ICMS Highlights

Edition 8
April 2017

Mimicking living cells

INTERVIEW
/ Jan van Hest

Bringing materials to life

INTERVIEW
/ Tom de Greef

& more...

Institute for Complex Molecular Systems

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

ICMS Highlights

Dear reader,

It is with great pleasure that I present the 8th edition of our ICMS Highlights, a magazine for and by our members and friends. Science is all about people, and the ICMS brings scientists of different disciplines together from all over the world to discuss and explore topics of mutual interest. With this issue I am not only pleased to introduce new members and visiting scientists but also happy to welcome Dr. Monique Bruining, our new managing director.

Together we continue to push the frontiers of knowledge in functional supramolecular systems, bio-inspired engineering, and complexity topics far beyond molecular systems, while also supporting the activities of the Eindhoven Polymer Laboratories and the Eindhoven Multiscale Institute. We recently hosted an exciting Complexity Winter School that was organized by Rutger van Santen, Mark Peletier and Erik Steur. Leading scientists visited Eindhoven to discuss all aspects of complexity, with Professor Tamás Vicsek as one of the highlights. Another lecture series was initiated by Professor Willem Mulder – visiting professor from Mount Sinai in New York and alumnus of our University – about immunoengineering, a research topic with a great future.

The future success of the many students and young researchers at this institute is a fundamental reason for our existence. We hope that the opportunities created by the ICMS will help them all to excel in their current and future interdisciplinary environments.

We hope you enjoy reading our 8th Highlight,

Bert Meijer
Scientific director

Calendar

May 11, 2017
ICMS Industrial Challenge
Location: Ceres

May 12, 2017, 15.00 hr
ICMS Masterclass Willem Mulder / Menno de Winther
Location: Ceres

May 19, 2017, 15.00 hr
ICMS Discussion meeting Nick Tito
Location: Ceres

June 2, 2017, 15.00 hr
ICMS Discussion meeting Sven Kokkelmans
Location: Ceres

June 16, 2017, 15.00 hr
ICMS Discussion meeting Stefan Meskers
Location: Ceres

Oct 12, 2017, 17.00 hr
ICMS Nobel Prize evening
Location: ZD

Oct 27, 2017
ICMS guest lecture Wilfred van der Donk
Location: Ceres

The complete calendar can be found on our website.

Content

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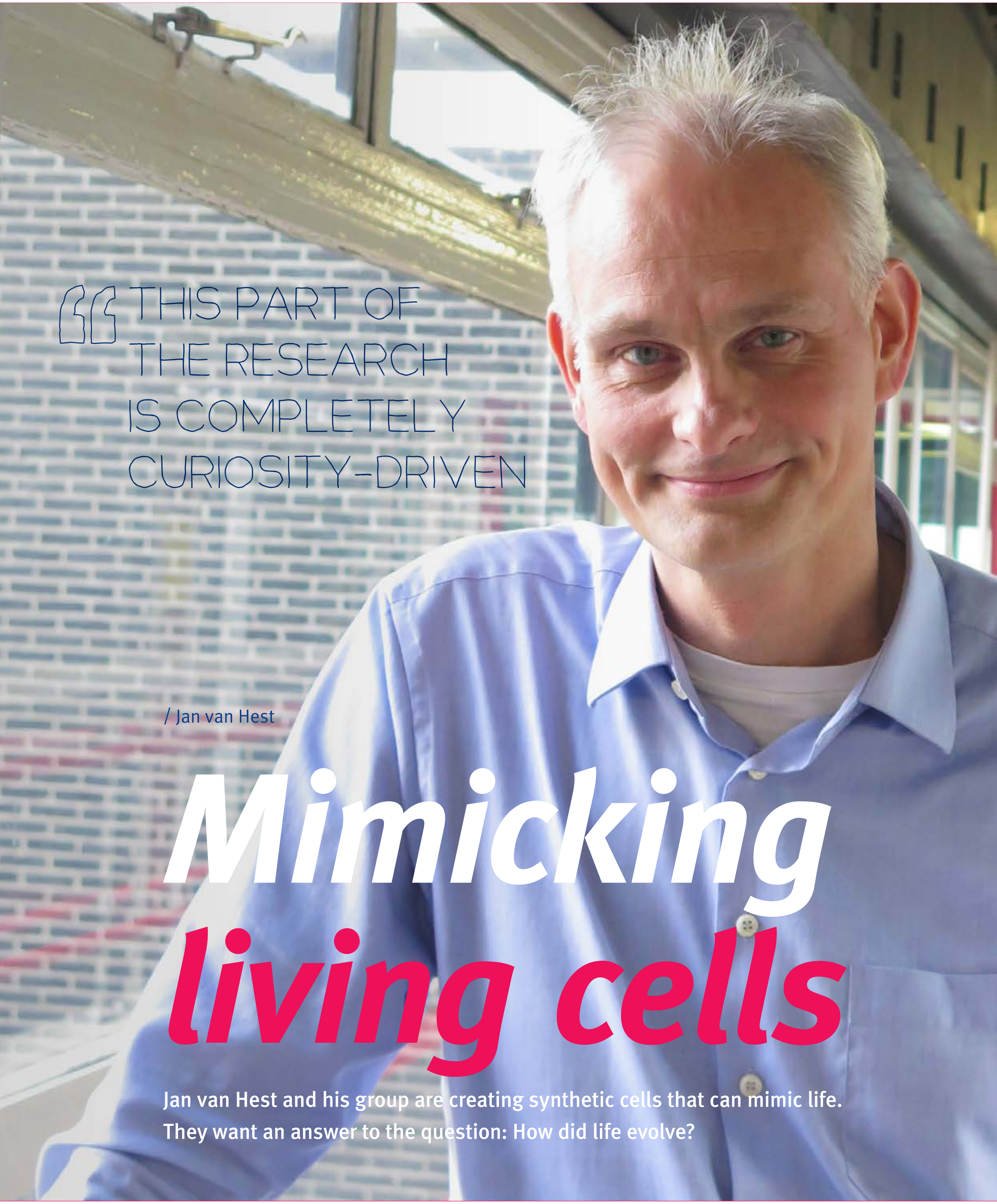
Cover
Artist impression of the oscillating motion of liquid crystal polymers under continuous light irradiation, inspired by the work of Ghislaine Vantomme and Anne Hélène Gelebart.



> THIS PART OF THE RESEARCH IS COMPLETELY CURIOSITY-DRIVEN
>
> / Jan van Hest

Mimicking living cells

Jan van Hest and his group are creating synthetic cells that can mimic life. They want an answer to the question: How did life evolve?

"We are inspired by nature," explains an enthusiastic Van Hest. "We make systems that can be used for nanomedicine. We are developing smart compartments smaller than a micron. We try to make a compartment with the properties of a living cell. We do this with a bottom-up strategy, which means that the molecules we develop can assemble themselves into a structure. By controlling this assembly process, we can incorporate all kinds of functions."

"This part of the research is completely curiosity-driven," explains Van Hest. "We want to know how life evolved. The step from a non-living to a living system is a very intriguing one. How is this possible? To quote Feynman, you can only understand a system if you can build one."

When mimicking life, do the researchers encounter any ethical issues? Van Hest: "We will encounter them at a certain moment. We have not achieved making anything that is faintly similar to a living cell, so I think we are still far away from ethical discussions. And, it is not the intention of this field of research to create synthetic life. The intention is to understand how life has evolved."

Medicine

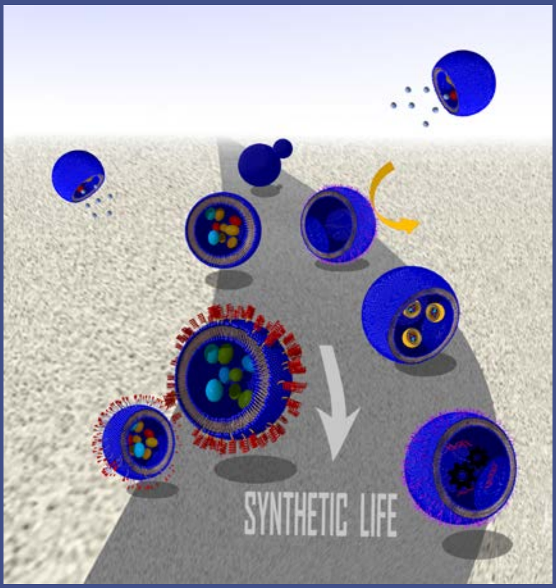
Besides the fundamental part of the research, Van Hest's group also works on a more applied side of mimicking life. "We want to make compartments that can be used for an effective transport of molecules inside the body. This is an important development in the area of drug delivery. The brain is one of the most difficult parts for medicine to reach. There is this blood-brain-barrier, which regulates very carefully which molecules can pass. This is a bottle-neck for medicine that needs to reach the brain, for example medicine for Parkinson's."
"In the future, we aim to develop compartments that can interact with this barrier and trigger the uptake of those particles. The medicine to treat the diseases are already there, the only bump is this barrier. As soon as we fix this, the development accelerates because therapies are already lined up to be implemented."

Van Hest: "This is one of the most challenging projects we have. I think it is important to have such a long term aim for your research. This is a problem we as mankind need to solve. It is a great motivation to contribute to this. You feel like you really contribute to society."

Enriched job

Van Hest: "We have the ability to tailor-make all kinds of molecules. This is exactly what ICMS is about. I've only been here a couple of months, but I've met many people and still haven't explored all possibilities for collaboration yet." Van Hest's job is also varied by being a teacher. "I like to inspire and educate a new generation of researchers. It is lovely to see that your passion can inspire the youth to develop their own ideas. If you are creative, if you don't restrict yourself too much, you can really take a step forward."

