2023 Annual Report

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adolphe merkle institute
excellence in pure and applied nanoscience

About the
Adolphe Merkle Institute

The Adolphe Merkle Institute (AMI) is an independent competence center at the University of Fribourg that focuses on research and education in soft nanomaterials.

We owe our existence to Dr. Adolphe Merkle, a successful local entrepreneur who established the Adolphe Merkle Foundation to strengthen research and teaching at the University of Fribourg. His CHF 100 million endowment constitutes one of Switzerland's most important private donations in favor of academic research.

Founded in 2008, AMI is, in many aspects, unique in the landscape of Switzerland's research institutions. Our focus on soft nanomaterials is unmatched in Switzerland and beyond. Our research combines fundamental and application-oriented aspects in a multidisciplinary setting. Through collaborations with industrial partners, AMI aims to stimulate innovation, foster industrial competitiveness, and improve the quality of life.

Our researchers are currently organized into four primary and two junior research groups, which offer complementary expertise and interests in strategically important areas: BioNanomaterials, Polymer Chemistry and Materials, Soft Matter Physics, Biophysics, Smart Energy Materials, and Mechanoresponsive Materials. Interdisciplinary collaborations between our researchers are the basis for the successful and efficient execution of complex research projects that transcend the boundaries of traditional scientific disciplines. This environment and world-class research facilities make AMI a desirable destination for master's and PhD students, postdocs, and senior researchers.

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_ A message from the Director

Prof. Ullrich Steiner

Dear reader,

As always, it is with great pleasure that I present the Adolphe Merkle Institute's latest annual report, in which we look back at the previous year's most important activities, accomplishments, and developments.

After a year marked by a significant transition for the Institute's leadership in 2022, 2023 was highlighted by a major new collaborative project between Fribourg and New York in soft matter physics to experimentally prove a half-a-century-old theory. The BioNanomaterials group and colleagues also called for better nanowaste management, putting AMI's role in developing new norms and practices in the spotlight.

As always, our research endeavors and successes are the beating heart of this annual report. The Polymer Chemistry and Materials group investigated the recycling and reuse of polymers to reduce their impact on the environment and increase circularity.

Our Smart Energy Materials group focused on hybrid halide perovskites for innovative computing systems, focusing on non-volatile memory and brain-inspired applications. The ability to emulate synaptic functions with these materials could open new avenues for developing advanced computing systems that can operate more like the human brain.

The BioPhysics group developed a groundbreaking technique for analyzing the size and shape of protein aggregates implicated in Parkinson's disease and other neurodegenerative disorders. This approach could enable detailed, single-particle analysis of protein aggregates.

The Soft Matter Physics group investigated the secrets behind the extraordinary black appearance of the *Euprotaetia inexpectata* beetle, whose shell is one of nature's most effective light-absorbing surfaces and could inspire ultra-black materials for various applications, from solar panels to stealth technology.

The Mechanoresponsive Materials group has been developing an innovative method for analyzing mechanical stress and strain in polymers, using mechanochromic molecules that change color or fluorescence when subjected to mechanical forces to visualize and map these stresses at the microscopic level.

Finally, the BioNanomaterials group has developed a multicellular 3D model of the human omentum, a visceral peritoneal fold within the abdominal cavity model, to study ovarian and peritoneal cancer formation. This is aimed at providing a better understanding of how these cancers spread. The group has also pursued its investigations into microplastics, developing a workflow to detect and observe interactions with marine life.

You will find more coverage of some of the achievements of our researchers in our "In Brief" section, with highlights from the last year that range from significant awards to innovative collaborations and promotions.

We hope you enjoy reading this report, and thank you for your interest in our institute, our team, and our activities.

Ullrich Steiner
AMI Director and Chair of Soft Matter Physics


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LabAirTec
15 02 99
Centrifuge Tubes

7

Pursuing excellence

Synergy
_ Collaborating to trap light

Clouds are an example of efficient light reflection

Researchers at the Adolphe Merkle Institute, the University of Fribourg, and New York University are investigating materials that could diffusely reflect all rays of incoming light, with long-term potential applications for example in light-based computing. Their work is being funded by a Swiss National Science Foundation (SNSF) Sinergia grant worth nearly CHF 2.8 million.

Clouds, milk, bones – all have one thing in common: they're white because their constituents are sized and arranged in ways that efficiently reflect light. AMI's Chair of Soft Matter Physics Prof. Ullrich Steiner and Prof. Frank Scheffold (Department of Physics, University of Fribourg) will attempt along with their colleague Prof. David Pine (New York University) to further our understanding of reflection by creating materials that integrate a phenomenon applicable to all kinds of waves but has yet to be observed experimentally for light in bulk materials. This phenomenon was described in the 1950s by the physicist and Nobel-prize winner Philip Anderson, who showed how an electron and its quantum wave could be trapped in a disordered medium. This so-called 'Anderson localization' was then proposed to be also applicable to light waves. One way of understanding this is visualizing a complex maze where the walls are made of randomly placed mirrors. Light entering the maze might become "trapped" in certain areas due to the random reflections, analogous to how electrons become localized in disordered materials.

"The question on our minds is whether these waves can actually be scattered in a random medium in such a way that they never emerge," explains Steiner. "This theoretically predicted effect has never been observed experimentally."

Anderson localization of light would in theory generate perfect reflection, and anything close would generate strong reflection already for very thin layers of a material. Scheffold has already shown with computer simulations that so-called disordered hyperuniform materials could reflect, with the right nano-architecture, nearly all incoming light. These structures, which are starting to be discovered in nature, fall somewhere between highly organized crystals and disordered materials. Researchers see several potential applications by creating a channel within the material. By doing so, light could not escape and be guided. This type of material could be used to develop ultrafast optical computers and devices, replacing certain types of electronics.

To create a material with strong localization characteristics, the researchers will develop nanoscale building blocks designed to form three-dimensional networks. The design of these blocks will allow them to tweak morphologies, from perfectly periodic lattices to almost randomly assembled networks. “This will allow us to explore the order-disorder parameter space in an unprecedented fashion, providing a new avenue in the study of light localization in disordered but highly correlated network morphologies,” adds Steiner.

“The question on our minds is whether these waves can actually be scattered in a random medium in such a way that they never emerge.”
Prof. Ulllrich Steiner,
AMI Chair of Soft Matter Physics

The research is funded by an SNSF Sinergia grant worth CHF 2.77 million over four years. The Sinergia program promotes the interdisciplinary collaboration of two to four research groups that propose breakthrough research. The project reflects that by drawing on the strengths of the different research groups. The Pine laboratory in New York has developed over the past two decades a colloidal system that provides unprecedented control over mesoscopic (1 μm) network assembly. His sculpted colloids are tiny tetrahedral building blocks, from which colloidal diamond lattices can be constructed. They can be designed to create lattices with varying local constraints, allowing a continuous crossover from ordered diamond networks to those with a controlled increase in disorder. These lattices can then be replicated into high-refractive index materials. AMI’s Soft Matter Physics group has developed high-resolution tomography methods allowing researchers to characterize the order-disorder interplay of seemingly disordered materials in great detail, as well as reducing light absorption in materials. These techniques will be applied to characterize the disordered diamond-based lattices that will be produced in this project. Finally, the Scheffold laboratory has wide experience in characterizing the multiple scattering of light in optically dense materials. This will be vital to demonstrate experimentally that strong localization of light is indeed observed in the manufactured materials.

Potential practical applications of Anderson localization

Optical Fibers and Communications
Anderson localization could be used to improve signal transmission in optical fibers. It may also allow for better image transport through disordered materials, potentially leading to thinner and more flexible fiber optic cables.

Electronics and Conductivity
The phenomenon helps explain why some materials become insulators under certain conditions. This understanding is crucial for developing and optimizing electronic components, especially as devices get smaller and quantum effects become possibly more prominent.

Photonics and Light Control
Anderson localization could be used to manipulate light in photonic devices. This could lead to novel optical sensors or allow to control light emission in LEDs and lasers.

28

NATIONALITIES

PRESENT AT AMI WITH REPRESENTATIVES FROM EVERY CONTINENT.

7

PROFESSORS

WORKING ACROSS THE FIELDS OF POLYMER SCIENCE, MATERIALS, PHYSICS, CHEMISTRY, AND BIOLOGY.

65%

OF ALL RESEARCH EXPENDITURES

WERE COVERED BY THIRD-PARTY FUNDING. SOURCES INCLUDED THE SWISS NATIONAL SCIENCE FOUNDATION, THE EUROPEAN UNION, INNOSUISSE, AND INDUSTRIAL PARTNERS.

OVER

6,200

CITATIONS

OF AMI PUBLICATIONS IN THE SCIENTIFIC LITERATURE IN 2023.

4

APPLICATION-ORIENTED

PROJECTS

FINANCED BY INNOSUISSE, THE SWISS INNOVATION AGENCY, AND OTHER PARTNERS.

73

SCIENTIFIC PUBLICATIONS

IN TOP-RANKED JOURNALS SUCH AS ADVANCED MATERIALS, SMALL, NATURE CHEMISTRY, ANGEWANDTE CHEMIE, MATERIALS TODAY ADVANCES, ACS APPLIED MATERIALS & INTERFACES, MACROMOLECULES, NATURE NANOTECHNOLOGY, POLYMERS, ENVIRONMENTAL SCIENCE & TECHNOLOGY, NATURE MATERIALS.

480+

ALUMNI

INCLUDING POSTDOCTORAL RESEARCHERS, PHD STUDENTS AND INTERNS.

Cleaning up

_ Calling for better nanowaste management

Just like regular trash management, nanowaste should be regulated

Waste containing nanomaterials — or nanowaste — is an emerging safety concern worldwide, requiring environmentally sound management and regulation that still need to be established. Researchers from the Adolphe Merkle Institute's BioNanomaterials group and colleagues have pointed out the gaps and provided initial solutions for guidance.

