies for atmospheric aerosols, free nanoparticles are coated on-the-fly in newly developed condensation cells. The monitoring and analysis of these semivolatile coatings rely on atmospheric-pressure electron microscopy, as provided by the ELMI facility in the LL&M, see Fig. 2.

Beyond the ongoing work on organic aerosols, new concepts for SPMS-based detection of bioaerosols and airborne pathogens are being developed. One example is a novel field-deployable Er:YAG solid-state laser [11], which resonantly excites the O–H stretch vibration of water, leading to explosive droplet disruption and ionization of embedded biomolecules. These developments highlight how research in the LL&M department accelerates and expands by bridging physics, analytics, environmental sciences, and biology. ●

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Chromatic Swept-Source Laser Scanning

Toward a Cell-Resolving Confocal Slit Lamp for Ophthalmology

KARSTEN SPERLICH, SEBASTIAN BOHN AND OLIVER STACHS

The slit lamp, originally invented by Allvar Gullstrand, a key diagnostic tool in eye care and research, offers cross-sectional views of the cornea and lens. But the resolution is limited and cellular structures are not visible. In contrast, in vivo corneal confocal microscopy (CCM) enables high-resolution imaging at cellular level [1]. Its clinical use is limited by slow, complex, and largely manual operation. Depth-resolved images, essential for slit-lamp-like cross-sections, require volumetric image stacks that are prone to motion artifacts and time-consuming due to the recording-to-reconstruction processes [2]. We developed a novel concept leveraging chromatic aberration in swept-source laser scanning systems to enable real-time, cell-resolving cross-sectional imaging of the cornea.

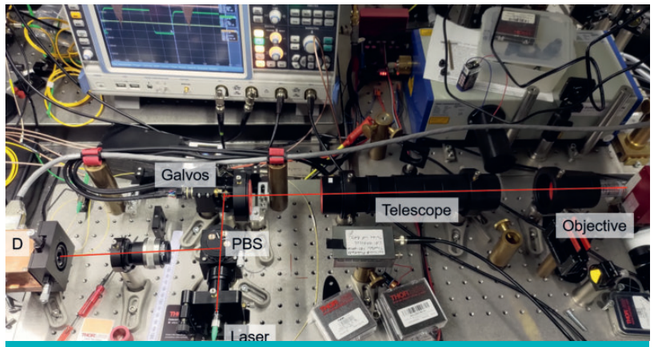

Figure 1: CSS-CCM setup combining a swept-source laser (only fiber shown and illumination path) and chromatic optics for real-time confocal cross-sectional imaging. Longer wavelengths are focused deeper into the tissue, while shorter wavelengths are focused more anteriorly. (D - detector; PBS - polarizing beam splitter)

Project Context

Imaging of the anterior segment of the eye is essential for diagnosing ocular surface diseases. While classical slit-lamp biomicroscopy and optical coherence tomography provide macroscopic or layer-resolved views, they lack the cellular resolution needed [3]. CCM, in contrast, achieves this resolution, but clinical usability is hampered by slow acquisition, involuntary eye movements, and post-processing requirements [3]. Cross-sectional images are particularly difficult to obtain, as current CCM systems acquire image stacks in surface-parallel (en face) direction and require complex volume reconstruction prior to sectioning.

Innovation and Methods

To address these limitations, we introduce Chromatic Swept-Source Corneal Confocal Microscopy (CSS-CCM), a novel approach that uses a swept-source laser in combination with a specially designed chromatic optical system. The core idea is to induce and exploit longitudinal chromatic aberration (LCA): as the wavelength of the laser changes periodically, different focal depths are illuminated, and the back-reflected light is detected confocally without any mechanical axial scanning. The system thus eliminates the need for mechanical z-scanning, reducing acquisition time and motion artifacts.

This optical design allows the system to acquire true cross-sectional (e.g., x-z-plane) images of the cornea—analogous to classical slit-lamp views but at cellular resolution and with unprecedented speed without the need for volume reconstructions. The lateral scan directions (x-y-plane) are realized using two galvano scanner mirrors enabling arbitrary lateral scan patterns.

Using Zemax-based optical simulations, a telescope configuration with chalcogenide glass was optimized to induce an LCA of 145 µm across a 70 nm sweep range centered at 1060 nm. This is sufficient to resolve key corneal layers.

Results and Outlook

The system enables the acquisition of depth-resolved slit images with 512 pixels lateral at up to 333 frames per second, each already representing a confocal cross-sectional image. Compared to classical CCM systems that require ~10 s/vol and further processing time, CSS-CCM generates similar data within fractions of a second. This marks a significant step toward real-time in vivo microscopy of the cornea.

Figure 1 presents the current development stage: a functional breadboard setup with all essential optical, mechanical, and detection components.

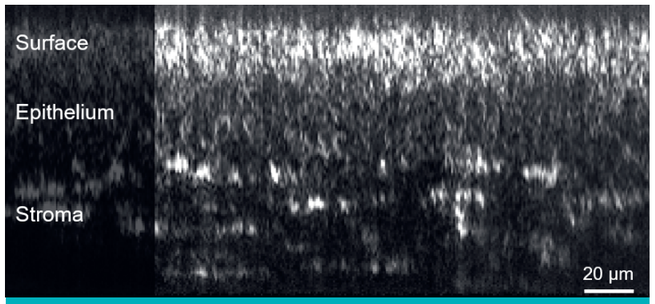

Figure 2: Example cross-sectional image of the first corneal layer of an enucleated porcine eye acquired using the CSS-CCM prototype. The visibility of the epithelial cells is currently limited. In the stroma, keratocyte nuclei are visible.

The custom-built detector unit is based on an avalanche photodetector module with a cooled sensor and analog temperature stabilization. Low-pass filters for the Peltier current and output signal, and battery-powered operating voltages ensure the highest possible signal-to-noise ratio (SNR).

This is necessary to achieve high recording speeds. Figure 2 shows a cross-sectional confocal image of a porcine cornea. The superficial cells at the corneal surface appear bright, whereas the epithelial cellular structures exhibit low contrast, rendering the underlying cells only faintly discernible. In contrast, keratocyte nuclei are clearly visible within the stroma. Volumes (260 µm x 260 µm x 150 µm) can be recorded at 3.6 vol/s. En face sections of the volume exhibit the cellular structure of the endothelium (See Fig. 3).

Although preliminary imaging at 815 nm was promising, the intrinsic contrast at 1060 nm is reduced compared to the established imaging at 670 nm. As a next step, we plan to operate at around 700 nm. This spectral range promises improved image contrast and a higher SNR, as Rayleigh scattering is 6 times and quantum efficiency of silicon-based sensors at least two times greater. Further, it is easier to achieve a high LCA at this wavelength, resulting in an increased axial scanning depth in the cornea.

The flexibility of the double-galvano scanner architecture enables dynamic adjustment of image position and orientation, facilitating oblique or non-planar sectioning. While for anterior imaging, immersion gel and optionally a sterile contact cap is required to suppress surface reflection artifacts, posterior sections can be imaged contact-free.

This technique holds promise for diagnosing and monitoring corneal neuropathies, dry eye disease, infectious keratitis, and early neurodegenerative changes in systemic diseases such as diabetes or multiple sclerosis.

Collaborations and Interdisciplinary Team

Key contributors from the Klinik und Poliklinik für Augenheilkunde, Universitätsmedizin Rostock are scientifically embedded within the framework of the Department Life, Light & Matter (LL&M). The development of the CSS-CCM system is rooted in a strong physics-driven foundation and the result of close collaboration within an interdisciplinary consortium: physicists and engineers specializing in biomedical optics and corneal diagnostics, optical simulation experts from the University of Rostock, and system design and automation specialists from the Institute for Automation and Applied Informatics at the Karlsruhe Institute of Technology. Central to this effort is the precise modeling and application of physical principles—particularly wave optics and laser-scanning confocal microscopy—which guide both system architecture and data interpretation. ●

Funding and Intellectual Property

The project is supported by the German Research Foundation (DFG) with 755 k€ in total funding. A corresponding patent has been filed through the University of Rostock.

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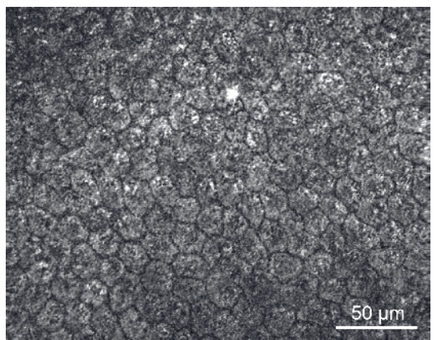

Figure 3: En face section at the endothelium of a reconstructed volume from a porcine cornea acquired using the CSS-CCM prototype. The endothelial cells and some cell nuclei are visible.

Light, Lifetime, Life

Mapping Biology with Fluorescence Lifetime Microscopy

SIMONE BALTRUSCH, ISABELL WENSKUS, SAMANEH SHAHAB

Fluorescence Lifetime Imaging Microscopy (FLIM) is an advanced imaging technique that maps the spatial distribution of fluorescence lifetimes within microscopic samples. Unlike traditional fluorescence intensity imaging, FLIM measures the decay time of a fluorophore's excited state, providing insights into the local molecular environment independent of fluorophore concentration. In biological research, FLIM is particularly valuable for studying cellular metabolism, protein-protein interactions (via Förster Resonance Energy Transfer, FRET), and microenvironmental changes such as pH, ion concentrations, or oxygen levels. Its label-free options make it especially useful for live-cell imaging and real-time observation of dynamic biological processes.

The basic principle underlying FLIM is that fluorescence emission is governed by stochastic quantum processes. After excitation by a short pulse of light, a fluorophore returns stochastically to its ground state by emitting a photon after a characteristic dwell time. This fluorescence lifetime—the average time a molecule spends in the excited state before photon emission—typically ranges from a few hundred picoseconds to several nanoseconds. The unpredictability of each molecule's return to the ground state forms the statistical basis of the method. The exponential decay of fluorescence intensity with time after a brief excitation pulse reflects this probabilistic nature. The "stop-watch" principle in FLIM is realised through time correlated single photon counting (TCSPC), where the arrival time of each detected photon is recorded relative to the excitation pulse [Fig.1]. This enables reconstruction of the fluorescence decay profile at each imaged pixel. The lifetime measurement is independent of fluorophore concentration or illumination intensity—thereby offering robust contrast based on the local molecular environment instead of mere intensity.