Van Hest started here in Eindhoven as a student 30 years ago. Being back in Eindhoven feels a bit like returning home. "I liked my previous job, but I was at a point I felt like something new could be an impulse for inspiration. Eindhoven approached me at exactly the right moment. It was a content-driven choice to return to Eindhoven, but it is a great experience to be back. And Eindhoven still has its can-do mentality. You want to create things, you want to solve problems. This is still in my genome, probably based on the education I had. Whatever you are, you are still an engineer."



Roadmap for new synthetic cells that can mimic life: How did life evolve?

/ Willem Mulder

The immunological problem meets the bioengineering solution

Targeting the innate immune system

There is increasing evidence that links environmental and biological stressors, neural signals and the immune system to disease. The key connecting components are myeloid cells, such as monocytes, macrophages and dendritic cells, which originate in the bone marrow and accumulate in diseased tissue. Moreover, recently it was shown that the innate immune system displays long-term changes in its functional program, based on the epigenetic programming of these myeloid cells.

This startling finding generates new exciting opportunities for therapeutic exploitation; specifically interfering in myeloid cell dynamics to allow for disease treatment in a highly precise, yet modular and durable fashion. My research primarily focuses on precision imaging and targeted therapy of immunological processes that drive disease (progression), primarily in cardiovascular disease and cancer. The strategy revolves around the design and development of nanomedicines that display strong, yet tunable, affinity with immune cell subpopulations, in conjunction with innovative translational imaging methods to noninvasively study their behavior in animal models.

Dutchman in (New) Amsterdam

At Mount Sinai in New York, I direct a multidisciplinary team of nanochemists, radiochemists, biomedical engineers and medical scientists to establish, evaluate and translate nanoimmunotherapies. We intimately collaborate with immunologists and given that my laboratory is part of Sinai's Translational and Molecular Imaging Institute (TMII), noninvasive imaging's marked integration defines our output. We are in the unique position where we can apply imaging to study how nanoimmunotherapies behave and modulate the immune system in live animals.

Simultaneously, my secondary appointment at the Academic Medical Center (AMC) of the University of Amsterdam (UvA) provides access to medical students who are well-trained to oversee logistically complex animal studies, involving mice, rabbits, pigs and even non-human primates.

Exploiting our body's own targeting verhicles

A key focus is the exploitation of one of our body's own nanoparticle transport systems, i.e., high-density lipoprotein (HDL). HDL is composed of a fatty molecules' core enclosed by a corona of phospholipids and apolipoproteins, the latter providing structural integrity and cellular specificity through domains that bind to scavenger receptors and other membrane proteins.

In the past ten years, we have demonstrated that we can label such HDL nanoparticles with nanocrystals, paramagnetic materials, fluorophores or radioisotopes to allow for their visualization using computed tomography (CT), magnetic resonance imaging (MRI), optical methods or positron emission tomography (PET), respectively. More recently, we have established a so-called HDL nanoparticle library containing nanomaterials of varying size, shape, composition, and with differential immune cell specificity. This facilitates for precisely designing HDL nanoimmunotherapies that specifically intervene in macrophage dynamics to treat cardiovascular disease.

> “I WISH TO ESTABLISH A DURABLE COLLABORATION BETWEEN ICMS AND TMII

ICMS visit and Immunoengineering Masterclass Series

The goal of my visit is multifold. First and foremost, I wish to establish a durable collaboration between ICMS and TMII, enabling the exchange of knowledge and personnel. Moreover, as we wish to “step up our game” technologically speaking at TMII, ICMS will acquire access to our unique environment for technology translation to animal disease models. TMII’s state-of-the-art infrastructure includes a comprehensive small animal imaging suite as well as fully equipped facility with the latest generation human scanners, including an integrated PET/MRI system.

Finally, the exciting new immunological concepts described in the introduction are – to a large extent – discoveries by Prof. Dr. Mihai Netea, an internist at the Radboud University who was presented with the Spinoza Award in 2016 for his work on ‘trained immunity’. Prof. Netea served as the first guest lecturer of a Masterclass Series aimed at bridging the gap between biology and technology from the immunoengineering vantage point. The Masterclass Series will continue on a monthly basis, during my visit. Details on the full program are available at **https://www.tue.nl/en/research/research-institutes/top-research-groups/institute-for-complex-molecular-systems/**

FACTS

A human hair measures

50,000 nm in width,

which is about the same as a 1000 nanoparticles queued side by side.

Cardiovascular diseases (CVDs) are the number one cause of death globally, with an estimated

17.5 million casualties in 2012,

representing more than 30% of all deaths.

NEWS, AWARDS & GRANTS

Professor Bert Meijer.

BERT MEIJER

awarded prestigious Nagoya Gold Medal

Japan's highest award for chemistry scientists, the Nagoya Gold Medal of Organic Chemistry, will this year be presented to Bert Meijer, TU/e professor of Organic Chemistry. Meijer thus joins an illustrious group of 22 predecessors, including several winners of Nobel Prizes, Franklin Medals and Wolf Prizes. The award will be presented on 22 December this year in Nagoya.

Meijer will receive his award at the Noyori Conference of Nagoya University where he will also give a presentation of his research whose focus on his underlying philosophy will spur on young chemists and students.
Apart from the Japan award, Bert Meijer will also receive an award in Belgium when he is awarded an honorary doctorate on 31 March from the University of Mons for his work on supramolecular materials and systems.

DNA computer brings

'INTELLIGENT DRUGS' A STEP CLOSER

Researchers at Eindhoven University of Technology (TU/e) present a new method that should enable controlled drug delivery into the bloodstream using DNA computers. In the journal Nature Communications the team, led by biomedical engineer Maarten Merkx, describes how it has developed the first DNA computer capable of detecting several antibodies in the blood and performing subsequent calculations based on this input. This is an important step towards the development of smart, 'intelligent' drugs that may allow better control of the medication for rheumatism and Crohn's disease, for example, with fewer side-effects and at lower cost.

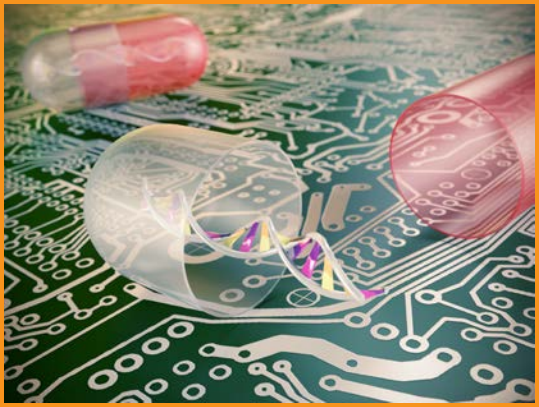


Illustration of the technique whereby DNA acts as a kind of computer - symbolized by the computer chip background - which allows for controlled drug delivery in the bloodstream.

New Horizons

for SyMO-Chem

The SyMO-Chem team

SyMO-Chem is a well-established company that offers services in the fields of organic, polymer (e.g. biomaterials) and analytical chemistry. The expertise of the company has recently expanded towards the field of physical chemistry. Now, SyMO-Chem can also uncover the internal structure of functional soft materials and characterize nanostructured liquids, to mention just a few examples. By offering these type of services, SyMO-Chem aims to develop as a versatile and innovative contract research company.

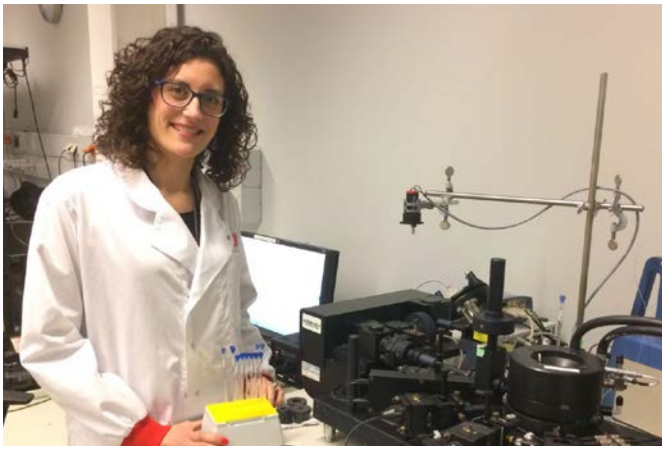
History and vision of SyMO-Chem

SyMO-Chem BV was initiated in 2000 by Henk Janssen and Bert Meijer as a spin-off from the Molecular Science and Technology (MST) department of the TU/e, an interdisciplinary department, nationally and internationally known for its valued contributions to, particularly, molecular science. Since 2008, SyMO-Chem has been a partner of the industrial Consortium of the Institute of Complex Molecular Systems (ICMS) that was founded to strengthen the relationship between academia and industry. Similarly, SyMO-Chem also serves as a bridge between the fundamental research that is typically conducted at the TU/e and the more application driven research that is usually performed in industry, offering contract research to help in synthetic tasks, materials research and sample characterization, or to find solutions to problems that can arise during product development. This work is always done confidentially.

