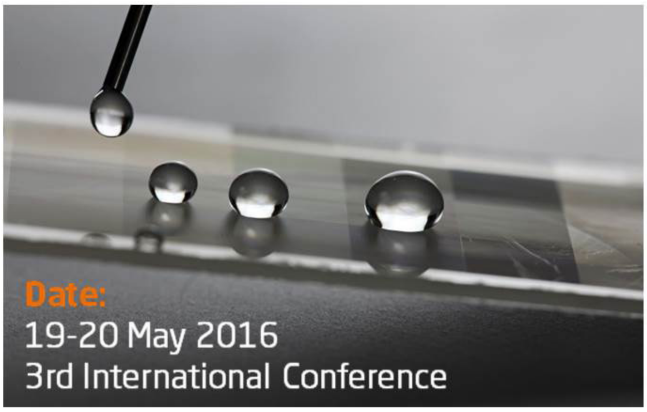
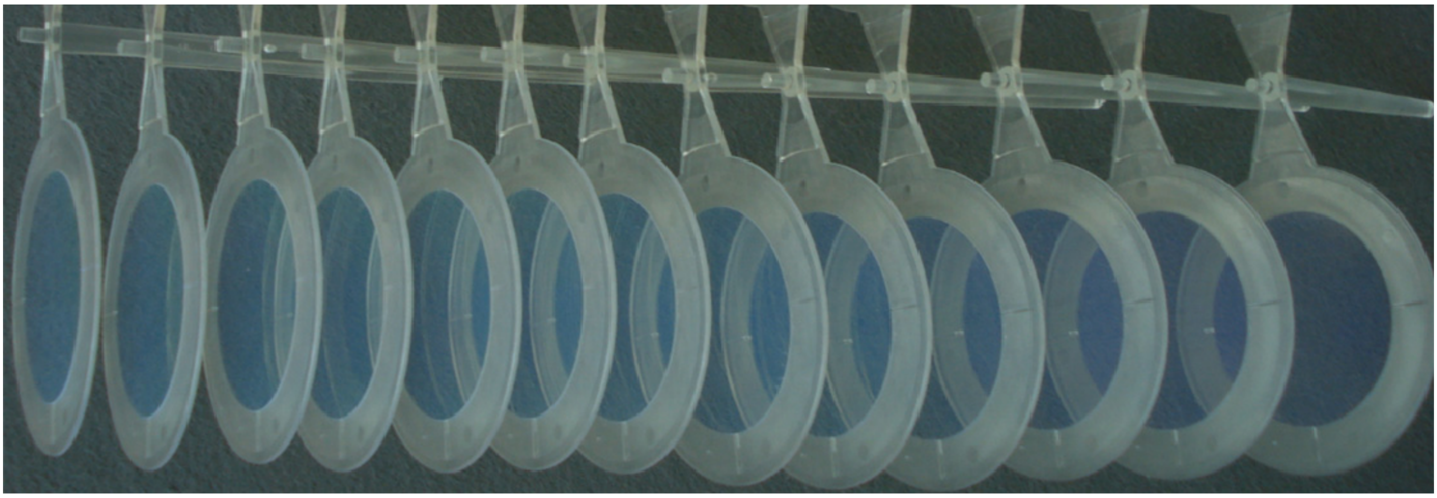
PRN 2016 Polymer Replication on Nanoscale





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 the Institute of Polymer Nanotechnology (INKA) & DTU

