2017 _Annual Report

UNI
FR
UNIVERSITÉ DE FRIBOURG
UNIVERSITÄT FREIBURG

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 the domain of soft nanomaterials.

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

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, more generally, improve the quality of life.

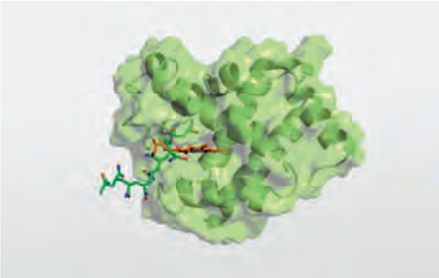
Our researchers are currently organized in five research groups, which offer complementary expertise and interests in strategically important areas: BioNanomaterials, Macromolecular Chemistry, Polymer Chemistry and Materials, Soft Matter Physics, and Biophysics. Interdisciplinary collaborations between 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 our world-class research facilities make AMI a desirable destination for master's and PhD students, postdocs, and senior researchers.

Table of contents

14

Education
Interdisciplinary focus boosts master's program

40



Research perspective
Where biology and polymers meet

AMI turns 10!

_ A message from the director

Christoph Weder

I am delighted to present to you the Adolphe Merkle Institute's annual report, in which we share with you recent activities, achievements, and developments.

This issue marks our tenth anniversary, which is a good moment to pause, take stock, and assess our progress as well as our current status. When AMI was first launched, we spent much thought on formulating a strategic plan that guided us as we developed and expanded the Institute. While our blueprints have been refined a few times, I think it is a fair assessment that at age 10, AMI is actually very close to the originally envisioned steady state. On the one hand, this is certainly something that we all can be proud of and with several events. On the other hand, however, the closer we have come to complete building the Institute, the more uneasy I feel about the implications of such a steady state. Evolution teaches us that species must rapidly adapt to a changing environment in order to thrive or even survive, and the core of this principle clearly also applies to all types of organizations. In this sense, I think we are well served to think of the present as a transient state. I think if we keep asking (and answering) questions that ask how AMI should evolve, we not only stand a good chance of adapting to a changing environment in a timely manner, but we can aspire to actively drive such changes.

In this spirit, all of the AMI professors have contributed brief perspective articles to this report, in which we share our thoughts on in which direction our respective research fields might develop. Of course, the report also showcases some of our most important research breakthroughs of the past year. In papers published in Nature, our BioPhysics group reported a seminal study on mimicking the electric organ of the electric eel, while the Soft Matter Physics group demonstrated that many types of flowers feature nanostructured petals whose shiny blue color attracts bees. In groundbreaking studies the BioNanomaterials group addressed the fact that nanoparticles are readily internalized by cells, but their behavior once inside is still rarely documented. The Polymer Chemistry and Materials team developed several new concepts to render polymers mechanochromic, and the Macromolecular Chemistry group established a new approach to tuning materials' surface properties.

Our international research collaborations were significantly expanded in 2017, when we were awarded grants from the European Union's Horizon 2020 program and the Swiss and the US National Science Foundations to launch the Innovative Training Network (ITN) "CityCare" and the Partnerships for International Research and Education (PIRE) network on Bio-Inspired Materials and Systems, which connect AMI researchers with peers in other European countries and the USA, respectively. Both programs emphasize scientific excellence and innovation, have the goal to enhance researchers' career prospects through fostering international experiences, and integrate education and research on an international level.

At AMI, we continue to value our partnerships and are once again grateful for all the interest, courtesy, and support that we received throughout 2017. We will continue our efforts to realize Adolphe Merkle's vision of establishing AMI as a leading competence center for fundamental and applied interdisciplinary research in the field of soft nanomaterials.

Christoph Weder
AMI Director and Professor for Polymer Chemistry & Materials

7

Pursuing excellence

PIRE

_ An international collaboration to develop bio-inspired materials and systems

Alexandre Redondo was the first Swiss student to join PIRE

Researchers from AMI and four American universities are pursuing a novel partnership funded by the US and Swiss National Science Foundations to develop functional materials inspired by substances found in nature.

A $5.5 Mio grant, awarded in September 2017 by the US National Science Foundation (NSF) as part of the Partnerships for International Research and Education program (PIRE), supports research and training activities at Case Western Reserve University, the University of Delaware, the University of Chicago, and the University of California at San Diego, all USA. The corresponding actions in Fribourg are enabled by a complementary CHF 1.5 million grant from the Swiss National Science Foundation (SNSF), which became effective the same month. This is the first time that the SNSF is participating as a partnering agency in the PIRE program, which is led by the American agency and aims to build research capacities through international collaborations, promote excellent science, and tackle some of today's most pressing research questions. In all, AMI's six professors, 11 faculty members from the US partners, as well as 15 PhD students (10 in the US, five in Switzerland) are contributing to the program. The Swiss team is led by Christoph Weder, Professor of Polymer Chemistry and Materials and Director of AMI, as well as of the Swiss National Center of Competence in Research (NCCR) Bio-Inspired Materials. Weder says, "the research beautifully combines the scientific competences of the US and Swiss groups, and the exchange programs provide unique training opportunities for the students."

According to Weder, the training activities established by the PIRE collaboration notably complement and integrate with the student exchange programs and other training activities established by the NCCR, which is also headquartered at the University of Fribourg.

Over a period of five years, faculty and students in the US and Switzerland will study and develop materials that mimic, for example, the sticky and durable caddisfly silk, the adaptable skin of sea cucumbers, and a substance that directs cellular behavior. "We're studying materials and objects found in nature and then reducing the materials for practical use," states LaShanda Korley, Distinguished Associate Professor of

Materials Science and Engineering at the University of Delaware and principal investigator of the project.

Alexandre Redondo was the first PhD student to join the PIRE collaboration on the Swiss side. As part of the AMI Soft Matter Physics group, he aims to develop polyurethane plastics reinforced with cellulose nanocrystals (nanocomposites) that mimic the mechanical properties of spider silk. The interdisciplinary nature of the projects was one of the reasons he was attracted to AMI. "I'm a chemist by training, so this is an opportunity to learn about other disciplines, as well as work with materials," he explains. Redondo will notably study the mechanical properties and crystalline structure of the polyurethane plastics he will assemble.

Other projects of the collaboration include the study of materials inspired by sea cucumbers, squids, and pine cones, as well as the development of artificial neurons for robot control and of mechanically adaptable functional fibers.

The materials made in this project should eventually be tested in a worm-like robot that may one day burrow through the earth or building wreckage on search and rescue missions, crawl inside waterlines and oil and gas pipelines to inspect them, and, if miniaturized, deliver a stent or remove plaque by crawling through a blood vessel.

Pollution

_ CityCare to take skin protection to a different level

The skin is on the frontline in the fight against environmental aggression

Researchers from the Adolphe Merkle Institute are working to improve the understanding of the damaging effects of air pollutants on cutaneous responses as part of an Innovative Training Network (ITN) funded by the European Union's Horizon 2020 research and innovation program.

Scientists from the AMI BioNanomaterials group, the University of Ferrara in Italy, and Dow Silicones Belgium, which is coordinating the CityCare program, are also investigating innovative solutions for better skin protection against environmental stressors, such as ultraviolet (UV) radiation, ozone, and pollutants.

25

NATIONALITIES

ARE PRESENT AT AMI, WITH STAFF COMING FROM EUROPE, NORTH AMERICA, SOUTH AMERICA, AFRICA AND ASIA.

6

PROFESSORS

SPECIALIZING IN POLYMER SCIENCE, MATERIALS, PHYSICS, CHEMISTRY, AND BIOLOGY.

56%

OF ALL RESEARCH EXPENDITURES

WERE COVERED BY THIRD-PARTY FUNDING FROM SOURCES SUCH AS THE SWISS NATIONAL SCIENCE FOUNDATION, THE EUROPEAN UNION, INDUSTRIAL PARTNERS, AND THE SWISS COMMISSION FOR TECHNOLOGY AND INNOVATION.

566

PUBLICATIONS

SINCE 2008.

7

PROJECTS

WITH INDUSTRY PARTNERS UNDERWAY IN 2017.

101

SCIENTIFIC PUBLICATIONS

IN TOP-RANKED JOURNALS SUCH AS NATURE, JOURNAL OF THE AMERICAN CHEMICAL SOCIETY, CHEMICAL REVIEWS, ADVANCED MATERIALS, ANGEWANDTE CHEMIE, ACS NANO, SCIENTIFIC REPORTS, SCIENCE ADVANCES, ENERGY & ENVIRONMENTAL SCIENCE, NANOSCALE.

190

ALUMNI

INCLUDING POSTDOCTORAL RESEARCHERS, PHD STUDENTS, AND INTERNS.

“Such programs are highly relevant to bring together researchers with complementary expertise from across the world and to generate knowledge with international teams,” points out AMI BioNanomaterials co-chair Professor Barbara Rothen-Rutishauser.

The skin, which is the largest organ of the human body, is on the frontline in the fight against environmental aggression. One of its major roles is to provide a protective barrier against physical or chemical factors. Its protective ability is limited, however, and cutaneous problems arise when an increased exposure to environmental stressors exceeds the skin’s normal defensive ability.

Because of its critical location, the skin is continuously exposed to natural environmental factors, such as ultraviolet (UV) radiation, ozone, and extreme weather conditions. Pollutants directly generated by human behavior and activities, such as cigarette smoke and motor exhaust fumes, also impact our well-being. As a result of the increasing complexity of our habitat, attacks against the skin are also more and more frequent.

This complexity means that we are exposed to more than one single pollutant at any given time. The living environment, especially in urban areas, is becoming incresingly polluted due to higher ozone concentrations and a higher level of particle emissions associated with urban traffic and domestic heating. The CityCare researchers believe that multiple exposures could have additive, if not synergistic, noxious effects on the skin. To prove this, the ITN aims to provide a better understanding of these effects on the skin’s biological and biomechanical properties.

At AMI, the research will build on previous projects. “So far, our main research focus has been to study the effects of ambient air pollution, such as diesel and gasoline exhaust, or volcanic ash particles, in lung cell cultures. With the CityCare project, the aim is to study damaging effects in skin models, since skin is very sensitive to pollutants,” explains Rothen-Rutishauser. “We can adapt some of our experience, such as particle exposure and endpoint analysis, to 3D skin models.”

No one denies that there is an urgent need to protect people from urban pollution. There is, however, no single class of compounds that has been identified as being able to protect the skin against the whole spectrum of environmental stressors. Sunscreens, for instance, are only useful against UV radiation.

One of the main objectives of the CityCare project is to identify innovative personal care solutions that can provide long-lasting and broad spectrum skin protection benefits against environmental stressors.

The program has the vocation of training three early-stage researchers at the boundaries of highly interconnected domains such as cell biology, skin science, cosmetic science, and polymer chemistry.

During their three-year assignment, the students are to receive intensive research training opportunities in domains such as skin physiology, (pro-)inflammatory mechanisms, tissue engineering, interfacial chemistry, and polymer chemistry, but also in knowledge management and business behaviors. At AMI, the students will spend time learning about tissue engineering and analyzing effects upon exposure of skin models to diesel particles, for example.

Researchers involved in the program are also encouraged to be mobile during their assignment to expose them to complementary research activities, training courses, and various professional environments. Added benefits should include better scientific and communication skills and strong networking opportunities.

CityCare is the second ITN in which AMI is currently involved. The Institute is currently the leading institution of the ITN PlaMatSu (Plant Materials and Surfaces), coordinated by Macromolecular Chemistry Professor Nico Bruns, which involves researchers from the University of Cambridge in Britain and the University of Freiburg in Germany.

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Sklodowska-Curie grant agreement No 765602.

Alumni
_ Launching academic careers

Dr. Dafni Moatsou, Dr. Christophe Monnier, Dr. Laura Rodriguez-Lorenzo, Prof. Yoshimitsu Sagara (left to right)

Every year, newly minted PhDs and postdoctoral researchers leave the Adolphe Merkle Institute to start the next stage of their careers. For many, this means taking up positions in industry, for example.

Others, however, embark on an academic career, a choice that promises many challenges as they seek to become independent researchers in their own right. For those who choose this path, their experiences at AMI often constitute a vital milestone in their career.

In recent years, former AMI staff members have become professors and lecturers at universities in the United States, the United Kingdom, France, and Japan. Prof. Yoshimitsu Sagara was a postdoc in the Polymer Chemistry and Materials group, supported by the Japan Society for the Promotion of Science. Immediately after leaving AMI three years ago, he took up an assistant professorship at Hokkaido University, Japan, while continuing his collaboration with the Institute. In Fribourg, thanks to his funding, he was able to focus on his own research subjects. "The most important achievement that I accomplished during my stay at AMI was to lay the basis for several new research topics that I am now working on in Japan," he explains.

