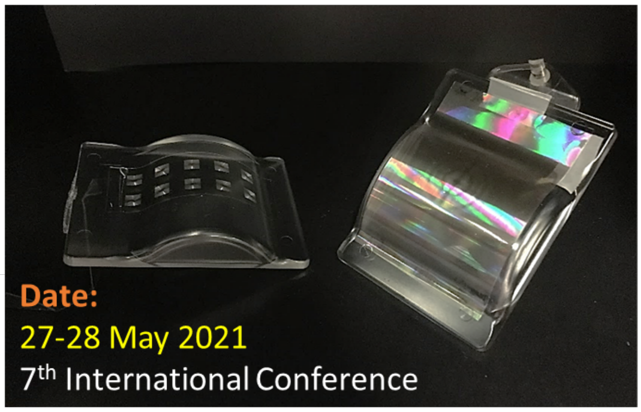
PRN 2021

Polymer Replication on Nanoscale



Scope of the Conference

The conference addresses issues in large scale replication of micro- and nanostructures in polymeric materials including:

- Fabrication of structured molds, inserts or shims for polymer replication
- Industrial replication technologies, injection molding and roll-to-roll techniques
- Materials for replication of polymer micro- and nanostructures
- Applications for functional micro- and nanostructured polymer surfaces
- Metrology and characterization of micro- and nanostructured polymer surfaces
- Simulation and computing of phenomena in micro- and nanoscale replication

Organized by INKA - Institute of Polymer Nanotechnology

n|w University of Applied Sciences and Arts Northwestern Switzerland

WELCOME

27 - 28 May 2021

PRN 2021 Polymer Replication on Nanoscale

Per Magnus Kristiansen

Welcome to the PRN2021 online

On behalf of the organizers, I wish you all a very warm welcome to this year's PRN 2021 online, the meanwhile 7th International Conference about Polymer Replication on Nanoscale, which, despite the special circumstances, has managed to attract more than 50 participants.

It is a great pleasure to host this gathering of leading experts from academia and industry in the field of Polymer Replication on Nanoscale, which happens to coincide with the 15th Anniversary of the Institute of Polymer Nanotechnology (INKA), a truly fruitful "joint venture" between the Paul Scherrer Institute and FHNW.

Switzerland's polymer industry encompasses close to 900 companies along the entire value chain, focusing on high-quality specialized products with pronounced emphasis on life sciences, optics, security and watch-making. Particularly in these markets, functionalization of polymers by topographical surface structuring, as well as by chemical surface modification, offers tremendous potential for advanced polymer products and consequently continues to receive substantial attention.

The PRN2021 aims at providing an up-to-date overview on the state of the art and newest findings in R&D on polymer replication on the micro- and nanoscale. Traditionally, a strong focus is kept on advances related to technology and application development as well as a good portion of the science behind.

For this purpose, we have assembled a diverse program with a good mix of invited and contributed oral presentations as well as plenty of opportunities for networking within the online zoom platform.

We would have loved to offer you in addition an industry-oriented exhibition as well as a live poster session but due to the pandemic situation, this did very unfortunately not materialize. Let's keep the faith that PRN 2022 can take place as a physical meeting again.

With these words, I wish you two pleasant and inspiring days online, and we hope that this event can be repeated next year in the form we were used to.

Per Magnus Kristiansen

PROGRAM

27 – 28 May 2021 – **FINAL VERSION**

PRN 2021 Polymer Replication on Nanoscale

Thursday 27 May 2021

Individual pre-conference meetings (09:00-11:30)
(organized mutually between interested participants)

11:30-12:45 Lunch break

PRN 2021 Online Conference

12:45-13:00 ***Welcome online*** (zoom meeting opens 15 min ahead)

13:00-13:15 Per Magnus Kristiansen (INKA FHNW, Switzerland)
"Welcome to the Polymer Replication on Nanoscale 2021"

Session 1: Mastering, Tooling and Integration (13:15-14:45)
Chair: Per Magnus Kristiansen (FHNW, Switzerland)

13:15-13:35 Invited: Ronald Holtz (FHNW, Switzerland)
"State of the art and future potential of lasers for micro-machining of polymeric materials"

13:40-13:55 Nan Zhang (UCD, Ireland)
"Development of a novel high-performance self-lubricating micro/nano mould based on 2D material nanocomposite"

14:00-14:15 Jerome Werder (FHNW, Switzerland)
"Origination of super-smooth micro-optical elements"

14:20-14:30 Laurent Feuz (FHNW Switzerland)
"The role of arts in science" (Launch of the PRN image award)

14.30-14:40 Nan Zhang (UCD) & Per Magnus Kristiansen (FHNW)
"Advanced Manufacturing of Micro-/Nanstructured Polymer Surfaces"
Announcement of a Special Issue of micromachines

14.45-15:30 *Coffee break* (break-out sessions + Session 1 Q&A)

15:30-15.55 Invited: Reinhard Voelkel (Süss Microoptics, Switzerland)
"*Microlens Imprint for Automotive Lighting*"

Session 2: Nanoimprint Lithography (16:00-17:20),
Chair: Helmut Schift (PSI, Switzerland)

16:00-16:15 Celestino Padeste (PSI, Switzerland)
"Polymer supports for serial protein crystallography at X-ray free electron lasers"

16:20-16:35 Benjamin Gallinet (CSEM, Switzerland)
"Nanoimprint and metallo-dielectric coatings for high field of view diffractive optical couplers and narrowband filters"

16:40-16:55 Yuyang Zhou (UCD, Ireland)
"Development of coronavirus-resistant films by combining nanomaterials with nanoimprinting"

17:00-17:15 Shahana Bishnoi (DTU, Denmark)
"Microfabrication of shape and size specific hydrogels to serve as artificial red blood cells"

17:20-17:50 *Coffee break* (break-out sessions + Session 2 Q&A)

17:50-18:15 Invited: Jim Watkins (Univ. Amherst, USA)
"Hierarchical Carbons and Ceramics via Polymer Replication at the Nanoscale: Integration of Nanoimprinting, Self-Assembly, and Flash Photothermal Processing"

18:20-18:30 Closing remarks by Laurent Feuz (FHNW, Switzerland)

18:30-19:30 Virtual beer & networking (optional)

Friday 28 May 2021

08:45-09:00 ***Welcome online*** (zoom meeting opens 15 min ahead)

Session 3: Industrial Replication Technologies I (09:00-10:30)
Chair: Per Magnus Kristiansen (FHNW, Switzerland)

09:00-09:25 Invited: Thomas Mortelmans (PSI, Switzerland)
"Thermoplastic 3D nanofluidic devices for biosensing "

09:30-09:45 Nekane Lozano Hernandez (Eurecat, Spain)
"Microtexturation of liquid silicone rubber surfaces by injection moulding using hybrid polymer inlays"

09:50-10:05 Guggi Kofod (Rel8 Asp, Denmark)
"A traceability system for injection molding"

10:10-10:25 Carlos Sáez (Eurecat, Spain)
"Replication of hierarchical nanostructures on Polycarbonate via Isothermal injection moulding using NIL-textured films"

10:30-11:00 *Coffee break* (break-out sessions + Session 3 Q&A)

11:00-11:20 Selected people from the INKA Team (FHNW, Switzerland)
"Virtual Lab Tour – insights into our infrastructure & applied R&D in the field of functional polymer surfaces – and beyond"

Session 4: Industrial Replication Technologies II (11:20-12:40)
Chair: Laurent Feuz (FHNW, Switzerland)

11:20-11:35 Invited: André Bernard (matriq AG, Switzerland)
"The watermark for plastics: creating the digital twin"

11:40-11:55 Helmut Schift (PSI, Switzerland)
"How to keep a good skin without peeling: bonding of a roll-to-roll extrusion coated film on a back injection molded polymer body"

12:00-12:25 Invited: Rafael Taboryski (DTU, Denmark)
"Roadmaps for large area nano-pattern replication"

12:30-13:00 *Pre-lunch break* (break out sessions + Session 4 Q&A)

13:00-14:30 *Lunch break* (time for individual networking)
Session 5: Metrology, Simulation and Modeling (14:30-15:30)
Chair: Jerome Werder (FHNW, Switzerland)

14:30-14:45 Tamara Aderneuer (CSEM Muttenz, Switzerland)
"Advanced metrology of freeform micro-optical elements"

14:50-15:05 Nikolaos Lempesis (EPFL, Switzerland)
"Controlling wettability through modeling-based surface topography engineering"

15:10-15:25 Jelle Snieder (TU Delft, The Netherlands)
"Simulating the Layer Thickness in Roll-to-Roll UV Nanoimprint Lithography"

15:30-16:00 *Coffee break* (break-out sessions + Session 5 Q&A)
last chance for Best Talks Award voting!

16:00-16:15 Announcement of Best Talk Awards

16:15-16:30 Closing by Per Magnus Kristiansen (FHNW, Switzerland)
"Polymer Replication on Nanoscale – quo vadis?"

16:30 This is the end of PRN2021

Dr. Reinhard Voelkel, CEO SUSS MicroOptics SA, Switzerland

"Microlens Imprint for Automotive Lighting"

Reinhard Voelkel received his Diploma in Physics in 1989 and his PhD in 1994 from the University of Erlangen-Nuernberg, Germany, where he worked at the Applied Optics Institute (Prof. Adolf W. Lohmann, Prof. Johannes Schwider) on holographic optical elements for optical interconnects and backplanes. After his PhD he joined the Institute of Microtechnology (Prof. René Dandliker, Prof. Hans Peter Herzig) at the University of Neuchatel, Switzerland, working on micro-optics for biosensors, optical interconnects, photolithography systems, miniaturized imaging and camera systems. Reinhard Voelkel is co-founder and CEO of SUSS MicroOptics SA, a leading supplier of micro-optical components and systems located in Neuchâtel, Switzerland. He is a member of the German Optical Society (DGaO), the Swiss Optical Society (SSOM), the European Optical Society (EOS), SPIE and the Optical Society of America (OSA). He was nominated SPIE Fellow in 2018.

Prof. Dr. Roland Holtz, FHNW University of Applied Sciences and Arts Northwestern Switzerland, Institute of Product and Production Engineering

"*State of the art and future potential of lasers for micro-machining of polymeric materials*"

Roland Holtz has been developing laser applications since 1992. He studied mechanical engineering and has additional degrees in business development and welding engineering (EWE). In 1996 he was involved in the foundation of the laser application center of the Otto-von-Guericke-University in Magdeburg. From 1999 until 2012 he was working for LASAG AG in Thun in different roles, as head of laser application, head of business development, head of marketing & sales and member of the executive board. From 2011 to 2017 he was managing director of the start-up Class 4 Laser Pro AG in Lyss. He is chairman of the expert committee FA6 „Beam Technology", and member of scientific management board of the German welding society (DVS - Deutscher Verband fuer Schweissen und verwandte Verfahren e. V.). Since 2014 Ronald Holtz is Professor at the FHNW University of Applied Sciences and Arts Northwestern Switzerland (FHNW) and head of the 3D-laser micromachining Group at the Institute of Product and Production Engineering (IPPE). In 2019 he co-founded the FHNW spin-off company TLD photonics AG.

Dr. André Bernard, matriq AG, Switzerland

"The watermark for plastics: creating the digital twin"

André serves as CEO and cofounder of matriq AG in St. Gallen, where he markets a technology for securely and individually marking plastic products. Befor e, he was 15 years professor and head of the institute for micro- and nanotechnology (MNT) at NTB Buchs, a university of applied sciences. He studied biochemistry and immunology at the University Zurich and electrical engineering at ETH Zurich and earned a doctoral degree at IBM research lab in Rüschlikon. He then was founder and CEO of indigon gmbh, a startup in Tübingen (D) in the area of medical diagnostics (lab-on-disc). He is an expert at Innosuisse, the Swiss innovation agency and has 2011 cofounded the foundation innocuisine for the advancement of science and innovation in gastronomy. André has more than 40 publications (h-index: 25, RG Score: 31.55, citations >6'400), 8 patents, and 2 children.

Thomas Mortelmans, Swiss Nanoscience Instiute, Switzerland

"Thermoplastic 3D nanofluidic devices for biosensing "

Thomas Mortelmans, born 1994 in Tienen, studied biomedical sciences with a specialisation in bio-electronics and nanotechnology at Hasselt University, Belgium. During his master thesis, he focussed on the synthesis of stimuli-responsive polymeric nanocarriers for controlled differentiation of dental pulp stem cells. In 2017 he started his doctoral studies at the Swiss Nanoscience Institute, combining both state-of-the-art nanofabrication techniques with bio-medically relevant applications. His research is focussed on the development of a three-dimensional (3D) PMMA microfluidic size sorter for use in life sciences. The project is a collaboration between the Laboratory of Micro-and Nanotechnology (LMN) at the Paul Scherrer Institute and the Center for Cellular Imaging and NanoAnalytics (C-CINA) at the Univesity of Basel. Thomas has a keen interest in interdisciplinary research projects that situate themselves at the interface of material sciences, nanotechnology and biomedicine.

Prof. James (Jim) Watkins, University of Massachusetts Amherst, USA

"Hierarchical Carbons and Ceramics via Polymer Replication at the Nanoscale: Integration of Nanoimprinting, Self-Assembly, and Flash Photothermal Processing"

Jim Watkins is Professor of Polymer Science and Engineering and Director of the Institute for Hierarchical Manufacturing (IHM), at the University of Massachusetts Amherst. Professor Watkins received his B.S. and M.S. degrees in Chemical Engineering from the Johns Hopkins University and his Ph.D. in Polymer Science and Engineering from the University of Massachusetts. He joined the Chemical Engineering faculty at UMass in 1996 and the Polymer Science and Engineering Faculty in 2005. From 2006 to 2018 Professor Watkins served as PI and Director of the Center for Hierarchical Manufacturing (CHM) a U.S. National Science Foundation (NSF) Nanoscale Science and Engineering Center (NSEC). Upon completion of NSF funding, the CHM transitioned to the IHM and currently supports the work of approximately 20 faculty involved in nanomanufacturing and additive manufacturing. From 2014-2018 Professor Watkins served as the founding Director of the Center for Personalized Health Monitoring (CPHM) and led the development of the Advanced Print and Roll-to-Roll Manufacturing (APRM) Demonstration facility, a comprehensive user facility for printed and flexible electronics and devices. Since 1996, Professor Watkins has guided the research of more than 40 Ph.D. students, has authored more than 125 papers, has been granted 12 patents, and has presented more than 225 invited lectures. He is a recipient of the Camille Dreyfus Teacher-Scholar Award and a David and Lucile Packard Foundation Fellowship for Science and Engineering. He received the UMass Chancellor's Award for Research and Creative Activity and is a fellow of the American Physical Society.

Prof. Dr. Rafael Taboryski, DTU Nanolab, Denmark

"Roadmaps for large area nano-pattern replication"

Rafael Taboryski received his PhD in physics from University of Copenhagen in 1992. His postdoctoral research was carried out at Cambridge University (UK) and at the Niels Bohr Institute in Copenhagen on electronic quantum phenomena. He joined DTU Physics in 1994 as assistant professor. In 2001 he left DTU for a R&D position in Sophion Bioscience, where he headed the development of a microfluidic platform for drug screening. In 2007 he came back to DTU, and is now full professor in "nanostructured polymer surfaces" at DTU Nanolab. His present research is concerned with micro- and nano-fabrication of functional surfaces on both semiconductor and polymer materials platforms. Explored functionalities range from optics, over wetting properties to microfluidics. RT's publication record comprises 100+ peer-reviewed papers on nanofabrication.