n|w University of Applied Sciences and Arts Northwestern Switzerland

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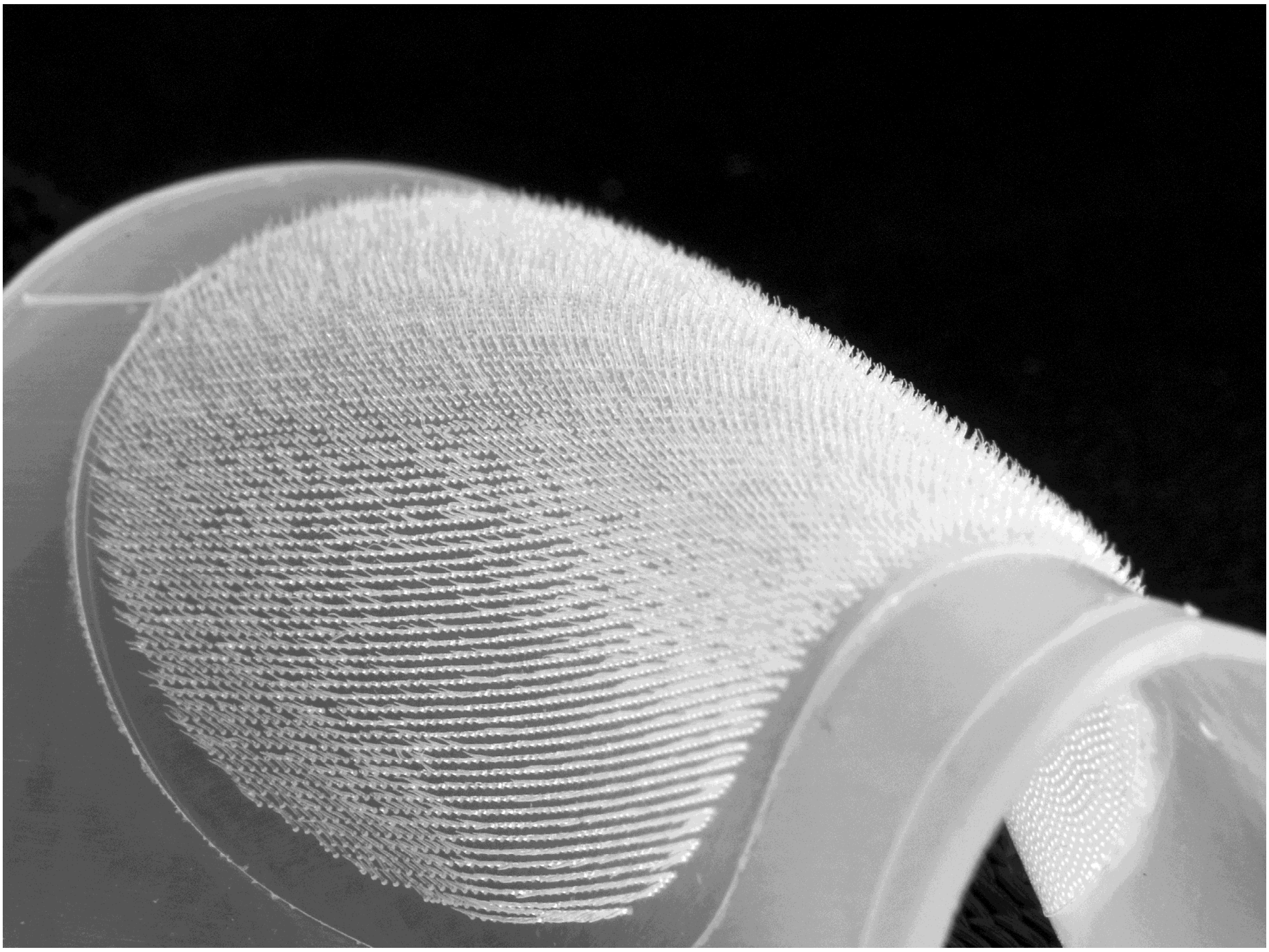
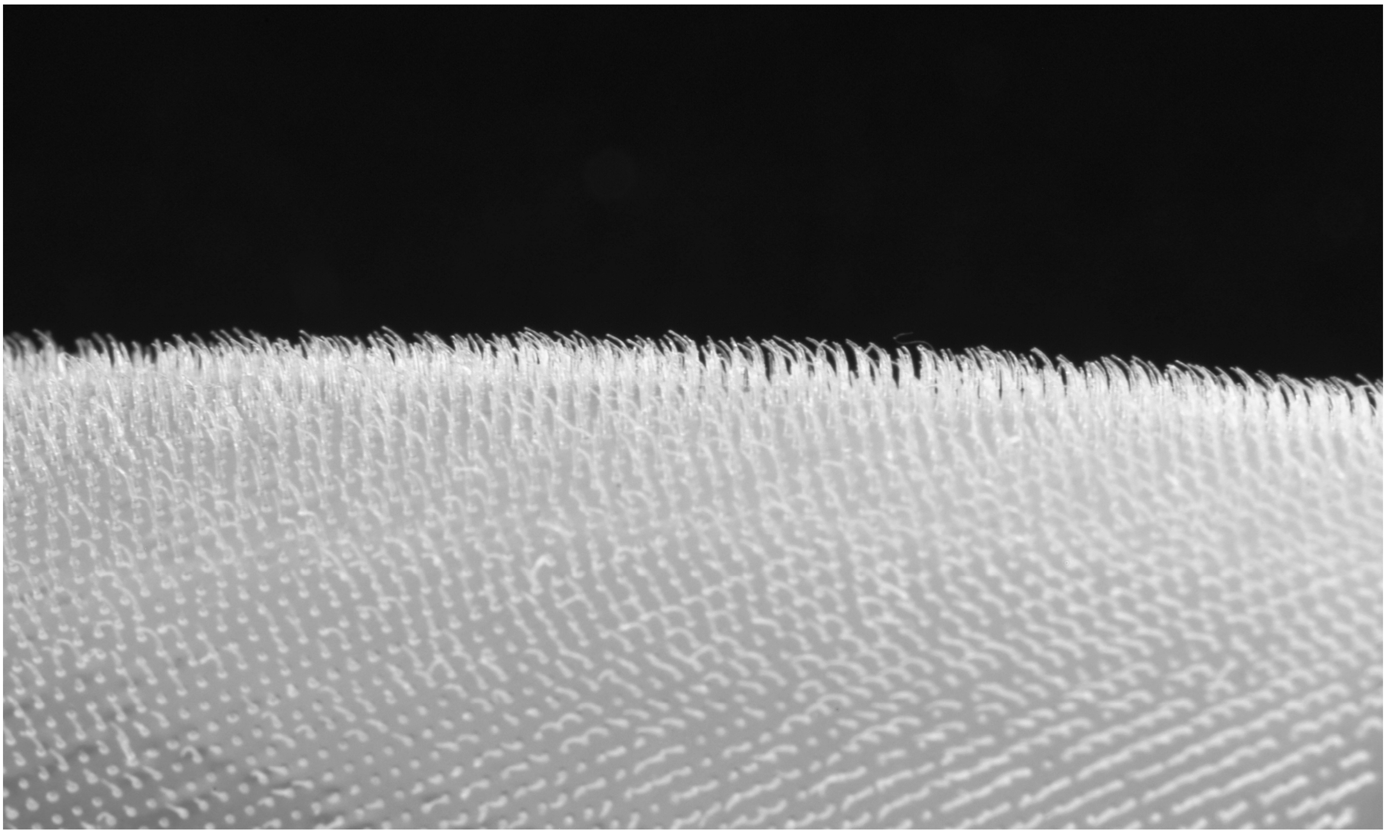


