ICMS Highlights

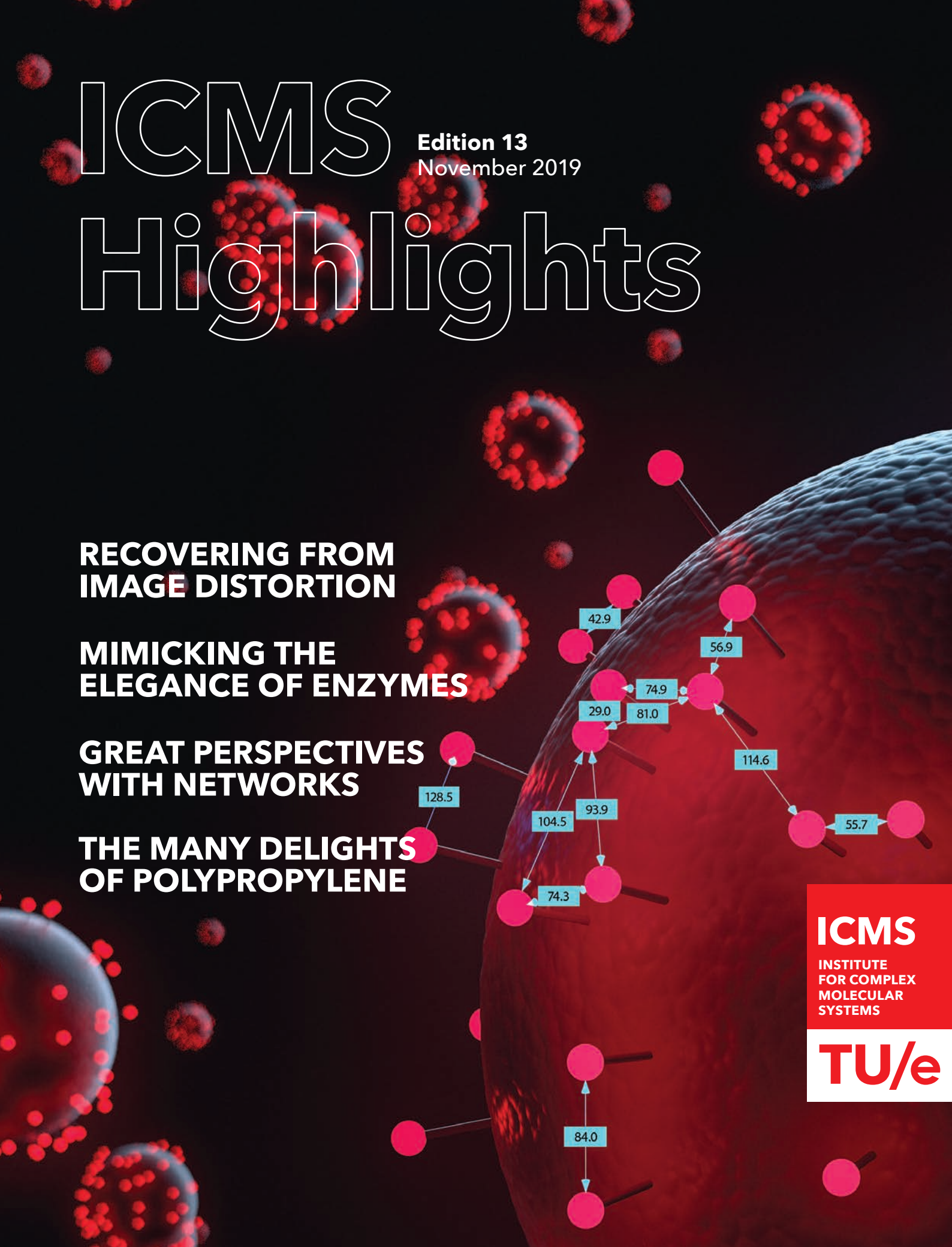
Edition 13
November 2019

RECOVERING FROM IMAGE DISTORTION

MIMICKING THE ELEGANCE OF ENZYMES

GREAT PERSPECTIVES WITH NETWORKS

THE MANY DELIGHTS OF POLYPROPYLENE



ICMS
INSTITUTE FOR COMPLEX MOLECULAR SYSTEMS
TU/e

INTRODUCTION

ICMS Highlights

Science as we know it today goes far beyond just understanding phenomena in the world around us. Acquired sets of knowledge from different origins are increasingly used to design and develop a variety of advanced materials and biological systems. Both in materials science and biology, ICMS researchers join hands and apply acquired knowledge to achieve progress. For instance in precision immunotherapy, using nano-medicine to intervene in selected biological processes, and in the integration of advanced materials into devices.

In this edition, we want to take a moment and thank our valued colleague Gerrit Peters, who recently retired from the department of Mechanical Engineering. He has supported the TU/e polymer community with his pleasant character and polymer expertise. We also welcome Pim van der Hoorn and Erik Steur, who will set out to connect mathematics with many other scientific fields. We are proud that Eline van Haaften, one of our young scientists, received a Cum Laude for her PhD project on the mechanics of lab-made blood vessels. Furthermore, Ilja Voets, who gave her inaugural lecture last October, was awarded both the (Bio)Macromolecules Young Investigator Award and the Gold Medal of the Royal Netherlands Chemical Society. And last, but certainly not least, we are excited about the research of Danqing Liu, who strives to make robots sweat, developing smart surfaces that act as artificial skin.

We hope you enjoy reading this edition of our ICMS Highlights, where passionate researchers present their scientific dreams and hope to inspire you on your next steps in science.

Jan van Hest
Scientific director

Monique Bruining
Managing director

Calendar

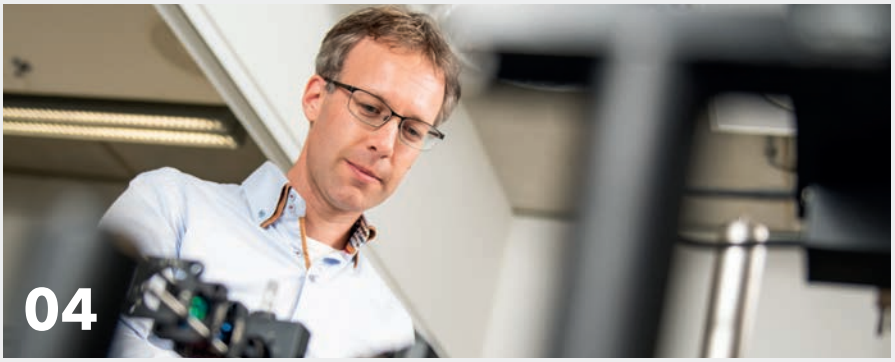
November 6, 2019
Mainz
ICMS & MPIP SYMPOSIUM

November 28, 2019
Ceres building, 17.00 hrs
ICMS STUDENT MIXER

January 28, 2020
START OF ICMS SCIENTIFIC SKILLS COURSE

March 26 and 27, 2020
Auditorium, Blauwe Zaal
ICMS ANNUAL SYMPOSIUM

Content



COVER A view on surface inhomogeneity of nanoparticles, where microscopy meets mathematics.

ADVANCED ANALYSIS OF COMPLEX MOLECULAR SYSTEMS

Peter Zijlstra

Recovering from image distortion

Being able to visualize the functionalized surface of a nanoparticle with molecular resolution would be helpful for many fields. With the recently granted Innovative Training Network SuperCol, Peter Zijlstra is taking on the challenge to generate novel imaging tools.

It seems straightforward. You have a collection of identical nanoparticles and, to give them an additional property, you attach chemical groups to their surface. And as the particles are identical, their functionalized counterparts will be as well. Unfortunately, reality paints a completely different picture, says Peter Zijlstra, assistant professor of Molecular Plasmonics at the departments of Applied Physics and Biomedical Engineering. “Right now, we can only determine an average. We take a solution of the functionalized particles, we measure the effect and then we can deduce

the average number of functional groups per particle. But we know that in reality there are huge differences between functionalized particles. Both the number of groups and their distribution on the surface show a large variation."

For biomedical applications, such as sensing or drug delivery, it is crucial to have a well-defined, homogenous population of functionalized particles. Zijlstra: "We use functionalized nanoparticles for sensing applications that detect biomolecules, such as antibodies or inflammation markers, and we have noticed that each particle responds differently. Some particles hardly bind to the biomolecule, whereas others generate a very high signal and yet others perform somewhere in between. That is a real problem for these types of applications, but it is very hard to optimize the functionalization process when you have only average values to work from. We don't know what we need to do to create a more homogenous distribution, because we don't know what the actual distribution is. So it is clear that we need to know exactly what the particles really look like."

SUPERRESOLUTION MICROSCOPY

That is why Zijlstra, who has a background in microscopy, is on the trail of superresolution microscopy. "A very powerful technique, but not yet for the study of our nanoparticles. As each particle acts like a fishbowl, the light gets scattered in all directions and the result is a distorted image." That may sound discouraging, but not to Zijlstra. "We know that there is a particle that distorts the image, but because we know the shape and size of the particle we also know the nature of the distortion. So we should be able to work our way back and correct the optical image to show us what the particle really looks like. And when we know that, we can work towards the rational design of functionalized nanoparticles.

Then we can develop better optimization protocols and create opportunities for generating new functionalities that enable responsive materials or materials with superselectivity." That is, in a nutshell, the program of the recently granted Innovative Training Network (ITN) SuperCol, which will be managed by Zijlstra and was initiated together with Ilja Voets.

Next to managing the consortium, Zijlstra will busy himself with cracking the relationship between the distortion of the microscopy image and the real distribution of the functional groups on the particles. He will also work on applying these concepts to switchable sensors. "The novelty of our approach is that we will combine measurements and models. We will compare experimental images of very well-defined particles with the models, and use that to correct the superresolution images. It all revolves around the shape of the 'spot'. This is not perfectly round, because the particles distort the light and that is where we can extract information about the exact location of the functional groups. One of our aims is to develop software that can perform this interpretation step."

"THIS IS ABOUT CURIOSITY-DRIVEN RESEARCH IN SUPER RESOLUTION MICROSCOPY AND COLLOID CHEMISTRY."

PERFECT FIT

The SuperCol consortium encompasses 8 academic partners and 11 companies and will use its approximately €4 million budget to train 15 PhD students over the coming four years. Why the choice for an ITN as a funding instrument? "This is about curiosity-driven research in superresolution microscopy and colloid chemistry,that will generate opportunities for applications in biomedicine and new materials. Moreover, through our contacts with companies, we learned that they urgently need people who are qualified in this area. It just all fits together perfectly and really matches the criteria for an ITN. And because this is such a broad challenge that requires various areas of expertise, you need critical mass to really have an impact and get things going." Each PhD student will perform part of the research at one of the participating companies. "It is striking that most companies in the consortium do not work on biomedical applications, but are very interested in our research for other applications, mostly in materials. That shows the relevance of this ITN."

The ICMS-IBEC Travel Grant scheme enabled Edgar Fuentes to visit Eindhoven and perform experiments at ICMS.
"It was a good and challenging exercise."