Nanowaste includes manufacturing waste materials, end-of-life nano-enabled products, and waste (unintentionally) contaminated with engineered nanomaterials. More than 60 percent of engineered nanomaterials (up to 300,000 tons annually, not including nanoplastics) are estimated to end up in landfill. And while there are currently no global definitions or classifications for nanomaterials or nanowaste, there is a need for tangible solutions related to risk assessment, categorization, labeling, collection, storage, transport, recycling, and elimination.

Writing in the leading scientific journal *Nature Nanotechnology*, researchers from the AMI BioNanomaterials group, along with colleagues from the University of Fribourg and EPFL, have been advocating for awareness of the issue, and the need for technical and legally binding nanowaste guidelines strictly based on the precautionary principle. These should rely on state-of-the-art knowledge of nanomaterial behavior, and a lenient definition of nanomaterials.

"Nanomaterials exhibit unique physicochemical behaviors due to their specific sizes, compositions, surfaces, and shapes, necessitating specialized waste management approaches compared to regular chemical waste," explains BioNanomaterials co-chair Prof. Alke Fink.

Developing these initial guidelines requires case-by-case risk assessments of the specific nanowastes generated, a detailed understanding of national and international hazardous waste and materials regulations, and collaboration with laboratory staff to derive user-friendly ways to collect, store, and eliminate this waste.

As the researchers point out, a series of measures have already been implemented, in collaboration with the University of Fribourg safety officers, at the Institute. These include proper labeling and storage, due to the absence of nanowaste-specific regulations, according to national and international hazardous material legislation, detailed guidelines on how to dispose of nanowaste correctly, and consolidation of this waste into a few legally permissible categories.

> "Nanomaterials exhibit unique physicochemical behaviors due to their specific sizes, compositions, surfaces, and shapes, necessitating specialized waste management approaches compared to regular chemical waste."
> *Prof. Alke Fink, BioNanomaterials Co-Chair*

"It was important for AMI as a nanoscience center to play a leading role in helping kickstart this process," points out Fink. "The initiative has to come from scientists as we have the best understanding of nanomaterials."

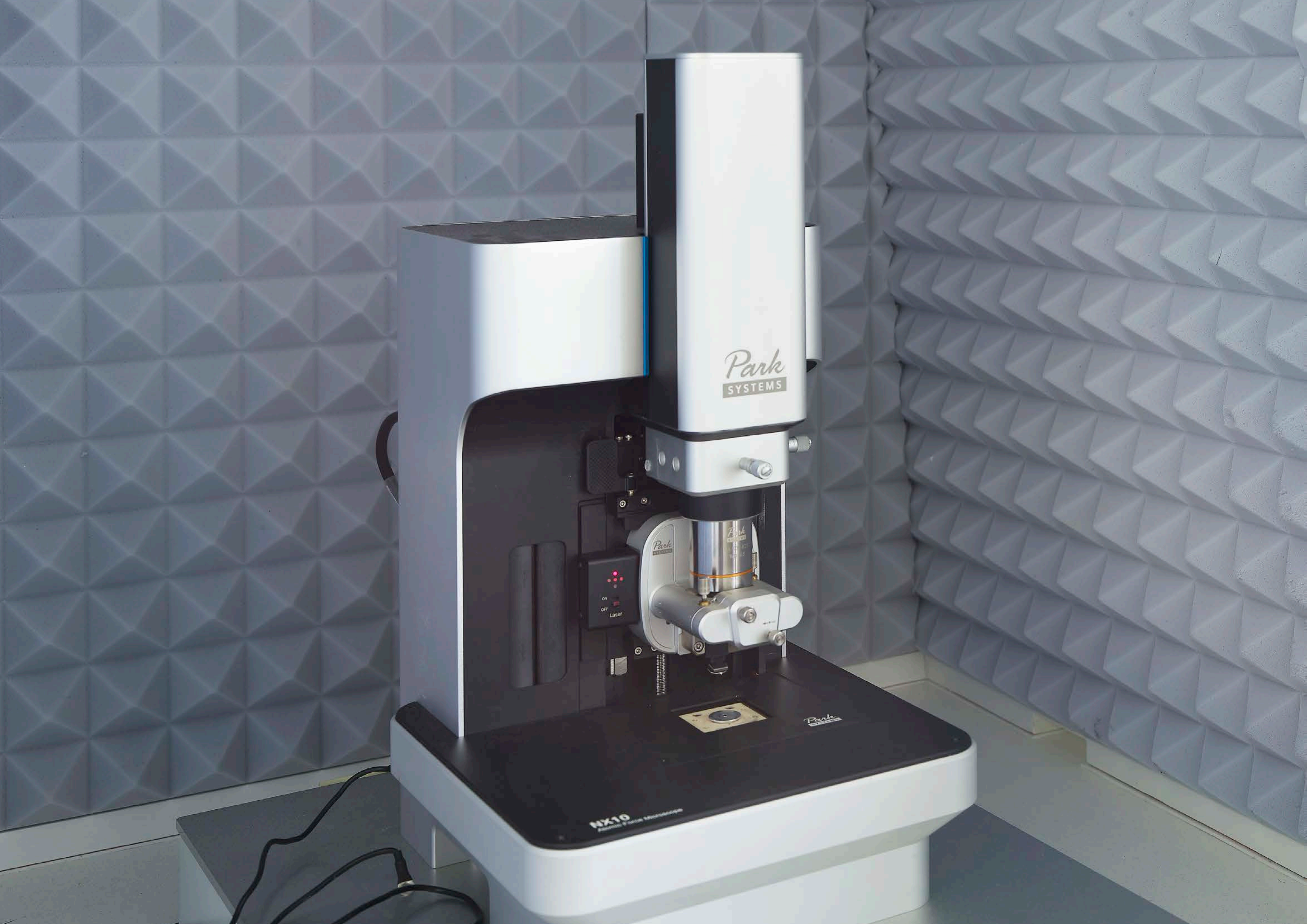
For research laboratories, such guidelines are especially important due to the high complexity of the waste generated, the presence of a great variety of untested materials, and the many different laboratory users, say the authors. More explicit rules for nanowaste, such as specific pictograms, could also help to harmonize nanowaste management in industry, prevent the misclassification of dangerous substances into nonhazardous categories, and avoid unintentional exposure of people and the environment to hazardous nanomaterials.

The recommendations presented in the article are targeted at researchers and policymakers in academia and industry. To protect human health and the environment, the researchers urge increased awareness and action to manage nanowaste, as well as the explicit inclusion of nanowaste management into multinational agreements. "The Basel Convention, which governs hazardous waste, could for example be amended to explicitly address nanowaste, ensuring international compliance and safety," adds Fink.

They also caution policymakers to avoid double standards that would stifle the replacement of more hazardous conventional chemicals with novel, less harmful, and degradable nanomaterials.

Reference

Schwab, F.; Rothen-Rutishauser, B.; Scherz, A.; Meyer, T.; Karakoçak, B. B.; Petri-Fink, A. The Need for Awareness and Action in Managing Nanowaste. *Nat. Nanotechnol.* **2023**, 1–5. https://doi.org/10.1038/s41565-023-01331-4.


Park
SYSTEMS
ON
OFF
Laser
NX10

40

ACTIVE RESEARCH PROJECTS

IN FIELDS SUCH AS BIO-INSPIRED MATERIALS, PEROVSKITE SOLAR CELLS, PHOTONIC STRUCTURAL MATERIALS, MECHANOCHEMISTRY, SUPRAMOLECULAR POLYMERS, DETECTION AND CHARACTERIZATION OF NANOPARTICLES, NANOPORE FABRICATION, SINGLE-MOLECULE DETECTION.

CHF 9.13 M

SPENT OVERALL IN 2023

RESEARCH EXPENDITURES WERE CHF 7.87 MILLION, A SLIGHT INCREASE OVER 2022.

46%

OF STAFF AT AMI ARE WOMEN

37

SEMINARS

GIVEN BY EXTERNAL RESEARCHERS, AND AMI STUDENTS.