"AMI helps you prepare for higher level research positions and scientific leadership while letting you set up important collaborations that contribute to the improvement of your own national and international network."
Laura Rodriguez-Lorenzo, International Iberian Nanotechnology Laboratory

Yet, working at AMI as a postdoc provides more than just research perspectives. "I was able to prove to myself that I could work on a large selection of projects in parallel, advise PhD students and lab technicians, take responsibility for internships and master's students, as well as collaborate with clinicians and physicists alike," says Dr. Laura Rodriguez-Lorenzo, a Fellow at the International Iberian Nanotechnology Laboratory in Portugal. Rodriguez-Lorenzo, who was a group leader in the BioNanomaterials team, points to AMI's interdisciplinary character as being particularly important for career opportunities. "This interdisciplinarity enables the development of complex projects within the framework of national and international networks," she adds. "AMI helps you prepare for higher level research positions and scientific leadership while letting you set up important collaborations that contribute to the improvement of your own national and international network."

Dr. Christophe Monnier, a former PhD student who was part of the BioNanomaterials group, and who is now a postdoc at the University of California, Santa Barbara, USA, says AMI provides other important insights. "I learned how important it is to carefully select whom you collaborate with: true discoveries are only made when honesty, trustworthiness, competence, and a common, inherent passion of advancing a project are the core values shared among you and your peers."

Dr. Dafni Moatsou is another former postdoc from the Polymer Chemistry and Materials group, and is now a junior group leader at the Karlsruhe Institute of Technology in Germany. She says AMI has another benefit that people underestimate as part of their career development: its relatively small size, which helps facilitate exchanges. "At AMI, one has complete access to top-notch facilities, outstanding administrative and research support, while everyone knows each other by their first name," she explains. "There does not seem to be a barrier in terms of hierarchy, age, gender, spoken language, or scientific or ethnic background. "

"You get easy and uncomplicated access to cutting-edge facilities, and there is a great interdisciplinary entourage and strong intergroup interactions," agrees Monnier. However, the support at the Institute helps researchers learn more than just how to manage research projects. "At AMI, I discovered what goes on behind the scenes. There is so much more to research and education than just courses and experiments and nobody tells you about these things until you are thrown in at the deep end," Moatsou points out. "Luckily, I was introduced to proposal writing, funding management, dissemination logistics, and public relations while only being a postdoc at the Institute, which makes it so much easier now that I alone am accountable for all of this in my current position."

AMI's Director and Professor of Polymer Chemistry and Materials, Christoph Weder, also draws a deep satisfaction from seeing Institute staff move up the academic career ladder. "I love mentoring postdocs and group leaders that are drawn to academia," he explains. "I get to share with them my experiences beyond science, and explain how the academic world works. There are so many things that are important that you do not learn in school. And I am really happy when I see that the young researchers we train are successful in making the next step."

What the future holds for these young academics remains very much open. For Rodriguez-Lorenzo, there can always be surprises down the road. "I have learned over the course of my life that there are millions of factors that I cannot control and that can change all your plans in a millisecond." However unpredictable the road to a career in academia may be, Monnier adds, "I hope it will lead me to a place where I enjoy working as much as I did at AMI during my doctoral studies."

Education

_ Interdisciplinary focus boosts master's program

Just over two years ago, the Adolphe Merkle Institute launched a new master's program aimed at students interested in the chemistry and physics of soft matter. The initial group of candidates is now entering the final phase of their training, benefiting from the interdisciplinary curriculum, the small size of the program, and the personal attention they receive from their professors.

The first students, including American student Jessica Caldwell, were recruited in a variety of ways, the most efficient being old-fashioned word of mouth. "The professor under whom I studied had actually come here to the Adolphe Merkle Institute to finish his PhD," Caldwell explains. "He knew several people here and told me about their material science program, which had been my research focus for the past few years." Others learned about the program directly at the University of Fribourg, or via web search, for example. A concerted effort has also been made to reach out to potential students at education fairs in Switzerland as well as abroad.

So how has the master's program been able stand out in a field where the competition for talent is fierce? Interdisciplinarity is perhaps the trump card in this case. Soft matter science is by its very nature interdisciplinary, bridging not only chemistry, physics, and biology, but also materials science and engineering. For Jake Hooton, a second-year student, this was certainly one of the attractions that led him to Fribourg. "The interdisciplinary nature of this master's program is a big advantage – it allows you to diversify and broaden your background beyond one specific discipline," he points out.

Courses go into great depth on a variety of topics such as nanomaterials, microscopy and scattering techniques, soft matter and biophysics, polymer chemistry, and fundamental cell biology, but also allow students to learn about soft skills, including science writing and ethics, as well as innovation. The clear focus of these studies helps convince students to sign up. "The program is clearly centered on materials," explains master's student Isabella Mombrini. "Moreover, two semester projects are part of the proposed studies, with the possibility to practice what we learn in the lab." Hooton agrees, adding that the broad range of laboratory training is profitable. "This allows you to make an informed decision about in which labs you want to begin longer projects and further study," he states.

There are other advantages when studying at AMI, according to student Phattadon Yajan. "There are opportunities to use sophisticated equipment and work in cutting-edge laboratories," he says. "Knowledge is gained through lectures by highly qualified professors. And the short projects offered during the second and third semester were very helpful when it comes to making a decision about the master's project topic." The students also appreciate the close proximity to staff. "There is a high staff-student ratio, meaning that you can always ask questions and it is easy to make connections in all of the different research groups," reveals Hooton. Yajan concurs, highlighting the ease of interaction with professors, senior scientists, and PhD students. "Being part of a small community like the one at AMI allows you to build close relationships with other people."

> "The program will be developing constantly, since we try to integrate our students' ideas, wishes, and criticism."
> *Professor Alke Fink, program co-director*

The program launched with a handful of students. "This allowed us to get things started, figure out where to adapt, and where to improve," explains the program

Most of the current AMI master's students are likely to pursue a PhD

co-director, Professor Alke Fink. "The program will be developing constantly, since we try to integrate our students' ideas, wishes, and criticism. We are now ready to grow."

Soft matter, the core of the master's curriculum, includes polymers, colloids, foams, gels, and biological tissue, along with others that are part solid and part liquid and are often easily deformable. Soft materials are everywhere and many industries, including the traditional materials sector as well as the medical, pharmaceutical, and food industries, depend increasingly on professionals with specific training in this domain.

To gain a better understanding of this relationship, students are even able to get specific experience in the industrial sector as part of the program. Yajan is the first to have completed an internship with a company as part of his training. "This has helped decide which direction I should take in the future," he declares. "This was an opportunity to work on multiple small projects, something you would not normally experience in the traditional academic environment."

The students see their time studying for their master's degree at AMI as a positive experience. "I would recommend this program to students looking to implement the knowledge acquired during their undergraduate studies," adds Yajan. "The classes offered in this program help create bridges between disciplines. If you are unsure of which field to study, this provides a good insight into what might interest you for future studies."

So where will the master's students be headed next? "I think most of them are looking into pursuing a PhD," explains Fink. "They are very well prepared to make this step, thanks to the intense research experience gained over the past two years."

Aural comfort

_ Custom-shaping consumer products with novel materials

Improved fitting helps ensure proper performance and user acceptance of hearing aids

Researchers from the Adolphe Merkle Institute are collaborating with Swiss hearing aid manufacturer Sonova to develop new shape-memory polymers, which allow the customization of devices and enhance their functionality.

Anyone who has used earphones knows the problem: finding buds that fit perfectly can be a challenging and time-consuming exercise. Proper fitting is even more important for users of hearing aids, who normally wear their devices all day and depend on their operation. Indeed, proper coupling of a hearing aid and ear is the key to its performance and acceptance, as critical aspects such as amplification, sound quality, and wearing comfort depend on the fitting. As alternatives to standardized earpieces, hearing aid makers have therefore started to provide customers with personalized devices that are shaped to match the patient's anatomy. The leading approach to achieve this relies on 3D printing the earpiece after first taking an impression of the ear and digitizing the imprint. While the products made in this manner define the state of the art in hearing technology, the fabrication approach is complex and requires several visits to the audiologist.

A team that involves developers from hearing aid maker Sonova and researchers from AMI's Polymer Chemistry and Materials group may have found a way to simplify the customization process. "The basic idea builds on the outcomes of our earlier efforts to create mechanically adapting polymers," says Professor Christoph Weder. Within the scope of the National Research Program 62 "Smart Materials," researchers from his group explored polymers that change their mechanical properties upon exposure to a stimulus such as moisture, light, or heat. The materials caught the attention

33

ACTIVE RESEARCH PROJECTS

IN FIELDS SUCH AS NEXT-GENERATION SOLAR CELLS, MALARIA DIAGNOSTICS, PROTEIN ANALYSIS, ADHESIVES, INTELLIGENT NANOMATERIALS, AND BIO-INSPIRED MATERIALS.

CHF 10.8 mio

SPENT IN 2017

RESEARCH SPENDING ROSE FROM CHF 7.5 MILLION TO CHF 8.5 MILLION.

40%

WOMEN

60%

MEN

WORKING AT AMI.

116

PEOPLE

WORKING AT AMI INCLUDING PHD STUDENTS, POSTDOCTORAL RESEARCHERS, PROFESSORS AND SUPPORT STAFF.

50%

OF AMI STAFF

ARE DOCTORAL STUDENTS.

of engineers at Sonova, and in the ensuing dialogue it became clear that a so-called shape-memory polymer, which, in addition to changing its mechanical properties, can also alter its shape, could serve as the basis for earpieces that can be shaped directly in a patient's ear.

"In-situ customization would be a great step forward in providing an even larger customer group with a more comfortable individualized ear mold, allowing a much longer wearing time per day. Today, we have to manage a trade-off between standard earpieces, which can be taken home directly but are slightly less comfortable, and individualized shells, which require an impression taking and a return visit. In situ customization would greatly simplify the process of getting an individual mold," says Dr. Stefan Launer, Vice-President of Science and Technology at Sonova.

"Our breakthrough was enabled by rational materials design that relied on our understanding of the structure-property relationships of such materials."
Dr. Anuja Shirole, Polymer Chemistry and Materials group

The concept involves heating a pre-shaped earpiece above a threshold temperature, where the shape-memory polymer turns into a soft, elastic material that can easily be deformed. The earpiece is then cooled and placed into a patient's ear, where it adopts a conformal shape that is fixed over the course of a few minutes. For the process to work without having to place a hot earpiece into the ear, the material must remain malleable for a short while after cooling, instead of rigidifying immediately.

"Interestingly, despite extensive research efforts on the development of shape-memory polymers in many groups around the world, there are few examples of materials in which a temporary shape can be conveniently fixed at body temperature," says Weder, adding that no material having the right set of properties was commercially available when a joint research project with Sonova was launched four years ago. However, this could soon change.

With funding from the Commission for Technology and Innovation (now Innosuisse), and Sonova, AMI researchers have solved this problem and created a family of shape-memory polymers that have just the right combination of properties.

"Our breakthrough was enabled by rational materials design that relied on our understanding of the structure-property relationships of such materials, but it also reflects persistence, and certainly a good portion of luck," explains AMI's Dr. Anuja Shirole, who began working on the project for her PhD. "We are also fortunate to be able to work so closely with the Sonova engineers, who keep us focused on the target and by using early laboratory samples to fabricate demonstrators and prototypes provide valuable feedback and motivation."

The results so far have encouraged Sonova to pursue the project. "First prototypes demonstrated by the project team clearly show the feasibility of in-situ customization for earpieces. The next steps will focus on design, upscaling, and extensive verification and validation of this technology," adds Launer.

The AMI researchers are also optimistic about future results. "As the new materials were made by combining two commercially available polymers in a clever manner, the scale-up to a technologically useful scale might be relatively straightforward," reckons Weder. The new materials also appear to hold great promise for other applications that range from mouth guards, sportswear, and equipment to materials for biomedical applications. The project partners have already filed several patent applications to protect materials and possible applications.

Sonova, Switzerland

Sonova, headquartered in Stäfa, Switzerland, is the leading provider of innovative hearing care solutions. The Group operates through its core business brands Phonak, Unitron, Hansaton, Advanced Bionics, and AudioNova. Sonova offers its customers one of the most comprehensive product portfolios in the industry – from hearing instruments to cochlear implants to wireless communication solutions. The Group's sales and distribution network, the widest in the industry, comprises over 50 of its own wholesale companies and more than 100 independent distributors. This is complemented by Sonova's retail business, which offers professional audiological services through a network of approximately 3,500 locations in 18 countries. Founded in 1947, the Group has a workforce of over 14,000 employees. AMI and Sonova have been collaborating since 2014.

In brief

National and international recognition

The Adolphe Merkle Institute's director, Professor Christoph Weder, was named a Fellow of the Division of Polymer Chemistry of the American Chemical Society (ACS).