Edgar Fuentes

ICMS - IBEC COLLABORATION

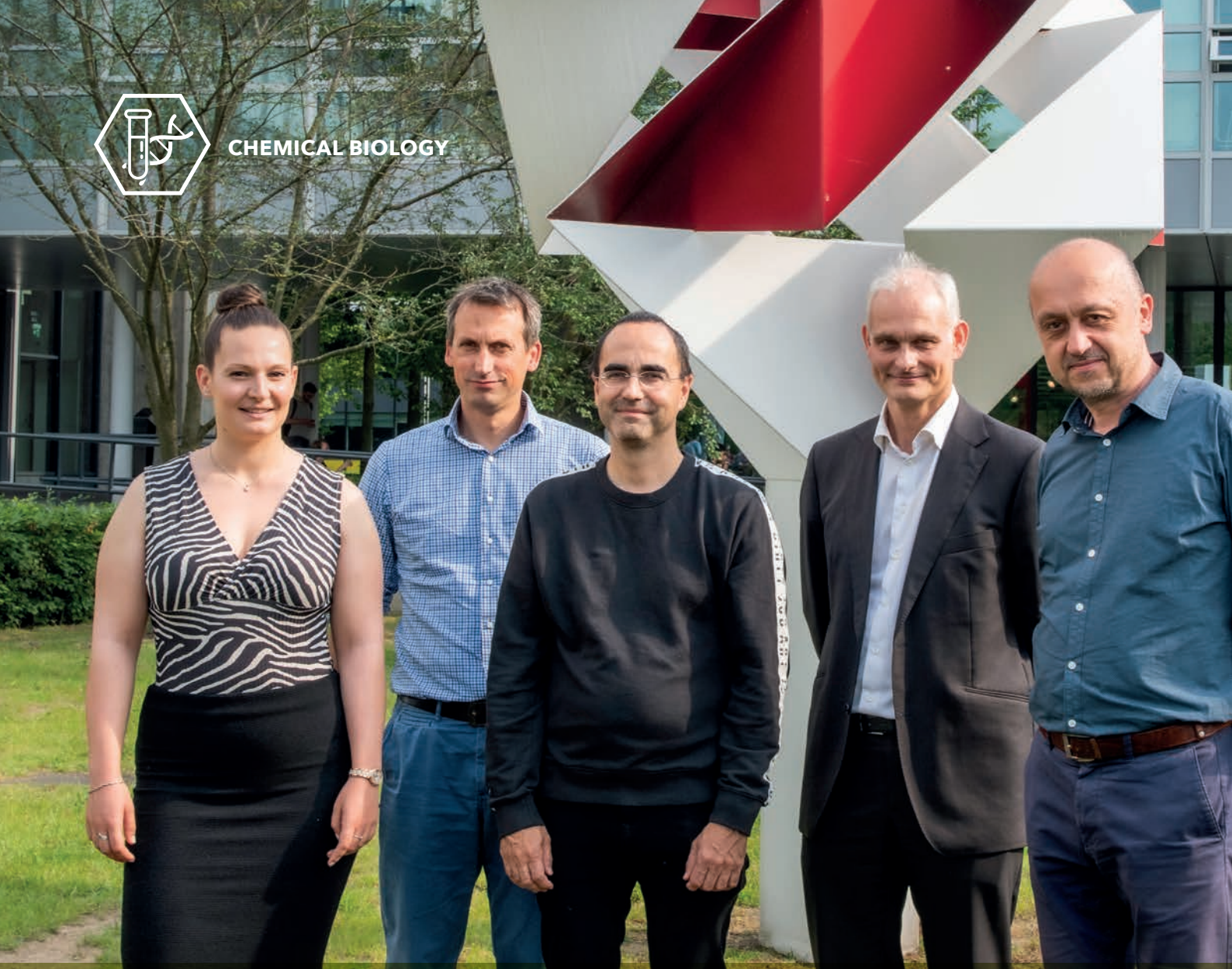
A fruitful week in Eindhoven

Edgar Fuentes is a PhD student in the Nanoscopy for Nanomedicine group at the Institute for Bioengineering of Catalonia (IBEC) in Barcelona. There, he focuses on the synthesis of novel smart supramolecular materials for drug delivery. "That requires a deep understanding of their behavior and the underlying mechanisms, which in turn requires extensive characterization of the materials", he explains. To this end, the IBEC group started a collaboration with the group of Ilja Voets at ICMS. "Their work on self-assembled systems gives them a broad perspective when it comes to suggesting experiments, interpreting data and helping with characterization techniques, in which they are particularly experienced", Fuentes says.

"THIS GRANT WAS A GREAT OPPORTUNITY. IT ENABLED ME TO LEARN TECHNIQUES AND DO EXPERIMENTS THAT WERE NOT POSSIBLE AT IBEC."

Working directly with the Voets-group, specifically with fellow PhD student Marieke Gerth, would be very useful, and the ICMS-IBEC Travel Grant offered the means to organize a visit. "I saw this grant as a great opportunity for me and for the project. It enabled me to learn about their specific techniques and do some experiments that were not possible at IBEC." Fuentes' visit to Eindhoven was short, which meant a lot of work in little time. "I stayed one week and Marieke kindly offered to prepare everything in advance, so we were able to start immediately after my arrival. It was an intense week in which we performed a first round of experiments, discussed and analyzed the results, and managed to plan and perform a second round of experiments."

Despite the hard work, it was worthwhile. "What was especially valuable to me was sharing knowledge with scientists experienced in my field, using instruments that are not available at IBEC, and learning new characterization methods. At the same time, however, I had to plan my experiments in advance from a long distance, taking into account the time I had available. For me, this was a good and challenging exercise." Upsides for the research were also generated. Fuentes: "It was interesting to correlate the results we obtained at IBEC with those of complementary characterization methods at ICMS. That gave us a deeper understanding of the materials we are working on." He urges other researchers to also apply for a travel grant. "ICMS offers a very good environment where different disciplines merge to build new knowledge. I enjoyed interacting with the ICMS scientists, both during work hours and afterwards while having a pint of beer."



Learning lessons in nanomedicine

NANOMED RESEARCHERS REFLECT ON HOW TO DEVELOP SUCCESSFUL DELIVERY SYSTEMS

From left to right; Roxane Ridolfo, Enrico Mastrobattista, Jean Christophe Leroux, Jan van Hest, Stefaan De Smedt

Early June, ICMS hosted the final symposium of the European Innovative Training Network NanoMed, chaired by ICMS Scientific director Jan van Hest. It provided a perfect occasion for a discussion on nanomedicine with Van Hest and NanoMed team members Jean Christophe Leroux (ETH Zürich), Enrico Mastrobattista (Utrecht University), and Stefaan De Smedt (Ghent University). They were joined by NanoMed early-stage researcher Roxane Ridolfo (TU/e).

The concept of nanomedicine carries many promises of using nano-sized carriers to deliver drugs to specific locations in the body and enable targeted therapies. But it has been carrying these promises for quite some time now. So what's going on? Is nanomedicine finally knocking at the door of the clinic?

Jean Christophe Leroux, professor in Drug Formulation and Delivery at ETH Zurich, points out that it could be argued that nanomedicine is a big success. "But then you include all particles in the nano-size range, including antibodies and viruses. If you focus on synthetic delivery systems such as liposomes and polymer carriers, then the success rate is less impressive, to say the least." Enrico Mastrobattista, professor of Pharmaceutical Biotechnology and Delivery at Utrecht University, agrees. "I think we have to admit that progress has been slow, but there definitively has been progress. Several nanomedicines have been marketed and many others are being developed for clinical use. At the same time, we have had to face the fact that nanomedicines are by no means the holy grail to cure all diseases. Over the last decades, we have been able to establish the limitations of what it can do."

WHY PROGRESS HAS BEEN RELATIVELY SLOW

ICMS Scientific director Jan van Hest, professor of Bio-organic Chemistry at Eindhoven University of Technology, points to the fact that it always takes quite some time for new developments to get to the clinic. "For instance, the first biocompatible polymers were developed at the end of the seventies. It took over two decades before they were finally tested in the clinic and matured into real application. The thing is, as a result of the approval process, the only version of a polymer permitted in the clinic is the original developed all those years ago.

>>

"THE MORE COMPLEX YOUR MATERIAL, THE MORE COMPLEX IT WILL BE TO OVERCOME BIOLOGICAL BARRIERS."

This means we can only make limited use of additional knowledge that we gain over the years. So every new generation of nanomedicine particles requires new analysis and evaluation before it can enter the clinic. This often takes additional decades." That being said, Van Hest acknowledges that nanomedicine started out with far too simplistic views on many aspects. For instance, the models developed on how particles would circulate in the human body turned out to be not so straightforward. Stefaan De Smedt, professor in Physical Pharmacy and Biopharmacy at Ghent University and director of the Ghent Research Group on Nanomedicines, agrees: "Many of us have overlooked the complexity, both from a materials point of view and from a biological perspective. As a pharmacist, I know the difficulty of controlling the distribution of drug molecules in the body. With nanomedicines this is even more complex. In particular, the biological variation between patients, which always poses a challenge in medicine, is problematic for nanomedicine. Achieving a distribution of particles is all about crossing the biological barriers between the separate functional parts of the human body. And the more complex your material, the more complex it will be to overcome these barriers. Add that to the huge inter-patient variability and the conclusion could be that we'll never be able to overcome this kind of complexity." Van Hest is more optimistic and points out that the lessons learnt do lead to improvement. "We now know that for every specific disease - and even for distinguishable patient groups - specific precision nanomedicines will have to be developed. And in some cases indeed these have already been developed. By the way, this knowledge also changes the perspective on nanomedicine's track record. Many former studies include negative responders that - as we now know - should have been excluded right from the start. It would have given statistical reviews on the efficiency of nanomedicine a more positive outcome."

THE SIMPLER, THE BETTER

"In retrospective, nanomedicines have been investigated for all sorts of indications, even where it did not make any sense", says Leroux. "That has to change, obviously". To which De Smedt adds: "It is crucial to consider what you want to deliver, where you want to deliver it, and in what way. That should all be very well defined." This triggers Van Hest to some introspective analysis: "As chemists, we might have been too focused on developing certain carrier concepts towards extreme sophistication and add multiple functionalities. Although that entails very nice science and breakthrough papers, it results in delivery systems that are unnecessarily complicated. Which prevents them from becoming actual products. The simpler the system, the better." Although Leroux agrees on the latter, he stresses that "if we are to advance fundamental knowledge, we do need people with no boundaries, who are - to a certain extent - not bothered by this kind of restrictions. We should not be stopped from doing things that are believed to be too fancy. On the other hand, we also need people that are determined to bring nanomedicine to the clinic, so they should be bothered by the restrictions. What is important is that we all are in touch and discuss our findings. Nowadays there is too many research that is neither scientifically interesting nor clinically relevant. That is the main problem of nanomedicine, it dilutes everything." For early-stage researcher Roxane Ridolfo, who is a PhD student with Van Hest, nanomedicine "is all about multidisciplinarity. My background is in polymer chemistry but I have learned to work in a cell lab, and thanks to the wide NanoMed network I have a broad perspective on nanomedicine. I find it particularly important that this also includes clinicians since they are 'first in line' to get nanomedicines to the market. I find it very relevant that they provide us with their insights right from the start." Regarding the scientific community, Ridolfo finds it somewhat frustrating that scientific papers are very focused on the successes. "From a young researcher's perspective, it is also very useful to acknowledge what is not working. So that when we arrive at the scene, we are able to make real improvements, and not only make incremental adjustments to already successful systems."

"THERE IS TOO MUCH RESEARCH THAT IS NEITHER SCIENTIFICALLY INTERESTING NOR CLINICALLY RELEVANT."