97

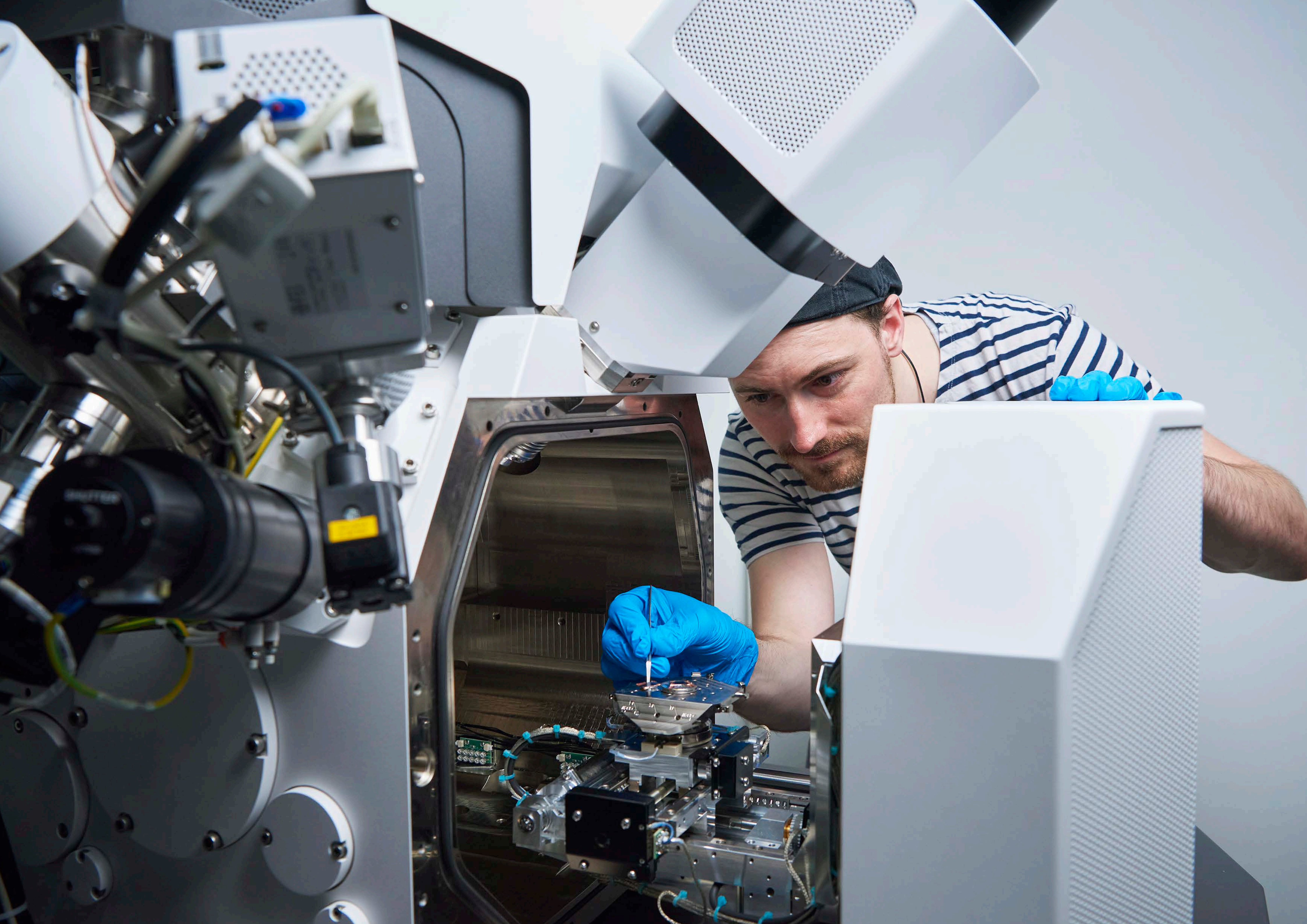
PEOPLE

WORKED AT AMI AT THE END OF 2023, INCLUDING PHD STUDENTS, POSTDOCTORAL RESEARCHERS, PROFESSORS, SUPPORT STAFF, AND INTERNS.

40%

OF THE AMI RESEARCHERS

ARE DOCTORAL STUDENTS.



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_Research at AMI

Efficiently recycling
_ Breaking down polymers

Researchers from the Adolphe Merkle Institute's Polymer Chemistry and Materials group are investigating the recycling and reuse of polymers with the goal of reducing their impact on the environment and increasing circularity.

Since the beginning of the 20th century, synthetic plastics and other polymeric materials have become an integral part of our daily lives, but their production from petrochemical feedstock and current end-of-life scenarios are not sustainable. Moreover, conventional polymers, such as those used in plastic bottles and other packaging applications, are not easily degradable and contribute to environmental pollution.

"Plastic pollution is a really important issue, so devising energy- and cost-efficient strategies for their depolymerization and the recovery of their structural components in high yield and purity is key to a circular plastics economy," explains Prof. Christoph Weder.

Recycling is particularly difficult for polymer networks, which are used in applications where high durability is important, for example, automotive tires, and wind turbine blades. These products create large amounts of waste that is difficult or impossible to recycle. One approach to solve this problem is to form the networks with dynamic bonds, which under certain conditions can break and reform easily. This concept gained significant traction in the last decade when researchers started producing a class of plastics known as vitrimers. Despite their network structure, these materials flow when heated and can, therefore, be reshaped – i.e., recycled – multiple times without a loss in mechanical properties, which is one of the key problems in the mechanical recycling of conventional plastics.

To create such vitrimers, researchers have exploited different kinds of reversible bonds, including so-called vinylogous urethanes (VU). This bond type has been used to make many different vitrimers that were demonstrated to be mechanically recyclable. Interestingly, the chemical recycling of such materials has been largely ignored. In chemical recycling processes, the polymer is chemically degraded to its building blocks, i.e., the monomers, which can subsequently be used to make new polymers. Chemical recycling affords products of higher quality than mechanical recycling, but it is generally less cost- and energy-effective than mechanical recycling and has a larger environmental footprint.

The AMI researchers recently demonstrated that polymers based on VU bonds can be chemically recycled at ambient temperatures upon reaction with water. This approach allows for the recovery of the original materials, even when the polymers are originally part of a waste mix that emulates typical household waste. "The depolymerization rate can be easily adjusted using factors such as the reaction temperature, the amount of water, and the nature and ratio of the two monomers," explains Weder. "We can also fine-tune the mechanical properties of the resulting materials."

The fact that the conditions under which the VU based polymers are degraded by water can be widely controlled is important. The AMI researchers demonstrated that it is, on the one hand, possible to design polymers that degrade in water within hours, and this can help to reduce the environmental impact when such materials are released into the environment. On the other hand, they also produced materials that are highly stable in pure water. In this case, an additional solvent that transports the water into the polymer is required to degrade the material. This approach affords water-proof materials, which, however, can be recycled on demand. "We hope our results will encourage researchers to pursue the further development of chemical recycling of VU-based polymers," says Weder.

References:

Ma, Y.; Jiang, X.; Shi, Z.; Berrocal, J. A.; Weder, C. Closed-Loop Recycling of Vinylogous Urethane Vitrimers. *Angew. Chem. Int. Ed.* **2023**, 62, e202306188.

Ma, Y.; Jiang, X.; Yin, J.; Weder, C.; Berrocal, J.A.; Shi, Z.; Chemical Upcycling of Conventional Polyureas into Dynamic Covalent Poly(aminoketoenamide)s; *Angew. Chem. Int. Ed.* **2023**, 62, e202212870.

Prof. Christoph Weder is AMI's Chair of Polymer Chemistry and Materials. He joined the Institute from Case Western Reserve University in 2009. In 2010, he became the Institute Director, serving in this position for 12 years. From 2014 to 2020, he was also the Director of the National Competence Center in Research (NCCR) Bio-Inspired Materials, based at AMI.

Polymers

Team

Prof. Christoph Weder, Dr. José Berrocal, Luca Bertossi, Véronique Buclin, Dr. Satyajit Das, Matilde Folkesson, Dr. Georges Formon, Chantal Graafsma, Luca Grillo, Dr. James Hemmer, Xueqian Hu, Derek Kiebala, Davide Lardani, Chaninya Mak-Iad, Franziska Marx, Marta Oggioni, Ilaria Onori, Chris Rader, Anita Roulin, Dr. Athanasios Skandalis

Key Publications

1. Mori, R.; Weder, C.; Sagara, Y. Mechanical (De)Activation of Rotaxane Mechanophores: Axle Length Matters. *Macromolecules* **2023**, 56, 9248–9254.

2. Hemmer, J.R.; Bauernfeind, V.; Rader, C.; Weder, C.; Berrocal, J.A. Triarylmethane mechanophores enable full visible spectrum mechanochromism. *Macromolecules* **2023**, 56, 8614–8622.

3. Marx, F.; Beccard, M.; Ianiro, A.; Dodero, A.; Neumann, L.; Stoclet, G.; Weder, C.; Schrettl, S. Structure and Properties of Metallosupramolecular Polymers with a Nitrogen-based Bidentate Ligand. *Macromolecules* **2023**, 56, 7320–7331.

4. Kiebala, D.J.; Style, R.; Vanhecke, D.; Calvino, C.; Weder, C.; Schrettl, S. Sub-micrometer mechanochromic inclusions enable strain sensing in polymers. *Adv. Funct. Mater.* **2023** 2304938.

5. Muff, L.; Mills, A.S.; Riddle, S.; Buclin, V.; Roulin, A.; Chiel, H.J.; Quinn, R.D.; Weder, C.; Daltorio, K.A. Modular design of a polymer-bilayer-based mechanically compliant worm-like robot. *Advanced Materials* **2023**, 34, 2210409.

Perovskites

_ Designing artificial synapses for brain-inspired computing

The Adolphe Merkle Institute's Smart Energy Materials group has investigated hybrid halide perovskites for innovative computing systems, focusing on non-volatile memory and brain-inspired applications. Their results highlight the significant potential of these materials in creating more efficient and reliable resistive switching memory devices and artificial synapses.

Brain-inspired, or neuromorphic, computing suggests a fundamentally different way to process information with energy efficiency and the ability to handle vast amounts of data. Conventional computing systems are considered inefficient because of their heightened power consumption due to the so-called "von Neumann bottleneck," which refers to the constrained throughput between memory and processing units. On the other hand, the brain performs both "tasks" in a single unit, which consumes only about 20 watts, compared to the megawatts of power currently required by a digital supercomputer simulation of an equivalent artificial neural network. By mimicking the brain's approach to information processing, Neuromorphic systems can achieve substantial energy savings and handle real-world applications more effectively.

The Smart Energy Materials group, led by Prof. Jovana Milic, in collaboration with Prof. Mahesh Kumar from the Indian Institute of Technology in Jodhpur (IITJ), studied layered Ruddlesden-Popper hybrid perovskites based on benzylammonium cations that included either bromide or iodide in their composition. They were interested in hybrid perovskite materials because of their unique soft yet crystalline structure and mixed electronic-ionic conduction that has potential in artificial synapses and numerous other applications, including for solar cells and LEDs. The focus for this project, though, was the switching behavior of the perovskites for use in neuromorphic computing. The memory devices demonstrated notable resistive switching characteristics associated with ion movements, essential for non-volatile memory applications. Unlike conventional 3D perovskites previously explored, these layered (2D) perovskites displayed higher stability during operation. Moreover, the study revealed that iodide-based devices exhibited gradual set and reset processes with reduced power consumption, while bromide-based devices showed more abrupt switching behavior but with superior on/off ratios. These variations provide options for optimizing device performance based on specific application requirements.