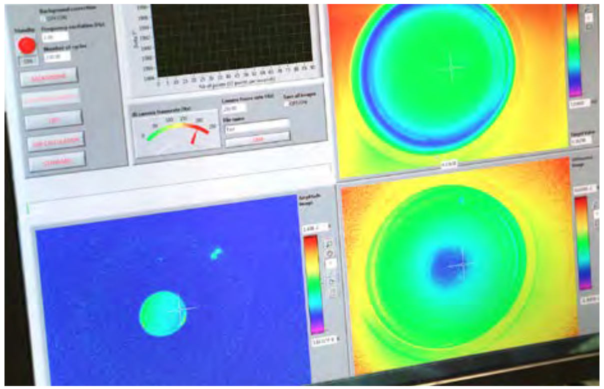
He was one of just four awardees in 2017 and the only academic recognized. Nominations are based on demonstrated achievements in and contributions to polymer science and the profession.

Weder was also named as an individual member of the Swiss Academy of Engineering Sciences (SATW). He was recognized for his pioneering work in the development of new nanomaterials that bridge fundamental research and practical applications, as well as for his contribution to the development of AMI. Individual members, who are appointed for life, are outstanding experts from the fields of education, research, commerce, and industry and politics.

NanoLockin innovation recognized

The Adolphe Merkle Institute was once again among the winners of the Ypsomed Innovation Fund's Innovation Award for research, development and technology transfer in January 2017.

AMI BioNanomaterials co-chair Professor Alke Fink received the third place prize of CHF 10'000 for the NanoLockin project. NanoLockin, which recently became AMI's first start-up, is developing an infrared measurement system to detect, count, and observe nanoparticles by stimulating them with light.



Going Wild!

The Adolphe Merkle Institute was present at the Zurich Zoo's Going Wild! weekend at the beginning of September.

Butterflies and beetles were on display as part of the bio-inspired science exhibits on show, presented by the Soft Matter Physics group (Michael Fischer, Dr. Ilja Gunkel, Cédric Kilchoer, and Dr. Bodo Wilts). Other research groups participating in the weekend included staff from Switzerland's two Federal Institutes of Technology.


BUCHI
Heating Bath
B-491

21
_Research at AMI

Bio-inspired

_ Harnessing the power of the electric eel

To develop a biocompatible power source, researchers at the Adolphe Merkle Institute, along with colleagues from the University of Michigan and the University of California San Diego, have sought inspiration from a fascinating source: the electric eel.

The ongoing integration of technology into living organisms requires some form of power source that is biocompatible, flexible, and able to draw energy from inside a biological system. One possible application would be a self-charging power source for implantable devices such as heart pacemakers, sensors, drug delivery pumps, or prosthetics. Generating electricity inside the body would have a number of advantages, eliminating the need for replacement surgery, for example, or providing sustained power for wearable devices such as electrically active contact lenses with an integrated display.

With this in mind, a research team led by the AMI Professor of BioPhysics, Michael Mayer, focused on one animal capable of creating its own electricity: *Electrophorus electricus*, a knifefish commonly called the electric eel. Capable of generating up to 600 volts and 100 watts to stun prey or defend itself, the animal can also modulate its electrical output, usually to help it navigate through murky waters.

The researchers began by reverse-engineering the animal's electric organ. The organ is made up of long, thin cells known as electrocytes, which span 80% of the eel's body in parallel stacks. Triggered by the eel's brain, these cells each generate a small voltage simultaneously by allowing sodium ions to rush into one side of the cell and potassium ions out of the other side of the cell. The voltages along stacks of these cells add up to a large potential.

The team designed an eel-inspired power source that generates electricity based on the salinity difference between fresh water and salt water. Sea salt is made of a positive ion (sodium) and a negative ion (chloride). When a permeable compartment of salt water is put in contact with a similar compartment of fresh water, the salt has a natural tendency to migrate into the fresh compartment until all of the water has the same salt concentration.

If a membrane that is more permeable to positive ions than to negative ones is placed between these two compartments, however, the positive ions rush into the low salt compartment, leaving behind a negatively charged high salt compartment. A similar effect can be exploited with a second membrane that is more permeable to negatively charged ions. Arranging these compartments and membranes in a repeat sequence thousands of times makes it possible to generate 110 volts.

Each component of this so-called reverse electrodialysis power source is made of a hydrogel, a polymer cage that contains water and can conduct salt ions. "Living tissues are very complex, so instead of creating a one-to-one mimic of the electric organ, we used a more reductive design approach that allowed us to substitute a distinct type of hydrogel for each functional component of the active cells," explains postdoctoral research Tom Schroeder.

These components can be assembled on clear plastic sheets using a commercial 3D printer. Like the eel, the power source has individual compartments with small capacities, so the voltages must be triggered at the same time. The eel does this with its nervous system; the researchers achieve this task most efficiently by bringing all of the cells into contact simultaneously, using a folding strategy of the printed sheet that was originally developed to unfold solar panels in space.

Results are still far from matching the capacities of the eel. While the fish can fuel its electrical organs by eating, the prototype system requires the application of an external current to recharge. To reach a useful power level for implants, thinner and improved hydrogel membranes are required, along with strategies allowing their reactivation inside a living organism.

Reference

Schroeder, T.B.H.; Guha, a.; Lamoureux, A.; VanRenterghem, G.; Sept, D.; Shtein, M.; Yang, J.; Mayer, M. An electric-eel-inspired soft power source from stacked hydrogels, *Nature*, **2017**, 552, 214-218.

Dr. Tom Schroeder joined the Biophysics group at AMI in 2016, following Prof. Michael Mayer's move to Fribourg from the University of Michigan. He completed his PhD in 2017 and is now a senior researcher at the Institute. His research interests include membrane biophysics, functional hydrogels, and biomimicry.

BioPhysics

Team

Prof. Michael Mayer, Dr. Saurabh Awasthi, Dr. Lennart de Vreede, Olivia Eggenberger, Dr. Aziz Fennouri, Gogol Guha, Jared Houghtaling, Dr. Jonathan List, Dr. Peter Nirmalraj, Tom Schroeder, Shuran Xu, Dr. Cuifeng Ying

Key Publications

1. Yamashita, Y.M.; Chen, C.; Mordovanakis, A.; Hunt, A.J.; Mayer, M.; Cummings, R.; Sept, D. Cytokine receptor-Eb1 interaction couples cell polarity and fate during asymmetric cell division, *eLife* **2018**, 7:e33685

2. Yusko, E.C.; Bruhn, B.R.; Eggenberger, O.M.; Houghtaling, J.; Rollings, R.C.; Walsh, N.C.; Nandivada, S.; Pindrus, M.; Hall, A.R.; Sept, D.; Li, J.; Kalonia, D.S.; Mayer, M. Real-time shape approximation and fingerprinting of single proteins using a nanopore, *Nat. Nanotech*, **2017**, 12, 360

3. Fennouri, A.; Mayer, S.F.; Schroeder, T.B.H.; Mayer, M. Single channel planar lipid bilayer recordings of the melittin variant MelP5, *Biochimica et Biophysica Acta (BBA) – Biomembranes*, **2017**, 1859, 2051

4. Takaoki Koyanagi, Kevin J. Cao, Geoffray Leriche, David Onofrei, Gregory P. Holland, Michael Mayer, David Sept, Jerry Yang. Hybrid Lipids Inspired by Extremophiles and Eukaryotes Afford Serum-Stable Membranes with Low Leakage, *Chem. Eur. J*, **2017**, 23, 6757

On target

_ Blue halo guides bees to flowers

Researchers at the Adolphe Merkle Institute, the University of Cambridge, and London's Kew Royal Botanical Gardens have demonstrated that many types of flowers produce a so-called "halo" that produces a blue shine, allowing bees to identify them more easily. This color is produced by the nanostructure of a flower's petal, which scatters light in the blue to ultraviolet spectrum.

Electron microscopy imaging has revealed that on the surface of flower petals, tiny ridges and grooves line up next to each other "like a packet of dry spaghetti." But when analyzing different species, the researchers discovered that these structures vary greatly in height, width and spacing. In fact, even on a single petal, these light-manipulating structures were found to be surprisingly irregular. This is a phenomenon physicists describe as "disorder," suggesting that different flowers should have different optical properties. Despite this, the flowers all produce a similar visual effect in the blue to ultraviolet wavelength region of the spectrum – the "blue halo" effect.

The researchers, including the AMI Soft Matter Physics Professor Ullrich Steiner, concluded that these "messy" petal nanostructures likely evolved independently many times across flowering plants. These plants all managed to develop the "blue halo" that increases their visibility to pollinators – an example of what is known as convergent evolution.

All flowering plants belong to the angiosperm lineage. The researchers analyzed some of the earliest diverging plants from this group and found no halo-producing petal ridges. However, they did find several examples of halo-producing petals among the two major flower groups (monocots and eudicots) that emerged during the Cretaceous period over 100 million years ago – coinciding with the early evolution of flower-visiting insects, in particular nectar-sucking bees.

This suggests that the petal ridges that produce "blue halos" evolved many times across different flower lineages, all converging on this structure to achieve optical signaling for pollinators. Species the team found to have halo-producing petals include primroses, daisies, and hibiscuses. All the analyzed flowers revealed significant levels of apparent "disorder" in the dimensions and spacing of their petal nanostructures. Previous studies have shown that many species of bees have an innate preference for colors in the violet-blue range. However, plants do not always have the means to produce blue pigments. "Many flowers lack the genetic and biochemical capability to manipulate pigment chemistry in the blue to ultraviolet spectrum," says Steiner. "The presence of these disordered photonic structures on their petals provides an alternative way to produce signals that attract insects."

By manufacturing artificial surfaces that replicated this phenomenon, the scientists were able to test the effect on pollinators, in this case foraging bumblebees. Their findings, published in the journal Nature, demonstrate that bees can see the blue halo and use it as a signal to locate flowers more efficiently.

The researchers recreated "blue halo" nanostructures and used them as surfaces for artificial flowers. In a "flight arena," they tested how bumblebees responded to surfaces with and without halos.

These experiments showed that bees can perceive the difference between the different surfaces, finding those with halos more quickly – even when both types of surfaces were colored with the same black, yellow or even blue pigments. Using rewarding sugar solution in one type of artificial flower, and bitter quinine solution in the other, the scientists found that bees could use the blue halo to learn which type of surface contained the reward.

The researchers say these findings open up new opportunities for the development of surfaces that are highly visible to pollinators, as well as for exploring how living plants control the levels of disorder on their petal surfaces.

Reference

Moyroud, E.; Wenzel, T.; Middleton, R.; Rudall, P.J.; Banks, H.; Reed, A.; Mellers, G.; Killoran, P.; Westwood, M.M.; Steiner, U.; Vignolini, S.; Glover, B.J. Disorder in convergent floral nanostructures enhances signalling to bees, *Nature*, **2017**, 550, 469

Prof. Ullrich Steiner joined AMI in 2014 as the chair of Soft Matter Physics. Previously, he held professorships at the University of Cambridge in England and the University of Groningen in the Netherlands. A Fellow of the Royal Society of Chemistry, he studied physics at the University of Konstanz in Germany and at the Weizmann Institute of Science in Israel.

Soft Matter Physics

Team

Prof. Ullrich Steiner, Dr. Antonio Abate, Narjes Abdollahi, Johannes Bergmann, James Dolan, Dr. Esteban Bermudez, Michael Fischer, Antonio Guenzler, Dr. Ilja Gunkel, Dr. Hua Xiao, Cédric Kilchoer, Karolina Korzeb, Mirela Malekovic, Andrea Palumbo, Bart Roose, Saeed Sadeghi, Sandy Sanchez, Dr. Alessandro Sepe, Sheng Xiaoyuan, Preston Sutton, Dr. Bodo Wilts

Key Publications

1. Wilts, B.D.; Wijnen, B.; Leertouwer, H.L.; Steiner, U.; Stavenga, D.G. Extreme Refractive Index Wing Scale Beads Containing Dense Pterin Pigments Cause the Bright Colors of Pierid Butterflies, *Adv. Opt. Mater*, **2017**, 5, 1600879

2. Khaderi, S.N.; Scherer, M.R.J.; Hall, C.E.; Steiner, U.; Ramamurty, U.; Fleck, N.A.; Deshpande, V.S. The indentation response of nickel nano double gyroid lattices, *Extreme Mech Lett*, **2017**, 10, 15

3. Fischer, M.G.; Hua, X.; Wilts, B.D.; Gunkel, I.; Bennett, T.M.; Steiner, U. Mesoporous Titania Microspheres with Highly Tunable Pores as an Anode Material for Lithium Ion Batteries, *ACS Appl Mater Interfaces*, **2017**, 9, 22388

4. Dehmel, R.; Dolan, J.A.; Gu, Y.; Wiesner, U.; Wilkinson, T.D.; Baumberg, J.J.; Steiner, U.; Wilts, B.D.; Gunkel, I. Optical Imaging of Large Gyroid Grains in Block Copolymer Templates by Confined Crystallization, *Macromolecules*, **2017**, 50, 6255

5. Dehmel, R.; Baumberg, J.J.; Steiner, U.; Wilts, B.D. Spectrally resolved surface plasmon resonance dispersion using half-ball optics, *Appl. Phys. Lett.*, **2017**, 111, 201102

Interactions

_ Understanding nanoparticle integrity inside cells

Researchers at the Adolphe Merkle Institute have highlighted the need for applying complementary analysis methods in order to study nanoparticle behavior inside cells, pointing to shortfalls in some techniques.