Mastering, Tooling and Integration

Chair: Per Magnus Kristiansen (FHNW, Switzerland)

13:15-13:35 Invited: Ronald Holtz (FHNW, Switzerland)

"State of the art and future potential of lasers for micro-machining of polymeric materials"

13:40-13:55 Nan Zhang (UCD, Ireland)

"Development of a novel high-performance self-lubricating micro/nano mould based on 2D material nanocomposite"

14:00-14:15 Jerome Werder (FHNW, Switzerland)

"Origination of super-smooth micro-optical elements"

14:20-14:30 Laurent Feuz (FHNW Switzerland)

"The role of arts in science" (Launch of the PRN image award)

14.30-14:40 Nan Zhang (UCD) & Per Magnus Kristiansen (FHNW)

"Advanced Manufacturing of Micro-/Nanstructured Polymer Surfaces"
Announcement of a Special Issue of micromachines

14.45-15:30 ***Coffee break*** (break-out sessions + Session 1 Q&A)

15:30-15.55 Invited: Reinhard Voelkel (Süss Microoptics, Switzerland)

"Microlens Imprint for Automotive Lighting"

State of the art and future potential of lasers for micro-machining of polymeric materials

R. Holtz, M. Guilherme, A. Stumpp, B. Lüscher, F. Senn, P. Vollenweider

FHNW University of Applied Sciences and Arts Northwestern Switzerland, School of Engineering, Institute of Product and Production Engineering, Windisch, Switzerland

The laser beam gained importance as a tool for processing polymers at a similarly early stage as for metals. Since the 1980s, the laser beam has been used industrially for welding, cutting and marking applications on plastic materials.

Due to the material composition and the resulting absorption properties, a whole range of laser types can be used as tools for machining of non-transparent polymer materials, which are also used for metallic materials. Compared to metals, however, not all polymeric materials go through reversible phase changes, so that materials with a low decomposition temperature can only be processed with the laser to a limited extent. For the most part, transparent polymers also behave differently than other transparent material classes such as glasses and inorganic crystals.

Ultrashort pulse lasers have established themselves as tools for micro-machining since the 2000s. Initially employed as a tool for high-precision cutting of medical technology products and for micro-machining applications in the watch industry, these types of laser have gained enormous importance for the manufacturing of semi-finished products in consumer electronics. The spectrum ranges from cutting displays and optical glasses made of sapphire or hardened glass to the structuring the surfaces of optical components.

In addition, ultrashort pulse lasers are increasingly being used for the production of tools and molded tool parts. Compared to classic machining processes and eroding, ablation by means of ultra-short pulse laser pulses is characterized by very high flexibility and high precision combined with a high level of design freedom in the 3D space. Due to the short pulse length, there is only very little thermal input into the material.

Both with respect to transparent materials themselves and for molding tools used in replication processes, there is an interesting and large potential for polymers to take advantage of ultrashort pulse laser ablation.

On the one hand, this concerns the use of the laser tool for the production of injection molding tools with a high level of utility in terms of structural accuracy, variety of geometries as well as manufacturing time and costs.

On the other hand, first results indicate that ultrashort pulses are also suitable for direct surface structuring of some transparent polymers, so that replication becomes obsolete. Thus, there is concrete potential for direct manufacturing of optical elements by means of laser micro-structuring, which opens up promising new application possibilities for transparent polymers.

In this talk, an overview of the state of the art of laser micro-machining and an outlook on current research and development work will be presented.

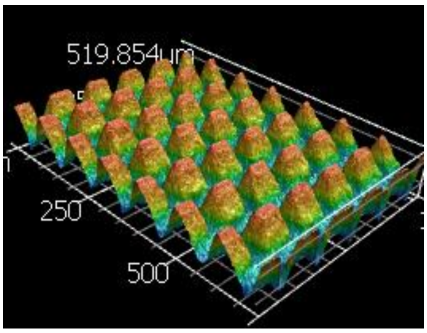


Figure 1: laser machined microstructure on stainless steel injection molding tool

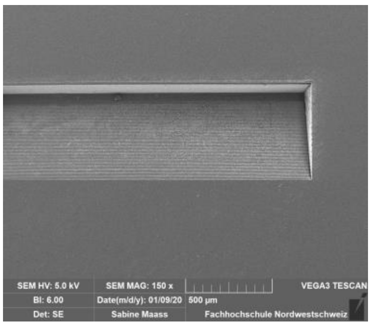


Figure 2: direct laser machined structure on PEEK foil

Development of a novel high-performance self-lubricating micro/nano mould based on 2D material nanocomposite

Nan Zhang[1], Honggang Zhang[1], Fengzhou Fang[1]

[1] Centre of Micro/Nano Manufacturing Technology (MNMT-Dublin), School of Mechanical & Materials Engineering, University College Dublin, Dublin 4, Ireland

Micro/nano surface structures have been widely used in microfluidics, bionic functionalities, haptic effects, hydrophobic and hydrophilic structures, in areas that are as diverse as diagnostics, medical devices, and optics[1]. When prototyping and mass-producing such polymeric micro/nano components using moulding or forming processes, it is distortion and damage of surface features that are the most common defects, caused by interfacial friction and adhesion (Figure 1 (a)). This eventually causes problems of bonding delamination, functional failure and poor imaging quality. Surface coatings are normally used to reduce friction. However, coatings, such as molecular coatings, gas-phase lubricants, and liquid lubricants, are easily worn off, evaporate or cause contamination. Hard coatings, such as MoS_2, fluoropolymer coatings, diamond-like carbon (DLC) coating, can peel off from a mould during demoulding, due to residual stress, poor adhesion and may not sustain with high temperature. Applying a coating could change the dimensions of nanometric scale structures and it is difficult to uniformly coat the sidewall of a micro mould cavity, particularly if it has a narrow entrance or high aspect ratio.

We have developed patent-pending technology of fabrication of 2D material reinforced nanocomposite micro/nano mould. Layered 2D materials, including graphene oxide (GO), molybdenum disulfate (MoS_2), and tungsten disulfide (WS_2), were used as dispersed phase in electroforming electrolytes for fabrication of precision self-lubricating mould [2]. Our results demonstrated that nickel/WS_2 mould tools presented the most significant microhardness improvement, followed by nickel/GO and nickel/MoS_2 mould tools, respectively. Maximum microhardness of ~660 HV together with the minimum crystallite size of 12 nm, was achieved from 0.5 g/L WS_2, indicating a 3.67 times microhardness increase and 3 times crystallite size reduction relative to pure nickel mould tool. The enhanced microhardness can be attributed to 2D materials-induced crystal refinement, inherent hardness, and incorporation content of 2D materials. Additionally, friction and wear tests revealed that a low concentration (0.14 g/L) of WS_2 achieved the lowest coefficient of friction (COF) and superior wear resistance, where the COF in the initial friction stage and stable wear stage was 0.08 and 0.18, respectively, implying a decrease of 42.8% and 72.3%, respectively, and 27 times increase in a lifetime in the initial friction stage, compared with those of pure nickel mould tool. Such a significant improvement in tribological properties was due to the formation of self-lubricating transfer film by the interlayer shear effect of few-layered 2D materials nanosheets. In all, this work developed a new concept of high-performance 2D materials-based nickel composite mould tools and validates their mechanical and tribological performance enhancement for potential micro/nano mould tool applications.

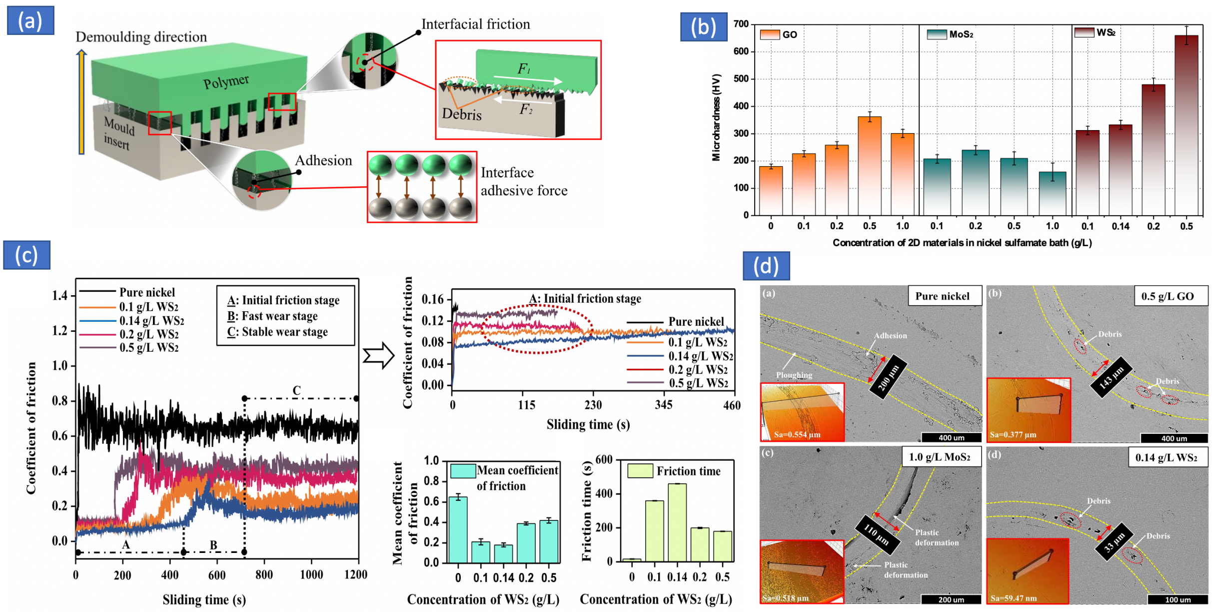


Figure 1: Concept of self-lubricating mould and initial validation: (a) concept; (b) hardness of electroformed mould; (c) tribology properties and (d) morphology.

References:

1. N. Zhang, A. Srivastava, B. Kirwan, R. Byrne, F. Z Fang, D. J. Browne, & Zhang, N., Srivastava, A., Kirwan, B., Byrne, R., Fang, F., Browne, D. J., & Gilchrist, M. D. (2015). *J. Micromech. Microeng.* **25** (9), 095005.
2. N. Zhang, H.G. Zhang, F. Z. Fang, *Ultrason. Sonochem.* **62** (2020): 104858.

Origination of super-smooth micro-optical elements

J. Werder[1], M. Marhöfer[1], A. Karpik[1,2], P.M. Kristiansen[1,2,4]

[1] INKA Institute of Polymer Nanotechnology, FHNW University of Applied Sciences and Arts Northwestern Switzerland, Windisch, Switzerland

[2] Laboratory for Micro- and Nanotechnology, Paul Scherrer Institute, Villigen, Switzerland

[3] University College Dublin, School of Mechanical and Material Engineering, Belfield, Dublin 4, Ireland

Manufacturing asymmetric micro-optical components while maintaining the lowest possible roughness values is a challenge. Conventional processes (except the LIGA process) lead to increased surface roughness which is not suitable for optical applications. Depending on the process, different roughness values are obtained, leading to widening of the light beams, and causing diffuse light scattering.

In the search for suitable process chains to produce micro-optical freeform surfaces, two processes are being investigated at INKA. TASTE (Thermally Activated Selective Topography Equilibration) [1], a process originally developed at PSI, was adapted to higher roughness values at INKA and successfully implemented in a process chain. The method was successfully used for the simulation and validation of micro-optical freeform surfaces at CSEM [2]. However, the TASTE process chain is quite complex, which is why the application possibilities of the method remain limited.

The principle of CO_2 laser assisted surface smoothing (CLASS) has also been demonstrated at INKA. CLASS has the potential to overcome the limitations of the TASTE process. Due to the heat coupling by the CO_2 laser, the process is suitable for a wider range of polymers with respect to their glass transitions. Even larger initial roughness can be smoothened without affecting the dimensional stability.

The high speed of the CLASS process allows efficient implementation into existing process chains. The aspects of heat build-up and different roughness types require more detailed investigations of the process under stable boundary conditions. These and other aspects of laser micromachining of polymers are investigated within several ongoing research projects with diverse funding background [3].

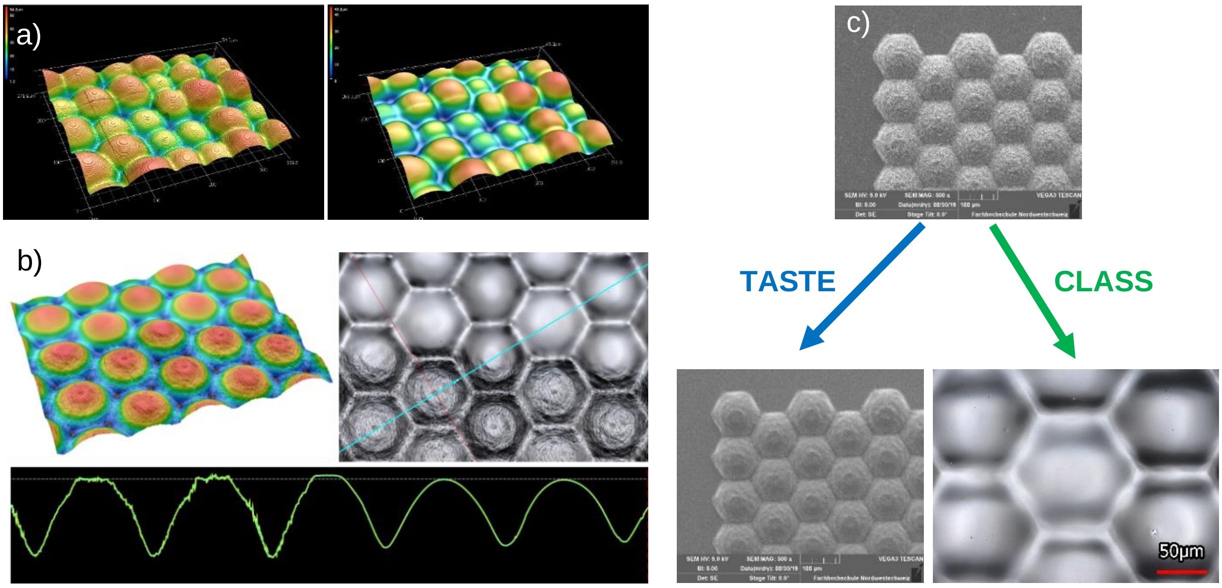


Figure 1: Origination of super-smooth micro-optical elements: a) TASTE process on a micro-optical free-form surface. b) CLASS process on a laser-ablated optical microstructure. The roughness values could be reduced by a factor of four. c) Comparison of both methods on the same microstructure, demonstrating that CLASS allows smoothing of a higher initial surface roughness than TASTE.

References

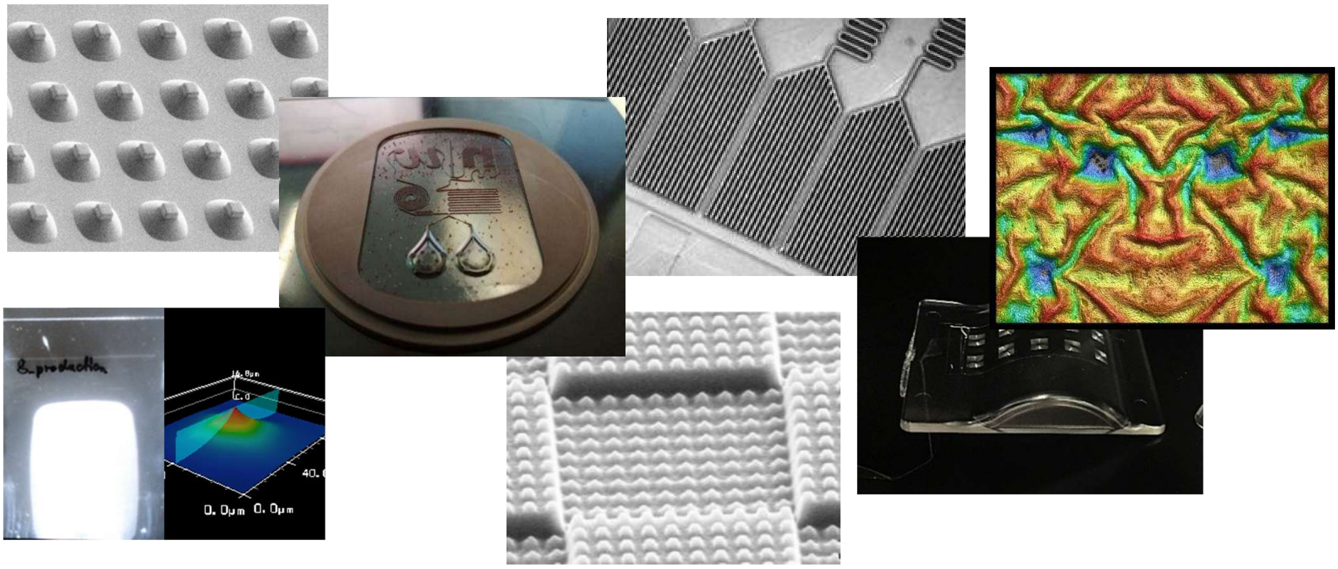
1. N. Chidambaram, R. Kirchner, R. Fallica, L. Yu, M. Altana, and H. Schift, 2017, “Selective Surface Smoothening of Polymer Microlenses by Depth Confined Softening,” Adv. Mater. Technol., 2(5), p. 1700018.
2. T. Aderneuer, O. Fernandez, A. Karpik, J. Werder, M. Marhöfer, P. M. Kristiansen, and R. Ferrini, "Surface topology and functionality of freeform microlens arrays," Opt. Express 29, 5033-5042 (2021).