NANOMED
The Marie Skłodowska-Curie Innovative Training Network NanoMed was formed to train a new generation of multi-disciplinary nanotechnology experts concerned with the effective translation of molecular innovations into clinically applicable therapeutic solutions. Over the past four years, fifteen early-stage researchers have been developing a broad understanding of the entire process of nanomedicine therapy development, from bench to bedside. They have developed unique cross-disciplinary skills in chemistry, pharmacology and chemical engineering at GMP level to allow them to develop the effective, safe and efficiently producible nanomedicines of the future.

"THE IMMUNE SYSTEM IS AN IDEAL TARGET SINCE NANOPARTICLES ARE PREFERABLY TAKEN UP BY IMMUNE CELLS."

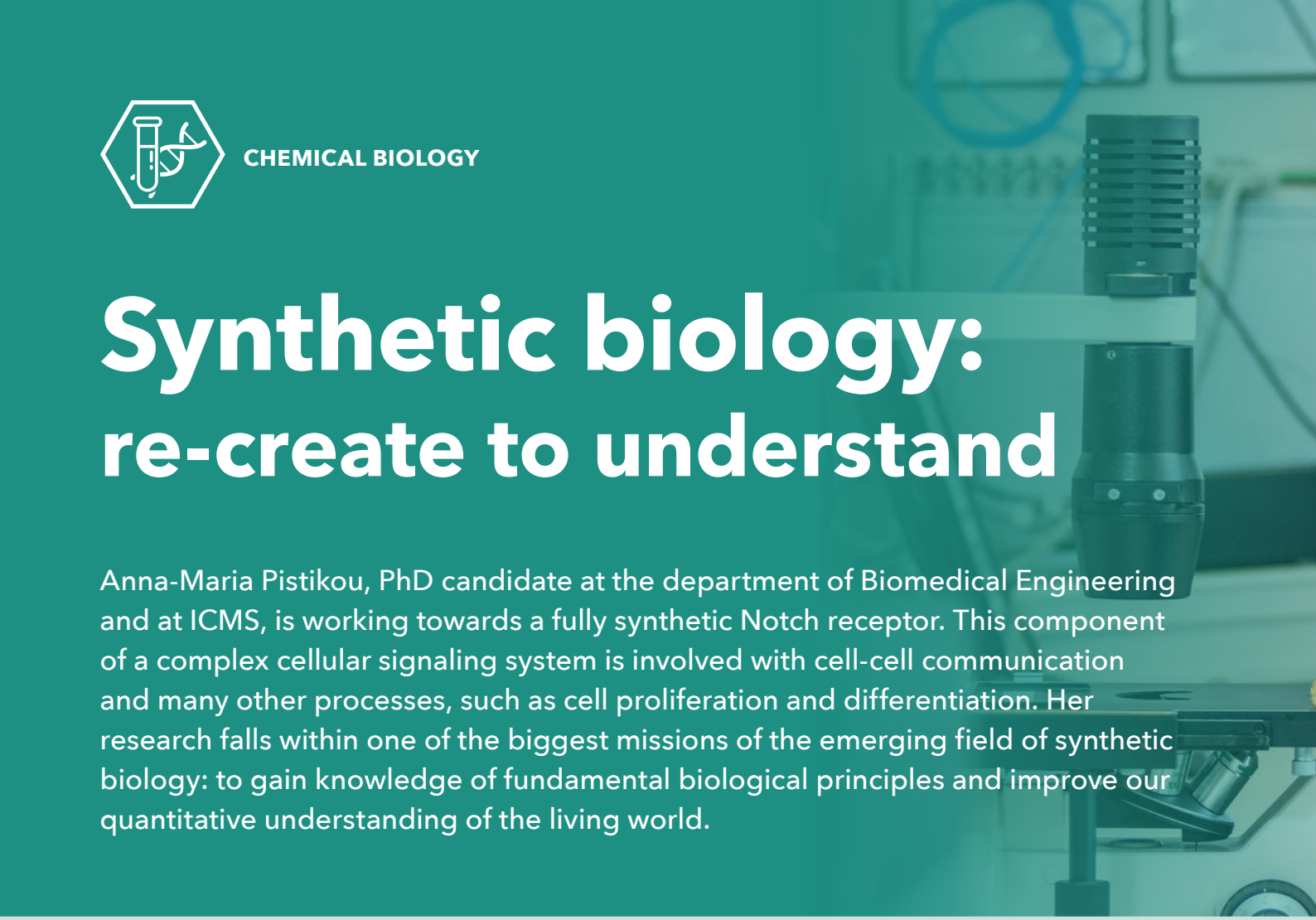
It's not that she accuses researchers of deliberately withholding negative results, since they do come to light in discussions at conferences or through social media. "But in most papers, only a few lines are dedicated to the stuff that doesn't work. I think that should change." Mastrobattista confirms she has a point there and adds that it is the same with companies disclosing their clinical progress. "Often, the views of the clinicians involved are more nuanced and less optimistic. You really need to put effort in obtaining the relevant information."

GREAT POTENTIAL FOR IMMUNE THERAPY

Mastrobattista is optimistic about the future. "For instance, now there's a product on the market, called Onpattro, for siRNA therapy using a lipid nanocarrier targeting the liver. Many nanomedicines have a tendency to end up in the liver. That can be a problem, but in this case it has been turned into an advantage. So if you know your disease and you know what your nanomedicine can do, sensible therapies can be developed." He expects immunomodulation to become a field where great progress can be made. "That's where we use nanoparticles to modulate the immune system to prevent antibody formation and improve the success rate of biological drugs. Such therapies are now tested in clinical studies and the results are quite hopeful." Van Hest agrees that the immune system is an ideal target since nanoparticles are preferably taken up by immune cells. "Nanoparticles are in fact a very natural way of assisting immune cells in treating certain diseases." However, De Smedt has some reservations: "I understand the reasoning and enthusiasm, but I wonder if we are not - yet again - setting out from a perspective of hope rather than of full understanding. I like to be optimistic and I really want to bring this field forward. But I think that all along the way we have to always remain critical about what we are doing." Van Hest responds: "I agree that we should refrain from general statements such as 'if you can regulate the immune system through nanomedicine, you can treat every kind of disease'. There will always be diseases that will 'escape' the targeted pathways. On the other hand, if you can treat just one auto-immune disease via a nanomedicine approach, that would already be considered a great success. Again, this means we have to choose our targets wisely."

CHEMICAL BIOLOGY

Synthetic biology: re-create to understand



Anna-Maria Pistikou, PhD candidate at the department of Biomedical Engineering and at ICMS, is working towards a fully synthetic Notch receptor. This component of a complex cellular signaling system is involved with cell-cell communication and many other processes, such as cell proliferation and differentiation. Her research falls within one of the biggest missions of the emerging field of synthetic biology: to gain knowledge of fundamental biological principles and improve our quantitative understanding of the living world.

Powerful but scary. That is how many people might perceive the concept of synthetic biology. Not surprisingly so, since it aims to engineer biology and possibly 're-create life from scratch'. For Anna Pistikou, a PhD candidate in the Synthetic Biology group of associate prof. Tom de Greef, synthetic biology is all about understanding life by 'actually building it'. But how to put design and engineering at the service of biology and nature? Pistikou: "Above all, synthetic biology involves a switch in mentality. From Nature's observation to its explanation. And from the study of existing organisms to the engineering of organisms that may not even exist in the natural world."

POSITIVE AND NEGATIVE FEEDBACK LOOPS

In synthetic biology, the focus is often on small parts of a natural biological system. Those parts are characterized, often simplified, and ultimately re-used as components of a bigger biological system that is fully 'engineered' in the lab. A convenient starting point is the creation of simple gene regulatory circuits, which carry out functions in an analogous manner to electrical circuits. "As for electrical circuits", explains Pistikou, "nature has positive and negative feedback loops". A positive feedback loop occurs when the product of a reaction leads to an increase in that reaction, moving a specific system away from its equilibrium state. Alternatively, a negative feedback loop occurs when the product of a reaction leads to a decrease in that reaction. In this way, the system gets closer to a steady, stable state.

REBUILDING NOTCH

Pistikou: "The goal of my PhD project is to engineer a negative feedback loop for mammalian cells. I am particularly interested in the Notch signaling pathway, which regulates cell-cell communication in most animals and controls a multitude of cellular processes during embryonic and adult life". The Notch signaling system relies on two main components: a receptor and a ligand. The Notch receptor spans the cell membrane, with part of it inside and part of it outside the cell. When its counterpart, the Notch ligand, binds to the outside part of the receptor, it induces the cleavage of the inner part of the receptor. This then enters the cell nucleus where it can modify gene expression.

The Notch receptor that Pistikou is trying to rebuild is the so-called LaG17-synNotch receptor. "It has been established", she says, "that

Anna-Maria Pistikou

when this receptor binds to its ligand, a cascade mechanism starts. A microRNA is subsequently expressed, which regulates the gene expression of the cell. This ultimately inhibits the expression of the receptor that triggered the entire process, thus closing a negative feedback loop".

"THE GOAL OF MY PHD PROJECT IS TO ENGINEER A NEGATIVE FEEDBACK LOOP FOR MAMMALIAN CELLS."

To re-create the negative synNotch feedback in the lab, Pistikou 'feeds' mammalian cells with bits of genetic information, that push the cell to express the synNotch receptor. "We have already demonstrated, both via imaging and flow cytometry, that this method works and that the receptor is present. We can also control expression within a single cell". The following step will be to recreate the same process in neighboring cells communicating with each other, and, in the long run, to use that knowledge to understand specific disease mechanisms.

FUTURE APPLICATIONS

"For instance, in a recent publication", explains Pistikou, "it was shown that, when the native Notch receptor is activated, neural stem cells maintain their stemness nature". In other words, these cells keep on self-renewing and give rise to new neurons and other cells of the nervous system. Alterations in this behavior have been pinpointed as the possible cause of certain cancers of the nervous system, in particular the neuroblastoma. While for Pistikou there certainly is ''a long way to go'', she hopes that the synthetic tools she is developing in the lab might once be used to explain genetic aberrations occurring in life-threatening diseases such as this one. Indeed: Re-create to understand.

News, awards & grants

Danqing Liu, assistant professor. Department of Chemical Engineering and Chemistry

Making robots sweat with smart surfaces that act as artificial skin

411.000 euros for Danqing Liu to develop smart surfaces releasing drugs for wound healing or acting as artificial skins for robots.

THE INDUSTRIAL CONSORTIUM WELCOMES NEW MEMBERS

ICMS is excited to announce its renewed partnership with Clariant, and to welcome FujiFilm as the newest member of the Industrial Consortium

FUJIFILM

ERC Advanced Grants for TU/e professors Bakkers and Den Toonder

TU/e professors Erik Bakkers and Jaap den Toonder have both been awarded an Advanced Grant of the European Research Council. Bakkers (department of Applied Physics) will receive 2.5 million euros to carry out this research on the teleportation of Majorana particles. Den Toonder (Mechanical Engineering) will get three million euros for the development of a new system to better understand the effect of forces and flows on cells and tissues.

Prof.dr.ir. Ilja Voets awarded with Biomacromolecules/ Macromolecules Young Investigator Award

Two ERC starting grants on cell communication and faster algorithms

3 million euro to study the communication of human cells with their natural surrounding and to design faster algorithms in computer science.