Nanomedicine promises better, more efficient and affordable healthcare. It could provide solutions to illnesses such as cancers, cardiovascular diseases, multiple sclerosis, neurological afflictions including Alzheimer's and Parkinson's, and diabetes. It is also hoped that research in nanomedicine will help us understand more about how the human body functions at the molecular and nano-scales, allowing for the development of more targeted treatments. The global market for nanomedicine is estimated to increase substantially over the next decade, reaching more than $350 billion by 2030.

Despite the promising outlook, however, little is known about how nanoparticles interact with the human body. "Nanoparticles are internalized by cells, but their behavior once inside is still rarely documented. Few studies have considered the effects of the intracellular environment on nanoparticles," explains AMI BioNanomaterials co-chair Barbara Rothen-Rutishauser.

For the past three years, PhD student Ana Milosevic and her colleagues have been investigating the fate of fluorescently encoded gold nanoparticles after cellular uptake, potential particle aggregation, and the integrity of the surrounding polymer layer into which a fluorophore was integrated. Their research has focused in particular on digestive organelles known as lysosomes, an acidic and confined space in cells where most of the observed nanoparticles accumulate after uptake into the cell.

"Lysosomes play a significant role in the fate of nanoparticles, since they are the final resting place of internalized nanoparticles," says Milosevic. "Lysosomes digest internalized substances and recycle the remaining components for further use. They constitute a rather hostile environment for anything that they ingest."

Gold nanoparticles were chosen for this project as they are frequently used in biomedical research. Their size and shape can be tuned, and other traits such as their optical properties, biocompatibility, and potential for surface functionalization are considered highly desirable. These nanoparticles can also be functionalized with polymers, many of which include fluorescent dyes, making them a promising imaging method for a variety of biological in vivo and in vitro applications.

"Fluorescent signals are a useful tool in biology and medicine to analyze nanoparticle uptake by cells and their intracellular fate using techniques such as fluorescent microscopy and flow cytometry," Rothen-Rutishauser points out.

Results so far have shown that the strong salt content and low pH environment of the lysosomes strongly affect the stability and integrity of negatively-charged polymer-grafted gold nanoparticles. This leads to aggregation, and conformational changes of the polymer, followed by a loss of the fluorescence property of the fluorophore. Nanoparticles can undergo significant changes because of the specific environment provided by the lysosomes.

The AMI researchers say that it is important now to more thoroughly investigate the effects of a specific biological environment on all of the components that scientists rely on to detect a nanoparticle, including fluorescence.

"Only by gaining a more fundamental understanding of how the intracellular environment can affect nanoparticle behavior can we design specific particles which are either inert, or can degrade or release a drug in acidic conditions," adds Rothen-Rutishauser. "This will highly improve the safe design of nanomedicines."

Reference

Milosevic, A.M.; Rodriguez-Lorenzo, L.; Balog, S.; Monnier, C.A.; Petri-Fink, A.; Rothen-Rutishauser, B. Assessing the Stability of Fluorescently Encoded Nanoparticles in Lysosomes by Using Complementary Methods, *Angewandte Chemie International Edition*, **2017**, 56, 13382.

A Serbian national, Ana Milosevic received a Master's in Biochemistry at the University of Belgrade in 2013. She joined AMI's BioNanomaterials group to pursue a PhD in 2014. Her research was funded by the National Centre of Competence in Research Bio-Inspired Materials based at the Adolphe Merkle Institute.

BioNanomaterials

Team

Prof. Alke Fink, Prof. Barbara Rothen-Rutishauser, Liliane Ackermann, Dr. Sandor Balog, Hana Barosova, Christoph Bisig, Dr. Mathias Bonmarin, David Bossert, Joel Bourquin, David Burnand, Savvina Chortarea, Federica Crippa, Leopold Daum, Dr. Barbara Drasler, Dr. Estelle Durantie, Manuela Estermann, Dr. Khay Fong, Dr. Christoph Geers, Laetitia Haeni, Daniel Hauser, Philipp Lemal, Dr. Laura Rodriguez-Lorenzo, Mattia Maceroni, Ana Milosevic, Christophe Monnier, Dr. Thomas Moore, Dr. Fabienne Schwab, Dr. Dedy Septiadi, Dr. Miguel Spuch-Calvar, Yuki Umehara, Dominic Urban, Dr. Dimitri Vanhecke

Key Publications

1. Crippa, F.; Moore, T.L.; Mortato, M.; Geers, Ch.; Haeni, L.; Hirt, A.M.; Rothen-Rutishauser, B.; Petri-Fink, A. Dynamic and biocompatible thermo-responsive magnetic hydrogels that respond to an alternating magnetic field. *J Magn Magn Mater*, **2017** 427:212.

2. Chortarea, S.; Barosova, H.; Clift, M.J.D.; Wick, P.; Petri-Fink, A.; Rothen-Rutishauser, B. Human Asthmatic Bronchial Cells Are More Susceptible to Subchronic Repeated Exposures of Aerosolized Carbon Nanotubes At Occupationally Relevant Doses Than Healthy Cells. *ACS Nano*, **2017**, 11(8):7615.

3. Vanhecke, D.; Rodríguez-Lorenzo, L.; Kinnear, C.; Durantie, E.; Rothen-Rutishauser, B.; Petri-Fink, A. Assumption-free morphological quantification of single anisotropic nanoparticles and aggregates. *Nanoscale*, **2017**, 13;9(15):4918.

4. Drasler, B.; Sayre, P.; Steinhäuser, KG.; Petri-Fink, A.; Rothen-Rutishauser, B. In vitro approaches to assess the hazard of nanomaterials. *NanoImpact*, **2017**, 8, 99 (2017).

5. Monnier, C.A.; Crippa, F.; Geers, Ch.; Knapp, E.; Rothen-Rutishauser, B.; Bonmarin, M.; Lattuada, M.; Petri-Fink, A. Lock-In Thermography as an Analytical Tool for Magnetic Nanoparticles: Measuring Heating Power and Magnetic Fields. *J. Phys. Chem. C*, **2017**, 121, 27164.

Fine tuning

_ Controlling the growth of polymer layers

Tuning a material's surface properties by decorating it with polymers can help prevent problems such as microbial adhesion or corrosion, or improve interactions with cells and living tissue. Researchers from AMI's Macromolecular Chemistry group have developed a novel technique to control how fast and to what extent polymer layers can grow on a surface.

Material scientists, chemists, and physicists have developed a whole series of strategies to modify and functionalize surfaces. This can be to create scaffolds for tissue engineering, cell-sensitive platforms, anti-fouling surfaces, and biosensors, for example. This usually requires modifying a synthetic surface using chemical reactions or some form of physical treatment, the aim being to induce and control a biological process in the surrounding environment. These methods are not necessarily very efficient or precise, however.
The AMI scientists teamed up with researchers from Zurich's Federal Institute of Technology (ETHZ) to try another approach, exploiting a surface's propensity to either repel proteins or attract them when bathed in a protein-rich solution, and focusing on enzymes, which are a category of proteins as well as being catalysts. They chose to investigate the influence of protein-repellency on enzymatic polymerizations on surfaces. "Biocatalytic surface-initiated polymerizations hold great promise for a biocompatible modification of surface, but have hardly been investigated on a fundamental level," explains Nico Bruns, AMI professor of Macromolecular Chemistry. "Thus, we took the challenge to study the effect of the protein affinity of a surface on the biocatalytic polymerization."

"We want to use this method to modify surfaces with practical relevance, such as biomaterials or biosensors."
Nico Bruns, Professor of Macromolecular Chemistry

The goal was to manipulate the polymerization activity of enzymes in order to trigger and modulate the growth of synthetic macromolecules, in the form of so-called polymer "brush" assemblies, i.e., surface coatings of polymers tethered to a surface. They can be used to stabilize colloids, reduce friction between surfaces, and provide lubrication in artificial joints, for instance. The researchers were able to successfully demonstrate that a high level of control over a surface's affinity toward a catalytically active biomolecule allows the precise fabrication of polymer films at the molecular and structural levels.

The enzymes help create polymers by binding monomers into extended chains on top of specific surfaces. The team was also able to demonstrate that this process functions better if the surfaces are "sticky" to proteins. Moreover, by using polymers that can be switched between a protein-adsorbent and a protein-repellant state, the polymerizations can be switched between an effective polymer chain growth and a very slow chain growth.

This fundamental work demonstrates how the affinity of a surface towards proteins can be used to control and influence the enzyme-catalyzed growth of polymer layers, and therefore opens up new ways to tune the properties of surfaces, such as by coating nanoparticles with defined polymer layers. "We want to use this method to modify surfaces with practical relevance, such as biomaterials or biosensors," adds Bruns.

Reference

Divandari, M.; Pollard, J.; Dehghani, E.; Bruns, N.; Benetti, E.M. Controlling Enzymatic Polymerization from Surfaces with Switchable Bioaffinity, *Biomacromolecules*, **2017**, 18, 4261

Dr. Jonas Pollard has been a member of AMI's Macromolecular Chemistry group since 2013. He successfully defended his PhD thesis in 2017. Pollard is currently working on a malaria diagnostics project at the Institute that is backed by the BRIDGE program, a program funded by Innosuisse and the Swiss National Science Foundation.

Macromolecular Chemistry

Team

Prof. Nico Bruns, Edward A. Apebende, Livia Bast, Thanh Quy Dang, Bernadetta Gajewska, Dr. Clément Mugemana, Dr. Michaela Pellizzoni, Jonas Pollard, Samuel Raccio, Omar Rifaie Graham, Dr. Kyle Rodriguez

Key Publications

1. Noushin Hasanabadi, N.; Nazockdast, H.; Gajewska, B.; Balog, S.; Gunkel, I.; Bruns, N.; Lattuada, M. Structural Behavior of Cylindrical Polystyrene-block -Poly(ethylene-butylene)-block -Polystyrene (SEBS) Triblock Copolymer Containing MWCNTs: On the Influence of Nanoparticle Surface Modification, *Macromol. Chem. Phys* **2017** 218, 1700231

2. Ulrich, S.; Hemmer, J.R.; Page, Z.A.; Dolinski, N.D.; Rifaie-Graham, O.; Bruns, N.; Hawker, C.J.; Boesel, L.F.; Read de Alaniz, J. Visible Light-Responsive DASA-Polymer Conjugates, *ACS Macro Lett.* **2017**, 6, 738

3. Renggli, K.; Sauter, N.; Rother, M.; Nussbaumer, M.G.; Urbani, R.; Pfohl, T.; Bruns, N. Biocatalytic atom transfer radical polymerization in a protein cage nanoreactor, *Polym Chem.* **2017** 8, 2133

Signaling deformation

_ Polymers respond to mechanical force

“Responsive” polymers, which change their properties upon exposure to a pre-defined stimulus in a highly selective manner, represent an emerging family of materials that promise to enable countless new technologies. Many examples of chemically, thermally, optically, or electrically responsive materials have been demonstrated, whereas comparably few polymers that respond in a useful and predictable manner to mechanical forces are known.

When polymers are exposed to excessive stress, their normal response is fatigue or failure as a result of unspecific breaking of chemical bonds in individual polymer molecules. By contrast, many biological systems have found ways to translate mechanical force into useful responses. For example, in the human auditory system, hair cells translate sound vibrations into electrical signals. While the underlying processes of a transduction of mechanical forces are complex and difficult to copy in artificial materials, the possibility of creating polymers that mimic this behavior is of significant interest. Members of Professor Christoph Weder’s Polymer Chemistry and Materials group have developed so-called mechanochromic polymers that change their color or fluorescence properties when mechanical stress is applied. “Reliably detecting mechanical deformation in polymeric materials is of great practical interest, for example, to monitor the structural health of objects or parts where mechanical failure could be critical, or for packaging materials that visually indicate tampering,” points out group leader Dr. Stephen Schrettl. Over the past year, the AMI researchers have made several breakthroughs in this field. They have demonstrated a simple, yet powerful concept to detect mechanical deformation in polymers by incorporating microcapsules filled with suitable sensor molecules, such as dyes whose fluorescence color depends on the immediate environment. “The application of any form of mechanical force breaks the microcapsules in the affected area, the sensor molecules are released, and a clearly visible change of the fluorescence color is observed,” says PhD student Céline Calvino. “One attractive feature of this approach is that the same capsules can be integrated into different types of polymers.” Another advantage of the concept is that the fluorescence signal of the undamaged capsules is a built-in internal standard that allows for a straightforward assessment of the extent of the inflicted damage.