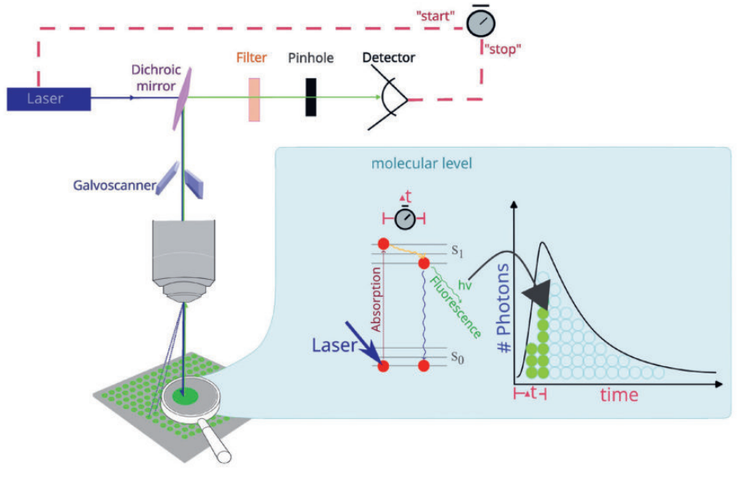

Figure 1: Concept of fluorescence lifetime imaging microscopy (FLIM). The dichroic mirror separates excitation and emission light, while the galvoscanner sequentially directs the excitation beam to individual pixels, enabling site-specific detection. The recorded emission from each pixel is analysed by time-correlated single photon counting (TCSPC) electronics, schematically represented as a stopwatch, to determine fluorescence lifetimes.

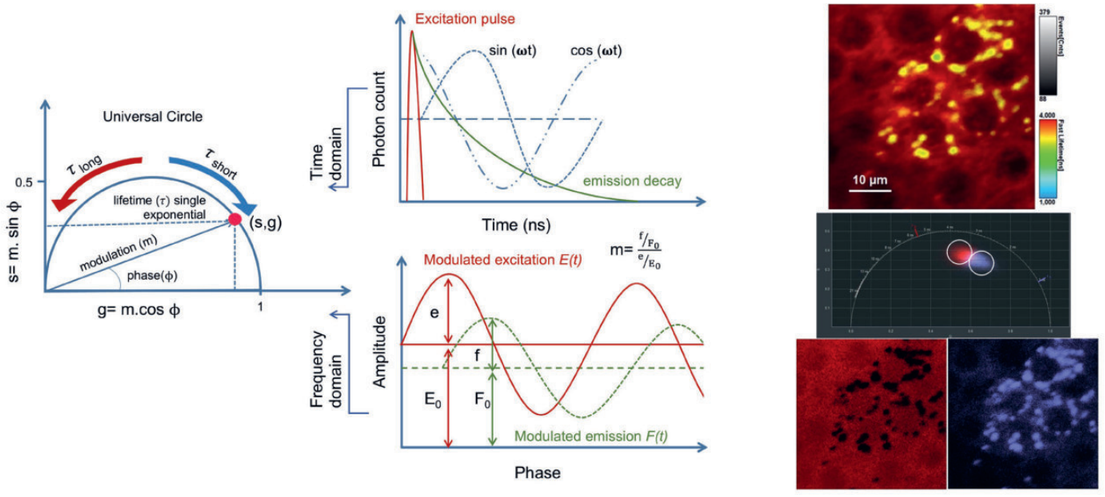

Figure 2: Phasor plot principle for fluorescence lifetime analysis. Left: Schematic showing the transformation of fluorescence decay data into the frequency domain using sine and cosine Fourier components (g, s), which are mapped onto the universal semicircle. The position on the phasor plot directly reflects the fluorescence lifetime—short and long lifetimes appear at distinct positions along the semicircle. Right: FLIM image and phasor plot of human eye lens capsule. After a fit-based method the phasor analysis with pattern matching was applied to distinguish different biological structures. In the blue pattern mitchondria are clearly visbible.

For FLIM imaging, a time-resolved confocal fluorescence microscope (MicroTime 200, PicoQuant, Berlin, Germany) was used. Data analysis were carried out using both a fit-based approach and phasor plot analysis, complemented by additional pattern matching. The latter has the advantage of enabling visualisation and differentiation of fluorescence lifetime components without the need for complex curve fitting (https://www.picoquant.com/).

For data analysis two approaches are mainly applied: Time-domain fitting involves modeling the photon arrival histograms at each pixel with exponential decay functions to extract lifetime components. Phasor plot analysis offers a model-free alternative by representing each pixel's decay curve graphically using sine and cosine transformations [Fig.2]. This method allows for easy differentiation of distinct lifetime signatures and metabolic states without the need for fitting models.

FLIM provides biomedical research with insights into cellular processes. Metabolically active mitochondria are essential energy suppliers for cells. Due to their NADH content, they exhibit strong autofluorescence and have a characteristic lifetime depending on their activity state. FLIM can be used to describe age-related changes in the muscles [Fig.3] and the lens of the eye [fig 2, right], leading to a better understanding of age-related diseases such as muscular dystrophy and cataract. ●

additional project work:

- https://www.focusonmicroscopy.org/2025-program-online/?source=pp&event_id=8024&tab=pdf&a_id=9598

- https://www.focusonmicroscopy.org/2025-program-online/?source=pp&event_id=8024&tab=pdf&a_id=9603

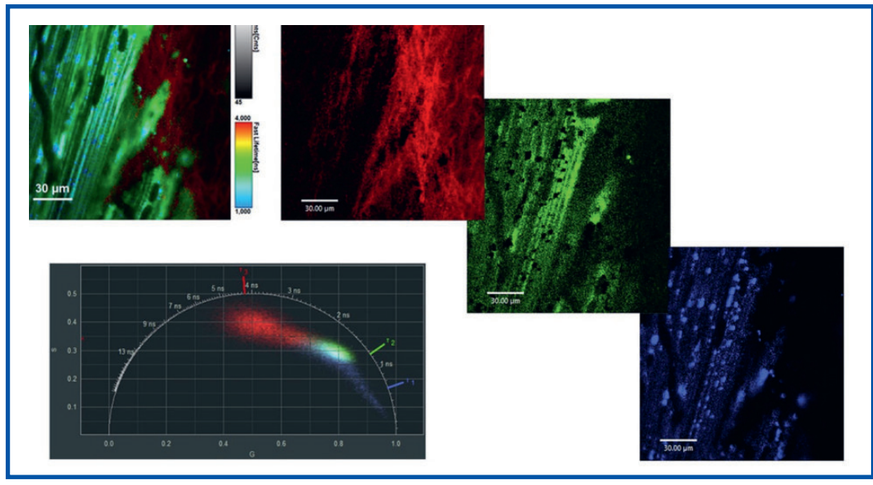

Figure 3: FLIM image and phasor plot of murine soleus muscle. A fit-based analysis was carried out first (top left side). The colours represent the mean decay times. Additionally, a phasor plot based method was applied and the colours show the different patterns, especially mitochondria are clearly visible in the blue pattern.

Plasmons Unmasked

Unlocking Nanoparticle Modes Under the Electron Microscope

KEVIN OLDENBURG, KARL-HEINZ MEIWES-BROER, INGO BARKE

When light or an electron beam interacts with a nanoparticle containing mobile electrons, such as metals like silver, the conduction electrons can move resonantly at specific frequencies. These collective electron oscillations—known as localized surface plasmon resonances (LSPRs)—produce very distinct changes in how the nanoparticle absorbs and scatters light or electrons, which can be detected with suitable experimental techniques.

Plasmons are used in various real-world applications. For example, their ability to concentrate light into tiny volumes is exploited in techniques such as surface-enhanced Raman spectroscopy (SERS) and in designing photonic devices for solar cells or even medical therapies. Since LSPRs are exceptionally sensitive to changes in the surrounding environment, they are excellent candidates for sensors: a slight alteration—such as the adsorption of a molecule—can shift the plasmon to lower energies, signalling that something has changed.

However, this same high sensitivity poses a challenge when one wishes to study the "intrinsic" or pristine plasmon energy. For fundamental research, it is important to know what the resonance would be in free space (or on an "innocent" support) rather than being masked by environmental effects. In many cases researchers try to decouple the particle from its surroundings or use theoretical corrections based on effective medium approximations. Unfortunately, these approaches often assume that the substrate's influence is isotropic which is obviously not the case, as the substrate is typically present only at one side of the particle. Plasmons represent oscillating electric dipoles, resulting in oscillating image charges in the substrate that act back on the plasmon system. Photoemission electron microscopy (PEEM) experiments using metal silver nanoparticles with typical diameters around 15 nm [1] revealed that such laser excited "virtual plasmonic dimers" give rise to higher-order modes (e.g. quadrupole oscillations) which otherwise cannot be excited by light. Hence, the substrate vastly alters the plasmonic response in a nontrivial way.

One might expect that a promising approach to reduce the effect of a substrate on nanoparticle plasmons is to keep it further away, e.g. by some kind of weakly interacting spacer layers. But our recent results [2] turn this intuitive picture on its head: small silver clusters deposited at the rim of a thin carbon film form a "cliffhanger" geometry in which the largest part of each particle is suspended over vacuum while it remains anchored to the substrate. Using high-resolution electron energy loss spectroscopy (EELS) within a scanning transmission electron microscope (STEM), we mapped out how the plasmon resonance energy varied across the nanoparticle (see Figure 1, left). Surprisingly, we found that the strongest redshift—that is, the greatest substrate-induced shift of the plasmon energy—occurred when the excitation was farthest from the substrate. This counterintuitive "nonlocal" effect arises because the supporting carbon film breaks the spherical symmetry of the tiny particle, lifting the degeneracy between different plasmonic modes and inducing mode splitting, resulting in distinct resonance frequencies (see Figure 1, right). Intriguingly, the plasmon modes that feel the strongest influence from the supporting film extend farthest into the vacuum, where they can be selectively excited.

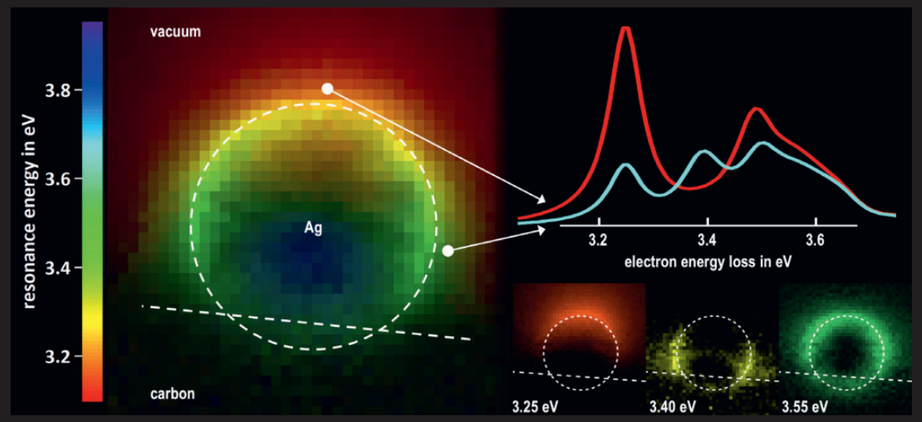

Figure 1: Plasmon resonance energy map of an 11 nm diameter silver nanoparticle (left). The apparent resonance energy varies locally due to mixing of different plasmon modes, driven by spatial variations in their intensity. These modes are visualised in the energy-filtered plasmon resonance maps (bottom right), and their contributions are confirmed by spectral simulations of the corresponding electron energy loss spectra (top right).