3. Funding by the Nanoargovia program of the Swiss Nanoscience Institute (LASTRUPOL), the Aargauer Forschungsfond (LaStruPol II) and the European Union under Horizon 2020 MSCA-ITN program (SIMPPER_MedDev)

Image Award

27 - 28 May 2021

PRN 2021 Polymer Replication on Nanoscale



Submission: Please send the best images of your research, stating a title, short description, and scale to prn2020.technik@fhnw.ch

Requirements: The image should have been created during research conducted in 2021

Submission Deadline: October 1st 2021

Announcement of winners: December 2021

Celebration of winners: PRN 2022

Prizes:

1st CHF 500.-
2nd CHF 250.-
3rd CHF 100.-

Big thanks to our silver sponsors

csem

NIL TECHNOLOGY

SNI SWISS NANOSCIENCE INSTITUTE
EINE INITIATIVE DER UNIVERSITÄT BASEL UND DES KANTONS AARGAU

micromachines

IMPACT FACTOR 2.523

Covered in: PubMed

an Open Access Journal by MDPI

Advanced Manufacturing of Micro- and Nanotextured Polymer Surfaces

Guest Editors:

Dr. Nan Zhang
School of Mechanical and Materials Engineering, University College Dublin, Dublin, Ireland

nan.zhang@ucd.ie

Prof. Dr. Per Magnus Kristiansen
Institute of Polymer Nanotechnology, FHNW University of Applied Sciences and Arts Northwestern Switzerland, Windisch, Switzerland

magnus.kristiansen@fhnw.ch

Deadline for manuscript submissions:
30 November 2021

Message from the Guest Editors

Dear Colleagues,

The global trend towards miniaturization has been expanding into many areas of human life, enabled by the realization of ever-smaller mechanical, optical, medical, and electronic products. Due to comparably low cost and industrial up-scalability, polymer materials are favorable for the production of surface micro- and nanoscale surface topographies for integrated systems, such as microfluidic devices, micro-optics, and functional surfaces. Polymer micro/nano manufacturing technologies are broadly composed of molding and forming processes as well as additive and subtractive manufacturing processes.

This Special Issue is dedicated to recent advances in research and development within the field of advanced manufacturing of micro- and nanotextured polymer surfaces. We are looking for papers that report recent findings and developments in manufacturing technologies and applications for polymeric micro- and nanoscale surface topographies.

Dr. Nan Zhang
Prof. Dr. Per Magnus Kristiansen
Guest Editors

Microlens Imprint for Automotive Lighting

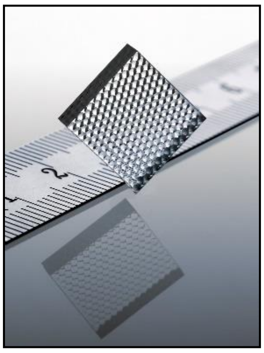
Reinhard Voelkel

SUSS MicroOptics SA, Rouges-Terres 61, 2068 Hauterive, Switzerland

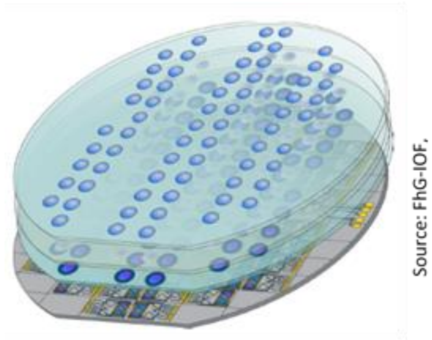
Refractive and diffractive micro-optical components are a very promising novel approach for illumination in automotive lighting. The first application was a microlens-array-based projectors for a welcome light carpet (BMW) invented by the Fraunhofer IOF in 2014. Today, micro-optics is used for illumination and projection within head lights, interior and exterior lighting, rear lights and LIDAR.

The preferred manufacturing technology is SUSS microlens imprint lithography (SMILE) using a mask aligner to imprint microlens arrays (MLA) or diffractive optical components (DOE) onto one or two sides of a glass wafer (C1, C4, C5). Wafers with microlens arrays, aperture arrays, structured absorbers or other structures are the stacked in a mask aligner (C3, C6). We will present an overview of state-of-the-art of manufacturing technology and applications.

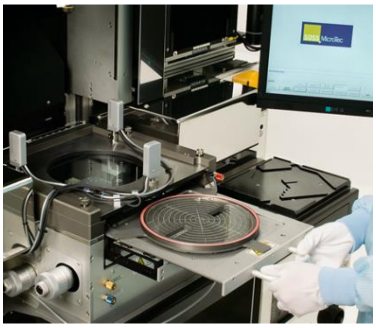
C1: Micro-Optics wafer manufacturing in cleanroom



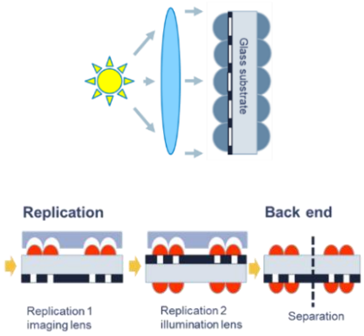
C2: Microlens Array (MLA) for Array-Projector (light carpet)



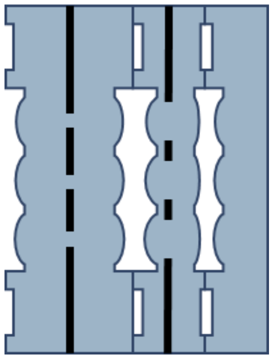
C3: Wafer-Level Packaging (WLP) of Wafer-Level Optics (WLO)



C4: SUSS Mask Aligner for Microlens Imprint Lithography (SMILE)



C5: Scheme of a microlens array projector (top) and imprint process (below)



C6: Scheme of a complex Wafer-Level Optical module comprising different lens and aperture layers.

Figure 1: Important elements in the manufacturing of microlens arrays (C1 to C4) and schematic illustrations of target applications (C5 to C6).

Nanoimprint Lithography

Chair: Helmut Schift (PSI, Switzerland)

16:00-16:15 Celestino Padeste (PSI, Switzerland)

“Polymer supports for serial protein crystallography at X-ray free electron lasers”

16:20-16:35 Benjamin Gallinet (CSEM, Switzerland)

“Nanoimprint and metallo-dielectric coatings for high field of view diffractive optical couplers and narrowband filters”

16:40-16:55 Yuyang Zhou (UCD, Ireland)

“Development of coronavirus-resistant films by combining nanomaterials with nanoimprinting”

17:00-17:15 Shahana Bishnoi (DTU, Denmark)

“Microfabrication of shape and size specific hydrogels to serve as artificial red blood cells”

17:20-17:50 ***Coffee break*** (break-out sessions + Session 2 Q&A)

17:50-18:15 Invited: Jim Watkins (Univ. Amherst, USA)

"Hierarchical Carbons and Ceramics via Polymer Replication at the Nanoscale: Integration of Nanoimprinting, Self-Assembly, and Flash Photothermal Processing”

18:20-18:30 Closing remarks by Laurent Feuz (FHNW, Switzerland)

Polymer supports for serial protein crystallography at X-ray free electron lasers

A. Karpik[1,2], M. Carrillo[1], I. Martiel[1], P.M. Kristiansen[2,3] and C. Padeste[1]

[1] Paul Scherrer Institut, 5232 Villigen PSI, Switzerland
[2] INKA Institute of Polymer Nanotechnology, FHNW University of Applied Sciences and Arts Northwestern Switzerland, 5210 Windisch, Switzerland
[3] University College Dublin, School of Mechanical and Materials Engineering, Belfield, Dublin 4, Ireland

Serial macromolecular crystallography is a powerful new method for protein structure determination at X-ray free electron lasers (XFELs) and synchrotron X-ray sources [1,2]. It is based on collecting diffraction patterns from large numbers of small protein crystals and allows solving protein structures directly from protein microcrystals, which are too small for standard X-ray techniques. To deliver the protein microcrystals at high frequency to the probing X-ray beam, novel protein crystal handling methods such as the so-called fixed target technology have been developed. In this approach, the crystalline sample is deposited on a thin film support, which is mounted on a scanning stage and scanned across the beam, thus sequentially probing the individual microcrystals with the tightly focused x-rays.

Here, we present fabrication strategies for polymer-based supports, which take advantage of the low X-ray absorption and scattering background of polymer materials, the absence of X-ray diffraction if using amorphous polymers, the high design flexibility and the potential for mass-fabrication at low cost. We will discuss our developments for measurements at cryo-conditions, where efficient blotting of the crystallization buffer is of highest importance, as well as for studies at room temperature, where specially designed enclosures protect the protein crystals from drying out and denaturation.

For cryo-applications, perforated polymer films as thin as 2–3 µm are produced using nanoimprint lithography (Fig. 1) [3]. A stamp with arrays of micro-pillars is embossed into a spin-coated double-layer, which consists of 2–3 µm COC on top of a water-soluble interlayer. After a short plasma etch to remove the residual layer in the embossed holes, a supporting frame is 3D-printed directly onto the membrane, and the supports are released from the underlying silicon wafer by immersion into water, which dissolves the water-soluble polymer. Perforations of 2–3 µm in diameter at 4–6 µm period were found to provide high blotting efficiency, while the film maintained sufficient stability for deposition of the protein crystal suspension and subsequent cryogenic flash-cooling. X-ray diffraction with very low scattering background signal has been demonstrated in experiments at both synchrotron and XFEL sources.

For room temperature measurements, we developed an entirely polymeric enclosure system consisting of 3D-printed top and bottom frames with a suspended continuous polymer film of a few micrometers in thickness, which can slide onto a frame holding a central support membrane. In this case, the central membrane was 25-50 µm thick with imprinted pyramidal shaped holes. It is designed for capturing individual protein crystals at predefined positions in order to optimize the hit-rate of the probing X-ray beam. The enclosure system maintained enough humidity to keep protein crystals stable during XFEL-experiments of up to one hour.

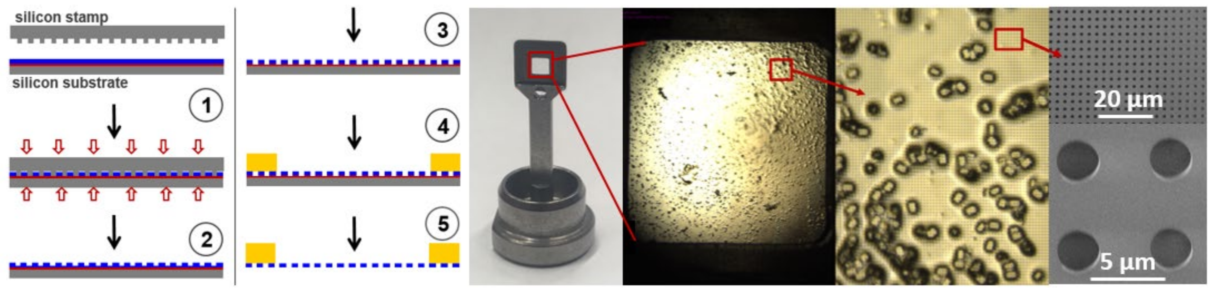


Figure 1. From left to right: Fabrication of ultrathin perforated polymer supports; support mounted on a sample holder; optical images of deposited microcrystals; SEM images of the perforated membrane.

References

1. S. Boutet et al., Science ***337*** (6092), 362-364 (2012).
2. T. Weinert et al., Nat. Commun. ***8***, 542 (2017).
3. A. Karpik, I. Martiel, P.M. Kristiansen, C. Padeste. Micro and Nano Engineering ***7***, 100053 (2020).

Nanoimprint and metallo-dielectric coatings for high field of view diffractive optical couplers and narrowband filters

B. Gallinet, F. Lütolf, F. Herzog, C. Schneider, J. Heidler, R. Krähenbühl, A. Luu-Dinh, F. Zanella, R. Ferrini

CSEM SA, Muttenz, Switzerland

We report on a nanoimprinted diffractive waveguide with refractive index superior to 1.9, for a field of view of 60°. A coupling efficiency above 50% average over the entire field of view and for unpolarized light is obtained by subsequent thin film coating of index 2.3. We also use dielectric and metallic thin film coatings on nanoimprinted gratings to generate narrowband filters for multispectral imaging applications.

Diffractive couplers are essential components in waveguide combiners for augmented reality. This approach shows limitations in the field of view, determined by the waveguide refractive index. Nanoimprinting with large refractive indexes overcome this limitation. By using a nanoimprint process for indexes above 1.9, we can manufacture a waveguide combiner with a field of view of 60° of the transported image (Fig. 1a-b). Another limitation is in the efficiency of the incoupling grating, which is limited by the aspect ratio of the imprinted structures. Using a high index dielectric coating (ZnS), we can enhance the efficiency above 50% for the entire field of view and for unpolarized light. This effect is obtained through the excitation of guided mode resonances in the optical coupler [1].

Nanoimprint and thin film coatings have also been reported to generate filtering in the zeroth order of transmission through the excitation of surface plasmon resonances. Thanks to nanostructured filters, the fabrication process of filter arrays requires only a few process steps. As only a variation of the underlying grating periodicity is necessary to generate the different filters. A common imprint master can be used to all filters. However, surface plasmons suffer from optical losses and the resulting filter bandwidth is relatively large, especially in the visible range. We show that nanoimprinted hybrid metallo-dielectric filters yield a bandwidth of 20nm, while keeping a good blocking rate (Fig. 1c-d) [2].

Nanoimprint and thin film coatings together enable the manufacturing of a broad range of devices with tailored functionalities. Applications include augmented reality, multispectral imagers or optical sensors.

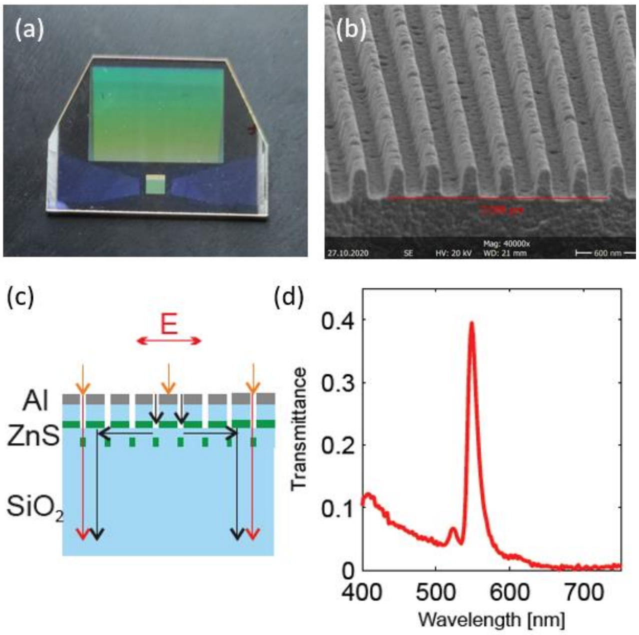


Figure 1: (a) Waveguide combiner for augmented reality based on 1.9+ refractive index UV nanoimprint. (b) Microscopic cross section of the grating coupler. (c) Resonance mechanism of narrowband filters based on corrugated metallo-dielectric thin films. (d) Measured transmittance spectrum.

