Karlsruhe Institute of Technology

3D MATTER MADE TO ORDER

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

Future 3D Additive Manufacturing | The 3DMM2O Conference

3D Nano- and Micro-Manufacturing:

Technology and Technical Applications

Abstract Booklet

April 3 – 8, 2022

Schöntal Monastery, Germany

Welcome

Dear Colleagues and Friends,

It is our great pleasure to welcome you to the **Future 3D Additive Manufacturing – The 3DMM2O Conference 2022: 3D Nano- and Micro-Manufacturing: Technology and Technical Applications.**

This is the second iteration of the annual conference on topics surrounding 3D Additive Manufacturing organized by the Cluster of Excellence 3D Matter Made to Order (3DMM2O), a joint Research Cluster of Karlsruhe Institute of Technology (KIT) and Heidelberg University (Uni HD).

The conference aims at providing the latest research developments and future trends in 3D nano- and micro-manufacturing technologies as well as applications in research and industry based thereupon.

Lectures by international speakers, poster sessions and social networking events will give you an insight in alternating apects of 3D Additive Manufacturing as well as the opportunity for inspiring and fruitful scientific discussions and exchange.

Eva Blasco
Heidelberg University

Gerardo Hernández-Sosa
Karlsruhe Institute of Technology

Christine Selhuber-Unkel
Heidelberg University

Martin Wegener
Karlsruhe Institute of Technology

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10:00 – 10:10 AM	Innovations in 2PP-Based 3D Printing Open Up New Horizons in Research and Industry	**Martin Hermatschweiler**
10:10 – 10:45 AM	*Coffee Break*	
10:45 – 11:30 AM	Dynamic Functional Photoresists for Light Driven Additive Manufacturing	**Christopher Barner-Kowollik**
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10:15 – 10:45 AM	Coffee Break	
10:45 – 11:45 AM	3D Printing of Bioinspired Materials	**André Studart**
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1:30 – 2:30 PM	Biofabrication Using Spider Silk Proteins	**Thomas Scheibel**
2:30 – 3:15 PM	3D Direct Laser Writing in Synthetic Cells	**Kerstin Göpfrich**
3:15 – 3:35 PM	Selected Talk: 3D Extrusion Printing of Smart Biocompatible Inks for Bioengineering Applications	**Veronika Magdanz**
3:35 – 4:00 PM	*Coffee Break*	
4:00 – 5:00 PM	Efficient, Compact, Complex Hardware Via Additive Manufacturing	**Luis Fernando Velásquez-García**
5:00 – 5:20 PM	Selected Talk: *In-Situ* Material Replacement for Efficient High-Resolution Multi-Material 3D Laser Printing	**Robert Kirchner**
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Friday, April 8

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9:00 – 10:00 AM	Volumetric Printing by Reverse Tomographic Projections in Non Transparent Resins	**Christophe Moser**
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10:30 – 11:15 AM	Logic and Memory Devices Realized by 2D/3D Printing of Functional Materials	**Jasmin Aghassi-Hagmann**
11:15 – 12:00 PM	Exploring Small β-Sheet Protein Folding Motifs as a Model System for the Design of Miniaturized Proteins	**Franziska Thomas**
12:00 – 12:45 PM	Nanophotonic Devices by Inkjet Printing	**Uli Lemmer**
12:45 – 1:00 PM	Best Poster Award & Farewell	
1:00 – 1:45 PM	*Lunch I*	
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	Departure	

Speakers'

Monday, 04.04.
1:30 – 2:30 PM

Prof. Dr. Rainer Adelung

Institute for Materials Science

Kiel University, Germany

3D PRINTED ORGANIC-INORGANIC AND NANO-MACRO SCALE HYBRIDS FOR SENSOR AND BIOMEDICAL APPLICATIONS

Remaining challenges in additive manufacturing are still the combination of various material classes like metals, semiconductors, ceramics and organic materials ranging from graphene to biological tissue. Furthermore, combining macroscopic devices with nanoscale precision structuring with macroscopically expanded applications and devices is another challenge. These demanding combinations are required by many applications in different fields that demand a high amount of functionality, e.g. for sensor applications or biomedical engineering. The presentation covers beside recent developments some solution ideas to these challenges by introducing 3D printed devices and application examples. As demonstrators for sensors, chemiresistive sensor arrays that employ semiconductor nanoscale features in microscopic devices[1] and sensors for diabetes detection [2] based on acetone sensing in ppm levels by printing mixed semiconductor oxides[2]. To illustrate applications on the biomedical side where, e.g., nanoscale protein structures, hydrogels and semiconductors are combined, a 3D printed smart wound scaffold with a light triggered growth factor release and antibacterial activity is explained and shown[3].

[1] L. Siebert et al., ACS Appl. Mater. Interfaces 11, 25508 (2019)
[2] L. Siebert et al., Nano Energy 70, 104420 (2020)
[3] L. Siebert et al., Advanced functional Materials 31, 2007555 (2021)

Abstracts

In Alphabetical Order

Friday, 08.04.
10:30 – 11:15 AM

Prof. Dr. Jasmin Aghassi-Hagmann

Institute of Nanotechnology (INT)

Karlsruhe Institute of Technology, Germany

LOGIC AND MEMORY DEVICES REALIZED BY 2D/3D PRINTING OF FUNCTIONAL MATERIALS

The talk will give an introduction into device fabrication and electrical characterization of inkjet-printed passive and active devices including electrolyte-gated transistors based on indium oxide semiconductors[1,2], diodes and memristors.

Voltage dependent impedance spectroscopy as well as low frequency noise characteristics[3] of electrolyte-gated transistors will be discussed and correlated to the dynamic device performance and electronic transport properties.

In addition, memory devices such as resistive switching devices based on Ag/ZnO/Au sandwich structures[4] which reveal high ON/OFF ratios up to 10^7, excellent retention behavior exceeding 10^4 seconds and no obvious degradation after 50 switching cycles at low operation voltage around 1V will be discussed.

These features and the ability to form logic and memory devices renders the technology useful for low-noise applications such as sensor periphery circuits.

[1] Progress Report on "From Printed Electrolyte-Gated Metal-Oxide Devices to Circuits", Cadilha Marques, G.; Weller, D.; Erozan, A. T.; Feng, X.; Tahoori, M.; Aghassi-Hagmann, J., 2019. Advanced materials, 31 (26), Article no: 1806483. doi:10.1002/adma.201806483
[2] Hybrid low-voltage physical unclonable function based on inkjet-printed metal-oxide transistors, Scholz, A.; Zimmermann, L.; Gengenbach, U.; Koker, L.; Chen, Z.; Hahn, H.; Sikora, A.; Tahoori, M. B.; Aghassi-Hagmann, J., 2020. Nature Communications, 11 (1), Art.-Nr. 5543. doi:10.1038/s41467-020-19324-5
[3] Low-frequency Noise Characteristics of Inkjet-Printed Electrolyte-gated Thin-Film Transistors, Feng, X.; Singaraju, S. A.; Hu, H.; Marques, G. C.; Fu, T.; Baumgartner, P.; Secker, D.; Tahoori, M. B.; Aghassi-Hagmann, J.2021. IEEE Electron Device Letters. doi:10.1109/LED.2021.3072000
[4] Inkjet-printed bipolar resistive switching device based on Ag/ZnO/Au structure, Hongrong Hu, Alexander Scholz, Surya Singaraju, Yushu Tang, Gabriel Cadilha Marques, and Jasmin Aghassi-Hagmann, submitted

Speakers'

Wednesday, 06.04.
10:45 – 11:30 AM

Prof. Dr. Christopher Barner-Kowollik

Queensland University of Technology, Australia

(Karlsruhe Institute of Technology, Germany)

DYNAMIC FUNCTIONAL PHOTORESISTS FOR LIGHT DRIVEN ADDITIVE MANUFACTURING

The lecture will provide an overview of our most recent results in the realm of designing photoresist that feature advanced properties after being printed via two photon 3D laser lithography or one photon printing techniques.

The properties particularly include post-printing adaptability as well as degradability by various outer stimuli – including by the mildest trigger of all, darkness. A particular emphasis will be placed on illustrating the advanced photochemical concepts that drive modern resist design and how they interface with specific applications.

Maria Farsari, Ph.D.

Institute of Electronic Structure and Laser

IESL-FORTH, Greece

LASER-BASED ADDITIVE MICROMANUFACTURING FOR CELL GROWTH

A critical component for successfully engineering complex 3D tissue from a cell source is the production and utilisation of the appropriate 3D scaffold. Indeed, cells seeded on a flat surface grow typically in a monolayer fashion, while 3D cell cultures can only be achieved via their growth in a 3D micro-environment. The success of these scaffolds in their use for tissue engineering is critically dependent on their mechanical and surface properties, and microstructure.

In this seminar, I will present our latest results into combining laser-based additive manufacturing, mechanical metamaterials, and novel photopolymers, attempting to address some major tissue engineering challenges.

Tuesday, 05.04.
9:15 – 10:15 AM

Larisa Florea, Ph.D., Assistant Professor

Trinity College, Dublin, Ireland

4D MICRO-STRUCTURES – FUNCTIONALITY WITH A SPLASH OF COLOUR

Direct laser writing (DLW) by multi-photon polymerisation represents an attractive route towards the creation of 3D assemblies from a wide range of materials.

This talk will focus on the use of soft polymers and responsive materials for the realisation of 4D micro-structures that can respond to external stimulation, actuate on demand, and sense and report on their local chemical environment. Inspired by nature's structurally coloured materials, we recreate the vividness of natural structural colouration via DLW in responsive polymer systems.

The presence of the soft stimuli-responsive matrix enables us to accurately modulate the perceived colour across the visible and NIR range, in response to light, temperature, humidity, and chemical environment.

Dr. Kerstin Göpfrich

Max Planck Institute for Medical Research

Heidelberg University, Germany

3D DIRECT LASER WRITING IN SYNTHETIC CELLS

Towards the ambitious goal of manufacturing synthetic cells from the bottom up, various cellular components have already been reconstituted inside of lipid vesicles. However, once encapsulated, the positoning of these components is challenging.

Here, by using two-photon 3D laser printing, 2D and 3D hydrogel architectures were manufactured with high precision and nearly arbitrary shape inside of preformed giant unilamellar lipid vesicles (GUVs). The required water-soluble photoresist is brought into the GUVs by diffusion in a single mixing step. Crucially, femtosecond two-photon printing inside the compartment does not destroy the GUVs.

Beyond this proof-of-principle demonstration, early functional architectures were realized. In particular, a transmembrane structure acting as a pore was 3D printed, thereby allowing for the transport of biological cargo, including DNA, into the synthetic compartment. Furthermore, we attempt to develop new types of photoresists alongside DNA-based architectures, with which we can realize more complex functions inside of synthetic cells.

These experiments show that two-photon 3D laser microprinting can be an important addition to the existing toolbox of synthetic biology.

Referenz: https://onlinelibrary.wiley.com/doi/abs/10.1002/adma.202106709

Tuesday, 05.04.
10:45 – 11:45 AM

Maria Guix, Ph.D.

Institute of Bioengineering of Catalonia, Spain

BRINGING COLOR AND LIFE TO 3D ROBOTICS

One of the main challenges in the field of synthetic and biological microrobots is the development of robust control systems to achieve the desired guidance and/or actuation[1]. Reaching full automation, where the robot' path and actuation are predetermined and programmed, is still one of the main challenges in the micro and nanomotors' community. By integrating colored tracking fiducials in the micrometric robot' body, it is possible to develop less computationally expensive color-based tracking algorithm, even providing real-time data to the end user for finer robot control[2].

By using 3D printing techniques, we achieved the integration of structural color in micrometric robotic systems, obtaining well-defined features with vivid colors useful for vision-based algorithms and non-toxic[3]. This fabrication approach is of great interest for its potential scale-up in other robotic platforms for automation purposes, as well as for improved manipulation in tissue engineering applications and mechanobiology studies.

On the other hand, the integration of cells in robotic systems can directly provide some of the desired capabilities inherent to such living entities, including self-healing, energy efficiency, high power-to-weight ratio, adaptability, or bio-sensing capabilities[4]. We develop a millimeter-sized skeletal-muscle based biobot with an integrated compliant skeleton based on a 3D-printed serpentine spring[5].

Such configuration not only provides mechanical integrity to the bio-derived system, but also self-stimulation in absence of any external electrical input, useful for training purposes to achieve an increased force output. Simulations of the mechanical properties to obtain the optimal geometrical stiffness were carried out.

Also, mechanical self-stimulation allows to control a defined self-assembly geometry of the cell-laden scaffold, useful to explore new living robot configurations.

The versatility of 3D printing techniques provides a useful toolbox to develop robotic systems, allowing not only an easy integration of distinctive elements for control purposes, but also the fabrication of dynamic elements with self-training capabilities that when combined with 3D cell-laden scaffold they result in more advanced and highly functional robotic platforms.

[1] Guix, M., Mayorga-Martinez, C. C., Merkoçi, A. (2014) Chem. Rev., 114, 6285−6322.
[2] Guix, M., Wang, J., An, Z., Adam, G., Cappelleri, D. J. (2018) IEEE Robot. Autom. Lett., 3, 3591-3597.
[3] Koepele, C. A., Guix, M., Bi, C., Adam, G., Cappelleri, D. J. (2020) Adv. Intell. Syst, 2, 1900147.
[4] Appiah, C., Arndt, C., Siemsen, K., Heitmann, A., Staubitz, A., Selhuber-Unkel, C. (2019) Adv. Mater. 31, 1807747.
[5] Guix, M., Mestre, R. Patiño, T., De Corato, M., Fuentes, J., Zarpellon, G., Sánchez, S. (2021) Sci. Robot. 6, eabe7577.
[6] Mestre, R., Patiño, T., Barceló, X., Anand, S. Pérez-Jiménez, A., Sánchez, A. (2019) Adv. Mater. Technol. 4, 1800631.

Monday, 04.04.
9:15 – 10:15 AM

Richard Hague, Ph.D., Professor

University of Nottingham, United Kingdom

ADDITIVE MANUFACTURING 2.0: MOVING BEYOND GEOMETRY FOR THE PRINTING OF FUNCTIONAL, MULTI-MATERIAL PRODUCTS

Though capable of tremendous geometrical design freedoms, conventional Additive Manufacturing (AM) is mainly restricted to "passive", structural components. This presentation will overview the emerging area of "multifunctional" AM, where multiple materials are co-deposited to enable the move beyond geometry, thereby enabling the printing of complex, functionalized, "active" printed devices.

The talk will detail the ongoing work within the Centre for Additive Manufacturing (CfAM) at the University of Nottingham where significant research efforts into next-generation, multifunctional AM is being undertaken. Principally funded by EPSRC and working with key industry, this research is exploiting novel techniques for the co-deposition of both structural and functional materials for electronic, pharmaceutical and biological structures and devices over varying length scales.

Prof. Dr. Uli Lemmer

Light Technology Institute & Institute of Microstructure Technology, Germany

Karlsruhe Institute of Technology

NANOPHOTONIC DEVICES BY INKJET PRINTING

Inkjet printing (IJP) is a versatile method for additive manufacturing of electronic and optoelectronic devices with a typical spatial resolution on the order of 30 microns. For realizing photonic nanostructures using this approach, the deposited materials have to be controlled on a subwavelength length scale. Here, we demonstrate that this can be realized, both, in vertical and in lateral direction.

Using the spontaneous phase-separation of two polymers from a common ink, we realize quasi-periodic and disordered assemblies of light scatterers. The phase separated nanostructures feature sizes that can be tuned from a few microns down to the sub-100 nm level. Applications are in the field of photonic sensors and optoelectronic thin film devices.

An even more precise control is necessary for realizing one-dimensional photonic crystals (dielectric mirrors) by IJP. Such an approach enables digitally controlled dielectric mirror pixels for various opto-electronic applications.

Speakers'

Tuesday, 05.04.
1:30 – 2:15 PM

Prof. Dr. Pavel Levkin

Institute of Biological and Chemical Systems

Karlsruhe Institute of Technology, Germany

3D PRINTING OF INHERENTLY NANOPOROUS POLYMERS VIA POLYMERIZATION-INDUCED PHASE SEPARATION: PROPERTIES AND APPLICATIONS

3D printing offers enormous flexibility in fabrication of polymer objects with complex geometries. However, it is not suitable for fabricating large polymer structures with geometrical features at the sub-micrometer scale. Porous structure at the sub-micrometer scale can render macroscopic objects with unique properties, including similarities with biological interfaces, permeability, special wettability and extremely large surface area, imperative inter alia for adsorption, separation, sensing or biomedical applications.

Here, we introduce a method combining advantages of 3D printing via digital light processing and polymerization-induced phase separation, which enables formation of 3D polymer structures of digitally defined macroscopic geometry with controllable inherent porosity at the sub-micrometer scale. We demonstrate the possibility to create 3D polymer structures of highly complex geometries and spatially controlled pore sizes from 10 nm to 1000 µm. Produced hierarchical polymers combining nanoporosity with micrometer-sized pores demonstrate improved adsorption performance due to better pore accessibility and favored cell adhesion and growth for 3D cell culture due to surface porosity.

This method extends the scope of applications of 3D printing to hierarchical inherently porous 3D objects combining structural features ranging from 10 nm up to cm, making them available for a wide variety of applications.

Mangirdas Malinauskas, Ph.D.

Group of Nanophotonics, Laser Research Center, Physics Faculty,

Vilnius University, Lithuania

MESOSCALE LASER 3D PRINTING: FROM RENEWABLE PLANT-BASED RESINS TO CRYSTALLINE INORGANICS

An ultrafast laser mesoscale lithography will be presented rediscovering underlying photo-physio-chemical reactions determining its technical applications. A current progress in state-of-the-art and potential in 3D as well as 4D printing of diverse materials ranging from biocompatible, biodegradable and renewable organics to amorphous, ceramic and crystalline inorganics will be covered.

Technology's applications towards prototyping and producing bio-medical implants, micro-optical and nano-photonic components as well as creating micro-fluidic sensors will be shown. A special emphasis on the development and applications of microfabricated structures for life-sciences will be given, namely customization of laser direct write lithography-made 3D scaffolds for optimized *in vivo* outcome. Furthermore, the possibility to employ the technique for precision additive manufacturing out of plant-based resins and pure inorganics will be demonstrated.

Finally, some unique functional properties of selected prototypes will be provided in detail validating their high efficiency performance and resiliency under harsh conditions.

Monday, 04.04.
10:45 – 11:45 AM

Shoji Maruo, Ph.D., Professor

Yokohama National University in Tokyo, Japan

MULTI-MATERIAL MICRO-STEREOLITHOGRAPHY USING MULTIPLE DROPLETS OF PHOTOCURABLE MATERIALS

In recent years, multi-material additive manufacturing has attracted attention as a method for the integrated manufacture of highly functional devices. Several micro-stereolithography techniques have been demonstrated to fabricate micro-scale multi-material 3D structures using one-photon or two-photon polymerization. Multi-material micro-stereolithography methods can be classified as microfluidic, tank-based and droplet-based methods with respect to the material exchange method.

The droplet-based method has the advantage of easy material exchange and low material wastage during exchange. In this talk, I will introduce lab-made multi-material micro-stereolithography systems using multiple droplets of photocurable materials. Using the single-photon system, multi-color polymer structures were fabricated using photocurable resins with different colors. Multi-material glass structures were also fabricated using photocurable silica slurries.

In addition, a multi-material two-photon lithography system was also developed using multiple droplets. Micro-optical elements such as diffraction gratings and GRIN lenses were fabricated using photocurable resins with different refractive indexes.

These multi-material micro-stereolithography systems will be useful for producing functional microdevices including micro-optical elements, metamaterials and scaffolds.

Virgilio Mattoli, Ph.D

Istituto Italiano di Tecnologia, Italy

TOWARD MEMS DIRECT FABRICATION BY TWO PHOTON LITHOGRAPHY

An ultrafast laser mesoscale lithography will be presented rediscovering underlying photo-physio-chemical reactions determining its technical applications. A current progress in state-of-the-art and potential in 3D as well as 4D printing of diverse materials ranging from biocompatible, biodegradable and renewable organics to amorphous, ceramic and crystalline inorganics will be covered.

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Finally, some unique functional properties of selected prototypes will be provided in detail validating their high efficiency performance and resiliency under harsh conditions.

