Dies Natalis presentations on the occasion of the 53rd Dies Natalis of the Eindhoven University of Technology, Eindhoven, 24 April 2009

Gepubliceerd: 24/04/2008

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Dies Natalis

Presentations on the occasion of the 53rd Dies Natalis of the Eindhoven University of Technology

Eindhoven, 24 April 2009
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Polymers are an integral part of our daily lives. Large-scale industrialization has served as a basis for the ubiquitous application of polymers, bringing them to people everywhere. In broader society, polymers are often synonymous with inferior quality and pollution. Today, we’ll show you that this need not be true. The polymers we make in this country are stronger than any other material mankind has ever produced, including steel. This makes polymers suitable for applications such as armor, cockpit doors, and surgical threads. Moreover, new recycling procedures make polymers reusable or biodegradable.

The polymer network

Polymers are an integral part of our daily lives. Large-scale industrialization has served as a basis for the ubiquitous application of polymers, bringing them to people everywhere. In broader society, polymers are often synonymous with inferior quality and pollution. Today, we’ll show you that this need not be true. The polymers we make in this country are stronger than any other material mankind has ever produced, including steel. This makes polymers suitable for applications such as armor, cockpit doors, and surgical threads. Moreover, new recycling procedures make polymers reusable or biodegradable.

The boundaries of such high-tech applications are constantly shifting. Polymer research faces a number of challenges. There is an increasing demand call in society for further improvement of materials. Polymers are, for example, increasingly being applied in cars, as they reduce weight and energy consumption. However, this also means we need to develop polymers with novel properties, such
as heat resistance, transparency, conductivity, etc. We need polymers that are better tunable, but also recyclable. And this goes for multiple areas of application. Moreover, we need production methods that are more energy efficient and less dependent on mineral oil.

Polymer innovation
The challenges are broad and scientifically complex, which means we need multidisciplinary research to address them appropriately. For instance, bioscience teaches us that polymers need not necessarily be made from crude oil. Today, we’ll hear that living cells and enzymes may be used to synthesize polymers. This will provide even more sustainable production processes.

Polymer industry and polymer science are highly developed in the Netherlands. Research is conducted within a close-knit network, in which a pivotal role is played by the Dutch Polymer Institute (DPI), an organization that funds exploratory research in the area of polymeric materials and plastics. As a university, we were among the parties that took the initiative to establish the DPI, together with industry associates and the Dutch government. Our aim was to bring together the scientific skills of university research groups across Europe in order to fulfill the industrial need for innovation.

About a year ago, the ambitious Polymer Innovation Program was approved, ensuring that the DPI can pursue its activities for the coming eight years. The new program will focus on the contribution of polymers to the quality of life, sustainability, and economic growth. The new program not only stimulates research and development, but also knowledge transfer by means of a separate foundation, the DPI Value Centre.

Polymer research is important for industry in our region. Specialty products, requiring advanced knowledge and skilled workers, add value to our industry. Not just in the facilities that produce them, but throughout the value chain that conceives new products, applies new polymer materials, and markets them. To ensure that our industry achieves its full potential, we must retain our position in the vanguard of knowledge acquisition and innovation in this exciting field.
“Where innovation starts” – the slogan of the Eindhoven University of Technology closely matches DSM’s strategic focus. With our products and services in Life Sciences and Materials Sciences – and increasingly at the crossroads of both – we aim to improve the quality of life. In 2010, we aim to achieve EUR 1 billion in additional innovation-related sales.

Our strategy, Vision 2010, is driven by a number of long-term societal trends relating to energy and climate change, health and wellness, globalization and increased connectivity, as well as emerging economies. These burning issues include the world’s dependency on fossil fuels, highlighting the need to seek new ways of producing energy and materials. The growing world population is another issue, driving a growing interest in the field of nutrition, addressing issues relating to obesity as well as famine. Our graying population presents other challenges, driving innovations in the field of health and wellness. At the same time, society is demanding new functionalities...
driven by the growing need for connectivity. Meanwhile, emerging economies continue to grow rapidly as economic prosperity is spread more evenly across the globe. All of these trends present DSM with abundant opportunities to help meet needs that are as yet unfulfilled. DSM’s strategy goes hand in hand with ongoing focus on sustainability. We need to work towards a world in which everyone pursues a sustainable existence. This is not only an economic necessity, but also my personal belief. We can neither achieve nor claim success in a society that fails. That is why the theme we are addressing today is so important. Where we can, DSM responds to global needs through innovation. We have a unique combination of Life Sciences on the one hand and Materials Sciences on the other. It is the cross-fertilization of these two that offers a broad spectrum of innovation opportunities. Real or radical innovation is almost always achieved through cross-fertilization. This is why polymer technology remains one of the innovative spearheads of our company.