Services expansion of the company towards physical chemistry

SyMO-Chem is currently run by a team of about 10 experienced and motivated PhDs and technicians with backgrounds in the diverse fields of organic, polymer and analytical chemistry. The company has access to the state-of-the-art infrastructure of MST and ICMS that includes equipment for mass spectrometry and mass analysis, NMR spectroscopy, general other spectroscopies (UV-Vis, PL, FT-IR, CD, polarimetry), chromatography, thermal analysis (DSC) and peptide synthesis among others. With over 15 years of experience, the company has performed research and services in the chemical, pharmaceutical and life-sciences fields for national and international companies, large or small (e.g. SMEs or start-up's), as well as for universities. Sometimes clients of SyMO-Chem wish to publish exciting findings, and this had led to open literature research papers with for example Tagworks Pharmaceuticals on their innovative bio-orthogonal "click-to-release" chemistry, with SupraPolix on their supramolecular materials portfolio and with the University of Wageningen (WUR) on poly(propylene imine) (PPI) dendrimer based nanoprobes. Additionally, in the biomaterials field, SyMO-Chem has contributed to the development of synthetic materials for (in situ) tissue engineering, for example in co-operations within various research consortia that also include partners at the TU/e. With the vision to expand the above described expertise of the company and aiming to reach an even broader range of customers, dr. Neus Vilanova Garcia has recently been incorporated into the SyMO-Chem team. Neus is a physical-chemist specialized in revealing the colloidal aspects of soft matter such as interparticle interactions, particle shape and size, phase behavior of surfactants or rheological properties of gels. Hence, the newly offered services span from the evaluation of materials generated in research projects, to formulation studies, to sample characterization of colloidal solutions, solid or liquid dispersions (micelles, liposomes, nanoparticles, emulsions, etc), liquid crystalline materials, gels or foams. To do so, SyMO-Chem has access to an exceptional list of instruments such as X-ray Scattering (SAXS and WAXS), Light Scattering (DLS and SLS), Diffusive Wave Spectroscopy (DWS), optical, confocal and electronic microscopes, a refractometer and a densimeter, to mention just few.

SyMO-Chem is now able to investigate phenomena that occur at the molecular nanoscopic level up to the mesoscale level, what makes the company even more versatile. SyMO-Chem is looking forward to new challenges, by tackling, for example, problems of clients by researching from different points of view, thereby trying to understand the underlying reasons of why such problems may occur. By combining the years of experience of the company with the wide range of equipment it has access to, SyMO-Chem offers high-quality, quick and reliable research. Therefore, SyMO-Chem is a valuable business partner for those who seek outsourcing capacity, expertise and advice in various fields of chemistry, now including physical chemistry. For more information, please visit the SyMO-Chem webpage at www.symo-chem.nl, or contact them directly.



Dr. Neus Vilanova Garcia

SyMO-Chem

/ Tom de Greef

Tom de Greef (1980, Eindhoven, The Netherlands) is Associate Professor at the Department of Biomedical Engineering. In 2004, Tom graduated cum laude in Biomedical Engineering at the Eindhoven University of Technology. In 2008, he completed his Ph.D. at the Department of Chemistry, under the guidance of professors E. W. Meijer and R. P. Sijbesma. After moving to the Computational Biology group headed by prof. P. A. J. Hilbers at the Department of Biomedical Engineering (TU/e), he became assistant and associate professor in the same department in 2010 and 2016, respectively. His research interests includes supramolecular chemistry and synthetic biology, with particular focus on understanding signalling networks using a build-by-learning approach in which he uses both microfluidic and nanoscopic tools. With his research, de Greef is a core member of the Institute for Complex Molecular Systems (ICMS).

From supramolecular chemistry to synthetic biology

Supramolecular polymer chemistry lies at the intersection of supramolecular chemistry and polymer science, and focuses on the development of individual monomeric units, held together by strong, directional and reversible noncovalent interactions. Over the past few decades, the attention towards this novel class of materials increased tremendously because of their excellent mechanical properties, their good processability at low temperatures, and the broad range of applications.

de Greef: “From a certain point of view, supramolecular chemistry per se is as a science ad hoc. It all starts with a good idea, its realization, and the final observation and measurement. The challenge starts when trying to convert supramolecular chemistry into a quantitative science, using computational models and simulations, and link the observed behaviours to complex living systems. In Nature, many examples of one-dimensional supramolecular architectures assembled from monomeric protein building blocks exist such as microtubuli and actin fibers. By combining careful measurements with theoretical modelling, we discovered that synthetic supramolecular polymers follow identical growth mechanisms as protein-based aggregates. The analogy allowed us to use 40 years of knowledge on protein aggregation to develop strategies to control the self-assembly of synthetic monomers into supramolecular polymers. Ultimately, I think the holy grail in supramolecular chemistry is to predict the self-assembly pathways of any molecule using only the molecular information encoded in its structure. This is a difficult problem as it crosses many length and time scales.”

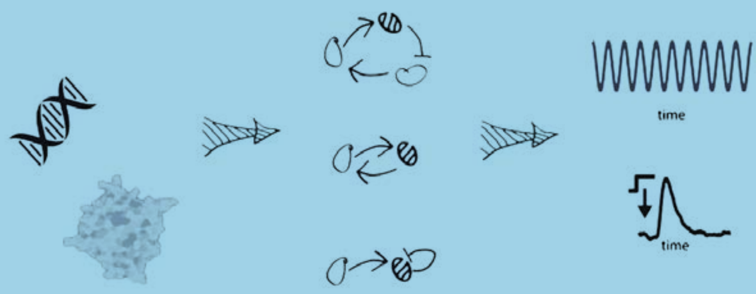


Figure 1: Schematic illustration showing the forward engineering of cell-free genetic networks with preprogrammed temporal functions such oscillations and adaptation.

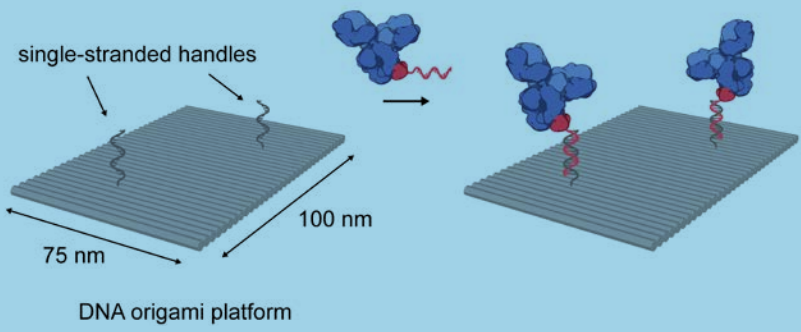


Figure 2: Schematic illustration showing the nanopatterning of DNA origami with antibodies.

Synthetic biology: in search of a new field

de Greef: “When I started as a PI in the BMT department in 2010 I was searching for a new line of research. In the young scientific field of synthetic biology, I found the unique and exciting possibility to make breakthrough discoveries. As a Biomedical Engineer, I have been always intrigued by concerted stimulations and responses of complex living systems, but during my PhD and the Postdoc my attention mainly focused on the exciting area of synthetic chemistry. Moving towards synthetic biology was for me the perfect chance to reunite the different directions my academic career followed so far.”

Cellular reprogramming and biochemical networks

Fingerprints of all the living systems are complex spatiotemporal behaviours, which can be mimicked in vitro by synthetic signalling networks and chemical information processing systems. Via the use of experiments, micro-engineering tools and modelling, the ambition of de Greef and his team is to unravel and control complex regulatory behaviour of networks of biochemical interactions, and ultimately formulate generalizable design principles.

de Greef: “The possibility of reprogramming cells using a cell-free prototyping approach has become very popular in the emerging field of synthetic biology in recent years. For example, we have developed advanced microfluidic methods for the faster optimization of molecular interactions outside the cell. Using cell-free lysates mainly obtained from E. coli, we can “run” genetic networks in a microfluidic reactor. Because of the simplicity of this approach compared to working with living cells, we can quickly iterate different designs or change molecular parameters that are important for a given system function. We then place these optimized circuits back into their native cellular environment and investigate their performance in living cells. Using this approach we aim at a more controlled and accelerated reprogramming of living cells, which might have tremendous advantages for therapeutic applications.”

DNA origami and cellular Signalling

de Greef: “Beside my studies on synthetic signal transduction networks, I recently started diving into the field of DNA origami which allows me to create non-arbitrary two- and three-dimensional shapes at the nanoscale via the folding of DNA. Particularly, I focus on multivalent receptor-ligand interactions and enzyme kinetics using DNA origami scaffolds, in the attempt to gain a quantitative understanding on the role of multivalency in signal perception and transduction. Even though DNA origami has many potential applications, cancer immunotherapy is the one that fascinates me the most. To give one example, the PD-1L (programmed cell death ligand-1), highly expressed in cancer cells, when binding to the PD-1 receptor of T cells, is responsible for suppression and apoptosis of the T cells. This leads to immune-system down regulation and self-tolerance promotion. Using DNA origami coated with multiple copies of anti-PD-1 and placed at well-defined distances could allow us to unravel how blocking of the PD-1 receptor is influenced by the affinity and avidity of the molecular interactions.”

Synthetic biology, what’s next?