A significant discovery was the transformation from digital (a sharp set and reset process) in the bromide perovskite to analog resistive switching (gradual change in resistance states) in the iodide systems, operating like synapses in the brain. This unique transformation is critical for the advancements of modern computing, allowing for more gradual changes in resistance. As a result, iodide-based devices also showed promising synaptic behavior, including key characteristics such as potentiation (the strengthening of synaptic connections between neurons), depression (a reduction in synaptic strength that occurs in response to activity), and paired-pulse facilitation (a process by which neural activity is increased or made more efficient due to prior activation). These properties are vital for mimicking biological synapses.

The findings from this study, published in the journal Materials Advances, highlight the potential of layered hybrid halide perovskites for future applications in neuromorphic computing. The demonstrated ability to emulate synaptic functions with these materials opens new avenues for developing advanced computing systems that can operate more like the human brain.

"Our research showcases the versatility and potential of layered hybrid perovskites for memory and neuromorphic applications," says Milic. "The transition from digital to analog resistive switching in these materials is particularly exciting for developing more efficient and biologically inspired computing technologies in the future."

References

Ganaie, M.; Bravetti, G.; Sahu, S.; Kumar, M.; V. Milić, J. Resistive Switching in Benzylammonium-Based Ruddlesden-Popper Layered Hybrid Perovskites for Non-Volatile Memory and Neuromorphic Computing. *Mater. Adv.* **2024**, 5 (5), 1880–1886.

Dr. Gianluca Bravetti joined the Smart Energy Materials group in 2023 as a postdoctoral researcher after completing his PhD with Italy's Consiglio Nazionale delle Ricerche in Lecce. His work focused on a Swiss National Science Foundation (SNSF) Spark project aimed at developing metal-free all-organic molecular perovskites for optoelectronics and energy technologies.

Smart Energy Materials

Team

Prof. Jovana Milic, Ghewa Alsabeh, Dr. Gianluca Bravetti, Jovan Lukic, Weifan Luo, Murad Najafav, Mengqiong Zhu

Key Publications

1. Kim, S.-J.; Kumar Chitumalla, R.; Kim, J.-M.; Jang, J.; Oh, J.-W.; Milić, J. V.; Seo, J.-Y. Controlled Growth of Hybrid Halide Perovskites by Crown Ether Complexation for Perovskite Solar Cells. *Helv. Chim. Acta* **2023**, 106 (4), e202200193.

2. Ochoa-Martinez, E.; Bijani-Chiquero, S.; Martínez de Yuso, M. del V.; Sarkar, S.; Diaz-Perez, H.; Mejia-Castellanos, R.; Eickemeyer, F.; Grätzel, M.; Steiner, U.; Milić, J. V. Nanocrystalline Flash Annealed Nickel Oxide for Large Area Perovskite Solar Cells. *Adv. Sci.* **2023**, 10 (23), 2302549.

3. John, T.; Cordova, K. E.; Jackson, C. T.; Hernández-Mondragón, A. C.; Davids, B. L.; Raheja, L.; Milić, J. V.; Borges, J. Engaging Early-Career Scientists in Global Policy-Making. *Angew. Chem. Int. Ed.* **2023**, 62 (34), e202217841.

4. Krause, S.; Milić, J. V. Functional Dynamics in Framework Materials. *Commun Chem* **2023**, 6 (1), 1–8.

5. Ferdowsi, P.; Bravetti, G.; Schmidt, M. C.; Ochoa-Martinez, E.; Bijani, S.; Rizzo, A.; Colella, S.; Steiner, U.; Ehrler, B.; Kubicki, D. J.; Milić, J. V. Host–Guest Complexation in Wide Bandgap Perovskite Solar Cells. *Solar RRL* **2024**, 8 (1), 2300655.

Nanopores

_ Characterizing toxic protein aggregates quickly

A groundbreaking technique developed by the Adolphe Merkle Institute's BioPhysics group promises to improve our understanding and potential treatment of Parkinson's disease and other neurodegenerative disorders. Using nanopore technology, this new method allows for the size and shape analysis of protein aggregates known as α-synuclein (αSyn) oligomers.

Neurodegenerative diseases, including Parkinson's, dementia with Lewy bodies, and multiple system atrophy, share a common feature: the misfolding and aggregation of the αSyn protein. These aggregates, or oligomers, are thought to play a critical role in the progression of these diseases. However, studying these oligomers has proven difficult due to their small size, varied nature, and formation process.

In a study published in the journal *ACS Nano*, the AMI BioPhysics group introduced a method utilizing polymer-coated solid-state nanopores to measure resistive pulses. This innovative approach allows scientists to characterize individual αSyn oligomers in solution rapidly and with high resolution. "This technique provides unprecedented detail on the size and shape of αSyn oligomers, which are important for understanding their toxicity," explains the AMI Chair of BioPhysics, Prof. Michael Mayer. "It overcomes the limitations of previous methods, offering superior resolution and faster analysis."

The study reveals that this nanopore-based method can identify ten distinct subpopulations of αSyn oligomer sizes, ranging from small aggregates to larger structures. These findings were validated through comparison with traditional techniques such as transmission electron microscopy and mass photometry. However, one advantage of this new approach is that the analysis occurs in the solution of oligomers and is, therefore, much faster.

Moreover, the new method can approximate the shapes of these oligomers, providing insights that align with previous estimates obtained through more labor-intensive methods like cryo-electron microscopy. This capability is significant because the shape and size of oligomers are linked to their ability to form toxic pores in cell membranes, a likely factor in their neurotoxicity.

Given the putative association between elevated levels of αSyn oligomers and the onset of neurodegenerative diseases, this method could become an enabling tool for early diagnosis. Traditional immunoassays often struggle to differentiate between oligomers and other forms of αSyn, but the nanopore technique's precise size and shape measurements could provide more reliable biomarkers.

"This technology could lead to more accurate and earlier diagnosis of diseases like Parkinson's," says Mayer. "It also opens new avenues for developing treatments that target specific oligomeric forms of αSyn, potentially halting or even reversing disease progression."

This approach could enhance our understanding of numerous neurodegenerative diseases beyond those caused by αSyn by enabling detailed, single-particle analysis of protein aggregates. "Our goal is to make this method widely accessible," adds Mayer. "With further development, it could become a standard tool in both research and clinical settings, providing critical data to help combat these devastating diseases."

Reference

Awasthi, S.; Ying, C.; Li, J.; Mayer, M. Simultaneous Determination of the Size and Shape of Single α-Synuclein Oligomers in Solution. *ACS Nano* **2023**, 17 (13), 12325–12335.

Prof. Michael Mayer is AMI's Chair of BioPhysics, a position he took up in 2015. Previously, he was a professor of biomedical engineering and biophysics at the University of Michigan (United States) where he had been working since 2004. He is also AMI's Deputy Director since 2022.

BioPhysics

Team

Prof. Michael Mayer, Dr. Saurabh Awasthi, Wachara Chanakul, Jessica Dupasquier, Dr. Alessandro Ianiro, Edona Karakaci, Asia Lanuti, Dr. Yu-Noel Larpin, Yuanjie Li, Dr. Pau Molet Bachs, Dr. Anasua Mukhopadhyay, Dr. Liviana Mummolo, Carolina Pierucci, Marian Reincke, Dr. Maria Sanz, Dr. Christian Sproncken, Anna Wald, Andela Vracar, Dr. Justus Wesseler

Key Publications

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2. Yousefi, A.; Ying, C.; Parmenter, C. D. J.; Assadipapari, M.; Sanderson, G.; Zheng, Z.; Xu, L.; Zargarbashi, S.; Hickman, G. J.; Cousins, R. B.; Mellor, C. J.; Mayer, M.; Rahmani, M. Optical Monitoring of In Situ Iron Loading into Single, Native Ferritin Proteins. *Nano Lett.* **2023**, 23 (8), 3251–3258.

3. Awasthi, S.; Mayer, M. Single Particle Mass Photometry Provides Size Distributions of Tau Oligomers in CSF Samples Revealing Strong Differences between Samples from Alzheimer's Patients and Healthy Controls. *Alzheimers Dement.* **2023**, 19 (S2), e067661.

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5. Awasthi, S.; Mummolo, L.; Li, Y.; Bryan, L.; Nirmalraj, P. N.; Balog, S.; Yang, J.; Mayer, M. Fluorescently Labelled Tau Protein: Highlights of Analytical Sciences in Switzerland. *CHIMIA* **2023**, 77 (12), 874–874.

Back to black

_ Beetle indicates the path to highly absorptive materials

Researchers from the Adolphe Merkle Institute's Soft Matter Physics group have unveiled the secrets behind the extraordinary black appearance of the *Euprotaetia inexpectata* beetle. Its shell is one of nature's most effective light-absorbing surfaces and could inspire ultra-black materials for various applications, from solar panels to stealth technology.

Structural absorption is a phenomenon that occurs when superficial features enhance the capacity of a material to absorb light. Surfaces that absorb more than 99 percent of incident light are commonly referred to as 'super-black' or 'ultra-black.' A notable property of these black surfaces is their lack of specular reflection, which occurs when light is reflected in a single outgoing direction, much like a mirror. The most widely recognized high-absorptivity materials are vertically aligned carbon nanotubes and etched nickel-phosphorous alloys with absorptivity values above 99.9 percent over the entire visible wavelength range. The unique properties and appearance of materials with very low reflectivities make them ideal for many applications, including solar energy conversion, stray light capture in optical instruments, and artistic displays.