References

1. G. Quaranta, G. Basset, O.J.F. Martin, B. Gallinet, *Laser & Photonics Reviews,* ***12*** (9), 1800017 (2018)
2. B. Gallinet, G. Quaranta, C. Schneider, *Adv. Opt. Techn.*, ***10*** (1), 31-38 (2021)

Development of coronavirus-resistant films by combining nanomaterials with nanoimprinting

*Yuyang Zhou [1], Nicola F. Fletcher[2], Jaythoon Hassan[3], Douglas Carton[1], *Nan Zhang[1], Michael D. Gilchrist[1]*

[1] School of Mechanical & Materials Engineering, [2] School of Veterinary Medicine,
[3] National Virus Reference Laboratory, University College Dublin, Dublin 4, Ireland
Correspondence to: nan.zhang@ucd.ie

As of April 24th 2021, the SARS-CoV-2 (COVID-19) pandemic has infected 146m people and caused more than 3m fatalities in more than 200 countries worldwide. Second, third and fourth waves of the virus are still occurring around the world. With the continuing crisis, researchers and companies are actively developing technologies to combat and cope with this and variant corona viruses. Thanks to the recent advent of several COVID-19 vaccines, the efforts against the pandemic have now reached a historic turning point. However, living with the coronavirus into the future is increasingly likely, due to its pervasiveness and its continuing mutation. Plastic products, including food packaging and commodity plastic products are widely used in all our daily lives. Recent research has confirmed that SARS-CoV-2 can remain active on plastic for 72 h, which poses a high risk of indirect transmission by touching contaminated surfaces [1]. Even though plastic surfaces can be disinfected using ethanol, hydrogen peroxide, or sodium hypochlorite, the process of sanitisation is laborious and requires the use of cleaning agents, can be difficult to achieve and needs periodic repetition, which is not always feasible [2].

We have developed a versatile and highly efficient polymer film to deactivate SARS-CoV-2 using nanoparticle coatings on nano-scale conical pillars using ultrasonic spray coating and nanoimprinting (Fig. 1). The nano-structural design potentially increases the effective contact area of SARS-CoV-2 with nanoparticle coatings for more efficient deactivation. Antiviral assays were carried out on 15 samples and infectivity quantified using the Tissue Culture Infectious Dose (TCID50). Original PE and PET films showed no antiviral properties using a full length clinical isolate of SARS-CoV-2 (2019-nCoV/Italy-INMI-1). Similarly, patterned surfaces also displayed no antiviral activity. Upon the coating of NPs on the film, significant deactivation of SARS-Cov-2 was observed after only one-hour viral contact. AgNPs were found to be more effective in their antiviral function than CuNPs. In general, a 100-fold reduction in infectivity could be achieved merely after 1 hour contact with the functionalized films using our designed protocol. Nanopatterns were confirmed to enhance the anti-COVID effectiveness by increasing the contact area. This project provides a novel, scalable, low-cost production method for fabrication of anti-virus films.

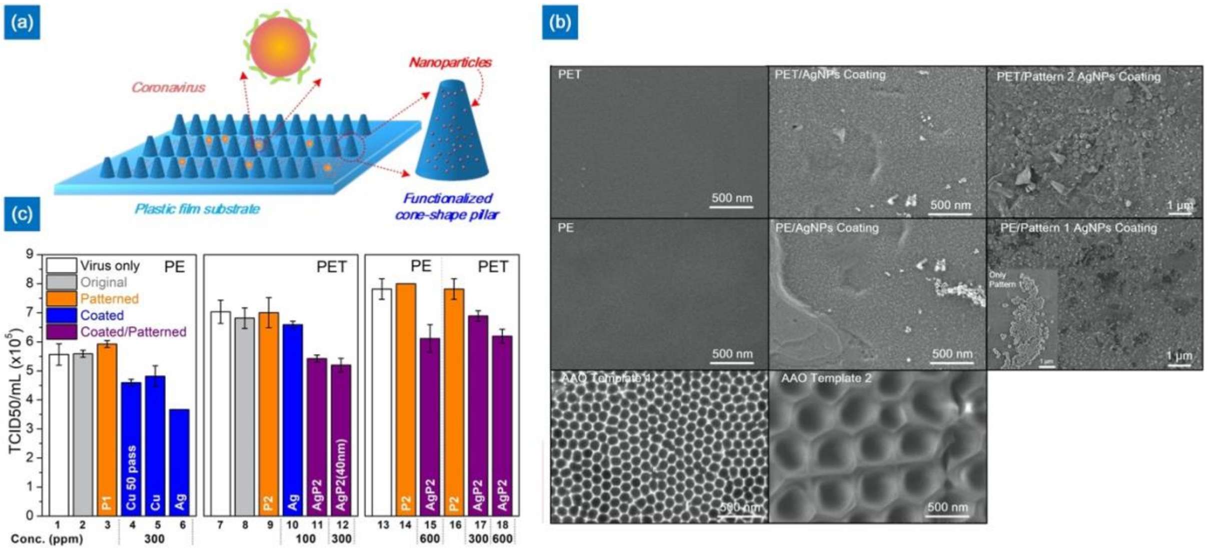


Figure 1: Concept of nanopatterned antiviral film: (a) concept; (b) Films coated with nanopatterns and AgNPs and CuNPs; (c) anti-COVID 19 assessments of treated films using TCID50 assay.

Acknowledgements:
We gratefully acknowledge support that has been provided by Science Foundation Ireland and I-Form (Grants 20/COV/V0310 and 16/RC/3872).

References:

1. Balasubramaniam, B., Prateek, S.R., Saraf, M., Kar, P., Singh, S. P., ... & Gupta, R.K. (2021). *ACS Pharmacol & Transl Sci*. 4(1), 8-54.
2. Kampf, G., Todt, D., Pfaender, S., & Steinmann, E. (2020). *Journal of Hospital Infection*, 104(3), 246-251.

Microfabrication of shape and size specific hydrogels to serve as artificial red blood cells

Shahana Bishnoi[1,2], Ritika Singh Petersen[2], Lasse Højlund Thamdrup[1], Leticia Hosta-Rigau[1], Stephan Sylvest Keller[2]

[1] Department of Health Technology, Technical University of Denmark, DK-2800 Kgs. Lyngby
[2] National Centre for Nano Fabrication and Characterization, Technical University of Denmark, DK-2800 Kgs. Lyngby

Donor blood is a vital resource to account for blood loss experienced during accidents, trauma and surgeries. The collection, storage and transfusion of this blood is however a tedious process. This is due to hindrances associated with its short shelf life, limited availability, risks of disease transmission and the need for typing and matching to name a few. [1] Thus, the creation of red blood cell substitutes (RBCS) is an important challenge in the biomedical field. Several RBCS have been reported and some have even received limited approval for use in critical situations where donor blood is not available.[2] However, an important limitation of the reported RBCS is their short circulation life-times. In order to meet the high oxygen demands of our bodies, RBCS displaying extended vascular residence times are highly sought after.

Unlike native RBC, most of the current RBCS are spherical assemblies, since they have been mainly fabricated by bottom-up approaches.[3] Thus, we hypothesize that by mimicking the unique physical aspects of native RBC, we can create RBCS with longer circulation times than those reported so far. Therefore, we aim to create a library of biomimetic hydrogel microparticles with varying shapes and sizes to achieve long circulating RBCS.

Hydrogel microparticles maintaining the aspect ratio of RBC in various shapes and sizes were fabricated to serve as a preliminary library for RBCS. To fabricate these, a master template in Silicon with features identical with those of the desired particles was fabricated by using photolithography and reactive ion etching (RIE) (Fig.1A). Arrays of 25 µm tall circular, elliptical, square and rod-shaped structures were obtained. The fabricated master was used to imprint wells with the inverse geometry in a Cyclo Olefin Polymer (COP) sheet by hot embossing (Fig.1B). The non-toxic flexible COP stamp was wetted with uncured Polyethylene glycol (PEG) hydrogel formulation and the solution was pressed into the wells by roll-to-plate embossing. Next, a flexible Poly-vinyl alcohol (PVA) substrate was placed onto the filled COP stamp. The stack was subjected to high pressure and the hydrogels were cross-linked in a UV nanoimprint lithography (UV-NIL) system. In this process, the COP stamp mechanically punched through the hydrogel flash layer and the PEG hydrogel microparticles were transferred onto the PVA substrate (Fig.1C). The hydrogels were then easily harvested by dissolving the water soluble PVA substrate.

The loading of the fabricated hydrogel particles with hemoglobin is currently being explored.

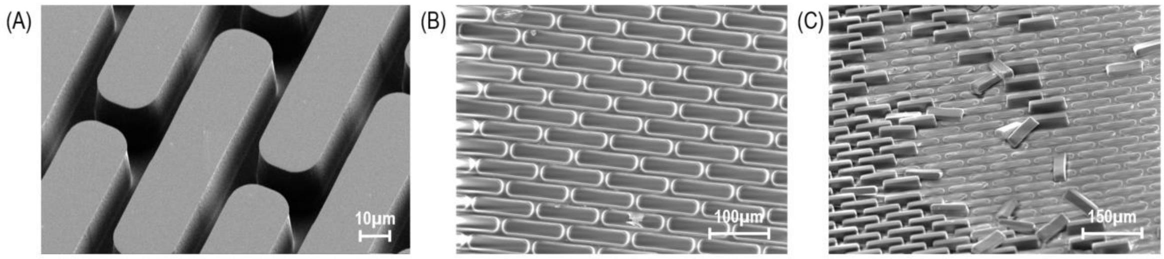


Figure 1: SEM images of the 100 µm x 25 µm x 25 µm rod shaped - (a) structures fabricated on a Si master template by photolithography and RIE, (b) wells imprinted on a COP foil via hot embossing and (c) PEG hydrogel microparticles on a PVA substrate fabricated by roll-to-plate embossing and UV nanoimprint lithography

References

1. Jansman, Michelle MT, and Leticia Hosta-Rigau. "Recent and prominent examples of nano-and microarchitectures as hemoglobin-based oxygen carriers." Advances in colloid and interface science 260 (2018): 65-84.
2. Coll-Satue, Clara, Shahana Bishnoi, Jiantao Chen, and Leticia Hosta-Rigau. "Stepping stones to the future of haemoglobin-based blood products: clinical, preclinical and innovative examples." Biomaterials Science (2020).
3. Chen, Kai, Timothy J. Merkel, Ashish Pandya, Mary E. Napier, J. Christopher Luft, Will Daniel, Sergei Sheiko, and Joseph M. DeSimone. "Low modulus biomimetic microgel particles with high loading of hemoglobin." Biomacromolecules 13, no. 9 (2012): 2748-2759.

Hierarchical Carbons and Ceramics via Polymer Replication at the Nanoscale: Integration of Nanoimprinting, Self-Assembly, and Flash Photothermal Processing

*Uzodinma Okoroanyanwu, Ayush Bhardwaj, Huafeng Fei, and James J. Watkins**

Polymer Science and Engineering Department
and Institute or Hierarchical Manufacturing
University of Massachusetts
Amherst, MA 01003 USA

Nanoimprint lithography (NIL) and micro-replication technologies provide pathways for the rapid and cost-effective patterning of polymer substrates. Unfortunately these same approaches can't often be practically applied directly to other functional materials, including metal oxides, ceramics, carbons and carbon/graphene composites. Recently we outlined an approach for creating patterned crystalline metal oxides for applications in optics, energy storage and injection mold inserts by combining NIL with nanoparticle-based inks.[1,2] Here we demonstrate a rapid and efficient approach to patterned ceramics, mesoporous carbons and carbon/graphene composites by first imprinting a polymeric precursor to the desired materials and then converting that material to the target ceramic or carbon composition within milliseconds using flash photothermal processing. Moreover functional, hierarchical materials can be produced by using NIL to pattern the materials at the 100s of nm to micron scales while simultaneously using self-assembly of the polymeric precursors to control architectures within the patterned materials at the sub-100 nm scale.

Patterned ceramics including silicon carbide (SiC), silicon oxycarbide (SiOC) and silicon nitride (SiN) are important materials for use in harsh environments, and in some cases energy storage, where their excellent mechanical and refractory properties benefit the applications. Over the past several decades, preceramic polymers that can converted to the desired ceramic phase have garnered significant attention. One downside of the use of such preceramic polymers is the significant thermal processing times required for their conversion. Recently we demonstrated that high quality SiC and SiOC can be produced within milliseconds via photothermal pyrolysis of polycarbosilanes and polysiloxanes using a high-intensity pulsed xenon flash lamp in air at room temperature.[3] The millisecond duration of the pulse is shorter than the thermal equilibrium time of the preceramic polymers, enabling conversion to the ceramic phase prior to significant energy transfer to the substrate. This process is therefore unique for ceramic processing on or adjacent to thermally sensitive materials. Patterned ceramics can be easily produced by simply imprinting the preceramic polymer prior to pulsed flash lamp processing. We provide several examples and demonstrate the utility of the materials for electrochemical energy storage.

Mesoporous carbons are attractive for energy storage as electrodes for batteries and supercapacitors as well as a myriad of other applications. Materials with controlled nanoscale porosity can be produced via carbonization of carbon precursors structured via self-assembly using block copolymers (BCPs), wherein once phase of the BCP serves as a sacrificial porogen during carbonization. In this regard the structure of the self-assembled polymer precursor is replicated in the carbon. Recently we demonstrated that pore size range in mesoporous carbons can be significantly extended to up to 100 nm by using brush block copolymers as templates for the precursor.[4] Moreover, we further demonstrated that simple pattering of the self-assembled carbon precursors using NIL prior to thermal or photothermal carbonization yields hierarchical carbon structures with excellent performance in energy storage applications, including batteries and supercapacitors.[5]

In summary, recent years have shown significant progress towards the use of polymer replications at the nanoscale to yield functional materials and devices comprised of materials that do not benefit from the same ease of direct processing and patterning approaches that can be applied to the polymers themselves. Combinations of polymer patterning techniques with rapid and efficient post-pattering approaches to materials chemistry and conversion, such as high intensity photothermal processing using flash lamps, offers new opportunities for efficient and cost-effective device fabrication across a variety of materials sets.

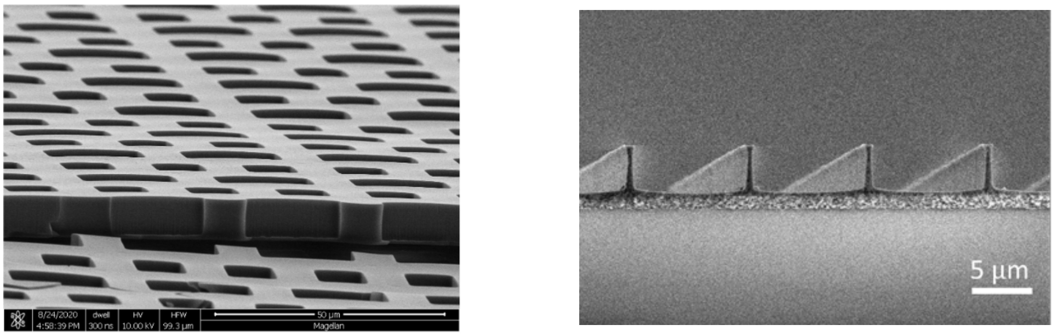


Figure 1. Patterned SiC ceramic produced by imprinting a polycarbosilane preceramic polymer followed by flash lamp processing to yield SiC within seconds. Patterned mesoporous carbon composite lithium ion battery anode produced by imprinting a self-assembled carbon precursor film followed by photothermal processing. The cross-section reveals its hierarchical structure, which results from combining polymer replications by self-assembly and NIL.

References

1. Kothari, R.; Beaulieu, M. R.; Hendricks, N. R.; Li, S. K.; Watkins, J. J. *Chemistry of Materials* 2017, 29 (9), 3908.
2. Arisoy, F.D.; Czolkos, I; Johansson, A; Nielsen, T; Watkins, J.J. *Nanotechnology*, 2020, 31, 015302
3. Okoroanyanwu, U.; Bhardwaj, A.; Einck, V.; Ribbe, A.; Hu, W. G.; Rodriguez, J. M.; Schmidt, W. R.; Watkins, J. J. *Chemistry of Materials* 2021, 33 (2), 678.
4. Fei, H. F.; Li, W. H.; Bhardwaj, A.; Nuguri, S.; Ribbe, A.; Watkins, J. J. *Journal of the American Chemical Society* 2019, 141 (42), 17006.
5. Song, D. P.; Li, W. H.; Park, J.; Fei, H. F.; Naik, A. R.; Li, S. K.; Zhou, Y. L.; Gai, Y.; Watkins, J. J. *Carbon* 2021, 174, 439.