An alternative approach for creating mechanochromic materials that is currently attracting much interest is the incorporation of mechanically responsive molecules, known as “mechanophores,” into polymer molecules. These motifs feature weak chemical bonds that are designed to break upon application of a mechanical force, causing a color change or other useful responses. One key limitation, however, is that the bond cleavage can also be triggered by other forms of energy, most notably exposure to light or heat, reducing the specificity and practical usefulness. To overcome this problem, researchers at AMI and colleagues abroad have devised a fundamentally different type of mechanophore, one that operates based on a spatial separation of two interacting chromophores. Incorporated into a polymer, this new type of mechanophore responds exclusively to mechanical force.

“This process is specific, efficient, instantly reversible, and elicits an easily detectable optical signal that directly correlates with the applied force. The new mechanophores respond to ultra-low forces, which is useful for a broad range of applications,” explains AMI alumnus Prof. Yoshimitsu Sagara of Hokkaido University, Japan, who conceived the design. “We are in the process of demonstrating that the devised strategy is a generally useful method for different polymer types that also enables us to detect the low forces that play an important role in biological processes.”

Before such molecules become readily applicable though, their synthesis needs to be simplified. According to Weder, the first embodiments of the new mechanophores required close to twenty synthetic steps. “Let’s see if we can get this down to five or less,” he adds, setting a clear goal for the coming years.

References

Calvino, C.; Guha, A.; Weder, C.; Schrettl, S.; Self-Calibrating Mechanochromic Fluorescent Polymers Based on Encapsulated Excimer-Forming Dyes; *Advanced Materials* **2018**, 30, 1704603.

Sagara, Y.; Karman, M.; Verde-Sesto, E.; Matsuo, K.; Kim, Y.; Tamaoki, N.; Weder, C.; Rotaxanes as mechanochromic fluorescent force transducers in polymers; *J. Am. Chem. Soc.* **2018**, 140, 1584.

Dr. Stephen Schrettl is a group leader in the AMI Polymer Chemistry and Materials group. Schrettl studied chemistry at the Freie Universität Berlin in Germany. He received his PhD in Materials Science from Lausanne's Federal Institute of Technology (EPFL) in 2014 and joined AMI in 2015 as a postdoctoral researcher.

Polymer Chemistry and Materials

Team

Prof. Christoph Weder, Véronique Buclin, Céline Calvino Carneiro, Dr. Shraddha Chhatre, Dr. Anselmo del Prado Abellan, Gwendoline Delepierre, Anne-Cécile Ferahian, Diana Hohl, Aris Kamtsikakis, Marc Karman, Marco Mareliati, Worarin Meesorn, Dr. Dafni Moatsou, Baptiste Monney, Dr. Lucas Montero, Jens Natterodt, Laura Neumann, Apiradee Nicharat, Luis Olaechea, Dr. Carlo Perotto, Rateeya Saikaew, Anita Roulin, Felipe Saenz, Janak Sapkota, Julien Sautaux, Dr. Stephen Schrettl, Anuja Shirole, Sandra Wohlhauser, Dr. Justin Zoppe.

Key Publications

1. Herbert, K.M.; Schrettl, S.; Rowan, S.J.; Weder, C.; Solid-state Multi-stimuli, Multi-responsive Polymeric. *Macromolecules* **2017**, 50, 8845.
2. Montero de Espinosa, L.; Meesorn, W.; Moatsou, D.; Weder, C.; Bio-inspired Mechanically Morphing Polymer-Based Materials. *Chem. Rev.* **2017**, 117, 12851.
3. Vadrucci, R.; Monguzzi, A.; Wilts, B.; Simon, Y.C.; Weder, C.; Efficient Low-Power Light Upconversion in Nanophase-separated Polymers. *Advanced Materials* **2017**, 29, 1702992.
4. Lavrenova, A.; Balkenende, D.W.R.; Schrettl, S.; Sagara, Y.; Simon, Y.C.; Weder, C.; A Mechano- and Thermoresponsive Photoluminescent Supramolecular Polymer. *J. Am. Chem. Soc.* **2017**, 139, 4302.
5. Zoppe, J.; Dupire, A.; Lachat, T.; Lemal, P.; Rodriguez-Lorenzo, L.; Petri-Fink, A.; Weder, C.; Klok, H.A.; Cellulose nanocrystals with tethered polymer chains: chemically patchy versus uniform decoration. *ACS Macro Letters* **2017**, 6, 892.
6. Natterodt, J.C.; Sapkota, J.; Foster, E.J.; Weder, C. Fabrication and Properties of Polyethylene / Cellulose Nanocrystal Composites. *Biomacromolecules* **2017**, 18, 517.

In brief

Homecoming

The former president of the Federal Institute of Technology in Lausanne (EPFL), Prof. Patrick Aebischer, was a guest of the Fribourg Innovation Club at the Adolphe Merkle Institute in December. Aebischer, who stepped down from the EPFL presidency in 2017, grew up in Fribourg and carried out part of his medical studies at the local university. The fireside chat, moderated by AMI PhD student Olivia Eggenberger and former deputy director Dr. Marc Pauchard, focused largely on how the canton of Fribourg could improve its positioning as a center for innovation. AMI is one of the sponsors of the Innovation Club, which aims to help students develop and implement innovative ideas.

Swiss NanoConvention

The annual Swiss Nanoconvention, Switzerland's biggest nanoscience event, was held in Fribourg for the first time with the support of the canton, with over 300 Swiss and international researchers attending. The conference was organized by the Swiss Micro & Nanotechnology network, and chaired by AMI Professors Barbara Rothen-Rutishauser, and Alke Fink, as well as senior scientist Dr. Dimitri Vanhecke.

Topics covered included nanoscale optics, material safety, nanomaterials in consumer products, bio-inspired materials, and graphene research. In addition, more than 30 exhibitors participated in the two-day event, including a number of local companies. The Nanoconvention also hosted the closing event of the National Research Program 64 "Opportunities and Risks of Nanomaterials," launched in 2010.

Innovation workshop

The Adolphe Merkle Institute hosted the first Workshop on Stimulating Student Innovation and Entrepreneurship in November.

Organized by AMI's deputy director Dr. Marc Pauchard in collaboration with Dr. Eliav Haskal (NCCR Bio-Inspired Materials) and Prof. Philip Bubenzer (Fribourg School of Management), the workshop's goal was to compare and contrast Swiss experiences and ecosystems around innovation support and entrepreneurship for cantonal universities and universities of applied sciences. It also aimed to provide insights into methods for encouraging an innovation culture for students interested in intra- and entrepreneurship, and to build a network of innovation experts to develop best practices for student support.

PhD prize

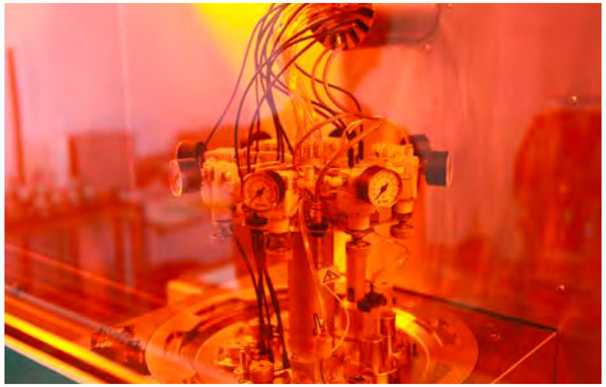
Dr. Christoph Monnier, a former member of the Adolphe Merkle Institute's BioNanomaterials group, was the recipient of the University of Fribourg's 2017 prize for the best thesis in experimental sciences.

Monnier, who is currently a postdoctoral researcher at the University of California, Santa Barbara, USA, completed his PhD in 2016. His thesis, "Magnetic nanoparticles and liposomes: A material study on their potential as mediators for hyperthermia, thermal labelling and controlled drug release," played a major role in the development of the NanoLockin project at AMI.

Alternative research methods

Adolphe Merkle Institute Professor Barbara Rothen-Rutishauser was awarded the Run4science Prize, worth CHF 25,000, in April 2017 for her project "Automatized engineering of human epithelial tissue barriers by a bioprinting approach – the next generation of in vitro alternatives."

The project, presented by the BioNanomaterials group co-chair, aims to establish standardized bioprinting platforms for human epithelial tissue barriers, such as those found in the lungs, intestines, and kidneys. These types of automatized and highly reproducible platforms will be important for high-throughput risk assessment and drug efficacy screening for researchers, the regulatory authorities, and the pharmaceutical industry.



The Run4science association aimed to reduce animal experimentation by promoting alternative research methods and encouraging their use by the scientific community. Funds for projects were raised by an annual fun run and through sponsorship.

PhD award

Dr. David Thévenaz, a former member of Professor Christoph Weder's Polymer Chemistry and Materials group at the Adolphe Merkle Institute, was one of five winners of the Swiss Nanotechnology PhD Award handed out at the 2017 Swiss NanoConvention in Fribourg.

Thévenaz, who finished his PhD in 2016, was recognized for his thesis "Metal-Complex-Containing Luminescent Polymeric Nanoparticles," and his paper "Temperature-responsive low-power light upconverting polymeric nanoparticles," published in the journal Materials Horizons.

The five prizes, worth CHF 2,000 each, are awarded by the Swiss Micro- and Nanotechnology Network. The aim is to recognize excellent scientific first-author publications published by PhD students in the field of nanotechnology and nanoscience.

Safety prize

Adolphe Merkle Institute Professors Barbara Rothen-Rutishauser and Alke Fink were awarded the 2017 CUSSTR Prize for helping improve nanosafety.

Along with their colleagues Dr. Amela Groso, Dr. Thierry Meyer, and Professor Heinrich Hofmann of Lausanne's Federal Institute of Technology (EPFL), the co-chairs of the BioNanomaterials group were recognized for their development of a nanomaterials decision tree. Their work was first published in 2016 in the Journal of Nanobiotechnology. The researchers adapted and developed a method for nanomaterial risk management in laboratories that is easy to understand and apply. Activities related to nanomaterials are classified into three levels, along with concrete preventive and protective measures and associated actions.

The CHF 2,000 prize was awarded by the workplace health and environmental protection commission of western Switzerland's higher education and research institutions (CUSSTR).

State visit

The cantonal governments of Fribourg and Geneva met at the Adolphe Merkle Institute for a joint session in June. After the meeting, AMI director Professor Christoph Weder presented the Institute's research activities to the ministers. Other visits in 2017 included the delegates of western Switzerland's cantonal construction departments as well as the editors-in-chief of western Switzerland's German-language newspapers.

Science Slam

Adolphe Merkle Institute staff members Laura Neumann (Polymer Chemistry & Materials) and Dr. Dimitri Vanhecke (BioNanomaterials) finished in the top two positions of the University of Fribourg's 2017 German-language Science Slam competition. PhD student Neumann earned the audience's approval with her story of how to repair a broken heart with polymers, while senior scientist Vanhecke rekindled an old relationship with evolution. Michael Fischer (Soft Matter Physics) also took part, while Dr. Ilja Gunkel (Soft Matter Physics) was a member of the organizing committee.

BRIDGE to success

Dr. Jonas Pollard, of Professor Nico Bruns' Macrocolecular Chemistry group, joined an elite group of researchers as one of the first 11 recipients to be funded by the national BRIDGE Proof of Concept program.

Pollard, who completed his PhD in 2017, is using the funding for a project on malaria diagnostics via polymerization reactions. BRIDGE helps young researchers to apply their research results and gain the confidence needed to make a market entry. The projects may target innovations of all kinds from all research areas. Funding lasts up to 18 months. BRIDGE is managed by the Swiss National Science Foundation and Innosuisse, the Swiss Innovation Promotion Agency.

TecDays

Professor Barbara Rothen-Rutishauser (BioNanomaterials) joined over 50 other technology specialists at Fribourg's St. Michel College for a TecDay organized by the Swiss Academy of Technical Sciences.

The students were invited to attend a variety of sessions on topics ranging from exoplanets to radioactive waste. Professor Rothen-Rutishauser was on hand to present the intricacies of nanoscience and nanotechnology.

Saint Nick

The Adolphe Merkle Institute was the recipient of an unexpected public relations boost during the traditional Saint Nicholas parade held in Fribourg every year in December.

Saint Nick, who gives a speech from the cathedral balcony after riding through the city on his donkey, told the 30,000 spectators hanging on to his every word that AMI was synonymous with innovation in the canton.


10x/23

37

Research Perspectives

Developing future power
_ Soft Matter Physics

Prof. Ullrich Steiner, Chair of Soft Matter Physics

The sustainable generation of energy and its storage are two sides of the same coin. In order to wean our energy-hungry society from the use of fossil fuels – with its inevitable negative consequences for Earth's climate – a complete paradigm change is needed, which would affect nearly every aspect of society.