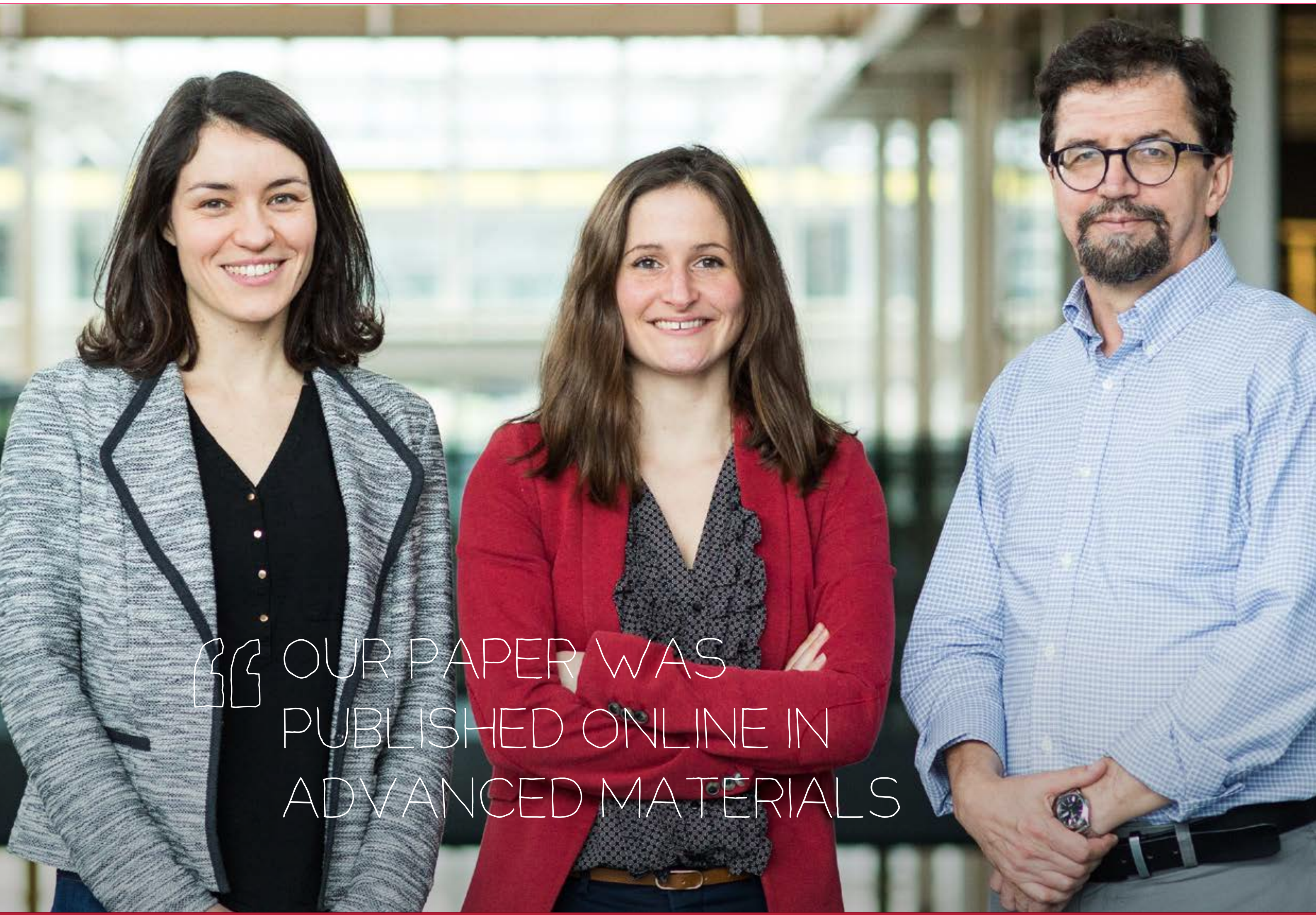
de Greef: “I truly believe that the future of synthetic biology revolves around the possibility to engineer living and artificial cells, which can sense biochemical signals from the body, process them and give specific responses using autonomous closed-loop feedback circuits. Examples include artificial cells based on liposomes, reprogrammed bacteria that monitor inflammation in your gut or genetically modified T cells that carry synthetic receptors which can target and destroy tumor cells with high specificity.”

The ICMS experience

During the last years, de Greef set up several international collaborations, which nourished the portfolio of long-lasting collaborations with the chemical biology division (Prof. Brunsveld, prof. Meijer, Prof. Merkx). Other examples of collaborations within the ICMS are with dr. Bart Markvoort, prof. van Santen and prof. Peletier in the area of molecular simulations and complexity science, the recent partnerships with prof. Cecilia Sahlgren, expert in cell-cell interactions and Notch signaling, and with dr. Jurjen Tel, Immunologist who was recently appointed as Assistant Professor in the Soft Tissue Engineering and Biomechanics group.
“I honestly believe that the only way to compete worldwide with top universities is to work together, as a collective. Being all part of the ICMS institute helped us tremendously in that respect.”

The Cram Lehn Pedersen

In 1987 the Nobel Prize in Chemistry was awarded jointly to Donald J. Cram, Jean-Marie Lehn and Charles J. Pedersen “for their development and use of molecules with structure-specific interactions of high selectivity”. Since 2011, the Cram Lehn Pedersen Prize was named in their honour. This year the prize was assigned to Tom de Greef for his significant, original and independent work in supramolecular chemistry. de Greef received a monetary honorarium, free registration to the International Symposium on Macrocyclic and Supramolecular Chemistry (ISMSC) meeting and the possibility for a lecture at the meeting as well as two additional research presentations in the country where the meeting is held.



Maximum effect

Bringing Materials to Live

Birds, fish, bacteria, but also molecules, can exhibit collective behaviour. But so far, we have no idea on how individual interactions lead to emergent properties. Studying liquid crystals from both a physical and a chemical standpoint can bring us closer to the minimal requirement for collective, molecular behaviour.

The timing of the interview turns out to be perfect. There is hot news to share, according to Anne Hélène Gelebart and Ghislaine Vantomme. Gelebart is a PhD student in the group of Dick Broer and Vantomme is a postdoc in the group of Bert Meijer.“Yesterday evening, our paper was published online in Advanced Materials. We can show you what it is about”, they say in unison as they start looking for the right movie on their tablet. There it is. The screen shows something in black and white that is frantically flapping, but it's not immediately clear what we're looking at. “What you see here is a small strip of light-responsive liquid crystal polymer film, which is clamped down by a pair of tweezers on one end”, Gelebart explains. “When exposed to light, the strip starts bending, until it becomes immersed in its own shadow. At that point, the bending stops and the strip relaxes back to its original form, but while doing so, the shadow fades and the light will hit the strip again, leading to renewed bending. As long as the light is on, this process keeps on repeating itself and the result is a steady, rhythmic flapping motion.” A rather fast motion too, it is hard to distinguish the different phases of bending and relaxation. And that all because of a molecular change.

Morphing materials

An impressive sight and both Gelebart and Vantomme seem very pleased with the result. But how long does it last? It is only a small, thin strip that doesn't look terribly robust. What about fatigue in the material? “We don't see any signs of that”, says Vantomme. “These molecules are very stable and the polymer material is as well. These strips can go on moving for a long time. Also storage is not a problem. The moment you shine the light on a strip, even after being stored for a while, it just immediately starts moving again. The motion is purely due to energy transduction in the material, as long as there is an input of energy, it will keep on moving.”

Meanwhile, Oleg Lavrentovich has joined the conversation, which brings us to the actual reason for organizing this group interview. He is in Eindhoven for a short stay as a visiting scientist as part of a collaboration between his group and the Broer and Meijer groups at the ICMS. Lavrentovich is Trustees Research Professor with the Liquid Crystal Institute at Kent State University in Ohio. He studies the physics of liquid crystals and is interested in their structural and dynamic behaviour in response to various (weak) physical and chemical signals and stimuli. “My research concerns dynamic, morphing materials that self-organize and I'm interested in different approaches to responsive materials and in using different actuators”, says Lavrentovich. “One of our topics concerns liquid crystal-based hybrid materials. These are responsive to an electric field ánd change colour as a result. The response ranges from UV to visible light to deep infrared, but there is no chemical reaction involved. It's only based on physical reactions; the material is only morphing.” Including a chemical perspective may lead to all kinds of exciting properties and that brings him to the ICMS. “The groups here are world-leading in making materials that build on molecular orientation. It is really interesting to see if we can combine our hybrid materials with liquid crystal elastomers that are capable of a chemical response.”

Bacterial superbodies

But what will, further down the line, such a combination bring us in terms of new characteristics and

FACTS

- Liquid Crystals were discovered

129 years ago.

- Today’s smartphones and tablet computers would not exist without the Liquid Crystal Displays technology.
- The LCD market is expected to reach 170 billion dollar by 2020.

applications? Lavrentovich: “It is always important that the physical property fits the actual device it is applied in. Think for example of a smart window. The colour change in the window should be programmable and that requires polymer stabilisation to enable tuning. You don't want the window to change colour all the time with every small change in light intensity.” He stresses that his primary interest is not in applications. “No, I'm interested in understanding what happens and why. Once we thoroughly understand how these materials react and respond, we can start trying to control the system to exhibit functional behaviour.” Those systems could include living elements. The Lavrentovich groups is currently exploring how these materials can be used to control the swimming motions of bacteria, which might offer inspiration for soft robotics.

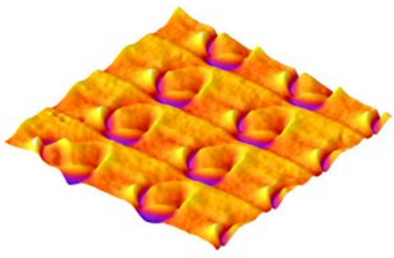
> “At the heart, this is all about out-of-equilibrium systems”

Bacteria are known to form 'superbodies' in which they all collaborate to perform tasks that individual bacteria could never manage. “Such a bacterial superbody can navigate obstacles by changing shape. Such a property that offers inspiration for robotics. If you have a robot that can disassemble to, for example, pass through a narrow or low opening, and then reassemble again, that would be very interesting for something like transporting cargo. Bacteria can do this because of their collaborative behaviour.” Gelebart sees the analogy with the molecular structure of liquid crystals. “The alignment in the liquid crystal polymer, splayed or nematic, determines the deformation in the material. The molecules in these materials exhibit collaborative behaviour as well.”

Probing the minimum

However intriguing, robotics-type applications are still far ahead of us. So, to wrap up, what do they see as critical issues to address to take these materials and their (desired) properties to the next level? The sensitivity of the material needs to be increased, according to Gelebart. “We now need a relatively intense light source, but what we want is the system to work using the full spectrum white light and somehow concentrating that into a useful wavelength.” That will require changing the properties of the material, Vantomme adds. “We will need new supramolecular systems with tuneable architectures and functions.” On a more generic level, they indicate that a better understanding of the minimal requirements to access the non-equilibrium state is strongly needed.