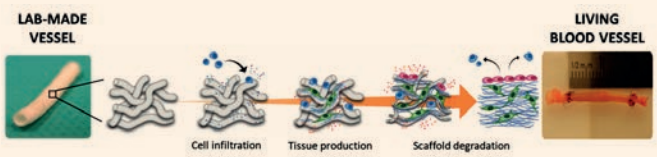
Nicholas Kurniawan (left); Jesper Nederlof (right).

The European Commission has awarded two ERC starting grants of nearly 1.5 million euro each to two young scientists from TU/e: Nicholas Kurniawan, from the department of Biomedical Engineering, and Jesper Nederlof, from the department of Mathematics and Computer Science. Kurniawan will study the communication over time between cells and their natural environment within the human body. Nederlof will design faster algorithms for hard computational problems in computer science. The grants provide the two researchers with the opportunity to further elaborate their own ideas during a period of five years.

Lab-made blood vessels: mechanics matters

CUM LAUDE FOR PHD PROJECT ON THE MECHANICS OF LAB-MADE BLOOD VESSELS

Eline Van Haaften, PhD candidate. Photo: TU/e.



From synthetic tubes to living blood vessels. Illustration by assist. prof. Anthal Smits.

Mimicking the elegance of enzymes

Anja Palmans

In April, Anja Palmans became full professor at the department of Chemical Engineering and Chemistry. She draws her inspiration from the way nature uses enzymes. Maybe we can't fully copy them, but we can learn a trick or two from them.

Anja Palmans is full professor of Supramolecular Chemistry and Catalysis. She studied Chemical Engineering at TU/e. She worked at DSM Research and returned to TU/e in 2002. The research of Anja Palmans develops along two lines. The first is aimed at mimicking multistep synthesis as it occurs in Nature. The second line concerns the control of the dynamic behaviour of supramolecular copolymerizations.

WHY IS A POLYMER SCIENTIST INSPIRED BY ENZYMES?

"Enzymes are fantastic catalysts and crucial to life. It is amazing how quickly and effectively they work in a cell. For me, it was disturbing to discover how little is needed to let it all go wrong. When I heard about diseases such as Pompe and Fabry, it was really a shock to realize that these are both caused by a single enzyme that does not fold properly. As a result, the enzyme is no longer able to clean up waste products. This causes a debilitating and ultimately fatal metabolic disease."

"I found that startling, so I started to dig into it. I thought it would be nice if we could copy that enzyme - without its defects. But upon some reflection, I saw how complicated its workings are. Synthesizing that is far beyond our capacities. But of course, you can start simpler. So we first tried to make synthetic polymers fold, more or less as proteins do. This folding creates an interior compartment that is shielded from the outside. You can embed a catalyst inside this folded macromolecule. That way, you can use water as a solvent, even if the catalyst normally wouldn't dissolve in it. As long as the outside of the folded package is hydrophilic, you don't need other solvents."

"After five years of hard work, we now know how to do that. The folded structures that we make don't have the perfection of natural enzymes. But it's a first step."

WHAT'S YOUR PROGRESS TOWARDS TAMING NATURAL ENZYMES?

"One idea is to combine a natural enzyme with synthetic enzymes. The aim is to let the real enzyme make an interesting product that is difficult to synthesize. The synthetic enzyme then modifies it to change its properties in a way a natural enzyme wouldn't be able to do."

"Personally, I am very interested in combining synthetic enzymes with bacteria. We want to make synthetic enzymes that create a cyclopropyl ring. These rings relay important properties in a variety of drugs. Bacteria cannot make them. The coupling with an artificial enzyme can then be an important improvement of the production process of these drugs. I find this exciting. This is fine chemistry of high precision."

"WE WANT TO UNDERSTAND HOW WE CAN CONTROL THE MICROSTRUCTURE OF SUPRAMOLECULAR COPOLYMER CHAINS."

YOUR CHAIR IS ALSO ABOUT SUPRAMOLECULAR CHEMISTRY.

"Our knowledge of synthetic polymers can also be extended to supramolecular polymers. Jointly with ICMS, we study supramolecular copolymerizations, to understand what happens if you start with a mixture of different types of monomers. The result strongly depends on the reactivity of the participating monomers. This is well understood for monomers that polymerize into covalent polymers, but not so for the monomers that form supramolecular polymers. Supramolecular copolymerization is more complicated as the bonds between the monomers are reversible. We want to understand how we can control the microstructure of supramolecular copolymer chains, and thereby, ultimately, the properties of the materials formed."

WHEN WILL WE SEE MEDICAL APPLICATION OF YOUR FINDINGS?

"I can get very excited when we attain a deeper understanding. I am not a scientist who is driven by the desire to change the world. We need to understand basic mechanisms first. It is sometimes difficult to explain students where this eventually will lead to. You don't always know. We started with an interest in a serious metabolic disease. Maybe we'll end up with drugs for totally different diseases. You can't point out to students what's behind the horizon. And you need not to. Once students are absorbed by their research, it is a basic curiosity that drives them. Thanks to the students, we now understand a lot more about these folding polymers. ICMS offers them the opportunity to fully develop their skills, helped by all kinds of people from different backgrounds. It is all teamwork. Students and postdocs toil every day to achieve this."

Theses

APRIL 2019 – SEPTEMBER 2019

Investigation of exciton properties in organic materials via many-body perturbation theory
JENS WEHNER
May 7, 2019
PhD advisors:
prof.dr.ir. B. Koren,
dr. B. Baumeier

Engineering stabilizers for 14-3-3 protein-protein interactions
SEBASTIAN ANDREI
May 9, 2019
PhD advisors:
dr. C. Ottmann,
prof.dr.ir. L. Brunsveld

Mechanical performance of glassy polymers: influence of physical ageing and molecular architecture
COEN CLARIJS
May 10, 2019
PhD advisors:
prof.dr.ir. L.E. Govaert,
prof.dr.ir. P.D. Anderson,
dr. V. Leo

Macrophage-driven in situ cardiovascular tissue engineering: balancing biomaterial degradation and neo-tissue formation
TAMAR WISSING
May 14, 2019
PhD advisors:
prof.dr. C.V.C. Bouten,
dr.ir. A.I.P.M. Smits

On the description, quantification, and prediction of deep eutectic mixtures
LAURA KOLLAU
May 22, 2019
PhD advisors:
prof.dr.ir. R. Tuinier,
dr. A.C.C. Esteves,
dr. M. Vis

Molecular dynamics modelling of the mechanics of cells
PRANAV MADHIKAR
May 28, 2019
PhD advisors:
prof.dr. M.E.J. Karttunen,
dr. B. Baumeier

Molecular origin of physical ageing and rejuvenation in glassy polystyrene
KALOUDA GRIGORIADI
June 5, 2019
PhD advisors:
prof.dr.ir. P.D. Anderson,
dr. M. Hütter,
dr.ir. L.C.A van Breemen

Relating energy levels of organic semiconductors to solar cell performance
ROBIN WILLEMS
June 6, 2019
PhD advisors:
prof.dr.ir. R.A.J. Janssen,
dr.ir. M.M. Wienk

Engineered bioactive supramolecular materials based on ureido-pyrimidinones
MATILDE PUTTI
June 18, 2019
PhD advisors:
prof.dr.dr. P.Y.W. Dankers,
prof.dr. C.V.C. Bouten

Strain-induced initiation and progression of articular cartilage damage
LORENZA HENAO-MURILLO
June 25, 2019
PhD advisors:
prof.dr. K. Ito,
dr. C.C. van Donkelaar

Estimations of mechanical properties of intact and damaged bone from high resolution CT-images
ANDRÈS ARIAS-MORENO
June 27, 2019
PhD advisors:
prof.dr. K. Ito,
dr.ir. B. van Rietbergen

Computational modelling of bile acid and lipid metabolism
FIANNE SIPS
July 3, 2019
PhD advisors:
prof.dr.ir. N.A.W. van Riel,
prof.dr. P.A.J. Hilbers

Preclinical outcomes and translational challenges of material-based in situ vascular tissue engineering
RENEE DUIJVELSHOFF
July 4, 2019
PhD advisors:
prof.dr. C.V.C. Bouten,
prof.dr.dr. P.Y.W. Dankers

Characterisation of crystallisation kinetics and mechanical properties of polyamide 12
FABIO PAOLUCCI
July 4, 2019
PhD advisors:
prof.dr.ir. G.W.M. Peters,
prof.dr.ir. L.E. Govaert

Differentiated polymers through the use of activated carbonates
JAN HENK KAMPS
September 4, 2019
PhD advisors:
prof.dr. R.P. Sijbesma,
dr.ir. J.P.A. Heuts

Living kidney membranes based on supramolecular materials
RONALD VAN GAAL
September 5, 2019
PhD advisors:
prof.dr.dr. P.Y.W. Dankers,
prof.dr. C.V.C. Bouten

Structural changes in ethylene epoxidation catalysts investigated by transmission electron microscopy
ARNO VAN HOOF
September 5, 2019
PhD advisors:
prof.dr.ir. E.J.M. Hensen,
dr. H. Friedrich

Complex pathways in block copolymer dispersions: self-assembly, phase behaviour and crystallization
ALESSANDRO IANIRO
September 17, 2019
PhD advisors:
prof.dr.ir. R. Tuinier,
dr. A.C.C. Esteves

Charge and exciton transport in organic semiconductors: the role of molecular vibrations
XANDER DE VRIES
September 18, 2019
PhD advisors:
prof.dr. P.A. Bobbert,
prof.dr. R. Coehoorn

Substrate curvature as a regulator of cellular orientation and migration
MAIKE WERNER
September 19, 2019
PhD advisors:
prof.dr. C.V.C. Bouten,
dr. N.A. Kurniawan

Self-regulated out-of-equilibrium polymer assemblies
HAILONG CHE
September 20, 2019
PhD advisors:
prof.dr.ir. J.C.M. van Hest,
dr. L.K.E.A. Abdelmohsen

Functional supramolecular additives
BASTIAAN IPPEL
September 24, 2019
PhD advisors:
prof.dr.dr. P.Y.W. Dankers,
prof.dr. C.V.C. Bouten

Biographers of the exciton

PhD students Xander de Vries and Aart Ligthart work closely together to detect and describe the life of excitons in OLEDs. Their studies at ICMS result in more accurate simulations, which will speed up the development of screens for your mobile phone.

"You first." "No, you first." The most important meetings of theoretical chemist Xander de Vries and physicist Aart Ligthart start like that. Ligthart: "It's always an exciting moment when we compare the results of our most recent work." The two scientists study the same light-emitting layers, but whereas Ligthart measures their characteristics in the laboratory using advanced spectroscopic techniques, De Vries uses computer modelling techniques to calculate the same parameters theoretically.

A small difference holds good news: it means that the modelling work leads to realistic results. But what happens when there is a gap? Ligthart: "First of all, that leads to discussion. What factors did Xander include in his calculations? What not, and how could that have influenced the outcome?" De Vries adds: "Or I ask Aart about the intensity of the laser pulse he used in his experiment. We keep each other's feet firmly on the ground." They both feel that working together so closely and critically, combining theory and experiment, speeds up the research. De Vries: "I think there's a lot to win in academic research by working in interdisciplinary teams the way we do."

COUNTLESS OPTIONS FOR IMPROVEMENT

Currently, the biggest challenge in OLEDs (organic light-emitting diodes) is making them as efficient and robust as their inorganic counterparts: LEDs. We all use LEDs, to light our houses and streets. "But you can't make a flashlight or traffic light based on OLEDs, yet", says Ligthart. However, they are already being used in screens for smartwatches, top segment mobile phones, and televisions. OLEDs are more expensive than the 'classical' LCD screens, but use less energy (and thus save batteries) and are flexible.

