BEYOND! 2D

Abstract Booklet

Ringberg, October 11-14, 2017

Max Planck Institute of Microstructure Physics
Weinberg 2 | 06120 Halle (Saale) | Germany
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Aim of the Workshop

Today's computing and data storage technologies are innately two-dimensional. This workshop is concerned with innovations in the preparation and use of materials and devices that are innately three-dimensional that might allow for novel technologies for data processing and storage, and for many other technologies for example for energy and sustainability.

There are many beautiful examples of innately 3D materials that range from biological and bio-inspired materials, that includes a wide variety of self-organized materials, to mesostructured materials that include quantum and photonic materials, to artificially engineered multilayered materials with unique properties of the ensemble that go beyond the properties of the individual layers themselves. The emerging world of topological materials is extensive with fascinating properties derived from the surfaces and edges of 3D bodies.

This workshop will include leading scientists from a wide range of disciplines to discuss the state-of-the-art of "Beyond 2D" materials, devices and system.

We look forward to an exciting workshop at Ringberg Castle.

Best regards,

Stuart Parkin

Start / End Time

We invite you to arrive on October 11th at Ringberg between 3-6 pm. At that time rooms will be available for check-in. On Thursday you are invited to join a guided tour of the Castle by the manager Mr. Essl. He will show us around and provide us with some historical background information on the castle and its secrets. Be curious!

We end our workshop on October 14th after breakfast. Please check-out till 9 am as rooms need to prepared for the new arrivals in the afternoon.

Address | Info on Accommodation

Schloss Ringberg
Schlossstraße 20
83708 Kreuth
| Phone:+49 (0)8022 27 90 | http://www.schloss-ringberg.de/contact
The **internet access code** is available in the reception hall.

Breakfast is served from 8-9 am.

Munich Airport to Tegernsee Bahnhof (by Train/Taxi)

For your arrival/departure by public transportation please check the time table of "Deutsche Bahn" at http://www.bahn.de/p_en/view/index.shtml. Please exit at Tergernsee. Make sure that you board the part of the train going to Tegernsee and not to Lenggries. Train will be split on its way from Munich.

You can buy your ticket online, upon arrival at the vending machines or at the ticket counter before entering the S-Bahn area at the airport. Your destination is "Tegernsee Bahnhof" and the train ride takes approx. 2 hours.

Please use a taxi from the train station "Tegernsee" towards the castle. Taxi Kaufmann has a guest list and is informed about all arrival times that have been sent beforehand. You can reach the Taxi company by phone +49 (0)8022/ 5555 (code: MPI-Halle). If you haven't informed us about your arrival time make sure to call Taxi Kauffmann at least 30 min. prior to your arrival at Tegernsee station.

For any questions you can contact Simone Jäger at +49 (0) 172/ 76.79.965.

Electrochemical Additive Manufacturing of Metal Micro-structures with the FluidFM

Tomaso Zambelli

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FluidFM is a force-controlled nanopipette [1], combining AFM technology and microfluidics. A fluidic channel is incorporated directly in a hollow AFM cantilever. This channel ends in a nanosized aperture at the apex of the AFM pyramidal tip, allowing for local dispensing of soluble molecules in air and in liquid, while retaining the inherent imaging capabilities and force feedback of an AFM system.

Recently, we have achieved 2D electrochemical patterning with sub-micron precision by reduction of copper as well as diazonium salts filled in the microchannel with subsequent *in-situ* AFM imaging [2]. Furthermore, we recognized that this method offered an access to the 3rd dimension.

Micro- and nanometer scale patterning of functional materials is of great interest in various fields such as microelectronics or micro-electromechanical systems (MEMS) design [3], but also for biosensing and biomedical applications, where manipulation techniques often have to be suitable for use in a liquid environment. In this context, we succeeded in using the system in the same electrochemical configuration for 3D additive manufacturing of copper on the micrometer scale [4]. In the proposed protocol, we take advantage of the FluidFM probes as a local source of Cu^{2+} in a macro electrochemical cell. The nanopipette is approached to the working electrode and metal ions are provided by inducing a liquid flow. Thus, metal can be reduced locally under the FluidFM probe. Conveniently, the inherent force sensing capability of the cantilever provides a means to automate this process: Whenever the growing metal deposit touches the tip apex, the cantilever bends, and its deflection is registered so that the probe may be positioned to the next place, where the process continues. Therefore, our protocol enables true voxel-by-voxel (i.e. layer-by-layer) printing with consequent almost complete geometry freedom (see the three intertwined helixes).