Why polymers?
Some may perceive them as old or boring, since polymers have been around for a long time, but we should bear in mind that polymers provide the building blocks for many new and exciting innovations in existing and new applications, and that they have a huge impact on daily life. Polymers remain an area in which a great deal of innovation is possible and taking place.

DSM has developed special polymers that are very light as well as very strong. In the transport industry, low weight is crucial to ensure lower energy consumption. In fact, every improvement in polymers affects transport. You can no longer win the Tour de France on an aluminum bike, and without polymers, modern aircraft would have difficulty taking off. When vehicles weigh less, they consume less energy. And so they increasingly consist of light polymers with corrugations and other reinforcements that rival steel for strength. Particularly now, during a period of economic downturn, replacing metal to reduce weight and fuel consumption, is more important than ever. Consumers and car manufacturers alike are focusing on smaller, lighter and more efficient cars. New, tighter emission regulations will hasten this,

despite the current dire market conditions. New (DSM) polymers with high temperature stability now make it possible to apply these products under the car hood as well. Packaging is another field where polymers contribute to sustainability. Cheese is wrapped in the most high-tech material that our industry produces. The foils may have ten different layers, each with different functions to keep our food fresh. Sometimes oxygen is absorbed to prevent decay, or a modified atmosphere is maintained. That increases shelf life and reduces the amount of food that is wasted and discarded. In most Western countries, 30 to 40 percent of food is thrown away uneaten. We can feed the world, if we succeed in making food less perishable.

In the medical field, polymers also contribute to our health and wellbeing. DSM produces high-quality polymers that are used in implants. Here too, weight and strength is a key issue. The challenge is to combine this with biocompatibility and durability. You shouldn’t
have to replace artificial joints because they are worn out. That’s why innovations are needed to improve the polymers used in implants. That would also contribute to cost reduction in health care and, more importantly, the personal well-being of patients. In the past, pills were prescribed when you were unwell, then organ transplantation was developed, and soon we will be rebuilding the body, or at least parts of it, with the aid of polymers. In our Biomedical Materials group, we are already actively involved providing materials for artificial lumbar discs and joint replacements.

Polymers can also serve to protect people from harm. Our polymers can be made so strong that they may stop bullets. Their light weight makes it possible to armor cars, aircraft and personnel without compromising usability. The challenge is to improve on this unlikely combination of properties. Our Dyneema fibers, which are used to reinforce armor, have an extremely high strength-to-weight ratio. They are light enough to float on water, but have high energy absorption characteristics.

In short, polymers have an important role to play in addressing a multitude of truly global challenges: reduction of energy consumption, health and wellness, as well as safety and protection.

**Advances in polymers**

Our highly durable Dyneema fibers, which are resistant to moisture, UV light, and chemicals, are 15 times more resistant to abrasion than carbon steel. Technically, Dyneema is an ultra high molecular weight polyethylene (UHMWPE) fiber. It has extremely long chains, with hundreds of thousands of atoms in a single molecule. That makes it the strongest fiber in the world. A length of Dyneema measuring 1 mm in diameter can bear a load of up to 240 kg. Only a spider’s web has better characteristics on a weight-for-weight basis.

These kinds of products are the result of our longstanding commitment to and investment in research. And it takes patience to develop them, because a particular invention may fulfill as yet undiscovered global needs. The Dyneema fiber, for instance, was invented at DSM’s research laboratories in the late 1960s.

We patented a gel-spinning process for its manufacture in 1978. Commercial production started in 1990. This illustrates that it may take many years before a revolutionary new idea evolves into large-scale commercial practice.

We now make several grades of Dyneema fiber to serve very different needs and continue to see new application areas. One new area of application is in biomedical materials, an area in which Materials Sciences meet Life Sciences. Dyneema Purity is used to repair shoulder joints where extreme strength is needed.