There are no principle barriers for OLEDs to achieve LED-efficiencies, but there are countless options on how to get there. A white OLED consists of at least three emitting layers stacked on top of each other: red, green and blue. The efficiency can be increased by using a new type or modified phosphorescent molecule; by applying higher or lower concentrations, in thicker or thinner layers, in one, two or three colours; or by adding layers to slow down or speed up particular charge carriers. De Vries: "A model that accurately predicts which changes are worth testing in the laboratory, will speed up the development." >>

Xander de Vries and Aart Ligthart work at ICMS under supervision of Peter Bobbert and Reinder Coehoorn, respectively, in the group Molecular Materials and Nanosystems at the department of Applied Physics. Their studies were part of the European project MOSTOPHOS: MOdelling STability of Organic PHOSphorescent light-emitting diodes.

Xander de Vries (left) and Aart Ligthart (right)

Is that model capable of calculating the ultimate OLED? "Unfortunately that is not the case", De Vries answers. "It just works 'one way'. You put in a molecular structure and the model calculates if that would be an improvement." Simulations are getting pretty accurate though, he adds. "Spin-off companies pop-up that develop and sell this kind of software."

HOPPING EXCITONS

The key to improving OLED efficiency and lifetime is reducing losses, says Ligthart. When voltage is applied to an OLED, electrons and holes are generated at opposite poles. Electrons and holes meet each other in one of the layers, creating energy-rich excitons. These may produce light if they are able to transfer their energy to fluorescent and phosphorescent molecules. However, still too often, excitons perish, generating heat instead of light. Ligthart: "The model sort of describes the lives of excitons: their birth, their hopping to other molecules and their death."
De Vries: "Actually the model is a stack of models. We work at a mesoscopic scale, where molecules in the model are reduced - by another model - to points with particular characteristics." De Vries succeeded in adding information about the vibrational structures of molecules to the model, improving the prediction of charge and exciton transfer. But accuracy is not the only important characteristic of a model, De Vries emphasizes. A simulation also needs to be fast enough. "If calculations take a few weeks on a supercomputer, companies will stick to development based on best guesses and trial and error." De Vries uses a cluster of 1200 'cores' for his calculations, representing a computing power comparable to that of about 300 PCs. Before starting his PhD study at ICMS, De Vries was modelling astrochemical processes. De Vries: "In space, chemical reactions can only occur at grains: ice-dust particles. That is because in vacuum energy can't be dispatched. Modelling a reaction between two molecules in space therefore has parallels with exciton transfer between molecules in an OLED. When I heard that stochastic Monte Carlo calculations could also be useful in OLEDs, I was immediately interested. Astrochemistry is a fascinating field, but in the end, I'd like to have a job in industry."

TEAMWORK

Ligthart often got the question why he started a PhD on OLEDs - these had already been invented, so what was he doing? "What intrigues me most is the possibility to mathematically describe complex systems", he explains. "Now we are using modelling to describe an OLED. In the near future, once you can add morphology, scientists will simulate solar cells. And one day, people will be able to describe whole cells - life - starting from the atoms. That's still far away, but I find that fascinating."

At the moment, Ligthart is writing his thesis. De Vries defended his dissertation last September, but he continues as a postdoc for a few months to finish the project. And what after that? De Vries smiles: "It will be a kind of divorce. We've been a good team right from the start." Both are looking for a job in industry. Ligthart: "I won't continue in academia, as I'm just not that curious about the smallest possible detail. But I do want to tackle a technically complex problem, in a team".

"WHEN I HEARD THAT STOCHASTIC MONTE CARLO CALCULATIONS COULD BE USEFUL IN OLEDS, I WAS IMMEDIATELY INTERESTED."

Elizabeth McKenzie

Excited by industrial challenges

INDUSTRIAL CONSORTIUM

If we are to tackle the major and pressing societal and industrial challenges of our time, we have to go beyond traditional borders. That is in the DNA of ICMS, and it also motivates Elizabeth McKenzie, the new ICMS Industrial Consortium Coordinator. Here, she outlines the importance of industrial partnerships, the role of ICMS, and her vision for strengthening these alliances.

My past experiences, as a researcher and in research & development, have afforded me the opportunity to be involved in the beautiful and high-impact science that is produced at the interfaces between scientific disciplines. My exciting new role at ICMS gives me the scope to continue in this vein, and in a greater capacity. In this respect, it is important for me to continually have my finger on the pulse of what's happening within the ICMS community – an exciting mission!

MUTUAL BENEFITS

The interdisciplinary environment and collaborative ethos make ICMS an attractive place to industrial stakeholders. The mutual benefits to cross-sectoral collaborations are obvious: companies are able to access expertise and facilities otherwise unavailable to them, and fundamental research ideas of academics can be translated into new innovations. Many companies are already involved in collaborations with individual ICMS researchers; however, the benefit of being an industrial partner of the whole institute is that it provides an open door to a much wider scientific community that is brimming with ideas.

UNORTHODOX APPROACHES

As the Industrial Consortium Coordinator, I work to connect companies with the right researchers. I am convinced that including researchers from different disciplines provides the opportunity for exciting and unorthodox approaches to industrial challenges. I also support access to the infrastructure, and facilitate the search for funding opportunities. Together, these core facets help to stimulate excellent and innovative science.

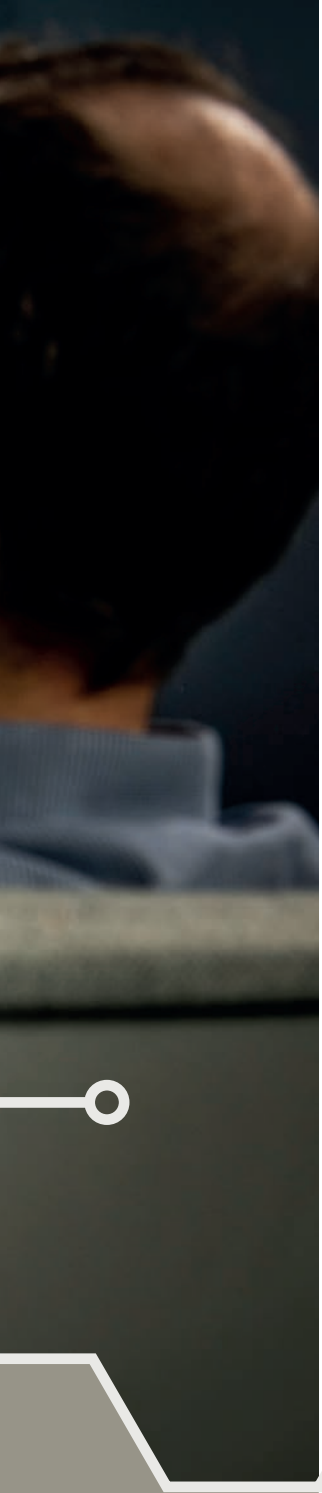
The Industrial Consortium has been an integral part of ICMS since its birth, and many partners have benefited greatly from tapping into our expert network. My vision for the Industrial Consortium is that, through strategic engagement, it will grow to represent the diversity of the research that we do here at ICMS, and that it will include many different types of companies – from SME's to multinationals. Taking advantage of available funding initiatives, the Industrial Consortium will strengthen industrial connections and help to propel research ideas into the next phase. I am confident that our continued efforts in this area will be fruitful, turning initial partnerships into lasting alliances.

Are you interested in becoming a member of the Industrial Consortium? For more information, visit the website www.tue.nl/icms or contact Elizabeth at B.E.McKenzie@tue.nl.

GRIP ON COMPLEXITY

Richard Post (left) and Lorenzo Albertazzi (right)

New microscope techniques at ICMS enable the imaging of particles that are much smaller than the wavelength of light. Until recently, such superfine resolution was considered impossible. Richard Post and Lorenzo Albertazzi now use this cutting-edge technology to study nanoparticles for cancer drugs. They have just published their groundbreaking insights in Nature Communications.



Observing a cancer drug in action

HOW DID YOU FIND EACH OTHER?
Post: "We joined over coffee, with mathematicians and biochemists. As a third-year bachelor student in mathematics, I wanted to do a project on probabilistic theory, supervised by Remco van der Hofstad. Lorenzo Albertazzi and Daan van der Zwaag were working on microscopy of the behavior of nanoparticles for targeted drug delivery. At that time, it was thought that they were homogeneously - fully randomly - distributed. As we sat together, we made some sketches and immediately felt that a mathematical model would be helpful. It would give us more grip on the behavior of those particles."

"Getting the language right was one of the first things to do. As biochemists and mathematicians, we had totally different concepts of homogeneity in our minds. Such differences pose a challenge to multidisciplinary research. To most people, ´homogeneous´ means 'evenly distributed'. But an even configuration is not random. On the contrary, it is very much ordered. You can get it when particles repel each other. Then there is a force at work. When a distribution is truly random, it is totally unordered. You expect places with some clustering and some sparser places. That's what you get when there is no interaction."

"IT IS CRUCIAL TO KNOW HOW PARTICLES ATTACH TO THE CELL SURFACE, AND HOW THE LIGANDS ARE DISTRIBUTED."

HOW DO YOUR PARTICLES DELIVER A DRUG?
Albertazzi: "We have in mind to use nanoparticles and nanofibers that are loaded with a drug. We want them to travel through the body towards the places where the drug is needed, in the tumor. That way, the dose is targeted and there are fewer side effects. To achieve this, we provide the particles with ligands that can recognize markers on the surface of cancer cells. So it is crucial to know how particles attach to the cell surface and how these ligands are distributed. We can now observe that in great detail with a technique called direct stochastic optical reconstruction microscopy (dSTORM). This gives us the best available resolution. But we need to interpret the signals from the microscope. That is where a mathematical model can help." >>

"FINALLY, WE MANAGED TO PROVE THAT THE PARTICLES ON OUR SURFACES WERE NOT HOMOGENEOUSLY DISTRIBUTED, CONTRARY TO THE ACCEPTED WISDOM."

WHAT'S THE MATHEMATICIAN'S LINE OF ATTACK?

Post: "We started on a very basic level. We made a crude model of the particle dynamics, the release of photons, and the accuracy of the sensors. Some of these processes are known in fairly good detail. It is tempting to include all familiar details in the model. That's what you often see in modelling: established parts are well elaborated, unexplored processes remain rather vague. We took a more balanced approach. Key to our method is that we kept the same level of detail for all aspects of the model. Whenever the discussion went in depth on only part of the model, I rigorously stopped it. Even when we were thrilled about it. Of course, our initial picture was too simplistic. But it gave us a grip on the bigger picture. From there on, we started to add detail. We asked ourselves: what is the most important aspect we ignored? We then incorporated that in the models. As a mathematician, you start at zero and add building blocks one by one, until your model can reproduce the observed data."

Albertazzi: "We also needed to account for the differences between particles. The body can produce nanoparticles that are almost identical. The industry can produce identical cars with 10,000s of parts. That is easy on the macroscale. Yet on the microscale, we have to arrange 10 to the power 20 atoms to make these particles. With these mind-boggling numbers, there inevitably is some variation. Nature is a much better chemist then we are."

HOW DID YOU SEE THE PARTICLES?