Hairy microstructures in thermoplastic elastomers
produced by variothermal injection compression molding (Photo: C. Rytka)



WELCOME

19 - 20 May 2016

PRN 2016 Polymer Replication on Nanoscale

Per Magnus Kristiansen

Welcome to the PRN2016

On behalf of the organizers, I wish you all a very warm welcome to the FHNW University of Applied Sciences and Arts Northwestern Switzerland on the occasion of the third PRN conference, which has attracted more than 80 participants from all over the world.

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 coincides with the 10^{th} 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 more than 850 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, the functionalization of polymers by topographical surface structuring offers tremendous potential for advanced polymer products and consequently receives increasing attention.

The PRN2016 aims at providing an up-to-date overview on the state of the art and newest findings in research on polymer replication on 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, company exhibitions, an attractive poster session, as well as plenty of opportunities for networking.

With these words, I wish you a couple of pleasant and inspiring days in Windisch, and we hope that this event can be repeated next year.

Per Magnus Kristiansen

PROGRAM

19 - 20 May 2016

PRN 2016 Polymer Replication on Nanoscale

Thursday 19 May 2016

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

11:30-12:30 Lunch in cantina or restaurant (not included)

PRN 2016 Conference

12:30-12:50 Welcome Coffee

12:50-13:10 Per Magnus Kristiansen (INKA FHNW, Switzerland) and Jürg Christener (Director FHNW, School of Engineering)
"Welcome to the Polymer Replication on Nanoscale 2016"

Session 1: Mastering, Tooling and Integration (13:10-15:00)
Chair: Robert Kirchner (INKA PSI, Switzerland)

13:10-13:40 Invited: Anders Kristensen (DTU, Denmark)
"*Plasmonic colors; no fish - snake scale!*"

13:40-14:00 Nachiappan Chidambaram (INKA PSI, Switzerland)
"Surface confined equilibration for super-smooth surfaces"

14:00-14:20 Guggi Kofod (Inmold A/S, Denmark)
"Free-form nanostructured tools for plastic injection moulding"

14:20-14:40 Karin Prater (EPFL, Switzerland)
"Glassy carbon masters for plastic injection molding"

14:40-15:00 David Kallweit (CSEM, Switzerland)
"Sophisticated nanostructuring of arbitrary steel grades and geometries: planar, curved or within cavities"

15:00-15:30 Networking / coffee break

Session 2: Nanoimprint Lithography (15:30-18:00),
Chair: Helmut Schift (INKA PSI, Switzerland)

15:30-16:00 Flash presentations on poster contributions
Various titles

16:00-16:20 Christoph Baum (Fraunhofer IPT, Germany)
"Comparison of drum production methods for roll-to-roll nano imprint lithography"

16:20-16:40 Angélique Luu-Dinh (CSEM, Switzerland)
"Applications of photocurable polymers for casting of micro- and nanostructures"

16:40-17:00 Michele Pianigiani (ThunderNIL, Italy)
"Pulsed nanoimprint lithography"

17:00-17:20 Michael Haslinger (Profactor, Austria)
"Soft nanoimprint lithography on 3D-printed curved surfaces"

17:20-17:50 Invited: Jens Gobrecht
(INKA FHNW/PSI, Switzerland)
"20 years of surface nanoreplication – from science to applications"

17:50-18:00 Closing by Clemens Dransfeld (FHNW, Switzerland)
"Polymers between fibres - learning from polymer replication"

18:00-19:00 Networking & beer / poster session

19:00-19:15 Transfer by train

19:30-22:00 Conference Dinner

Friday 20 May 2016

Session 3: Industrial Replication Technologies I (09:00-10:50)
Chair: Per Magnus Kristiansen (INKA FHNW, Switzerland)

09:00-09:30 Invited: Oliver Humbach (temicon GmbH)
"Industrial replication of micro and nanostructured polymer films and components"

09:30-09:50 Mohammad S.M. Saifullah (A*STAR, Singapore)
"Fabrication of polycarbonate lens with double side anti-reflection structures via nanoinjection molding"

09:50-10:10 Werner Balika (Sony DADC, Austria)
"High precision injection molding for industrial manufacturing of MTP-sized microfluidic chips"

10:10-10:30 Veronica Savu (Morphotonix Sarl, Switzerland)
"Zero-added manufacturing cost and passport-grade security solution for rigid plastics"

10:30-10:50 Yu Jiang (University of Eastern Finland)
"Fabrication and applications of injection molded micro-micro hierarchical structures"

10:50-11:20 Networking / coffee break

Session 4: Industrial Replication Technologies II (11:20-12:40)
Chair: Christian Rytka (INKA FHNW, Switzerland)

11:20-11:40 Clemens Holzer (Montanuniversität Leoben, Austria)
"Instrumented injection mold for the measurement of demolding energies of micro-structured parts"

11:40-12:00 Kati Mielonen (University of Eastern Finland)
"Curved hierarchically micro–micro structured polypropylene surfaces by injection molding"

12:00-12:20 Swathi Murthy (DTU, Denmark)
"Systematic study of high throughput fabrication of nano holes and nano pillars in polymer foils by roll-to-roll-extrusion coating"

12:20-12:40 Henrik Pranov (Heliac A/S, Denmark)
"Large scale nano and microstructured polymer foil production for the Concentrated Solar Power industry"

12:40-14:10 Lunch & Networking / poster session

Session 5: Simulation & Applied Nanostructures (14:10-16:00)
Chair: Rafael Taborisky (DTU, Denmark)