Electrodynamics simulations based on the boundary element method (BEM) supported these experimental findings. Opposed to the common expectation that a dielectric medium simply causes a uniform redshift in resonance energy, the actual situation is much more complex. In particular, the dipole mode excited over vacuum (away from the carbon) experiences enhanced image charge effects and screening compared to other modes.

This work shows that even for essentially spherical nanoparticles—which are often assumed to have simple, "intrinsic" plasmon energies—the supporting substrate can induce significant spatial variations in the observed resonance energy. This insight helps explain some of the long-standing discrepancies in literature reports on silver nanoparticle plasmon energies. Simple corrections based on effective media might miss these nonlocal and symmetry-breaking effects.

High-resolution spatial mapping enabled by the STEM within ELMI-MV at the Department Life, Light & Matter was essential for revealing subtle nonlocal substrate effects. By scanning the interior of the nanoparticle, we could see how different regions contributed uniquely to the overall plasmon structure and its energy – a critical step toward more accurate modelling and tailored applications in sensing and nanotechnology. ●

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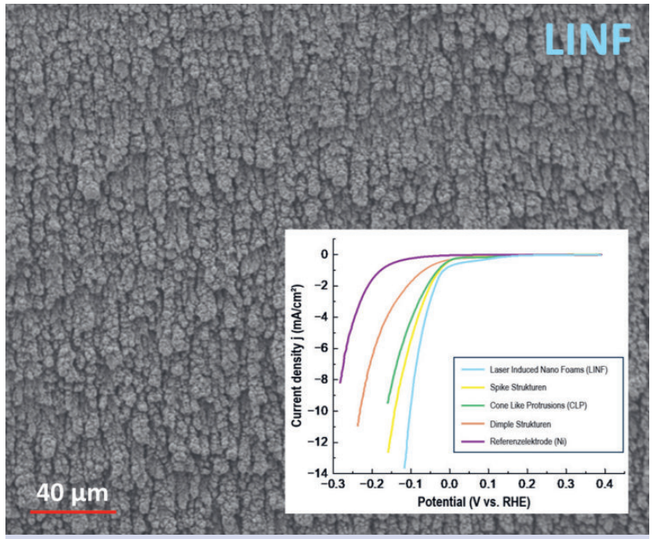

Applied Laser Structuring (Schweißtechnische Lehr- und Versuchsanstalt SLV)

The research project HydroLAS – Laser Functionalisation of Electrode Surfaces was carried out at the SLV between 2022 and 2024. The aim was to use ultrafast laser processes to create micro- and sub-microstructures on nickel electrodes in order to improve the efficiency of hydrogen production in electrolysers.

As an application-oriented and interdisciplinary member of the LLM, the SLV collaborated with the Leibniz Institute for Catalysis (LIKAT) in this project and acted at the interface of materials science, laser processing, and electrochemistry. While the SLV developed and characterised the laser microstructures, the electrochemical tests for hydrogen evolution were performed at LIKAT.

The challenge in electrolysis is that oxygen reactions limit kinetics and gas bubbles block active sites, lowering efficiency. HydroLAS addressed this by generating hydrophilic as well as gas-repellent laser textures that improve electrolyte wetting and accelerate bubble detachment. Various micro- and sub-microstructures such as riblets, cone-like protrusions (CLP), and especially laser-induced nano foams (LINF) were produced and microscopically analysed.

Performance tests at LIKAT demonstrated that the electrochemically active surface area (ECSA) could be increased by up to a factor of 91 with LINF. The figure above symbolically shows an SEM view of the LINF structures, as well as the significant reduction of overpotential in H_2 production achieved by these structures compared to the unstructured reference. This led to considerably enhanced activity. Moreover, gas bubbles detached much faster from the structured electrodes, reducing transport resistances and further improving process efficiency.

Overall, HydroLAS demonstrates the strong potential of USPL-based surface functionalisation for hydrogen production. The cooperation within the LLM between SLV and LIKAT illustrates how interdisciplinary collaboration can accelerate the development of sustainable energy technologies.

Nanostructures strengthen Aluminium Alloys

BENJAMIN MILKEREIT, MAMI MIHARA-NARITA, CALIN D. MARIOARA, KEVIN OLDENBURG5, OLAF KESSLER

The Department Life, Light and Matter strives to analyse, understand and control fundamental processes in natural science, medicine and engineering on the atomic/molecular scale. Within the topic Matter at the Nanoscale, we aim to develop new materials with innovative properties by designing their nanostructures. Aluminium-alloys as a construction material are a typical example. The resistance to plastic deformation, i.e. yield strength, of pure Al must be significantly increased in order allow an application as construction material. To achieve this, alloying elements are added to aluminium. These alloying elements shall form high number densities of nano-scaled particles, which hinder dislocation glide and thereby increase the strength. These particles are usually produced by heat treatment, which consists of solution annealing, quenching and ageing. During solution annealing, alloying element atoms dissolve into the aluminium matrix. During quenching, this state is frozen in a supersaturated solid solution with a high potential for precipitation. During ageing, nano-scaled precipitates are formed, following an alloy-specific sequence of evolving chemical compositions and crystal structures [1].

Quenching is usually a critical step in this heat treatment. If cooling is too slow, precipitates form at high temperatures and become too coarse to increase the strength [2]. The critical cooling rate required to keep the solution completely supersaturated and exploit the maximum potential for increasing strength depends on the alloy composition. The LLM Competence Center °CALOR performs in-situ analysis of cooling rate-dependent phase transformations, especially using differential scanning calorimetry (DSC) in a unique rate range from about 10^{-5} K/s to about 10^{5} K/s. For complementary investigations on the micro- and nanostructure of the alloys, °CALOR cooperates with the Electron Microscopy Center of the University Medical Center (scanning electron microscopy, SEM) and with the LLM Competence Center ELMI-MV (scanning transmission electron microscopy, STEM). Therefore, transmissive aluminium alloy samples with thicknesses below 100 nm have to be prepared by sophisticated mechanical grinding and electrochemical polishing.

Recently, we have extensively cooperated with Prof. Dr. Mami Mihara-Narita (Nagoya Institute of Technology, Japan) and Dr. Calin D. Marioara (SINTEF, Trondheim, Norway). New aluminium alloys from Japan based on a composition of Al-6Zn-0.75Mg (mass %) have been investigated. These AlZnMg alloys are characterised by the unique fact, that nano-scaled structures, so-called GP (Guinier-Preston) zones, are formed already during slow cooling at low temperatures. Fig. 1 shows an in-situ DSC measurement at slow cooling, performed at the LLM Competence Centre °CALOR. Two precipitation peaks can be seen. First, the equilibrium phase $MgZn_2$ precipitates between approximately 320 and 180 °C. Further cooling to temperatures below 100 °C results in the formation of GP zones. They nearly double the aluminium alloy hardness from about 35 HV to about 70 HV in the as-cooled condition. With natural ageing at room temperature, the hardness increases further to about 115 HV, i.e. about three times the initial value. The GP zones are globular and have diameters of a few nanometres. Fig. 2 shows a detailed atomic resolution image of a GP zone, obtained at ELMI-MV. It consists of basic structural building blocks of alloying element atoms, known as truncated cube octahedra, which are arranged in rows in specific crystal directions, thus forming the structure of the GP zone [3].

This alloy can be used for processes and applications that require slow cooling. These can be, for example, forged components with large wall thicknesses or components that are particularly susceptible to distortion, as the latter is promoted by rapid quenching. The addition of further alloying elements (e.g. Fe, Si or Zr) can significantly change the phase transformation behaviour of the alloy [4]. Further cooperation is intended with the LLM Competence Center Magnetic Resonance (MagRes) as well as with groups working in quantum technologies to develop new methods for in-situ analysis of phase transformations. Having a comprehensive understanding of the relation between processing, micro- and nano-structure formation and macroscopic properties is crucial to develop new construction materials. ●

This international cooperation has been supported by Mare Balticum Fellowships for Prof. Dr. Mami Mihara-Narita and Dr. Calin D. Marioara to visit Rostock University. We acknowledge funding of the Mare Balticum Fellowships by the Pro-Rector for Research, Talent Development and Equal Opportunities of Rostock University.

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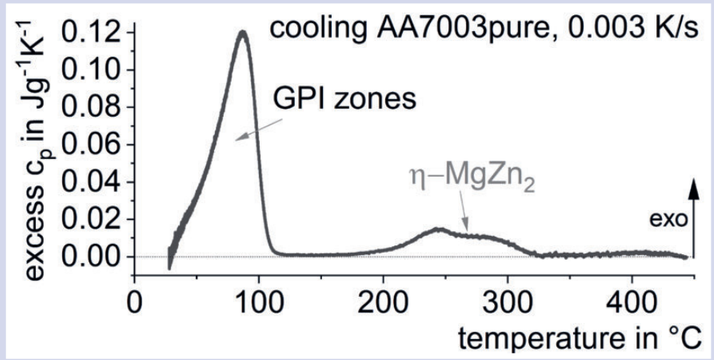


Fig. 1 DSC cooling curve at 0.003 K/s indicating a two-stage precipitation process of 1. Coarse micrometre sized $MgZn_2$ particles and 2. Strength increasing nano-scaled GP I zones.

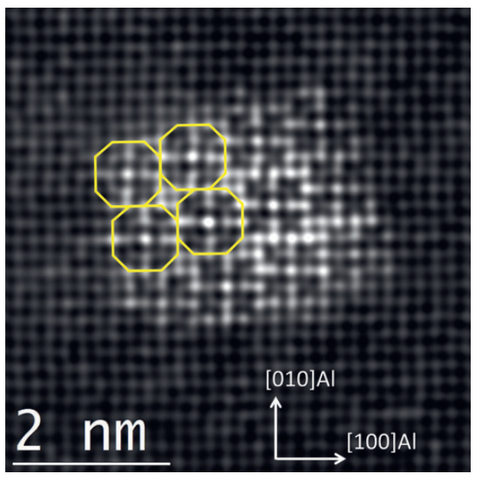
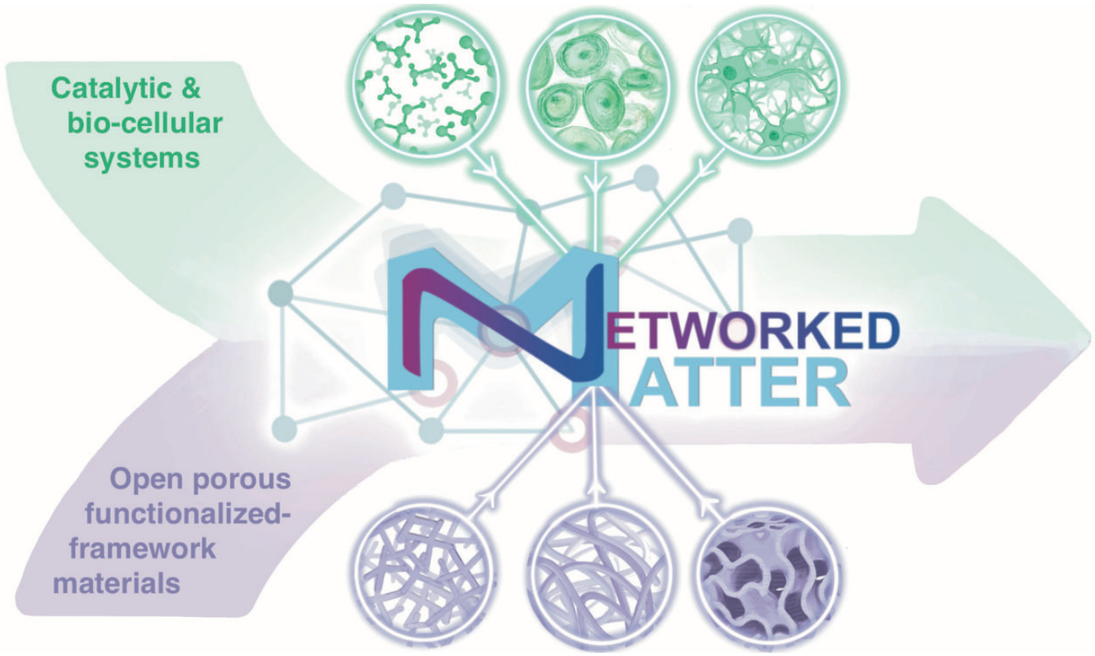