“At the heart, this is all about out-of-equilibrium systems. We lack a proper description of what to minimize in dynamic systems”, says Lavrentovich. “How do we achieve orientational order in a dynamic system? We see it in dispersions of bacteria, we also see it in flocks of birds and other gatherings of moving objects. It all boils down to interactions between individuals that translate into orientational order. But we often don't understand how that translation works.” Vantomme agrees: “We want to improve our system and move to more complex motions, but in order to do so, we need to screen the limit. What are the minimal requirements to translate molecular motion at the macroscopic scale? We don't know that yet, but once we do, we can really start studying collective molecular behaviour.”



Dynamic surface profile of a liquid crystal material prepared by Ms. Greta Cukrov, a PhD student in Dr. Lavrentovich’s group at the Liquid Crystal Institute, Kent State University, during her stay at Prof. D. Broer and Prof. A. Schenning’s laboratory at the TU/e

EPL Update

Strengthening our reversible materials and additive manufacturing programs

A recently awarded 2.5 M€ NWO-TA grant will further strengthen the reversible materials and additive manufacturing research efforts within the Eindhoven Polymer Laboratories. The grant was awarded to a consortium of EPL-affiliated research groups from Chemical Engineering and Chemistry, Maastricht University, DSM, TNO, Xilloc and Brightlands Materials Center for the project Dynamic Polymer Materials for Additive Manufacturing.

Additive Manufacturing

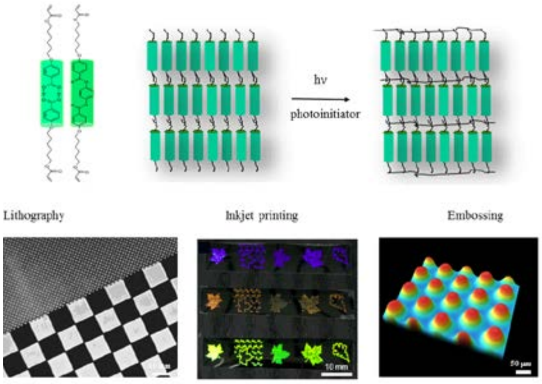
Additive manufacturing (or 3D printing) is a rapidly growing field that is increasingly moving away from rapid prototyping to faster and custom-made manufacturing. This development is accompanied by an increasing demand for better and novel materials, and faster and more robust in 3D printing processes. In order to capitalize on current needs and anticipate future demands, EPL started a comprehensive and multi-disciplinary research program in this field together with Brightlands Materials Center (BMC) two years ago. Eight PhD students in EPL groups in the Mechanical Engineering (W) and Chemical Engineering & Chemistry (ST) departments have already started working on projects that range from fundamental material and rheological properties, material characterization to the development of novel printing materials.

Currently, only a very limited number of polymers is suitable for use in 3D printing applications, and the main aim of the new project *Dynamic Polymer Materials for Additive Manufacturing* is the development of the next generation of polymeric printing materials. These materials will be based on dynamic chemical bonds that can adapt to variable processing conditions leading to greatly improved mechanical properties and/or to responsive printed objects. In collaboration with industrial partners and under the umbrella of BMC's Additive Manufacturing program, these concepts will be applied in three different applications. Firstly, the Supramolecular Polymer Chemistry group (ST) will focus on developing materials for improved sintering in selective laser sintering (SLS), which complements the running projects focussed on understanding the fundamental aspects of sintering within the Polymer Technology group (W). Secondly the Functional Organic Materials and Devices group (ST) will focus on the development of advanced responsive 3D microstructures in stereolithography and ink jet printing. Finally, Lorenzo Moroni's group at MERLN Institute for Technology-Inspired Regenerative Medicine of Maastricht University will focus on the development of dynamic and reversible materials for regenerative medicine applications in collaboration with the Supramolecular Polymer Chemistry group (ST).

Dynamic Polymer Materials in 3D Printing

Selective laser sintering is a 3D printing technique in which a laser is used to selectively sinter polymer particles in a powder bed, building up a 3D object in a layer-by-layer fashion. This technique is very powerful for the fabrication of complex polymeric objects, but is limited by the fact that to date only a very small number of polymers is known to be printable with this technology (of commercial relevance only Nylon-12 and PEEK). One reason for this is that for many polymers the sintering process in which two individual powder particles merge is not efficient, which leads to poor mechanical properties of the printed part. The sintering process consists of the formation of an interface between the individual particles, followed by polymer chain diffusion and entanglement formation. This is where dynamic chemistry can play a role. Using polymeric materials based on reversible networks should result in significantly reduced viscosities and hence increased diffusion under the processing conditions (bonds open), but increased mechanical strength at application temperature (bonds closed). Alternatively, the use of vitrimers, in which exchange reactions lead to dynamic crosslinks, is expected to improve bond formation across particle boundaries. Both approaches are thus expected to improve the sintering process and to expand the range of printable polymers. In addition to complementing the current research efforts in understanding the fundamentals of the laser sintering process, this research line also complements the reversible materials research in the EPL-affiliated Theory of Polymers and Soft Matter research group (Dept. of Applied Physics).

The second research line combines additive manufacturing with stimuli responsive materials to fabricate 4D polymer materials. Manufacturing techniques such as 3D inkjet printing and stereolithography will be combined with responsive liquid crystalline (LC) polymer networks, which are able to respond to a variety of external stimuli in a reversible way without the need of a solvent. Nature-like hierarchal structures will be explored with an emphasis on addressable and responsive systems.



Hierarchical structured liquid crystal polymer networks for advanced responsive 3D materials

Finally, dynamic and reversible chemistries will be implemented in the materials used to print 3D tissue constructs. Currently, the field is limited by the printing of unresponsive naturally derived and basic synthetic polymers and hydrogels that are extruded or (photo)crosslinked during or after deposition to maintain high fidelity structures. Within the current approaches, there is a noted lack of well-defined and customizable synthetic systems that allow for precise control over the materials properties and the bioactivation of the material. The ability of reversible and mechanically instructive materials will be explored to influence stem-cell behavior and elevate biofabrication for tissue engineering.

In conclusion, these exciting new and coherent research lines complement and strengthen existing research efforts within EPL and help position EPL itself as a top player in the fields of *reversible materials* and *additive manufacturing*.

ICMS TOP PUBLICATIONS

October 2016 – March 2017

1. *A.T. Haedler, S.C.J. Meskers, R.H. Zha, M. Kivala, H.W. Schmidt, E.W. Meijer*
Pathway complexity in the enantioselective self-assembly of functional carbonyl-bridged triarylamine trisamides
J. Am. Chem. Soc. 138, 10539-10545 (2016)

2. *J. Holub, G. Vantomme, J.M. Lehn*
Training a constitutional dynamic network for effector recognition: storage, recall, and erasing of information
J. Am. Chem. Soc. 138, 11783-11791 (2016)

3. *M. Garzoni, M.B. Baker, C.M.A. Leenders, I.K. Voets, L. Albertazzi, A.R.A. Palmans, E.W. Meijer, G.M. Pavan*
Effect of H-bonding on order amplification in the growth of a supramolecular polymer in water
J. Am. Chem. Soc. 138, 13985-13995 (2016)

4. *H.C.G. de Cagny, B.E. Vos, M. Vahabi, N.A. Kurniawan, M. Doi, G.H. Koenderink, F.C. MacKintosh, D. Bonn*
Porosity governs normal stresses in polymer gels
Phys. Rev. Lett. 117, 217802 (2016)

5. *G.M. Bögels, J.A.M. Lugger, O.J.G.M. Goor, R.P. Sijbesma*
Size-selective binding of sodium and potassium ions in nanoporous thin films of polymerized liquid crystals
Adv. Funct. Mater. 26, 8023-8030 (2016)

6. *W.P.E.M. op 't Root, G.J.H. Brussaard, P.W. Smorenburg, O.J. Luiten*
Single-cycle surface plasmon polaritons on a bare metal wire excited by relativistic electrons
Nature Commun. 7, 13769 (2016)

7. *W. Mtangi, F. Tassinari, K. Vankayala, A.V. Jetzsch, B. Adelizzi, A.R.A. Palmans, C. Fontanesi, E.W. Meijer, R. Naaman*
Control of electrons' spin eliminates hydrogen peroxide formation during water splitting
J. Am. Chem. Soc. 139, 2794-2798 (2017)

8. *O.J.G.M. Goor, H.M. Keizer, A.L. Bruinen, M.G.J. Schmitz, R.M. Versteegen, H.M. Janssen, R.M.A. Heeren, P.Y.W. Dankers*
Efficient functionalization of additives supramolecular material surfaces
Adv. Mater. 29, 1604652 (2017)

9. *E.A. Novikova, M. Raab, D.E. Discher, C. Storm*
Persistence-driven durotaxis: generic, directed motility in rigidity gradients
Phys. Rev. Let. 118, 078103 (2017)

10. *W. Engelen, L.H.H. Meijer, B. Somers, T.F.A. de Greef, M. Merkx*
Antibody-controlled actuation of DNA-based molecular circuits
Nature Commun. 8, 14473 (2017)

11. *J.J.M. Lenders, L.A. Bawazer, D.C. Green, H.R. Zope, P.H.H. Bomans, G. de With, A. Kros, F.C. Meldrum, N.A.J.M. Sommerdijk*
Combinatorial evolution of biomimetic magnetite nanoparticles
Adv. Funct. Mater. 27, 160634 (2017)

12. *V.A. Milichko, S.V. Makarov, A.V. Yulin, A.V. Vinogradov, A.A. Krasilin, E. Ushakova, V.P. Dzyuba, E. Hey-Hawkins, E.A. Pidko, P.A. Belov*
Van der Waals-organic framework as an excitonic material for advanced photonics
Adv. Mater 29, 1606034 (2017)

This overview lists publications in high end journals with ICMS as affiliation.

New ICMS Managing Director

Monique Bruining

Very soon I will be joining the ICMS community and will have the opportunity to meet you all in person. I would like to take a moment to introduce myself briefly.