14:10-14:40 Invited: Hayden Taylor
(University of California, Berkeley USA)
"Computationally inexpensive, multi-scale simulation of polymeric embossing and imprinting"

14:40-15:10 Invited: Victor Cadarso (INKA PSI, Switzerland)
"Photonic nanofences: Fabrication challenges of high aspect ratio polymeric nanostructures"

15:10-15:30 An Eng Lim (Nanyang Technological University, Singapore)
"Effects of nanostructured surfaces on electro-osmotic flow"

15:30-15:50 René Hensel (Leibniz INM, Germany)
"Engineering of bio-inspired fibrillar dry adhesives"

15:50-16:00 Closing by Per Magnus Kristiansen
(INKA FHNW, Switzerland)
"Polymer Replication on Nanoscale – quo vadis?"

16:00 This is the end of PRN2016

Agneszieka Telecka (DTU Nanotech, Denmark)
Superhydrophopic nanostructured polypropylene foils fabricated by roll-to-roll extrusion coating

Maria Matschuk (Inmold S/A, Denmark)
Large-scale fabrication of single and multilayer polymer foils with nano- and microstructures

Robert Kirchner (INKA PSI, Switzerland)
High resolution 3D topographic patterns using grayscale electron beam lithography and thermal reflow

Nicolas Feidenhans (Danish Fundamental Metrology Ltd and DTU Nanotech, Denmark)
Characterization of nanostructures from visual color

Danilo Quagliotti (DTU MEK, Denmark)
Metrology of sub-micro structured polymer surfaces

Matteo Calaon, represented by Danilo Quagliotti (DTU MEK, Denmark)
High throughput polymer micro replication quality assurance using 3D optical high-speed metrology

Nis Korsgaard Andersen (DTU Nanotech, Denmark)
Super hydrophobic microstructures by isothermal injection molding

Celestino Padeste (INKA PSI, Switzerland)
Functionalization of polymer films using lithographic radiation-induced grafting

Jonathan Schmidli (INKA FHNW, Switzerland)
Replication of microstructures in thermoplastic films using wire-cloth as stamp for hot embossing and R2R embossing

Alexandra Kämpfer-Homsy (Univ. Appl. Sci. Western Switzerland)
Fabrication of high transmission microporous membranes by proton beam writing and soft lithography

Jordi Pina-Estany, represented by Andrés-Amador García Granada (IQS Universitat Ramon Llull, Spain)
Fluent solver expanded to the nano-world

Nastasia Okulova (Danapak Flexibles A/S & DTU, Denmark)
Investigating the micro-replication regime for structures produced by an extrusion coating process

Calypso Beloli (Roctool, France)
High Definition Plastics™ Molding by Dynamic Heating

Victoria Manzi-Orezzoli (Paul Scherrer Institute, Switzerland)
Tunable patterned wettability in porous media: Gas diffusion layers for PEFCs

Prof. Dr. Anders Kristensen, DTU Nanotech, Denmark

"Plasmonic Colors; No Fish - Snake Scale!"

Professor Anders Kristensen received his PhD in Physics from the Niels Bohr Institute fAPG, University of Copenhagen in 1994. He joined DTU Nanotech in 2001, where he does research on optofluidics - the integration of micro-/nano- photonics and -fluidics for novel sensing and actuation schemes. His current research include photonic crystal sensor surfaces for refractometric imaging, opto-thermal actuation and laser manipulation, nanoplasmonics for light confinement and integrated delivery og light at the nanoscale, and plasmonic color metasurfaces for decoration and laser nano-lithography. This research is supported by polymer micro-fabrication technology research and development, where he has pioneered nano imprint lithography in Denmark. Professor Kristensen has headed natio nal and european research programmes on advancing polymer nano- and micro-fabrication technology for industrial production: PolyNano (DK) - Strategic Research Center in Precision and Nanoscale Mass Replication of Biochips, PLAST4FUTURE (EC) - Injection moulding production technology for multi-functional nano-structured plastic components enabled by Nano Imprint Lithography..