Fig. 2 HAADF-STEM (High-Angle Annular Dark-Field Scanning Transmission Electron Microscopy) image of a Zn–Mg rich GP zone, obtained using a technique that provides atomically resolved images with contrast proportional to the atomic number (Z-contrast). The zone is composed of a number of connected truncated cube octahedra along the <411>Al directions, four of which are marked with yellow lines.



Networked Matter

Joint Research Initiative of Kiel and Rostock Universities towards a CRC/Transregio in Materials Science

RALF JAISER, HERMANN SEITZ, BERIT ZELLER-PLUMHOFF, RALF ZIMMERMANN AND RAINER ADELUNG, JACQUELINE CLÜVER

Interdisciplinary research means networking across scientific disciplines and the integration of the respective methods and knowledge into a joint quest to answer a scientific question. The Networked Matter initiative takes this principle to heart and turns networks into material reality. The research focuses on complex dynamic systems, such as chemical or biological systems, which can also be understood as networks. In terms of chemistry, these are chemical reaction networks which can be altered by e.g. catalysts. In terms of biology, these are cellular networks or tissues. These systems are united by the problem that they are often too fast, too small or generally too inaccessible to capture, decipher or control their entire complexity. The idea of the initiative is to harness these systems by embedding them as guests in host material systems of open-porous scaffolds, which themselves can be understood as networks. Functionalisation of these scaffolds will enable accessing the complex embedded network in a targeted manner, both in terms of control and measurement. This intertwined functionalised combination of networks is Networked Matter.

Networked Matter is a Research Initiative between Kiel University and the University of Rostock. Both are united in their institutionalisation of interdisciplinary research. While Kiel has four interdisciplinary research areas - Kiel Life Science (KLS), Kiel Marine Science (KMS), Kiel Nano, Surface and Interface Science (KiNSIS) and Societal, Environmental and Cultural Change (SECC) - the University of Rostock has an Interdisciplinary Faculty with four departments: Life, Light & Matter (LL&M), Maritime Systems (MTS), Ageing of Individuals and Society (AGIS) and Knowledge - Culture - Transformation (WKT). Among these each four independently developed, yet complementary subject areas, KiNSIS and LL&M have joined forces and developed Networked Matter on their interdisciplinary scientific and engineering basis. The first version of a draft proposal for a CRC/Transregio has been submitted to the DFG at the beginning of 2025. Furthermore, the initiative brought together all existing four CRCs related to KiNSIS and LL&M for the InMAT 2025 conference in Rostock in spring.

Networked Matter first of all requires the provision of suitable host material systems. These material systems stem from a wide range of scales, from the nanoscale with metal organic frameworks to microscopic 3D printing. The connecting element is the open-porous nature of the host materials, which not only provides space for the guest systems but also enables the exchange of fluids. The next step is the functionalisation of the scaffolds. Options range from simple coatings to control colour and thus light absorption, to

nanoparticles that enable interaction between host and guest in the networked system. This allows a variety of possibilities including both the desired measurement and control of the guest systems. The resulting general concept is shown in Figure 1.

The essential step is the incorporation of target systems into these host materials. Within the CRC/Transregio proposal, two areas of application are being pursued: Catalysis and biological tissue. The open-porous materials with their large surface areas are ideally suited to carrying catalysts. Hollow tubes in the system make it possible to introduce or remove specific substances in order to monitor or control the reaction. Furthermore, targeted heating or spectroscopic analysis of the reaction in interaction with fluorescent particles is possible. Biological systems find a habitat in the open-porous scaffolds that makes it possible to ensure the targeted supply of nutrients and at the same time enables optical, electrical and material access - again with the idea of allowing both measurement and control.

In addition to focussing on the materials design and development in combination with driving the applications, key components of the Networked Matter initiative include the advancement of analysis methods and modelling techniques. The strengths of KiNSIS and LL&M are particularly evident in analytics, as many complementary opportunities for material characterisation and operando analysis already exist. In the long term, Networked Matter is also intended to create a theoretical concept that can be used to describe complex networked systems in general.

To foster the collaboration between the different groups at both universities within the Networked Matter initiative and provide proof-of-concepts, seed funding for student assistants was kindly made available by the University of Rostock. A number of cooperative projects were conducted, resulting in several productive mutual visits between research groups in Kiel and Rostock, as well as six additional publications that have been submitted or accepted, with more to come.

One example of such a collaborative project is the project **Spark Plasma Sintering of Interconnected Porous Piezoelectric LNKN Ceramics for Bone Tissue Regeneration.** This project was a collaboration between the Chair of Microfluidics at the University of Rostock and the Functional Nanomaterials Group at the Institute of Materials Science, Kiel University. The aim of this pilot study was to develop novel porous piezoelectric ceramics based on lithium-potassium-sodium niobate (LNKN) with a targeted, interconnected pore structure for use in regenerative medicine, particularly in the treatment of critical-size bone defects.

Within the Networked Matter concept, the porous piezoelectric ceramics represents the host material developed to promote the biological tissue

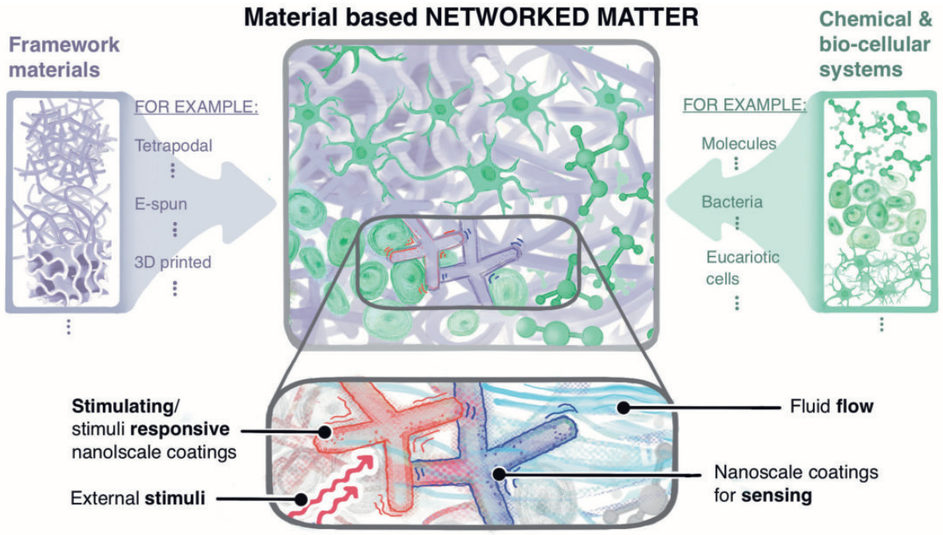
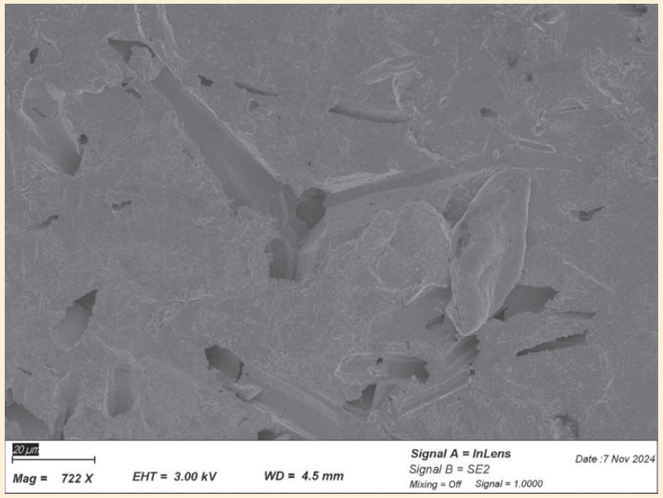


Figure 1: Networked Matter is created from the combination of open-porous Framework Materials and Chemical and bio-cellular systems to be examined. Fluid flow and external stimuli can reach the target systems, while functionalisation allows for dedicated sensing or actuation of the Networked Matter system.



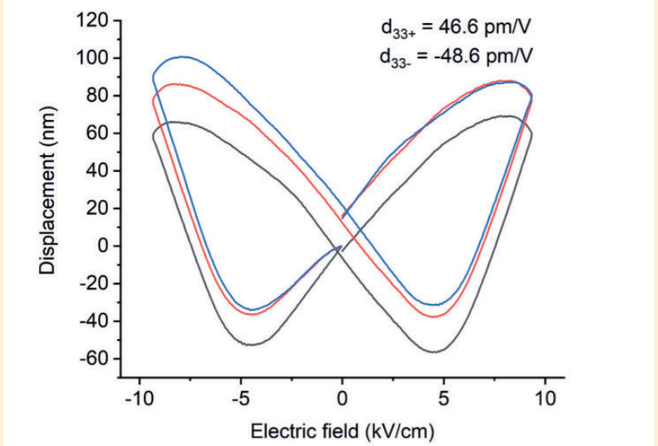


Figure 2: (top) SEM image of the porous LNKN ceramic material; (botton) Hysteresis curve ("butterfly loop") of the piezoelectric response.

ingrowth. This is a critical concept, as bone defects, especially those that exceed the body's natural regenerative capacity, remain a major challenge in regenerative medicine. The use of piezoelectric materials, which generate electric charge under mechanical load, opens up new perspectives. The natural piezoelectric properties of bone tissue can be mimicked using suitable piezoelectric biomaterials that promote cell proliferation and bone regeneration. To meet these requirements, a ceramic material with high mechanical stability, biocompatibility, and a tailored pore structure was to be developed.