The *Euprotaetia inexpectata* beetle, found in various regions, including the Philippines, has a shell that absorbs up to 99.5 percent of light, making it one of the blackest natural substances recorded. The key to this phenomenon lies in the beetle's elytra – its hardened forewings – which are covered with tiny micropillars. These structures significantly enhance light absorption, reducing reflectivity to as low as 0.1 percent. The low reflectance values are in part based on light guided through Mie scattering. This scattering is significant at dimensions comparable to the wavelength of the incident light. For example, multiple Mie scattering due to interactions with water droplets causes clouds to appear white. "Mie scattering at the micropillar of the beetle guides the light through the pillar, from where it is efficiently scattered in the forward direction, into the beetle's cuticle," explains Dr. Viola Vogler-Neuling. "The pillar itself and the cuticle absorb the light through integrated melanin, the same absorbing pigment that darkens our skin, hair, and eyes."

This research underscores the independent evolution of highly absorptive surfaces in nature. The beetle's unique construction adds to understanding how diverse organisms have evolved to minimize light reflection for survival benefits, such as camouflage or communication. Similar super-black appearances are found in butterflies, birds, and spiders, but the mechanisms can differ significantly. "One example is the bird of paradise, which exploits highly modified barbule arrays in their super-black feathers that enhance multiple light scattering," adds Vogler-Neuling. "The light is scattered more often and is partially absorbed during each scattering event."

The insights gained from the *Euprotaetia* beetle could inspire potential bio-inspired applications for creating highly absorptive materials. By mimicking the beetle's micropillar structures, scientists could develop ultra-black surface coatings for a range of applications, from solar panels to stealth technology. And compared to other ultra-black materials like carbon nanotubes or nickel-phosphorous alloys, these structures would be non-toxic and not require complex wastewater treatment.

Reference

Parisotto, A.; Vogler-Neuling, V. V.; Steiner, U.; Saba, M.; Wilts, B. D. Structural Light Absorption in Elytral Micropillars of *Euprotaetia Inexpectata* Beetles. *Mater. Today Adv.* **2023**, 19, 100399.

Dr. Viola Vogler-Neuling joined the AMI Soft Matter Physics group in 2022 after completing her PhD thesis at the Federal Institute of Technology in Zurich. In 2024, she was promoted to group leader. Her current research interests include photonic crystals and bio-inspired photonics.

Soft Matter Physics

Team

Prof. Ullrich Steiner, Doha Abdelrahman, Bilel Abdennadher, Martino Airoldi, Viola Bauernfeind, Nicolas Bruder, Victoire de Cabannes de Cauna Kenza Djegdhi, Dr. Andrea Dodero, Andrea Escher, Dr. Ilja Gunkel, Florin Hemmann, René Iseli, Thomas Kainz, Tri Minh Nguyen, Andrea Palumbo, Alessandro Parisotto, Cristina Prado, Dr. Matthias Saba, Cédric Schumacher, Niklas Schwarz, Brian van Büren, Dr. Viola Vogler-Neuling.

Key Publications

1. Bauernfeind, V.; Djeghdi, K.; Gunkel, I.; Steiner, U.; Wilts, B. D. Photonic Amorphous I-WP-Like Networks Create Angle-Independent Colors in Sternotomis Virescens Longhorn Beetles. *Adv. Funct. Mater.* **2024**, 34 (35), 2302720.

2. Tri Nguyen, M.; Quang Pham, H.; Augusto Berrocal, J.; Gunkel, I.; Steiner, U. An Electrolyte Additive for the Improved High Voltage Performance of LiNi 0.5 Mn 1.5 O 4 (LNMO) Cathodes in Li-Ion Batteries. *J. Mater. Chem. A* **2023**, 11 (14), 7670–7678.

3. Dodero, A.; Djeghdi, K.; Bauernfeind, V.; Airoldi, M.; Wilts, B. D.; Weder, C.; Steiner, U.; Gunkel, I. Robust Full-Spectral Color Tuning of Photonic Colloids. *Small* **2023**, 19 (6), 2205438.

4. Abdelrahman, D.; Iseli, R.; Musya, M.; Jinnai, B.; Fukami, S.; Yuasa, T.; Sai, H.; Wiesner, U. B.; Saba, M.; Wilts, B. D.; Steiner, U.; Llandro, J.; Gunkel, I. Directed Self-Assembly of Diamond Networks in Triblock Terpolymer Films on Patterned Substrates. *ACS Appl. Mater. Interfaces* **2023**, 15 (50), 57981–57991.

5. Wang, W.; Günzler, A.; Wilts, B. D.; Steiner, U.; Saba, M. Unconventional Bound States in the Continuum from Metamaterial-Induced Electron Acoustic Waves. *AP* **2023**, 5 (5), 056005.

Breaking point

_ Predicting polymer failures

The Adolphe Merkle Institute's Mechanoresponsive Materials group has developed an innovative technique for analyzing mechanical stress and strain in polymers. This method uses mechanochromic materials, which change color or fluorescence when subjected to mechanical forces, to visualize and map these stresses at the microscopic level.

Understanding how defects in polymer materials react under mechanical stress is crucial for preventing catastrophic failures. Defects often cause localized stress and strain that can lead to crack initiation and propagation. Traditional methods of studying these phenomena lack the resolution to capture the intricate details at the molecular level. Mechanochromic mechanophores, which change their optical properties (color or fluorescence) in response to mechanical deformation, provide a promising solution. These mechanophores allow for the visualization of stress and strain distributions within polymers in real time. However, existing mechanochromic materials, typically based on rupturing covalent bonds, require significant force to activate and often provide irreversible signals, limiting their usefulness in detecting early-stage mechanical processes.

The research from the Mechanoresponsive Materials group introduces a novel protocol that combines optical microscopy, tensile testing, and image processing to create detailed maps of local strain around defects in polymers. This method uses mechanophores with weaker bonds that respond to smaller forces compared to pre-existing mechanophores, making them suitable for detecting low-stress mechanical processes. The scientists used three different supramolecular mechanophores to investigate their thesis. These mechanophores showed reversible optical changes under testing, enabling repeated measurements.

The researchers incorporated the mechanophores into polyurethane films, and then introduced circular defects. The films were then put under tension while optical changes were monitored with a fluorescence microscope. The researchers calibrated the mechanochromic response against the applied strain, allowing them to convert fluorescence images into maps of local strain distributions. This approach was validated using the three different mechanochromic systems and extended to study more complex strain distributions in polymers containing inorganic microparticles. The study found that local strain around defects can differ significantly from the applied external strain. The strain maps revealed intricate deformation patterns that would be missed by traditional bulk measurement techniques. For instance, regions near defects exhibited much higher local strains, which are critical for understanding the onset of material failure. The method proved to be sensitive and versatile, capable of detecting both macroscopic and microscopic strain variations.

This new strain-mapping approach provides a powerful tool for studying mechanical deformation in polymers. By enabling detailed visualization of strain distributions at the microscopic level, it enhances the ability to predict material failure and design more resilient polymeric materials. The protocol is generalizable and can be applied to a wide range of polymers and mechanophore types, paving the way for potential broader adoption in material science research.

Reference

Traeger, H.; Kiebala, D.; Calvino, C.; Sagara, Y.; Schrettl, S.; Weder, C.; Clough, J. M. Microscopic Strain Mapping in Polymers Equipped with Non-Covalent Mechanochromic Motifs. *Mater. Horiz.* **2023**, 10 (9), 3467–3475.

Mechanoresponsive Materials

Team

Prof. Jessica Clough, Yang Li, Hrishikesan Kalpakassery Pattam, Iulia Scarlat

Key Publications

1. Muramatsu, T.; Shimizu, S.; Clough, J. M.; Weder, C.; Sagara, Y. Force-Induced Shuttling of Rotaxanes Controls Fluorescence Resonance Energy Transfer in Polymer Hydrogels. *ACS Appl. Mater. Interfaces* **2023**, 15 (6), 8502–8509.

2. Clough, J. M.; Kilchoer, C.; Wilts, B. D.; Weder, C. Hierarchically Structured Deformation-Sensing Mechanochromic Pigments. *Adv. Sci.* **2023**, 10 (13), 2206416.

3. Traeger, H.; Kiebala, D.; Calvino, C.; Sagara, Y.; Schrettl, S.; Weder, C.; Clough, J. M. Microscopic Strain Mapping in Polymers Equipped with Non-Covalent Mechanochromic Motifs. *Mater. Horiz.* **2023**, 10 (9), 3467–3475.

Prof. Jessica Clough joined the Institute in 2020 as a post-doctoral researcher in the Polymer Chemistry and Materials group. In 2022, she was awarded a five-year PRIMA grant by the Swiss National Science Foundation, leading to her promotion as Assistant Professor and the creation of the Mechanoresponsive Materials group.

Women's health
_ Understanding ovarian cancer

Researchers from the Adolphe Merkle Institute's Bio-Nanomaterials group and other institutions have developed a multicellular 3D human omentum model to study the formation of ovarian and peritoneal cancer. This is aimed at providing a better understanding of how these cancers spread.

The most common types of ovarian and peritoneal cancers are diagnosed in most cases at an advanced stage, with the likelihood of surviving more than five years just around 20 per cent. When these different cancers metastasize, the majority present a preference for the greater omentum, a visceral peritoneal fold within the abdominal cavity. Understanding this spreading process could provide vital insights into the cancers.

The overall aim of this collaboration was to understand the role of the omentum in the context of this complex disease thereby studying its architecture in-situ, generate a human omentum cell atlas, identify mechanisms in cancer cells promoting spread towards the omentum, generate a molecular information at the single cell level and to design, based on the in-situ information, a relevant 3D human model investigating ovarian cancer cell.