Upon introducing the microprinting protocol with copper, we discuss our current efforts to adapt it to other metals.

[1] A. Meister et al., Nano Lett. ***2009*** *9:2501*

[2] L. Hirt et al., RSC Adv. ***2015*** *5:84517*

[3] L. Hirt et al., Adv. Mater. ***2017*** *29:1604211*

[4] L. Hirt et al., Adv. Mater. ***2016*** *28:2311*

Biographical Sketch

Tomaso Zambelli studied physics at the Padua University (IT) and earned his PhD at the Fritz-Haber Institute of the Max-Planck-Society (Berlin, DE) under the supervision of Professor Ertl investigating catalytic reactions on metal surfaces with STM. After two years as postdoctoral fellow in CNRS institute in Paris (FR) defining new strategies for local metal electrodeposition on Si surfaces with STM, he was appointed as "Chargé de Recherches" at the CEMES-CNRS institute in Toulouse (FR) in the Groupe NanoSciences where he carried out single-molecule studies by STM and AFM obtaining the "Habilitation à diriger des recherches". He joined LBB at ETH Zurich (CH) in 2006 receiving the "venia legendi" for Nanobiotechnology in 2011. He initiated the development of the FluidFM technology which now represents now his major research interest in the areas of single-cell manipulation and 3D microprinting.

From Extended Surface to High-Performing Catalysts - Synthetic Design at Nanoscale

Yu Huang

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Material formation in nature is precisely controlled in all aspects from crystal nucleation, growth to assembly to deliver superior functions. Specific biomolecule-material interactions have been hypothesized to play important roles in these processes. Proteins, polymers and small molecules have been extensively explored to replicate the degree of control in material formation in vitro and for nonbiogenic materials. However the organic-inorganic interfacial interaction is still far from being understood which hinders the further advancement of biomimetic material formation. In this talk I will share our efforts on decoding the myth of biomolecular specificity to material surface and their roles in controlling crystal nucleation and growth. The selection of facet specific short peptides and their abilities in guiding predictable morphology control of Pt nanocrystals will be first demonstrated. Then detailed experimental and theoretical studies on binding mechanism will be discussed. Based on mechanistic understanding, we designed small molecules bearing molecular signature for facet specific adsorption to modulate the nucleation/growth of the Pt and Pt alloy nanocrystals to deliver the expected nanostructures and functions. At the end of talk I will share our recent research on improving catalytic functions of nanocrystals through synthetic design. These studies open up opportunities in understanding the molecular details of inorganic-organic interface interaction, which can one day lead to the development of a library of molecular functions for biomimetic materials design and engineering.

Biographical Sketch

Dr. Yu Huang received her B.S. in Chemistry from University of Science and Technology of China, and her Ph.D in physical chemistry and M.A in Chemistry from Harvard University. Before she embarked on her independent career at UCLA She was awarded the prestigious Lawrence Fellowship and held a joint postdoctoral position with Lawrence Livermore National Laboratory (LLNL) and MIT.

At UCLA Prof. Huang's research focuses on mechanistic understanding of nanoscale phenomena and on exploiting the unique properties of nanoscale materials for various applications. Taking advantage of the unique roles of nanoscale surfaces and interfaces, she is creating methodologies to apply the latest developments in nanoscale materials and nanotechnology for probing nanoscale processes that can fundamentally impact a wide range of technologies including materials synthesis, catalysis, fuel cells, and devices applications.

Prof. Huang's achievements have gained her international and national recognitions including the International Precious Metal Institute (IPMI) Carol Tyler Award, the Materials Research Society (MRS) Fellow, the Presidential Early Career Award in Science and Engineering (PECASE), the National Institute of Health (NIH) Director's New Innovator Award, the Defense Advanced Research Projects Agency (DARPA) Young Faculty Award, the World's Top 100 Young Innovators award, the Sloan Fellowship, the International Union of Pure and Applied Chemistry (IUPAC) Young Chemist Award, and the Nano 50 Award.