Friday, 08.04.
9:00 – 10:00 AM

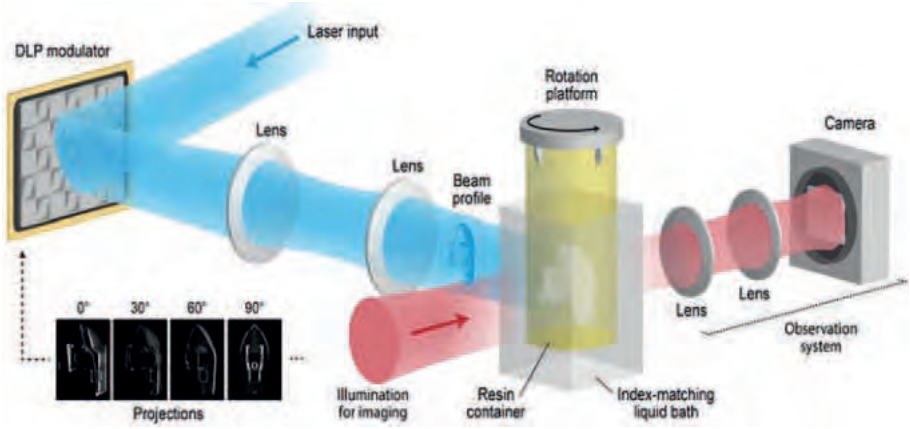
Christophe Moser, Ph.D., Associate Professor

EPFL Lausanne, Switzerland

VOLUMETRIC PRINTING BY REVERSE TOMOGRAPHIC PROJECTIONS IN NON TRANSPARENT RESINS

In volumetric additive manufacturing, an entire three-dimensional object is simultaneously solidified by irradiating a liquid photopolymer volume from multiple angles with dynamic light patterns[1,2,3]. This technique based on 3D light dose accumulation produces the object in 3D without any layers and support structures.

The printing time is only a few tens of seconds for several cubic centimeters with excellent part fidelity. To date, 3D object using only transparent resins have been demonstrated. We will show new results of 3D prints in non-transparent resins which opens new material possibilities.



Volumetric printing by reverse tomography with feedback [2]

[1] Loterie D., Delrot P. and Moser C., Volumetric 3D Printing of Elastomers by Tomographic Back-Projection, DOI: 10.13140/RG.2.2.20027.46889, 2018.
[2] Loterie D., Delrot P., and Moser C., High-resolution tomographic volumetric additive manufacturing, Nature Communications, Vol. 11, 2020.
[3] Bernal P. N., Delrot P., Loterie D., Li Y., Malda J., Moser C., Levato, R., Volumetric Bioprinting of Complex Living-Tissue Constructs within Seconds, Advanced Materials, 2019.

Prof. Dr. Bastian Rapp

Laboratory of Process Technology | NeptunLab

Department of Microsystems Engineering (IMTEK)

Albert-Ludwigs University of Freiburg, Germany

NEXT GENERATION 3D PRINTING: THE EMERGENCE OF ENABLING MATERIALS

3D printing is the manufacturing revolution of the 21st century. The invention of printing by Johannes Gutenberg over 500 years ago, the ability to generate, replicate and disseminate artifacts has changed human history significantly. Recent decades have seen printing moving from two-dimensional to three-dimensional.

Just as the printing press enabled individuals to share, distribute and archive information, printing in 3D will enable to share, improve and generate objects from digital designs via the internet. This technology has the potential to eventually resolve the boundaries between classical industries specialized on manufacturing and the end user which classically only used objects generated by someone else.

Additive manufacturing and 3D printing have seen significant improvements in terms of processing and instrumentation with the aim of increasing the complexity of the objects constructible, increasing resolution and lateral dimensions as well as speed of manufacturing. Interestingly, the choice of materials has not been increasing significantly. Most 3D printing techniques still use polymers or composites (e.g., with ceramic particles). Selective Laser Sintering (SLS) is the only process which has been extended to include metals.

One of the oldest materials mankind has used was missing: Glass. Account of man-made objects in glass date back to 5000 BC. Glass has numerous advantageous properties including unmatched optical properties, mechanical, thermal as well as chemical stability to name but a few.

In 2016 we have contributed a prototyping process in glass which uses a glass nanocomposite which can cured by light and sequentially thermally annealed to result in highly-transparent fused silica glass. With a contribution in Nature, this process was finally successfully transferred to 3D printing. Recently, we demonstrated industrial-scale polymer replication using this technology in an article in Science.

This closes an important gap in the material palette of modern 3D printing processes enabling, for the very first time, the free-form generation of highly transparent fused silica glass by a state-of-the-art 3D printing process. This has major implications for many applications ranging from 3D printing of complex lenses for smartphone cameras, next-generation microprocessors, all the way to ornaments or intricate glass panels used in buildings.

Key words: materials, additive manufacturing, glass, injection molding, 3D printing

Tuesday, 05.04.
3:15 – 4:00 PM

Dr. Marta Ruscello

Forward AM, BASF 3D Printing Solutions, Germany

THE IMPORTANCE OF DESIGN FOR ADDITIVE MANUFACTURING: CREATING PERFORMANCE MATERIALS USING COMPUTER AIDED ENGINEERING

With the establishment and further advancement of Additive Manufacturing (AM), the knowledge about material and design – and their interplay – constantly evolves. Knowing that choosing the right material for each application has proven to be essential, there is another important, if not decisive, factor: the design of the part.

Virtual Engineering plays a vital role in Additive Manufacturing. How successfully a 3D printed part performs depends on two fundamental elements – its material and its geometry. Thinking of the fact that even the strongest material is prone to break when being applied in a poor design underlines the importance of well-thought applied simulation tools in AM – ensuring the right design for each individual application.

Leveraging clinical and individual data, digital simulation tools enable engineers to digitally generate, simulate, and manufacture finely tuned lattices. This opens up the possibility of significantly enhancing 3D printed parts for various industry verticals, such as automotive, medical or consumer goods.

This talk will provide new insights into how BASF 3D Printing Solutions GmbH leverages the simulation tool Ultrasim® to push lattice innovations forward.
It will be examined how to identify the right lattice for each individual project and application – providing enhanced mechanical properties and better protection, cushioning, and comfort when compared to traditional foam.

Sourabh K. Saha, Ph.D. Assistant Professor

Georgia Institute of Technology, Atlanta, USA

HIGH-THROUGHPUT TWO-PHOTON LITHOGRAPHY VIA TEMPORALLY FOCUSED LIGHT SHEETS

High-throughput fabrication techniques for generating arbitrarily complex three-dimensional structures with nanoscale features are desirable across a broad range of applications including healthcare, transportation, and computing.

Two-photon lithography (TPL) is a promising additive manufacturing (AM) technique that relies on nonlinear light absorption to fabricate complex 3D structures with polymeric nanoscale features. However, commercially available serial point-by-point writing scheme of TPL is too slow for many applications.

We have developed a high-throughput nanoscale AM technique based on parallelization of TPL. Our technique has increased the processing rate by a thousand times while preserving the nanoscale feature sizes. It relies on simultaneous spatial and temporal focusing of an ultrafast laser to implement projection-based layer-by-layer printing using arbitrarily patterned light sheets.

This talk will focus on how we broke the traditional tradeoff between rate and feature size – a tradeoff that had persisted in the field for more than two decades. Our method allows access to difficult to explore regions in the design space, increasing both the potential for cost-effective high-throughput processing and the geometric complexity of the printed objects.

Thursday, 07.04.
1:30 – 2:30 PM

Prof. Dr. Thomas Scheibel

Bayreuth University, Germany

BIOFABRICATION USING SPIDER SILK PROTEINS

Proteins reflect one fascinating class of natural polymers with huge potential for technical as well as biomedical applications. One well-known example is spider silk, a protein fiber with excellent mechanical properties such as strength and toughness. We have developed biotechnological methods using bacteria as production hosts which produce structural proteins mimicking the natural ones[1, 2]. Besides the recombinant protein fabrication, we analyzed the natural assembly processes and we have developed spinning techniques to produce protein threads closely resembling natural silk fibers. In addition to fibers, we employ silk proteins in other application forms such as hydrogels, particles or films with tailored properties, which can be employed especially for biomaterials applications[3]. We could e.g. design spider silk-based sheets and scaffolds that prevent adherence of microbes. Without adherence biofilm formation cannot occur, which lowers the frequency of infections in surgical patients. However, the spider silk sheets and scaffolds do not kill any cells. Unlike current treatments they prevent infestation to begin with. The designed spider silk scaffolds are even bio selective, meaning that this designer silk repels microbes while allowing human cell attachment and proliferation[4].

Spider silk hydrogels can be even employed as bioinks for biofabrication (i.e. 3D bioprinting together with cells)[5], but also non-aqueous solvents can be used to 3D-fabricate spider silk scaffolds[6]. Their elastic behavior dominates over the viscous behavior over the whole angular frequency range with a low viscosity flow behavior and good form stability. No structural changes occur during the printing process, and the hydrogels solidify immediately after dispense plotting. Due to the form stability it was possible to directly print multiple layers on top of each other without structural collapse. Cell-loaded spider silk constructs can be easily printed without the need of additional cross-linkers or thickeners for mechanical stabilization. Encapsulated cells show good viability in such spider silk hydrogels. Exemplarily, we use 3D-printed spider silk scaffolds for the growth of heart muscle patches[7, 8] or for generating nerve guiding conduits[9, 10].

Abstracts

[1] Heidebrecht, A., Scheibel T. (2013). Recombinant production of spider silk proteins. Adv. Appl. Microbiol. 82, 115-153
[2] Saric, M., Eisoldt, L., Döring, V., Scheibel, T. (2021) Interplay of Different Major Ampullate Spidroins During Assembly and Implications for Fiber Mechanics. Advanced Materials 33, 2006499
[3] Aigner, T.B., DeSimone, E., Scheibel T. (2018) Biomedical applications of recombinant silk-based materials. Advanced Materials 30, 1704636
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[10] Aigner, T.B., Haynl, C., Salehi, S., O'Connor, A., Scheibel, T. (2020) Nerve guidance conduit design based on self-rolling tubes. Materials Today Bio 5, 100042

Speakers'

Thursday, 07.04.
10:45 – 11:45 AM

Prof. Dr. André Studart

Department of Materials

ETH, Switzerland

3D PRINTING OF BIOINSPIRED MATERIALS

Biological materials exhibit heterogeneous architectures that are tuned to fulfill the functional demands and mechanical loading conditions of their specific environment. Examples range from the cellulose-based organic structure of plants to collagen-based skeletal parts like bone, teeth and cartilage.

Because they are often utilized to combine opposing properties such as strength and low-density or stiffness and wear resistance, the heterogeneous architecture of natural materials can potentially address several of the technical limitations of artificial implants or composites in general. However, current man-made manufacturing technologies do not allow for the level of composition and fiber orientation control found in natural heterogeneous systems.

In this talk, I will show that 3D printing routes using self-assembling inks offer an exciting pathway for the fabrication of biologically-inspired materials with unprecedented heterogeneous architectures and functional properties.

Prof. Dr. Franziska Thomas

Institute of Organic Chemistry

Heidelberg University, Germany

EXPLORING SMALL *β*-SHEET PROTEIN FOLDING MOTIFS AS A MODEL SYSTEMS FOR THE DESIGN OF MINIATURIZED PROTEINS

De novo designed biomolecules have a tradition of being applied as models to mimic natural systems or to create new functional assemblies, which work under physiological conditions. In this context, small protein folding motifs are highly interesting as the function of ideally every single amino acid residue is understood and the impact of modifications on the structure and/or function easy to determine. Due to the well-understood sequence-to-structure relationships, the coiled-coil motif is probably most frequently applied in synthetic-biological endeavors; however, other protein folding motifs more and more come to the fore.

Our research focuses on small β-sheet motifs, more specifically the WW domain and the SH3 domain, which recognize proline-rich peptide sequences. Using rational design or combinatorial approaches, we try to install reactivity or binding properties. In the case of the WW domain, we have designed a generic scaffold based on sequence-structure relationships that will be functionalized to bind, for example, metals, phosphorylated residues or carbohydrates. Such biomimetic peptide receptors are intended for applications in synthetic biology or biofunctionalization of materials.

Thursday, 07.04.
4:00 – 5:00 PM

Luis Fernando Velásquez-García, Ph.D.

Microsystems Technology Laboratories

Massachusetts Institute of Technology, USA

EFFICIENT, COMPACT, COMPLEX HARDWARE VIA ADDITIVE MANUFACTURING

Microsystems harness component miniaturization to attain better performance, looking to replicate the success of integrated circuit (IC)'s very large-scale integration (VLSI). For the longest time, most microsystems have been made in the cleanroom using the very same tools employed to manufacture IC VLSI chips; this problematic because semiconductor foundries (i) greatly restrict the materials and geometries that can be processed, (ii) use very expensive machinery that needs to be controlled by highly trained personnel, and (iii) are geared for 24/7 production of large quantities of archetypical goods.

Consequently, the commercialization of many great microsystem ideas has been hindered, either due to lack of adequate performance or to the cost and time required to produce the devices. Additive manufacturing (AM) is the layer-by-layer fabrication of objects using a computer-aided design (CAD) model; AM has associated exciting possibilities such as monolithic creation of complex, multi-material parts, customization, and low per-unit cost for small-batch to mid-batch production. Currently, commercial 3D printers create solid objects by layering volume elements (voxels) with characteristic dimensions on the order of tens of microns or smaller, making possible to implement true microsystems.

This talk will go over selected examples of additively manufactured developed by the Velásquez-García Group @ MIT; in many cases, the devices operate better than the state of the art, or are the first of their kind, as a semiconductor cleanroom version is unfeasible or impractical.

These results suggest that AM is a toolbox that can provide high-performance engineering solutions, with manufacturing times and costs better aligned to a wider range of business models compared to the semiconductor cleanroom.

Joel K. W. Yang, Ph.D., Assistant Professor

Singapore University of Technology and Design, Singapore

STRUCTURALLY COLORFUL OPTICAL ELEMENTS WITH SUB-MICRON 3D AND 4D PRINTING

Multiple pigments each relying on specific chemical compositions are needed to generate a full range of color. In contrast, structural colors allow one to potentially achieve a wide color gamut using only a single material, or a pair of materials. This shift from material requirements comes at the expense of lithographic needs. Hence, precision tools and processes are needed to produce the requisite nano-geometry for the desired colors.

In this talk, we review some concepts of color generation in metals and dielectrics, and discuss key approaches to generating structural color using two-photon polymerization lithography (TPL). A method to overcome the resolution limitations of TPL to produce colorful 3D photonic crystals will be presented. In addition, we present insight into a simpler nanopillar geometry that exhibits the ability to be individually colorful, i.e. not relying on diffractive effects.

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Selected Talks

Sorted by Date

A Selected Talk consists of a 10-minute talk and a 10-minute Q&A session.

Monday, 04.04. 5:00 – 5:20 PM	Tomographic Volumetric Additive Manufacturing of Silicon Oxycarbide Ceramics	**Jorge Madrid-Wolff**
Monday, 04.04. 5:20 – 5:40 PM	Bringing Electrochemical 3D Printing To The Nanoscale	**Dmitry Momotenko**
Tuesday, 05.04. 5:30 – 5:50 PM	Direct Deposition of High-Resolution 3D Nanostructures by Atomic-Layer Additive Manufacturing (ALAM)	**Sarah Tymek**
Tuesday, 05.04. 5:50 – 6:10 PM	Fast and Continuous Projection Two-Photon Printing	**Paul Somers**
Tuesday, 05.04. 6:10 - 6:30 PM	3D Printed Microstructures Via Photo-Raft Polymerization	**Arnaud Spangenberg**
Tuesday, 05.04. 6:30 - 6:50 PM	NanoCT with *In Situ* Mechanical Testing as a Tool for the Characterization of 3D Additive Manufactured Mechanical Metamaterials	**Rafaela Debastiani**
Thursday, 07.04. 3:15 - 3:35 PM	3D Extrusion Printing of Smart Biocompatible Inks for Bioengineering Applications	**Veronika Magdanz**
Thursday, 07.04. 5:00 - 5:20 PM	*In-Situ* Material Replacement for Efficient High-Resolution Multi-Material 3D Laser Printing	**Robert Kirchner**

Monday, 04.04.
5:00 – 5:20 PM

TOMOGRAPHIC VOLUMETRIC ADDITIVE MANUFACTURING OF SILICON OXYCARBIDE CERAMICS

Jorge Madrid-Wolff

Max Kollep[1], Georgia Konstantinou[1], Jorge Madrid-Wolff[1], Antoine Boniface[1], Pradeep Vallachira Warriam Sasikumar[2], Gurdial Blugan[2], Paul Delrot[3], Damien Loterie[3], Christophe Moser[1]

1: Ecole Polytechnique Federale de Lausanne, Switzerland;
2: Swiss Federal Laboratories for Material Science and Technology (Empa), Switzerland;
3: Readily3D, Switzerland

Ceramics are highly technical materials with properties of interest for multiple industries. Precisely because of their high chemical, thermal, and mechanical resistance, ceramics are difficult to mold into complex shapes. A possibility to make convoluted ceramic parts is to use preceramic polymers (PCP) in liquid form. The PCP resin is first solidified in a desired geometry and then transformed into ceramic compounds through a pyrolysis step that preserves the shape. Light-based additive manufacturing (AM) is a promising route to achieve solidification of the PCP resin. Different approaches, such as stereolithography, have already been proposed but they all rely on a layer-by-layer printing process which sets limitations on the printing speed and object geometry.

Here, we report on the fabrication of complex 3D centimeter-scale ceramic parts by using tomographic volumetric printing which is fast, high resolution and offers a lot of freedom in terms of geometrical design compared to state-of-the-art AM techniques. First, we formulated a photosensitive preceramic resin that was solidified by projecting light patterns from multiple angles. Then, the obtained 3D printed parts were converted into ceramics by pyrolyzing them in a furnace. We demonstrate the strength of this approach through the fabrication of dense microcomponents exhibiting overhangs and hollow geometries without the need of supporting structures, and characterize their resistance to high heat and harsh chemical treatments.

BRINGING ELECTROCHEMICAL 3D PRINTING TO THE NANOSCALE

Dmitry Momotenko

Department of Chemistry, Carl von Ossietzky University of Oldenburg, Oldenburg, D-26129, Germany
Laboratory of Biosensors and Bioelectronics, Institute for Biomedical Engineering, ETH Zurich, Zurich, CH-8092, Switzerland

Nanoelectrochemical methods rapidly develop into highly versatile and powerful tools in nanoscience for a variety of applications from imaging and sensing to nanoscale fabrication. Herein, we present how nanoelectrochemistry opens access to three-dimensional printing for the fabrication of complex features using state-of-the-art nanopipette-based scanning probe techniques. Electrochemical methods are intrinsically advantageous as they allow producing impurity-free metallic conductors with superb electrical and mechanical properties – materials so much needed for many applications spanning electronics, sensing, functional implants, and nanorobotics. But until now true nanoscale resolution (<100 nm) with electrochemical methods remained unattainable. Recently, we managed to overcome this limitation and set new a benchmark in electrochemical 3D printing[1]. By employing nozzles with dimensions as small as 1 nm, we demonstrate layer-by-layer manufacturing of 25 nm diameter voxels. Full control of the printing process allows adjustment of the feature size on-the-fly, printing tilted, and overhanging structures. On the basis of experimental evidence, we estimate the limits of electrochemical 3D printing and discuss the origins of this new resolution frontier.

[1] J. Hengsteler, B. Mandal, C. van Nisselroy, G. P. S. Lau, T. Schlotter, T. Zambelli, D. Momotenko, Nano Lett., 2021, DOI: 10.1021/acs.nanolett.1c02847

Tuesday, 05.04.
5:30 – 5:50 PM

DIRECT DEPOSITION OF HIGH-RESOLUTION 3D NANOSTRUCTURES BY ATOMIC-LAYER ADDITIVE MANUFACTURING (ALAM)

Sarah Tymek

S. Tymek[1], I. Kundrata[1,2], P. Wiesner[1,2],M. Barr[1], M. Plakhotnyuk[2], J. Bachmann[1,2,3]

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3: St. Petersburg State University, Institute of Chemistry, Universitetskii pr. 26,198504 St. Petersburg, Russia

Confining spatial ALD (atomic layer deposition) laterally to a spot with a size in the micron range allows one to perform ALD cycles by repeated passes of the deposition head above the substrate. The pattern defined by the motions of the deposition head may be arbitrarily complex. This concept allows for the definition of deposits in three dimensions in the manner of classical additive manufacturing (3D printing). However, the vertical resolution of the shapes generated is defined by the surface chemical principles of ALD, and therefore is on the order of single atoms. The lateral resolution depends on the printing head and the gas flows and its currently on the order of hundreds of µm.