Another successful material invented by DSM is Stanyl, a thermoplastic based on polyamide. It is uniquely heat-resistant, making it highly suitable for a broad range of automotive and electronic applications, where heat is often a factor. Examples include engine compartments or electronic connectors. New Stanyl types are also applied in memory card connectors and LEDs. Stanyl stands out from other materials due to its mechanical performance over the full temperature range. It is wear-resistant and has an outstanding flow in the mould, which allows it to be shaped into complicated designs.

Last year, we opened a market development plant for the first new polymer in the new millennium (!): Stanyl ForTii. This newly developed material, which is halogen free, answers market trends that call for miniaturization and convergence of electronic devices. It has an exciting and unique balance of properties that allows further miniaturization as well as higher data transfer rates in electronics. It also assists auto manufacturers and the aerospace industry in their ongoing weight-reduction efforts to achieve better fuel efficiency and lower costs.

**White biotechnology**

One of the biggest challenges in our industry is to develop polymers that don’t use fossil feedstock. In the long run, our oil reserves will be depleted and the remaining oil will become extremely expensive. That means we must find other sources. Furthermore, it seems that oil could well become obsolete as a source of new polymers. Stanyl ForTii was probably one of the last new polymers based on oil. Hardly any new polymers have been introduced over the past 10 years.

There will, however, be a new wave of polymers with new functionalities and new applications, all stemming from renewable resources. We are very well positioned to take up this challenge, as
In times of recession, it is especially important to concentrate on business that is future proof. That is why we remain fully committed to innovation and sustainability, today more than ever. In the field of polymers, innovation and sustainability go hand in hand and provide ample room for growth.

As a country we need to invest in our competencies, and this certainly includes polymers for sustainable development. In this respect, one of the most interesting journeys has only just begun.

Cooperation
We are, of course, delighted that the TU/e chose polymers as a focal point of research. It is exciting that the boundaries of our knowledge are constantly shifted in academia. This is exemplified by the work on supramolecular systems, such as conducted by Samuel Stupp, who will be honored with a doctorate honoris causa later today. But a word of warning is appropriate here: Universities should not neglect the classic disciplines, such as polymer chemistry, technology and processing. That is why we applaud the activities of the Eindhoven Polymer Laboratories (EPL), which also focuses on research closer to commercialization. We need both fundamental and applied research. We need to strike a balance between grazing and gaping.

For DSM, it is crucial to remain well rooted in the scientific fabric of our region. We need scientists and we need well-educated graduates for our industry. That is why we have decided to extend the excellent cooperation with the Dutch Polymer Institute (DPI), in which we participate together with the TU/e. We gave the go-ahead for another period of eight years. This is important to us, because we share the goals of achieving sustainable economic growth.
Without a doubt, polymer science and technology has increased almost exponentially at the TU/e campus over the past decade. The various polymer groups, spread over different departments, have found each other and cooperate in truly multidisciplinary projects that are coordinated, when necessary, by the local research school Eindhoven Polymer Laboratories (EPL).

Polymers have a low density, ease of processing and shaping, possibilities of functional integration, and an almost unlimited flexibility in molecular design. Moreover, polymers are generally relatively cheap, which makes them very different from most other materials we use to shape our world. These characteristics make polymers very useful for protection, insulation, transportation, communication, illumination, packaging, housing, furniture, clothing etc. There is a great demand for improved polymer systems in these application areas. This sets the focus for scientific research at EPL and elsewhere.

Han Meijer is full professor of Polymer Technology and scientific director of Eindhoven Polymer Laboratories (EPL). Born and educated in Amsterdam, he went on to obtain his PhD from the University of Twente in 1980. He then joined DSM Research and, in 1985, was appointed part-time professor at the department of Polymer Chemistry and Technology of the TU/e in the field of applied rheology. Since 1989, he has been full professor of polymer technology at the department of Mechanical Engineering. His present interests include structure development during flow and structure-property relations, micro-rheology and microfluidics, micro-macro-mechanics, modeling of polymer processing, and design in polymers. And the America’s Cup yacht race.
We recently redefined the focal points of research as follows:
1. Complex molecular systems;
2. Functional polymers and devices;
3. Multi-scale modeling and advanced characterization.

The first area seeks to establish how complex molecular systems form by self-organization and function, partly mimicking nature and life. The second area investigates how useful advanced devices can be made out of complex, usually functional, polymers. The third area addresses questions concerning our understanding of polymers and polymer systems.