Post: "It is the back and forth between the different people that leads to gradual progress. A chemist produces the particles. A physicist observes them with a microscope. A mathematician models this process to tell what the signals mean. It is a triad with three players. Through ICMS, we are all close together, and that gives synergy. During my master's studies, we continued to work on some details of the model. Finally, we managed to prove that the particles on our surfaces were not homogeneously distributed, contrary to the accepted wisdom." "This is great, in a way, because with these more clustered particles you would need fewer nanoparticles and a smaller drug dose to kill cancer cells. We were able to publish that in Nature Communications. And we gave a joint talk at the ICMS outreach symposium last March. Between the two of us, we could present the two angles of the research, which was received with great enthusiasm. That underlines the importance of bringing different disciplines together."

The research of Richard Post and Lorenzo Albertazzi was published in: R.A.J. Post et al. (2019) 'A stochastic view on surface inhomogeneity of nanoparticles', Nature Communications, 10:1663. doi:10.1038/s41467-019-09595-y.

Lorenzo Albertazzi is an associate professor at the TU/e department of Biomedical Engineering. He also leads the 'Nanoscopy for Nanomedicine' group at the Institute of Bioengineering of Catalonia (IBEC) in Barcelona. For most of his career he has been jumping between Chemistry and Biophysics; in his research he now aims to combine both to achieve a molecular understanding of synthetic materials in the biological environment, using optical microscopy and nanoscopy. Albertazzi studied Chemistry (MSc 2007) and Biophysics (PhD 2011) at Scuola Normale Superiore in Pisa, Italy.

Richard Post is a PhD student in statistics at the Department of Mathematics and Computer Science of TU/e. His thesis is focused on statistical methods for causal inference. Post studied industrial and applied mathematics in Eindhoven (2017). As a bachelor student, he worked on an interdisciplinary project within ICMS and used probability theory to improve the stochastic optical reconstruction microscopy. During his masters, he continued to be involved in research at ICMS and finished the ICMS certificate program.

Key publications

APRIL 2019 - SEPTEMBER 2019

01. 3D HELIX ENGINEERING IN CHIRAL PHOTONIC MATERIALS
A.J. Kragt, D.C. Hoekstra, S. Stallinga, D.J. Broer, A.P.H.J. Schenning
Adv. Mater. 31, 1903120 (2019)

02. A STOCHASTIC VIEW ON SURFACE INHOMOGENEITY OF NANOPARTICLES
R.A.J. Post, D. van der Zwaag, G. Bet, S.P.W. Wijnands, L. Albertazzi, E.W. Meijer, R.W. van der Hofstad
Nat. Commun. 10, 1663 (2019)

03. ATP-MEDIATED TRANSIENT BEHAVIOR OF STOMATOCYTE NANOSYSTEMS
H. Che, J. Zhu, S. Song, A.F. Mason, S. Cao, I.A.B. Pijpers, L.K.E.A. Abdelmohsen, J.C.M. van Hest
Angew. Chem. Int. Ed. 58, 13113-13118 (2019)

04. CLIMBING DROPLETS DRIVEN BY MECHANOWETTING ON TRANSVERSE WAVES
E. De Jong, Y. Wang, J.M.J. Den Toonder, P.R. Onck
Sci. Adv. 5, eaaw0914 (2019)

05. DNA-BASED COMMUNICATION IN POPULATIONS OF SYNTHETIC PROTOCELLS
A. Joesaar, S. Yang, B. Bogels, A. van der Linden, P. Pieters, B.V.V.S.P. Kumar, N. Dalchau, A. Phillips, S. Mann, T.F.A. de Greef
Nat. Nanotechnol. 14, 369-378 (2019)

06. ELUCIDATING THE ORDERING IN SELF-ASSEMBLED GLYCOCALYX MIMICKING SUPRAMOLECULAR COPOLYMERS IN WATER
S.I.S. Hendrikse, L. Su, T.P. Hogervorst, R.P.M. Lafleur, X.W. Lou, G.A. van der Marel, J.D.C. Codee, E.W. Meijer
J. Am. Chem. Soc. 141, 13877-13886 (2019)

07. ENHANCED DELAYED FLUORESCENCE IN TETRACENE CRYSTALS BY STRONG LIGHT-MATTER COUPLING
A.M. Berghuis, A. Halpin, Q. Le-Van, M. Ramezani, S. Wang, S. Murai, J.G. Rivas
Adv. Funct. Mater. 29, 1901317 (2019)

08. FUTURE OF SUPRAMOLECULAR COPOLYMERS UNVEILED BY REFLECTING ON COVALENT COPOLYMERIZATION
B. Adelizzi, N.J. Van Zee, L.N.J. de Windt, A.R.A. Palmans, E.W. Meijer
J. Am. Chem. Soc. 141, 6110-6121 (2019)

09. IMAGING-ASSISTED NANOIMMUNOTHERAPY FOR ATHEROSCLEROSIS IN MULTIPLE SPECIES
T. Binderup, R. Duivenvoorden, F. Fay, M.M.T. van Leent, J. Malkus, S. Baxter, S. Ishino, Y. Zhao, B. Sanchez-Gaytan, A.J.P. Teunissen, Y.C.A. Frederico, J. Tang, G. Carlucci, S. Lyashchenko, C. Calcagno, N. Karakatsanis, G. Soultanidis, M.L. Senders, P.M. Robson, V. Mani, S. Ramachandran, M.E. Lobatto, B.A. Hutten, J.F. Granada, T. Reiner, F.K. Swirski, M. Nahrendorf, A. Kjaer, E.A. Fisher, Z.A. Fayad, C. Perez-Medina, W.J.M. Mulder
Sci. Transl. Med. 11, eaaw7736 (2019)

10. IMPACT OF POLYMORPHISM ON THE OPTOELECTRONIC PROPERTIES OF A LOW-BANDGAP SEMICONDUCTING POLYMER
M. Li, A.H. Balawi, P.J. Leenaers, L. Ning, G.H.L. Heintges, T. Marszalek, W. Pisula, M.M. Wienk, S.C.J. Meskers, Y. Yi, F. Laquai, R.A.J. Janssen
Nat. Commun. 10, 2867 (2019)

11. LIQUID-LIQUID PHASE SEPARATION DURING AMPHIPHILIC SELF-ASSEMBLY
A. Ianiro, H. Wu, M.M.J. van Rijt, M.P. Vena, A.D.A. Keizer, A.C.C. Esteves, R. Tuinier, H. Friedrich, N.A.J.M. Sommerdijk, J.P. Patterson
Nat. Chem. 11, 320-328 (2019)

12. MIMICKING CELLULAR COMPARTMENTALIZATION IN A HIERARCHICAL PROTOCELL THROUGH SPONTANEOUS SPATIAL ORGANIZATION
A.F. Mason, N.A. Yewdall, P.L.W. Welzen, J. Shao, M. van Stevendaal, J.C.M. van Hest, D.S. Williams, L.K.E.A. Abdelmohsen
ACS Cent. Sci. 5, 1360-1365 (2019)

13. MORPHING OF LIQUID CRYSTAL SURFACES BY EMERGENT COLLECTIVITY
H.M. van der Kooij, S.A. Semerdzhiev, J. Buijs, D.J. Broer, D. Liu, J. Sprakel
Nat. Commun. 10, 3501 (2019)

14. MULTICORE LIQUID PERFLUOROCARBON-LOADED MULTIMODAL NANOPARTICLES FOR STABLE ULTRASOUND AND F-19 MRI APPLIED TO IN VIVO CELL TRACKING
O. Koshkina, G. Lajoinie, F.B. Bombelli, E. Swider, L.J. Cruz, P.B. White, R. Schweins, Y. Dolen, E.A.W. van Dinther, N.K. van Riessen, S.E. Rogers, R. Fokkink, I.K. Voets, E.R.H. van Eck, A. Heerschap, M. Versluis, C.L. de Korte, C.C. Figdor, I.J.M. de Vries, M. Srinivas
Adv. Funct. Mater. 29, 1806485 (2019)

15. PATHWAY CONTROL IN COOPERATIVE VS. ANTI-COOPERATIVE SUPRAMOLECULAR POLYMERS
L. Herkert, J. Droste, K.K. Kartha, P.A. Korevaar, T.F.A. de Greef, M.R. Hansen, G. Fernandez
Angew. Chem. Int. Ed. 58, 11344-11349 (2019)

16. POLYPEPTIDE NANOPARTICLES OBTAINED FROM EMULSION POLYMERIZATION OF AMINO ACID N-CARBOXYANHYDRIDES
J. Jacobs, D. Pavlovic, H. Prydderch, M.-A. Moradi, E. Ibarboure, J.P.A. Heuts, S. Lecommandoux, A. Heise
J. Am. Chem. Soc. 141, 12522-12526 (2019)

17. SUPER-RESOLUTION MAPPING OF ENHANCED EMISSION BY COLLECTIVE PLASMONIC RESONANCES
R.F. Hamans, M. Parente, G.W. Castellanos, M. Ramezani, J.G. Rivas, A. Baldi
ACS Nano 13, 4514-4521 (2019)

18. TEMPERATURE- AND LIGHT-REGULATED GAS TRANSPORT IN A LIQUID CRYSTAL POLYMER NETWORK
A. Cao, R.J.H. van Raak, X. Pan, D.J. Broer
Adv. Funct. Mater. 29, 1900857 (2019)

19. TRACTION FORCES AT THE CYTOKINETIC RING REGULATE CELL DIVISION AND POLYPLOIDY IN THE MIGRATING ZEBRAFISH EPICARDIUM
M. Uroz, A. Garcia-Puig, I. Tekeli, A. Elosegui-Artola, J.F. Abenza, A. Marin-Laurado, S. Pujals, V. Conte, L. Albertazzi, P. Roca-Cusachs, A. Raya, X. Trepat
Nat. Mater. 18, 1015-1023 (2019)

20. UNEXPECTEDLY STRONG CHIRAL AMPLIFICATION OF CHIRAL/ACHIRAL AND CHIRAL/CHIRAL COPOLYMERS OF BIPHENYLYLACETYLENES AND FURTHER ENHANCEMENT/ INVERSION AND MEMORY OF THE MACROMOLECULAR HELICITY
R. Ishidate, A.J. Markvoort, K. Maeda, E. Yashima
J. Am. Chem. Soc. 141, 7605-7614 (2019)

Great perspectives with networks

Pim van der Hoorn (left) and Erik Steur (right)

Networks play a crucial role in many complex systems. Erik Steur and Pim van der Hoorn study their behaviour in close cooperation with scientists from many different fields. But to make progress, you need to learn new languages first.

It is Pim van der Hoorn´s third day at TU/e. He brings to ICMS his experience from the Network Science Institute in Boston, where he worked for three years on networks and complex systems. “The institute was full of theoretical physicists, political scientists, social scientists, biologists and computer scientists. I developed mathematics as a foundation for their work on complex networks.”

In Eindhoven, he again takes on that role, together with his colleague Erik Steur. As Steur explains, “the ‘Complex Fridays’ that we started at ICMS encourage such interaction. The meetings stimulate discussions about research. We contribute from our perspective: the mathematics of complex systems. Others contribute from the perspective of their observations and engineering.”