We have demonstrated the self-limiting behavior of this atomic-layer additive manufacturing (ALAM) procedure for several materials. Under atmospheric conditions, the deposition of TiO_2 occurs with the same growth per pass as in conventional ALD. The cross-section of a deposit exhibits a horizontal surface and sharp edges. The self-limiting behavior of the surface chemistry is maintained. As an example of a noble metal, Pt grows in a highly crystalline and even oriented form.

Thus, ALAM is a novel method allowing for the direct generation of multimaterial structures without the need for preliminary or subsequent patterning. The combination of several materials in not only lateral juxtaposition but also vertical arrangement further enables one to use sacrificial deposits and generate complex three-dimensional structures.

Figure: A pattern consisting of 10 to 30 nm thick platinum line segments generated by direct ALAM. Area: 12×6 mm².

FAST AND CONTINUOUS PROJECTION TWO-PHOTON PRINTING

Paul Somers

Paul Somers[1], Zihao Liang[2], Jason E. Johnson[1], Bryan W. Boudouris[2,3], Liang Pan[1], Xianfan Xu[1]

1: School of Mechanical Engineering & Birck Nanotechnology Center, Purdue University
2: Charles D. Davidson School of Chemical Engineering, Purdue University
3: Department of Chemistry, Purdue University

Two-photon polymerization (2PP) has established itself as the predominant printing process for free-form 3D structuring on the micro/nanoscale, yet so far it has not seen widescale application at the industrial level, attributed mainly to the perceived slow processing rate due to a pointwise scanning method. Efforts for scaling the 2PP throughput have led to various new techniques[1,2]. Here, a rapid and continuous printing process is achieved through the implementation of a continuous, projection two-photon lithography system with high-speed patterning rates and stage speed[3]. The effective fabrication of thin, solid 2D layers using spatiotemporally focused light fields during the print process is investigated both numerically and experimentally, showing micron and submicron 2D layer thickness.

Fabrication of arbitrary 3D structures in a smooth, continuous fashion is demonstrated, exemplifying the ability to print aspherical and complex geometries simply and rapidly. The speed and scalability of the print process is shown in the fabrication of a millimeter scale structure with complicated geometry at a volumetric print rate greater than 10^{-3} mm^3 s^{-1}. Other interesting capabilities of the printing technique, such as grey-scale printing, will be discussed. This rapid, continuous printing process provides a promising opportunity for making 2PP feasible for the print throughput required in many applications.

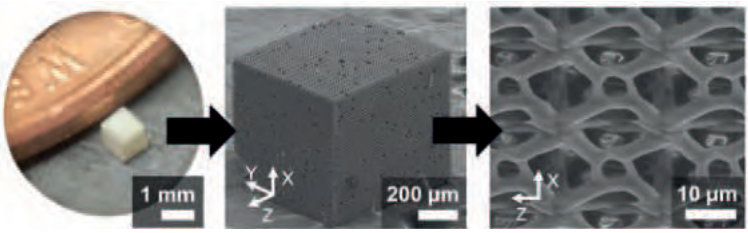

Figure 1. Millimeter scale structure with micrometer scale features fabricated with volumetric print rate of 1.08 x 10^{-3} mm^3 s^{-1}. Increased magnification from left to right[3].

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2. Saha, S. K. et al. Science. 366, 105–109 (2019).
3. Somers, P. et al. Light Sci. Appl. 10, 199 (2021).

3D PRINTED MICROSTRUCTURES VIA PHOTO-RAFT POLYMERIZATION

Arnaud Spangenberg

X. Wu, B. Gross[1,2], B. Leuschel[1,2], K. Mougin[1,2], S. Dominici[1,2], S. Gree[1,2], M. Belqat[1,2], B. Cabannes-Boué[1,2], A. Chemtob[1,2], J. Poly[1,2], A. Spangenberg[1]

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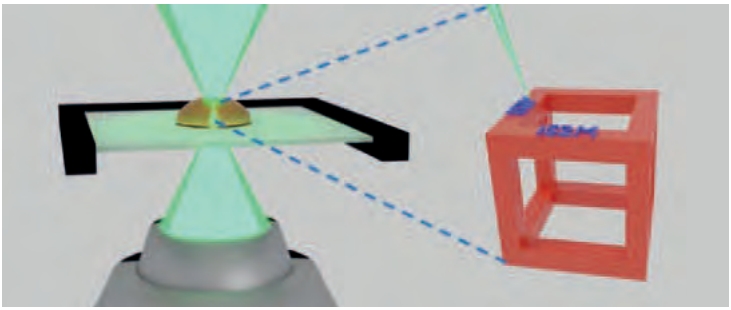
2 Université de Strasbourg, France

Recently, photo-controlled reversible addition-fragmentation chain transfer (RAFT) polymerization has been successfully applied in digital light processing 3D printing.[1-2] It provides a convenient way to tune the surface properties of the 3D printed object. However, so far, 3D microstructures and their surface's reconfiguration based on photo-induced RAFT polymerization have been scarcely investigated. In this work, one macro-photoiniferter, synthesized by photocontrolled RAFT polymerization, is applied to 3D direct laser writing.

Thanks to the exquisite spatial control of the photoreaction, 3D microstructures with feature sizes of around 500 nm are successfully obtained. Taking advantage of the presence of dormant polymeric RAFT agents, photo-induced post-modification of the printed microstructures is highlighted via the elaboration of multi-chemistry patterns including thermo-responsive ones.[3] These results open new perspectives in multi-material and 4D micro-printing.



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NANO-CT WITH *IN SITU* MECHANICAL TESTING AS A TOOL FOR THE CHARACTERIZATION OF 3D ADDITIVE MANUFACTURED MECHANICAL METAMATERIALS

Rafaela Debastiani

R. Debastiani[1,2,3], C. M. Kurpiers[2,4], R. Schwaiger[2,5], P. Gumbsch[1,2,6,7]

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7 Fraunhofer Institute for Mechanics of Materials IWM, 79108, Freiburg, Germany

With an intermediate resolution between light and electron microscopes, the commercial lab-based X-ray microscope (Xradia Ultra 810) with mechanical *in situ* testing, here referred to as nanoCT, is a versatile new tool for structural characterization of complex 3D samples down to 50 nm resolution with and without loading. It allows for the observation of microstructural changes as a function of time and mechanical load. With its low energy X-ray source (Cr source, 5.4 keV) and Zernike phase contrast, the setup is ideal for analyzing low-density samples, such as polymers and soft tissues.

Tetrahedral microlattices manufactured using 3D direct laser writing method and different laser parameters were characterized using the nanoCT (Fig. 1) with and without loading.

Through phase and absorption contrasts and a voxel size of $(128\ nm)^3$, differences in the structures, volume density and mechanical responses, as well as defects and pores within the different polymeric samples, could be identified.

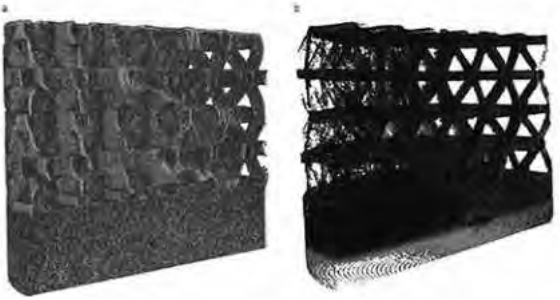

Figure 1: Volumetric reconstruction of tetrahedral metamaterial showing the structural differences depending on the fabrication parameters. Samples diameter: 60 µm. Samples manufactured with laser power [%] a) 40, b) 25.

3D EXTRUSION PRINTING OF SMART BIOCOMPATIBLE INKS FOR BIOENGINEERING APPLICATIONS

Veronika Magdanz

Veronika Magdanz[1], Zoran Cenev2, Guillem Lopez[1], Gregory Beaune[2], Jaakko Timonen[2], Maria Guix[1], Samuel Sanchez[1,3]

1 Institute for Bioengineering of Catalonia (IBEC), The Barcelona Institute of Science and Technology (BIST). Barcelona, Spain
2 Department of Applied Physics, Aalto University School of Science, Finland
3 Institució Catalana de Recerca i Estudis Avancats (ICREA), Barcelona, Spain

3D printing has opened new possibilities not only in additive manufacturing, but also in tissue engineering and soft robotics. Developing novel printing inks is expanding the range of applications. Here, we are presenting some approaches to 3D extrusion printing biocompatible structures with advanced features, such as pH, thermal and magnetic response. This allows the on-demand adaptability of their shape and triggered cargo release (Fig.1a). Poly-N-isopropylacrylamide is presented as one optional material to obtain shape-changing structures by 3D printing this hydrogel and applying reversible temperature triggers (Fig.1b). These adaptable microstructures can be explored for tasks in soft microrobotics such as cargo loading and release purposes. The addition of gold nanorods allow the laser-triggered thermoresponse by photothermal mechanism and thereby release of cargo (Fig.1c).

Further, Gelatin-based inks are demonstrated as a biodegradable material with excellent cell compatibility. Their versatility allows the addition of magnetic particles for remote positioning and actuation of such structures (Fig.1d). Finally, pH response of gelatin-based structures is also explored as an option for cargo loading and release by pH stimulus.

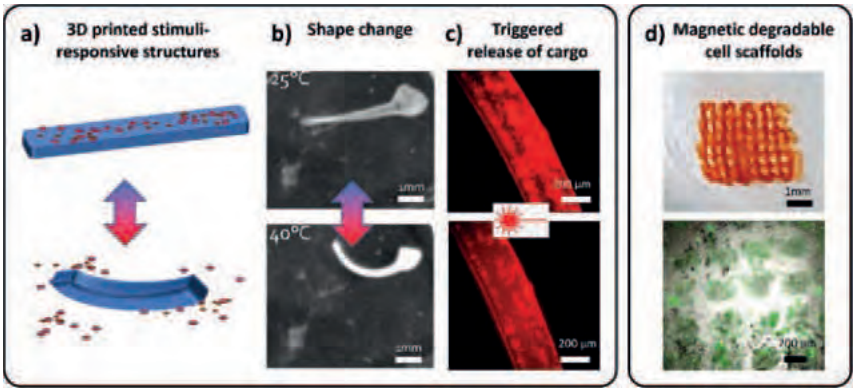

Figure 1:
a) Schematic of 3D extrusion printed responsive structures with ability to change shape and release cargo in response to temperature.
b) Shape change of 3D printed PNIPAM structures when changing temperature from 25°C (top) to 40 °C (bottom).
c) Release of fluorescently labelled microparticles (red) from PNIPAM filaments when 747nm light is applied for 8 minutes. Top image: Before light exposure, bottom: after light exposure.
d) Magnetically responsive GelMa cell scaffolds can be created by 3D printing hydrogels with embedded ferrofluid (top). Degradation of that same magnetic GelMa scaffold in cell culture after 3 days. The scaffold is dissolved by proteases released by the HeLa cells while they grow. Composite image of bright field, red and green channel that display dead and live cells, respectively.

Thursday, 07.04.
5:00 - 5:20 PM

IN-SITU MATERIAL REPLACEMENT FOR EFFICIENT HIGH-RESOLUTION MULTI-MATERIAL 3D LASER PRINTING

Robert Kirchner

Y. Yu, Y. Gao, M. H. Wong, S. Toukabri, J. Knorr, R. Kirchner

The immediate availability and generally low costs render additive fabrication a valuable solution for prototyping and medium-volume manufacturing. Ultimately, full digital fabrication down to atom-scale with full control over each individual atom would be desirable. One process that comes closest to this is 2-photon or multi-photon 3D laser writing. To realize true digital fabrication, three issues have to be solved: I) a broad spectrum of materials, II) tools for multi-material processing, and III) scaled processes for high throughput have to be available. In multi-photon laser writing, the material palette is continuously growing. More materials and faster processing will come from academic push and in-dustrial pull.

Multi-material micro-nano-printing currently advances additive fabrication[1-4]. We contribute a novel material exchange concept for multi-photon systems with the *in-situ* material replacement being confined around the exposure focus using an open fluidic system. Our concept directly replaces print-ing material with new printing material. Only one final development is required. Our solution enables a very high overlay precision down to a few 10 nm (e.g., by piezo stages). Even with linear stages im-proved printing accuracy below ±1 µm can be achieved. We used commercial IP-Dip, pentaerythritol triacrylate (PETA), and PETA doped with BODIPY PM567 laser dye to demonstrate a clean material separation (Fig. 1). The Frauenkirche Dresden was printed in two segments (Fig. 2) with the initial PETA being replaced on the 63x immersion objective by dye-doped PETA between each segments printing.

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[4] L. Yang, F. Mayer, U. H. F. Bunz, E. Blasco, M. Wegener, Multi-material multi-photon 3D laser mi-cro- and nanoprinting, Light: Advanced Manufacturing 2, 296-312, 2021.

Fig. 1 a) SEM for overview and
b) fluores-cence microscopy demonstrate clear ma-terial separation.

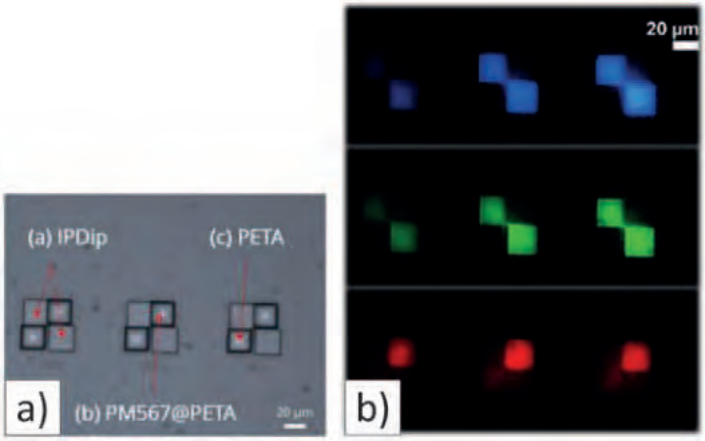
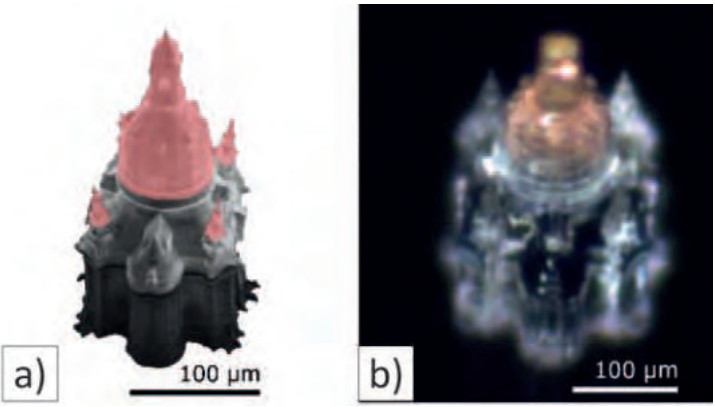


Fig. 2 a)False colored SEM and
b) dark-field microscopy of 2-segmented multi-material printed 3D structure.



Flash Talks

Monday, 04.04.

5:40 – 5:42 PM	3D Fabrication of Microvascular Networks on Artificial Organ Models for Endoscopic Surgical Simulation	**Felix Fischer**
5:42 – 5:44 PM	Towards 3D Magnon Spintronics	**Huixin Guo**
5:44 – 5:46 PM	Laser Powder Bed Fusion Generated Magnetic and Plasmonic Parts from Nano-Additivated Polymer Powders	**Carlos Doñate Buendía**
5:46 – 5:48 PM	Selective Positioning of Different Cell Types on 3D Scaffolds Via DNA Hybridization	**Enrico Domenico Lemma**
5:48 – 5:50 PM	Two-Photon 3D Laser Printing Inside Synthetic Cells	**Tobias Abele**
5:50 – 5:52 PM	Tissue Organisation Controlled by Curvature	**Barbara Schamberger**
5:52 – 5:54 PM	*In Situ* Pyrolysis of 3D Printed Microstructures – an ESEM Study	**Qing Sun**
5:54 – 5:56 PM	Metal Oxide Memristive Devices Fabricated by Inkjet Printing	**Hongrong Hu**
5:56 – 5:58 PM	Immobilization of Cancer Cells in Artificial Tumours Triggers Biomechanical Heterogeneity and the Formation of Polyploid Giant Cancer Cells	**Aldo Leal-Egaña**
5:58 – 6:00 PM	3D Microfabrication of Structured Stimuli Responsive Hydrogel Actuator Systems	**Tobias Spratte**

Sorted by Date

Thursday, 07.04.

5:20 – 5:22 PM	Light Based 3D-Bioprinting Systems to Resemble Skin Models	**Angela Cirulli**
5:22 – 5:24 PM	Stretchable and Healable Bioelectronic Materials	**Fabio Cicoira**
5:24 – 5:26 PM	4D Microprinting of Liquid Crystal Elastomers: a Facile Approach Toward Multi-Functional Microstructures	**Li-Yun Hsu**
5:26 – 5:28 PM	Quantum-Mechanical Study of Photoinitiators for 3D Laser Nanoprinting	**Anna Mauri**
5:28 – 5:30 PM	Comparison of UV Projection and Multiphoton Direct Writing Techniques In Throughput and Dimensions	**Arnoldas Solovjovas**
5:30 – 5:32 PM	3D Printed Capillary Channels for Guiding Functional Conductive Materials in Optoelectronics	**Kai Xia**
5:32 – 5:34 PM	3D Printing Of Reactive Nanoporous Polymers Via Polymerization-Induced Phase Separation and Thiol-Ene Chemistry	**Fatma Aslan**
5:34 – 5:36 PM	Development of a Three-Dimensional, Vascular Tumor Model	**Sonja Leopold**
5:36 – 5:38 PM	Illuminating Materials: Ideal Light-Matter-Interactions in Biomedical Additive Manufacturing	**Leonard Siebert**
5:38 – 5:40 PM	Two Steps Towards Novel 3D Laser Nanoprinters	**Tobias Messer**
5:40 – 5:42 PM	New Materials for Direct Laser Writing on the Basis of Vinylcyclopropanes	**Saskia Braun**
5:42 – 5:44 PM	Development of Hydrogels for Use in Tissue Engineering for the Production of Organ Models Using the 3D Bioprinting Process	**Alisa Grimm**
5:44 – 5:46 PM	Electrochemical Multi-Metal Nano- and Micro-3D Printing	**Julian Hengsteler**
5:46 – 5:48 PM	Fish Retinal Organoid Culture as a System to Study Cell Fate Decisions During Retinal Development	**Lucie Zilova**
5:48 – 5:50 PM	High Aspect Ratio 3D Microstructures Using Near-Field Electrospinning	**Ahsana Sadaf**

Monday, 04.04.
5:40 – 5:42 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

3D FABRICATION OF MICROVASCULAR NETWORKS ON ARTIFICIAL ORGAN MODELS FOR ENDOSCOPIC SURGICAL SIMULATION

Felix Fischer[1]

F. Fischer[1], D. Li[1,2], X. Tan[1,3], D. Y. Kim[1], M. Jeong[1], A. Miernik[4], T. Qiu[1,2]

1 Cyber Valley Group – Biomedical Microsystems, Institute of Physical Chemistry, University of Stuttgart
2 Max Planck Institute for Intelligent Systems, Stuttgart
3 Department of General, Visceral and Transplant Surgery, University Hospital Tuebingen
4 Department of Urology, University Medical Center Freiburg

The rapid evolvement of surgical techniques and equipment demands realistic *in vitro* testing environments – artificial organ models. They allow the effective training of medical personnel on difficult surgical cases without harming a patient. Recently, the fabrication of artificial organs as a surgical simulation platform was enabled by the advancement of 3D printing technologies. However, most current directly 3D-printed organ models do not meet the requirements for surgical training since they lack of high-resolution anatomical details and are limited to materials that are much stiffer than real human soft tissues.

Here, we present a method that combines high-resolution 3D printing and polymer injection micro-molding to achieve microvascular networks on the inner lumen wall of an artificial organ. A kidney organ is used for demonstration. The 3D shape of the hollow renal collecting system is reconstructed based on a high-resolution CT (computer tomography) scan of a human kidney (see Figure), and replicates the real anatomy with sub-millimeter resolution. The 3D blood vessel network is designed using endoscopic images and successfully embedded on the surface of the collecting system to render a realistic endoscopic view to the trained surgeons. Furthermore, a biomimetic double-network hydrogel is customized and applied with the same fabrication method, which offers realistic acoustic properties for ultrasonic examination and high-fidelity cutting behavior in electrocautery and Holmium laser surgeries.

It is expected that our new 3D organ models will be broadly applied to future medical trainings, surgical planning and the development of new medical instruments.