Dutch Polymer Institute

The Dutch Polymer Institute (DPI) supports our research in Eindhoven with roughly 50% of its budget. The DPI is a public-private organization with a mission to stimulate university research with industrial relevance. It has defined a possible fourth area of focus, namely materials design and engineering. This reflects the industrial need to design and engineer new polymer materials, partly based on bio-based renewable resources.

Naturally, many research projects cross the boundaries between these areas of focus. Good cooperation with other disciplines is guaranteed by cross-appointments of various key experts in these fields.

We currently have 210 researchers at EPL, comprising 45 tenured staff, who direct temporary staff including 45 post-docs and 120 PhD students. Over the past seven years, the period in which EPL was officially recognized by The Royal Netherlands Academy of Arts and Sciences (KNAW), we produced 189 dissertations and 1,949 publications, with the aid of external funding of EUR 62.6 million in total. This amounts to an average of 27 dissertations and 280 publications a year. Our annual external funding of EUR 9 million is provided by the National Science Foundation NWO (30%), the Dutch Ministry of Economic Affairs (30%), industry (15%), and the European Community (10%). The remaining 15% is covered by matching funds from the university.

TU/e boasts a phenomenal and unrivaled range of polymer research. Moreover, the quality of research is well above average, with all EPL groups achieving excellent scores in successive international research assessments. Our work has far-reaching impact and is extensively cited in scientific publications.

Disposable bioreactor

The standard of some of our research is exemplified by the disposable bioreactor that we designed and realized in cooperation with the department of Biomedical Engineering. Tissue engineering of autologous heart valves is based on a patient’s own stem cells, taken from his or her bone marrow. This research work is carried out by Frank Baaijens’ group at the department of Biomedical Engineering. To specialize the cells into a heart muscle, mechanical stimulation is required during formation and growth. Patient-specific heart valves take about four weeks to grow on a biodegradable polymer. During that period, the growing cells gradually adopt the shape and function of the polymer.

If the development of this tissue engineering is going to be successful,
the process has to be scaled up dramatically. Worldwide, about 250,000 valve transplantations are performed every year. Per patient, three valves must be grown, the best of which are implanted. That means there is clearly a need for flexible, integrated, cheap and disposable bioreactors.

We have realized a design that exploits the capability to mold two components into a single product, combining rigid and soft polymers. The rigid polymer forms the body of the reactor, in which a scaffold is placed and to which tubing is connected. The soft polymer constitutes the flexible membranes and steering valves that control the fluid during fabrication and testing of the heart valves. This is done under non-fouling, non-contaminating, sterile conditions.

**Microfluidic reactor**

As a sequel to this bioreactor, we have designed a microfluidics reactor. In this project, we have combined hard and soft polymers on a smaller scale, allowing for miniaturization while maintaining integration and function.

A microfluidic reactor not only requires channels through which fluids flow, but also a well-defined mixing operation. Mixing is important for fast heating and cooling, for controlled start of a reaction by adding components, but also for reaction quenching, for example by washing. Reynolds numbers are low and Péclet numbers are high in small channels, so mixing is realized through chaotic advection. This means the Baker’s transformation is the preferable way to go. We have designed and realized a splitting and recombining serpentine micromixer that almost perfectly mimics this transformation. This opens routes to control the start of reactions, but also the sequencing.

Moreover, miniaturization allows the integration of multiple reactors in a single device. In the prototype design, we can combine up to five different fluids that are pumped using the peristaltic motion of a sequence of flexible steering valves, actuated by a number of tiny linear motors. The first goal is the precise step-by-step synthesis of oligomers like peptides. This will be realized in the near future in the Institute of Complex Molecular Systems (ICMS) headed by professor Bert Meijer.
Creating a renewable source of clean energy is a prime challenge of today’s society. With 100,000 terawatts of sunlight reaching the earth, the potential of solar energy exceeds by several orders of magnitude the requirements of the global population, which will amount to around 20 terawatts in 2050. The energy efficiency with which photovoltaic solar cells directly convert sunlight into electricity exceeds that of other technologies involving biomass, wind or hydroelectric power. In line with this high potential, the photovoltaic market is growing 30-40% annually and is likely to become one of the largest industrial activities worldwide this century.