Prof. Dr.-Ing. Jens Gobrecht, FHNW University of Applied Sciences and Arts Northwestern Switzerland, Institute of Polymer Nanotechnology / Paul Scherrer Institut (PSI)

"20 years of surface nanoreplication: from science to applications"

Jens Gobrecht, born 1951 in Berlin, studied physics at the Technical University of Berlin and concluded with a diploma in engineering in 1976. His PhD project on electrochemical solar cells was carried out at the Fritz-Haber Institute of the Max-Planck Society in Berlin. 1980/81 he worked on a post-doc position at the National Renewable Energy Laboratory in Golden, USA on heterojunction photovoltaic devices. After that he worked for 12 years in various functions at the ABB Corporate Res earch Center in Baden, Switzerland, mainly in the areas of Bi-CMOS silicon device processing, electronic packaging, power electronic circuits and in management, also on the corporate level. In 1993 Jens Gobrecht joined the Paul Scherrer Institute with the task to build up the newly founded Laboratory for Micro- and Nanotechnology. This lab today has about 60 coworkers active in basic and applied research in the areas of X-ray optics and lithography, nano-magnetics, molecular nanoscience and micro- and nanofabrication technologies. In 2005 Jens Gobrecht was appointed Professor at the FHNW University of Applied Sciences Northwestern Switzerland and head of the new „Institute of Polymer Nanotechnology", this in addition to his continuing duties at PSI. Jens Gobrecht is author or co-author of over 120 scientific publications, inventor or co-inventor on 30 patents and has successfully applied for more than 30 research grants at national and international funding agencies. He serves regularly as referee for scientific journals, as expert on international review panels and as co-advisor for PhD theses. In 2007 J. Gobrecht co-founded "Eulitha AG", a company active in EUV-based nanolithography..

Dr. Oliver Humbach, temicon GmbH, Germany

"Industrial Replication of Micro and Nano-structured Polymer Films and Components"

CV Dr. Oliver Humbach studied Physics at the University of Muenster in Germany and received his PhD at the University of Duisburg in 1995 with focus on optoelectronic integrated semiconductor chips. Since then, Dr. Humbach has more than 20 years of industrial experience in the fields of optics, semiconductors and micro/nano technologies. From 1995 - 2001 he has been Head of Product Development for optical fibers at Heraeus Quarzglas GmbH in Hanau. In the years from 2001 - 2005 he joined technotrans AG as Managing Director of the Micro Technologies Division with special focus on electroforming and wet-processing equipment for the production of micro/nano molds and shims. In 2005 Dr. Humbach founded temicon GmbH in Dortmund and is today CEO and main chair holder. The strongly growing technology company with over 40 employees is producing micro/nano tools, films and components for many different applications like LED lighting, display and life science..

Hayden Taylor, University of California, Berkeley USA

"Computationally inexpensive, multi-scale simulation of polymeric embossing and imprinting"

Hayden Taylor is an Assistant Professor in the Department of Mechanical Engineering at the University of California, Berkeley. He was previously an Assistant Professor at Nanyang Technological University in Singapore, a Postdoctoral Research Fellow in the Biosystems and Micromechanics group at the Singapore-MIT Alliance for Research and Technology, and a Research Associate in the Microsystems Technology Laboratories at MIT. Hayden was born in Bristol, United Kingdom, in 1981. He attended Bristol Grammar School and Trinity College, Cambridge, receiving the B.A. and M.Eng. degrees in Electrical and Electronic Engineering in 2004. He was sponsored as an undergraduate by ST Microelectronics. He is a Senior Scholar of Trinity College, Cambridge, and received the Cambridge University Engineering Department's Baker Prize in 2004. Hayden received the Ph.D. in Electrical Engineering and Computer Science from MIT in 2009, working with Professor Duane Boning. Hayden is a member of the IEEE, the Institution of Engineering and Technology, and the Institute of Physics. He was an Institution of Electrical Engineers Jubilee Scholar 2000-4, and was a Kennedy Scholar for the academic year 2004-5.