Industrial Replication Technologies I

Chair: Per Magnus Kristiansen (FHNW, Switzerland)

09:00-09:25 Invited: Thomas Mortelmans (PSI, Switzerland)

"Thermoplastic 3D nanofluidic devices for biosensing "

09:30-09:45 Nekane Lozano Hernandez (Eurecat, Spain)

"Microtexturation of liquid silicone rubber surfaces by injection moulding using hybrid polymer inlays"

09:50-10:05 Guggi Kofod (Rel8 Asp, Denmark)

"A traceability system for injection molding"

10:10-10:25 Carlos Sáez (Eurecat, Spain)

"Replication of hierarchical nanostructures on Polycarbonate via Isothermal injection moulding using NIL-textured films"

10:30-11:00 ***Coffee break*** (break-out sessions + Session 3 Q&A)

11:00-11:20 Selected people from the INKA Team (FHNW, Switzerland)

"Virtual Lab Tour – insights into our infrastructure & applied R&D in the field of functional polymer surfaces – and beyond"

Thermoplastic 3D nanofluidic devices for biosensing

Thomas Mortelmans [a,b], *Dimitrios Kazazis*[a], *Celestino Padeste* [a,b], *Xiaodan Li* [a,b], *Per Magnus Kristiansen*[b,c,d], *Yasin Ekinci* [a,b]

[a] Paul Scherrer Institute, 5232 Villigen-PSI, Switzerland
[b] Swiss Nanoscience Institute, University of Basel, 4056 Basel, Switzerland
[c] INKA Institute of Polymer Nanotechnology, FHNW University of Applied Sciences and Arts Northwestern Switzerland (FHNW), 5210 Windisch, Switzerland
[d] University College Dublin, School of Mechanical and Materials Engineering, Belfield, Dublin 4, Ireland

In typical micro and nanofluidic devices, the channel's height (along the z-axis) remains constant [1]. However, by varying the latter, many new functionalities, such as, for instance, advanced flow focusing can be realized [2]. We use state-of-the-art nanofabrication methods and cost-effective replication techniques to fabricate three-dimensional (3D) capillary nanofluidic devices capable of precise particle manipulations in the sub-micron regime.

Our design and fabrication methods that we developed enable nanoscale topography variation on a millimeter length scale in a well-controlled manner. We used grayscale electron beam lithography (g-EBL) to pattern a nanofluidic device containing a 3D profile in its channel [3]. However, as g-EBL is a direct writing technique, its upscaling potential is inherently limited. In an effort to address this, we replicated the high-resolution e-beam structure into Ormostamp (Microresist). This negative copy (master) contains all the nanoscale topographical features present in the original design. After the application of an anti-adhesion silane coating, can be used in nano-imprint lithography. Here, we hot embossed the master structure into a poly(methyl methacrylate) film. The 3D nanoscale profile was well-retained throughout the fabrication process (Fig. 3).

The device fabrication was finalized by closing the nanofluidic channels with an unpatterned optical grade PMMA film. To do so, the surfaces of both the imprinted and non-imprinted PMMA films were activated through UV/Ozone-exposure at 172 nm. This highly energetic exposure reduces the average molecular weight at the surface with respect to the bulk material [4]. As a consequence, the glass transition temperature is also reduced, allowing for thermal bonding at lower temperatures without causing device deformation. The particle sorting capabilities of the devices were tested in a proof-of-principle experiment. More specifically, a mixture of calibration-grade fluorescent polystyrene particles of different sizes was loaded into the 3D PMMA device. Their trapping position was measured through confocal fluorescence microscopy and confirmed size-dependent immobilization of the particles down to a diameter 500 nm.

As an alternate device fabrication route, injection molding in combination with g-EBL was investigated. We show that it is possible to directly perform nickel electroforming from g-EBL structures in PMMA resist to reliably fabricate a high-quality nickel shim. As an additional benefit, the sub-field stitching lines in the e-beam resist were smoothed out when transferred to the nickel shim, reducing the overall pattern roughness (Fig. 4). The nickel shim was used to injection mold 3D nanofluidic devices in PMMA and cyclic-olefin polymer (COP) (Fig. 5). The injection-molded devices contain various structures, such as rectangular lines, which simultaneously offer support during bonding and enable a higher degree of control over the fluid filling front upon device loading (Fig. 6).

In our ongoing work, we aim to use distinct size-dependent immobilized particles to perform multiplexed on-chip immunoassays for a variety of diseases. Moreover, to minimize sample handling and accelerate antibody detection, we are working on the integration of different functionalities, such as the on-chip isolation of blood plasma, directly from whole blood.

References

1. A.M. Streets, Y. Huang, Chip in a lab : Microfluidics for next generation life science, Biomicrofluidics. **7** (2013) 1–23.
2. P. Paiè, F. Bragheri, D. Di Carlo, R. Osellame, Particle focusing by 3D inertial microfluidics, Microsystems Nanoeng. **3** (2017) 1–8.
3. T. Mortelmans, D. Kazazis, V.A. Guzenko, C. Padeste, T. Braun, H. Stahlberg, X. Li, Y. Ekinci, Grayscale e-beam lithography: Effects of a delayed development for well-controlled 3D patterning, Microelectron. Eng. **225** (2020) 111272.
4. A. Schleunitz, V.A. Guzenko, M. Messerschmidt, H. Atasoy, R. Kirchner, H. Schift, Novel 3D micro- and nanofabrication method using thermally activated selective topography equilibration (TASTE) of polymers, Nano Converg. 1 (2014) 7.

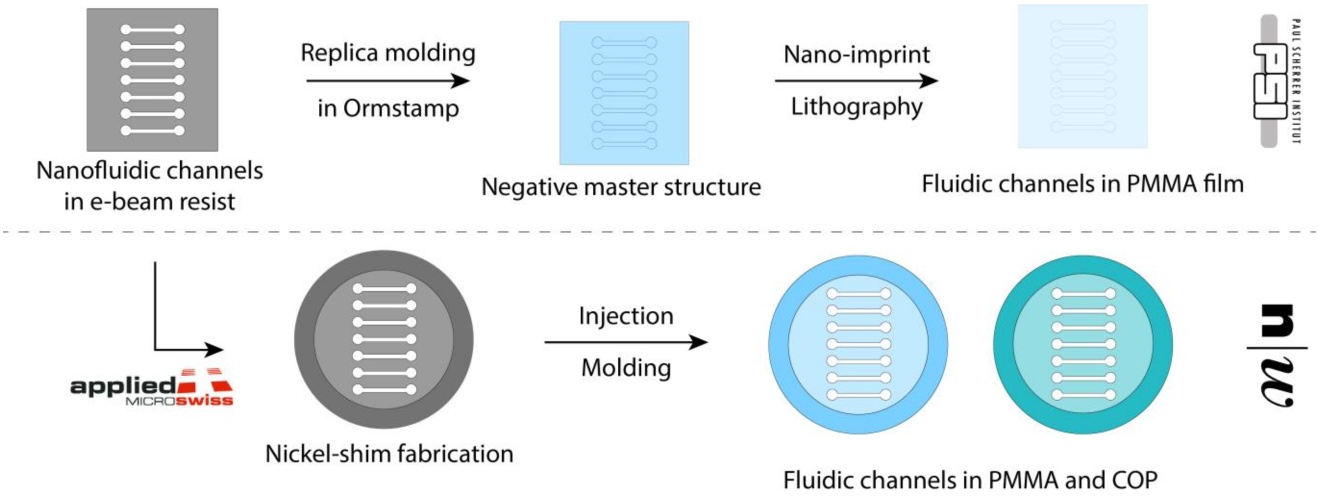


Figure 1. A schematic illustrating the two investigated fabrication routes for 3D nanofluidic thermoplastic devices: nano-imprint lithography (top) and injection molding (bottom)

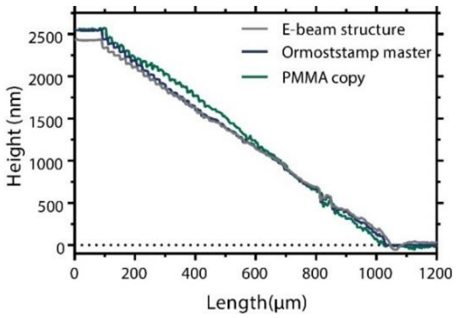


Figure 3. 3D profile during nano-imprint fabrication route

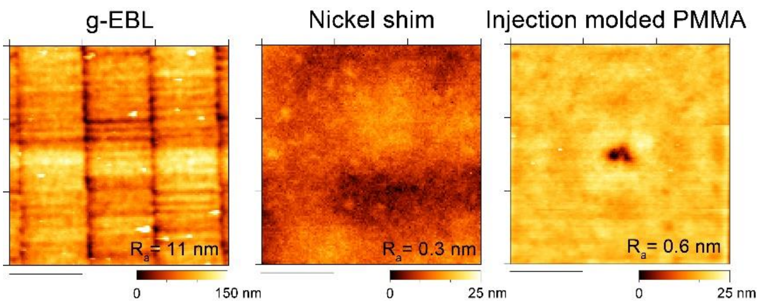


Figure 4. AFM images of the nanofluidic inflow region at different fabrication steps showing decreasing roughness. Scale bar is 5 µm.

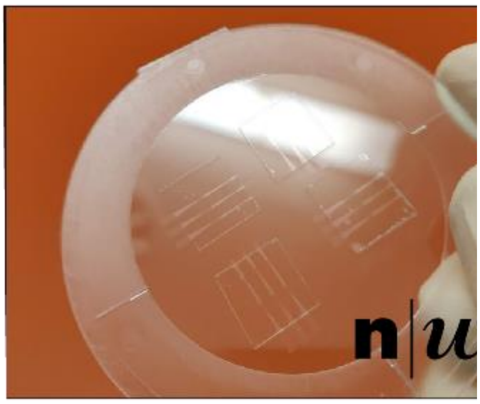


Figure 5. Injection-molded PMMA part with four bonded nanofluidic devices.

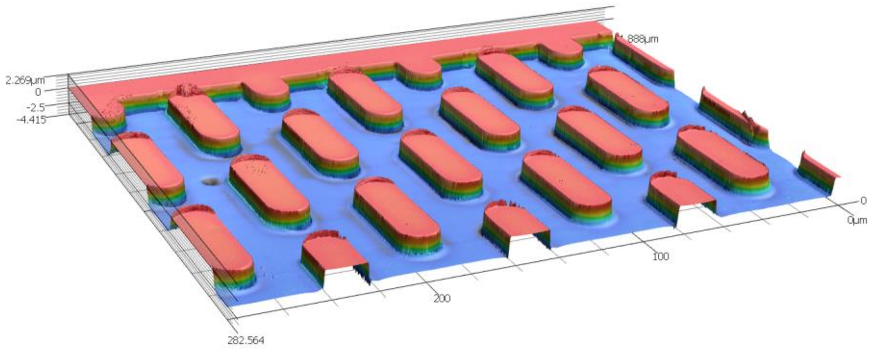


Figure 6: Injection molded line structures inside nanofluidic device for additional support during bonding. Scale bar in micron.

A traceability system for injection moulding

G. Kofod [1]

[1] Rel8 Aps, Hoersholm, Denmark

We have recently developed a system for introducing traceability in injection moulding, by means of nanostructured 2D barcodes. The system overcomes several of the practical issues in Direct Part Marking, allowing scannable markings on smaller plastic parts than has been practical before.

Traceability developments, also in plastic manufacturing, have been driven by various industry needs – from food to auto to pharma, industries are required to re-call products when systematic manufacturing defects are found. However, the marking of plastic products has remained difficult until now, as cost, complexity and risk of marking is often considered prohibitive. Hence, most plastic components have no or rudimentary markings today. One way to overcome this would be with a marking system that marks within the moulding cavity, which requires flexibility and adequate contrast of the markings.

Most plastic components have high complexity due to functionality, materials choice, aesthetics, and need to reduce material consumption. Hence, the available space for marking is typically limited, especially for smaller parts. Further, when barcode size is reduced, the graining of pixel boundaries can cause barcodes to become poor quality. Finally, plastic comes in a variety of colors, and especially white plastic can be difficult to mark with scannable barcodes.

We have developed a system which enables 2D barcodes replicated on plastic parts during the moulding cycle. The barcodes are based on box-shaped nanostructures with diffraction. Mastering occurs by lithographical means, while implementation on steel insert tools occurs via a coating protocol. Replicated barcodes can be scanned directly from the plastic by various means. We present this approach as a general method to achieve traceability for some plastic parts, in production and beyond. The method is currently offered to potential customers under a brand name.

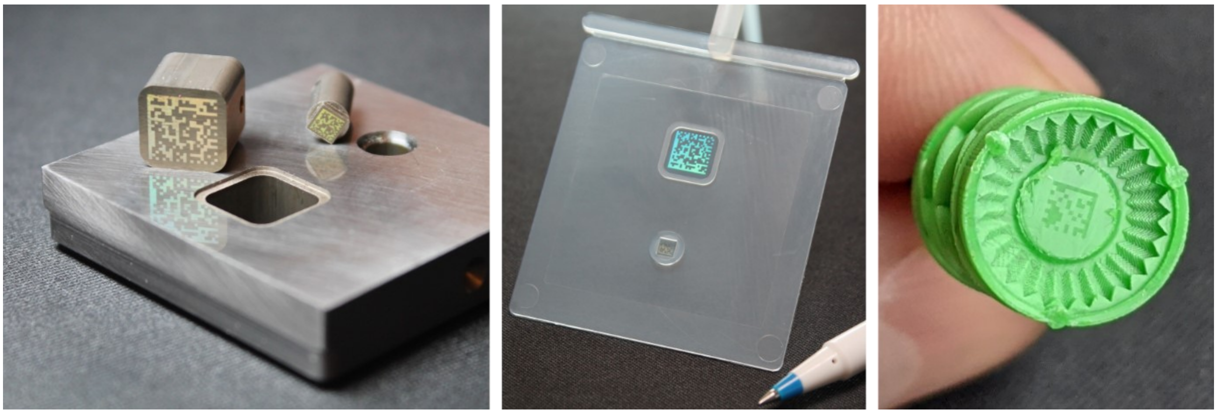


Figure 1: (left) A mould part having two inserts of differing sizes. (center) The moulded part, showing detectable barcodes within protective frames. (right) A moulded part (PP) showing a 3x3 mm2 barcode of Datamatrix 10x10 symbology, decoding as [004001].

Microtexturization of liquid silicone rubber surfaces by injection moulding using hybrid polymer inlays

N. Lozano-Hernández[1,2], G. Pérez-Llanos[1,2], L.J. Del Valle[1], J. Puiggali[2], E. Fontdecaba[3]

[1] Eurecat, Centre Tecnològic de Catalunya, Unit of Plastic materials and processes, Av. Universitat Autònoma, 23, 08290 Cerdanyola del Vallés, Spain

[2] Departament d'Enginyeria Química, Universitat Politècnica de Catalunya (UPC), C/ Eduard Maristany 10-14, 08019, Barcelona, Spain

Micro and nanotexturization of polymeric surfaces may provide different functionalities, such as superhydrophobicity, self-cleaning or antibacterial capabilities. These surface texture properties are promising for many surface engineering applications. In this work, the replication of textures was carried out by liquid silicone rubber (LSR) injection moulding. LSR has a great interest in the medical industry due to its biocompatibility. These medical applications have interesting synergies with surface texturing since it is possible to obtain pieces with antibacterial properties, cell alignments and tunable wettability. The replication process consists of the overmoulding of a polymeric textured film. At the end of the process, a textured part is obtained while the imprinted film remains in the mould. This film can be used in several replication cycles. Textured polymeric films were obtained by nanoimprint lithography, which is more effective than using textured moulds. Also, textured films present a heat-insulating capability, which delays the silicone vulcanization and allows a complete filling of nanostructures [1]. The flexibility of these films during mould release can help prevent the breakage of micro-textures. Moreover, the low viscosity attained during the processing of LSR makes it a good candidate for surface replication [2]. The present work aims to study the replication of different shaped textures in a diameter range between 2 and 50 μm. The injection moulding parameters were optimized to increase the replication grade. Furthermore, the influence of both the texture position concerning the injection point and the thickness of the part have been evaluated. The resulting improvements in the wettability behaviour and cell alignment of the textured surfaces have been determined and discussed.