Spark Plasma Sintering (SPS) technology was used to fabricate the novel LNKN ceramic. SPS is an advanced sintering method in which electrical current, either pulsed or unpulsed, is directly passed through a graphite die and the powder to be compacted. The combination of simultaneous pressure and Joule heating enables extremely fast heating rates and short sintering times. This results in particularly dense grain and phase boundaries, which are crucial for the physical and functional properties of the material. Compared to conventional sintering techniques, SPS offers significantly higher control over microstructure and material characteristics.

To achieve an interconnected pore network, tetrapodal zinc oxide (t-ZnO) structures were used as sacrificial templates. These microstructures consist of four rod-shaped arms growing in a tetrahedral arrangement from a central junction point. They were provided by the group of Prof. Adelung at Kiel University. Their use enables the targeted formation of open and interconnected pores within the LNKN ceramic. After sintering, the t-ZnO can either be etched out or, due to its antibacterial properties and biodegradability, remain within the material.

For the initial samples, LNKN nanopowder was mixed with 20 weight percent t-ZnO and subsequently sintered under varying conditions using SPS. The resulting ceramics were thoroughly characterized. Scanning electron microscopy (SEM) images before and after etching clearly revealed a porous structure (Fig. 2). The removal of the t-ZnO sacrificial template was confirmed through surface morphology changes and X-ray diffraction (XRD) analysis.

The fabricated LNKN/t-ZnO ceramics achieved a relative density of approximately 96%. The piezoelectric coefficient d33 of the polarized ceramic was 10.0 ± 1.7 pC/N, close to the natural piezoelectric coefficient of human bone. The inverse piezoelectric response exhibited the characteristic "butterfly loop" deformation, a classic feature of ferroelectric materials such as LNKN (Fig. 2). These results were reproducible and confirm the successful integration of material selection, structural design, and SPS processing.

The results obtained so far demonstrate that the combination of SPS technology and t-ZnO sacrificial structures represents a promising strategy for the fabrication of porous, functional LNKN ceramics. The achieved material density, mechanical integrity, and piezoelectric performance provide a solid foundation for further biofunctional studies.

However, microscopic analyses suggest that the selected t-ZnO content of 20 wt% may not be sufficient to generate fully interconnected pore structures throughout the entire volume. Future investigations will therefore focus on varying the t-ZnO content and examining the spatial homogeneity of porosity. In addition, long-term stability under physiological conditions, biocompatibility, and potential immunomodulatory effects will be explored.

The work carried out in this pilot study by the partners at the University of Rostock and Kiel University highlights the technological and functional potential of SPS-sintered LNKN bioceramics structured with t-ZnO. The successful fabrication of interconnected porous LNKN ceramics with piezoelectric properties marks an important step toward functional bone substitute materials. Spark Plasma Sintering technology, in combination with biofunctional space holders such as t-ZnO, offers a promising platform for the further development of piezoelectric biomaterials for regenerative medicine. ●

How mathematics revolutionises biochemistry

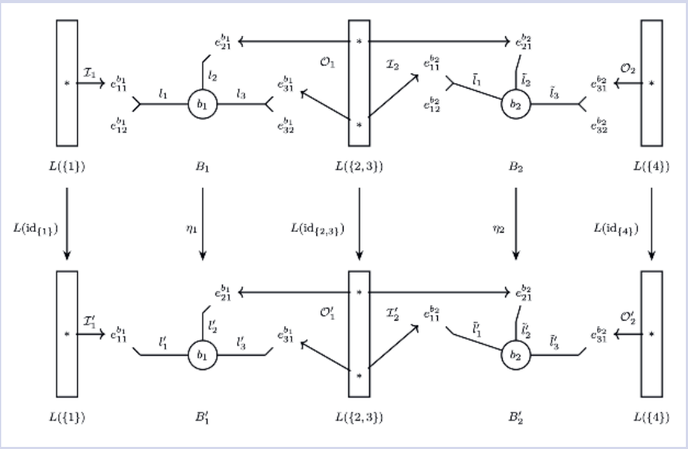


Figure: Symbolic illustration of how morphisms can act as building blocks to assemble complex biochemical maps.

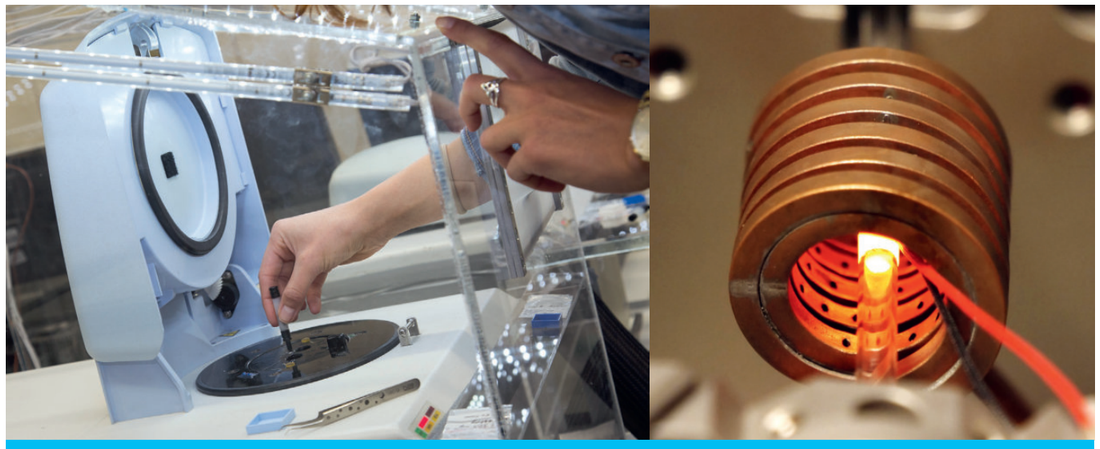
Visualising the dark inner workings of cells is a major challenge — pathways tangle, dozens of molecules interact, and experts often struggle to connect local details with global insight. A collaboration between Rostock and Kiel, including postdoc Adittya Chaudhuri (University of Rostock), just offered a promising new direction: by combining category theory with the Systems Biology Graphical Notation (SBGN), their team has built a flexible mathematical scaffold for biochemical maps.

The problem: SBGN diagrams are powerful for human-readable pathway maps but lack a formal semantic backbone. Modelers usually translate visual diagrams into differential equations, Petri nets or graph models — as if visualization and formal modelling were separated tasks. The team closes that gap. They use the theory of structured cospans to define a symmetric monoidal double category whose horizontal morphisms correspond to SBGN Process Descriptions. This lets one compose (glue together) smaller sub-networks into larger ones (compositionality) or zoom out by abstracting details — all within a rigorous framework.

One of the key outcomes: you can formally reason about how a sub-process affects the rest of the network, and vice versa. In other words, the method offers a mathematically consistent "surgery kit" to cut, paste, and simplify complex biochemical systems — without losing track of formal correctness.

In the next steps, one can imagine this framework being integrated with simulation tools, used to standardise pathway databases, or extending it to other diagrammatic formalisms beyond SBGN. Mathematics provides not just abstraction — here, it becomes a new lens for biochemistry.

Chaudhuri, Köhl, Wolkenhauer, 2024; doi:10.48550/arXiv.2410.18024



Competence Center for Calorimetry and Thermal Analysis-°CALOR

Thermal Properties and In-situ Analysis of Phase TransformationsOlaf

Figure: Steel sample (about Ø 5 x 10 mm) rapidly heated to about 1000 °C in a quenching dilatometer by an induction coil. Temperature is measured by thin thermocouple wires spot-welded on the sample. Length changes are transferred by quartz push-rods to a Linear Variable Differential Transformer (LVDT).

OLAF KESSLER, BENJAMIN MILKEREIT

Calorimetry and Thermal Analysis Laboratory Rostock (°CALOR) is an interdisciplinary competence centre of the Department Life, Light and Matter (LLM) of Rostock University. It aims to analyse, understand and control fundamental processes in natural science, medicine and engineering on the atomic/molecular scale.

We focus on structural and functional materials (metals, polymers, ceramics) as well as on media for energy storage and transport. Our research infrastructure includes a comprehensive platform for measuring temperature-dependent thermophysical properties and for in-situ analysis of phase transformations and chemical reaction kinetics using calorimetry, dilatometry, and thermogravimetric methods. These phase transformations encompass solid–solid transitions, melting and solidification processes, as well as evaporation phenomena.

Instrumental Equipment

Competence Centre °CALOR´s unique feature is an extremely large range of applicable heating and cooling rates from about 10^{-4} K/s up to about 10^{6} K/s in a device-specific temperature range of about -100 °C up to about 1500 °C. In LLM Research Building, we offer several state-of-the-art Differential Scanning Calorimeters (DSC), both heat-flux and power compensated types, several microchip-based Fast Scanning Calorimeters (FSC), reaction calorimeters, dilatometer, quenching dilatometer and thermobalances.

Research and Method Development

Our research focusses on development of new thermal analysis methods, especially Fast Scanning Calorimetry (FSC), fundamental understanding of the correlation between materials, manufacturing processes, material micro/nano-structures and properties, design of materials with new nano-structures and properties as well as challenging materials data for process simulation.

Synergies in the Research Building

Competence Center °CALOR is mainly run by interdisciplinary groups from materials science, technical thermodynamics, microfluidics and chemistry and is open for cooperation with other groups of Department LL&M as well as with external partners from academia and industry. We perform fundamental and applied research mainly in mechanical engineering, materials science, additive manufacturing, energy technologies and biomedical engineering.

°CALOR closely cooperates with other competence centres of Department Life, Light and Matter, especially Center of Electron Microscopy (ELMI-MV), Optical Microscopy and Spectroscopy (MicroSpec), Magnetic Resonance (MagRes) as well as Mass Spectrometry to develop correlative analytic methods.

Transfer and Cooperation

The spin-off company RoNa Tech GmbH commercialises our expertise especially in microchip-based Fast Scanning Calorimetry (FSC) and works next door also in LLM Research Building. ●

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https://rona-tech.de/?

Center for Electron Microscopy MV ELMI-MV

Atomic-Scale Imaging and Correlative Electron Spectroscopy

KEVIN OLDENBURG, CHRISTIAN KLINKE

The Center for Interdisciplinary Electron Microscopy MV (ELMI-MV), located in the research building Life, Light & Matter (LL&M), provides highly specialized infrastructure for high-resolution electron microscopy. Its central equipment comprises are two (scanning) transmission electron microscopes ((S)TEM), which combine atomic-scale structural analysis with elemental characterization and spectroscopic methods. ELMI-MV offers research institutions worldwide access to state-of-the-art microscopy for interdisciplinary research, including materials science, physics, and the life sciences.

Synergies in the Research Building:
ELMI-MV complements the core analytical technologies at the LL&M research facility and works closely with the competence centers for mass spectrometry, microscopy & spectroscopy, and InterSurf. In combination with Raman, IR, fluorescence, and photoemission techniques, ELMI-MV enables comprehensive correlative analysis of materials, interfaces, and biological structures at the nanoscale.

Transfer and Third-Party Projects:
The methods and instruments are applied in interdisciplinary third-party funded projects, including catalysis research, bioanalytics, semiconductor and energy technology. ELMI-MV supports collaborative projects with infrastructure, method development, and data analysis – from imaging individual atoms to observing dynamic processes in living cells or reactive materials.