3D Fabrication and Assembly by Curving, Bending and Folding

David H. Gracias

Professor, Department of Chemical and Biomolecular Engineering, Department of Materials Science and Engineering, Johns Hopkins University, Baltimore, MD 21218, USA | dgracias@jhu.edu

The interplay between bending rigidity and out-of-plane stresses, capillary forces or swelling in thin films can be manipulated so as to cause patterned 2D films to curve, bend and fold into 3D materials and devices. In this talk, the design, fabrication and characterization of such materials and devices will be described. The emphasis of our approach has been on ensuring mass-production of micro, nano and smart 3D devices in a high-throughput manner with diverse materials such as 2D layered materials (e.g. graphene), device grade silicon and related materials and hydrogels. By leveraging the precision of planar lithography approaches such as photo, e-beam and nanoimprint methodologies, a range of functional patterns can be incorporated into these thin film self-assembling systems so as to provide value for optics, electronics and medicine. These include metamaterials, flexible devices, curved microfluidics, drug-delivery capsules, anatomically realistic models for tissue engineering, antennas, e-blocks, sensors, soft-robotic actuators and surgical tools. In addition, the use of DNA sequences within these folding materials can be used to endow programmability of shape change based on specific DNA input sequences.

Biographical Sketch

Prof. Gracias is a Professor at the Johns Hopkins University (JHU) in Baltimore. He did his undergraduate at the Indian Institute of Technology, received his PhD from the University of California at Berkeley in 1999 and did post-doctoral work at Harvard University, all in Chemistry or related fields.

His independent laboratory, since 2003, has pioneered the development of 3D, integrated micro and nanodevices using a variety of patterning, self-folding and self-assembly approaches. Prof. Gracias has co-authored over 150 technical publications, is a co-inventor of 30 issued patents and has delivered over 100 invited talks at leading conferences, workshops and universities.

Prof. Gracias has received a number of national and international awards including the NIH Director's New Innovator Award, Beckman Young Investigator Award, NSF Career Award, DuPont Young Professor Awards, Camille Dreyfus Teacher Scholar Award, Humboldt Fellowship for Experienced Researchers. He is a Fellow of the American Institute for Medical and Biological Engineering (AIMBE) and a senior member of the IEEE.

Ultimately Dense and Efficient Future Computers

Bruno Michel

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Liquid cooling enables an unprecedented density in future computers to a level similar to a human brain. This is mediated by a dense 3D architecture for interconnects, fluid cooling, and power delivery of energetic chemical compounds transported in the same fluid. Vertical integration improves memory proximity and electrochemical power delivery creating valuable space for communication. This strongly improves large system efficiency thereby allowing computers to grow beyond exa-scale. A dense and efficient µServer has been demonstrated as a first milestone along this roadmap. A universal concept is presented showing that volumetric density drives efficiency in information processing irrespective of switch technology and architecture and can replace the currently slowing Moore's law. By adopting some of the characteristics of the human brain, computers have the potential to become far more compact, efficient, and powerful. And this, in turn, will allow us to take full advantage of cognitive computing – providing our real brains with new sources of support, stimulus, and inspiration.

Biographical Sketch

Bruno Michel received a Ph.D. degree in bio-chemistry/biophysics from the University of Zurich subsequently joined IBM Research to work on scanning probe microscopy and later on the development of accurate large-area soft lithography. Dr. Michel started the Advanced Micro Integration group to improve thermal interfaces and miniaturized convective cooling for processors and concentrated photovoltaic systems. Main current research topics of the Zurich group are microtechnology / microfluidics for nature-inspired miniaturized tree-like hierarchical supply networks, 3D packaging, and thermophysics for improved understanding of heat transfer in nanomaterials and structures. Main current research topics are datacenter energy re-use for future green IT and 3D packaging with interlayer cooling and electrochemical chip power supply. Dr. Michel started the energy aware computing initiative at IBM and triggered the Aquasar project to promote improved efficiency and energy re-use in future green datacenters and photovoltaic thermal solar concentrators.

2D vs 3D Cell Cultures Systems in Biomedical Studies

Giovanna Brusatin

University of Padova, Italy | giovanna.brusatin@unipd.it

Development of cell culture systems are indispensable for advancing in basic biology and clinical translations.

Breakthroughs have been discovered using 2D with defined and controlled physical properties such as stiffness and geometry, evidencing that signals that cells receive from the physicality of their microenvironment are absolutely essential for their survival and to direct their fate. These results go far beyond the limit of the classically preferred culture model, 2D cell monolayers cultured on adhesive rigid and flat plastic petri dish substrates.

However, cells grown in vivo within a complex 3D soft microenvironment and 3D cultures have been more recently introduced for in vitro studies, showing structurally and functionally different behavior of embedded cell aggregates or organoids.

At the meeting, I will introduce the use of chemically defined biomaterials for the preservation of pancreatic progenitor traits ex-vivo.