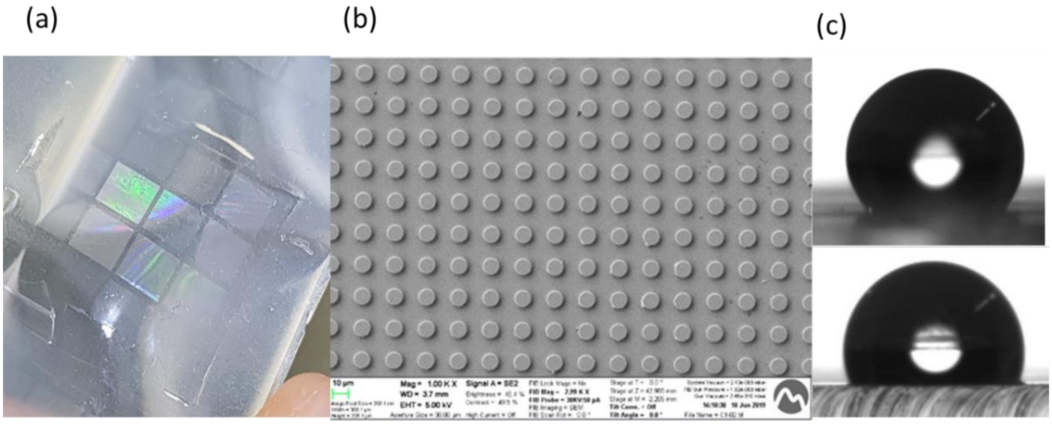


Figure 1: (a) Photograph of texturized surface of a silicone part. (b) Scanning electron microscope (SEM) image of pillars of 10 μm of diameters and 2 μm height. (c) Changes in contact angle of a drop in the flat and textured surface.

References

1. J. M. Stormonth-Darling, N. Gadegaard, Macromol. Mater. Eng. 297, 1075–1080 (2012)
2. C. Hopmann, C. Behmenburg, U. Recht, K. Zeuner. *Silicon*, 6:35-43, (2014)

Replication of hierarchichal nanostructures on Polycarbonate via Isothermal injection moulding using NIL-textured films

C. Sáez-Comet [1], E. Fontdecaba [1], N. Lozano[1], Francesc Pérez-Murano[2], Olga Muntada[2]*

[1]Eurecat, Centre Tecnològic de Catalunya, Unit of Polymeric Materials and Processes, Parc

Tecnològic del Vallès, Av. Universitat Autònoma, 23, Cerdanyola del Vallès 08290 (Barcelona), Spain

[2] Institute of Microelectronics of Barcelona (IMB-CNM, CSIC), C/Til·lers, Campus Universitat Autònoma de Barcelona. Cerdanyola del Vallès. Barcelona, Spain

Polycarbonate is a thermoplastic material of great interest for a variety of uses and applications in sectors such as automotive, optics, health-monitoring and analytical devices, consumer electronics…etc. The surface properties of this polymer can be modified and enhanced in order to provide it with added functionalities, increasing its uses and applications. Such added functionalities include modification of surface-wetting properties, special optical characteristics or even modification of mechanical properties such as friction or abrasion.

In the research we intend to present, the obtention of periodical micro- and nanotextures on the surface on polycarbonate parts is explored using injection moulding to manufacture the final parts, while Nanoimprint lithography is used as replication method to obtain the textured template films, both in coated and uncoated state. Thermoforming is also explored as a transformation technology to obtain 3D nanotextured shaped films with potential uses and relevance as functionalized decorative films on IMD, IML or IME manufacturing processes.

The use of such type of polymeric inserts provides the benefit of a low cost tooling and enables the thermoplastic processing at lower temperatures and with less complex tooling than when using metallic inserts, but still some improvements related to insert durability, process consistency have to be addressed.

The obtention process of the initial textured films, injection moulded parts and thermoformed films is covered in this research, and the findings related to the initial replication method, injection moulding and thermoforming process conditions and characterization of the samples will be explained. Broadly speaking, two main findings are reported: isothermal injection moulding can successfully replicate 3-level hierarchical micro/nanostructures on polycarbonate, and the preservation of hydrophobic characteristics up until substantial draw ratios (significant for the mentioned film-based fabrication techniques) in the case of the microtextured & thermoformed PC films that are latter thermoformed is achieved.

In future research, the process robustness and optimization, tooling durability and further specialized characterization associated to the presence of specific nanostructures will be carried out.

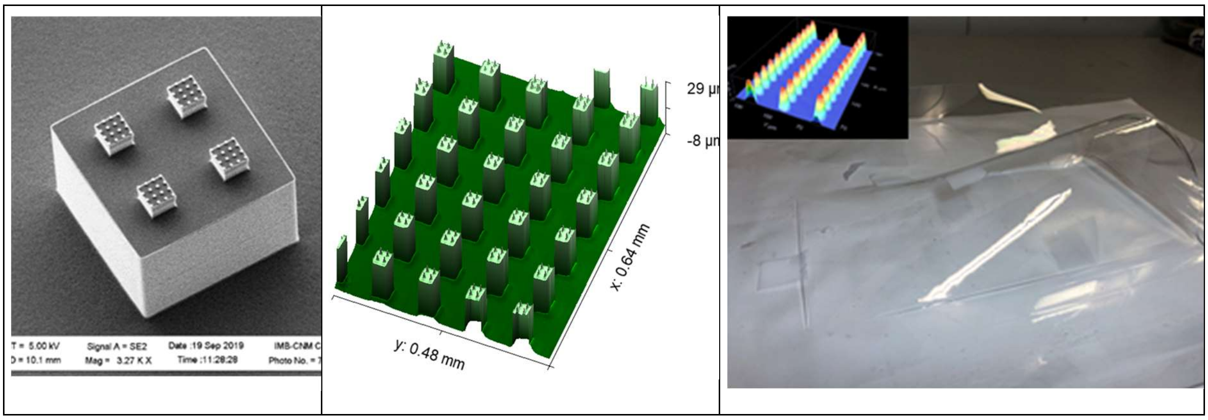


Figure 1: Details of the initial Si-stamp with three hierarchical levels (upper left), PDMS replica (upper right) and resulting injected polycarbonate part (lower left). Also, an image of the thermoformed structured films is shown.

References

1. Stormonth-Darling, John Moir (2013) Fabrication of difficult nanostructures by injection moulding. PhD thesis, University of Glasgow.
2. Holzer C, Gobrecht J, Schift H, Solak H. Replication of Micro- and Nanostructures on Polymer Surfaces. Macromol Symp [Internet]. 2010;296(1):316–23.
3. T. Senn, C. Waberski, J. Wolf, J.P. Esquivel, N. Sabaté, B. Löchel, 3D structuring of polymer parts using thermoforming processes, Microelectron. Eng. 88 (2011) 11–16. https://doi.org/10.1016/j.mee.2010.08.003

Industrial Replication Technologies II

Chair: Laurent Feuz (FHNW, Switzerland)

11:20-11:35 Invited: André Bernard (matriq AG, Switzerland)

"The watermark for plastics: creating the digital twin"

11:40-11:55 Helmut Schift (PSI, Switzerland)

"How to keep a good skin without peeling: bonding of a roll-to-roll extrusion coated film on a back injection molded polymer body"

12:00-12:25 Invited: Rafael Taboryski (DTU, Denmark)

"Roadmaps for large area nano-pattern replication"

12:30-13:00 *Pre-lunch break* (*break out sessions + Session 4 Q&A*)

The individual watermark for plastics: creating the digital twin

André Bernard[1], Klaus Dietrich[1], Cornelia Nef[2], Mathias Mächler[2]

[1] matriq AG, St. Gallen, Switzerland

[2] Eastern Switzerland University of Applied Sciences, Institute IMP, Campus Buchs, Switzerland

Individual marking of plastic products is important for many applications such as quality control, individual device identification, logistics, and it is even mandatory for MedTech products (e.g. UDI) and certain automotive parts. Today's standards are laser engraving, ink jetting, and adhesive labels, which are all downstream processes adding time, space, complexity by handling automation, and costs to marking. The marking market is $7 billion by 2024, over 14'000 companies in EU are operating as plastics manufacturer.

matriq has invented and patented a technology called *DynamicMold* that enables marking with individual 2D codes directly inside the forming process, i.e. inside the injection molding machine. This is also referred to as direct part marking. A mold insert is introduced into the mold, in the same way comparable with temperature or pressure sensors, Figure 1. This insert issues a digital date/time stamp or a DataMatrix code (ECC 200) on each injection-molded device within a few tens of microseconds, in such a way that the cycling time is unchanged. 10^{16} different error-correcting codes are accessible using a 14-by-14 DataMatrix code generator, matriq's DM-*qode mold insert*.

Nearly 200 individually addressable heaters create a contrast pattern onto the surface of each injection-molded piece. Microtechnology (MEMS) enables the fabrication of these tiny heater arrays with their unprecedented performance in the harsh environment of injection molding, sustaining pressures of up to 2000 bars, mold temperatures up to 150 °C and polymer temperatures up to 400 °C. Up to 700 °C heat pulses can be generated. The triggering for marking is autarkic and machine independent. Interfacing to business and production software (MES, ERP) is given through OPC UA. A built-in application-specific integrated circuit (ASIC) was designed to give every mold insert a unique control.

Using these individual 2D codes it is feasible to serialize every single product and create a digital twin from each of them (out of billions in a series). The mold insert carries sensors that monitor the molding process inside the cavity. The electronic surveys the microheater constantly. Process data and date of use and user of the device can be associated and aligned during their life cycle along the value chain of the product.

matriq was founded 2019 as a spin-off from the Eastern Switzerland University of Applied Sciences OST (formerly NTB, Institute for Micro- and Nanotechnology) and is based in St. Gallen in the Innovation Center Startfeld.

In conclusion, matriq's *DynamicMold* provides the unique watermark for plastics for traceability, identity, brand trust, and industry 4.0.

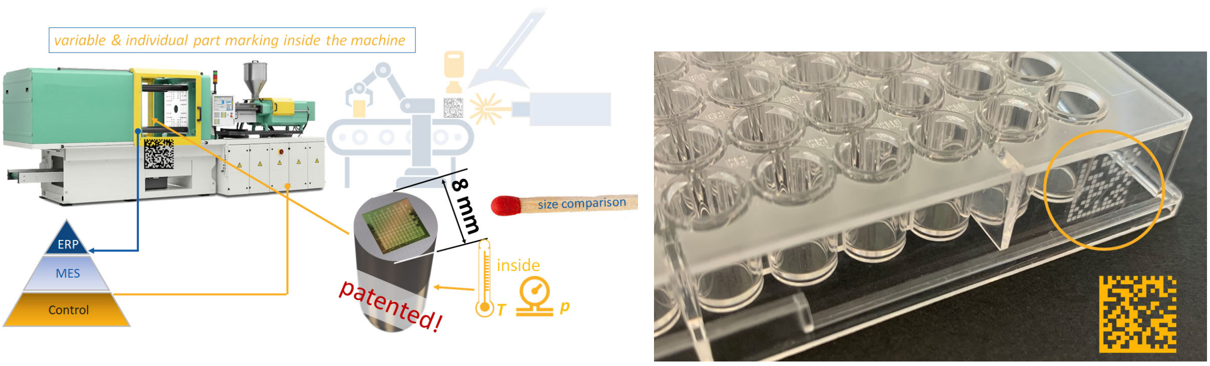


Figure 1: (left) A pen-sized mold insert is placed into the mold for individual direct part marking and replaced downstream marking processes and complex robotic handling systems. (right) A marked plastic product (here a microtiter plate) carries a DataMatrix code on its surface.

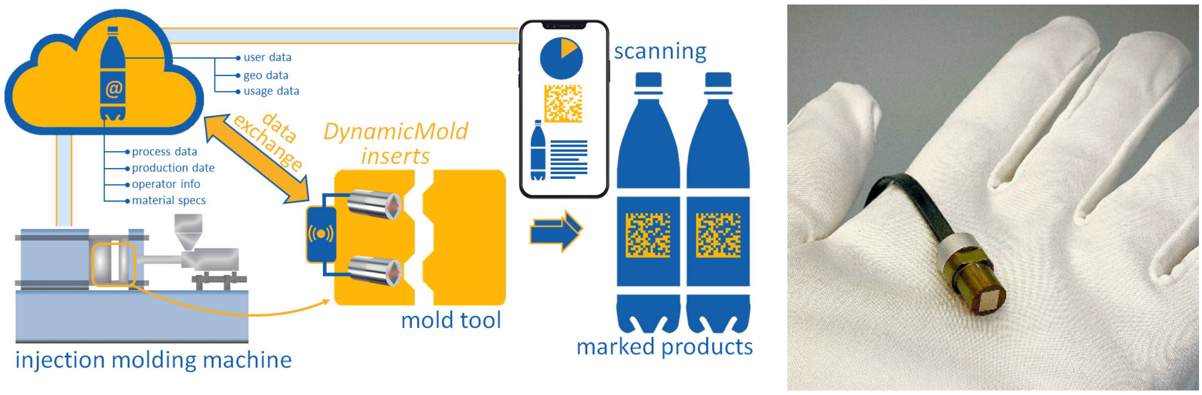


Figure 2: (left) Typical two cavity mold setup with matriq mold inserts. The generated codes are coordinated and stored in the database. With a reader app all code-linked parameters can be accessed and directly associated with the production data and its digital twin. (right) Picture of matriq's DM-*date*, the first digital date&time stamp for injection molding.

Contact: matriq AG
Lerchenfeldstrasse 3
9014 St. Gallen
Switzerland

matriq.ch
andre.bernard@matriq.ch

How to keep a good skin without peeling: bonding of a roll-to-roll extrusion coated film on a back injection molded polymer body

S. Xie[1], J. Werder[2], H.Schift[1]

[1] Paul Scherrer Institute, Laboratory for Micro- and Nanotechnology, 5232 Villigen PSI, Switzerland
[3] FHNW University of Applied Sciences and Arts Northwestern Switzerland,
INKA Institute of Polymer Nanotechnology, 5210 Windisch, Switzerland

Back injection molding (BIM) is a mass-manufacturing process for adding films with integrated functions onto the surface of bulky plastic products. In addition to its traditional use in surface decorating, labeling and laminating plastic products, BIM also offers a fast solution of integrating printed flexible electronics onto 3-dimensional polymer parts. We have utilized this fabrication process that combines the planar surface patterning by nanoimprint lithography (NIL) and BIM, which realizes embedded sub-micron wide, millimeter long conductive metal wires on a cylinder-shaped surface [1,2]. In comparison to normal injection molding (IM), where the plastic part replicates the surface pattern from a patterned cavity surface, BIM enables to independently pattern a flat polymer film (skin) and then bond it to a plastic element (body) during the BIM process. The hybrid part forms upon filling a mold cavity with a viscous melt. We have performed initial research with an amorphous thermoplastic polymer, poly (methyl methacrylate) (PMMA) as both film and melt [2]. Good bonding conditions can be found for PMMA, when materials with similar T_g are used. However, further investigation is needed on materials such as polyethylene terephthalate (PET) that is conventionally used as substrate for flexible electronics. In this case, the melt for constituting the polymer element can be either PMMA, as in the previous research, or PET. The specific challenge is then to find good bonding conditions, since as a semi-crystalline polymer, PET does not have a pronounced T_g and therefore the interdiffusion of polymer chains during bonding is limited in comparison to the amorphous PMMA.

As an extension to our previous work focusing on PMMA, we demonstrate the combination of roll-to-roll extrusion coating (R2R-EC) and BIM to fabricate micro- and nanostructured double-layer polymer films on non-flat surfaces and compare it to the results obtained with NIL [3]. In R2R-EC, a molten polymer film is extruded through a flat nozzle, then stretched and finally laminated onto a carrier film (substrate). At T_{tool} of 40°C, the PET film bonds weakly with solidified PET melt, and the bonding is enhanced as T_{tool} increases. However, the film can still be peeled off from the surface with gentle force, e.g., by hand. Surface activation, such as oxygen plasma treatment on the PET film surface, significantly strengthens the bonding between the film and the solidified melt. Already with a mild activation, the bonded PET films cannot be detached without damaging the film. We made a hand-operated pull-off test to evaluate the pull-off force of the bonded film. In both cases of PET/PET and PET/PMMA bonding, the pull-off force is <1 N for non-treated films, and >10 N for plasma-treated films.