COLLECTIVE PHENOMENA

Bringing together those different views is also the essence of the Grip on Complexity program, which ICMS started last year. The program aims at getting a grip on situations where a large number of components interact. In isolation, these interactions might be fairly simple and well understood. But together in a larger aggregate, all kinds of feedback and surprising effects may develop, which can

Erik Steur (1982) studied Mechanical Engineering at TU/e. He was a postdoc at the Laboratory for Perceptual Dynamics at KU Leuven and ICMS. In 2017, he started as an assistant professor at TU Delft. Since September 2019, he is an assistant professor Mechanical Engineering at TU/e. His research interests include the theory of nonlinear networked dynamical systems, synchronization of dynamical systems, and time-delay systems.

Pim van der Hoorn (1985) studied mathematics in Utrecht and Twente. He worked as a postdoc at the Network Science Institute in Boston. He studied the mathematical foundations of network science, using probability theory, statistics, random graphs and graph limits.

"A DEEPER UNDERSTANDING OF COLLECTIVE EFFECTS CAN LEAD TO BETTER CONTROL STRATEGIES AND TO THE DESIGN OF NOVEL COMPLEX SYSTEMS."

render the system unpredictable, and which may give rise to unforeseen collective phenomena. A deeper understanding of these collective effects can lead to better control strategies and to the design of novel complex systems.

Van der Hoorn: "Talking to engineers, we discover the mathematical problems that are beneath the surface. I would never have seen them without talking to others. It is in such interactions that everyone learns a lot. The scientists of ICMS really want to obtain a full understanding. That gives us the space to develop the mathematics that underpins their problems."
Networks are an important theme in complexity science. A virus spreads through a web of contacts. Catalysis runs through a web of interactions. In calculations, networks are often modelled as being immutable. But in reality, many complex networks are very dynamic, Van der Hoorn explains. "I study how networks change - how points connect to each other and how structures arise from it. Very simple processes may give rise to a fascinating connectivity." Steur´s interest is complementary. "I focus on what happens on these networks. How do connections enable a certain dynamical behavior? What function do those connections have? Together, we combine two essential aspects of networks".

BRAIN STRUCTURE

Erik Steur started researching dynamics on networks in Eindhoven during his PhD. It was the brain that first inspired his research. Its network structures are constantly changing. Impressions and experiences bring dynamics into play, which eventually become fixed in the brain structure. For example, cells that fire synchronously reinforce their mutual connections. The 100 billion neurons of the brain and their 100 trillion interconnections are never at rest. Van der Hoorn underlines the abstraction that a model provides. "Experts on brain research make every effort to measure brain activity properly, using a variety of different scanning techniques. From that, brain activity can be deduced. But that is still a very rough simplification. You often can´t see the activity of individual neurons. They are much too small. That is why you need stochastics to understand the network and signal processes. There are probably a number of different networks that fit the data from brain scans. As a mathematician, I can identify a proper collection of network structures to model this. But only in close cooperation can you give meaning to that and arrive at a good model."

COMMON VOCABULARY

Steur adds that their research will focus on a wide variety of engineering problems. "Insights developed for one application can often be applied in a different setting. But you can only do that after you have come to understand that setting thoroughly. In a collaboration, you need to learn each other's language first. When I started working on biochemical reaction networks, I had to find out what a chemist means by equilibrium. As a systems and control scientist, I didn't interpret that in terms of thermodynamics. Developing a common vocabulary is a huge challenge. But it is necessary, otherwise you will never find out the real questions that underly the research."

The program Grip on Complexity connects mathematics with many other scientific fields. Its overarching goal is to understand how systems – created by nature or mankind – are formed through local interactions and self-organizing principles.

News, awards & grants

Ilja Voets wins KNCV Gold Medal

PROFESSOR ANTI FREEZE PROTEINS CONNECTS CHEMISTS, PHYSICISTS, AND BIOLOGISTS.

The Royal Dutch Chemical Association (KNCV) has awarded the KNCV Gold Medal 2019, the highest Dutch award for chemical top talent under forty years of age, to Prof Dr Ir Ilja Voets. She is Professor of the research group Self-Organizing Soft Matter at the Department of Chemical Engineering and Chemistry.

Bert Meijer

AWARDED SECOND HONORARY DEGREE BY LEADING UNIVERSITY

Professor Bert Meijer.

With the distinction the Freie Universität Berlin honours the outstanding quality of Meijer's scientific work.

One polymer to make two semiconductors, by controlling the solvent

Mengmeng Li (left),
Professor René Janssen (right).

RESULTS PUBLISHED IN NATURE COMMUNICATIONS PAVE THE WAY TO PROGRAMMABLE ELECTRONIC INKS.

Conjugated polymers are important materials because of their special electronic and optical properties and low cost, making them very promising for a wide range of applications. An international research team led by Professor René Janssen developed a method to create two subtypes of one polymer, with different semiconductor characteristics, simply by changing the solvent from which the polymer film is created. This opens the door to the development of programmable electronic inks. The results are published today in Nature Communications.

Vidi grants for patient-specific nanoparticles and 3D ultrasound

LORENZO ALBERTAZZI AND RICHARD LOPATA EACH RECEIVE VIDI GRANT OF 800.000 EUROS

NWO today announced the annual awards of the Vidi grants of 800.000 euros. There are two TU/e recipients, both from the Department of Biomedical Engineering: Lorenzo Albertazzi and Richard Lopata. Albertazzi wants to attack cancer cells with patient-specific nanoparticles and Lopata is going to develop new 3D ultrasound imaging techniques for patients that are at risk of having a ruptured aorta.

Lorenzo Albertazzi (left) and Richard Lopata (right)

Glow-in-the-dark paper and sustainable oil take steps to market

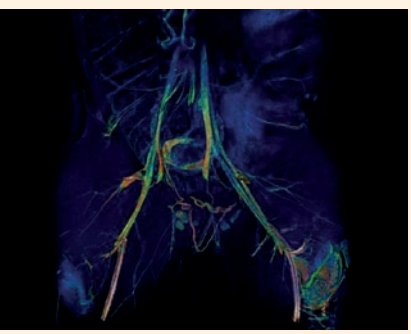
TWO TU/E PROJECTS CAN BE FURTHER COMMERCIALIZED THANKS TO FINANCING FROM NWO.

A special glowing paper strip to quickly show infectious diseases, and a technology from spin-off Vertoro to develop a sustainable oil from biomass. These two TU/e projects can be further commercialized thanks to financing from NWO.

Research leader Maarten Merkx with one copy of the 'glow-in-the-dark' test.

IBEC and TU/e celebrate the second symposium as a result of the partnership between both research centers

Josep Samitier, director of IBEC, and Jan van Hest director of ICMS opened the symposium by welcoming more than 80 participants from both institutions. Two IBEC group leaders, Vito Conte and Lorenzo Albertazzi, already have dual appointments with ICMS.



Willem Mulder is closing the gap between application of nano-immunotherapy on mice and on humans

His study demonstrates that the therapy is effective across species, bringing the day it can be used to cure humans much closer.
(Results published in the journal Science Translational Medicine Aug 2019)

This image is a 3D volume-rendering of the MRI sequence used for assessment of vessel wall permeability (3D dynamic contrast-enhanced MRI) of one of the pigs in the study, before and after treatment with the nanoimmunotherapy.

MATERIALS
FOR REGENERATIVE
MEDICINE

How heart valves stiffen under strain

The Canadian mechanobiologist Craig Simmons visited ICMS in October. We talked with him about the surprising origin of heart valve diseases and how his discoveries open a new path for treatment. Simmons observes many parallels between his research at the University of Toronto and the research in Eindhoven.

WHAT LINKS ICMS WITH YOUR RESEARCH?

"ICMS captures much of what we're trying to achieve in our heart research center in Toronto. The challenge for both of us is working on complex problems from different angles. We bring distinct disciplines together and let people work side by side. You need them to physically bang into each other and exchange ideas. We both try to create that. You need a critical mass and complimentary expertise to advance."

"I am really impressed by the scope of the labs at ICMS. In the cell lab, for example, many groups are working together, some on bone, some vascular, but all are working with bioreactors. We have conceptually similar ideas."

HOW DID YOU GET A MULTIDISCIPLINARY MINDSET?

"I started as a mechanical engineer. I did computational work as a student, and became interested in the biology driving the phenomena we were studying. That´s why I did a postdoc in biology. So I shifted toward another discipline."

One person usually can´t master all details from different disciplines. You can't fill all the gaps. So my lab is made up of people who come in as an engineer or a biologist. They learn from each other, but remain specialists with a strong foundation in their field. The challenge is to balance depth and width. Our team members have to be able to operate at the boundary between disciplines. An engineer builds a system and knows how it will be applied. Someone else understands the biological context in far more detail. People bring different perspectives. It is in interaction that a multi-disciplinary project gets its shape.

WHY HEART VALVES?

"When we obtained funding to start our center, we spent the first nine months just talking to one another. The funding was impressive, but we first needed to find common ground to decide on how to spend it. We learned about each other's research and thoughts. Then we came up with the challenges that we uniquely could tackle with our complementary expertise and our shared knowledge. When other people later joined, we made them acquainted with our common language and goal. It is a way of thinking."

"One place where mechanics and biology come together is the heart valve. It is a part of the heart that is under a high mechanical strain. About a quarter of the population will develop a disease of the heart valves, about one in fifty people will need to have a heart valve replaced. We don´t have any other treatment. The heart valves experience high mechanical forces that may accelerate the disease process. The valve gets stretched every second or so and is exposed to high blood flow. We do experiments to understand the effect of these strains on cells and molecules."

HOW ARE HEART VALVES AFFECTED?

"The experiments involve cell cultures that are mechanically stimulated using bioreactors. With microgenomics we probe the gene expression in the stimulated areas. Here you see how cutting edge engineering and biology join forces. This way we discovered that heart valve disease is not simply a matter of 'wear and tear'. The mechanical strain induces inflammation, scarring, and bone

"WE DISCOVERED THAT HEART VALVE DISEASE IS NOT SIMPLY A MATTER OF 'WEAR AND TEAR'."

Craig Simmons

formation, which leads to stiffening of the valve. This means that the mechanics changes the biological processes, and in turn, the biology changes the mechanics. We have identified genes that regulate this. These regulators may offer us an approach to stop calcification and fibrosis. Eventually, we work towards repairing heart valves in the body."

YOUR RESEARCH INSPIRED ICMS WORK ON BLOOD VESSELS. WHAT'S YOUR TAKE ON THAT?

"Tomorrow, I will be on the opposition committee for the thesis defense of Eline van Haaften. It is about cardiovascular tissue regeneration. I learned a lot from the thesis. We do tissue engineering as well. There are many similarities between blood vessels and heart valves. Some of the same signaling processes and sensing mechanisms are at play. So there's a fundamental mechanobiological connection between our fields."

Craig Simmons studies the mechanical and biological triggers that lead to heart valve disease. His team uses cellular and molecular biology to identify the signatures of diseased heart tissue. The research identified molecular regulators that cause calcification and fibrosis. The lab also works toward engineering living heart valve tissue to repair defective valves.

Craig Simmons is a full professor at the University of Toronto, where he heads the Translational Biology and Engineering Program in the Ted Rogers Centre for Heart Research. He studied Mechanical Engineering at MIT and in Toronto. Simmons contributes to the fields of heart valve mechanobiology and tissue engineering, and microfluidics.

Limited room to manoeuvre forces you to be really creative

Jody Lugger

The gap between academic explorations and industrial reality is wide, says ICMS graduate Jody Lugger. But even so, collaboration is worthwhile. “Both sides need external input to gather fresh ideas.”