Dr. Victor Cadarso, Paul Scherrer Institute, Switzerland

"Photonic Nanofences: Fabrication challenges of high aspect ratio polymeric nanostructures"

Dr Cadarso was born in 1981 in Sabadell (Barcelona). He studied Physics in the Autonomous University of Barcelona (UAB) and received his PhD in Dec. 2008 in the National Centre for Microelectronics (IMB-CNM). His work was awarded both by the Catalan Society of Technology and the UAB physics department. In 2009 he joined the Swiss Federal Institute of Technology, Lausanne (EPFL) as a Marie Curie Fellow under the mentoring of Prof Jürgen Brugger. Since April 2013, Dr Víctor J. Cadarso is researcher in the Polymer Nanotechnology Group in the Laboratory for Micro and Nanotechnology (LMN) at the Paul Scherrer Insitut (PSI) in the frame of an Ambizione Fellowship from the Swiss National Science Foundation (SNF). His research is focused in a multidisciplinary domain involving micro and nanotechnology, polymeric materials, optics and photonics, microfluidics, sensing applications, lab-on-a-chip and integrated systems..

Mastering, Tooling and Integration

Chair: Robert Kirchner (INKA PSI, Switzerland)

13:10-13:40 Invited: Anders Kristensen (DTU, Denmark)
"Plasmonic colors; no fish - snake scale!"

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"Sophisticated nanostructuring of arbitrary steel grades and geometries: planar, curved or within cavities"

Plasmonic colors; Not fish – snake scale!

A. Kristensen[1], X. Zhu[1] , E. Højlund-Nielsen[1], C. Vannahme[1], N. A. Mortensen[2]

[1] Technical University of Denmark, DTU Nanotech, 2800 Kongens Lyngby, Denmark
[2] Technical University of Denmark, DTU Fotonik, 2800 Kongens Lyngby, Denmark

We describe plasmonic colors based on the concept of localized surface plasmon resonances (LSPR) for decoration of high volume manufactured plastic products [1,2]. Color printing on nanoimprinted plasmonic metasurfaces is achieved by laser post-writing, for flexible decoration of high volume manufactured plastic products. Laser pulses induce transient local heat generation that leads to melting and reshaping of the imprinted nanostructures.

Different surface morphologies that support different plasmonic resonances, and thereby different color appearances, are created by control of the laser pulse energy density. All primary colors can be printed, with a speed of 1 ns per pixel, resolution up to 127,000 dots per inch (DPI) and power consumption down to 0.3 nJ per pixel. A palette of bright and angle-insensitive colors, spanning the entire visible spectrum, is realized by utilizing the hybridization between LSPR modes in aluminium nano-disks, and nano-holes. Research grade, clean-room fabricated plasmonic metasurfaces are transferred to industrial production of plastic consumer products. Plastic components are embossed or injection moulded with a nano-textured surface, comprising an array of nano-scale pillars. The master-original for the square-centimeter nano-texture is realized by means fast e-beam writing [3]. The nano-disk/nano-hole plasmonic metasurface is formed when a thin film of aluminium is deposited on top of the nanopillar array. The nanotextured plasmonic metasurface is covered with a transparent protective coating, which can withstand the daily life handling.

This approach also supports a cradle-to-cradle production philosophy: Plastic products can be injection moulded using a single plastic base material, where the color decoration is realized by the as-injection-moulded nano-textured surface, covered by a thin (10-20 nm) metal film plus a 1-20 µm protective coating. After use, the product can be grinded, where the thin film coatings, which are the same for all products, represents a contamination level in the sub ppm level of the base material granulate – which is thereby directly re-usable.