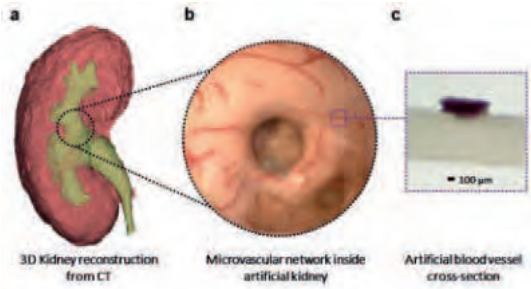


Figure: High-Resolution Computer Tomography Scan of a Human Kidney

Monday, 04.04.
5:42 – 5:44 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

TOWARDS 3D MAGNON SPINTRONICS

Huixin Guo

Huixin Guo[1] and Dirk Grundler[1,2]

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2 Institute of Electrical and Micro Engineering, EPFL, 1015 Lausanne, Switzerland

There has been a surge of theoretical and experimental studies in three-dimensional nanomagnetic materials recently due to potentially novel physical phenomena and applications. We combine a polymeric 3D nanoscaffold written by two-photon lithography (TPL) with the conformal coating of a ferromagnetic metal by atomic layer deposition (ALD [1,2]. Thereby we aim at the realization of a 3D magnonic crystal.

TPL is a powerful technique which offers unprecedented possibilities to create 3D nanoscaffolds of interconnected polymeric nanowires (Fig 1a). Through a heat-induced shrinking process following Ref. [3], the lattice parameter of the woodpile structure is reduced below the limitation given by the nanoscribe exposure process (Fig 1b). ALD has the advantage of avoiding growth-induced anisotropies, precisely controlling the film thickness, and conformally coating without shadowing effect. We apply plasma-enhanced atomic layer deposition of the ferromagnetic metal Ni using an optimized ALD pulse sequence and a post-processing annealing treatment[1].

Thereby we prepare a 3D magnetic architecture (Fig 1c). Thermal magnon modes of such 3D magnetic architectures have been detected by microfocus-Brillouin Light Scattering (BLS) at room temperature (Fig 1d). Furthermore, a fabrication method is demonstrated to directly integrate the 3D magnetic nanostructure to a circuit utilising focused ion beam cutting and deposition of Pt (Fig 1c). The integration supplies a promising platform to investigate the magnetotransport effects in the complex 3D nanomagnets. Our work represents a significant step towards exploring the intriguing magnetotransport and spin dynamics properties of 3D magnetic architectures and sheds light on 3D spintronics and magnonics research. The research is financially supported by SNSF via grant number 197360.

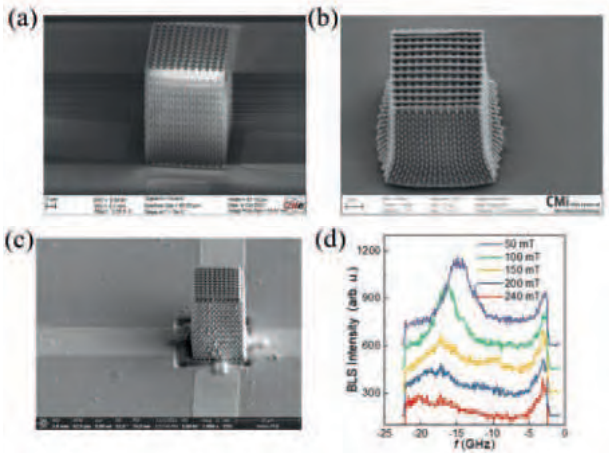

Figure 1:
(a) SEM image of a 3D nanoscaffold consisting of interconnected nanowires with a lattice parameter of 1.57 µm.
(b) SEM image of a 3D nanostructure after heat-induced shrinkage.
(c) 3D nanostructure conformally coated by 10 nm thick Ni and electrical contacts integrated by combined FIB cutting and deposition of Pt.
(d) Microfocus-BLS spectra of thermally excited magnons taken in different applied field.

[1] M. C. Giordano et al., ACS Appl. Mater. Interfaces. 12, 40443 (2020).
[2] M. C. Giordano et al., Nanoscale 13, 13451 (2021).
[3] Y. Liu et al., Nat Commun 10, 4340 (2019).

Monday, 04.04.
5:44 – 5:46 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

LASER POWDER BED FUSION GENERATED MAGNETIC AND PLASMONIC PARTS FROM NANO-ADDITIVATED POLYMER POWDERS

Carlos Doñate Buendía

C. Doñate-Buendía[1], A. Sommereyns[2,3], M. Schmidt[2,3], S. Barcikowski[4], B. Gökce[1]

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3 Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany
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Additive manufacturing techniques like laser powder bed fusion (LPBF) allow key advantages for the fabrication of objects and parts such as custom design and fast processing. However, the library of materials processable by LPBF is limited, reducing the possibility of manufacturing parts with custom functionalities. To address this limitation, a complete and general route to incorporate laser-generated nanoparticles to base powders employed for LPBF is proposed, Fig. 1.

The process success is demonstrated for different nanoparticle types (silver, carbon, iron oxide…). Showing the possibility to widen the selection of processable materials by LPBF (i.e. TPU[1]) and providing additional optical and magnetic[2] functionalities to materials already employed such as polyamide 12 (PA12), Fig. 1[1,2].

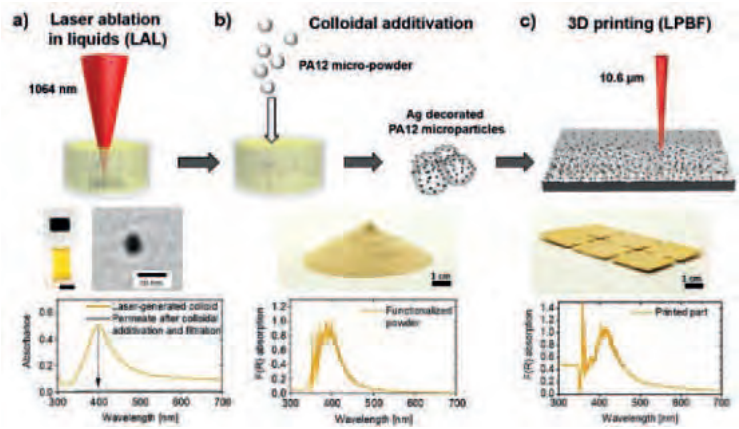

Figure 1
a) Schematic procedure employed for the generation, supporting and LPBF processing of nanoadditivated polymer powders.
b) LPBF generated parts employing the nano-additivated polymer powders.
c) LPBF produced Ag-PA12 part.

[1] T. Hupfeld, S. Salamon, J. Landers, A. Sommereyns, C. Doñate-Buendía, J. Schmidt, H. Wende, M. Schmidt, S. Barcikowski, B. Gökce, 3D printing of magnetic parts by laser powder bed fusion of iron oxide nanoparticle functionalized polyamide powders, J. Mater. Chem. C. (8), 12204–12217 (2020).
[2] T. Hupfeld, A. Wegner, M. Blanke, C. Doñate-Buendía, V. Sharov, S. Nieskens, M. Piechotta, M. Giese, S. Barcikowski, B. Gökce, Plasmonic Seasoning: Giving Color to Desktop Laser 3D Printed Polymers by Highly Dispersed Nanoparticles, Adv. Opt. Mater. (8), 2000473 (2020).

Monday, 04.04.
5:46 – 5:48 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

SELECTIVE POSITIONING OF DIFFERENT CELL TYPES ON 3D SCAFFOLDS VIA DNA HYBRIDIZATION

Enrico Domenico Lemma

E.D.Lemma[a], R.Tabone[b], K. Richler[a], A.K.Schneider[c], C.M. Niemeyer[c], C.Bizzarri[b], and M.Bastmeyer[a]

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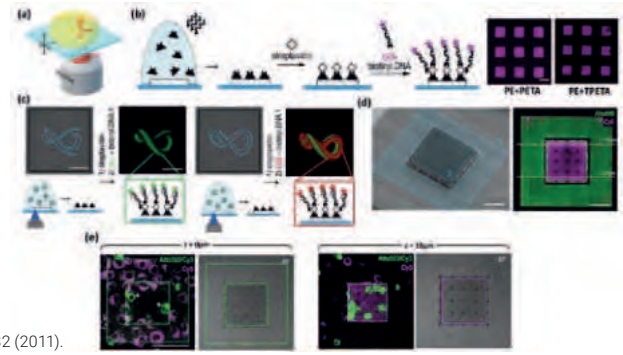
c Institute for Biological Interfaces, KIT, Karlsruhe, Germany.

In the last decade, a great effort has been devoted to realizing cell culture conditions mimicking the physiological complex microenvironment in which cells carry out their functions. Two-photon lithography (2PL, fig. 1a) has given a major contribution to this field, since several scaffolds for studying cell biology with different properties made via 2PL have been reported[1]. A logical improvement in this field is the implementation of techniques allowing for the precise positioning of distinct cell types in a 3D microenvironment. Current techniques, e.g., antibody-antigen binding, remain challenging for selective single-cell-type tagging as they lack of specificity. Other critical issues include antibody internalization from the cells surface, availability and costs.

Here, 3D microscaffolds fabricated via 2PL were locally decorated with single-strand DNA (ssDNA) exploiting light-induced click chemistry, for selective cell adhesion. Firstly, a UV-reactive material (i.e. a photo-enol, PE) was synthesized and mixed to well-known acrylate-based photoresists for 2PL (i.e. PETA and TPETA) and a suitable photoinitiator. According to previous literature, the aldehyde group of the photo-enol can enolize upon UV irradiation and subsequently react with a double carbon bond (e.g. of a maleimide molecule) via a Diels-Alder 4+2 cycloaddition click reaction (fig.1d)[3]. Therefore, a solution of biotinylated maleimide in DMF was placed on the 2D and 3D microstructures and exposed to a focused 405nm laser, allowing for covalent binding of the maleimide to the PE; streptavidin was then incubated, followed by an incubation step with the fluorescently-labelled biotinylated oligonucleotide (fig.1b). It was also possible to tune the degree of functionalization by adjusting the laser intensity and exposure time.

The procedure was repeated sequentially on the same structure for two different oligonucleotides (fig.1c) and on 3D structures (fig.1d). In order to test the selective binding affinity of cells to ssDNA, two different cell lines (i.e., NIH3T3 and U2OS) were decorated with cholesterol-TEG complementary strands and incubated for 30min on functionalized 3D scaffolds.

As expected, cells hybridize more effectively on complementary oligonucleotides than on surfaces with non-complementary ssDNA (fig.2e). Cells could then be fixed and stained via immunochemistry, showing that the proposed technique can be further exploited to study cells behaviour and answer fundamental biological questions with currently available staining/imaging techniques.



[1] M. Hippler, et al., Adv. Mater. 31 (2019).
[2] B. Richter, et al., Adv. Mater. 29 (2017).
[3] T. Gruendling, et al., Macromol. Rapid Commun. 32 (2011).

Monday, 04.04.
5:48 – 5:50 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

TWO-PHOTON 3D LASER PRINTING INSIDE SYNTHETIC CELLS

Tobias Abele

Tobias Abele[1,2,3], Tobias Messer[3,4], Kevin Jahnke[1,2,3], Marc Hippler[3,5,6], Martin Bastmeyer[3,6,7], Martin Wegener[3,4,5], Kerstin Göpfrich[1,2,3]

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4: Institute of Applied Physics, Karlsruhe Institute of Technology, Germany;
5: Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany;
6: Zoological Institute, Karlsruhe Institute of Technology, Germany;
7: Institute for Biological and Chemical Systems - Biological Information Processing (IBCS-BIP), Karlsruhe Institute of Technology, Germany

Toward the ambitious goal of manufacturing synthetic cells from the bottom up, various cellular components have already been reconstituted inside lipid vesicles. However, the deterministic positioning of these components inside the compartment has remained elusive. Here, by using two-photon 3D laser printing, 2D and 3D hydrogel architectures are manufactured with high precision and nearly arbitrary shape inside preformed giant unilamellar lipid vesicles (GUVs).

The required water-soluble photoresist is brought into the GUVs by diffusion in a single mixing step. Crucially, femtosecond two-photon printing inside the compartment does not destroy the GUVs. Beyond this proof-of-principle demonstration, early functional architectures are realized. In particular, a transmembrane structure acting as a pore is 3D printed, thereby allowing for the transport of biological cargo, including DNA, into the synthetic compartment.

These experiments show that two-photon 3D laser microprinting can be an important addition to the existing toolbox of synthetic biology.

Monday, 04.04.
5:50 – 5:52 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

TISSUE ORGANISATION CONTROLLED BY CURVATURE

Barbara Schamberger

Barbara Schamberger [1], Sebastian Ehrig [2], Thomas Dechat [3], Silvia Spitzer [3], Peter Fratzl [4], John W. C. Dunlop [1], Andreas Roschger [1]

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3. Ludwig Boltzmann Institute of Osteology, Vienna, Austria
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Surface curvature can influence single cell and cell monolayer orientation [1]. Less is known about the interplay between curvature and the organization of multilayered tissue. Here we present evidence that tissue organization is strongly controlled by substrate curvature.

Tissue consisting of pre-osteoblast cells (MC3T3-E1) was grown up to 32 days on scaffolds with constant mean curvature and negative Gaussian curvature (manufactured as described in [Ehrig 2019]). Tissue growth was quantified by bright-field microscopy while the organization of actin stress-fibers was obtained using fluorescence staining and 3D confocal- and light-sheet microscopy.

By comparing results from previous experiments where tissues have been grown on substrates of same dimension but opposite sign of principal curvatures, we investigate the influence of surface curvature on stress-fiber alignment and chirality. While previous experiments showed a left-handed spiral pattern at the outer layer of the tissue [2], our time-series approach reveals that the cell-orientation within the outermost layer of the tissue changes during growth resulting in different layers with distinct actin organizations. These layered orientations are conserved in the resulting tissue.

Although it is still not clear what triggers this self-organization behavior, our experimental approach provides new insights into the emergence of chirality.

[1] Callens, S. J., et al. (2020). Biomaterials 232: 119739.
[2] Ehrig, S., et al. (2019). Science advances 5(9): eaav9394.

Monday, 04.04.
5:52 – 5:54 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

IN SITU PYROLYSIS OF 3D PRINTED MICROSTRUCTURES – AN ESEM STUDY

Qing Sun

Qing Sun[1*], Christian Dolle[1], Chantal Kurpiers[2], Ruth Schwaiger[3], Peter Gumbsch[2,4], Yolita M. Eggeler[1*]

1 Microscopy of Nanoscale Structures & Mechanisms (MNM), Laboratory for Electron Microscopy (LEM), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany;
2 Institute for Applied Materials (IAM), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany;
3 Institute of Energy and Climate Research, Forschungszentrum Jülich GmbH, Jülich, Germany;
4 Fraunhofer Institute for Mechanics of Materials IWM, Freiburg, Germany

Glassy carbon has been well known as a material to compete with silicon in the field of microchips. One promising method to fabricate micro- or nanoscale carbon is to pyrolyze the pre-patterned polymer precursor. However, the details of the pyrolysis process, such as concurring diffusive chemical reactions, gaseous evaporation, the roles of environment or surface area are still only scarcely described.

To close this gap in knowledge we present the case study of an *in situ* pyrolysis process, conducted in an environmental scanning electron microscope (ESEM). We use direct laser writing of IP-Dip photoresist to print microstructures, directly on MEMS chips[1]. By tuning dimensions of rectangular microstruts we study the surface-to-volume effect upon pyrolysis.

In this work, the microstruts are subjected to temperatures between 450 -500 °C and vacuum states varying from high to low vacuum in order to dip into the role of the inert surroundings. The structural changes are continuously monitored by secondary electron imaging. We track the changes of the microstruts that shrink to over 50% of the initial sizes and describe the temperature dependency of the deformation in high vacuum via effective activation energies that are independent of the size of the investigated structures.

Upon changing the environmental conditions, the shrinkage behavior turns out to be fundamentally different, largely kinetically hindered and a prevalence of the aspect ratio on the final size becomes apparent.

For an overall picture of the structural changes, we investigate focused ion beam (FIB) cross-sections of the heated microstruts. The cross-sectional samples not only allow insights into the reshaping during deformation but also offer the possibility to study local chemical changes by electron energy loss spectroscopy. Here, we find the generation of a core-shell structure with a subtly different spectroscopic fingerprint around the deformed microstruts.

Based on our findings, the theoretical description of pyrolysis can be improved. We envision that precise tuning of the final mechanical and electronic properties may lead to functional metamaterials beyond structural strengthening applications.

[1] Q. Sun et al., Microscopy and Microanalysis 27(S2) (2021) 83-84.
[2] The authors acknowledge financial funding by the German Research Foundation (DFG) under Germany's Excellence Strategy (EXC-2082/1-390761711).

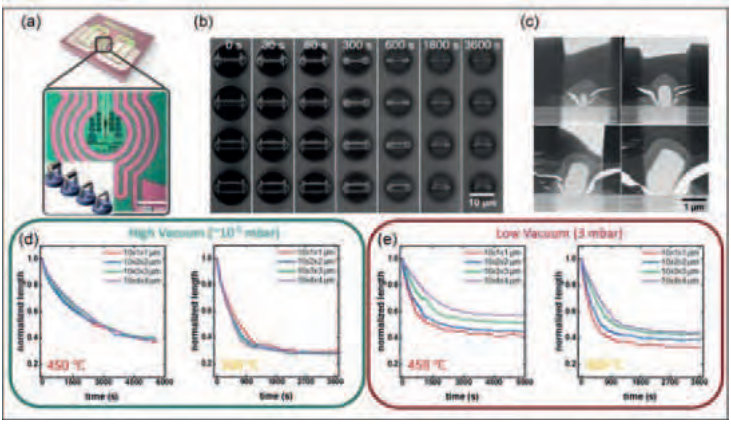

Figure 1.
(a) Heating chip with encircled heating zone linked to a zoomed-in light microscopy image which shows the printed microstruts in the heating centre. Inset: Rendered visualization of the studied microstruts with different volumes.
(b) Time series montage of in situ heating experiment in ESEM.
(c) Cross-section micrograph of heated and thus shrunken microstruts prepared by FIB micromachining.
(d) Evolution of length extracted at 450 and 500° C under high vacuum conditions.
(e) Evolution of length extracted at 450 and 500° C under low vacuum conditions.

Monday, 04.04.
5:54 – 5:56 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

METAL OXIDE MEMRISTIVE DEVICES FABRICATED BY INKJET PRINTING

Hongrong Hu

Hongrong Hu, Gabriel Cadilha Marques, Alexander Scholz, Jasmin Aghassi-Hagmann

Karlsruher Institut für Technologie

Resistive switching is the underlying characteristic of memristive devices, which arouses numerous interests from both academia and industry. This emerging device exhibits a huge potential as non-volatile data storage and as a novel paradigm in computing, such as neuromorphic computing. Currently, most of the reported memristive devices are fabricated by traditional manufacturing techniques such as vacuum deposition and photolithography. Many new digital manufacturing techniques, such as inkjet printing, are facilitating the development of electronics due to its advantages like ease of fabrication, cost-effectiveness, rapid prototyping capability, and compatibility with a wide range of substrates.

In this context, we have fabricated different memristive devices based on various metal oxides materials by inkjet printing. Through a proper material combination of electrodes and active layers, we can achieve multiple resistive switching behavior, such as digital and analog types. The digital type of memristor (based on ZnO) exhibits potential in the application as information storage with excellent performance, for instance, low operation voltage, high on/off ratio to 107, long retention time exceeding 104 seconds, and good endurance up to 500 resistive switching cycles. The conductance of analog type devices (based on WO3) can be gradually manipulated to emulate different behaviors of the biological synapse, such as short time plasticity, long term potentiation, and long term depression, which can be employed as hardware to implement neuromorphic computing.

Monday, 04.04.
5:56 – 5:58 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

IMMOBILIZATION OF CANCER CELLS IN ARTIFICIAL TUMOURS TRIGGERS BIOMECHANICAL HETEROGENEITY AND THE FORMATION OF POLYPLOID GIANT CANCER CELLS

Aldo Leal-Egaña

Adrian Büheler[1], Mahshid Monavari, Aldo R. Boccaccini[1], Gaelle Letort[3], A. Leal-Egaña[1,4].

1 Institute of Biomaterials, Friedrich-Alexander University Erlangen-Nuremberg. Germany.
2 Institute of Biochemistry. Emil-Fischer-Center, Friedrich-Alexander University Erlangen-Nuremberg. Germany.
3 Institute Pasteur. Paris, France.
4 Institute of Molecular System Engineering. University of Heidelberg. Germany.