The engineering of in vitro 3D culture microenvironments still requires efforts to develop biomaterials, in particular hydrogels, and use microfabrication techniques to complex 3D soft microenvironment and generate defined shapes, which more closely mimics the natural environment of cells. New opportunities in these directions will be discussed.

Biographical Sketch

1996 Ph.D. Materials Engineering.

1991 MSc in Physics.

Associate Professor Science and Technology of Materials and Biopolymers at University of Padova. PI of Hymat lab (www.hymat.dii.unipd.it), Industrial Engineering Department, consisting of post-docs and PhD students with multidisciplinary expertise. Recent research activities mainly focus on design and engineering of polymeric and hydrogels materials for 2D and 3D micro- and nano-fabrication and microenvironments development, applied to biomedical studies. Author of more than 160 papers, 4 book chapters and 6 patents. (HI=26).

3D Wafer-Scale Fabrication of Hybrid Nanostructures

Peer Fischer [1, 2]

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[1] Max Planck Institute for Intelligent Systems, Heisenbergstr. 3, Stuttgart, Germany

[2] Institute for Physical Chemistry, University of Stuttgart, Pfaffenwaldring 55, Stuttgart, Germany

Abstract: In this talk I will discuss a nanofabrication scheme which allows us to quickly obtain 3D hybrid-nanostructures with controlled complex 3D morphology as well as material composition on entire wafers [1]. Micelle nanolithography coupled with extreme shadow-growth permits the parallel fabrication of 3D nanostructures (see Fig. 1). The nanostructured surfaces show interesting optical and magnetic properties. In addition, it is possible to transfer the nanostructrues to solution, where they can be used for a number of applications, such as self-propelled chemical nanomotors, or as sensors that show record local surface plasmon resonance sensitivities [2]. The same process allows us to grow the smallest ferromagnetic nanopropellers that have been realized to date and that can be used to penetrate biomedically relevant fluids and tissues [3].

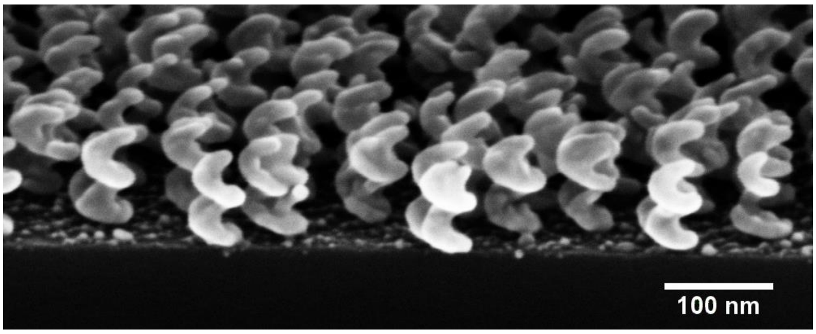

Fig. 1. Surface with chiral nanostructures (adapted from [1])

References

[1] "Hybrid nanocolloids with programmed 3D-shape and material composition", A.G. Mark, J.G. Gibbs, T.-C. Lee, P.Fischer, Nature Materials 12, 802 (2013).

[2] Jeong, H.-H.; Mark, A.M.; Alarcón-Correa, M.; Kim, I.; Oswald, P.; Lee, T.-C.; Fischer, P. Nature Comm. 7, 11331 (2016).

[3] "Nano-Propellers and their Actuation in Complex Viscoelastic Media", D. Schamel, A.G. Mark, J.G. Gibbs, C. Miksch, K.I. Morozov, A.M. Leshansky, P. Fischer, ACS Nano 8, 8794 (2014).

Biographical Sketch

Peer Fischer is a Professor of Physical Chemistry at the University of Stuttgart and he heads the independent Micro Nano and Molecular Systems Lab at the Max Planck Institute for Intelligent Systems in Stuttgart. He received a BSc. degree in Physics from Imperial College London and a Ph.D. from the University of Cambridge. He was a NATO (DAAD) Postdoctoral Fellow at Cornell University, before joining the Rowland Institute at Harvard. At Harvard he held a Rowland Fellowship and directed an interdisciplinary research lab for five years. In 2009 he received an Attract Award from the Fraunhofer Society which led him to set up a photonics lab at the Fraunhofer Institute for Physical Measurement Techniques in Freiburg. In 2011 he moved his lab to the Max Planck Institute for Intelligent Systems in Stuttgart.