Obstacles to the widespread introduction of this technology include the cost of materials and production speed. That is why there is a strong drive towards thin-film technologies in photovoltaic research, which is likely to reduce these obstacles. In this regard, polymer solar cells are particularly attractive, because they can reach favorable efficiencies and can be printed in roll-to-roll processes at very high...
speeds, possibly exceeding the throughput of any other technology by far. The prospect that lightweight and flexible polymer solar cells can be produced at high speed, in combination with high energy-conversion efficiency, has spurred interests from academia, research institutes and companies. As power conversion efficiency has improved, the field of polymer solar cells has, over the past decade, progressed from being a scientific curiosity to the point where it is now on the brink of becoming a breakthrough technology for the future.

**Innovation**

The Netherlands has a prominent international position in this area and has contributed significantly to salient improvements in fundamental knowledge, new materials, device architectures, and technology aspects that are moving this area forward at high speed. Comprehensive insight has been gained into crucial materials parameters, including morphology, energy levels, charge transport, and electrode materials. Although there is growing evidence that polymer solar cells may achieve their full potential in future, as sketched above, not all of the attractive properties have yet materialized. New innovations and further scientific insight are required.

At present, state-of-the-art polymer solar cells can achieve power conversion efficiencies of about 6%. Projected efficiencies of 10-12% are within reach and it is expected that efficiency will be even higher in future, when multi-junction solar cells can be employed.

By combining synthesis, processing, and materials science with device physics and fabrication, there is little doubt that these attractive performance levels will be achieved in the near future. To understand these challenges, one requires fairly detailed insight into the underlying operational principles. Polymer solar cells employ a nanoscopic phase separation or bulk heterojunction between two complementary molecular-based polymer semiconductors to convert sunlight directly into electricity. Their operation relies on a photoinduced electron transfer reaction at the interface of the two semiconductors in a process that mimics natural photosynthesis. Following this event, charges must escape from recombination, separate spatially, migrate to the appropriate electrodes, and finally be collected. Each of these processes poses intriguing scientific questions and exciting challenges to materials design. The nanoscale morphology of the intermixing between the two components plays a vital role in this complex sequence of events.

The power conversion efficiency of polymer solar cells depends critically on the quantum efficiency of photon to electron conversion that determines the current and the potential energy efficiency, which determines how much of the initial photon energy is preserved at the operating voltage of the cell.

**Spectroscopy**

Ultrafast spectroscopy studies have clearly established that charge generation can occur within a few tens of femtoseconds. Hence, after absorption of a photon, charge generation can occur with 100% yield. One of the crucial questions is: what happens to the charges after they have been generated? The low dielectric constant of
organic materials creates an energy barrier for charge separation that exceeds the thermal energy. Presently, it is not understood in detail how photogenerated charges escape from the interface where they were created and how they avoid geminate recombination. One of the current hypotheses is that the energy gained in the electron transfer reaction, or excess energy, is used to enable charge separation from the interface. The minimal amount of excess energy needed for full charge separation has direct consequences for the maximum efficiency that can be attained, because it represents a loss factor. Further gain in device performance can be expected by developing materials that create free charges in high yield with minimal energy losses.

Recently, the first multi-junction solar cells, comprising fully solution-processed, transparent intermediate contacts, were demonstrated as a new technology. The novel intermediate contact used in these cells serves to collect electrons generated in the front cell, so that they can be recombined with the gaps created in the back cell, thus closing the circuit. The advantage of a tandem cell – and of multi-junction cells in general – is that photon energy can be collected more efficiently.

In conclusion, by combining synthesis, processing and materials science with device physics and new fabrication technologies, the field of polymer solar cells has made significant progress in recent years, creating a realistic technology platform for abundant, clean energy in the future.
Samuel Stupp seeks to unravel the challenges that abound in the area of complex molecular systems and biomedical engineering. These challenges go beyond the boundaries of traditional chemistry. For more than a hundred years, chemists have focused on the synthesis and properties of molecules. More recently, however, it has become clear that molecules only possess useful functions in complex interplay with the surrounding matter. This insight bridges the gap between material science and chemistry. Sam Stupp was and is a pioneer in the field of molecular nanoscience and technology. He is uniquely skilled in converting novel scientific breakthroughs into useful applications.