One specific hallmark of cancer malignancy, is their capability to generate multiple phenotypes from one single genotype, a process known as Tumour Heterogeneity[1]. Among heterogenous populations, the presence of Polyploid Giant Cancer Cells (PGCC) has called the attention of clinicians and researchers in pharmacotoxicology. PGCC are characterized by the presence of multiple nuclei, and their resistance to chemotherapy *in vivo*[2]. Currently, there are few alternatives describing how to produce these cells *in vitro*, mostly based on the use of drugs disrupting the cell cycle.

In this work we hypothesize that culturing breast cancer cells into three-dimensional polymer-based scaffolds mimicking the elasticity of breast tumours can lead the generation of PGCC *in vitro.* To this purpose, MCF7 breast cancer cells were immobilized in alginate-gelatine microcapsules (named as Artificial Tumours in this work), having an elasticity of 25 kPa. These matrices have been designed to restrict -but not hinder- the proliferation and migration of cancer cells, simultaneously submitting them to strong mechanical stress[3].

After cell immobilization, capsules were dissolved at days 1, 2, 4, 7 and 10. Isolated cells were tested by single cell traction force microscopy, as well as quantifying their cell surface and number of nuclei by confocal microscopy. The experimental results obtained with immobilized cells were then compared to cells cultured on soft hydrogels having a similar elasticity to the microcapsules' bulk (23 kPa), and to MCF7 forming suspended spheroids, which are considered as gold standard for culturing cancer cells in 3D.

Our results show that cells cultured on flat surfaces exhibit a very homogeneous morpho-mechanical behaviour, differing from the trend shown by MCF7 cells cultured in 3D milieus. Furthermore, cells isolated from artificial tumours exhibit a clear increase in the number of polynucleated cells with time, in comparison to the other two conditions.

To determine if these phenotypes expressed several markers described in PGCC, we carried RNA-seq assays on these populations. Interestingly, our results are showing that cells cultured within artificial tumours strongly upregulate several markers characterising PGCC (i.e. Notch, SOX2, KRT19, ZNF217, etc), which were not clearly detected in cells cultured on the other two conditions.

These assays were then validated by comparing the resistance of MCF7 to cisplatin. Our toxicologic analysis clearly demonstrate that cells isolated from the bulk of the artificial tumours show an increased insensitivity to this drug, compared to cells cultured on 2D surfaces (IC50 = 21.40 v/s IC50 = 9.14 respectively).

All in all, our results demonstrate that mechanical stress, rather than 3D morphology only, stimulates the formation of PGCC, where the use of three-dimensional polymer-based scaffolds offers a new alternative to study the progression of this pathology *in vitro*.

[1] A. Leal-Egaña, M. Balland, A.R Boccaccini Trends in Biotechnology, 2020, 38, 142-153.
[2] Li R. and Zhu J. Nature Reviews in Molecular Cell Biology 2022, in the press.
[3] M. Fuentes-Chandía, ..//.. A. Leal-Egaña Advanced Biology, 2021, 5, 2000349.

Monday, 04.04.
5:58 – 6:00 PM
Poster Presentation:
Monday, 6:00 - 7:00 PM

3D MICROFABRICATION OF STRUCTURED STIMULI RESPONSIVE HYDROGEL ACTUATOR SYSTEMS

Tobias Spratte

T. Spratte, C. Arndt and C. Selhuber-Unkel

Institute for Molecular Systems Engineering, Heidelberg University, 69120, Germany

Controlled small scale cargo sorting is a challenging task due to the need of very precise and gentle handling of the transported objects, especially in the case of fragile loads, such as living cells. To fulfill such tasks, precisely designed microstructures made of soft materials are needed, which require highly advanced manufacturing methods.

This project focuses on the 3D microfabrication of a dynamically adjustable microactuator array made of thermoresponsive poly(N-isopropylacrylamide) (pNIPAM) hydrogel pillars. Stimulation of the pillars via heating or cooling leads to shrinkage or swelling of the material and can result in the formation of transport pathways for microscale objects (cf. Figure 1 a). Such microactuator systems could find application in small scale cargo sorting and microfluidics.

We recently discovered the potential of increasing the responsivity, response rate and mechanical forces exerted by the pNIPAM hydrogel by controlling the microstructure of the material[1]. As the actuation function of pNIPAM strongly depends on the in- and outflow of water, we believe that complex 3D architectures that control volume to surface ratios of the individual pillars, such as pores, lamellae, or protrusions, can significantly improve the actuation function of the system (cf. Figure 1 b). To fabricate these microstructures with very high resolution, a 3D additive direct laser writing (DLW) approach based on two photon polymerization (2PP) is used.

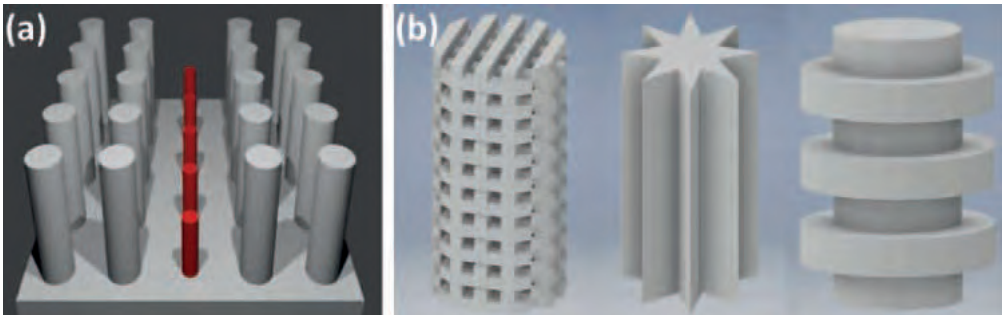

Figure 1. A microactuator array consisting of responsive hydrogel pillars is depicted (a). Complex 3D architectures (b) can improve the actuation function significantly.

[1] T. Spratte C. Arndt, I. Wacker, M. Hauck, R. Adelung, R. R. Schröder, F. Schütt, C. Selhuber-Unkel, "Thermoresponsive Hydrogels with Improved Actuation Function by Interconnected Microchannels", Adv. Intell. Syst., 2021, 2100081

Thursday, 07.04.
5:20 – 5:22 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

LIGHT BASED 3D-BIOPRINTING SYSTEMS TO RESEMBLE SKIN MODELS

Angela Cirulli

Angela Cirulli[1], Livia Neves Borgheti-Cardoso[1], Núria Torras[1], Jordi Comelles[1], Elena Martínez[1;2;3]

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3. Department of Electronics and Biomedical Engineering, University of Barcelona, Barcelona, Spain.

Bioprinting strategies allow to reconstruct 3D tissue models that resemble in structure and functions their native counterparts. This is performed by assembling biomaterials and cells with high precision, with a spatiotemporal control over cell-cell and cell-extracellular matrix communication. 3D bioprinting also allows to recreate specific complex-tissue properties such as shape, vasculature and multicellularity[1].

In this study we aim to recreate skin-like tissue models resembling both the epidermal and the dermal compartments using photopolymerizable polymers. Two light-based bioprinting approaches have been used for this purpose.

First, a skin prototype has been developed using a custom-made Direct Laser Writing (DLW) system working with visible light. Then, the size of the tissue-like constructs had been scaled up to the cm scale by using a commercial Digital Light processing stereolithography (DLP-SLA) system.

Both systems can polymerize cell-laden bioinks and the obtained hydrogels are able to support cell growth, proliferation and spreading within the scaffolds, resulting in high cell viability. In addition, epidermal cells grown on top of the cell-laden hydrogels have been able to grow and differentiate, generating full-thickness human-skin constructs.

1. Moroni L. et al. Nat. Rev. Mater. 3, 21-37 (2018)

Thursday, 07.04.
5:22 – 5:24 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

STRETCHABLE AND HEALABLE BIOELECTRONIC MATERIALS

Fabio Cicoira

Fabio Cicoira, Xin Zhou[2], JoElen Hagler[3], Yang Li

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Organic electronics, based on semiconducting and conducting polymers, have been extensively investigated in the past decades and have found commercial applications in lighting panels, smartphone and TV screens using OLEDs (organic light emitting diodes). Many other applications are foreseen to reach the commercial maturity in future in areas such as transistors, sensors and photovoltaics.

Organic electronic materials, apart from consumer electronics, are playing a central role in a myriad of novel applications that are becoming ubiquitous in our society, such as artificial muscles, electronic skin, prosthetics, smart textiles, rollable/foldable displays and biomimetics. Progress in these fields comes after decades of intense research and development in materials science and engineering, which have resulted in materials combining properties that are often mutually exclusive. For instance, materials showing high flexibility/stretchability, self-healing electronic/ionic conductivity, enhanced optoelectronic performance are now a reality.

Another flourishing field is that of organic bioelectronics, where devices such as conducting polymer electrodes are used for recording and stimulating neural, muscular and nerve activity. In such applications, organic polymers are very attractive candidates due to their distinct properties of ionic/electronic conduction, which leads to a lower impedance at the electrode/tissue interface, oxide-free interfaces, tunable mechanical properties, which allow films to be deposited on irregular surfaces and tunable surface chemistry, which permits to promote or hinder the adhesion of biomolecules. These features can be particularly useful for enhancing the performance and the biocompatibility of implantable electrodes and other biomedical or wearable devices.

My talk will deal with processing and characterization of conducting polymer films and hydrogels and devices for flexible, stretchable and healable electronics as well as for implantable electrodes. I will particularly focus on micro-patterning of conducting polymer films for flexible and stretchable devices, on processing strategies to fabricate stretchable and self-healing conductors, on the fabrication and characterization, *in vitro* and *in vivo*, of electrodes for deep brain stimulation and electromyography[1-9].

[1] Y. Li, S. Zhang, N. Hamad, K. Kim, L. Liu, M. Lerond, F. Cicoira, Tailoring the Self-Healing Properties of Conducting Polymer Films, Macromol. Biosci., i2000146, 2020.
[2] Y. Li, X. Li, S. Zhang, L. Liu, N. Hamad, S. R. Bobbara, D. Pasini, F. Cicoira, Autonomic Self-Healing of PEDOT:PSS Achieved via Polyethylene Glycol Addition, Adv. Funct. Mater., 30, 2002853, 2020.
[3] Y. Li, X. Li, R. N. Unnava Venkata, S. Zhang, F. Cicoira, Highly Stretchable PEDOT:PSS Organic Electrochemical Transistors Achieved via Polyethylene Glycol Addition, Flexible and Printed Electronics 4, 044004, 2019.
[4] N. Rossetti, P. Luthra, J. Hagler, A. H. J. Lee, C. Bodart, X. Li, G. Ducharme, F. Soavi, B. Amilhon, F. Cicoira, Poly(3,4-ethylenedioxythiophene) (PEDOT) Coatings for High-Quality Electromyography Recording, ACS Appl. Bio Mater. 2, 5154-5163, 2019.
[5] C. Bodart, N. Rossetti, J. Hagler, P. Chevreau, D. Chin, F. Soavi, S. Schougaard, F. Amzica, F. Cicoira, Electropolymerized poly(3,4-ethylenedioxythiophene) (PEDOT) coatings for implantable deep-brain stimulating microelectrodes, ACS Appl. Mater. Interfaces, 11, 17226-17233, 2019.
[6] S. Zhang, Y. Li, G. Tomasello, M. Anthonisen, X. Li, M. Mazzeo, A. Genco, P. Grutter, F. Cicoira, Tuning the electromechanical properties of PEDOT:PSS films for stretchable transistors and pressure sensors, Adv. Electron. Mater, 1900191, 2019.
[7] S. Zhang, F. Cicoira, Water-enabled Healing of Conducting Polymer Films, Adv. Mater. 29, 1703098, 2017.
[8] Highly stretchable electrospun conducting polymer nanofibers, F. Boubée de Gramont, S. Zhang, G. Tomasello, P. Kumar, F. Cicoira, Appl. Phys. Lett. 111, 093701, 2017.
[9] S. Zhang, E. Hubis, G. Tomasello, G. Soliveri, P. Kumar, F. Cicoira, Patterning of Stretchable Organic Electrochemical Transistors, 29, 3126-3132, 2017.

Thursday, 07.04.
5:24 – 5:26 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

4D MICROPRINTING OF LIQUID CRYSTAL ELASTOMERS: A FACILE APPROACH TOWARD MULTI-FUNCTIONAL MICROSTRUCTURES

Li-Yun Hsu

Li-Yun Hsu, Eva Blasco

Ruprecht-Karls-Universität Heidelberg Organisch-Chemisches Institut, Germany

4D printing has attracted large attention over the years. In brief, 4D printing consists of the fabrication of three dimensional (3D) smart systems which exhibit property changes in response to external stimuli in a controllable manner. Among all the stimuli-responsive materials available, liquid crystalline elastomers have been extensively explored at the macro-and meso-scales[1].

However, despite the advanced state of 3D printing technologies, especially two photon laser printing, the use of these materials at the micro-and nanoscale remains limited. One of the main remaining challenges is the incorporation of light-response due to incompatibility of most of the dyes either with the wavelength of printing or with the liquid crystalline inks[1].

Herein, we propose a facile strategy to overcome these limitations and demonstrate the fabrication of complex light-responsive liquid crystalline microactuators.

First, with the utilization of two-photon laser printing, also known as direct laser writing (DLW), liquid crystalline 3D microstructures were printed within a sandwich glass cell with a configured orientation. Thereafter, five different photo-responsive dyes absorbing in different regions of the spectrum, blue, green, or red, were incorporated by infiltrating it into the liquid crystalline matrix respectively. This enables the liquid crystalline structures to perform a programmable actuation under irradiation with a suitable wavelength. The post-modification process was monitored by the characterization of time-of-flight secondary ion mass spectrometry (Tof-SIMS) and Raman spectroscopy. The actuation behaviors were further investigated by image analysis and nano-indentation. Furthermore, by incorporating dyes that absorb at different regions, dual-motion of the actuators was also achieved by tunning the irradiation wavelength.

This strategy provides a flexible pathway to introduce a broad range of functionalities in the 3D microstructures regardless of their compatibility with the liquid crystalline ink or with the printing conditions.

[1] del, M., Sol, J. A. H. P., Schenning, A. P. H. J., Debije, M. G., Adv. Mater. 2022, 34, 2104390

Thursday, 07.04.
5:26 – 5:28 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

QUANTUM-MECHANICAL STUDY OF PHOTOINITIATORS FOR 3D LASER NANOPRINTING

Anna Mauri

Anna Mauri, Mariana Kozlowska, Wolfgang Wenzel

Institute of Nanotechnology (INT), Karlsruhe Institute of Technology (KIT), Germany

3D laser nanoprinting technique based on two-photon polymerization (TPP), is a powerful and versatile approach that allows for the fabrication of 3D complex functional materials on micro and nanoscale[1,2].

New insights into further optimization of TPP by even better photoresists can be achieved through the study of the properties and operation mechanisms of photoinitiators (PIs) towards faster 3D printing. However, since the photophysical properties of different photoresists used in 3D laser nanoprinting and their radical generation mechanisms are not fully known, I focus on the explanation of photochemical processes upon multiphoton absorption and on their hypothetical radical formation mechanisms.

Through the use of Density Functional Theory (DFT) and Time-Dependent DFT (TD-DFT), I calculate and explore the photochemical rates (internal conversion, intersystem crossing, fluorescence, phosphorescence, absorption cross-sections of multiphoton absorption) and the radical formation mechanisms of the main classes of investigated photoinitiators. This includes both Norrish type I or Norrish type II PIs, i.e.: Irgacure 369, 7-diethylamino-3-thenoylcoumarin (DETC) and ((2E,6E)-2,6-bis(4-(dimethylamino)benzylidene)-4-methylcyclohexanone (BBK).

I therefore explain the fragmentation reactions of Norrish type I PIs by the cleavage of the weakest bond and the hydrogen atom transfer (HAT) reaction in the presence of a co-initiator that characterizes the radical generation mechanism of Norrish type II PIs (Figure1).

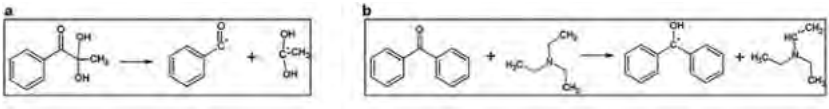


Figure 1:
a) Radical formation for Norrish Type I PIs.
b) Radical formation for Norrish Type II PIs.

1. Fischer, J. & Wegener, M. Three-dimensional optical laser lithography beyond the diffraction limit. Laser & Photonics Reviews 7, 22–44 (2013).
2. Yang, L. et al. On the Schwarzschild Effect in 3D Two-Photon Laser Lithography. Advanced Optical Materials 7, 1901040 (2019).

Thursday, 07.04.
5:28 – 5:30 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

COMPARISON OF UV PROJECTION AND MULTIPHOTON DIRECT WRITING TECHNIQUES IN THROUGHPUT AND DIMENSIONS

Arnoldas Solovjovas

Arnoldas Solovjovas, Jurga Jeršovaitė, Giedrius Balčas, Mangirdas Malinauskas

Laser Research Center, Faculty of Physics, Vilnius University, Lithuania

Stereolithography (SLA) and laser direct writing (LDW) are light-based 3D printing technologies and work on the photo-polymerization process. Both technologies start to differ in photo-sensitive resin types, light alignment strategy, exposure delivery scales, light source, etc. SLA is based on a linear absorption process, LDW on nonlinear optical phenomena[1].

In this work, we present our experimental results done both with SLA and LDW technologies. Below in Fig. 1. we depict a graph with fabrication time dependence to line-width of 3D printed rod structures. The yellow graph line represents measurements of structures fabricated with an SLA printer (Asiga Pico 2) and the blue line with LDW technology. We can notice that SLA is more efficient and is used to print structures with bigger dimensions (at least a few hundred micro-meters). Most important it consumes less time compared with multiphoton direct writing technology. From Fig. 1. we see that LDW prints rods of 26.1 µm width in ~17 min while SLA does it in 90 s. Yet there is one clear drawback: we save time with SLA printers only on bigger dimensions, but this technology has a feature size boundary of ~30 µm. LDW can print objects in nanometer dimensions. For bigger objects, LDW is available but ineffective when the printing process exceeds 12 hours.

Here we propose an approach to combine two lithography methods for multiscale structures once it has features smaller than 30 µm and volumes larger than 2 mm3 that would take more than 12 hours to produce it.

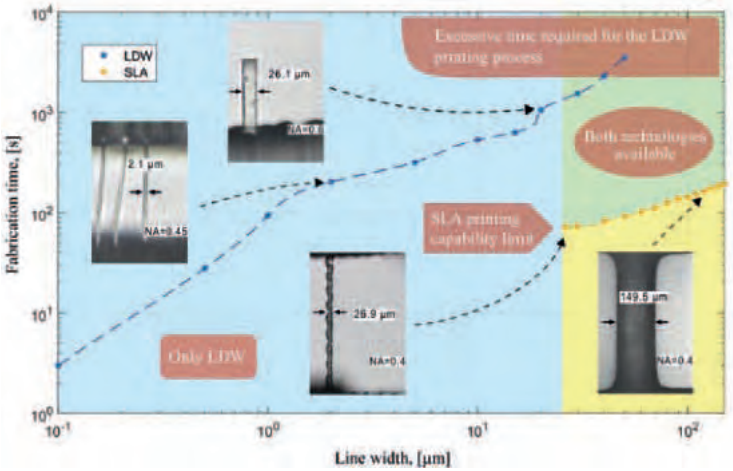


Fig. 1.
SLA and LDW technologies comparison in fabrication time dependence to printed line-width.

[1] L. Jonušauskas, S. Juodkazis, and M. Malinauskas, "Optical 3D printing: bridging the gaps in the mesoscale," J. Opt., 20, 5, 053001, May 2018, 10.1088/2040-8986/aab3fe.

Thursday, 07.04.
5:30 – 5:32 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

3D PRINTED CAPILLARY CHANNELS FOR GUIDING FUNCTIONAL CONDUCTIVE MATERIALS IN OPTOELECTRONICS

Kai Xia

Kai Xia[1,2], Clara Vazquez-Martel[3,4], Peter Krebsbach[1,2], Eva Blasco[3,4], Gerardo Hernandez-Sosa[1,2,5]

1 Light Technology Institute, Karlsruhe Institute of Technology,
2 InnovationLab, Heidelberg,
3 Organic Chemistry Institute, Heidelberg University,
4 Centre for Advanced Materials, Heidelberg University,
5 Institute of Microstructure Technology, Karlsruhe Institute of Technology

Solution-processed organic photodetectors (OPDs) have great potential for low-cost and large-area imagers. Their pixel sizes are determined by the area where the two overlapping electrodes typically remain in the millimeter range[1]. These feature size restrictions have prevented their utilization in high-end applications. Particularly for printed OPDs, this problem is mostly related to limitations in the resolution of common printing techniques. Therefore, an effective strategy is to reduce the electrode size by fluid management techniques after ink deposition[2,3].