By demonstrating the combination of two state-of-the-art manufacturing processes, the use of more complex geometries and polymers seem to be feasible to integrate micro to nanoscale structures and electrically conductive wires onto non-flat surfaces.

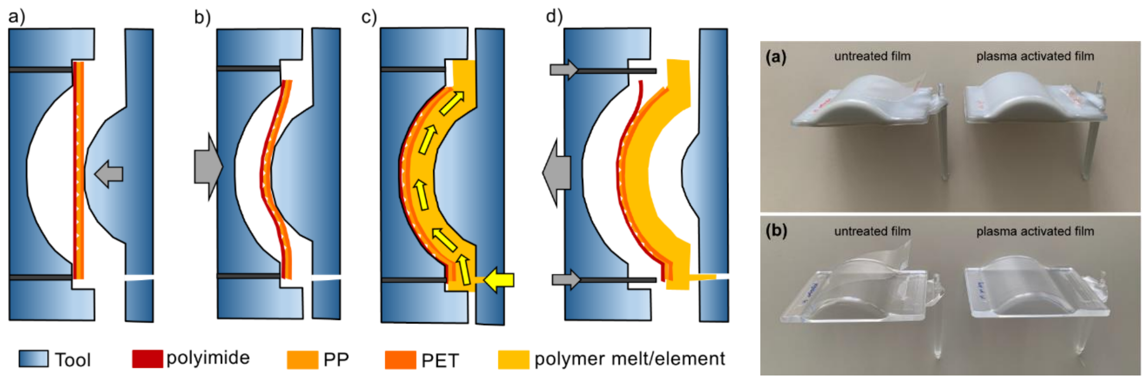


Figure 1: Left side: Schematic of the BIM process. Right side: Bonding between PET film and PET element (a) or PMMA element (b) without and with oxygen plasma surface activation.

References

1. B. Horváth, E. Al Jassin-Al-Hashemi, H. Schift, *Flex. Print. Electron.* 2019, 4, 035002 (10 pp).
2. S. Xie, B. Horváth, J. Werder, H. Schift, *Micro and Nano Eng.* 2020, 8, 100062.
3. S. Murthy, M. Matschuk, Q. Huang, et al. , *Adv. Eng. Mat.* 2016, 18(4), 484-489.

Roadmaps for large area nano-pattern replication

Rafael Taboryski

DTU Nanolab, National Centre for Nano Fabrication and Characterization,
Technical University of Denmark, Kgs. Lyngby Denmark

Top-down microfabrication technology can be applied to structure 100-300 mm Si wafers.[1] However, for some applications, e.g. in-plane optical elements for concentrated solar power, solar absorber foils, or lotus effect surfaces, much larger areas of micro- of nanostructured surfaces are often required. In this talk, I will discuss the roadmaps that can be used to replicate micro- and nanoscale structures, originated on small substrates such as 100-150 mm Si wafers, to m^2 areas in polymer materials, and how the replicated surfaces subsequently can be post processed, e.g. stitched and surface functionalized by coating, using industrial processes such as roll-to-roll extrusion coating (R2R-EC).[2]

.

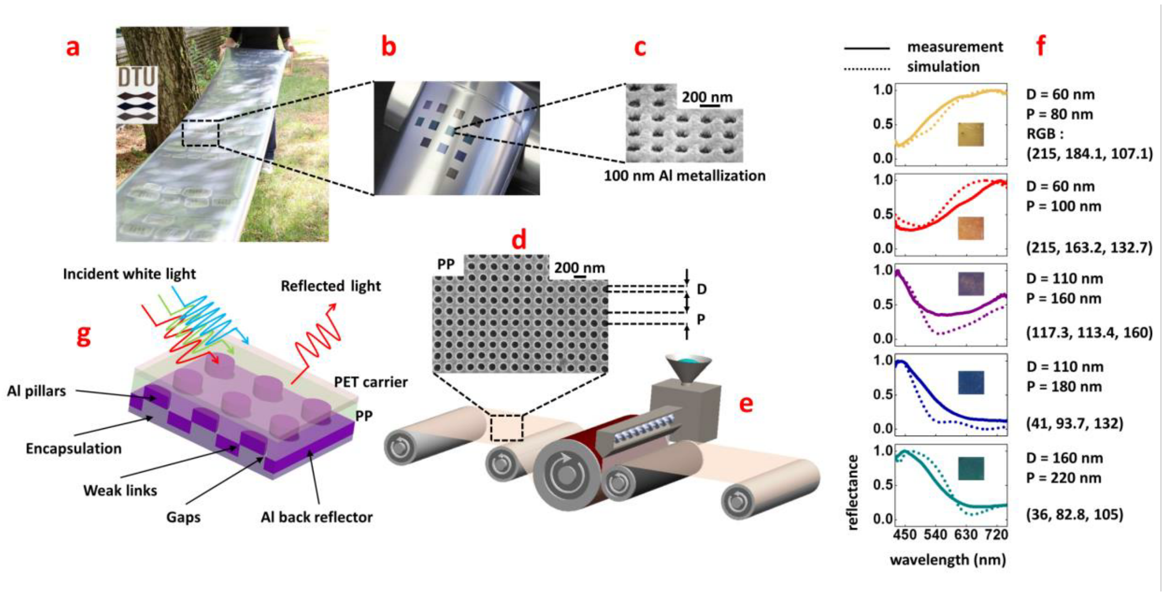


Figure 1: Reproduced from Murthy et al.[3] with permission of The Royal Society of Chemistry. Example of large area fabrication of plasmonic nanostructures by roll-to-roll extrusion coating (R2R-EC) and subsequent metal coating with Al (**a**). Zoom in (**b, c**). SEM image of the nano-pit array formed in polypropylene (**d**) by the R2R-EC process (**e**). Optical characterization and numerical simulations (**f**) of the resulting composite structure sketched in (**g**).

References

1. Keil, M. et al. Large plasmonic color metasurfaces fabricated by super resolution deep UV lithography. *Nanoscale Advances* (2021).
2. Murthy, S. et al. Fabrication of Nanostructures by Roll-to-Roll Extrusion Coating. *Advanced Engineering Materials* ***18***, 484-489 (2016).
3. Murthy, S. et al. Plasmonic color metasurfaces fabricated by a high speed roll-to-roll method. *Nanoscale* ***9***, 14280-14287 (2017).

Metrology, Simulation and Modeling

Chair: Jerome Werder (FHNW, Switzerland)

14:30-14:45 Tamara Aderneuer (CSEM Muttenz, Switzerland)

"Advanced metrology of freeform micro-optical elements"

14:50-15:05 Nikolaos Lempesis (EPFL, Switzerland)

"Controlling wettability through modeling-based surface topography engineering"

15:10-15:25 Jelle Snieder (TU Delft, The Netherlands)

"Simulating the Layer Thickness in Roll-to-Roll UV Nanoimprint Lithography"

15:30-16:00 ***Coffee break*** (break-out sessions + Session 5 Q&A) last chance for Best Talks Award voting!

16:00-16:15 Announcement of Best Talk Awards

16:15-16:30 Closing by Per Magnus Kristiansen (FHNW, Switzerland)

"Polymer Replication on Nanoscale - quo vadis?"

Advanced metrology of freeform micro-optical elements

T.Aderneuer[1,2], O.Fernández[1], R. Ferrini[1]

[1] CSEM Center Muttenz, Muttenz, Switzerland
[2] Swiss Nanoscience Institute, Basel, Switzerland

Freeform micro-optical elements (FMOEs) are applied in many different fields as automotive lighting, aerospace, augmented reality, and precision engineering. Their non-symmetric shape can overcome limitations of standard microlenses [1]. Advantages are for example elimination of aberrations, device miniaturization and cost reduction. New technologies make fabrication of larger volume and higher precision possible [2], but the inspection is still a challenge due to complex shapes. Here we present advanced characterization of microstructured surfaces using a combination of experimental and computational methods.

We developed a method using measured surface topology and linking it to optical functionality [3]. The measured shape of FMOEs is converted to a computational solid model, which can be used for optical simulations. We developed a process to transform the 3D point cloud data to NURBS surfaces. This type of surface representation allows processing very large data sets with high accuracy while keeping the file size significantly lower compared to representation by polygon meshes. To analyze geometric deviations which result in a change in optical functionality is particularly interesting for quality control processes. Furthermore, we present results of FMOE characterization with an optical bench. With this optical method, the microstructured surfaces are illuminated with a laser beam and the redistributed light is recorded.

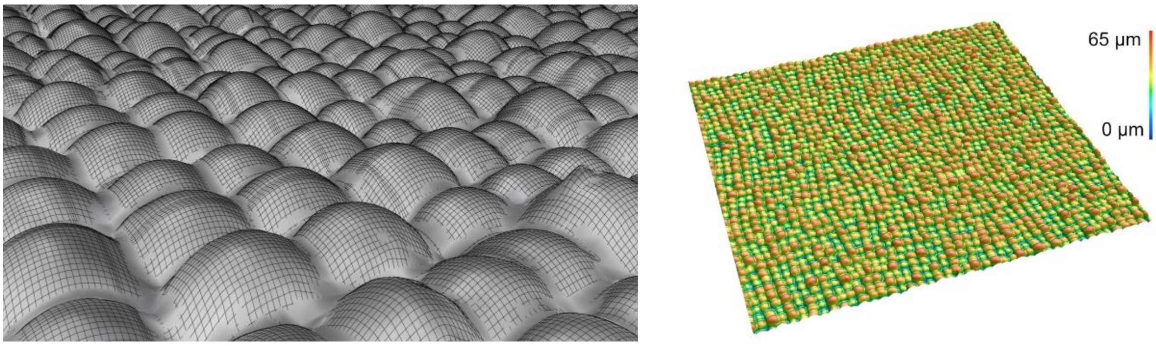


Figure 1: Left: NURBS surface representation based on measured surface topology. Right: Surface characterization of FMOEs with confocal laser scanning microscope.

In summary, we show characterization of FMOEs by transforming the measured surface shape into a computational 3D model, as well as using an optical bench to measure the light distribution resulting from the shape the FMOEs. Our characterization methods may also be applied for applications going beyond the field of optics. We see high potential for improved characterization of microstructured surfaces, whenever precise form investigation is important.

References

1. F. Fang, X.D. Zhang, A. Weckenmann, G.X. Zhang, C. Evans., "Manufacturing and measurement of freeform optics", *CIRP Annals*, **62** (2), 823–846, (2013)
2. T. Gissibl, S. Thiele, A. Herkommer, H. Giessen., "Sub-micrometre accurate free-form optics by three-dimensional printing on single-mode fibres". *Nature Communications*, 7,11763 (2016)
3. T. Aderneuer, O. Fernandez, A. Karpik, J. Werder, M. Marhöfer, P.M. Kristiansen, R. Ferrini, "Surface topology and functionality of freeform microlens arrays," *Opt. Express* **29**, 5033-5042 (2021).

Controlling wettability through modeling-based surface topography engineering

N. Lempesis[1,2] , R.J. Koopmans[1,2] , R. Diez-Ahedo[3] , P.M. Kristiansen[4,5,6]

[1] Plastics Innovation Competence Center, Passage du Cardinal 1, CH-1700 Fribourg, Switzerland
[2]College of Engineering and Architecture Fribourg HES-SO, Fribourg, Switzerland
[3] Tekniker, Iñaki Goenaga 5, 20600 Eibar, Spain
[4.] FHNW University of Applied Sciences and Arts Northwestern Switzerland, School of Engineering, Institute of Polymer Nanotechnology (INKA), Windisch, Switzerland
[5.] Laboratory for Micro- and Nanotechnology, Paul Scherrer Institute, 5232 Villigen PSI, Switzerland
[6.] University College Dublin, School of Mechanical and Material Engineering, Belfield, Dublin 4, Ireland

Engineering and eventually **controlling wettability** of a surface has attracted a lot of attention within the scientific community, in large part, due to the very broad spectrum of engineering applications associated with wetting. Numerous technological applications related to non-wetting textiles, anti-fogging, anti-icing, buoyancy, flow improvement and antibiofouling have seen the light of day in the recent years. Most of these engineering applications were **inspired by the behavior of biological systems** when interacting with various liquids. Development of new and refinement of already existing technologies for manufacturing materials that repel all kinds of liquids become increasingly important.
An improved **wetting model** was recently developed, which predicts topographical characteristics of surface textures exhibiting superomniphobic traits. The new model is based on the well-understood and readily used Cassie-Baxter model [1], providing, however, more realistic representations of the liquid-air interface. This was accomplished by considering realistic curved liquid-air interfaces through incorporation of the sagging height into the original Cassie-Baxter model. The proposed model **surpasses existing limitations** of the original Cassie-Baxter model thereby setting the foundations of a road map towards surface topography optimization and, eventually, superomniphobicity [2].
The improved wetting model was recently extended to account for more **complex 3D surface topographies**, while, on the other side, it got validated through scrutinized comparison of predicted contact angles with measured ones for a large variety of fabricated surface topographies and surface materials [3]. Model predictions were **consistently in remarkable agreement with experimental data** (deviations of 3-6%) and, in most cases, within statistical inaccuracies of the experimental measurements. Direct comparison between experiments and modeling results corroborated that surface topographies featuring re-entrant geometries promoted enhanced liquid-repellency, whereas **hierarchical multilevel surface topographies** enabled even more pronounced nonwetting behaviors. For the sinusoidal topography, consideration of a second superimposing topography level almost doubled the observed water contact angles, whereas addition of a third level brought about an extra 12.5% increase in water contact angle.
Modelling wettability accurately across different wetting liquids, surface materials and topographies sets the foundations of **a generic surface design methodology** enabling tailored wetting properties for numerous technological applications relevant to packaging, circular economy of materials, waste reduction, recycling, as well as conservation of energy and natural resources.

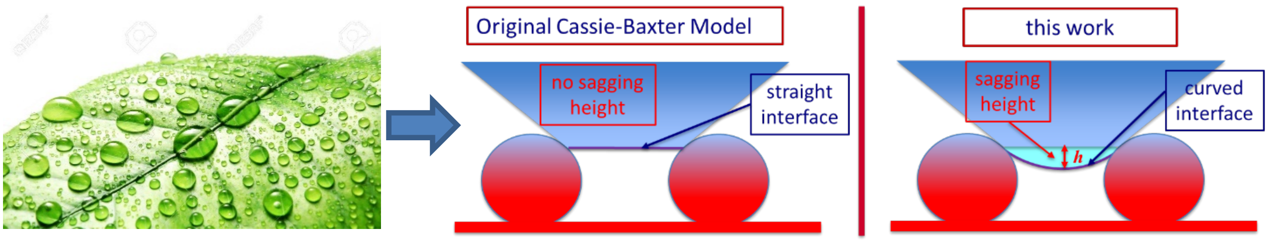


Figure 1: Nature itself can instigate and drive scientific innovation for the design of surface topographies with superomniphobic traits.

References

1. A.B.D. Cassie, S. Baxter, *Trans. Faraday Soc*. **40**, 546-551, (1944)
2. N. Lempesis, J. Ales, O. Gnatiuk, S.J.L. van Eijndhoven, R.J. Koopmans, *Surf. Topogr.: Metrol. and Proper.*, **8**, 025021, (2020)
3. N. Lempesis, R.J. Koopmans, R. Diez-Ahedo, P.M. Kristiansen, *Surf. Topogr.: Metrol. and Proper.*,(2021) *accepted*

Simulating the Layer Thickness in Roll-to-Plate UV Nanoimprint Lithography

J. Snieder[1,2], R.A.J. van Ostayen[1]

[1] Delft University of Technology, Delft, The Netherlands
[2] Morphotonics B.V., Veldhoven, The Netherlands

Ultraviolet nanoimprint lithography (UV-NIL) is a patterning technology to replicate micro- and nanostructures in a thin UV-curable resin. Morphotonics develops roll-to-plate UV-NIL equipment and processes to pattern discrete, large area substrates with functionally textured layers.