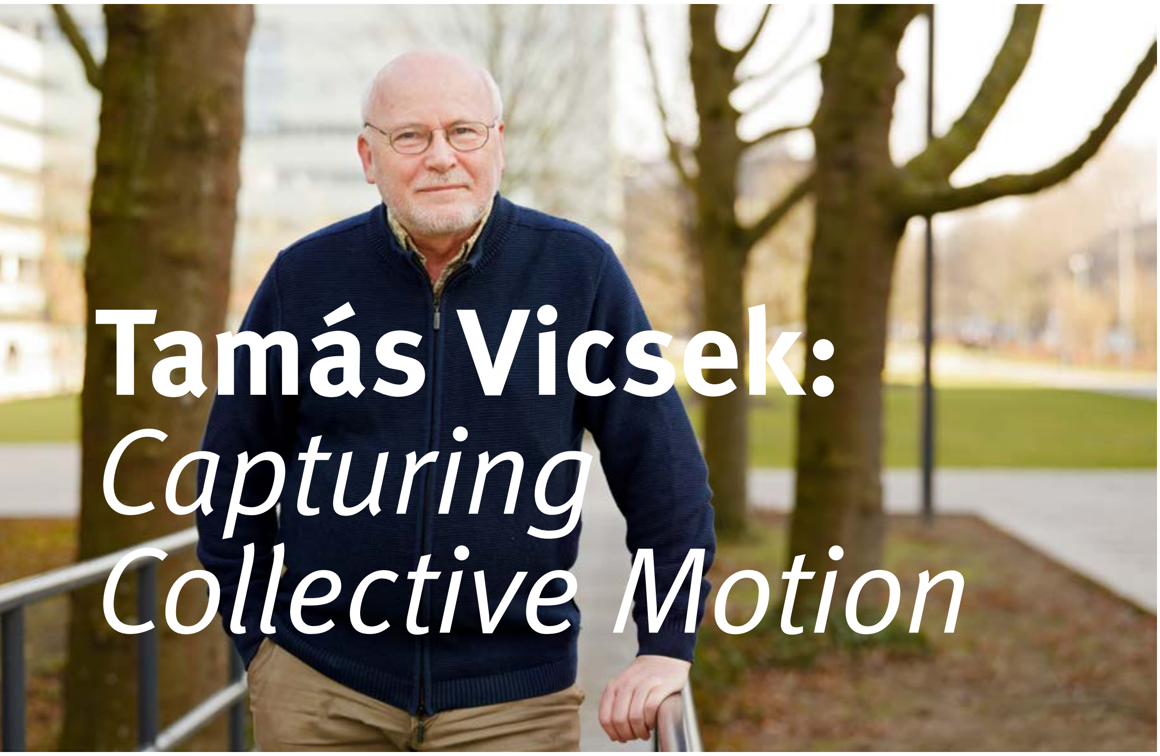
After obtaining my Master's degree in Chemical Technology (organic chemistry) from Eindhoven University of Technology in 1997, I moved to Maastricht University to work on my PhD. There I was able to combine my interests in chemistry and biology towards research focusing on ophthalmic biomaterials. After obtaining my PhD in 2001, I embarked on a career in industry at Johnson & Johnson, where I worked for 8 years, initially as a scientist and at a later stage in a technical support role for marketed products. The key element of this job was solving problems related to pharmaceutical ingredients. It is here that I learned that supporting researchers on their journey towards their goals and developing effective and efficient processes to facilitate research is my true passion. In 2008 I joined DPI (The Polymer Research Platform), where I was able to put this passion into practice by setting up international collaboration platforms where researchers from academia and industry met to build on each other's ideas and stimulate innovation.

I very much look forward to performing my new role at ICMS and to build on the foundation laid by Sagitta Peters and the entire ICMS community. My aim will be to create new opportunities related to academia, industry, and granting agents in the interest of multidisciplinary research. I am very excited to start at ICMS and to work with you on the challenges that lie ahead. Together we will take ICMS forward towards new horizons.

ICMS Industrial Challenge

This year the ICMS is introducing a new initiative to further grow and strengthen the scientific community encompassing ICMS members (MSc, PhD, postdocs, staff) and scientists from leading chemical companies. The ICMS Industrial Challenge (IIC) begins with representatives from participating companies presenting outstanding industrial problems. In teams, the IIC members will work with an industry representative to find an innovative, novel solution. The IIC commences with a Kick-Off event at the Ceres Building, TU/e on May 11th 2017 and culminates in a finale held at the ICMS Outreach Symposium in January 2018 where ideas will be presented and prizes awarded.

The IIC will stimulate long-term research collaborations and support the career development young TU/e researchers. For more information and to get involved visit **www.icmschallenge.nl**. Registration is now open!



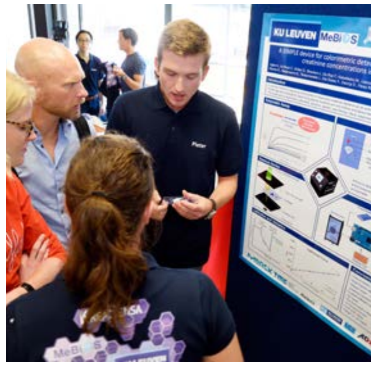
Tamás Vicsek: *Capturing Collective Motion*

The program for the second ICMS complexity winter school was comprised of a number of stimulating and informative lectures. One of the highlights was the lecture series of Tamás Vicsek, Professor of Physics at the Biological Physics Department of Eötvös Loránd University, Hungary. Over the course of three captivating lectures Professor Vicsek presented a fascinating introduction to collective motion, using both experiments and simulations, in systems ranging from bacteria to people, and from birds to drones. In addition, he presented a captivating talk to general audience in the Blauwe Zaal of the Auditorium in conjunction with Studium Generale at TU/e.

The Road to the Vicsek Model

"I originally wanted to become a biologist, not a physicist" remarked Vicsek during one of his ICMS lectures. If this had been the case then we may never have seen the emergence of one of the most cited algorithms in the field of collective motion – the now famous Vicsek model. With over 2,500 citations according to the Web of Science, Vicsek's paper "Novel Type of Phase Transition in a System of Self-Driven Particles" published in Physics Review Letters (PRL) in August 1995 has had a gargantuan influence on countless studies related to the collective motion of self-propelled or active particles. The model was inspired by the observation of rotating domains in bacterial colonies studied by Vicsek's collaborator Eshel Ben-Jacob from Tel-Aviv University.

"I don't recall the moment that I got the idea. I just remember walking up and down the corridor telling my colleagues that I developed the non-equilibrium equivalent of the Heisenberg model." In the Heisenberg model, a mathematical representation of magnetism, stationary spins orientate themselves subject to thermal or magnetic perturbations. However, in the Vicsek model, spins can move.



If different systems behave in the same way, there must be a

simple rule

to define this behaviour

The orientation of a given spin is updated using the mean orientation of spins within a specified distance of the spin and a random noise term. Despite the apparent simplicity of spin interactions, the model is capable of exhibiting numerous motion patterns depending on the choice of spin density and the size of the random noise. For example when the density is high and the noise is small all of the particles tend to move in the same direction.

You might think that the acceptance of such a high-impact paper would have been a formality but this was most certainly not the case. "The paper was sitting on the editor's desk for quite some time. During this period the editor was recovering from illness. After 6 months I sent a letter to the editor about the review process" recalls Vicsek. "One referee liked it while the second referee didn't take to it. After the paper was initially rejected I appealed to the chief editor of PRL, who reported positively on the paper and it was finally accepted." Despite the current number of citations it took some time before the model started to have an impact. "Of course I didn't name the model after myself. It was named "the Vicsek model" by a control theorist who cited the work a number of years later." The model then caught the attention of Stephen Smale, the renowned and influential mathematician who wrote a mathematical paper on the Vicsek model. Since then the model has been used in countless studies on collective motion.

Legacy of the Model

As demonstrated by its continued citation and reference, the Vicsek model is still of significant relevance in the study of collective motion. "If different systems behave in the same way, there must be a simple rule to define this behaviour" says Vicsek. The model's simple interaction rule captures the behaviours of many systems from bacteria to locusts and from birds to reindeer. While alternative numerical approaches will be developed, the Vicsek model will not only prove a valuable source of inspiration for the creators of these models, it will undoubtedly be applied in the studies of many other systems with emergent collective motion.

ICMS Complexity Winter School

NEWS, AWARDS & GRANTS

DR.IR. TOM DE GREEF

wins prestigious CLP Prize Supramolecular Chemistry

Yesterday it was announced that Tom de Greef is the winner of the 2017 Cram Lehn Pedersen Prize in Supramolecular Chemistry. According to the ISMSC International Committee who annually awards the prize to an outstanding, early-career supramolecular chemist, there were very strong candidates this year but De Greef rose to the top. Tom de Greef is part of the department of Biomedical Engineering.

The Cram Lehn Pedersen Prize, named in honour of the winners of the 1987 Nobel Prize in Chemistry, recognizes significant, original and independent work in supramolecular chemistry. Those who are within 10 years of receiving their PhD are eligible for the award. The winner will receive a monetary honorarium, free registration for the ISMSC meeting and give a lecture at the meeting as well as two additionally research presentations in the country where the meeting is held.

MAINZ Visiting Professorships awarded to

BERT MEIJER AND GEN TATARA

The Graduate School of Excellence "Materials Science in Mainz" (MAINZ) has again awarded visiting professorships to two outstanding scientists. The MAINZ Visiting Professorships 2016 were presented at a gala event on Monday evening to Professor Egbert Willem Meijer and to Dr. Gen Tatara, a theoretical physicist of the Japanese research institute RIKEN. Visiting professorships are a way to attract foreign scientists to the various departments of the MAINZ Graduate School so they can do part of their research here as well as work with the doctoral candidates studying at MAINZ. Their input can take the form of lectures, seminars, and workshops that help in training doctoral candidates at MAINZ. The visiting professorships have been awarded annually since 2013 to a maximum of two scientists.