Outlook:
The center will further expand its expertise in in-situ electron microscopy and deepen the integration of imaging, spectroscopy, and simulation. The development of correlative methods together with other competence centers in the department aims to strengthen research into dynamic processes in complex systems at the molecular level. www.elmi-mv.uni-rostock.de ●

Research Focus Areas:

- Structural analysis of materials with atomic resolution
- Element mapping and quantitative analysis of sample compositions
- Detection of plasmons, excitons, and electronic transitions
- In-situ microscopy under variable conditions (temperature, gas atmosphere, liquid)
- Investigation of catalytic reactions and biological samples in liquid cells
- Correlative microscopy by combining spectroscopy and imaging methods

Instrumentation:

- Transmission electron microscopes with atomic resolution
- Electron energy loss spectroscopy (EELS) for electronic properties
- X-ray spectroscopy (EDX) for elemental analysis
- In-situ cells for liquid- and gas-phase microscopy
- Analysis tools for elemental distributions, atomic lattices, nanoparticles, and cell structures
- Support from trained specialists for operation, maintenance, and data analysis

In Situ TEM: Observing Materials and Processes in their native Environment

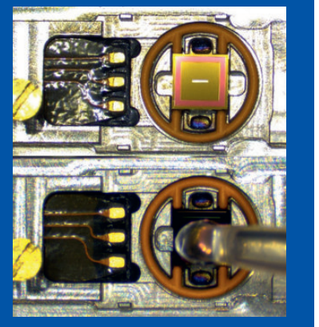


Figure 1 The open liquid cell (top) is filled with a 1µl droplet (bottom).

Our facility is equipped with a range of in situ TEM holders that allow materials and biological samples to be studied under realistic environmental conditions. These systems rely on small silicon chips with thin silicon nitride (SiN) membranes that are largely transparent to the electron beam. When two such chips are combined with a microscale gasket, they form a sealed reaction or observation chamber whose content can be precisely controlled.

In the gas cell configuration, a controlled gas flow passes through the chamber, enabling, e.g., chemical and catalytic studies at pressures up to 1 bar and temperatures up to 1000 °C. This allows direct visualization of reactions, phase transformations, and surface changes as they occur in real time. The liquid cell uses the same chip architecture but is preloaded with a defined liquid volume. In addition to static operation, it can also be used in flow mode, enabling the continuous exchange of liquid during imaging. Fig. 1 illustrates the assembly of the liquid cell: the top image shows the round gasket with a silicon chip (2 mm x 2 mm) equipped with an elongated SiN window (550 µm × 50 µm); below we see the filling of the chamber with a 1 µL droplet. Finally, the cover chip with the second membrane close the cell (not shown). Together, these in situ setups make it possible to correlate structural and chemical changes over time, revealing how materials or biological structures evolve under true operating conditions.

Competence Center for Interfaces and Surfaces-InterSurf

Functional and Responsive Interfaces at the Nanoscale

SYLIVA SPELLER, INGO BARKE

The Competence Centre InterSurf at the research building of the department LL&M brings together activities focused on the analysis and targeted design of functional surfaces and interfaces. Central to its work is understanding the coupling of physical, chemical, and biological structures at the nanometre scale – particularly under the influence of local stimuli such as electric fields, mechanical forces, and light. The goal is to develop active interfaces that respond controllably to their environment, enabling applications in medicine, sensor technology, energy systems, and materials science.

Research Focus:

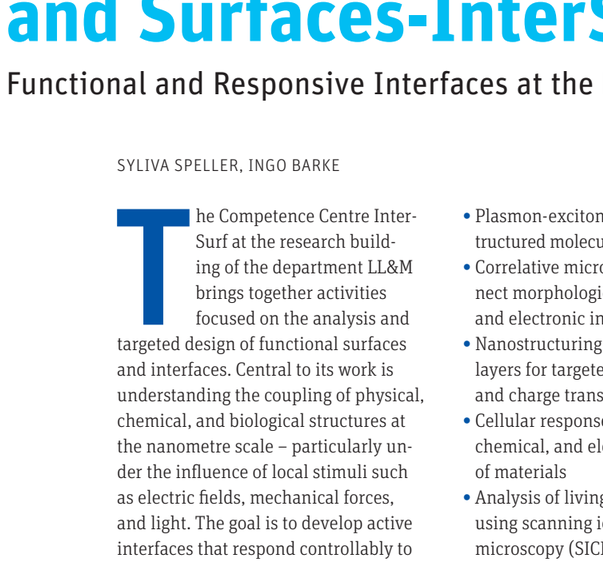
- Structure, dynamics, and function of molecular and biofunctional interfaces
- Transport processes at surfaces (e.g., charge and exciton transport)
- Plasmon-exciton coupling in nanostructured molecule-metal composites
- Correlative microscopy to interconnect morphological, optical, and electronic information
- Nanostructuring of molecular layers for targeted control of light and charge transport
- Cellular responses to structural, chemical, and electrical properties of materials
- Analysis of living cells at interfaces using scanning ion conductance microscopy (SICM)

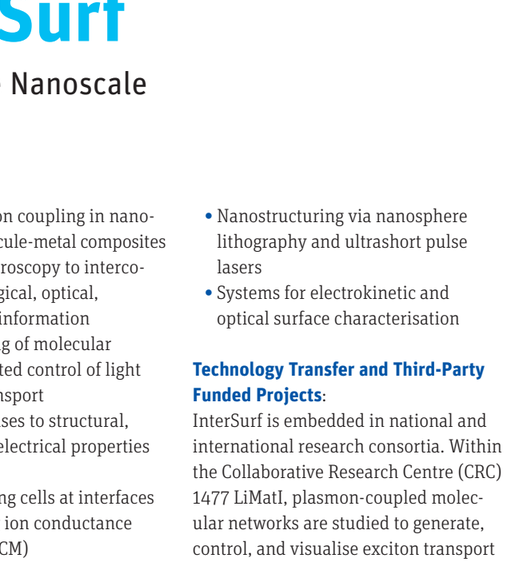
Instrumentation:

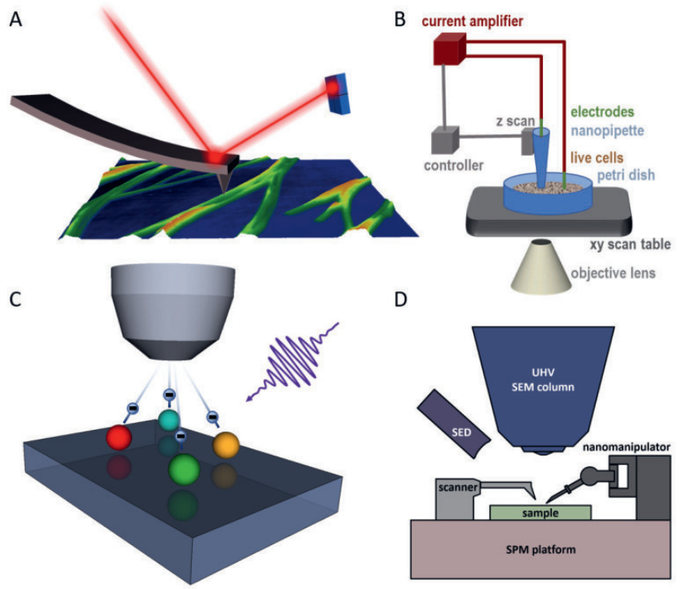
- Atomic force microscopes (AFM, A and D in the illustration) and scanning ion conductance microscopes (SICM, B), respectively
- Photoemission electron microscopy (PEEM), see C
- Electron microscopy (D) and optical fluorescence techniques
- Nanostructuring via nanosphere lithography and ultrashort pulse lasers
- Systems for electrokinetic and optical surface characterisation

Technology Transfer and Third-Party Funded Projects:

InterSurf is embedded in national and international research consortia. Within the Collaborative Research Centre (CRC) 1477 LiMatI, plasmon-coupled molecular networks are studied to generate, control, and visualise exciton transport at the nanoscale. Time-resolved optical and photoelectron-based microscopy techniques are used to analyse diffusive and ballistic transport processes, with the long-term aim to develop novel concepts for energy- and signal-conducting nanostructures. Additionally, the center investigates the effect of material surface charges on cellular behaviour within the CRC 1270 ELAINE – for instance







via nanoscale SICM measurements – and contributes to DLR projects characterising space-induced surface charging. Developed methods are applied in medical technology, aerospace, and functional materials research.

Future Perspectives:

InterSurf aims to expand its expertise in switchable and biohybrid interfaces. Key priorities include integrating plasmonic nanostructures with molecular layers, enabling direct interaction with living cells, and developing smart, stimuli-responsive surfaces. The close alignment of experimental methods with simulation-based approaches strengthens the Centre's role as an interdisciplinary platform for interface research within the Department LL&M. ●

Selected Publications:

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2. M. Wendt et al., J. Space Weather Space Clim. 14, 18 (2024), https://doi.org/10.1051/swsc/2024019
3. A. Skorska et al., Cell. Mol. Life Sci. 79, 149 (2022), https://doi.org/10.1007/s00018-022-04196-3
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5. K. Oldenburg et al., J. Phys. Chem. C 123, 1379 (2018), https://doi.org/10.1021/acs.jpcc.8b08928

Hybrid biomaterials for medical devices

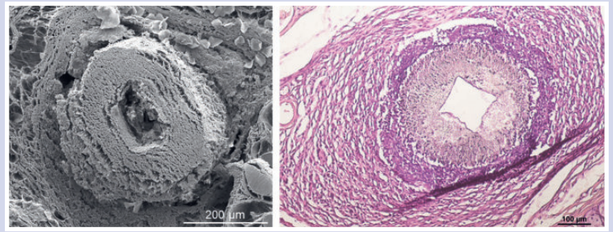


Figure 1: SEM micrograph of a hybrid polymer/metal rod with a solid magnesium core and nanofibrous PLLA covering.

The Institute for Biomedical Engineering (IBMT) as part of Rostock University Medical Center has a long-standing research tradition in the fields of biomaterials and implant technology. As a bridging institute between medicine, engineering and natural sciences, IBMT is an environment for biomedical teamwork together with LLM partners, medical professionals and industry.
Current applied research and product development focus on hybrid biomaterials for innovative medical devices and processes: (i) covered stents and absorbable scaffolds, (ii) electrospun nonwovens for medical devices, (iii) materials and devices for ophthalmic application, and (iv) Eustachian tube stents for otolaryngologic application. Technological innovations cover implant-based local drug delivery systems and surface modifications for responsive functionalized implants.

Temporary bioresorbable metal, polymer, and hybrid implants aim to enable next-generation diagnostic and therapeutic functions. see Fig. 1.

Following the 3R principle, in vitro cell culture systems accelerate development and reduce animal testing. Animal suffering is reduced through a combination with compact small animal biocompatibility models.
Flexible electronics arise from advanced chemical processing, enabling biosignal monitoring via biocompatible electrodes.