After finishing his PhD in the group of Rint Sijbesma in the spring of 2018, Jody Lugger moved on to the industrial side of materials research at SABIC in Bergen op Zoom, where he works in the Specialties Business Unit. He started as Scientist Emerging Technologies with the LNP Technology group, a position he is now combining with a role as Product Developer. ICMS Highlights talks to Lugger about the differences between academic and industrial priorities, the importance of creativity, and how working within ICMS prepared him well for his current professional environment.

CAN YOU BRIEFLY EXPLAIN WHAT YOUR TWO ROLES ENTAIL?

“Here at SABIC Specialties, we manufacture copolymers and compounds that combine the advantages of plastics with the specific characteristics of a variety of additives. As a result, we deliver materials with innovative properties. My main activities relate to product development, where I focus on new plastic grades. These projects are often driven by ‘market pull’, for example when customers face a problem with a material, or when they have an idea for a new application. Or there are new regulations that our materials need to comply with. In my role as a scientist, which takes up about a quarter of my time, I work on projects that are not directly driven by a current market need. This

'technology push', is about finding new solutions that can lead to future products."

WHEN YOU COMPARE YOUR CURRENT RESEARCH ENVIRONMENT TO THE ACADEMIC LAB, WHAT STANDS OUT?

"Well, the differences are huge. For example, in academia, one extraordinary effect of your material can be enough to justify a publication. You don't have to worry about practical considerations or limitations. In a commercial environment, however, you cannot ignore those. Improving a property is only relevant and interesting as long as you manage to comply with all the boundary conditions. Think about aspects such as safety, availability of raw materials, feasibility of production, etcetera. This means that your space to manoeuvre is much smaller than in academia. But this forces you to be really creative. It is very challenging to come up with something new when you have to take so many aspects into account."

WITH THAT IN MIND: ARE ACADEMIC FINDINGS USEFUL TO SOLVE THE PROBLEMS YOU ARE NOW DEALING WITH?

"To be honest, their direct usability is limited."

WHY IS THAT?

"For one thing, it is the scale of production. In academia, producing a small, lab-scale sample is sufficient. But for product development, volumes are crucial. We need to be able to produce at least 25 kilograms of material to run all the necessary tests. And more in general, I think that universities are rather naïve when it comes to the requirements for developing commercial products. A lot of academic research generates a single solution for a single problem, but in industry we are looking for more generic solutions that can address multiple problems. It is not surprising though. Universities focus on exploration and education, whereas industry is looking for ways to generate the biggest return on investment. These are just two different worlds, each with their own timelines, responsibilities and interests."

What does all this imply for academic-industrial partnerships? ICMS and SABIC have ongoing collaborations. "Even though there are major differences, I think collaborations can be very valuable for both sides. It is extremely important to get an outsider perspective, open your mind and get new ideas flowing.

For industry, the academic perspective can help to look beyond their routine practices, towards future developments. And for academic researchers, it is very insightful to get an idea of the real-world problems that their counterparts in industry are working on. It may also help to generate more focus and make academic research efforts more effective."

WAS YOUR TIME AT ICMS A GOOD PREPARATION FOR YOUR CURRENT POSITION?

"From a scientific and technical perspective, it was the perfect training environment. But what I cherish most from my time at ICMS is all the experience I gathered in working with multidisciplinary teams, consisting of people with very diverse backgrounds in terms of science, culture and nationality. It taught me to quickly get a grasp of new topics and new research fields, and make them my own. That experience proved to be very valuable to me. Working within ICMS gave me a broader view on science."

"IN INDUSTRY, WE ARE LOOKING FOR GENERIC SOLUTIONS THAT CAN ADDRESS MULTIPLE PROBLEMS."

EPL update

Gerrit Peters studied Mechanical Engineering at TU/e, where he obtained his MSc in 1983. He received his PhD from the University of Maastricht in 1987. In 2011, Gerrit was appointed as personal professor at the Department of Mechanical Engineering. Until recently he held the Chair of Theoretical and Applied Rheology. In July 2019 he retired. Key areas of his expertise are rheology of polymers and soft tissues, and structure development during polymer processing.

Gerrit Peters

The many delights of polypropylene

Gerrit Peters started his research into the rheology of polymers in 1987. The emphasis at the time was on a strong interaction between modelling and experiments. Modelling the behaviour of polymers during processing turned out to be a long-lasting adventure. After thirty years, he now has a good grasp of the flow and crystallization of a number of materials. We talk with him about the next big challenges in polymer research and his never-fading interest in the mechanical behaviour of living tissue.

"In the early 1970s, mechanical engineers had radical ideas about computers. They had closed large parts of the lab. They were no longer considered needed. The computers at that time could do much less than a telephone can now. This was the time of punch cards and a central computer on which everyone worked - including the secretariat. The idea was that we could master most material properties with the finite element method and other computer techniques."

THE NEXT REVOLUTION

"That was reversed in the 1980s, as I returned to the department of Mechanical Engineering in Eindhoven. It became clear that you need measurements to be able to realistically calculate its behaviour. Garbage in, garbage out. I was lucky that I came at a time that new groups were set up, and the links between model calculations and experiments became tighter. On the wave of that enthusiasm, I joined the Han Meijer group in 1987. The emphasis at the time was on polymer flow, so on rheology." "After spending years on rheology and process modelling, I jumped on the crystallization of polymers during processing - a topic much more complex than expected. I started making models with a single material, polypropylene, of which we used a single grade. That started as a European project. I was particularly inspired by the work of Hermann Janeschitz-Kriegl from Linz. We further developed his ideas. Modelling polypropylene turned out to be a long struggle. It is an incredibly complex material, with multiple morphologies and multiple phases. If I had known that before, I would never have started with that material."

>>

PROBING POLYPROPYLENE

"It is difficult to conduct experiments under conditions that are relevant to real processing, such as during injection moulding, and obtain fundamental knowledge at the same time. You need to observe the details at the nanometer scale of fast processes at high pressure. This can be done with, for example, intense X-rays. That´s why we have done many experiments at the synchrotron beamlines in Grenoble, of which the Dutch Belgium DUBBLE was the most important. This is how we slowly improved the models. It lead to a large article in Polymer in which we bring together the most extended theory and advanced experiments. Of course, now I am happy that at the time we chose polypropylene because we got it right in our fingers."

"Then we started working with many other materials, such as LLDPE, HDPE, nylon 6, nylon 12 and PLA. The facilities of the ICMS are essential for our research. Our commodity plastics are different from most materials ICMS works with. Yet they are as complex. It is all very non-linear. Crystallizing nylon 6 at a high temperature may take hours. But pull it and crystallization starts in milliseconds. That changes the speed in the order of a million."
"The biggest challenge now is to work with blends. You do not always need new materials to get new properties. Yet it can be very complex how the different components interact when flowing and crystallizing."

LIVING TISSUE

"The subject of my PhD project has never left me. It was on the mechanical properties of the ligaments around the elbow. Tissue has fascinated me ever since. Our work on artificial heart valves was on the cutting edge of polymer engineering. It is intricate to imitate an aortic valve, with its three beautiful flaps that open and close perfectly. That development was only abandoned when fantastic prospects of tissue engineering came up."

"We could also use our knowledge of soft tissue in the study of the deformation of the brain - the way the pudding in your head starts to move in the event of a car collision. At the bottom, the brain stem is fixed to the spinal cord. This is where you can get whiplash. We have measured and modelled the mechanical behaviour of the brain."
"We also continued the study of the skin together with Philips, that wanted to explore new ways of shaving. That´s all about pulling a hair. The razor blade should not pull too hard, that would tear the skin. We measured the deformation of the skin by looking at cross-sections with a camera and used the image information to model it."

OUR MOST IMPORTANT PRODUCTS

"After my retirement earlier this year, I still supervise some PhD students, together with colleagues. The biggest challenge now is to reach out. For example, our knowledge is not yet used in the commercial software that models injection moulding. By making our methods more accessible, the industry can follow up on them and determine the parameters for their simulation software."
"Our PhDs are the best way of transferring our knowledge. They often continue their career in industry. They are receptive to our approach. Graduates and PhDs are among the most important products that we deliver. They are the bridge between scientific knowledge and industry."

"THE BIGGEST CHALLENGE NOW IS TO WORK WITH BLENDS. IT CAN BE VERY COMPLEX HOW THE DIFFERENT COMPONENTS INTERACT WHEN FLOWING AND CRYSTALLIZING."

Institute for Complex Molecular Systems (ICMS)

CREATING FUTURE TECHNOLOGIES BY MASTERING COMPLEXITY

Advancing the fundamental understanding of complex molecular systems in materials science, energy, mobility, health, and life is the main driver of the Institute for Complex Molecular Systems. It addresses research challenges and pushes the boundaries of science by unifying basic principles of chemistry, biomedical sciences, engineering, physics and mathematics.

Since 2008, ICMS creates and maintains a versatile and fruitful research environment to:

- Expand and diversify the ICMS expert network;
- Identify the underlying academic research questions;
- Enrich the scientific toolbox and infrastructure;
- Educate talented researchers in an interdisciplinary environment;
- Inspire researchers through industrial research challenges.

The relationship with industry is strengthened via the ICMS Industrial Consortium – where science meets innovation. Furthermore, ICMS hosts the Advanced Study Center that serves as an intellectual home to scientists from all over the world, hosting discussions on the theme of complexity.

The ICMS supports the research of TU/e scientists in seven focus areas:

- Polymer Science and Technology
  We connect the entire chain of knowledge from theoretical calculations to understanding structure-property relationships, to be able to design improved and novel polymers with desired material properties.
- Chemical Biology
  We follow a molecular systems approach to understand and modulate biomolecular networks for the design of new therapies and diagnostics.
- Grip on Complexity
  We push forward the foundations and applications of complexity science in its broadest sense.
- Advanced Analysis of Complex Molecular Systems
  We are building a state of the art characterization centre for the 4D-analysis of complex molecular systems at different length and time scales.
- Molecular Devices
  We adopt an integrative approach for the design and synthesis of hierarchically structured functional and responsive materials for functional electronic and adaptive devices.
- Materials for Regenerative Medicine
  We are aiming to regenerate tissue and organ function with intelligent biocompatible materials, using a materials-driven approach.
- Functional Supramolecular Systems
  We investigate the construction of functional life-like supramolecular systems to push the frontiers of supramolecular chemistry.

More information can be found via www.tue.nl/icms.
Please contact us with specific questions or remarks via icms@tue.nl or +31 40 247 5074.

ICMS in PRESS

EDITORIAL
ICMS Highlights is the half-yearly magazine of ICMS for ICMS members, colleagues, collaboration partners, policy makers and affiliated companies. ICMS Highlights is published twice a year.

EDITORIAL STAFF
Cindy Plompen (editorial assistant), Harm Ikink

DESIGN AND PRINT
Echt Marketingcommunicatie, Eindhoven

ILLUSTRATIONS AND COVER
ICMS Animation Studio

ARTICLE CONTRIBUTIONS
Bram Vermeer, Esther Thole, Harm Ikink, Valentina Bonito, Marga van Zundert

PHOTOGRAPHY
Leonie Voets Imaging People

SECRETARIAL SUPPORT
Wendy Brouwers, Cindy Plompen

CONTACT
Eindhoven University of Technology
Institute for Complex Molecular Systems
P.O. Box 513, 5600 MB Eindhoven
The Netherlands
Telephone: +31 (0)40 247 5074
Email: icms@tue.nl


“SERVING YOUR
INNOVATION NEEDS”