Researchers have previously considered experimental tissue models with limited combinations of the different omentum cell types. These have however been unable to convey the complexity of the interactions of those cells, and the effects of these interactions on metastatic behavior. As part of a Sinergia project funded by the Swiss National Science Foundation, scientists from the AMI BioNanomaterials group and colleagues at the University of Basel chose to tackle the problem by developing a bioprinted 3D multi-cellular human omentum tissue model, consisting of mesothelial cells, fibroblasts, macrophages, adipocytes, and endothelial cells. This model parallels more closely with the local tissue heterogeneity of human omentum in vivo by considering the spatial arrangement of the different cell types. By exposing it to ovarian cancer cells, it provides a more accurate representation of the tumor microenvironment.

"With our most recent publication were able to show that viable multi-cellular ovarian cancer aggregates exhibited invasive behavior similar to metastasis when applied to our 3D tissue model," adds the AMI BioNanomaterials co-chair, Prof. Barbara Rothen-Rutishauser. "Our data suggest that our model can be used in future studies to investigate ovarian cancer cell invasion, metastatic behavior, and interaction between patient-derived cancer and omental cells, opening a path to more personalized treatments for ovarian cancer."

The researchers believe that their project has been a success, as it opens the door to future use of the 3D tissue model. Knowledge generated about the omentum tumor microenvironment using single-cell RNA sequencing during the Sinergia project will serve as the starting point to address specific research questions with the 3D model.

This project was funded by a grant ("The underestimated role of the human omentum in metastatic spread"), worth a total of almost CHF 2 million over four years. This grant promoted the interdisciplinary collaboration of four research groups, in this case the teams of Prof. Viola Heinzelmann (Department of Biomedicine at the University Hospital Basel and University of Basel), Prof. Uwe Pieles (University of Applied Sciences School of Sciences (FHNW)), Prof. Ivan Martin (Biomedicine, University of Basel) and and the AMI BioNanomaterials group.

"This kind of collaboration is extremely important, since it helps us develop a comprehensive and more efficient approach to problem-solving, something we would not necessarily achieve alone," adds Rothen-Rutishauser. "It also facilitates the transfer of knowledge and skills between institutions, enhancing overall scientific capacity."

Reference:

Estermann, M.; Coelho, R.; Jacob, F.; Huang, Y.-L.; Liang, C.-Y.; Faia-Torres, A. B.; Septiadi, D.; Drasler, B.; Karakocak, B. B.; Dijkhoff, I. M.; Petri-Fink, A.; Heinzelmann-Schwarz, V.; Rothen-Rutishauser, B. A 3D Multi-Cellular Tissue Model of the Human Omentum to Study the Formation of Ovarian Cancer Metastasis. *Biomaterials* **2023**, 294, 121996.


GyroMini

Marine ecology
_ Jellyfish absorb plastic pollution

Researchers from the Adolphe Merkle Institute's BioNanomaterials group have established a sophisticated workflow to detect and observe microplastic interactions with marine life. Their investigations focused on the *Cassiopea andromeda* jellyfish, a common coastal species.

Microplastics are tiny particles ranging from 1 micrometer to 5 millimeters in size resulting from the breakdown of larger plastic debris. Humans are potentially exposed to microplastics through oral intake, inhalation, and skin contact. Originating from the degradation of larger plastic debris and direct sources such as wastewater treatment plants, microplastics also infiltrate marine ecosystems, posing a potential threat to the organisms there. Despite their minute size, they have a widespread presence in the ocean, possibly affecting fish, crustaceans, sea turtles, and even jellyfish to name but a few.

Published in the journal *Environmental Science & Technology*, the study highlights the role of jellyfish, once considered minor players in marine food chains, in the transfer of marine contaminants. *Cassiopea andromeda*, a jellyfish species inhabiting the seabed of shallow coastal waters, was chosen for this research due to its proximity to land-based sources of plastic waste and its potential to serve as a bioindicator species.

Jjuvenile Cassiopea samples were analyzed using a combination of confocal laser scanning microscopy, transmission electron microscopy, and Raman spectroscopy to detect polyethylene terephthalate (PET) and polypropylene (PP), two common forms of plastic.. These advanced techniques allowed the researchers to confirm the presence and interactions of microplastics within the jellyfish tissues.

The study demonstrated that the properties of the microplastics, such as density and hydrophobicity influenced interactions between the jellyfish and the pollutants. This optimized analytical protocol marks a significant advancement in the detection of microplastics in marine organisms, overcoming previous challenges posed by the small size and low concentration of the particles in natural environments.

This research not only provides a deeper understanding of how microplastics interact with marine life but also establishes a platform for future studies. The developed protocol highlights that carbon-based particles can be clearly detected in carbon-based lifeforms and could be instrumental in assessing the broader ecological impact of microplastics.

"This is particularly important since our study shows how we could analyze environmentally relevant samples," explains BioNanomaterials co-chair, Prof. Alke Fink. "This would allow for a more holistic understanding of microplastic interactions with the jellyfish in their native environment and set the foundation for a better understanding of the quantitative impact of the particles on marine species."

The AMI BioNanomaterials group has been investigating micro and nanoplastics for several years, notably the production and characterization of plastic micro- and nanoparticles made from materials commonly used in the packaging industry. These particles are subsequently used as test materials for further in-vitro studies to determine the potential effects of plastic micro- and nanoparticles on human health.

Reference

Caldwell, J.; Loussert-Fonta, C.; Toullec, G.; Heidelberg Lyndby, N.; Haenni, B.; Taladriz-Blanco, P.; Espiña, B.; Rothen-Rutishauser, B.; Petri-Fink, A. Correlative Light, Electron Microscopy and Raman Spectroscopy Workflow to Detect and Observe Microplastic Interactions with Whole Jellyfish. *Environ. Sci. Technol.* **2023**, 57 (16), 6664–6672.

Jessica Caldwell first joined AMI as a Master's student in 2017, finishing her degree in 2019. She continued at the Institute as a PhD student in the BioNanomaterials group, investigating the preparation, detection, and characterization of micro- and nanoplastics. Jessica successfully defended her thesis in 2024, and is now carrying out postdoctoral research in Italy.

BioNanomaterials

Team

Prof. Alke Fink, Prof. Barbara Rothen-Rutishauser, Liliane Ackermann-Hirschi, Mauro Sousa de Almeida, Dr. Sandor Balog, Laura Baraldi, Dr. Amélie Bazzoni, Dr. Anne-Marinette Cao, Jessica Caldwell, Shui Ling Chu, Luigi di Stolfo, Dr. Jules Duruz, Roman Fortunatus, Christina Glaubitz, Gowsinth Gunasingam, Laetitia Haeni, Moritz Haeffner, Fatima Hameedat, Dr. Ruiwen He, Viktoriya Ivasiv, Dr. Sandeep Keshavan, Henry Lee, Dr. Wang Sik Lee, Isidora Loncarevic, Andriy Lubskyy, Aura Maria Moreno Echeverri, Maria Porteiro, Dr. Fabienne Schwab, Dr. Flavia Sousa, Eva Susnik, Dr. Patricia Taladriz, Dr. Dimitri Vanhecke, Mira Witzig, Phattadon Yajan

Key Publications

1. Susnik, E.; Bazzoni, A.; Taladriz-Blanco, P.; Balog, S.; Moreno-Echeverri, A. M.; Glaubitz, C.; Brito Oliveira, B.; Ferreira, D.; Viana Baptista, P.; Petri-Fink, A.; Rothen-Rutishauser, B. Epidermal Growth Factor Alters Silica Nanoparticle Uptake and Improves Gold-Nanoparticle-Mediated Gene Silencing in A549 Cells. *Front. Nanotechnol.* **2023**, 5.

2. Glaubitz, C.; Bazzoni, A.; Ackermann-Hirschi, L.; Baraldi, L.; Haeffner, M.; Fortunatus, R.; Rothen-Rutishauser, B.; Balog, S.; Petri-Fink, A. Leveraging Machine Learning for Size and Shape Analysis of Nanoparticles: A Shortcut to Electron Microscopy. *J. Phys. Chem. C* **2024**, 128 (1), 421–427.

3. Keshavan, S.; Bannuscher, A.; Drasler, B.; Barosova, H.; Petri-Fink, A.; Rothen-Rutishauser, B. Comparing Species-Different Responses in Pulmonary Fibrosis Research: Current Understanding of in Vitro Lung Cell Models and Nanomaterials. *Eur. J. Pharm. Sci.* **2023**, 183, 106387.

4. Lee, A.; Gosnell, N.; Milinkovic, D.; Taladriz-Blanco, P.; Rothen-Rutishauser, B.; Petri-Fink, A. Layer-by-Layer siRNA Particle Assemblies for Localized Delivery of siRNA to Epithelial Cells through Surface-Mediated Particle Uptake. *ACS Appl. Bio Mater.* **2023**, 6 (1), 83–92.

In brief

Public outreach

AMI staff were again out and about for the University of Fribourg's Explora open day in September. Students and staff took the opportunity to meet the public and talk about science, projects, and innovation with some fun activities. These open days are organized every two years by the university. The AMI BioNanomaterials Co-Chair, Prof. Barbara Rothen-Rutishauser, took part in October in the SATW TecDay at the Sursee college in

canton Lucerne. Around 1,000 students were registered for the day's 64 hands-on modules, with Rothen-Rutishauser focusing on nanomaterials. Altogether 100 experts came together to foster students' interest in science and technology careers.

Recognizing innovation

Dr. Flavia Sousa, a postdoctoral researcher in the AMI BioNanomaterials group, was chosen as one of the MIT Technology Review's Innovators Under 35 selection for 2023.