Peer Fischer holds an ERC Grant and in 2016 he won a World Technology Award. He is a member of the Max Planck – EPFL Center for Molecular Nanoscience and Technology, and the research network on Learning Systems with ETH Zürich. Peer Fischer is a Founding Editorial Board Member of the journal AAAS Science Robotics and a Fellow of the Royal Society of Chemistry. Professor Fischer has broad research interests including 3d nanofabrication & assembly, micro- and nano-robotics, active matter, interaction of optical, electric, magnetic, and acoustic fields with matter at small length scales, chirality, and molecular systems engineering.

Majorana fermion is a hypothetical fermionic particle which is its own anti-particle. Intense research efforts focus on its experimental observation as a fundamental particle in high energy physics and as a quasi-particle in condensed matter systems. I shall report the theoretical prediction and the experimental discovery of the chiral Majorana fermion in a topological state of quantum matter. In the hybrid system of a quantum anomalous Hall thin film coupled with a conventional superconductor, a series of topological phase transitions are controlled by the reversal of the magnetization, where the half-integer quantized conductance plateau (0.5e2/h) is observed as a compelling signature of the Majorana fermion.

From 2D Plates to 3D Structures: Playing with Carl Gauss

José Bico

PMMH-ESPCI, Paris, France | jbico@pmmh.espci.fr

Projecting the Earth on a planar map without distorting distances has long been a vain challenge, as rationalized two centuries ago by Carl Gauss in his seminal "theorema egregium". Similarly, transforming a 2D sheet into a 3D object can be a complicated issue when the transformation involves a change in the “Gaussian” curvature.

Plants and more generally living organism have however adopted a clever strategy to build complex patterns: differential growth. Can we find some inspiration from plant growth and develop structures as beautiful as petals or leaves? We will review some recent macroscopic model experiments on transformable plates with potential applications at small (or large) scales.

Biographical Sketch

2000 PhD thesis from Paris 6 University. Research conducted at the Laboratoire de Matière Condensée du Collège de France under the supervizion of David Quéré

1996 Master in Physical chemistry from Paris 6 University

1992-1996 Engineer diploma in Chemical engineering from ESPCI , Paris

Academic Positions

2000-2003 Postdoc fellow in the group of Gareth McKinley at the Hatsopoulos Microfluidics Lab, Department of Mechanical Engineering, MIT, USA

since 2003 Associate professor at ESPCI in the Laboratoire de Physique et Mécanique des Milieux Hétérogènes

Research background: wetting, super-hydrophoby, interfacial hydrodynamics, elasto-capillarity

Recent interests: physical mechanics, fracture, instability of slender structures

Block Copolymer Self-Assembly for 3D Nanostructures

Caroline Ross

Department of Materials Science and Engineering, MIT, Cambridge MA, USA | caross@mit.edu

Block copolymers microphase separate to form periodic patterns with features of a few nm and above, and have long been considered as an option for the next generation of lithography processed in semiconductor manufacturing. The self-assembled nanostructures adopt a variety of bulk geometries, including alternating lamellae, gyroids, arrays of cylinders or spheres, tiling patterns, or core–shell structures, depending on the molecular architecture of the polymer and the volume fraction of its blocks. Most research on block copolymer lithography has been based on the conventional planar process, but the inherently three-dimensional structure of block copolymer microdomains could enable the synthesis of 3D devices and structures directly. Here we discuss the geometry and templating of block copolymers and show how 3D structures can be controlled and designed.

Biographical Sketch

- Associate Head of the Department of Materials Science and Engineering
- Toyota Professor of Materials Science and Engineering
- B.A., Cambridge University, U.K. 1985
- Ph.D., Cambridge University, U.K., 1988

Prof. Ross' research is directed towards the magnetic properties of thin films and small structures, particularly for data storage and logic applications, and towards methods for creating nanoscale structures based on directed self-assembly and lithography. Current research on magnetic materials includes the synthesis and characterization of magnetic nanostructures for domain wall logic devices, the behavior of 360 degree domain walls, magnetic metallic particles formed by templated dewetting, magnetoelasticity, magnetic perovskites such as Fe- and Co-substituted strontium titanate, magnetooptical materials for integrated optical isolators, and self-assembled oxide nanocomposites. Ross also studies the self-assembly of block copolymers and develops methods for templating self-assembly in order to form well-organized structures useful in nanoscale fabrication and devices. The Thin Film Laboratory includes a pulsed laser deposition system and an ultra-high vacuum sputter system, in addition to a range of magnetic, magnetooptical, and magnetoelectronic characterization equipment.