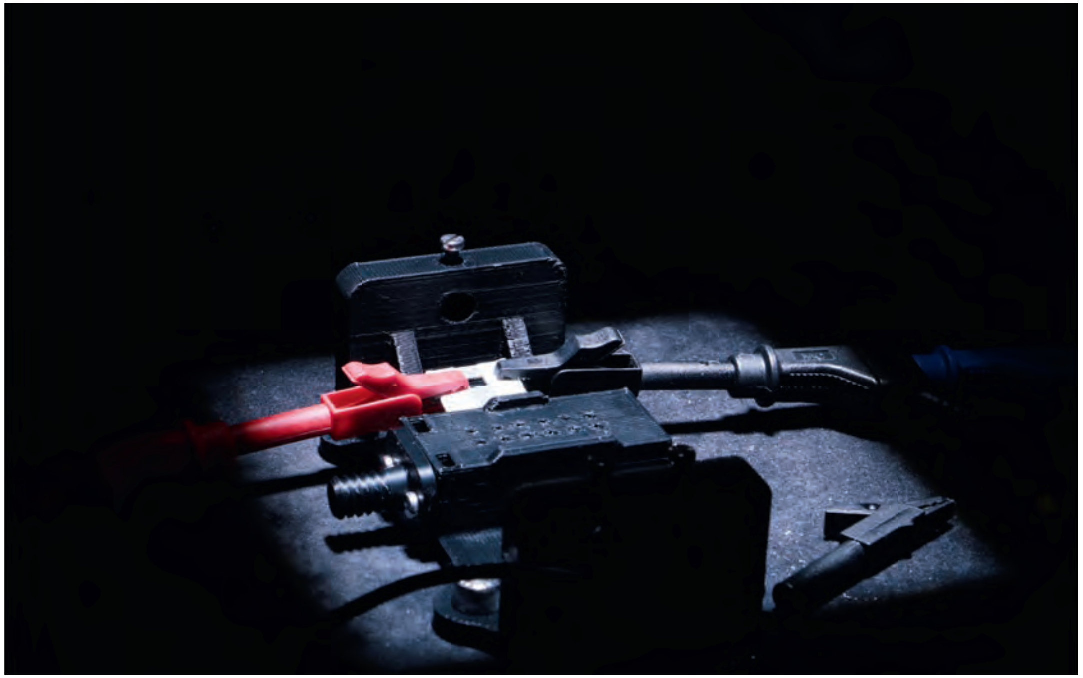
Scientific research and development will play an important role in this process, particularly nanoscience and technology. The conversion of incident energy from the sun – either directly by photovoltaics, or indirectly though wind energy – is becoming increasingly important in the power mix in many countries around the world. The transient nature of these energy sources, as well as the growing importance of electro-mobility, requires the efficient storage of electrical energy. While scalable technological solutions already exist in the form of single silicon solar cells and lithium-ion batteries, there is considerable potential and scope for new solutions.

The conversion of light to electricity is currently predominantly limited to rooftop solar panels, which produce power for the electrical mains grid, but also require energy-intensive semiconductor manufacturing processes. Increasingly, however, energy demand is delocalized and mobile, which suggests that new approaches are needed. The emerging Internet of Things, for example, consists of highly mobile low-power devices that cannot be directly connected to the power grid, and must therefore harvest energy from their immediate environment. This leads to the use of photovoltaic devices with new properties: they should be light, flexible, easy to manufacture, highly integrated into the manufacturing processes of the devices themselves, and safe to recycle at the end of the device's lifetime. Compared to rooftop photovoltaics, the requirements in terms of energy conversion efficiency and device lifetime are much lower for these devices, enabling the use of new materials and technologies that are less suitable for rooftop panels. The development of new photovoltaic materials for these applications offers tremendous scientific opportunities for the coming decades.

Recent advances in nanoscience and technology – both soft and hard – are currently paving the way for new solutions. With the emergence of perovskite photovoltaics, for instance, it is now clear that disordered materials containing both organic and inorganic components are able to rival solar cells made from silicon, a concept that was ridiculed as little as five years ago. Perovskite solar cells can be manufactured largely by the deposition of liquids at relatively low temperatures, a process that employs a fraction of the energy needed

> "The societal importance that drives the development of these new technologies is unlikely to abate during the coming decade."

to manufacture single crystalline silicon and its conversion into a solar cell. The intrinsic disorder in this new generation of photovoltaics, however, which also encompasses dye-sensitized and fully organic solar cells, requires an understanding of how different components within the devices assemble and how to control this assembly. A particular challenge concerns the interplay of structure and morphology within these materials, which affects photonic and electronic function.



The development of next-generation solar cells is progressing rapidly

Substantial progress has been made in recent years in the development of next generation photovoltaics, and ongoing research efforts are likely to bring these new concepts to the market, for the new applications previously outlined, for example.

Soft matter nanoscience will play an important role in this research effort, which requires the close collaboration of physicists, chemists, materials scientists, and engineers. Soft matter concepts, such as molecular self-assembly and the self-organization of colloidal building blocks, afford the morphological control that is required for the optimization of device performance. The conversion from an initial liquid state to a solid one, and ultimately to a polycrystalline assembly, involves the complex interplay of thermodynamic and kinetic processes, the understanding of which lies within the scope of physical chemistry in general and – since macromolecules are often involved – soft matter science in particular. Interestingly, the assembly of liquid and soft materials is often used in the manufacture of entirely inorganic nanostructured materials, whereby soft structure formation processes, such as molecular self-assembly, endow the final inorganic assembly with favorable structural properties.

While entirely different in their operational principle, lithium-ion batteries can also benefit from many of the soft matter concepts described above. To improve battery capacities – energy stored per weight or volume of the battery – lithium ions must be stored effectively in the anode and cathode materials that constitute the battery. At the same time, these ions must easily be able to move within and between these materials to provide high discharge currents and allow for the quick charging of the batteries. Again, while many of the electrode materials are inorganic, soft matter science is able to mold their structure and morphology during manufacture, which may ultimately result in the desired advantageous properties. A further goal in the improvement process is the replacement of the liquid electrolyte in these batteries, for instance by a solid polymer, which will make these batteries safer. Finally, material development employing soft matter concepts will also provide important support in the discovery of new battery chemistries.

The societal importance that drives the development of these new technologies is unlikely to abate during the coming decade. While significant progress is being made in energy production and storage, the complexity of the materials underpinning these new energy materials will require sustained research efforts in the foreseeable future.

Where biology and polymers meet

_ Macromolecular Chemistry

Prof. Nico Bruns, SNSF Professor of Macromolecular Chemistry

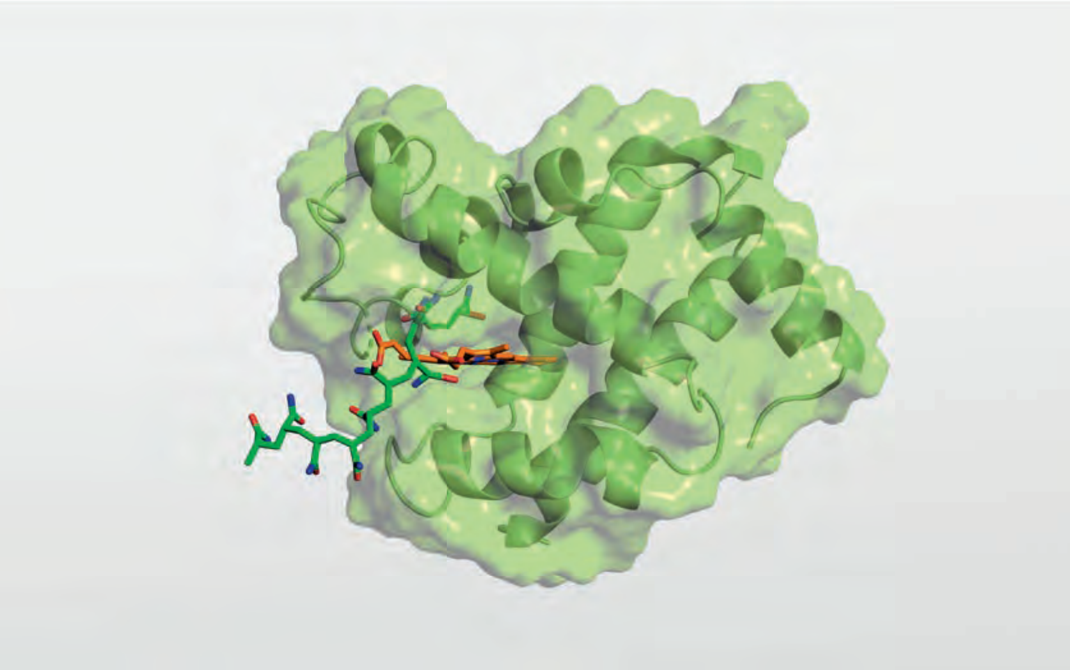
The molecular building blocks of life are often macromolecules. Some examples include DNA, proteins, and polysaccharides such as cellulose and starch. Macromolecules are large molecules that consist of many copies of a few different repeating units. Biological macromolecules share this general structure with synthetic polymers that are found in modern-day plastics.

Herman Staudinger, widely regarded as the founding father of polymer chemistry and winner of the Nobel Prize in Chemistry 1953 for establishing the concept of macromolecules, pointed out that macromolecules exist in nature and in synthetic polymers, and that theories of polymer chemistry could be applied to natural and synthetic polymers alike. For a long time, however, the synthesis of polymeric materials belonged to the realm of chemistry. Chemical conversions and catalysts were developed and optimized by chemists and chemical engineers using processes and production methods that could be applied at the industrial scale. Today, polymerization reactions are also employed around the world to synthesize nanomaterials in research laboratories, making them an important tool for scientists.

At the same time, the field of biochemistry and biotechnology has developed at a great pace, allowing for the production of DNA or proteins with unprecedented precision, or the manufacture of polyesters and polysaccharides in large bioreactors. These natural macromolecules are synthesized by natural catalysts such as enzymes or whole microorganisms in which cascades of enzymatic reactions produce the monomers and then assemble them into polymer chains. An example of this is the fermentative production of poly(hydroxyalkanoate)s, a class of bio-derived and biodegradable plastics. Often, biocatalysts have been engineered to be more effective, more robust, or more selective. Despite the advances in synthetic polymer chemistry and biotechnology, however, it is surprising how little overlap there is between the two communities. The use of biocatalysts to synthesize typical synthetic polymers such as poly(acrylate)s has only been tackled by a few research groups. Nevertheless, as the boundary between synthetic nanosystems and biological systems blurs, applying enzymes and cells to synthesize polymers offers tantalizing perspectives. For instance, enzymes are sustainable and non-toxic catalysts for the synthesis of polymers, and as such could help conduct polymerization reactions in a more environmentally friendly manner. In a more advanced version, plastics could be produced by microbes or algae in fermentation reactions, ideally starting from

> “It might even be possible to create self-replicating, organelle-like objects that could serve as mini-factories for the production of drugs within a specific tissue.”

bio-based feedstocks such as agricultural waste or by carbon dioxide fixation. To this end, the metabolic pathways in these cells will have to be engineered to produce these results. To achieve this goal, it is essential to deepen the understanding of enzymatic polymerization mechanisms at the molecular level and to apply this knowledge to create more efficient polymerization biocatalysts. The biocatalytic synthesis of polymers is not only relevant for the production of synthetic polymers, but could potentially also be used to



Representation of myoglobin-catalyzed polymerization with a bromine-terminated oligomer localized in the protein active site

create stable self-assembled nanostructures in living cells by biocatalytic polymerization. It might even be possible to create self-replicating, organelle-like objects that could serve as mini-factories for the production of drugs within a specific tissue. Alternatively, the polymers might act as drugs themselves, for example by binding and capturing invading viruses.

A further important aspect to be studied at the interface of enzymology and polymer science is the biocatalytic degradation of polymers. Enzymes can be engineered towards an optimized production of macromolecules, but they can also be developed to degrade certain macromolecules into their component building blocks. Thus, future generations of biocatalysts might be used in waste treatment and in recycling plants and therefore help to reduce the volume and impact of plastic waste.

Macromolecules are vital for both life and polymer sciences. Applying biochemical and biotechnological methods to the synthesis and degradation of polymers will create many opportunities for more environmentally friendly processes and for the creation of advanced nanosystems that function at the interface of materials and living matter.

Single protein biophysics to diagnose neurodegenerative diseases

_ BioPhysics

Prof. Michael Mayer, Chair of BioPhysics

The likelihood of suffering from neurodegenerative disorders such as Alzheimer's, Parkinson's, or Huntington's diseases increases sharply with age. Due to gains in average life expectancy, a recent study predicts the number of Alzheimer's patients in the EU alone to nearly double from seven million in 2013 to 13 million in 2040.

Currently, no effective treatment is available for Alzheimer's disease as patients are often in an advanced state of disease manifested in irreversible brain damage and cognitive decline by the time they are diagnosed. Hence, the medical community is striving to identify individuals with increased risk for the condition as early as possible in order to pursue prophylactic or therapeutic intervention before the onset of the disease and thus before irreversible brain damage has occurred.