Nobel prize for

BEN FERINGA

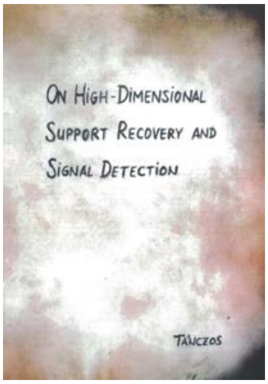
On Saturday December 10, Professor Ben Feringa received the Nobel Prize for Chemistry. Bert Meijer accompanied Ben, his chemical brother since their PhD studies in Groningen, on this special occasion in Stockholm, Sweden.

THESES ICMS

October 2016 – March 2017

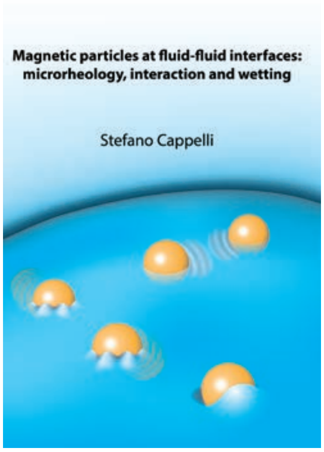
1 **On high-dimensional support recovery and signal detection**
Ervin Tamás Tánczos

September 13, 2016
PhD advisors:
prof.dr. R.W. van der Hofstad, dr. R.M. Pires da Silva Castro



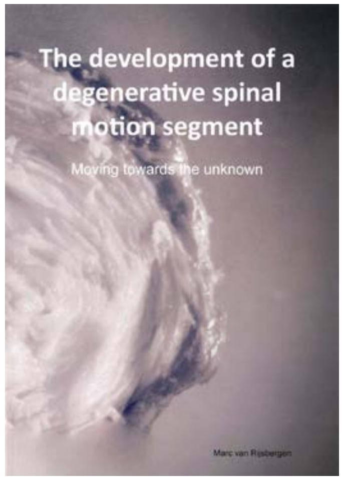
2 **Magnetic particles at fluid-fluid interfaces: microrheology, interaction, and wetting**
Stefano Cappelli

September 28, 2016
PhD advisors:
prof.dr.ir. M.W.J. Prins,
dr.ir. A.M. de Jong



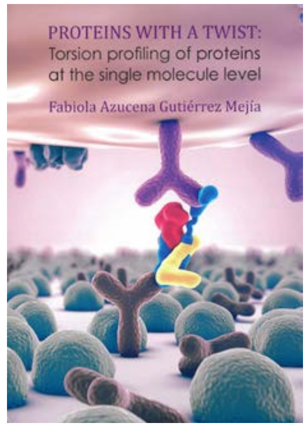
3 **The development of a degenerative spinal motion segment: Moving towards the unknown**
ir. Marc van Rijsbergen

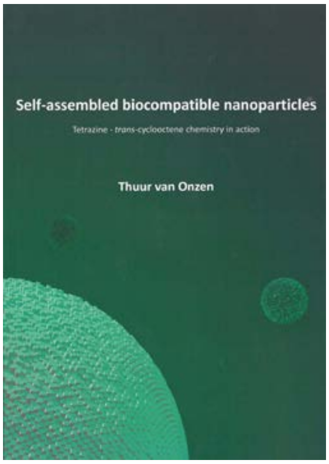
October 6, 2016
PhD advisors:
prof.dr. K. Ito,
dr.ir. B. van Rietbergen

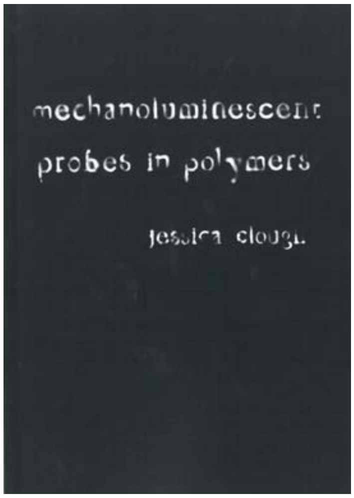


4 **Proteins with a twist: Torsion profiling of proteins at the single molecule level**
Fabiola Gutierrez Mejia

November 7, 2016
PhD advisors:
prof.dr.ir. M.W.J. Prins,
dr. L.J. van IJzendoorn







5 **Self-assembled biocompatible nanoparticles Tretrazine – trans – cyclooctene chemistry in action**
ir. Thuur van Onzen

November 9, 2016
PhD advisors:
prof.dr.ir. L. Brunsveld,
dr. L.-G. Milroy

6 **Mechanoluminescent probes in polymers**
Jessica Clough

November 15, 2016
PhD advisors:
prof.dr. R.P. Sijbesma, dr. S.C.J. Meskers

7 **Engineering protein switches for sensing and actuation**
Ir. Stijn Aper

November 16, 2016
PhD advisors:
prof.dr. M. Merkx,
dr.rer.nat. C. Ottmann

8

Notochordal cell-based regenerative therapies for intervertebral disc regeneration

ir. Stefan de Vries

November 21, 2016
PhD advisors:
prof.dr. K. Ito,
dr. M.A. Tryfonidou

9

Computational design of stents for tissue-engineered heart valve replacement

María Cabrera

November 16, 2016
PhD advisors:
prof.dr.ir. F.P.T. Baaijens,
prof.dr.ir. C.W.J. Oomens

10

A compact, ultracold atomic beam source for use in a focused ion beam

Steinar Wouters

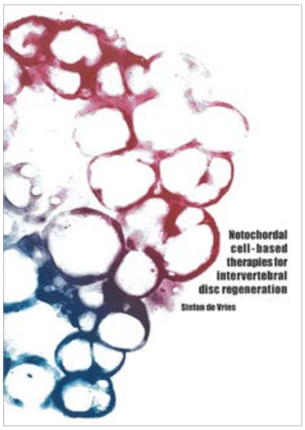
December 14, 2016
PhD advisors:
prof.dr.ir. O.J. Luiten,
dr.ir. E.J.D. Vredenbregt

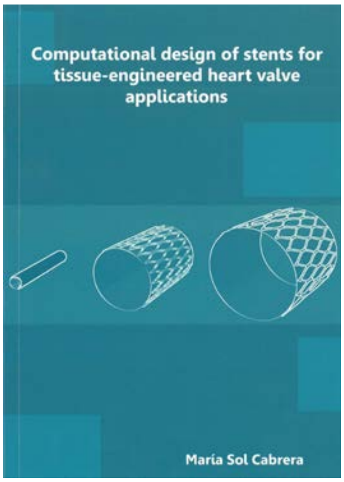
11

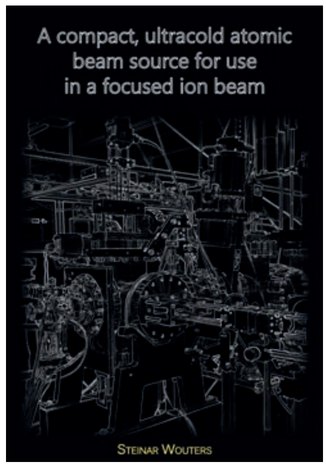
Genome-scale metabolic modelling of arabidopsis and tomato

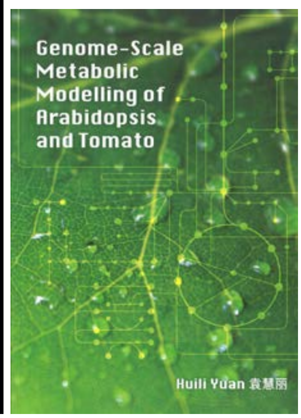
Huili Yuan

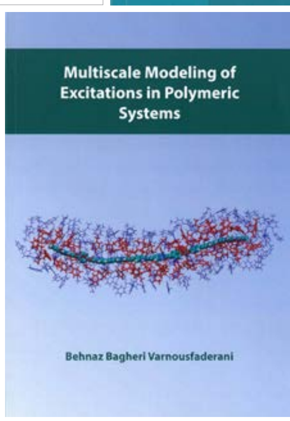
December 14, 2016
PhD advisors:
prof.dr. P.A.J. Hilbers,
prof.dr.ir. N.A.W. van Riel

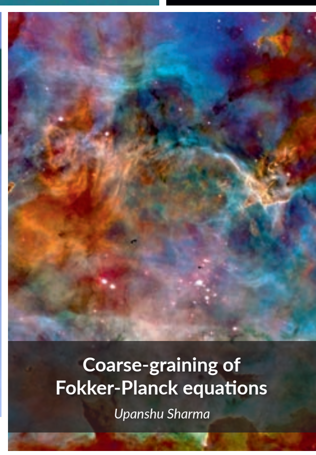


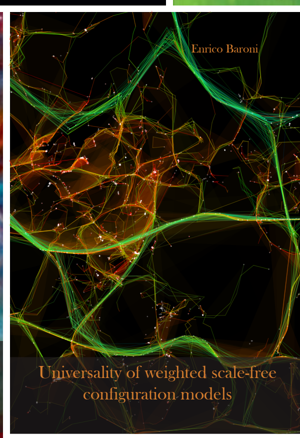












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Multiscale modeling of excitations in polymeric systems

Behnaz Bagheri Vanousfaderani

January 11, 2017
PhD advisors:
prof. dr. M.E.J. Karttunen, dr.Dipl. Phys. B. Baumeier

13

Coarse-groaning of Fokker-Planck equations

Upanshu Sharma

January 12, 2017
PhD advisors:
prof.dr. M.A. Peletier,
dr. H. Duong

14

Universality of weighted scale-free configuration models

Enrico Baroni

February 6, 2017
PhD advisors:
prof.dr. R.W. van der Hofstad,
dr. J. Komjáthy Júlia

Institute for Complex Molecular Systems

New technologies by mastering complexity

Mastering complexity requires a deep understanding on how matter – both natural and artificial – self-organizes into functional molecular systems. The Institute for Complex Molecular Systems, established in 2008, brings together mathematics, physics, biology, chemistry and engineering to stimulate education and research in this emerging field of science. Interdisciplinarity is the core of ICMS; with the input from leading specialists in different branches, new avenues are explored.