IBMT is aiming at participative technology development, integrating perspectives of developers and medical professionals, as well as systems and innovation researchers. Current regulatory challenges in clinical transfer of medical device/pharmaceutical combination products are being addressed by close academic/industry collaboration and thorough testing layouts in certified environments.

Competence Center for Magnetic Resonance-MagRes

Molecular and Structural Insights from Atoms to Materials

BJÖRN CORZILIUS, RALF LUDWIG AND SVEN GRUNDMANN

The Competence Center Magnetic Resonance (MagRes) is an integral part of the Life, Light & Matter (LL&M) research building and provides a central platform for the molecular characterization of solid and liquid systems. The focus is on solid-state NMR for the structural analysis of materials, including dynamic nuclear polarization (DNP) for signal amplification, nuclear spin relaxometry for the investigation of molecular dynamics over long time scales in complex mixtures, electron paramagnetic resonance (EPR) spectroscopy for the investigation of systems with unpaired electrons, and magnetic resonance imaging (MRI) for imaging and three-dimensional data acquisition in flowing media.

The aim is to gain a profound understanding of the relationship between molecular structure, dynamics, function, and macroscopic material properties—as a basis for the targeted development and optimization of functional materials in areas such as catalysis, energy storage, and medical technology. Furthermore, special methods are being developed at the Competence Center MagRes to better understand molecular function at the atomic level and thus to elucidate complex processes, e.g., in biomolecular systems or heterogeneous catalysts.

Key Research Areas:

- Characterization of catalytic reactions and surface processes
- Functionalization and structural elucidation of novel materials
- Dynamics in ionic liquids and electrochemical systems
- Analysis of glass transitions and relaxation processes in polymers
- Structure-dynamics correlations in soft matter, colloids, and porous materials
- Surface NMR with NMR with Dynamic Nuclear Polarization (DNP)
- Method development for site-specific signal amplification using DNP
- Method development for high-precision measurements of various fluid mechanics parameters in turbulent flows using nuclear magnetic resonance imaging.

Instruments:

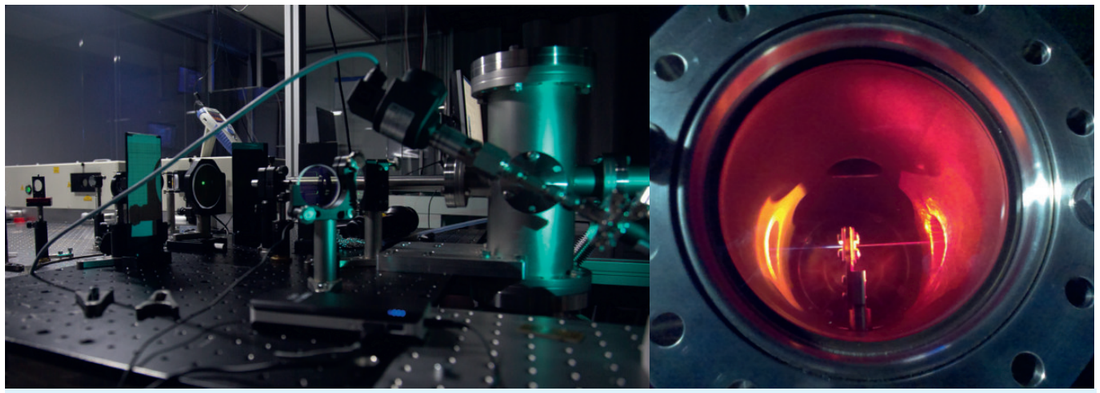
- 400 MHz solid-state NMR spectroeter with magic angle spinning (MAS)
- 263 GHz DNP for MAS NMR signal amplification
- 42 MHz fast field cycling (FFC) relaxometer with 3 T (128 MHz) extension
- 9 GHz continuous wave (cw) EPR spectrometer (in the Physical Chemistry extension building)
- Clinical 3 T whole-body MRI scanner with fluid mechanics laboratory equipment (in the MRI Flow Lab, Faculty of Mechanical Engineering and Marine Technologies)

Transfer and third-party funded projects:

The competence center MagRes is involved in a wide range of national and international third-party funded projects, particularly in the areas of method development, structural biology, materials development, catalysis research, sustainable energy systems, and medical technology. The methods developed to elucidate molecular structure-property relationships are applied in collaborations with industry and research partners and contribute to the development of sustainable materials and innovative diagnostic procedures.

Perspectives:

With the expansion of the DNP infrastructure and participation in the Transregio Collaborative Research Center TRR 386, the center has further strengthened its position as a central platform for high-resolution molecular analysis in the Department LL&M. In the future, the focus will be, besides others, on the development of highly specific methods for selective signal amplification using DNP, in particular for researching dynamic processes in materials and biological systems. ●



Competence Center for Optical Microscopy and Spectroscopy MicroSpec

Time-Resolved and High-Resolution Imaging of Dynamic Systems

STEFAN LOCHBRUNNER, SIMONE BALTRUSCH

The Competence Centre of Optical Microscopy and Spectroscopy (MicroSpec) in the Life, Light & Matter (LL&M) research building investigates biological systems, functional materials, and nanostructures using optical high-resolution microscopy and time-resolved spectroscopy. The focus is on light-induced, molecular and subcellular processes, whose dynamics and interactions are imaged and analysed with highest precision. At the same time, new microscopy and spectroscopy methods are also being developed.

The goal is to elucidate the underlying molecular mechanisms and thereby to gain new insights for applications in energy and catalysis research, materials science, and biomedicine. The centre actively promotes interdisciplinary method integration and offers access to innovative high-end techniques in optical microscopy and spectroscopy for users from various disciplines.

Key Research Areas

- Light-induced processes in molecular nanostructures and materials
- Interaction between proteins and metabolic components
- Molecular mechanisms in photocatalysis in the context of renewable energy research
- Subcellular and molecular changes in aging processes
- New imaging methods

Instruments

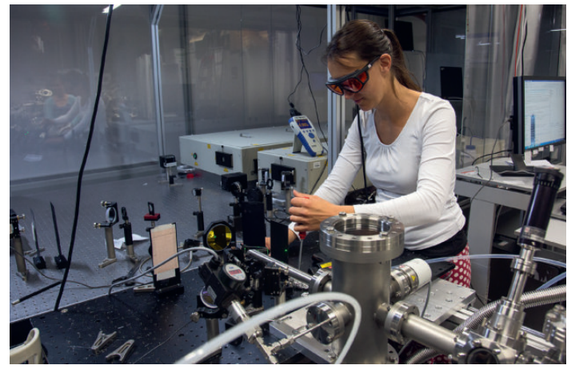
1. Fluorescence lifetime imaging microscope
2. Multi-photon microscope
3. Laser system for ultrashort, high-energy pulses
4. Pump-probe setup for femtosecond spectroscopy
5. Zeiss Versa 730 X-ray Microscope

Transfer and third-party funded projects

MicroSpec is contributing to numerous interdisciplinary collaborative research projects, i.e. to the collaborative research centre SFB 1477 'Light-Matter Interactions at Interfaces' (LiMatI), the international graduate school IRTG 2676 'Imaging quantum systems: photons, molecules, materials' (IQS) and the research training group GRK 2943 'Spectroscopic tools for challenging reduction reactions - catalytic coupling of CO_2' (SPECTRE). The developed methods enable in-situ analysis and real-time observation of molecular processes, for example in cell biology or functional materials. In cooperation with industrial partners and non-university institutions, the centre contributes to the development of new imaging techniques, the elucidation of reaction mechanisms, and the development of medical applications.

Perspectives

In the future, the centre will continue to expand its expertise in the field of time-resolved and imaging techniques - in particular by combining various microscopic methods for correlative analyses and by developing imaging methods with high temporal resolution. ●



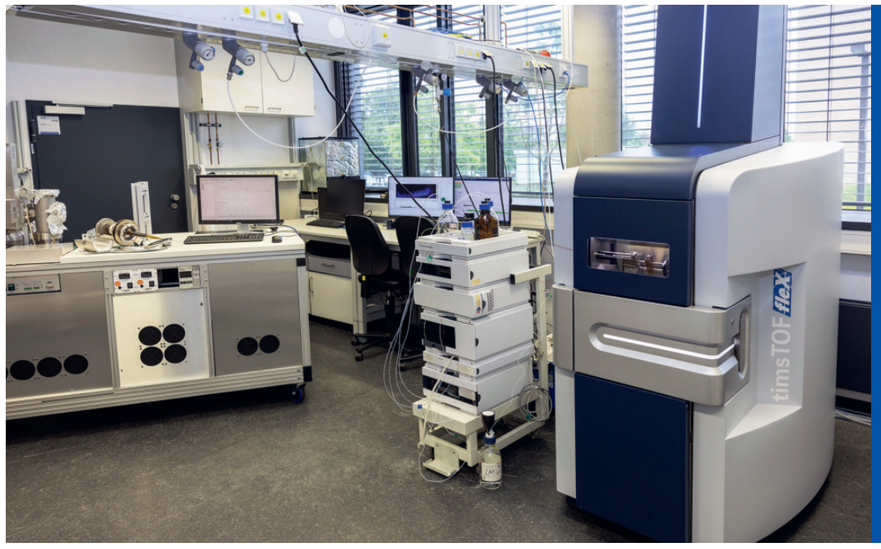


Fig. 1. Research laboratories of the Competence Center MassSpec. Left: Self-developed demonstrator of a high-resolution Orbitrap mass spectrometer for field deployment (AerOrbi); Right: Ion mobility mass spectrometer (Bruker timsToF flex) coupled with liquid chromatography.

Competence Center for Mass Spectrometry-MassSpec

Unravelling Complex Mixtures at the Molecular Level

CHRISTOPHER RÜGER, RALF ZIMMERMANN

The Competence Center for Mass Spectrometry (MassSpec) is part of the research building LLM and constitutes a central analytical platform within the department. It integrates methodological and technological expertise in the field of high-resolution chemical analytics, thereby contributing significantly to the research profile in environmental, materials, and life sciences. Complex mixtures of organic compounds can be investigated at the molecular level through the synergistic combination of different analytical techniques. This enables researchers to gain deeper insights into chemical, biochemical, and physicochemical processes, to appropriately adapt them, or to develop intelligent models.

A particular focus lies on the investigation of aerosol particles and materials relevant to the energy transition. In aerosol research, the interaction of nanoparticles with biological systems is of central importance. For assessing the toxicological response of a biological system, such as exposed lung cell models, detailed knowledge of chemical composition is crucial. Close collaboration with the life sciences and medicine is therefore emphasized. In the field of energy research, recycling processes for the circular economy and novel energy carriers, such as bio- or plastic pyrolysis oils, are in the spotlight. Especially for understanding technical conversion and transformation processes, high-resolution mass spectrometry proves to be of inestimable value.