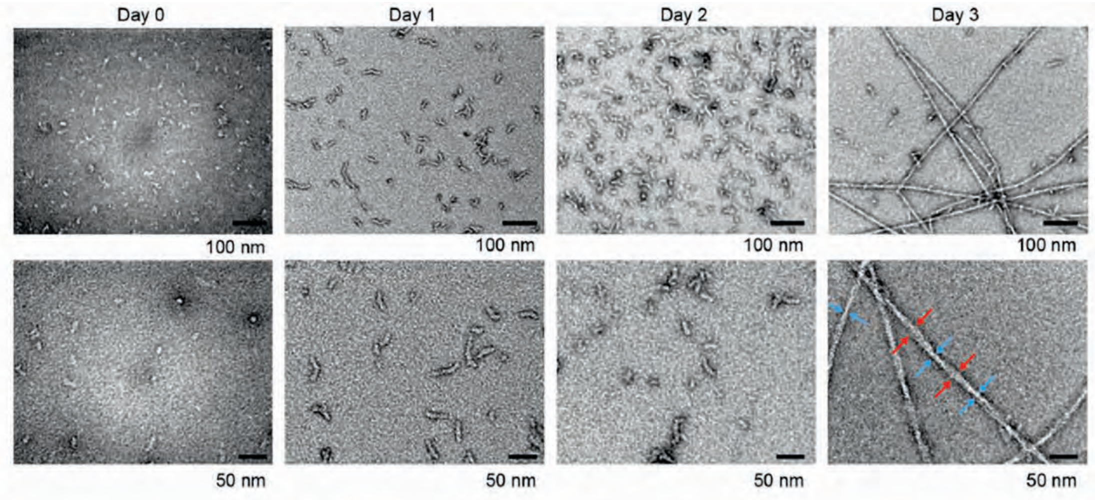
Reliable biochemical indicators of disease, so-called biomarkers, can help predict a patient's risk for developing certain diseases. The discovery of biomarkers for neurodegenerative disorders is urgently needed. Once identified and validated, these biomarkers will have to be monitored over years and at low cost. Ideally, biomarkers will not only identify people at risk but also measure the effectiveness of therapeutic intervention and contribute to our present understanding of genetic or lifestyle factors that lead to neuropathologies.

One promising candidate for a biomarker for neurodegenerative diseases are toxic protein aggregates, so-called amyloids, which accumulate in the brain of patients and form the senile plaques which are a hallmark of Alzheimer's disease. At present, amyloid biomarkers are measured in cerebrospinal fluid, but for a routine assay to be practical, it is critical to detect and characterize amyloids non-invasively from accessible body fluids such as blood, tears, saliva, or urine.

The task of characterizing amyloids from body fluids, however, is challenging in a number of ways. Amyloids are present at extremely low concentrations and form aggregates that change profoundly over time. These aggregates vary in size by a factor of over 1000 and can be in the shape of spheres, donuts, rods, or fibers. It is exactly these parameters – concentration, size, and shape – that determine amyloids' toxicity to brain cells. Recent evidence shows, for instance, that intermediately sized amyloids are distributed readily in the brain and are more toxic than the smallest or largest aggregates.

> "A clinically relevant assay must provide a comprehensive profile of amyloid particles and indicate their manifestation in the patient in order to assess a general risk or progression of neurodegenerative disease."

A clinically relevant assay must provide a comprehensive profile of amyloid particles and indicate their manifestation in the patient in order to assess a general risk or progression of neurodegenerative disease. Amyloid status in patient samples must therefore be performed before the amyloid composition in the sample has had time to change significantly. Thus, the assay must be rapid, sensitive, and yield a representative



Transmission electron microscopy (TEM) showing amyloid aggregate growth incubated in water over three days

characterization of the sample's amyloid components without interference from other sample constituents.

At present, no established diagnostic assay meets all of these demands. Advances in nanotechnology, however, have recently made it possible to characterize samples containing amyloids on a single particle basis. Rather than obtaining an average ensemble measurement, these new techniques make it possible to analyze the size and shape of individual amyloid particles. Comparing the frequency and variability of these physical properties allows one to determine the amyloid profile of a patient sample. This information enables clinicians to measure the levels of the most toxic or most predictive amyloids and to correlate them with the risk of developing disease or with the effectiveness of a treatment.

Over the course of the next five to ten years, the Biophysics group at AMI will continue to take advantage of rapid advances in nano-electronics and -fabrication to characterize amyloid biomarkers for neurodegenerative diseases in a rapid, reliable, and routine fashion and, ideally, at a sufficiently low cost that is suitable for long-term monitoring of millions of elderly people. Such next-generation single molecule bioanalytical techniques may detect early warning signs decades before the onset of disease and provide a criterion for beginning intervention to prevent or treat the disease before it is too late. It is also hoped that such methods will accelerate the development of therapies that prevent, or at least delay, irreversible brain damage from neurodegenerative diseases.

The fate of nanoparticles
_ BioNanomaterials

Prof. Alke Fink, co-Chair of BioNanomaterials

Prof. Barbara Rothen-Rutishauser, co-Chair of BioNanomaterials

Over the past decade, nanotechnology has developed rapidly and, due to their unique properties, engineered nanomaterials are already used in technology in many different ways.

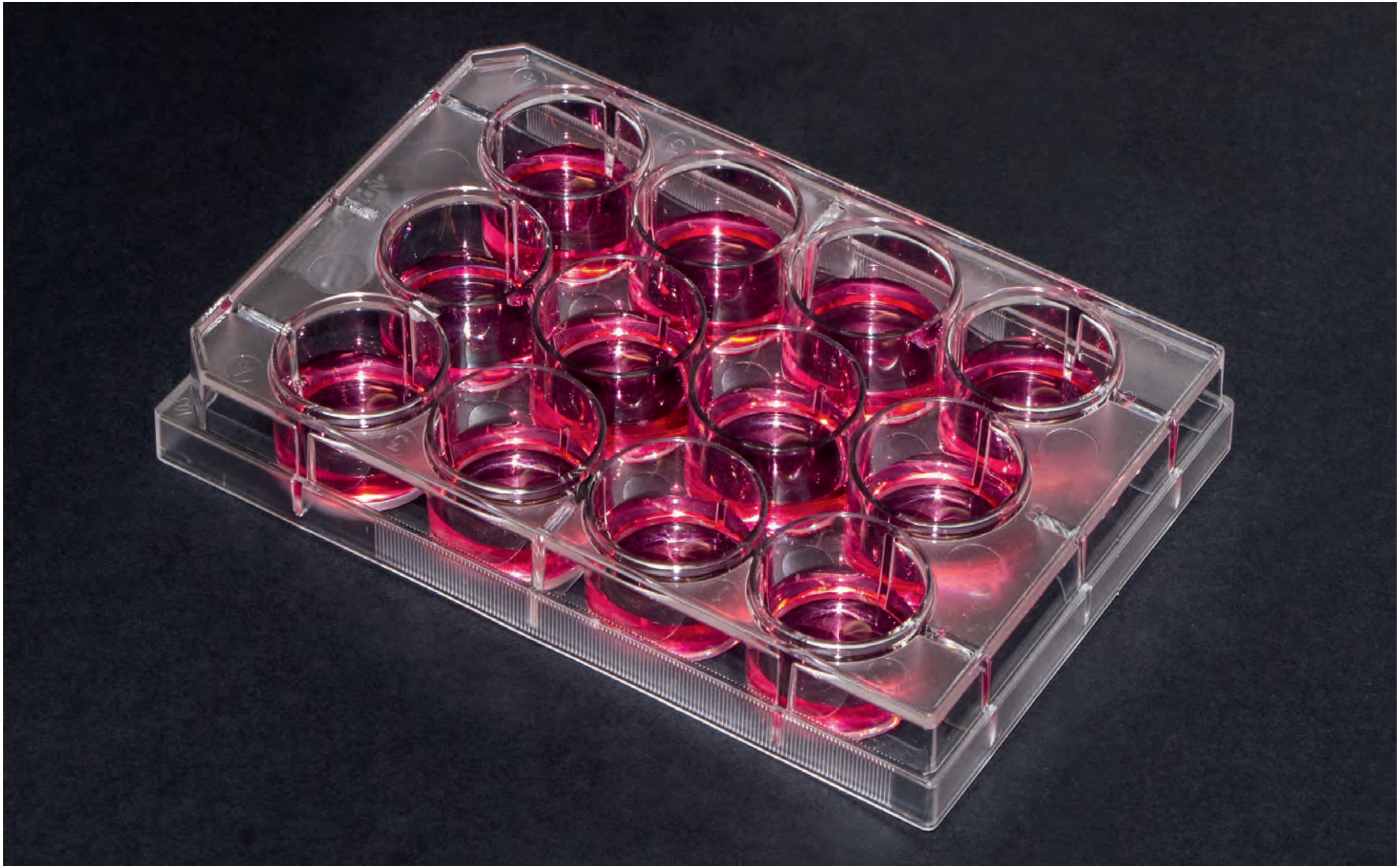
One important application is in nanocomposite materials, which are, for example, stronger, lighter, or more electro-conductive than more traditional materials. Nanoscale materials have also already been incorporated into a variety of personal care products to improve their performance, such as titanium dioxide and zinc oxide nanoparticles that are added into sunscreen to protect the skin while remaining transparent. Another example is silica dioxide, which is used in nanoparticulate form as a food additive because of its anti-caking properties. In 2011, the EU decided that all nanoparticles must be declared in consumer products. This is also the case in Switzerland, where "nano" must be declared in foodstuffs and cosmetics as of May 2017, with a transition period of four years for manufacturers to label their products clearly.

Cutting-edge methods used thus far to detect and characterize nanoparticles in chemically complex environments, such as electron microscopy or scattering techniques, are expensive and require time-consuming sample preparation as well as highly experienced scientists for the analysis and interpretation of the data. In addition, so far, no established and validated analytical methods are available for the regulatory authorities.

To overcome this, the BioNanomaterials group at AMI focused its research on establishing more affordable, easier to use, and more versatile instrumentation to detect nanoparticles in products, and on analyzing the physical and chemical properties of these nanoparticles. Such methods will progress in the coming years with an impact on academia and industry but also on regulatory processes.

Several nano-sized materials, such as liposomes and iron oxide, gold, or silica nanoparticles, have already been approved by the American Food and Drug Administration (FDA) for clinical trials. Nevertheless, several crucial challenges remain for nanomedicines to make clinically important progress, including a thorough understanding of the interaction of nanoparticles with cells, tissues, and organs. There is evidence that, depending on their physical and chemical properties and subsequent interactions, nanoparticles are indeed taken up by cells. However, their subsequent release, intracellular degradation of the materials, transfer to other cells, and translocation across tissue barriers – all relevant factors with an impact on efficacy – are still poorly understood. The involvement of these cellular clearance mechanisms strongly influences the long-term fate of used nanoparticles, especially if repeated exposures are also taken into account. Such studies are currently underway and will support the development of safe and effective medication but will also help to understand potential risks from these products for humans.

> "The involvement of [...] cellular clearance mechanisms strongly influences the long-term fate of used nanoparticles."



Cell cultures help evaluate the impact of nanoparticles on living tissue

There's a great future for multi-stimuli-responsive polymers!

_ Polymer Chemistry and Materials

Prof. Christoph Weder,
Chair of Polymer Chemistry
and Materials

Fifty years ago, the fictional Mr. McGuire predicted in the movie *The Graduate* that "there is a great future in plastics." Indeed, plastics and other types of polymers have since developed into one of the most widely used materials types and play an important role in almost every aspect of modern life, serving as the basis for clothes, paints, construction materials, household goods, toys, personal care products, automotive components, medical devices, and countless other products.

The widespread use of polymers is driven by the characteristics that they can easily be tailored to adopt very different properties, are generally inexpensive, and can be processed into products of any desirable shape.

The expansive use of polymers has been enabled by tremendous advances in every aspect of polymer science. Since the emergence of meaningful commercial polymer activities some eighty years ago, researchers have developed a range of methods to synthesize and characterize polymers and have advanced the fundamental understanding of the structure-property relationships of such materials. These achievements have made it easier – but by no means trivial – to rationally design and create new materials with novel properties or combinations of properties. In addition to improving polymers for and expanding their utility in traditional applications, researchers have increasingly focused on the design of advanced polymers with highly specialized functions. Illustrative examples of this more recent trend are electrically conducting and electroluminescent polymers, which can replace traditional (semi)conductors in some applications and enable plastic electronic devices, polymers that transport and deliver medication to targeted sites in a patient's body, and shape-memory polymers, which can be programmed to change their shape on command.

Such shape-changing polymers are part of a rapidly growing family of "stimuli-responsive" materials, which are sometimes also referred to as "smart" or "intelligent" on account of some analogies to living matter. These polymers offer properties that can be influenced in a useful manner through exposure to an external stimulus, such as heat, light, chemicals, mechanical force, and electric or magnetic fields. Examples of responses that have been demonstrated are changes of mechanical properties, color, fluorescence, shape and electrical, thermal, chemical, or other transport characteristics, and the list of functions that can be achieved is growing steadily. It is safe to expect a growing list of commercial products based on such materials that range from self-healing coatings to smart light management systems.