Our mission is to be a leading institute for research and education in the engineering of complex molecular systems. We do this via:

- Performing top research
- Training of talented young scientists
- Being the hotspot for interdisciplinary science activities of TU/e
- Foundation and housing of the Advanced Study Center

The scientific agenda consists of three lines of research:

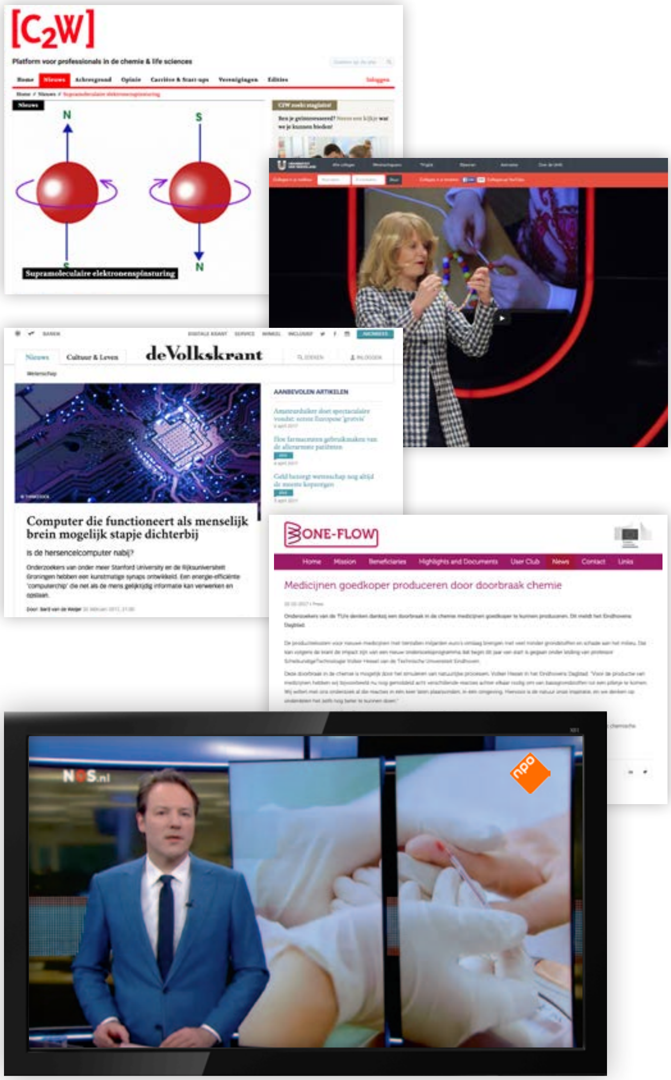
1. Functional molecular systems (program leaders prof.dr. Bert Meijer and prof.dr.ir. Jan van Hest)
2. Bio-inspired engineering (program leaders prof.dr.ir. Menno Prins and dr.dr. Patricia Dankers)
3. Complexity Hub (program leaders prof.dr. Rutger van Santen and prof.dr. Mark Peletier)

ICMS hosts the *Advanced Study Center*. This serves as an intellectual home to scientists from all over the world, hosting discussions on the theme of complexity. It is the home of *Eindhoven Multiscale Institute* (EMI) and *Eindhoven Polymer Laboratories* (EPL).

We aim at offering an ideal training environment for young students and scientists to prepare themselves for a career in science and engineering in a world of increased complexity. Therefore, master and PhD students can participate in certificate programs, in addition to their departmental programs. The relationship with industry is strengthened via the *Industrial Consortium* – where science meets innovation.

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
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Editorial staff
Carla Bouwman
(editorial assistant)

Design and print
ECHT marketingcommunicatie

Illustrations and cover
ICMS Animation Studio

Article contributions
Valentina Bonito, Odette Knappers, Esther Thole, By Barry Fitzgerald

Photography
Rien Meulman, Bart van Overbeeke Fotografie, Charlotte Grips, Cédric Huyghe

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

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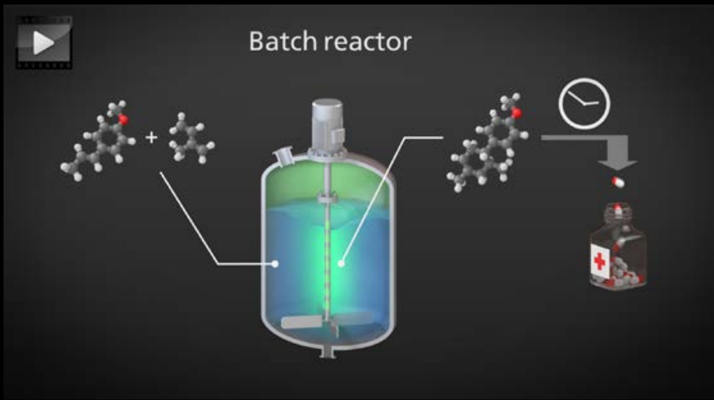

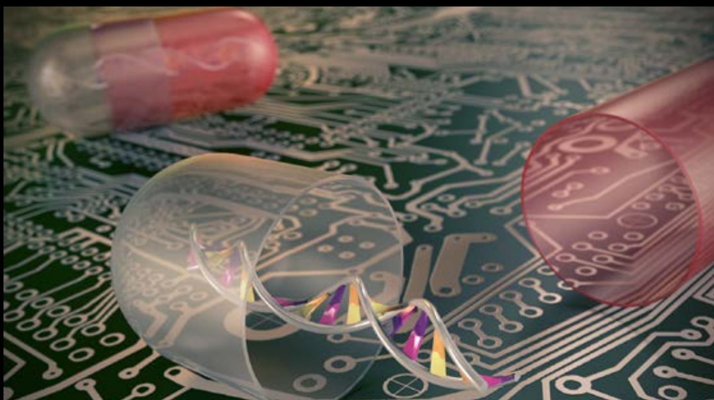

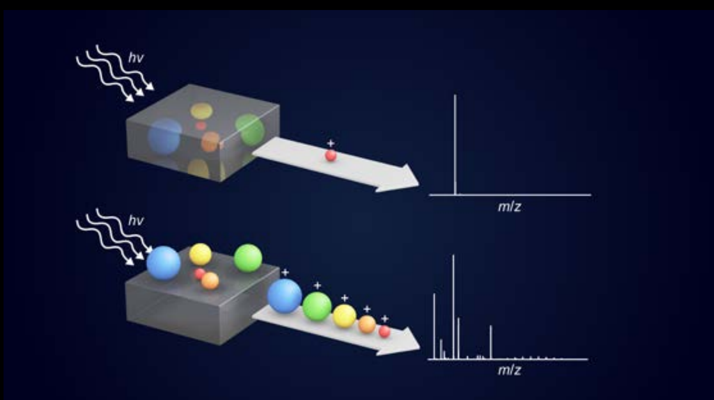

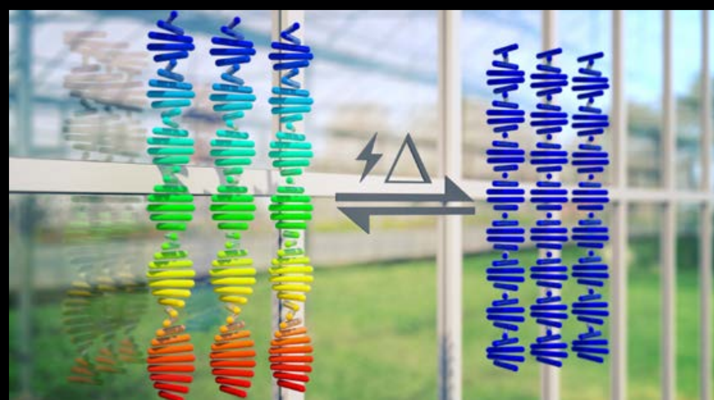

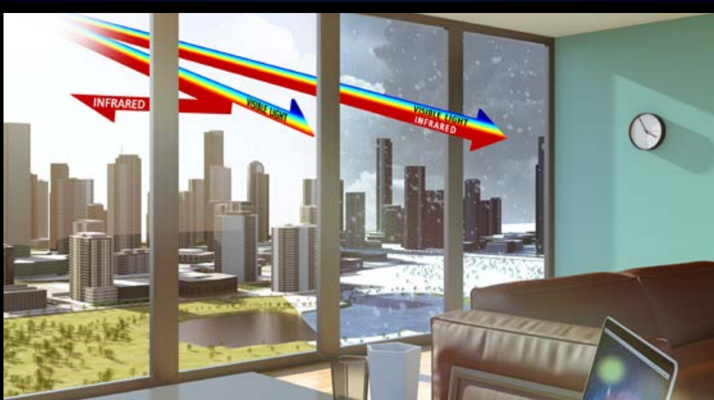

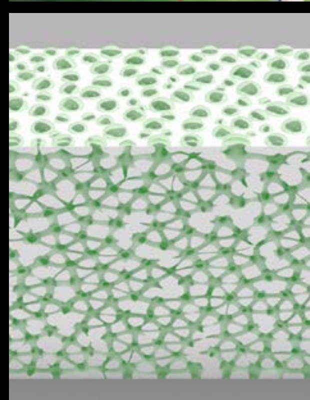

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