To address these diverse challenges, both established commercial mass spectrometric methods and innovative analytical approaches are applied. Particularly in the field of high-resolution mass spectrometry, the Competence Center has gained international recognition. Its laser-based ionization techniques, applied under vacuum or atmospheric conditions, are considered world-leading. Likewise, the coupling of separation and sample introduction techniques, such as liquid chromatography and thermal analysis, is continuously advanced. This ongoing adaptation of instrumental capabilities serves as a feedback mechanism to the evolving requirements of complex research fields and application areas

Research Priorities:

- Chemical characterization of complex molecular systems
- Analysis of particles and aerosols in the context of environment and health
- Investigation of technical processes in recycling and conversion processes
- Petroleum analytics and energy-transition materials, such as bio- and plastic pyrolysis oils
- Application of high-resolution mass spectrometry and advanced data processing
- Method development for laser-based ionization techniques

Instrumental Facilities:

The Competence Center MassSpec is equipped with a broad range of modern mass spectrometers for the comprehensive chemical analysis of complex organic mixtures. Key focus areas include high-resolution mass spectrometry (Fig. 2) and in-house developed mass spectrometers designed for field deployment in environmental research and for the study of technical processes (Fig. 1). Across four laboratories, the following systems are available:

- Ultra-high-resolution mass spectrometer (R › 500,000, Bruker FT-ICR with 7T superconducting magnet) and high-resolution mass spectrometer (R › 100,000, Thermo Fisher Orbitrap Velos) for molecular analysis of the most complex sample matrices
- High-resolution mass spectrometer with ion mobility (Bruker timsToF flex, R › 30,000) for the analysis of complex mixtures and comprehensive structural characterization using fragmentation techniques and ion mobility
- Various gas and liquid chromato graphs for mass spectrometric coupling
- Highly sensitive (ppt-ppb level) tandem mass spectrometer (Triple Quad) for targeted analyses
- Several ns- and fs-laser systems for time-resolved desorption and ionization of solid, evaporated liquid, or gaseous samples
- Thermal analysis coupled to high-resolution mass spectrometry for the investigation of highly viscous and solid materials up to 1100 °C
- Multiple single-particle mass spectrometers for real-time aerosol analysis
- Time-of-flight mass spectrometers with variable pressure stages for tailored laser ionization

Technology Transfer and Third-Party Projects:

The analytical methods developed at the Competence Center are applied both in fundamental research and in application-oriented contexts, such as environmental analytics, aerosol research, materials diagnostics, and medical technology. Collaborations extend to non-university research institutions and industrial partners, particularly in the development of analytical strategies for complex samples and reactive materials. Economic transfer of methods is facilitated through close collaboration with the spin-off company Photonion GmbH as well as through applications at industrial partners, including Bruker Daltonics, TotalEnergies S.A., and Inno-Las Laser GmbH.

Perspectives:

The further development of unique laser-based ionization techniques is a central future goal. These techniques, applied either under vacuum or atmospheric conditions, enable tailored analysis of target compounds, allowing important classes such as polycyclic aromatic hydrocarbons (PAHs) to be detected even in highly complex mixtures and at trace concentrations.

With the installation of an ion mobility mass spectrometer (Bruker timsToF flex, Fig. 1) in 2024, a routine system in omics research (proteomics, metabolomics, glycomics), the Center has consolidated its perspectives for medical and life science applications. Initial collaborations with University Medicine (Prof. Oswald) and Biochemistry (Prof. Nowaczyk) have already been successful. In cooperation with the life sciences (Prof. Andreas Richter), a new liquid chromatography–mass spectrometer will further expand the Center's capacity for highly sensitive analyses. In this context, interdisciplinary collaborations on plant–aerosol interactions are also being pursued.

The Competence Center actively seeks to strengthen its role in materials research, particularly in the fields of recycling and energy materials. This expertise, combined with state-of-the-art instrumentation, is expected to integrate the field of materials science more strongly into local, national, and international cooperation projects.

The Competence Center for Mass Spectrometry therefore serves as an ideal hub for the Interdisciplinary Faculty, the University of Rostock, and the research landscape of Mecklenburg-Western Pomerania at large, offering comprehensive analytical capabilities for a broad spectrum of complex materials. Its modern facilities, enhanced by in-house instrument developments, allow the analysis of virtually any gaseous, liquid, or solid organic mixture. ●

Fig. 2. Ultra-high-resolution Fourier Transform Ion Cyclotron Resonance Mass Spectrometer (FT-ICR MS) with 7 T superconducting magnet (Bruker Solarix).

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Friederici, L., et al. Waste Management 2024, 173, 10–21, DOI: 10.1016/j.wasman.2023.11.002.

Scientific Advisory Board

The Scientific Advisory Board supports the strategic orientation and interdisciplinary development of the Department Life, Light and Matter. Its members contribute expertise from physics, chemistry, materials science, and life sciences to strengthen the department's research profile and international visibility.

Prof. Dr. Matthias Driess • Professor of Metallorganic / Inorganic Materials, Technische Universität Berlin • Scientific Director of the Chemical Invention Factory (CIF) • Scientific Director of the joint laboratory of UniCat & BASF (BasCat)	**Prof. Dr. Petra Rudolf** • Em.Professor of Experimental Solid State Physics • Former Dean of Graduate Studies, University of Groningen
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Through their strategic advice, the members of the Advisory Board play a key role in guiding the department's long-term development and fostering interdisciplinary collaboration.

Applied Research at the Ocean Technology Campus

The Ocean Technology Campus Rostock is a cluster of businesses and institutions, combining research and industry in ocean science. Located in the fishing harbour of Rostock with close proximity to the Baltic Sea, the Ocean Technology Campus Rostock strives to create an innovation ecosystem where ideas can flourish. The campus' cutting-edge projects showcase a variety of developing technologies and services- from utilising artificial intelligence for probabilistic digital twins to building an underwater communication network.

One of its projects- OTC-ChemTracer- is concerned with developing an innovative measurement system using membrane inlet photoionization mass spectrometry (MI-PIMS) to detect pollutants and biological markers in seawater in real time. The system not only identifies substances but also locates their sources using concentration gradients and flow data. The planned system combines several key components such as a size-optimized mass spectrometer with high sensitivity, a membrane inlet unit that selectively extracts target analytes from the water, and multiple ionization methods (REMPI, SPI, EI) for flexible analysis of various substance classes. Further components include hyper-fast gas chromatography for rapid separation of complex mixtures and software with real-time data processing, integrated with flow and geospatial data. This technology enables detection limits in a lower ng/L range – a crucial step for reliably locating even the smallest amounts of pollutants.

With a wide range of possible applications, this measurement system can be used for environmental monitoring (e.g. oil spills or pipeline leaks), ecological tracking, detecting underwater munitions and chemical agents, and support scientific research and emergency operations. The collected data can also support marine data banks for citizen science purposes. OTC-ChemTracer involves highly-skilled partners such as the Chair of Analytic Chemistry at the University of Rostock processing data, developing membrane technology, and testing, and Photonion GmbH.

Members: The members of the Department Life, Light and Matter represent a interdisciplinary community of researchers from physics, chemistry, materials science, and life sciences. Together, they advance the department's mission to foster innovation through collaboration and to explore the interfaces between disciplines.

Faculty	Name	Research Area
UMR	Bader, Rainer	Biomechanics and Implant Technology
UMR	Baltrusch, Simone *	Medical Biochemistry and Molecular Biology
MNF	Barke, Ingo	Physics of Surfaces and Interfaces
MNF	Bauer, Dieter	Quantum theory and many-particle systems
LIKAT	Beller, Matthias	Applied Homogeneous Catalysis
LIKAT	Beweries, Torsten	Modern Concepts in Molecular Catalysis
MNF	Bokareva, Olga	Modeling of Metal Complexes during Catalytic Reactions
MNF	Boldt, Klaus	Physical Chemistry - Photonic Nanomaterials
MSF	Buchholz, Bert	Piston Engines and Internal Combustion Engines
MNF	Corzilius, Björn *	Solid-state NMR and Dynamic Nuclear Polarization
UMR	David, Robert *	Regenerative Medicine in Cardiac Surgery
UMR	Engel, Nadja	Oral and Maxillofacial Plastic Surgery
MNF	Fennel, Thomas	Strong-Field Nanophysics
UMR	Frank, Marcus *	Electron Microscopy Centre
UMR	Grabow, Niels *	Biomedical Engineering
MSF	Grundmann, Sven	Fluid Mechanics
MNF	Hage, Boris	Experimental Quantum Optics
MNF	Hagemann, Martin	Plant Physiology
MNF	Hanke, Frederike	Neuroethology
UMR	Jonitz-Heincke, Anika	Cell Biology and Tissue Regeneration
MSF	Keßler, Olaf *	Materials Science
MNF	Klinke, Christian *	Nanostructures and nanomaterials
UMR	Kluess, Daniel	Biomechanics and Implant Technology
MNF	Köckerling, Martin	Solid-State Chemistry
UMR	Köhling, Rüdiger	Neuroscience
MNF	Korn, Tobias	Two-dimensional crystals and heterostructures
MNF	Kragl, Udo *	Industrial Chemistry
MNF	Kraus, Dominik	High Energy Density Physics
MNF	Kühn, Oliver	Molecular Quantum Dynamics Group
AUF	Leinweber, Peter	Soil Science
MNF	Lochbrunner, Stefan *	Dynamics of Molecular Systems
MNF	Ludwig, Ralf	Physical and Theoretical Chemistry
UMR	Lutter, Christopher	Prevention in the Musculoskeletal System and Sports Orthopedics
MNF	Meiwes-Broer, Karl-Heinz *	Clusters and Nanostructures
MSF	Müller, Karsten	Technical Thermodynamics
MNF	Neymeyr, Klaus	Numerical Mathematics
MNF	Nowaczyk, Marc	Biochemistry
UMR	Peters, Kirsten	Cell Biology
SLV	Peters, Rigo	Applied Laser Technologies (company SLV MV)
LIKAT	Pospech, Jola	Catalytic Functionalizations
UMR	Pützer, Brigitte	Experimental Gene Therapy and Cancer Research
MNF	Redmer, Ronald	Statistical Physics
MNF	Reinhard, Friedemann *	Quantum Technology
MNF	Richter, Andreas	Physiology of Plant Metabolism
UMR	Schulz, André	Biomaterials in Ophthalmology
MSF	Seitz, Hermann *	Microfluidics
MNF	Speller, Sylvia *	Physics of Surfaces and Interfaces
UMR	Stachs, Oliver *	Experimental ophthalmology
MNF	Szameit, Alexander	Experimental Solid-State Optics
MNF	Tiggesbäumker, Josef	Clusters and Nanostructures
IEF	Uhrmacher, Adelinde	Modeling and Simulation Methods and Applications
IEF	van Rienen, Ursula	Electromagnetic Field Theory
MNF	Verevkin, Sergej	Physical and Theoretical Chemistry, Chemical Thermodynamics
MSF	Weißgräber, Philipp	Lightweight Design
MSF	Zeller-Plumhoff, Berit *	Data-Driven Analysis and Design of Materials
MNF	Zimmermann, Ralf *	Analytical Chemistry

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