Colloidal Autonomous Systems

Alessandro Chiolerio

Center for Sustainable Future Technologies, Istituto Italiano di Tecnologia, Torino, Italy | alessandro.chiolerio@iit.it

Organic, inorganic or hybrid liquid devices, kept in a fixed volume by surface tension or by a confining membrane that protects them from a harsh environment, in a biologically inspired vision would change shape according to a specific external command or by means of an internal adaptation, and provide a solution for innovative applications in extreme or otherwise challenging environments, such as gas giants, small extraterrestrial bodies, ocean depths, post-disaster scenarios, human body, just to mention some. The talk will give an initial assessment of existing capabilities that can be leveraged to pursue the topic of "Smart Fluid Systems" or "Colloidal Autonomous Systems".

Compared to conventional robotic systems (i.e., anything not liquid), colloid-based robotic systems offer enormous promises, in terms of versatility, adaptability, resiliency, distributed architecture, and autonomy, but have not yet been investigated. A liquid and deformable robot is a desirable platform for adapting to unpredictable terrain, navigating through small holes, or even for interacting with humans where unintentional infliction of harm is of great concern.

Furthermore, colloidal devices are innately three-dimensional and might allow novel data processing and storage, as well as offer a totally new paradigm for energy and sustainability.

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2. *Chiolerio, A. & Quadrelli, M.B. (2016). CERES (Colloidal EneRgEtic Systems), a Research Project Jointly Pursued by IIT and JPL, Project Report, 19th December 2016.*
3. *Chiolerio, A. & Quadrelli, M.B. (2017). Smart Fluid Systems: the advent of autonomous liquid robotics, Adv. Sci., (2017) 1700036.*

Biographical Sketch

Born in Asti on 30th July 1980, Alessandro got his PhD in Electron Devices on February 2009 at Politecnico di Torino, Physics Department, defending a thesis on spintronic devices. He did his Post Doc on electromagnetic properties of nanocomposites at the Materials Science and Chemical Engineering Department. He later joined as Researcher (2012-2015) the Center for Space Human Robotics for the development of soft resistive switching devices. Since 2016 he is at the Center for Sustainable Future Technologies of Istituto Italiano di Tecnologia, Torino, after the establishment of a new research line on colloidal autonomous systems and colloidal energetic systems. He was visiting researcher (2015 and 2016) at the Jet Propulsion Laboratory (Caltech-NASA) dealing with a project on advanced liquid robotics. He is full Professor in Condensed Matter Physics and associate in Electronics.

In parallel to his research activities, in 2008 he founded a spin-off company, Politronica Inkjet Printing S.r.l., whose core business is the digital printing of devices by means of smart inks featuring electromagnetic properties and 3D polymeric printing. Very recently, in 2016, he started a second company, Polìpo S.r.l., proposing an innovative process for the manufacturing of biodegradable polymers from vegetable-derived compounds.

He is co-author of about 80 papers in international peer-reviewed ISI journals, 15 proceedings of international conferences, 13 book chapters, 1 book and 10 patents. He contributed with oral presentations to 35 conferences, of which 20 on invitation (3 keynote lectures and a TEDx talk among the invited).

He is principal investigator for IIT of several european, regional and industrial projects and is routinely involved in technology transfer activities being the contact point between industries and research.

3D-Nanomachining and Devices

Erwin Berenschot[1], Edin Sarajlic[2] , Henri Jansen[3], Roald Tiggelaar[4], Han Gardeniers[1], Niels Tas[1]

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[1] *MESA+ Institute for Nanotechnology, Mesoscale Chemical Systems Group, University of Twente, Enschede, The Netherlands*

[2] *SmartTip B.V., Enschede*

[3] *DTU Danchip National center for Micro and Nanofabrication, Technical University of Denmark, Lyngby, Denmark*

[4] *MESA+ Institute for Nanotechnology, NanoLab Cleanroom, University of Twente, Enschede, The Netherlands*

There is an increasing interest in techniques for 3D-nanostructure formation, driven by the added functionality and area-density which is offered by the use of the 3D dimension. From an application point of view it is advantageous if these techniques are wafer-scale, or at least high parallel in nature.

In this presentation two nano-patterning techniques are introduced which are intrinsically suitable for 3D-nanostructure formation: edge lithography and corner lithography. They rely on the formation of nano-substructures at or in edges and sharp corners. Typically, straight edges and sharp corners are formed using the etched silicon crystal as a template. The thin film nano-substructures which are formed can be used as functional material or as masking material for the subsequent etching of the underlying silicon.

Examples of fabricated structures are nanowire pyramids, pyramids containing an aperture at the apex, nano-ridges and high density silicon wedge arrays.