Figure 1 (left) shows a schematic of the roll-to-plate imprint process, which uses four rollers, for imprinting and to guide a textured flexible stamp. The rollers are coated with an elastomeric layer. A pattern of UV-curable resin droplets is dispensed on the substrate. The front imprint roller presses the flexible stamp into the liquid UV-curable resin. The resin is cured between the two bottom rollers. A second roller delaminates the flexible stamp from the hardened resin, leaving a negative image of the texture on top of the substrate. Ideally, the final imprint layer has a small and uniform thickness over the entire substrate area. Full understanding of the relevant physics of the imprint process is desired to be able to further improve the predictability of the layer thickness for future applications.

In this work, a numerical model is developed to study the imprint layer height as a function of the process variables: imprint force and speed, roller diameter, resin viscosity, and thickness and material properties of the elastomeric layer. As a first step, the flexible stamp behavior is neglected (flat stamp, no textures), which makes the process similar to roll coating at very low velocity [1]. The numerical model includes multiple physics to form an Elasto-Hydrodynamic Lubrication (EHL) model [2][3]. The resin flow and elastic deformation of the elastomeric layer are modelled via lubrication theory and linear elasticity theory, respectively. Figure 1 (right) shows an exemplary result of the dimensionless resin film pressure and layer height. An almost parallel fluid film develops in the contact zone. The film pressure lies close to the Hertz dry contact pressure. The difference can be explained by the influence of the finite thickness of the elastomeric layer of the imprint roller.

The EHL model has already proven to be a very useful tool to gain insight in the influence of the various process variables on the imprint layer height. The first steps have been taken to accurately predict the layer height. In future, the model will be extended with other aspects of the roll-to-plate imprint process, such as the stamp behavior, influence of textures, substrate height variations, and boundary effects of the finite line contact. With these extensions, the layer height prediction will be further improved.

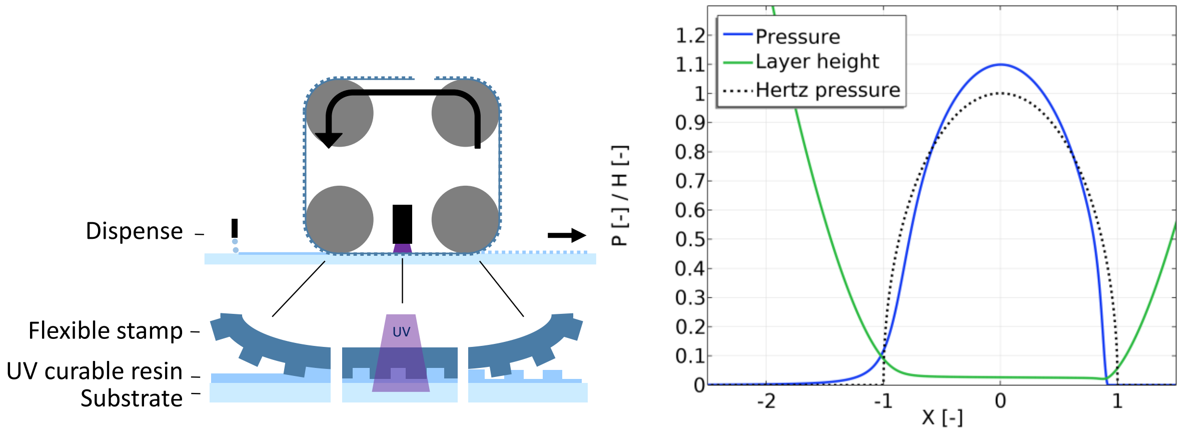


Figure 1: Left: schematic of the Morphotonics roll-to-plate imprint process. Right: exemplary result of the dimensionless pressure and film height in the EHL roller contact.

References

1. B. Grashof, A. Delgado, "Analysis of influencing parameters in deformable roll coating of counter-rotating rolls," J Coat Technol Res, **12** (1), 63–73, (2015).
2. W. Habchi, Finite element modeling of elastohydrodynamic lubrication problems. Hoboken, NJ: John Wiley & Sons, (2018).
3. H. Moes, Lubrication and Beyond – University of Twente Lecture Notes Code 115531; University of Twente: Enschede, The Netherlands, (2000).

We are grateful for the generous support by

Gold Sponsor

nano.swiss
Community Platform

Silver Sponsors

csem

SNI
SWISS NANOSCIENCE INSTITUTE
EINE INITIATIVE DER UNIVERSITÄT BASEL UND DES KANTONS AARGAU

NIL TECHNOLOGY

Bronze Sponsors

matriq
the polymer marking solution

PAUL SCHERRER INSTITUT
PSI

anaxam
analytics for advanced manufacturing

innovative surfaces™

Media Partner

micromachines
an Open Access Journal by MDPI

nano.swiss
Community Platform

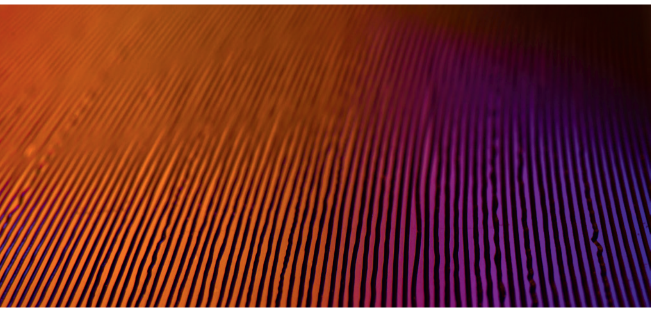
nano.swiss: A home for the application-oriented nano community

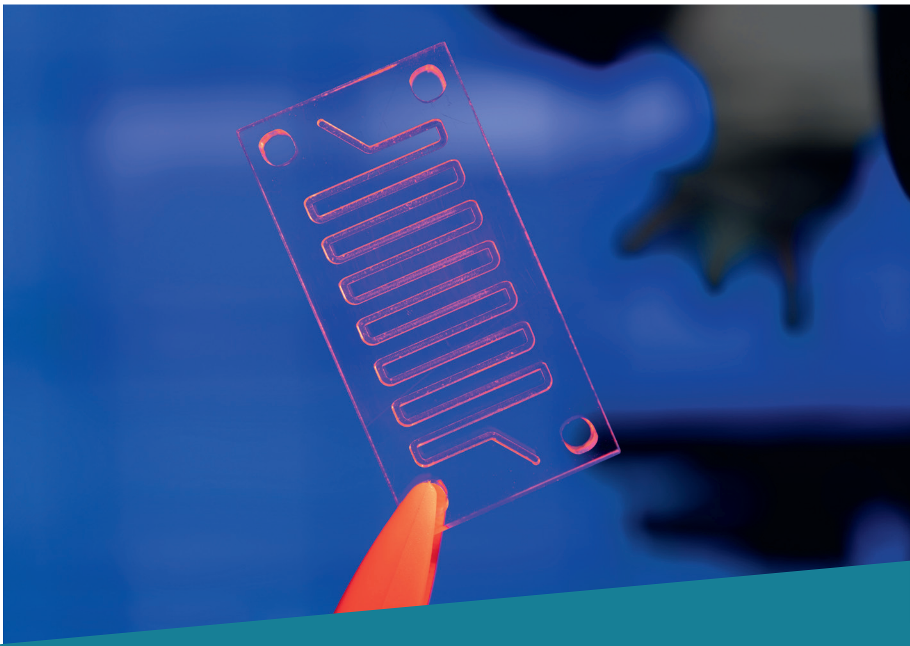
Nanotechnologies, nanomaterials and other advanced materials are highly innovative, but their use requires know-how that many smaller companies do not have. The Swiss community platform nano.swiss serves as an intermediary between users and research.

In 2019, nano.swiss was established by the Hightech Zentrum Aargau as a neutral, cost-free and Switzerland-wide platform. It aims at providing the players of the Swiss nano community with a well-structured online presence and supports technology transfer. To its users, nano.swiss offers access to research or application partners, new technologies, relevant news and events.

News and social media on nano.swiss

Since its launch, new functions have been added again and again. The platform now also has a social media presence via LinkedIn and Twitter, and the nano.swiss newsletter delivers curated content to over 3'000 qualified readers, mainly from applied research. Why not come – as an institute, company or simply out of interest – and see for yourself!





Powered by HIGHTECH ZENTRUM AARGAU

nano.swiss
Badenerstrasse 13
5200 Brugg

www.nano.swiss
info@nano.swiss
+41 56 560 50 50

an initiative of Hightech Zentrum Aargau AG

Large area diffraction gratings for augmented reality surface relief waveguide masters

T. Bro, V. Miljkovic, N. Hansson, A. Bisht, G. Skoblin, S. Acimovic, J. Fly, A. Mironov and B. Bilenberg

NIL Technology, Kongens Lyngby, DK-2800 (e-mail: thb@nilt.com)

To meet the demand for high quality augmented reality displays with larger field of view, large eye box and better image quality, large area diffraction gratings are needed. Across the industry different types of surface relief gratings for in-coupling and out-coupling are used in the waveguide designs to achieve the optimum performance of the waveguide. Typical gratings are slanted, blazed, binary and multi-level gratings. NIL Technology offers solutions for all of the above-mentioned types of gratings meeting the demand for high quality and size of in particular the output gratings from the market. The fabrication processes allow for complete design freedom to combine all types of gratings at any given placement and orientations.

Blazed gratings with pitches from 150 nm and up, with blaze angles from 10 to 50 degrees and very small anti blaze has been demonstrated, Figure 1 shows an example of a blazed grating. The fabrication technique ensures low surface roughness and high control of all design parameters.

Slanted gratings demonstrated by NIL Technology have high slant planarity, sharp corners and horizontal top and bottom planes, Figure 2 shows an example of a slanted grating.

Binary and multi-level gratings are typically used for out-coupling gratings, Figure 3 shows and example of a large area binary grating. Typical sizes are up to 15 cm2 for the AR displays with the largest field of view. These gratings are made with no visual stitch lines and a max error in pitch of 20 pm. The depth uniformity is better than 5% across the gratings. Figure 4 shows schematics of a typical high level master layout and Figure 5 an example of real device.

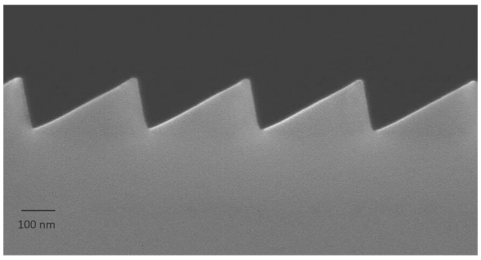


Figure 1. Blazed grating master with 325 nm pitch, 25 nm antiblaze and 30° blazed angle.

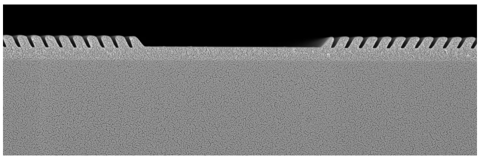


Figure 2. An example of a slanted grating master with 700 nm pitch and 45.5° blazed angle

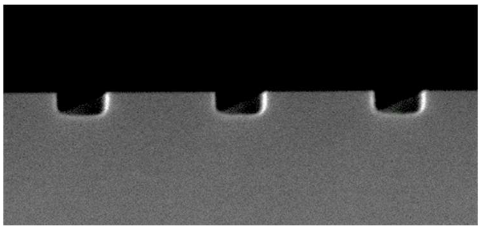


Figure 3. Cross section of large area binary grating

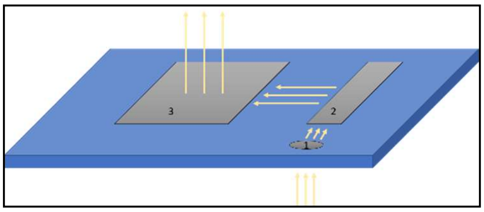


Figure 4. (1) IG (in-coupling grating) – typically blazed or slanted in mm^2. (2) OG1 (out-coupling or expander) – typically binary or slanted in cm^2. (3) OG2 (out-coupling eye box) – typically binary or slanted in cm^2.

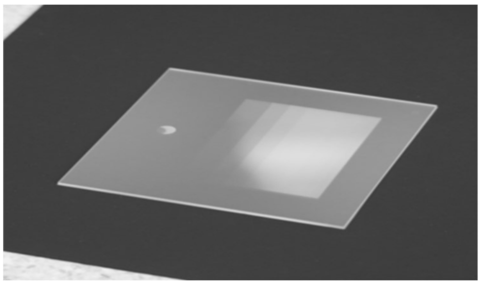
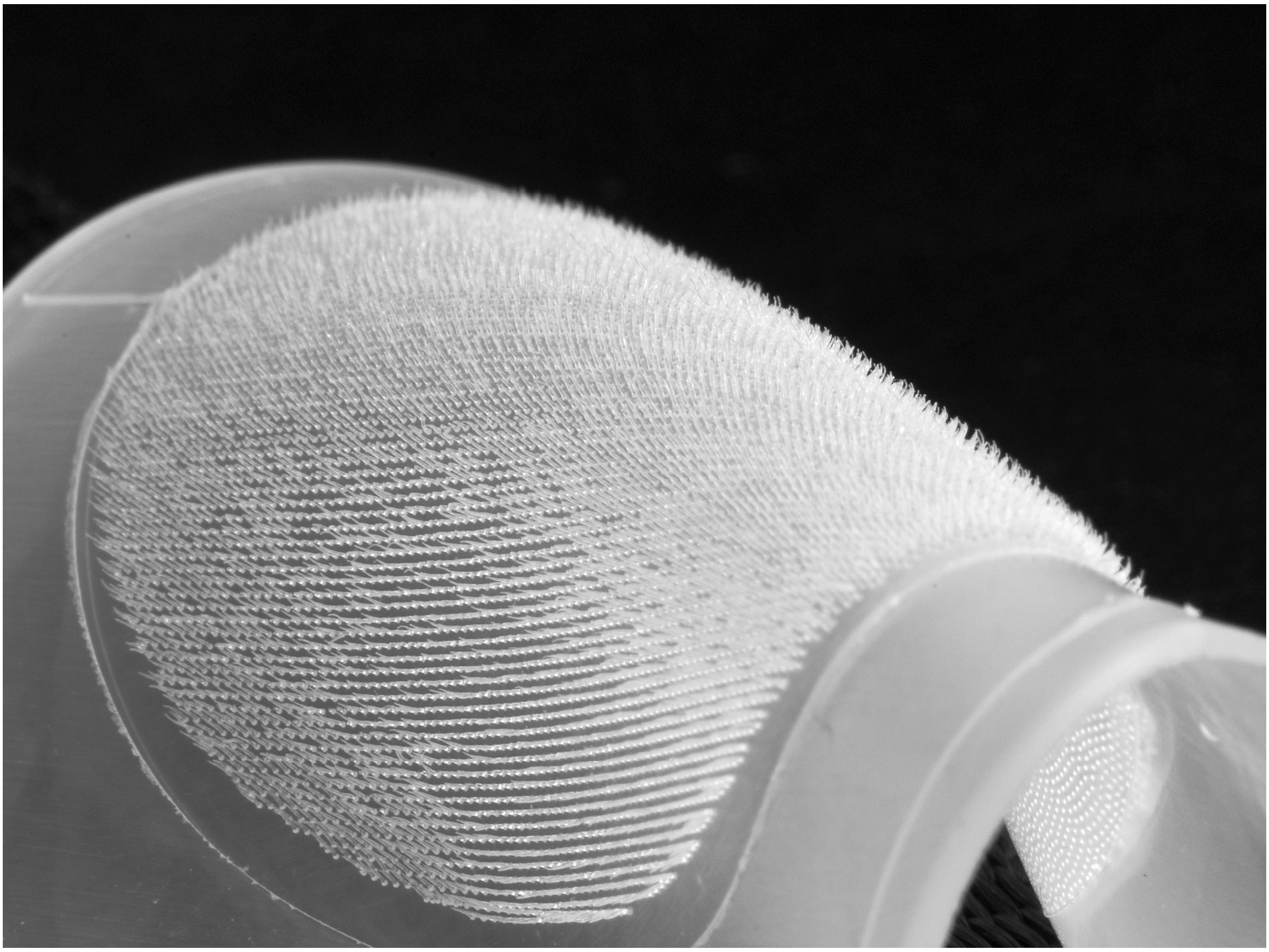


Figure 5. An example of real device and a representative example of waveguides

.

NOTE: THIS WORK IS NOT PRESENTED AT THE PRN 2021



Hairy microstructures in thermoplastic elastomers
produced by variothermal injection compression molding (Photo: C. Rytka)