Prof. dr. S.I. Stupp
Board of Trustees’ Professor of Materials Science, Chemistry & Medicine at Northwestern University, Illinois, USA

Honorary doctorate awarded to prof. dr. S.I. Stupp
Presented by prof. dr. E.W. Meijer

Honorary Doctorate

Samuel Stupp seeks to unravel the challenges that abound in the area of complex molecular systems and biomedical engineering. These challenges go beyond the boundaries of traditional chemistry. For more than a hundred years, chemists have focused on the synthesis and properties of molecules. More recently, however, it has become clear that molecules only possess useful functions in complex interplay with the surrounding matter. This insight bridges the gap between material science and chemistry. Sam Stupp was and is a pioneer in the field of molecular nanoscience and technology. He is uniquely skilled in converting novel scientific breakthroughs into useful applications.
Materials with Supramolecular Complexity: Potential Impact on Humans

Sam Stupp is a specialist in the area of molecular self-assembly – the concept of building functional systems using a bottom-up approach, arranging weak interactions between molecules in such a way that the molecules organize themselves into functional systems. This allows complex molecular structures to be created, which would be difficult to produce with a traditional top-down approach. The most sophisticated polymeric materials in electronics, energy or medicine rely on the self-assembly of individual molecular building blocks. This development has only just begun, but many new materials based on self-assembly are emerging from laboratories. Detailed insight into the different mechanisms of self-assembly is crucial to achieve progress in this area.

Biomedical technology is exploring highly intriguing applications for these new materials. In our bodies, artificial synthetic materials will be in direct contact with biological tissue. To be useful, the new materials have to be biocompatible and bioactive at the same time, which means that properties so characteristic of natural materials must be incorporated into these artificial materials.

Sam Stupp’s research group contributes in an unprecedented way to this field by combining knowledge in materials science, chemistry and self-assembly.

The group identified a set of molecules that combine the amphiphilic character of membranes with the bioactivity of oligopeptides. Once injected into tissue, the molecules form a gel in which the bioactive component triggers cell growth, yielding a profound biological response. More recently, the group reported on a system with two components, a long polymer and the small oligopeptide amphiphile. Upon mixing the two, the molecules self-arrange into a flexible and strong sac in which you can grow human stem cells. The sac could be used as a vehicle for cell therapy. Traveling through the body, this sac protects the new stem cells from the human body’s immune system. Upon arrival, the sac biodegrades, releasing the stem cells to do their work. This is not yet a clinical reality, but the highly innovative work of Samuel Stupp brings us closer to the application of this high-tech biomedical technology.

Similarly, the Eindhoven University of Technology is investing significantly in polymers, self-assembly, complex molecular systems, and highly advanced biomaterials for tissue engineering, with research groups in many departments, including the department of Biomedical Engineering and the Institute for Complex Molecular Systems. The research groups in Eindhoven are using their strategies to fulfill related but different goals. However, they share Sam Stupp’s conviction that control over self-assembly and self-organization will lead to unprecedented opportunities. Samuel Stupp has stated that “advancements in biology and engineering, coupled with the emerging areas of nanoscience and nanotechnology, have the potential to profoundly enhance human health and revolutionize the way medicine is practiced.” We fully agree with his far-ranging vision and sincerely hope his wish will be fulfilled.

Career

Samuel Stupp obtained his BSc at the University of California in Los Angeles and his PhD in Material Science & Engineering at Northwestern University in 1977. From 1980 through 1999, he was professor at the University of Illinois at Urbana-Champaign. In 1999, Stupp returned to his alma mater, Northwestern University, where he is also director of the Institute of BioNanotechnology in Medicine. During his career, he held many distinguished visiting professorships and received numerous prestigious awards, including the ACS Award for Polymer Chemistry in 2005, the MRS Medal Award in 2000, and the Humboldt Award in 1997.

It gives us great pleasure to award professor Stupp an honorary doctorate from our university, in recognition of his outstanding achievements in science and engineering. He is an acknowledged leader in the rapidly advancing fields of nanoscience and molecular self-assembly. Particularly, we honor him for his revolutionary research in soft matter and applications for complex molecular systems in biomedical technology. The Eindhoven University of Technology is proud to add Samuel Stupp’s name to its list of honorary doctorates.
Imprint

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Editor: Bram Vermeer Journalistiek
Design: vanRixtelvanderPut ontwerpers
Photography: Bart van Overbeeke, Aatjan Renders and Rob Stork
Print: Drukkerij Lecturis