The annual list recognizes outstanding innovators who are younger than 35. The awards span a wide range of fields, including biotechnology, materials, computer hardware, energy, transportation, communications, and the Web. At the Institute, Sousa focused on the development of new biological nanotherapies for brain cancer using polymeric and lipid nanoparticles. The Tech Review judges considered her research work as pioneering regarding the encapsulation of anti-angiogenic monoclonal antibodies and understanding the efficacy in treating glioblastoma by normalizing the tumor vasculature and microenvironment. Sousa was recently appointed as an Assistant Professor at the University of Groningen in the Netherlands.

Science outreach

The Institute's young researchers were particularly active in 2023 when it came to presenting their work to a wider public.

Wachara Chanakul was the winner of the University of Fribourg's Science Slam with his presentation "What if one day you forgot everyone you love?", focused on Alzheimer's Disease diagnostics. Carolina Pierucci, another member of the AMI BioPhysics group, was awarded the public prize for her presentation about the INTEGRATE project ("Towards the development of an electric organ to power artificial muscles"). Mauro Almeida of the BioNanomaterials group finished second in the university's Three-Minute Thesis competition (MT180) for his short talk on "talk "Deciphering nanoparticle endocytosis to improve therapeutic strategies." Almeida also took home the public prize for his efforts.

Innovation prize

The Granulytics team was the winner of the 2023 Innosuisse Business Concept Training Fribourg first prize, which was hosted at the Institute.

The prize included an innovation training trip to Oxford, UK for the lucky winners. Two AMI researchers, Andela Vracar and Yu Larpin, both from the BioPhysics group, were part of the team, along with Owais Hameed and Katrin Sophie Wendrich from the University of Fribourg. Their project focused on developing biological therapy against antibiotic-resistant bacteria for surgical site infections. The project has since become a spinoff, with Larpin as one of the co-founders, leveraging antimicrobial proteins and lipid nanocarriers.

Sparking ideas

Four Adolphe Merkle Institute researchers were awarded Spark grants by the Swiss National Science Foundation in 2023.

Dr. Anasua Mukhopadhyay of the BioPhysics group is aiming to develop a nanopore-based sensor to detect and quantify mutant protein aggregates that feature in Huntington’s disease, a so-far untreatable disorder that causes the breakdown of nerve cells in the brain. This could open the door to improvements in discovering and developing potential therapies. Dr. Viola Vogler-Neuling of the Soft Matter Physics group is investigating how structural color forms in nature in the pupae of butterflies. She is testing the hypothesis that these colors form through the self-assembly of lipidic lyotropic liquid crystals already used in drug delivery. By understanding this process, she hopes to mimic it to develop biocompatible and environmentally friendly photonic pigments for the food and cosmetics industry.

Prof. Jovana Milic of the Smart Energy Materials group is attempting to develop novel metal-free all-organic molecular perovskites using mechanosynthesis strategies. These materials are envisaged to feature exceptional ferroelectric properties, which would, unlike conventional perovskite ferroelectrics, not pose environmental concerns associated with toxic metal components. Finally, Dr. Ruiwen He of the BioNanomaterials group aims to establish an in vitro database of volatile organic compound (VOC) biomarkers for specific biological processes such as air pollution-induced lung inflammation. The result could help boost in vivo research and non-invasive clinical detection of air pollution-related lung diseases.

Spark funding is intended for projects with unconventional thinking and a unique approach. The focus is on promising ideas of high originality, relying on no or very little preliminary data that are unlikely to be financed by other available funding schemes. Applicants can request between CHF 50,000 and CHF 100,000 for a project duration of six to twelve months.

The applicants must have developed the idea for the proposal themselves and should be able to conduct the project without any instructions from third parties.

ERC grant

AMI Assistant Prof. Jovana Milic was awarded in September 2023 a prestigious European Research Council (ERC) Starting Grant for her project “Smart Hybrid Materials for Opto(electro)ionics”.

Milic has since taken up a position as an Associate Professor at the University of Turku in Finland to fulfill the grant conditions, which must be used in a nation associated with the Horizon Europe program. This is not currently the case for Switzerland. However, she remains affiliated with AMI. Milic joined the Institute in 2020 as a Swiss National Science Foundation PRIMA Fellow and was promoted to Assistant Professor by the University of Fribourg the following year.

Milic was also appointed in 2023 as one of the International Science Council’s 100 new Fellows, the organization’s highest honor conferred on an individual. The council recognizes with its fellowships outstanding contributions to promoting science as a global public good. It is the only international NGO bringing together international scientific unions and associations and national and regional scientific organizations such as academies and research councils from the natural sciences, social sciences, and the humanities. The Swiss Academy of Sciences and the Swiss Academy of Humanities and Social Sciences are both members.

Anti-viral bed canopy

The Institute’s young researchers were particularly active in 2023 when it came to presenting their work to a wider public. Visitors to the sitem-insel (Swiss Institute for Translational Medicine and Entrepreneurship) open door day in Bern in December 2023 had the opportunity to see an innovative prototype hospital bed canopy developed by the Nano Clean Air company in collaboration with AMI’s BioNanomaterials Co-Chair Prof. Barbara Rothen-Rutishauser and Northwestern Switzerland’s University of Applied Sciences. The canopy was designed to inhibit the transmission of respiratory viruses in multi-bed hospital rooms. In tests with salt aerosols, viruses, and bacteria, more than 95% of airborne pathogens do not reach the neighboring bed while offering potentially high protection for healthcare staff.

Promotion

Dr. Alessandro Ianiro, group leader in the AMI BioPhysics group, was appointed Assistant Professor in the Department of Chemistry at the Katholieke Universiteit (KU) Leuven in Belgium in September 2023.

Ianiro remains affiliated with the Institute as the scientific coordinator of the INTEGRATE project. INTEGRATE is a multidisciplinary research program funded by the European Innovation Council and the Swiss Secretariat for Education, Research, and Innovation worth €3 million (awarded in 2021). The main goal is to develop energy-autonomous prosthetics and robotic devices.

Fellowship

The Adolphe Merkle Institute's Co-Chair of Bio- Nanomaterials, Prof. Barbara Rothen-Rutishauser was named a Fellow of the International Society for Aerosols in Medicine (ISAM) in 2023.

This award recognizes recipients' achievements, commitment, and contributions to the society, as well as outstanding contributions in the field of aerosols in medicine. Rothen-Rutishauser received her award at the ISAM conference in Saarbrücken, Germany, along with three other researchers. Rothen-Rutishauser is a past president of the ISAM and has served on multiple international and national advisory committees, including Switzerland's Federal Commission for Air Hygiene.

The ISAM was founded in 1973 to promote and advance aerosol science internationally, focusing on the health effects of inhaled aerosols including inhaled drug delivery for prevention and treatment of human disease. Its conferences are among the world's largest conferences on respiratory health and inhaled drug delivery.

Falling Walls

The Adolphe Merkle Institute hosted the first edition of the Falling Walls Lab Fribourg, part of a global interdisciplinary pitch competition for students and early-career professionals.

Organized by the NCCR Bio-Inspired Materials, the competition had two winners from the University of Fribourg, Mout de Vrieze and Ivana Domljanovic. Both travelled to Berlin in November 2023 to take part in the global final held during the Falling Walls Summit.

Throughout the year, academic institutions host international Falling Walls Labs to showcase the quality, diversity, and passion of their region's most innovative minds. Participants are given three minutes to present their solutions to some of today's most pressing challenges.

In memoriam

In November 2023, we honored the memory of our late colleague Livia Bast with the public defense of her PhD thesis "Bio-Inspired Composite Materials based on Silk Proteins, Cellulose Nanocrystals and Polymers." The results of her work were presented by her doctoral advisor and AMI alum Prof. Nico Bruns.

Livia joined AMI in 2016 as a member of the European-funded Innovative Training Network PlaMatSu (Plant-Inspired Materials and Surfaces) spearheaded by Bruns.

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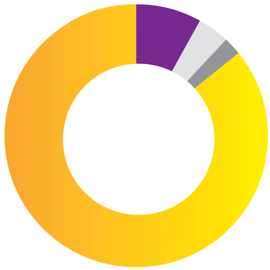
Finance & Organization

Finance

_ Cost structure at AMI

The Adolphe Merkle Institute's overall expenditures remained stable in 2023 at CHF 9.13 million. 86% of this sum was spent on research, while an additional 4% was invested in research equipment. Around 2% of the budget supported valorization activities such as technology transfer, communication, and marketing, with another 8% covering administration costs.

Overall expenses 2023
CHF 9.13 million



- Research / 86%
- Administration / 8%
- Research equipment / 4%
- Valorization / 2%

Funding sources of overall expenses 2023

- Adolphe Merkle Foundation / 33%
- Grants / 55%
- University of Fribourg / 11%
- Industry / 1%

Third-party funding 2023
CHF 5.13 million

- SNSF / 60%
- EU / 20%
- Other sources / 13%
- Innosuisse / 4%
- Industry / 3%

Organization

In late 2007, Adolphe Merkle set up the Adolphe Merkle Foundation and donated CHF 100 million to support the University of Fribourg. The donation has been used primarily to establish the Adolphe Merkle Institute.

The Institute Council plays an important role in controlling and supervising the development of the Institute at the University of Fribourg's science faculty. It guarantees optimal communication and coordination between the University and the Foundation and helps the Institute to fulfill its mission and to smoothly integrate into the university.

The Scientific Advisory Board is an independent team of experts with backgrounds and expertise in fields that are relevant for AMI. It provides an external view to help position the institute in its national and international environment.

The Executive Board oversees daily operations at AMI and meets once a week. All AMI professors are members of this management body along with the Associate Director. They are responsible for ensuring that the strategy approved by the Institute Council is implemented.