> "Somewhat akin to living systems, multi-responsive polymers can offer a broad range of complex properties and functions."

So far, research on stimuli-responsive polymers has been focused almost exclusively on materials that display one specific property change in response to one pre-defined stimulus. It is possible, however, to create multi-responsive polymers, i.e., materials that respond to multiple stimuli or offer more than one response. Somewhat akin to living systems, which have evolved to adapt and respond in complex ways to different environmental cues, multi-responsive poly-

Polymers can be easily tailored to adopt very different properties

mers can offer a broad range of complex properties and functions, including completely new, emergent functions. For instance, one can imagine new textiles that display switchable permeability and appearance in response to water or toxic chemicals, while at the same time recording physiological cues or converting motion into electrical energy that can be harnessed to power personal devices. One can also envision paints that change color and thermal conductivity upon exposure to light and heat and are useful for energy-efficient climate control of buildings, while also serving as sensors, for example to monitor structural health. In addition, one can target self-sealing and permeability-adjusting food packaging materials that also feature built-in sensors that indicate spoilage of the packaged goods. Given the endless possibilities to develop materials with a wide range of adaptive properties and the significant technological and societal impact that these may have, it appears safe to say that advanced, multi-responsive polymer systems are bound to attract significant attention in the coming decade.

Reference

Some of these thoughts and a summary of the state of the field can be found in a recent “Perspective” article: Herbert, K.M.; Schrettl, S.; Rowan, S.J.; Weder, C. Solid-state Multi-stimuli, Multi-responsive Polymeric Materials, *Macromolecules* **2017**, 50, 8845.


10ml
B-D

49

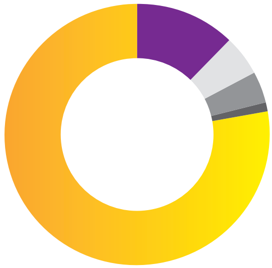
Finance & Organization

Finance

_ Cost structure at AMI

The Institute's overall expenditures in 2017 rose more than 20% to CHF 10.8 million. Nearly four-fifths of all expenses were for research and an additional 12% was invested in research equipment. Around 4% of the budget supported valorization activities such as technology transfer and communication & marketing, while another 7% went towards administrative costs. Compared to the previous year, third-party funding of research projects increased by CHF 0.6 million to CHF 4.8 million, covering 56% of all research expenditures. The most important sources were the Swiss National Science Foundation (SNSF), the European Union (EU), industrial partners, and the Swiss Commission for Technology and Innovation (CTI).

Overall expenses 2017
CHF 10.8 million



- Research / 78%
- Research equipment / 12%
- Administration / 5%
- Valorization / 4%
- Education / 1%

Funding sources of overall expenses 2017

- Adolphe Merkle Foundation / 33%
- Grants / 48%
- University of Fribourg, Canton Fribourg / 14%
- Industry / 5%

Funding sources of research projects 2017
CHF 8.5 million

- Adolphe Merkle Foundation / 31%
- Third-Party / 57%
- University of Fribourg / 12%

Third-party funding of research projects 2017
CHF 4.8 million

- SNSF / 58%
- EU / 16%
- Industry / 10%
- Other sources / 10%
- CTI / 6%

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 to 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

Members

Prof. em. Joseph Deiss (President)
Former member of the Swiss Government, former President of the General Assembly of the United Nations, Professor at the University of Fribourg

Isabelle Chassot
Head of the Federal Office of Culture, former State Minister in charge of Education, Culture and Sport of canton Fribourg, former President of the Swiss Conference of Cantonal Ministers of Education

Peter Huber
Group Director S&M, Meggitt PLC, UK, President of Meggitt Sensing Systems SA, Switzerland

Prof. Rolf Mülhaupt
Managing Director Freiburg Center of Interactive Materials and Bioinspired Technologies

Dr. Peter Pfluger
Consultant, former CEO of Tronics Microsystems, Phonak Group and Swiss Center of Electronics and Microtechnology (CSEM)

Prof. Claude Regamey
Former chairman of the Department of Internal Medicine, Hôpital Cantonal Fribourg, former President of the Ethical Committee of the Swiss Academy of Sciences

André Broye (Managing Director)

Institute Council

Members

Prof. Astrid Epiney (President)
Rector of the University of Fribourg, Professor at the Faculty of Law, University of Fribourg

Dr. Peter Pfluger (Vice-president)
Consultant, former CEO of Tronics Microsystems, Phonak Group and Swiss Center of Electronics and Microtechnology (CSEM)

Prof. Rolf Ingold
Vice-Rector for Research, University of Fribourg, Professor, Department of Informatics, University of Fribourg

Prof. Rolf Mülhaupt
Managing Director Freiburg Center of Interactive Materials and Bioinspired Technologies

Scientific Advisory Board

Members

Prof. em. Marcus Textor (President)
Former Head of Biointerface Group at Department of Materials, ETH Zürich, Switzerland

Prof. Giovanni Dietler
Head Laboratory of Physics of Living Matter, EPFL, Switzerland

Dr. Alan D. English
Senior Research Fellow (retired), DuPont Central Research and Development, USA

Prof. Paula Hammond
David H. Koch Professor in Engineering, and Executive Officer, MIT, USA

Prof. em. Dieter Richter
Former Head Institute of Solid State Research, Forschungszentrum Jülich, Germany

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

Executive Board

Prof. Christoph Weder
Director and Chair of Polymer Chemistry & Materials

Dr. Marc Pauchard
Associate Director and Head of Knowledge and Technology Transfer

Prof. Alke Fink
Co-Chair of BioNanomaterials

Prof. Michael Mayer
Chair of Biophysics

Prof. Barbara Rothen-Rutishauser
Co-Chair of BioNanomaterials

Prof. Ullrich Steiner
Chair of Soft Matter Physics

Prof. Nico Bruns
SNSF Professor of Macromolecular Chemistry

Administration

Dr. Marc Pauchard
Associate Director and Head of Knowledge and Technology Transfer

Scott Capper
Responsible for Communications & Marketing

Melissa Forney-Hostettler
Secretary

Dr. Frédéric Pont
Grant writer

Carine Jungo
Secretary

Catherine Jungo
Responsible for Human Resources

Samuel Laubscher
Responsible for IT Support

Thierry Mettraux
Responsible for Finance & Controlling

55

PhDs & Alumni

PhDs

Our new doctors

Savvina Chortarea
(BioNanomaterials)
"Realistic exposure scenarios to study nanoparticle-lung cell interactions"

Jens Natterodt
(Polymer Chemistry & Materials)
"Reinforcement of Commodity Polymers with Cellulose Nanocrystals"

Jonas Pollard
(Macromolecular Chemistry)
"Biocatalytic radical polymerization: from enzyme-mediated ATRP to the detection of biomolecules by polymerization"

Bart Roose
(Soft Matter Physics)
"Engineering metal oxides for UV-stable perovskite solar cells"

Tom Schroeder
(BioPhysics, University of Michigan)
"Energy Conversion from Gradients across Bio-Inspired Membranes"

Anuja Shirole
(Polymer Chemistry & Materials)
"Design, Processing and Characterization of Shape Memory Polymer Composites and Blends"

Alumni

People who left AMI in 2017

Antonio Abate
Soft Matter Physics

Savvina Chortarea
BioNanomaterials

Ana Cordeiro
National Centre of Competence in Research Bio-Inspired Materials

Thanh Quy Dang
Macromolecular Chemistry

Leopold Daum
BioNanomaterials

James Dolan
Soft Matter Physics

Cyrille Girardin
Administration

Clément Mugémana
Macromolecular Chemistry

Jens Natterodt
Polymer Chemistry and Materials

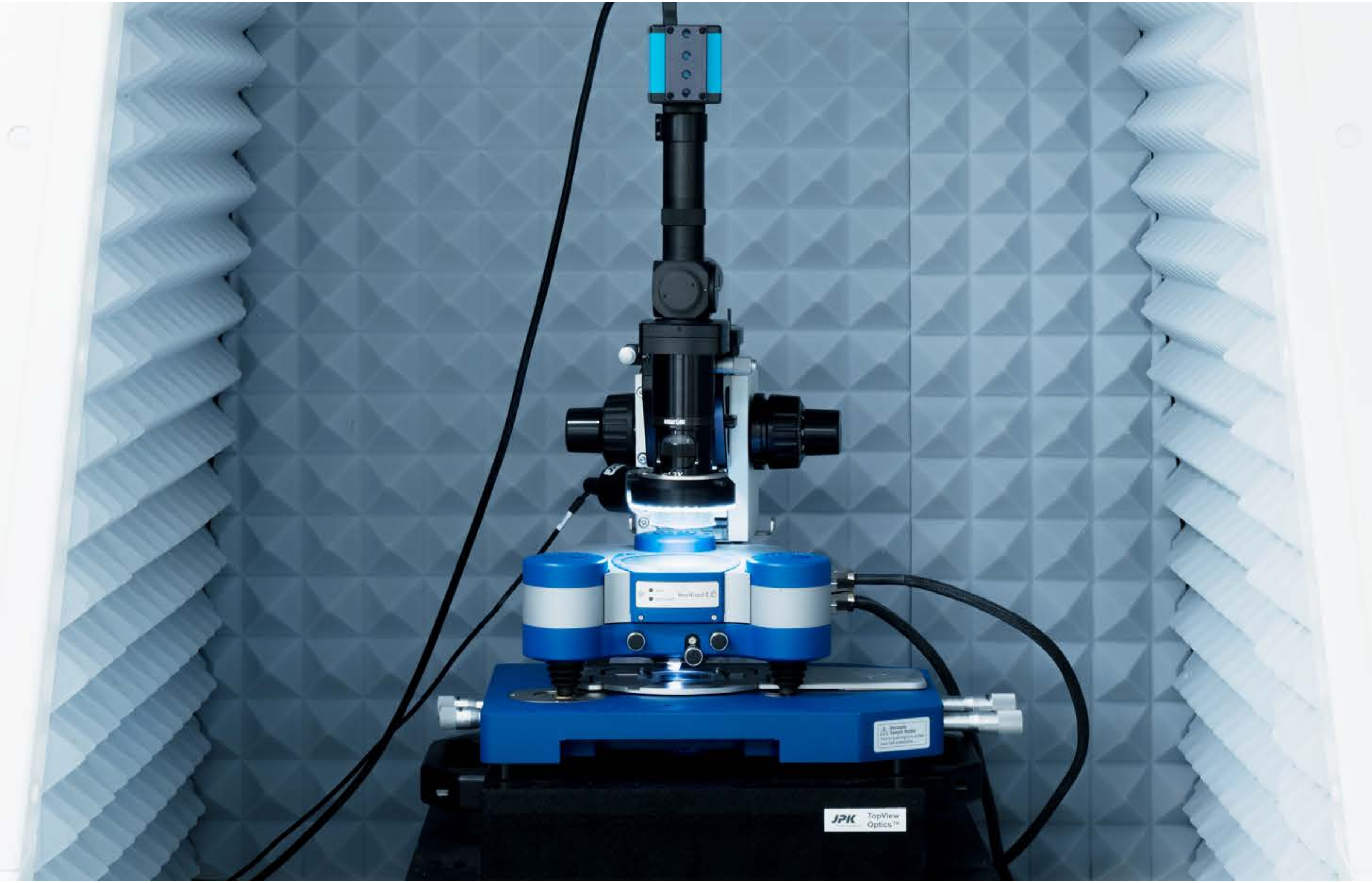
Nadine Noubissi
Administration

Luc Tinguely
Administration

Bart Roose
Soft Matter Physics

Saeed Sadeghi
Soft Matter Physics

Xiaoyuan Sheng
Soft Matter Physics


JPK
TopView
Optics™

Impressum

Editorial: Christoph Weder / Scott Capper

Text: Scott Capper / Editing & proof-reading: Annika Weder

Photos: Christopher Schaller, Fribourg / Scott Capper (pages 4, 12, 16, 19, 32, 34, 35, 39, 45) / BM PHOTOS, Marly (pages 12, 34, 47) / AMI (pages 12, 33) / Sonova (page 16) / Charles Ellena (page 19) / Bodo Wilts (page 19) / Marion Savoy (page 32) / Ted Byrne (page 32, 33) / Dominique Bersier, UniFR (page 33) / ALDO ELLENA (page 34) / Nico Bruns (page 35) / VINCENT MURITH, LA LIBERTÉ (page 35) / Bruns group (page 41) / Mayer group (page 43) / Miguel Spuch-Calvar (page 45) /

Illustrations: Noun Project, created by Anbileru Adaleru, Dan Garzi, Roy Verhaag, Norbert de Graaff, Creative Stall, Icon Island, Tania Jiménez, Tony Michiels, Milky (Digital innovation), Mauro Lucchesi

Graphic design: Manuel Haefliger, Grafikraum, Bern

Printer: Canisius Impression & Graphisme

ami.swiss