An important fabrication strategy which will be discussed is self-multiplying “fractal” machining of silicon, in which an increasing number of sub-structures is formed in every generation of the repetitive fabrication process.

Biographical Sketch

Erwin J. W. Berenschot received the B.Sc. degree in applied physics from the Technische Hogeschool in Enschede, The Netherlands, in 1990. From 1992 - 2013 he has been employed as a micro/nano – machining engineer at the Transducer Science and Technology group of the MESA+ Research Institute. In 2014 he moved to the Mesoscale Chemical Systems group of MESA+ . His main

research area is development and characterization of etching, bonding and deposition techniques for the fabrication of 3D-micro/nano systems.

He contributed to the invention of the UT nano-fountain pen in 2004. In 2005 he was co-inventor of corner lithography and in 2007 he was involved in the development of edge lithography. These silicon based nanomachining techniques result in 2009 in the development of waferscale fabricated free standing silicon tetrahedral (quantum) dots, followed by the development of self-multiplying fractal machining of silicon in 2012.

He has co-authored over 100 reviewed journal papers and is the inventor of 10 patents or patent applications. His work received over 3000 citations, h-index 30 (Scopus).

Application of Thin Film Coating Technologies Beyond 2D Films

Mato Knez [1,2]

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[2] IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

For the development of future devices controlled design of small scale functional materials is of crucial importance. Ideally, such design will be based on integration into or alteration of functionalities of existent materials with proven and efficient fabrication routes. Polymers, for example, have already established processes for mass production. However, modern applications often require further improvement of their physical or chemical properties, which is the main argument for research on further functionalization of polymeric materials.

Numerous techniques have been proposed for adding value to the functionalities of various substrates, including coatings by sol-gel methods, CVD, and so on. One very promising technique is atomic layer deposition (ALD), a thin film coating technology that precisely deposits thin 2D films on a variety of substrates at comparatively low temperatures. Various modifications of ALD, including area-selective ALD or vapor phase infiltration, allow introduction of metal containing moieties into carbon based or polymers substrates and in this way open the doors towards synthesis of entirely new classes of composites or hybrid materials.

This presentation will report on the various ways of using ALD beyond the traditional 2D coating and the resulting physical and chemical alteration of functionalities of a variety of substrates. Our findings show that the deposition processes open new opportunities for materials design complementary to traditional wet-chemical pathways, while at the same time the step from research to industrial production is easily possible through upscaling of the processes.

Biographical Sketch

Mato Knez studied chemistry at the University of Ulm (Germany) and finished his doctoral thesis in natural sciences at the Max-Planck Institute of Solid State Research in Stuttgart (Germany) in 2003. During his postdoctoral stay at the Max-Planck Institute MSP in Halle (Germany), he received the Nanofutur Award of the German Ministry of Education and Research in 2006 and grew a junior research group with focus on investigating functional materials grown by atomic layer deposition (ALD). Since 2012 he is Ikerbasque research professor and group leader at the research center CIC nanoGUNE in San Sebastián (Spain). Besides, he is teaching professor at the Technical University of Navarra (TECNUN). In 2012 he received the Gaede Prize of the German Vacuum Society. He is member of the international advisory board of the journal "Advanced Materials interfaces" (Wiley), editorial board member of Scientific Reports (Nature Publishing Group) and member of evaluation panels in various research societies and academies.

Meniscus-Guided 3D Nano-Printing

Ji Tae Kim

Department of Mechanical Engineering, The University of Hong Kong, Hong Kong | jtkim@hku.hk

3D printing has been emerging as a disruptive technology that can transform lifestyles, industries, and economies around the world. 3D printing – a class of techniques known as additive manufacturing – can provide the simplest ways to create complex objects and potentially unify the traditional manufacturing steps of molding, carving, welding, and assembly. To make the leap to become a true manufacturing platform for electronic and photonic industries, techniques in 3D printing basically should possess both nanoscale spatial resolution and freedom of materials selection.

I will present a "meniscus-guided" 3D printing method and its use for electronics and photonics integration. The method effectively exploits a mechanically flexible ink meniscus downsized by pulling to print various nanomaterials in three-dimension [1]. The printed size is accurately controlled down to ~ 50 nm by tuning the pulling speed. Since the ink meniscus can position various nanoscale dynamics in materials transfer, interaction, and reaction at will, the method has the printability of functional materials from polymers [1,2], CNTs [3], graphene [4], metals [5,6], to single nanoparticles [7,8], potentially realizing new concept 3D nanosystems for electronics and photonics [9]. I will also discuss future plan to further develop this meniscus-guiding method.