The Administration team provides support in many aspects of the Institute's daily work and acts as an interface between the University of Fribourg and AMI.

Foundation Board

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Former head of the Biointerface Group at Department of Materials, ETH Zürich, Switzerland

Prof. Ben Zhong Tang
Chair Professor of Chemistry, Hong Kong University of Science and Technology, China

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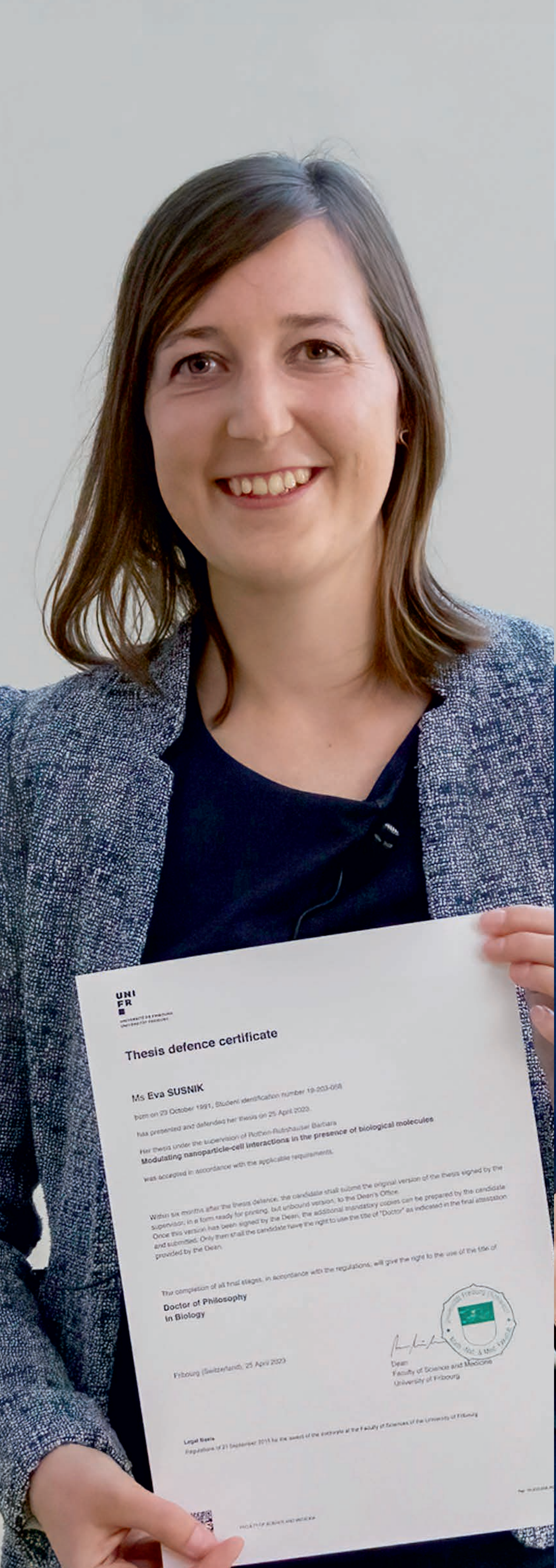
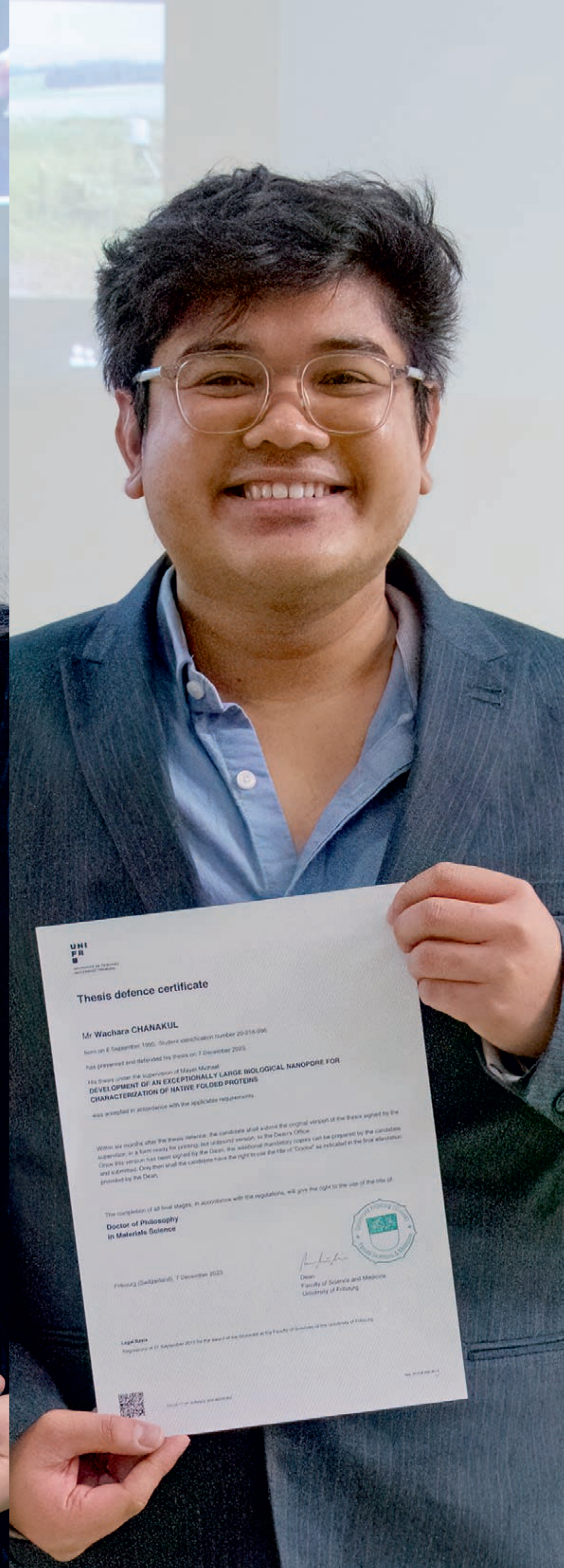

Thesis defence certificate
Ms Eva SUSNIK
Modulating nanoparticle-cell interactions in the presence of biological molecules
Doctor of Philosophy
in Biology


Thesis defence certificate
Mr Alessandro PARISOTTO
Order and disorder in natural photonic structures


Thesis defence certificate
Ms Edona KARAKAÇI
Plasmonic Optical Tweezers for Single Protein Dynamics Interrogation
Doctor of Philosophy
in Physics


Thesis defence certificate
Mr Wachara CHANAKUL
DEVELOPMENT OF AN EXCEPTIONALLY LARGE BIOLOGICAL NANOPORE FOR CHARACTERIZATION OF NATIVE FOLDED PROTEINS
Doctor of Philosophy
in Materials Science

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PhDs & Alumni

PhDs

Our new doctors

Mauro Almeida
(BioNanomaterials)
"Deciphering nanoparticle endocytosis to improve therapeutic strategies"

Livia Bast
(Macromolecular Chemistry)
"Bio-Inspired Composite Materials based on Silk Proteins, Cellulose Nanocrystals and Polymers"

Jessica Caldwell
(BioNanomaterials)
"Optimizing Analytical Pathways for Micro-, Submicron-, and Nanoplastics"

Wachara Chanakul
(BioPhysics)
"Development of an Exceptionally Large Biological Nanopore for Characterization of Native Folded Proteins"

Kenza Djeghdi
(Soft Matter Physics)
"Nanostructured self-assembled diamond-like morphologies in biological and polymeric materials"

Christina Glaubitz
(BioNanomaterials)
"From Powder to Cellular Response: The Pathway of Nanoparticle Analysis"

Edona Karakaçi
(BioPhysics)
"Plasmonic Optical Tweezers for Single Protein Dynamics Interrogation"

Andriy Lubskyy
(Macromolecular Chemistry)
"Engineering of myoglobin for reactions with organic radicals"

Franziska Marx
(Polymer Chemistry and Materials)
"Healable Metallosupramolecular Polymers"

Minh Trí Nguyen
(Soft Matter Physics)
"Improving electrode materials' performance in Li-ion batteries"

Alessandro Parisotto
(Soft Matter Physics)
"Order and disorder in natural photonic structures"

Eva Susnik
(BioNanomaterials)
"Modulating nanoparticle-cell interactions in the presence of biological molecules"

Alumni

People who left AMI in 2023

Doha Abdelrahman
(Soft Matter Physics)

Saurabh Awasthi
(BioPhysics)

Laura Baraldi
(BioNanomaterials)

Kenza Djeghdi
(Soft Matter Physics)

Andrea Escher
(Soft Matter Physics)

Christina Glaubitz
(BioNanomaterials)

Ilja Gunkel
(Soft Matter Physics)

Derek Kiebala
(Polymer Chemistry and Materials)

Asia Lanuti
(BioPhysics)

Andriy Lubskyy
(Macromolecular Chemistry)

Jovan Lukic
(Smart Energy Materials)

Franziska Marx
(Polymer Chemistry and Materials)

Valeria Mozzetti
(Administration)

Murad Najafav
(Smart Energy Materials)

Minh Tri Nguyen
(Soft Matter Physics)

Andrea Palumbo
(Soft Matter Physics)

Alessandro Parisotto
(Soft Matter Physics)

Cristina Prado
(Soft Matter Physics)

Chris Rader
(Polymer Chemistry and Materials)

Marian Reincke
(BioPhysics)

Maria Sanz
(BioPhysics)

Eva Susnik
(BioNanomaterials)

Christian Sproncken
(BioPhysics)

Brian van Büren
(Soft Matter Physics)

Anna Wald
(BioPhysics)

Phattadon (Samat) Yajan
(BioNanomaterials)

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