Here we present 3D printed capillary channels for the fabrication of solution-processed Ag electrodes. In our method, Ag ink is dropped at one end of these channels and flows to the other due to capillarity. Our method can realize models that have tunnels under the surface. Thus we significantly increase the possibilities of device fabrication compared to capillary channels fabricated by 2D imprinting techniques[3]. After optimizing the annealing process of Ag ink within capillary channels we achieved resistance values comparable to that of the inkjet-printed Ag ink on glass.

Currently, we have achieved width and spacing features ~ 300 µm, which will give us the possibility of fabricating electrodes for OPDs with active areas (< 0.09 mm2) that are much smaller than the size of many reported OPDs.

[1] Strobel, et al. Adv. Mater. 2020, 32, 1908258
[2] Eckstein, et al. Adv. Mater. 2016, 28, 7708
[3] Hyun, et al. Adv. Electron. Mater. 2016, 2, 1600293

Thursday, 07.04.
5:32 – 5:34 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

3D PRINTING OF REACTIVE NANOPOROUS POLYMERS VIA POLYMERIZATION-INDUCED PHASE SEPARATION AND THIOL-ENE CHEMISTRY

Fatma Aslan

Fatma Aslan[1], Zheqin Dong[1], Pavel A. Levkin[1]

1 Karlsruhe Institute of Technology (KIT), Institute of Biological and Chemical Systems – Functional Molecular Systems (IBCS-FMS), Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

3D printing of polymers with porous structures at the nanoscale is imperative for broad applications including adsorption, separation, sensing, and biomedical engineering, and has previously been realized by combining methacrylate polymerization with polymerization-induced phase separation[1].

Nevertheless, these methacrylate-based 3D networks demonstrated limited mechanical strength. To move 3D-printed nanoporous polymers beyond the limitations of methacrylate formulations, we developed a new strategy that combines DLP 3D printer, polymerization-induced phase separation, and thiol-ene click chemistry.

We demonstrate that nanoporous polymer materials can be 3D printed via thiol-ene polymerization using a desktop DLP printer, and ink formulations composed of commercially available thiol, -ene crosslinkers, and porogen solvents, which undergoes phase separation upon photopolymerization to generate the inherent porous structures.

These polymeric materials were comprehensively characterized to investigate their physicochemical features. Interestingly, the 3D-printed nanoporous thiol-ene polymers are mechanically resilient with good reversible compressibility (50% strain). Furthermore, the nanoporous thiol-ene polymers can be readily grafted in a subsequent thiol-Michael addition reaction to confer them with different properties and functionalities.

We believe this novel approach may facilitate the implementation of 3D-printed porous polymers particularly in drug delivery and biomedical area.

1] Dong, Z., et al (2021). 3D printing of inherently nanoporous polymers via polymerization-induced phase separation. Nature communications, 12(1), 1-12.

Thursday, 07.04.
5:34 – 5:36 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

DEVELOPMENT OF A THREE-DIMENSIONAL, VASCULAR TUMOR MODEL

Sonja Leopold

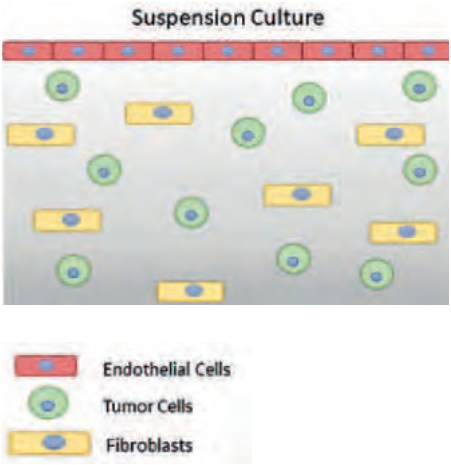
IFG-CB, KIT

In the field of tissue engineering, possibilities for the production of three-dimensional, artificial tissue models, which can be used for drug screens in research and the pharmaceutical industry, have been sought for some time. Such tissue models include artificial tumor models.

Tumors have the property that, above a certain size, they secrete growth factors that can initiate angiogenesis of endothelial cells. Angiogenesis is the formation of new blood vessels from existing ones. In this process, after activation by growth factors such as VEGF (vascular endothelial growth factor) or FGF (fibroblast growth factor), the endothelial cells of the already existing blood vessels grow in tubular structures along the growth gradient secreted by the tumor. This allows tumors to maintain their optimal nutrient and oxygen supply even as they increase in size, since metabolites and gases can only diffuse 100-200 µm into tissues without transport through blood pathways.

In my PhD thesis, I will develop a vascularized tumor model by inducing angiogenesis of endothelial cells via co-culture with tumor cells and fibroblasts to form new tubular structures. For this purpose, different models will be tested, a three-dimensional suspension culture and a culture with an embedded spheroid of tumor cells, which will mimic the morphology of an *in vitro* tumor.

In addition, all the materials and cells used should be suitable for 3D bioprinting so that such models can be 3D printed on organ-on-a-chip systems, for example.



Thursday, 07.04.
5:36 – 5:38 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

ILLUMINATING MATERIALS: IDEAL LIGHT-MATTER-INTERACTIONS IN BIOMEDICAL ADDITIVE MANUFACTURING

Leonard Siebert

L. Siebert[1], P. Schadte[1], H. Qiu[1], I. Teegen[1], J. Bahr[1] and R. Adelung[1]

1 Functional Nanomaterials Group, Institute for Material Science, Kiel University, Kaiserstr. 2, 24143 Kiel, Germany

Electromagnetic radiation has long since become one of the fabrication tools in additive manufacturing from methods like Stereolithography to Selective Laser Sintering. However, despite a mere tool for fabrication, the broad range of the electromagnetic spectrum can be also used for additional functionalities like smart triggers. Here, a selection of additive manufacturing-related biomedical applications will be presented, each showing a different innovative usage of light for adding functionality or obtaining insight in crucial material properties.

Firstly, soft surgery practice phantoms, made from hydrogel with tailored X-Ray opacity and mechanical properties for training of robot-assisted surgery are presented. By varying the contents of the hydrogels, the contrast during computer tomography (CT) measurements is adapted to represent real organs like liver and kidney. The intensity of crosslinking is used to modify the mechanical properties independently of the X-Ray opacity.

Secondly, light is shown to be used as a trigger in the release of growth factors that facilitate wound healing from 3D-printed smart hydrogel wound patches. The bio-active, anti-bacterial zinc oxide microcrystals in these patches are light-sensitive and can release surface-bound proteins upon illumination. *In vivo* experiments show increased wound healing capabilities of these hydrogel patches compared to pristine hydrogel. Aside from this, the same zinc oxide microcrystals' responsivity towards UV-light is utilized in additively manufactured, free-standing, flexible UV-light-sensors.

Lastly, the deep infrared wavelength of a CO2-Laser is utilized for efficient, oven-free laser sintering of ceramic pastes like silica and zirconia. Due to the long wavelength of the CO2-Laser, the radiation is absorbed efficiently by oxide ceramics. The dust-free, open source nature of this approach will be demonstrated for the production of dental crowns and novel shape memory ceramics.

Thursday, 07.04.
5:38 – 5:40 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

TWO STEPS TOWARDS NOVEL 3D LASER NANOPRINTERS

Tobias Messer

Tobias Messer[1], Vincent Hahn[1], N. Maximilian Bojanowski[1], Ernest Ronald Curticean[2], Irene Wacker[2], Rasmus R. Schröder[2], Eva Blasco[2], and Martin Wegener[1]

1 Karlsruhe Institute of Technology (KIT), Germany
2 Ruprecht-Karls-Universität Heidelberg, Germany

Nowadays, two-photon induced 3D laser lithography is a widely used technique for the manufacturing of three-dimensional microstructures such as micro-optics or cell scaffolds. However, efficient two-photon excitation (2PA) comes along with some issues: Due to the high intensities needed for sufficient 2PA, femto-second pulsed laser sources are required causing higher-order processes and leading to large and expensive setups.

Here, we introduce two-step absorption as a novel optical excitation process to replace ordinary 2PA1. The straightforward but elegant idea is to replace the intermediate dressed state of the photoinitiator molecule in 2PA by a real state. This allows for employing low-power continuous-wave light sources in the blue for excitation. In common resist systems, this would lead to forfeiting the ability of spatial confinement in arbitrary 3D structures due to ordinary one-photon processes[2]. Under suitable conditions, however, two-step absorption shows the same quadratic nonlinearity as 2PA.

We present a resist system containing a two-step capable photoinitiator, a standard monomer, and a scavenger, which is crucial for refined two-step polymerization. Further, we present 3D microstructures matching the state-of-the-art and beyond printed by an inexpensive, compact semiconductor laser diode at 405 nm wavelength. This opens the door to novel 3D laser nanoprinters drastically reduced in cost and size. A brief outlook to such devices is given.

Figure 1 (taken from [1]): Schematic illustration of the energy levels and excitation process in two-photon absorption (center) and two-step absorption (right).

[1] Vincent Hahn, Tobias Messer, N. Maximilian Bojanowski, Ernest Ronald Curticean, Irene Wacker, Rasmus R. Schröder, Eva Blasco, and Martin Wegener, Nat. Photon. 15, 932-938 (2021)
[2] Pascal Kiefer, Vincent Hahn, Martina Nardi, Liang Yang, Eva Blasco, Christopher Barner-Kowollik, and Martin Wegener, Adv. Opt. Mater. 8, 2000895 (2020)

Thursday, 07.04.
5:40 – 5:42 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

NEW MATERIALS FOR DIRECT LASER WRITING ON THE BASIS OF VINYLCYCLOPROPANES

Saskia Braun

We use 3D direct laser writing (DLW) to design macroscopic objects. A serious obstacle in DLW is volume shrinkage (up to 30%) during polymerization resulting in curvature of the written object at the substrate-polymer interface and volume reduction of the desired object.

High shrinkage reduces adhesion between the coating layer and the substrate in coating applications. Vinylcyclopropane (VCP) derivatives polymerize with lower shrinkage (up to 5%) and offer an attractive alternative to dimethacrylate resins.

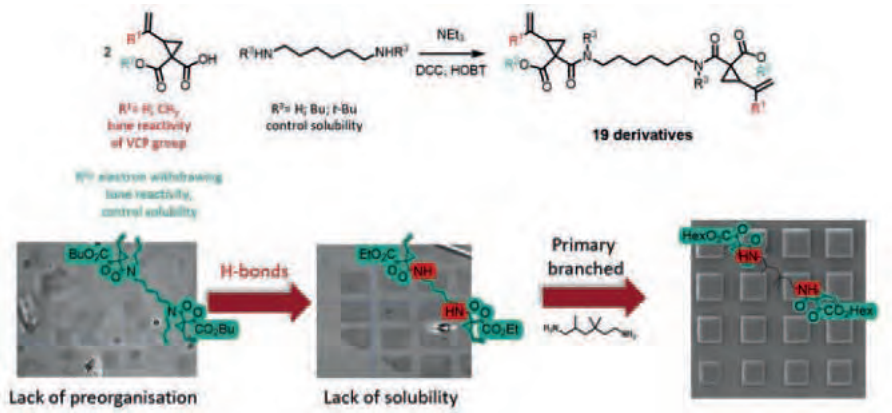
The first goal is to develop material systems, which do not undergo volume shrinkage after deposition and writing. Such a concept is already established for solution-based synthesis involving radical cyclopropane ring-opening strategies, which we will apply to network-forming materials suitable for our structuring process.

However, there are additional challenges to upgrade common VCPs for DLW.

A) The monomers have to carry at least 2 VCP units to allow crosslinking into an insoluble 3D object.

B) The monomers have to be either liquid or very well soluble in solvents with low vapour pressure and a high boiling point (≥ 150 °C) to allow DLW applications.

C) We find that preorganization of the monomers by directional hydrogen bonds is extremely beneficial for the efficiency of the DLW Process.



Thursday, 07.04.
5:42 – 5:44 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

DEVELOPMENT OF HYDROGELS FOR USE IN TISSUE ENGINEERING FOR THE PRODUCTION OF ORGAN MODELS USING THE 3D BIOPRINTING PROCESS

Alisa Grimm

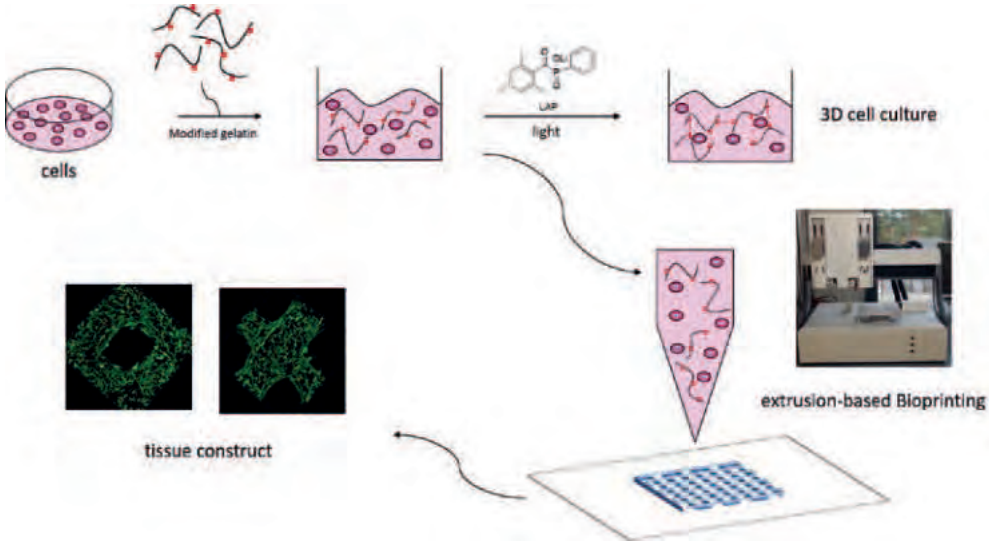
My research topic deals with the application of gelatin-based hydrogels, which are already established in the working group, for the construction of a heart model.

3D bioprinting makes it possible to produce artificial organ and tissue models in the field of tissue engineering. The future vision is that the artificially produced tissues will be used in the field of organ transplantation or drug screening.

So-called cell-loaded hydrogels have become established as materials for 3D bioprinting. These hydrogels must meet certain requirements so that the cells can be cultivated in them.

First, the hydrogel should mimic the extracellular matrix as much as possible, since this is the natural environment of the cells, and the cells within the hydrogel should have the ability to proliferate, migrate and differentiate.

Second, the hydrogel must be able to withstand the mechanical demands of 3D bioprinting.
So far in my PhD studies, human cardiac myocytes and partially human cardiac fibroblasts have been investigated for the suitability of gelatin-based hydrogels and further characterized the required 3D bioprinting parameters. It is yet to enable the cocultivation of these cells.



Thursday, 07.04.
5:44 – 5:46 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

ELECTROCHEMICAL MULTI-METAL NANO- AND MICRO-3D PRINTING

Julian Hengsteler

Julian Hengsteler[1], Albert Ripoll Oliveras[1], Andrei Zotov[1], Tomaso Zambelli[1] and Dmitry Momotenko[2]

1 Laboratory of Biosensors and Bioelectronics, Institute for Biomedical Engineering, ETH Zurich, 8092 Zürich, Switzerland
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The ability to fabricate complex, arbitrary-shaped metal objects with micro- to nanoscale dimensions is one of the great advantages of latest metal additive manufacturing methods. Advanced optical technologies, sensing, micro- and nanorobotics, more efficient energy storage - all require structural and functional elements with feature sizes in the micro- or even nanometer scale.

I*n-situ* metal synthesis, essential to electrochemical 3D printing methods, allows to 3D print metals with unprecedented resolution. In the past electrochemical 3D printing methods have shown the capacity to produce highly complex[1] yet mechanically stable[2] and electrically conductive metal structures all in a relatively simple manner. True nanoscale resolution of electrochemical 3D printing with meniscus confined electrodeposition reached voxel sizes below 100 nm[3].

To push the advances in 3D microfabrication further combining multiple metals in a single 3D printed part is needed. This way functional devices such as thermocouples or microbatteries can be fabricated with a high degree of freedom. In this work we present a new methodology for multi-metal meniscus confined electrodeposition. More specifically printing a pair of two different metals (e.g. Cu & Au) with one printing nozzle, a theta (double-barrel) pipette.

Using a voltage-controlled mechanism we show that the electrolyte composition in meniscus at the tip of the nozzle can be tuned for an on-the-fly metal choice. The experimental results are supported by finite-element analysis simulations. In addition to printing various metal-pairs from different ionic compositions we aim at controlling the metal composition of the printed parts from pure metals to alloys of different metal-metal ratios. Eventually this method will allow manufacturing of functional metal-metal interfaces or high-resolution electrode (anode-cathode) configurations for (electrochemical) sensors or energy storage devices.

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Thursday, 07.04.
5:46 – 5:48 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

FISH RETINAL ORGANOID CULTURE AS A SYSTEM TO STUDY CELL FATE DECISIONS DURING RETINAL DEVELOPMENT

Lucie Zilova

Lucie Zilova, Christina Schlagheck, Joachim Wittbrodt

Centre for Organismal Studies Heidelberg, Germany

Proper visual perception is strictly dependent on coordinated differentiation and correct assembly of multiple tissues of developing eye. During vertebrate development, the neuroepithelium of the optic vesicle differentiate into three main tissues: neuroretina (NR), retinal pigmented epithelium (RPE), and a ciliary margin zone (CMZ) harboring retinal stem cells on their boundary.

The mechanism of how a single progenitor gives rise to three different tissues, particularly to cells of CMZ, is not fully understood. Here we use retinal organoids derived from the teleost fish medaka (Oryzias latipes) as a model to study mechanisms that contribute to the bias of progenitors of the optic vesicle towards NR, RPE and CMZ cell fates.

We have previously demonstrated that fish primary embryonic stem cells efficiently assemble into 3D retinal organoids carrying progenitors of the optic vesicle neuroepithelium. Here we show that this simple retinal neuroepithelium can be directed into NR, RPE and CMZ tissues fates by modulation of single signaling pathway, Wnt/β-catenin pathway. While RPE specification requires high levels of Wnt/β-catenin signaling activity, NR specification can occur only in its absence.

Interestingly, intermediate levels of Wnt/β-catenin signaling activity result in acquisition of CMZ fate, indicating that the gradient of Wnt/β-catenin signaling built up during optic cup morphogenesis contributes to the acquisition of NR, RPE and CMZ fates and that possibly the interface between NR (with no Wnt activity) and RPE (with high Wnt activity) provides the niche for establishment of stem cell carrying CMZ.

Thursday, 07.04.
5:48 – 5:50 PM
Poster Presentation:
Thursday, 5:50 - 6:50 PM

HIGH ASPECT RATIO 3D MICROSTRUCTURES USING NEAR-FIELD ELECTROSPINNING

Ahsana Sadaf

Ahsana Sadaf, Monsur Islam, Dario Mager and Jan Korvink

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This study presents the fabrication of high aspect ratio 3D wall structures through the high-speed patterning of polymeric nanofibers from a charged droplet, through a force induced by a high electric field. By achieving high precision in material deposition, and faster printing speeds, NFES holds potential as a high-speed additive nanomanufacturing tool, contrasting with traditional lithography-based techniques.

Here, we focus on studying the effect of process parameters on layer-by-layer fiber deposition for the fabrication of 3D wall structures. In our study, we found that three parameters, namely the electrospinnable solution's vapour pressure and dielectric constant, and the substrate conductivity, played a crucial role in the 3D stacking of fibers, and hence in the resulting nano- and microstructure of the fabricated walls.

By adjusting these properties, we fabricated 3D stacked walls of polyethylene oxide. We could achieve an average aspect ratio of 191.7±52.6 (fig. 1), which is comparable in height to structures obtained using the LIGA process (LIGA remains the record-holder method for high-aspect ratio microstructuring), but which requires resist exposure to synchrotron radiation.