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Biographical Sketch

Assistant professor, Department of Mechanical Engineering, The University of Hong Kong, Hong Kong

Academic qualifications

2011 PhD in Materials Science and Engineering, Pohang University of Science and Technology, Korea

2006 BSc. Materials Science and Engineering, Pohang University of Science and Technology, Korea

Previous academic positions held

2015-2016 Senior research scientist, Korea Research Institute of Standards and Science, Korea

2014-2015 Postdoc, Max Planck Institute for Intelligent Systems, Germany

2012-2014 Postdoc, Max Planck Institute for the Science of Light, Germany

2011-2012 Postdoc, Pohang University of Science and Technology, Korea

Previous relevant research work

- Development of meniscus-guided 3D writing for functional materials.
- Integration of 3D electronic/photonic devices at nanoscale.
- Development of scanning-aperture electrostatic trapping method for single nanoparticles.
- Development of localized electrochemical deposition method.
- Real-time investigation of materials growth by micro/nano x-ray and optical imaging.

3D Nanofabrication: Limitations and Opportunities

Felix Holzner

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Nanofabrication is dominated by wide range of 2D nanolithography methods. However, conventional nanolithography methods struggle to fulfill the increasing demand for accurate 3D nanostructures. Usually, lithographically defined 3D nanostructures have to be made whether by accurate overlay of multiple lithography steps or directly by grayscale exposure of resist. The effort is significantly bigger than for 2D nanostructures and the possible accuracy of the final 3D nanostructures is strongly limited.

A new top-down nanolithography method, called NanoFrazor lithography, extends the limitations of both overlay and grayscale patterning to the single nanometer level. I will show a few examples where NanoFrazor lithography has been used to enable previously impossible applications. Furthermore, I will discuss how newly developed concepts for directed self-assembly and additive manufacturing can add complementary value for accurate 3D nanofabrication.

Biographical Sketch

Felix Holzner studied physics in New Zealand and Germany and received a PhD from ETH Zurich. He worked on experiments and simulations of 3D microfluidic devices and directed self-assembly of nanoparticles and biological cells. In 2009, he joined the Nanofabrication Group at the IBM Research Laboratory in Zurich where he started to work on Thermal Scanning Probe Lithography. After several technological breakthroughs, Felix shortened the name of the technology to “NanoFrazor” and founded SwissLitho in 2012 with the clear vision to enable superior nanofabrication for everyone. He strongly believes that the unique capabilities of the NanoFrazor enable new science and eventually even products not conceivable today.

Felix has a complete overview over all possible nanolithography technologies and a very deep understanding of the NanoFrazor technology and its applications. He is a regular invited speaker at international conferences. Felix received the IBM Plateau Invention Achievement Award and the ETH Pioneer Fellowship in 2012 and 2013, respectively. With SwissLitho and the NanoFrazor, he won numerous of the most prestigious startup and technology awards exceeding prize money of 500’000 CHF.

Felix lives his vision and leads SwissLitho as CEO.

Racetrack Memory: An Innately 3D Memory Device

Chirag Garg

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The introduction of the magnetic hard drive a few decades ago precipitated the information age and led to the boom of digital media, social networks and internet search engines. To keep up with the demands to store every bit of information for services such as cloud and data analytics, it is necessary to go beyond the conventional forms of storage and come up with a completely different approach. One such concept is the "racetrack memory", where information can be stored in the form of magnetic bits along a "racetrack" nanowire and be driven back and forth at nanosecond speeds. Arrays of such densely packed racetracks could form the basis of an ultra-dense three-dimensional solid state memory that could replace all forms of conventional storage. This talk will review current progress made on this topic and will discuss possible pathways and obstacles to its implementation.

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Biographical Sketch

Chirag Garg studied Ceramic Engineering at the Indian Institute of Technology, BHU (India) before enrolling for his PhD at the Max Planck Institute of Microstructure Physics in Halle (Germany). His research work was done at IBM Almaden Research Center (San Jose, USA) where he investigated electrically driven domain wall motion in magnetic nanowires under the supervision of Professor Stuart Parkin. In addition, he also investigated three-terminal devices based on the use of spin-orbit torques for applications in magnetic random access memory (MRAM). He will finish his doctorate soon and continue his work on the development of magnetic memories as a post-doc at IBM. He's interested in exploring new materials and fabrication techniques for memory and logic applications.

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