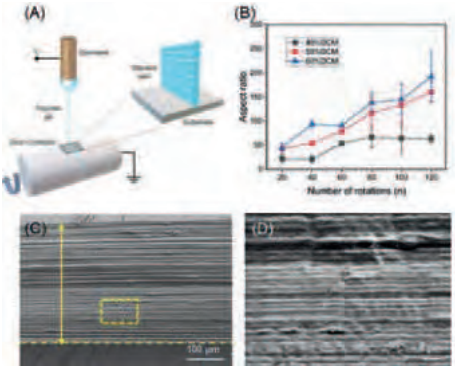

Fig. 1
(A) Schematic of the experimental set-up.
(B) Aspect ratio of a 3D stacked wall formed on a rotating drum counter electrode.
(C) SEM image showing stacked layers of fibers.
(D) Closeup of the rectangular section marked in (C).

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Poster Presen

Monday

3D Microfabrication of Structured Stimuli Responsive Hydrogel Actuator Systems	**Tobias Spratte**
Printing and Erasing of DNA-based Photoresists \\inside Synthetic Cells	**Tobias Walther**
Two-Photon 3D Laser Printing Inside Synthetic Cells	**Tobias Abele**
Intrinsic Light Localization in Photonic Icosahedral Quasicrystals	**Artem Sinelnik**
Generation of Cell Factories by 3D Structuring	**Mohammadreza Taale**
GUIDE Plus – Co - Creation Lab "Product Innovation" – From Lab Discovery to Business	**Marvin Kollwitz**
Future Scenarios of 3D Printing in Society	**Christoph Schneider (ITAS)**
Towards 3D Magnon Spintronics	**Huixin Guo**
Phase Field Model for Near-field Electrospinning	**Ka Chun Chan**
Influence of Mechanical Forces on Cell Identity in the Medaka Retinal Organoid	**Christina Schlagheck**
Light-Sheet 3D Microprinting via Two-Colour Two-Step Absorption	**Pascal Rietz**

tation 6:00 – 7:00 PM

Multi-focus Large FOV 3D Laser Nanoprinting by a Combination of Optical Micro-Elements	**Pascal Kiefer**
Sustainable Feedstocks for Additive Manufacturing: Are vegetable oils the solution?	**Clara Vazquez-Martel**
Direct Synthesis of Plasmonic Nanoparticles in Photopolymers for Improved 3D Lithography Part Production for Biomedicine Applications	**Philipp Gabriel**
Metal Oxide Memristive Devices Fabricated by Inkjet Printing	**Hongrong Hu**
3D Fabrication of Microvascular Networks on Artificial Organ Models for Endoscopic Surgical Simulation	**Felix Fischer**
Production and Downsizing of a Mechanically Strain-Stiffening Material Design Using 3D Micromanufacturing	**Malin Schmidt**
Immobilization of Cancer Cells in Artificial Tumours Triggers Biomechanical Heterogeneity and the Formation of Polyploid Giant Cancer Cells	**Aldo Leal-Egaña**
Selective Positioning of Different Cell Types on 3D Scaffolds Via DNA Hybridization	**Enrico Domenico Lemma**
Tissue Organisation Controlled by Curvature	**Barbara Schamberger**
In Situ Pyrolysis of 3D Printed Microstructures – an ESEM Study	**Qing Sun**
Laser Powder Bed Fusion Generated Magnetic and Plasmonic Parts from Nano-Additivated Polymer Powders	**Carlos Doñate Buendía**

PRINTING AND ERASING OF DNA-BASED PHOTORESISTS \\INSIDE SYNTHETIC CELLS

Tobias Walther

Tobias Walther[1,2,4], Kevin Jahnke[1,3,4],
Tobias Abele[1,3,4], Dr. Kerstin Göpfrich[1,2,3,4]

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3: Department of Physics and Astronomy, University of Heidelberg;
4: Cluster of Excellence 3D Matter Made to Order (3DMM2O)

In the pursuit to produce functioning synthetic cells from the bottom up, DNA nanotechnology has proven to be a powerful tool. However, the crowded yet highly organized arrangement in living cells, bridging from the nano- to the micron-scale, remains challenging to recreate with DNA-based architectures.

Here, laser microprinting is established to print and erase shape-controlled DNA hydrogels inside the confinement of water-in-oil droplets and giant unilamellar lipid vesicles (GUVs). The DNA-based photoresist consists of a photocleavable inactive DNA linker which interconnects Y-shaped DNA motifs when activated by local irradiation with a 405 nm laser. An alternative linker design allows to erase custom features from a preformed DNA hydrogel with feature sizes down to 1.38 µm.

The present work demonstrates that the DNA hydrogels can serve as an internal support to stabilize non-spherical GUV shapes. Overall, DNA-based photoresists for laser printing in confinement allow to build up architectures on the interior of synthetic cells with light, which diversifies the toolbox of bottom-up synthetic biology.

INTRINSIC LIGHT LOCALIZATION IN PHOTONIC ICOSAHEDRAL QUASICRYSTALS

Artem Sinelnik

Artem Sinelnik[1], Ivan Shishkin[2], Xiaochang Yu[3], Kirill Samusev[2], Pavel Belov[2], Mikhail Limonov[2], Pavel Ginzburg[4], Mikhail Rybin[2]

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2 ITMO University, Russia
3 Huazhong University of Science and Technology, China
4 Tel Aviv University, Israel

One of the most intriguing problems of light transport in solids is the localization that has been observed in various disordered photonic structures[1-4]. Here we report on the fabrication of submicron-size dielectric icosahedral quasicrystals by direct laser writing technology[5-6] and demonstrate the results of detailed studies of the photonic properties of these structures.

We found pronounced patterns of unconventional Bragg diffraction, which indicates the existence of multiple photonic pseudogaps. Furthermore, we present the first direct experimental observation of intrinsic light localization in defect-free quasicrystals. This result was obtained in time-resolved measurements at different laser wavelengths in the visible. We linked localization with the aperiodicity of the icosahedral structure, which led to uncompensated scattering of light from an individual structural element over the entire sphere, providing multiple scattering inside the sample and, as a result, the intrinsic localization of light.

Our results will fill the void in the field of light scattering between ordered and disordered structures and paves the way for a variety of applications in optics, from lasing and sensing to telecommunications using defect-free structures which support the intrinsic photonic wave localization.

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GENERATION OF CELL FACTORIES BY 3D STRUCTURING

Mohammadreza Taale

Mohammadreza Taale, Maria Villiou, Fereydoon Taheri, Federico Colombo, Tobias Spratte, Christine Selhuber-Unkel

Heidelberg University, Germany

Cell growth, adhesion and stem cell differentiation are controlled by biochemistry, but also by matrix mechanics and by the structural properties of the environment. The combination of well-defined scaffolds with external mechanical stimuli, i.e. forces, should allow for additional active stimulation of cells to control their properties. Using direct-laser writing, we vary the structural material features (e.g. fibers) of scaffolds by writing from the nanometer to the micrometer scale. This allows us to distinguish the impact of structural and mechanical scaffold properties on cells systematically.

Therefore, we have simplified the complex microstructure of cellular environment to fiber structure, which the effect of different parameters (e.g. fiber thickness, distance, curvature, nanostructure, stiffness) on fibroblast cells can then be tested in one sample. Silicone-based, hydrogel-based and fused silica glass-based scaffolds with different spatial distance (5 up to 50 µm) and fiber thickness (1 up to 20 µm) were printed successfully by using direct laser writing.

In addition, we explore the mechanostimulation of human mesenchymal stem cells and fibroblast cells by altering the mechanical properties of the scaffolds by varying the laser illumination time or using different photoresins. The scaffold material that we are investigating should serve as a “cell factory”, where cell properties are controlled by the scaffolds they grow in.

GUIDE PLUS — CO-CREATION LAB "PRODUCT INNOVATION" — FROM LAB DISCOVERY TO BUSINESS

Marvin Kollwitz

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The Co-Creation Lab (CCL) "Product Innovation" is part of the technology and knowledge transfer strategy of the University Duisburg-Essen. It is embedded in the "Zentrum für Gründungen und Innopreneurship der Universität Duisburg-Essen" (GUIDE), which is funded by the Ministry of Economic Affairs, Innovation, Digitalization and Energy of the state North Rhine Westphalia.

The goal of GUIDE is to support scientists interested in founding their own business and help to tackle the non-scientific challenges such as financing, patent law or to create a business plan for their start-up.

The CCL is located in Essen and focuses on product innovation and material development. It assists scientist, students and employees of the university in tackling the scientific and technical challenges that arise with inventive ideas. Our interdisciplinary team of product designers, chemists, engineers and 3D printing experts support the advancement of innovative product ideas, material development and creation of first prototypes. Various polymer 3D printing technologies such as filament extrusion, resin curing and powder printers as well as bioprinting capabilities are available.

FUTURE SCENARIOS OF 3D PRINTING IN SOCIETY

Christoph Schneider (ITAS)

Christoph Schneider, Paulina Dobroc

KIT, Germany

What could 3D printing do to society?

Could it make our economy more sustainable, or empower corporations, consumers or even citizens?

Is it realistic, that the technology enables disruptive change in ten or so years?

Which 3D printing technology is best suitable for use by “almost everyone” and what could be sustainability challenges of the technology?

We present speculative answers to these questions based on four scenarios that describe different use-cases of 3D printing. These scenarios have been developed in exchange with 3D printing researchers and practitioners, innovation researchers, social scientists and citizens. Through the four scenarios the poster analyzes the effects of 3D pritning on sustainability and accessibility of the technology.

The poster presentation invites to reflect on these scenarios and discuss the role that technology and research play in shaping such use-cases.

PHASE FIELD MODEL FOR NEAR-FIELD ELECTROSPINNING

Ka Chun Chan

Ka Chun Chan[1], Haodong Zhang[2], Fei Wang[2], Britta Nestler[2], Wolfgang Wenzel[1]

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2: Institute for Applied Materials, Karlsruhe Institute of Technology, Germany

Electrospinning is a well-established technique for the nanofibers fabrication, which could be down to the scale of tens nanometer, with different material compositions and structures. There is a broad range of applications of electorspinning, including catalysts, printed electronic, sensors and biomedical scaffolds.

Due to the electrostatic repulsion of the charged polymer fiber, the fabrication process are highly uncontrollable and imprecise. Near-field electrospinning (NFES) has been then developed to overcome the intrinsic instability of traditional electrospinning processes with a reduced electric field in a shorter deposition separation. Moreover, the electric force of the polymer jet is balanced by the surface tension at the interface and this caused the formation of Taylor cone, which generates nanofibers at nozzle and is a dominate factor to determine the quality of nanofibers fabrication.

Here we present a phase field method based on Taylor–Melcher leaky dielectric model, which has been used to describe electrohydrodynamic phenomena in poorly conducting liquids, to describe the nanofiber fabrication process and Taylor cone formation of the charged polymer jet. The model simulates the transient ejection of charged polymer jet from microscale nozzles, where the charged polymer fluid confined within the nozzle is subjected to an strong external electric field. By solving the coupled Navier–Stokes and charge conservation equations, the model is able to predict the polymer liquid motion and simulate the formation of the Taylor cone. It is also able to show the effect of different physical or material parameters, eg. applied voltage, surface tension and electrical permittivity of polymer, on the stability and quality of polymer nanofibers manufacturing.

With this model, we are allowed to analysis and optimize the experimental parameters and also the choice of polymer ink in order to generate stable, precise and controllable polymer nanofiber.

INFLUENCE OF MECHANICAL FORCES ON CELL IDENTITY IN THE MEDAKA RETINAL ORGANOID

Christina Schlagheck

Christina Schlagheck[1,2,3], Gero Hofmann[1], Federico Colombo[2,4], Marc Frederik Mayer[5], Natalie Munding[2,6], Falk Farkas[1], Svenja de Buhr[2,7], Frauke Gräter[2,7], Motomu Tanaka[2,6], Martin Wegener[2,5], Christine Selhuber-Unkel[2,5], Lucie Zilova[1,2], Joachim Wittbrodt[1,2]

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7: Heidelberg Institute for Theoretical Studies, Heidelberg University, Germany

During the development of an embryo, morphological changes shape cells and impact on tissue structure. To sustain growth, niches are formed which provide environmental input to the stem cells ranging from chemical signals to forces, such as tension, compression and membrane curvature acting on the tissues. In the embryo, the influence of single aspects of the mechanical component impacting on tissue identity is difficult to study.

Here, I make use of the organoid system of the medaka fish (Oryzias latipes) retina to study the impact of forces on cell identity. The medaka retina undergoes distinct morphological states during development and is comprised of three main cell layers arising from the same retinal progenitor cells (RGC): the neural retina (NR), the retinal pigment epithelium (RPE) and the peripheral retina (PR). The organoid system recapitulates early steps of retinal cell differentiation and gives rise to RGC and to NR, but so far does not fully resemble the distinct layered shape and cell composition. The organoids take a mainly ball-like shape serving the purpose of minimal surface tension. Therefore, the retinal organoid system offers the perfect platform to systematically test the definition of cell types in the retina by the application of external forces.

To do so, I expose organoids carrying the multipotent RPCs to mechanical constraints. I designed 3D printed forms and tested agarose scaffolds in which the organoids are placed and encounter differential spatially limiting structures. The organoids further differentiate in the constricted area and cell fate changes to RPE or the PR can be read-out by fluorescent reporter expression. I establish a workflow for the handling, scaffold preparation and the acquisition of live imaging data of about 100 organoids per experiment. Further, different types of mechanical input such as stretching are tested.

Later, I want to quantify the force applied to and encountered by the cells and define the time point when a change in cellular identity is occurring. Expression analysis by RNA-seq could then identify the activation of pathways induced by the force application and connected to the cell identity.

LIGHT-SHEET 3D MICROPRINTING VIA TWO-COLOUR TWO-STEP ABSORPTION

Pascal Rietz

Vincent Hahn[1,2], Pascal Rietz[1,2], Frank Hermann[1], Patrick Müller[2,3], Christopher Barner-Kowollik[2,6], Tobias Schlöder[2], Wolfgang Wenzel[2], Eva Blasco[4,5], and Martin Wegener[1,2]

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3D additive manufacturing is a cutting-edge technology enabling numerous applications. To serve this trend, high-speed high-resolution 3D printing techniques are required. Through a massive parallelization, projection-based optical approaches provide high printing rates. However, single voxel volumes often exceed 100 µm³. In contrast, multi-photon 3D nanoprinting, which is based on femtosecond laser pulses and scanning of a laser focus, routinely achieves < 1 µm³ volumes.

Here, we review our recent progress towards using two-colour two-step absorption combined with projection optics – an approach that we refer to as light-sheet 3D laser microprinting [1]. In light-sheet 3D laser microprinting, slices of a 3D object are projected by light from a continuous-wave laser of wavelength λ1 into a plane which is defined by a light-sheet beam of another wavelength λ2 from another continuous-wave laser. Only in regions which are simultaneously exposed by light of both wavelengths, a polymerizing chemical reaction of the liquid photoresist is triggered. This is achieved by an AND-type optical nonlinearity of the underlying photoinitiator, in which two-colour two-step absorption initiates the polymerization. This process builds on our previous work on one-colour two-step absorption and scanning of a laser focus [2]. Using the approach of light-sheet 3D microprinting and a suitable AND-type photoresist, printing rates approaching 107 voxels/s are achieved while maintaining voxel volumes < 1 µm³. We report on the light-sheet 3D microprinting setup as well as on the novel AND-type photoresist system.

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MULTI-FOCUS LARGE FOV 3D LASER NANOPRINTING BY A COMBINATION OF OPTICAL MICRO-ELEMENTS

Pascal Kiefer

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To meet the ever-increasing demands for large 3D laser nanoprinting structures of high complexity in biology, optics, material sciences, and pharmacy, the development of rapid lithography setups has become inevitable. To speed up the controlled curing of a liquid photoresist, a transition from serial scanning of a single focus to the point of highly parallelized manufacturing by e.g. projection-based[1] or multi-focus[2] setups is necessary.

While multi-focus approaches allow resolution-limited voxel sizes, they suffered from limited photoresist sensitivity and limited optical quality in the past. By a novel combination of a 3D laser nanoprinted diffractive optical element (DOE) with a multi-lens arrays (MLA), we enable a large low-aberration field of view while sensitive photoresists[3] guarantee printing even at large scan speeds and number of foci.

These advances facilitate the fabrication of large numbers of novel carrier particles for dry-powder inhalation[4]. To obtain suitable amounts for pharmaceutical studies, one has to produce particle numbers in the range of 107, which is not possible with conventional 3D laser nanoprinting setups.

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SUSTAINABLE FEEDSTOCKS FOR ADDITIVE MANUFACTURING: ARE VEGETABLE OILS THE SOLUTION?

Clara Vazquez-Martel

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Due to their versatility, adaptability, and durability, polymers are among the most attractive and widely used material class in additive manufacturing (AM)[1]. However, to bring the field of polymer AM to the next level and exploit its whole potential as a revolutionary manufacturing technique, sustainability must be addressed. In this context, sustainable sources for feedstocks are a crucial element to examine.

The use of biobased molecules derived from plants and microorganisms which can be modified and utilized as platforms for designing new polymers for AM is a promising approach[2]. For instance, vegetable oils are a very attractive plant-based feedstock due to their wide availability, low price, and interesting functionality[3–5]. Herein, novel sustainable formulations are developed for digital light processing (DLP) using five vegetable oils – sunflower, canola, soybean, olive, and sesame oil – as feedstock[6].

These vegetable oils are successfully modified incorporating photopolymerizable groups (= acrylates) enabling printability. The biobased formulations consisting of the functionalized oil and a photoinitiator are employed as inks for DLP without the need for further additives. The rheology and curing behavior of all vegetable oil-based inks, as well as the thermal and mechanical properties of the printed materials are carefully investigated. In summary, sunflower and canola oil derivatives offer a better cost-performance ratio than state-of-the-art soybean oil materials and can be employed for 3D printing of complex geometries with high speed and resolution.

We believe that this work enriches the opportunities of using biobased and inexpensive materials as high-performance polymer materials and opens new possibilities for the next generation of sustainable AM.

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DIRECT SYNTHESIS OF PLASMONIC NANOPARTICLES IN PHOTOPOLYMERS FOR IMPROVED 3D LITHOGRAPHY PART PRODUCTION FOR BIOMEDICINE APPLICATIONS

Philipp Gabriel

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Vat photopolymerization used in the additive manufacturing technique of 3D lithography has a high potential to be used for biomedical applications if combined with high design freedom and accuracy. But the process requires photoinitiators (PI) which are potentially toxic, limiting the biomedical applicability [1] and demanding the research of alternative additives. Here, first studies verified that adding minute amounts of plasmonic nanoparticles (NP) to the pre-polymer can partially replace the PI, without loss of structural accuracy [2], which also benefits from using laser-generated NP enabling an improved NP-polymer coupling due to their surfactant-free surface [3]. But, here, NP production was performed in an isopropanol mixed resin, which requires a subsequent vaporizing step.

We propose that the scalable laser-based synthesis enables the NP production directly in highly viscous polymer to produce NP-doped resins in a single step (Fig.1A). We used the laser ablation in liquids (LAL) method in which a metal target, placed in a vessel containing polymeric, laser-transparent nail polish (photopolymer), is irradiated with pulsed laser light. We found that this process allowed direct integration of the NP into the resin (Fig.1B, ref. [4]), improving its hardness, toughness, and resistance properties [5]. This opens new possibilities also in the field of lithography: printed parts doped with tunable levels of ligand-free, plasmonic NPs possibly improves the processability of the photopolymers and final part properties, potentially solving typical flaws, like brittle parts.

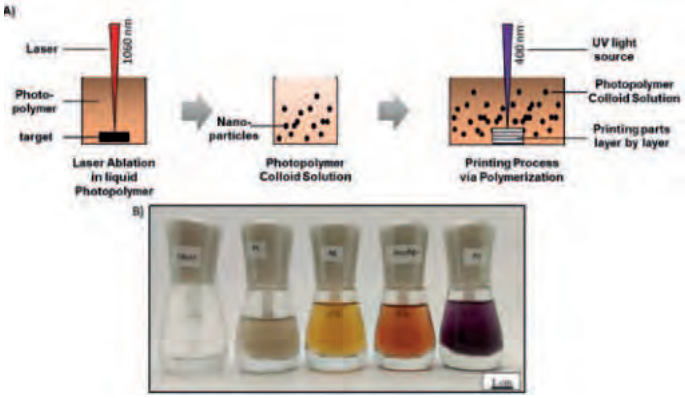

Figure 1:
A) Direct laser synthesis of plasmonic nanoparticles in resin, followed by the 3D printing process based on vat photopolymerization.
B) Nanoparticles in nail polish [4]

[1] Williams, G. et.al., Biomat., 26-11, 1211-1218, 2005
[2] Jonušauskas, L. et.al., Nanotech. 27, 154001, 2016
[3] Zhang, D. & Goekce, B. Appl. Surf. Sci., 392, 991-1003, 2017
[4] Lau, M. et.al., Ind. Eng. Chem. Res, 56, 3291–3296, 2017
[5] Lohani, A. et.al., ISRN Dermatol. 843687, 2014

PRODUCTION AND DOWNSIZING OF A MECHANICALLY STRAIN-STIFFENING MATERIAL DESIGN USING 3D MICROMANUFACTURING

Malin Schmidt

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By mimicking the biological principle of strain-stiffening in cells with a three-dimensionally structured material, a synthetic, mechanical metamaterial has been achieved. The strain-stiffening effect in this material design occurs due to the structural features of the complex three-dimensional material, which is based on slats between several backbones: During elongation of the material, the flexible slats touch each other leading to a stiffening of the material. At a certain degree of displacement, a final stiffness is reached.

The studied strain-stiffening effect is highly non-linear, tuneable, rate and material independent and reversible. It does not rely on the specific chemistry of a material so that different elastic materials can be employed. By variations and adaptation of the three-dimensional geometry of the material's structure, the mechanical properties can be finely tuned, allowing our metamaterial to provide optimal function and optimal mechanical properties for usage in biomedical applications. Compared to strain-stiffening samples in the cm-range, the production of highly detailed strain-stiffening samples in a micron range is hard to achieve with classic fabrication techniques like molding.

The reduction of size was investigated by using a novel additive micromanufacturing technique that is based on two-photon polymerization. Strain-stiffening samples were not only printed as single strain-stiffening microstructures but moreover, three-dimensional arrangements of strain-stiffening structures are studied. The properties of the structures are mechanically investigated to in future optimize them to resemble the mechanical properties of biological tissue like native blood vessels and thus promoting the integration of this strain-stiffening structure in future biomedical applications.

Poster Presen

Thursday

Development of Hydrogels for Use in Tissue Engineering for the Production of Organ Models Using the 3D Bioprinting Process	**Alisa Grimm**
Light Based 3D-Bioprinting Systems to Resemble Skin Models	**Angela Cirulli**
4D Microprinting of Liquid Crystal Elastomers: a Facile Approach Toward Multi-Functional Microstructures	**Li-Yun Hsu**
Quantum-Mechanical Study of Photoinitiators for 3D Laser Nanoprinting	**Anna Mauri**
Fabrication of Flexible Microfluidic Devices with Integrated Droplet Regulators Via Projection-Microstereolithography	**Niclas Weigel**
Electrochemical Multi-Metal Nano- and Micro-3D Printing	**Julian Hengsteler**
3D Printed Capillary Channels for Guiding Functional Conductive Materials in Optoelectronics	**Kai Xia**
3D Printing Of Reactive Nanoporous Polymers Via Polymerization-Induced Phase Separation and Thiol-Ene Chemistry	**Fatma Aslan**
Additive Manufacturing of Silica Glass and Zirconia Via Laser Assisted Direct Ink Writing	**Philipp Schadte**
Adhesion Miniproteins for Tissue Engineering	**Florian Häge**
In Silico Studies of the Helical Induction of Cis-Transoid Poly (4-Carboxyphenyl) Acetylene By Chiral Amines Reveal Local Electronic Transfer Roll	**Montserrat Penaloza-Amion**

tation 6:00 – 7:00 PM

Development of a Three-Dimensional, Vascular Tumor Model	**Sonja Leopold**
Wavelength and Pulse Duration Influence on Laser 3D Nanolithography	**Edvinas Skilutas**
Two Steps Towards Novel 3D Laser Nanoprinters	**Tobias Messer**
High Resolution Patterning of Doping in Semiconducting Polymer Films by Non-Resonant Laser Excitation	**Christian Rainer**
New Materials for Direct Laser Writing on the Basis of Vinylcyclopropanes	**Saskia Braun**
Electron-Beam Lithography of Cinnamate Polythiophene Films	**Maximilian Bojanowski**
Comparison of UV Projection and Multiphoton Direct Writing Techniques in Throughput and Dimensions	**Arnoldas Solovjovas**
High Aspect Ratio 3D Microstructures Using Near-Field Electrospinning	**Ahsana Sadaf**
Fish Retinal Organoid Culture as a System to Study Cell Fate Decisions During Retinal Development	**Lucie Zilova**
Illuminating Materials: Ideal Light-Matter-Interactions in Biomedical Additive Manufacturing	**Leonard Siebert**
Stretchable and Healable Bioelectronic Materials	**Fabio Cicoira**

FABRICATION OF FLEXIBLE MICROFLUIDIC DEVICES WITH INTEGRATED DROPLET REGULATORS VIA PROJECTION-MICROSTEREOLITHOGRAPHY

Niclas Weigel

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Additive manufacturing based on projection micro-stereolithography (PμSL) has emerged as a useful tool for the fabrication of micro-structured surfaces as well as objects with complex inner structure, e.g., microfluidic devices. By illuminating a liquid photopolymer formulation (resin) by dynamic mask projection in a layer-by-layer fashion, three-dimensional objects are obtained in monolithic fashion and micrometer-resolution. However, commercial photopolymer formulations often provide rather limited versatility regarding transparency, elasticity, wettability or XYZ-resolution. Exemplarily, in the field of microfluidics, we require exact control over composition, polymerization kinetics, viscosity, and functionality of photopolymer formulations[1].

On this account, we present a library of 3D-printable, flexible materials for high-resolution additive manufacturing via PμSL. After screening polymerization rates, mechanical properties and transmittances, our home-made resins allow for fabricating flexible 3D-printed parts with a resolution below 50 µm for straight rectangular channels, exhibiting proper solvent resistance as well as a sufficiently high transmittance to monitor droplet formation on-chip. Exemplarily, we show two designs of flexible microchannels for on-demand regulation of droplet sizes in microemulsion formation. Upon filling the regulator unit with air and its subsequent expansion the droplet channel compresses yielding a decrease of emulsion size[2].

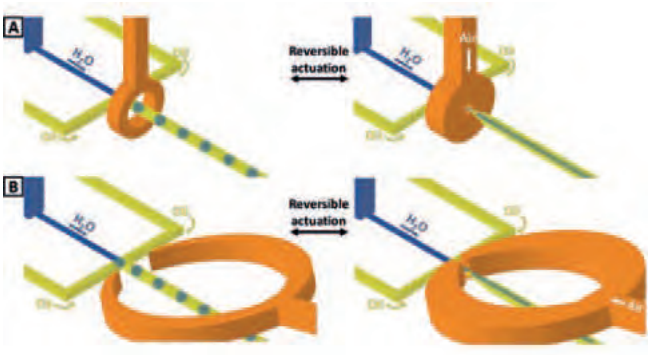

Figure 1.
A) Formation of emulsion droplets inside a microfluidic chip exhibiting a ring regulator design and droplet size control upon reversible actuation of the regulator.
B) Formation and control of droplets inside a microfluidic chip with pliers-shaped regulator design[2].

[1] M. J. Männel, N. Weigel, N. Hauck, T. Heida, J. Thiele Adv. Mater. Technol. 2021, 6, 2100094.
[2] N. Weigel, M. J. Männel, J. Thiele ACS Appl. Mater. Interfaces 2021, 13, 31086-31101.

ADDITIVE MANUFACTURING OF SILICA GLASS AND ZIRCONIA VIA LASER ASSISTED DIRECT INK WRITING

Philipp Schadte

P. Schadte[1], I. Teegen[2], F. Bendixen[1], H. Qiu[1], J. Bahr[1], J. Carstensen[1], L. Siebert[1], R. Adelung[1]

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Medical materials need to fulfill a great variety of requirements, which also include suitable mechanical properties. Depending on the application the properties can vary from soft and flexible to hard and stiff. While hydrogels can be used to form e.g. phantom bodies for surgical examination, hard materials like ceramics are harder to manufacture on a laboratory scale. Still, additive manufacturing (AM) of ceramics has made considerable progress over the last decade. However, the available approaches are limited and hold decisive drawbacks. Selective Laser Sintering (SLS) for instance, includes high machine costs and necessitates monodisperse particles. Combining SLS with Direct Ink Writing (DIW), a method which uses pastes to deposit powder dust-free, enables a facile and low power processing of ceramic materials. A high power CO2 laser was used to solidify the pastes layer by layer.

Thus, parts were manufactured in a single step with low cost setups and open source software. Additionally, the usage of powders with a polydisperse size distribution for the 3D Printing inks also holds the potential to eliminate the otherwise necessary subsequent sintering process. Therefore, this way of processing is extremely time and energy efficient. In the way, transparent parts from borosilicate glass with fine, free standing surfaces were produced in this work. Printability tests for the inks were performed and the interplay between the laser processing and slurry printing was investigated. Furthermore, a novel slurry deposition method has been developed to accommodate multi-material printing of extremely viscous fluids. Further developments in this technique will enable the manufacturing of parts from a great variety of materials in a cost and energy effective manner.

ADHESION MINIPROTEINS FOR TISSUE ENGINEERING

Florian Häge

Florian Häge, Franziska Thomas

Tissue Engineering requires artificial constructs to support the formation of tissue from cells. These scaffolds consist of microporous material that binds the cells of interest.

There are two common strategies to functionalize materials for cell responsiveness: the immobilization of cell adhesion motifs, which bind to a cell receptor[1], or of entire domains of cell binding proteins. However, the small motifs lack a defined three-dimensional structure and thus bioactivity and the large protein fragments are difficult to immobilize and often denature in the attempt[2].

We aim to unify the bioactivity of a cell binding protein with the chemical modifiability of cell adhesion motifs: the design of adhesion miniproteins based on independently folding peptide scaffolds with a cell binding active site.

Many protein-carbohydrate binding sites in extracellular matrix proteins are mediated by calcium ions[3]. We therefore based our designs on the active sites of two calcium-binding proteins: the cell-adhesion protein Laminin-α-2 (LG4) and the regulatory protein Calmodulin.

The natural model is incorporated into the sequence of a β-sheet peptide scaffold, such as the SH3 or WW domains, using computational modeling to ensure similar-to-native folding. We used intuitive design and the Rosetta modeling suite.

We already designed and synthesized multiple calcium-binding miniproteins that fold independently and will soon be tested for their carbohydrate binding activity.

Our goal is to design a biomimetic, easy to immobilize miniprotein that adds cell responsiveness to a microporous material and thus generate a functionalized material for retina tissue engineering.

Figure 1:
(A) The SH3-domain and the calmodulin-based Scan1.
(B) The WW-domain and the calmodulin-based WWcalm3.

1. D'Souza et al. Trends Biochem. Sci. 246–250 (1991).
2. Vasita et al. Curr. Top. Med. Chem. 8, 341–353 (2008).
3. Hohenester et al. Mol. Cell 4, 783–792 (1999).

IN SILICO STUDIES OF THE HELICAL INDUCTION OF CIS-TRANSOID POLY (4-CARBOXYPHENYL)ACETYLENE BY CHIRAL AMINES REVEAL LOCAL ELECTRONIC TRANSFER ROLL

Montserrat Penaloza-Amion

Montserrat Penaloza-Amion, Celso R. C. Regô and Wolfgang Wenzel

Institute of Nanotechnology (INT), Karlsruhe Institute of Technology (KIT), Germany

Helical conformation plays an essential role in biological structures such as proteins and DNA. Synthetic helical polymers depend on their inversion barrier and obtaining structural information of dynamic helical polymers requires advanced experimental techniques.

Yashima et.al. showed that chiral amines can induce one-handed helical structure in stereoregular cis-transoid poly((4-carboxyphenyl)acetylene) (poly-1), showing intense bands of circular dichroism (CD)[1-3].

To shed light on the helical induction process, helical models based on poly-1 were created using scan calculations over the dihedral backbone using density functional theory (DFT) on dimer of poly-1.

Clockwise (CW) and Counterclockwise (CCW) twist were identified at backbone dihedral values of 145 and -145 degrees, respectively. Dissociation energies were calculated using DFT in 4 monomer polymer-amine complexes using CW and CCW sense.

The results obtained reveal a clear affinity trend showing that R and S amine conformations have a major affinity for CW and CCW, respectively. Bader charge analysis reveals an important local effect in the contact point interaction between amines and polymer, explaining the affinity results.

1. Yashima, E., Maeda, K., Iida, H., Furusho, Y., & Nagai, K. (2009). Chemical reviews, 109(11), 6102-6211.
2. Yashima, E., Matsushima, T., & Okamoto, Y. (1997). Journal of the American Chemical Society, 119(27), 6345-6359.
3. Yashima, E., Goto, H., & Okamoto, Y. (1998). Polymer journal, 30(1), 69-71.

WAVELENGTH AND PULSE DURATION INFLUENCE ON LASER 3D NANOLITHOGRAPHY

Edvinas Skliutas

Edvinas Skliutas[1], Danielius Samsonas[2], Laura Sebestinaitė[1,2], Salvijus Ulevičius[1], Vytautas Jukna[1], Donatas Narbutis[3], Mikas Vengris[1,2], Mangirdas Malinauskas[1]

1 Laser Research Center, Faculty of Physics, Vilnius University, Saulėtekio Ave. 10, LT-10223 Vilnius, Lithuania
2 Light Conversion, Keramikų Str. 2B, LT-10234 Vilnius, Lithuania
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Non-linear absorption is the phenomenon of light-matter interaction, which plays a key role in laser 3D nanolithography [1]. It can be induced only at a certain value of light intensity I, called polymerization threshold, however, the optical damage threshold should not be exceeded. Both thresholds and feature sizes vary depending on the non-linearity of the absorption, which can be changed by applying different wavelengths (λ) of irradiation.
This work is dedicated to present the aforementioned dependencies obtained via the Resolution Bridges (RB) method [2]. To implement the experiment, an eligible light source was employed – an optical parametric amplifier-based laser system Cronus-3P (Light Conversion Ltd), powered by a Carbide laser operating at 1030 nm, 1 MHz, 40 W, accompanied by optical parametric amplifier I-OPA which enabled us to tune λ in the desired range from 700 nm to 1300 nm, and integrated group delay dispersion compensation unit to control pulse duration (τ = 100-300 fs) at the sample within the chosen λ range.

Presented experimental findings will supplement comprehension of light-matter interaction mechanisms in laser 3D lithography as they allow direct comparison by varying a single (λ, τ, I) parameter independently.

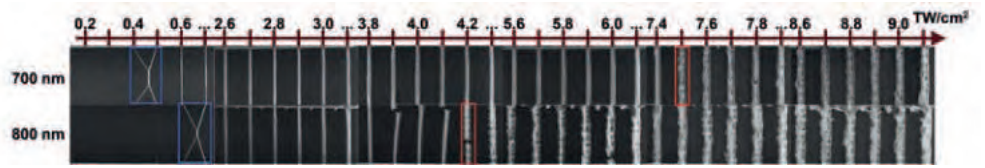

Fig 1.
An example of the manufactured RB at two different λ: 700 nm and 800 nm, when τ = 100 fs, maintaining the same intensity range and step value.
The blue and red zones show, at what intensity the polymerization threshold and optical damage threshold were observed.
A revelation of the increased number of successfully produced RBs allows a wider tunability in voxel dimensions once a specific wavelength is used.

[1] E. Skliutas, et al., Nanophotonics, vol. 10, pp. 1211-1242, (2021).
[2] R. DeVoe, et al., SPIE Proc., vol. 4797, pp. 310-316, (2003).

HIGH RESOLUTION PATTERNING OF DOPING IN SEMICONDUCTING POLYMER FILMS BY NON-RESONANT LASER EXCITATION

Christian Rainer

Christian Rainer[1,2], Aleksandr Perevedentsev[1,2], Gerardo Hernandez-Sosa[1,2,3], Uli Lemmer[1,3]

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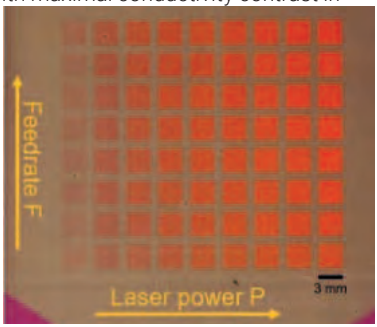
2 InnovationLab Heidelberg
3 Institute of Microstructure Technology, KIT

Organic field-effect transistors (OFETs) promise compelling applications in wearable microelectronics, chemical sensing and medicine. High contact resistance – one of the principal performance-limiting factors – can be ameliorated by local doping of the semiconductor regions adjacent to the electrodes. However, the existing approaches based on masked dopant evaporation[1] are incompatible with upscaling to high-throughput fabrication.

We advance a method of using laser radiation to pattern regions with maximal conductivity contrast in benchmark semiconducting polymers such as PBTTT and P3HT doped with the molecular acceptor F4TCNQ[2].



A cw laser system is used to irradiate pre-doped blade-coated films, whereby laser absorption and photo-thermal conversion enable local de-doping. Excitation wavelengths resonant (561 nm) or non-resonant (785 nm) with absorption of the neutral polymer are compared over a wide range of laser powers P and writing speeds v in terms of their simultaneous impact on semiconductor de-doping and degradation.

Control experiments performed on a hotplate indicate that high-throughput laser de-doping is possible with only minor degradation and loss of crystallinity (see optical micrograph for PBTTT). Furthermore, creating a nitrogen-rich atmosphere near the laser spot is shown to be a convenient means for reducing laser-induced degradation.

With foresight to eventual applications, the process is performed using an industrial inkjet printing platform (n.jet300, Notion Systems) that combines inkjet printing and laser processing capabilities. Further steps intend to utilize the inkjet capabilities to, e.g, deposit 'dopant blockade'[1] molecules for improving the long-term OFET stability.

[1] Kim et al., Adv. Funct. Mater. 2020, 30, 2000058; [2] Zapata-Arteaga et al., ACS Energy Lett. 2020, 5, 2972.

ELECTRON-BEAM LITHOGRAPHY OF CINNAMATE POLYTHIOPHENE FILMS

Maximilian Bojanowski

N. Maximilian Bojanowski[a,e], Christian Huck[b,c], Karl-Philipp Strunk[d], Lisa Veith[b], Jan Freudenberg[a], Irene Wacker[b], Rasmus R. Schröder[b], Petra Tegeder[b,c], Uwe H. F. Bunz[a,b]

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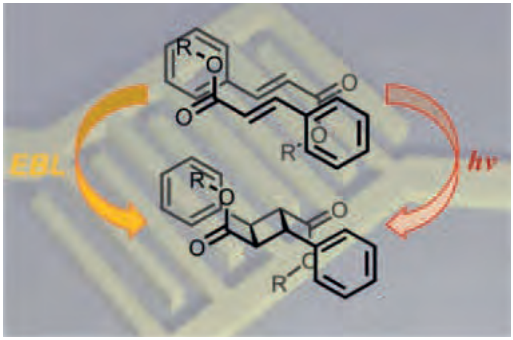
d. InnovationLab GmbH,
e. Institut für Nanotechnologie, Karlsruher Institut für Technologie

Manufacturing multi-layer electronic components requires control of size and structure of functional layers such as electrodes, semiconductors, and dielectrics. Miniaturization of organic electronics, such as the fabrication of small patterns of organic conductive materials, is challenging[1].



Photopatterning or direct laser writing are limited by diffraction or the photon absorbance of the π-conjugated material. Those limits do not apply for electron beam lithography (EBL). We exploit that low energy electrons induce reactions in condensed matter via electronic excitation, analogously to those induced by light stimuli [2]. Our EBL resist is based on cinnamates undergoing the well-known [2+2] cycloaddition reaction[3].

We compare the response of our cinnamate polythiophene in thin films towards photo- and electron-irradiation by IR transmission microscopy. Our results show that electron radiation excites the material prompting the cinnamic acid ester to dimerize according to the Woodward-Hofmann rules creating insoluble networks. Due to UV/VIS absorption by the conjugated system, EBL-induced reactions are more efficient and selective than those induced by photoirradiation. The material was patterned and doped into conductive nanorods. Exemplary, nano-sized finger structures of the transistors with overall of dimension well below 10 microns are constructed using crosslinked, doped polythiophene as source and drain electrodes.

[1] Y. Xu, F. Zhang, X. Feng, Small 2011, 7, 1338–1360.
[2] K. P. Strunk, N. M. Bojanowski, C. Huck, M. Bender, L. Veith, M. Tzschoppe, J. Freudenberg, I. Wacker, R. R. Schröder, A. Pucci, C. Melzer, U. H. F. Bunz, ACS Appl. Nano Mater. 2020, 3, 7365–7370.
[3] R. B. Woodward, R. Hoffmann, Angew. Chem. Int. Ed. 1969, 8, 781–853.

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