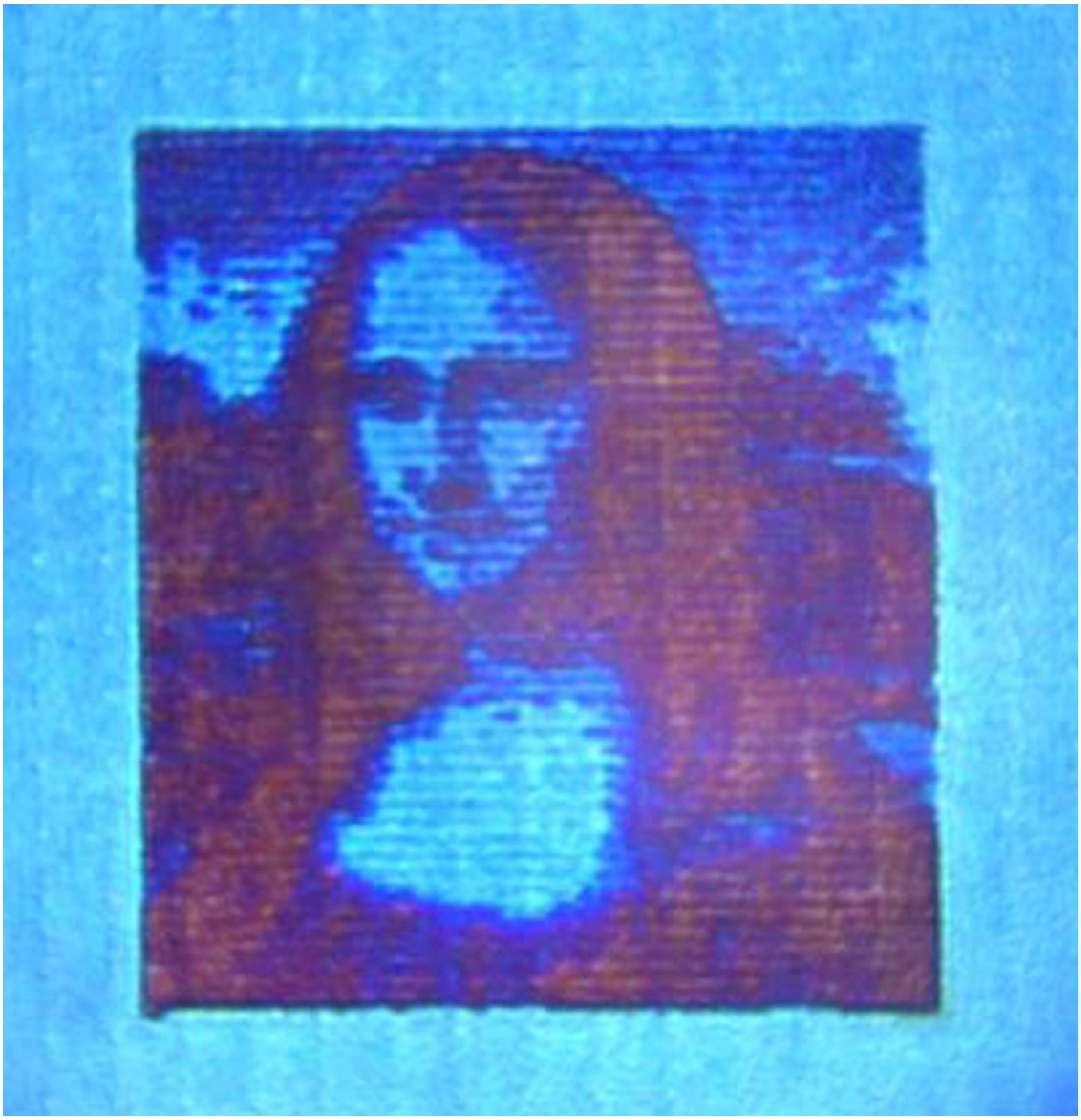

Figure 1: The world smallest laser printed Mona Lisa – printed by plasmonic laser printing. The picture is 50 x 50 μm^2 and fits into a single pixel on your iPhone's retina screen.

References

1. J. S. Clausen, E. Højlund-Nielsen, A. B. Christiansen, S. Yazdi, M. Grajower, H. Taha, Uriel Levy, A. Kristensen, N. A. Mortensen, *Nano Letters* **14**, 4499-4504 (2014)
2. X. Zhu, C. Vannahme, E. Højlund-Nielsen, N.A. Mortensen, A. Kristensen, *Nature Nanotechnology* **11**, 325–329 (2016)
3. E. Højlund-Nielsen, T. Greibe, N. A. Mortensen, A. Kristensen, *Microelectronic Engineering* **121**,104-107 (2014)

Surface confined equilibration for super-smooth surfaces

N. Chidambaram[1], R. Kirchner[1], M. Altana[2], S. Neuhaus[3], M. Kristiansen[3], H. Schift[1]

[1] Paul Scherrer Institute, Laboratory for Micro- and Nanotechnology, 5232 Villigen PSI, Switzerland
[2] Heptagon Oy, Moosstrasse 2, 8803 Rüschlikon, Switzerland
[3] University of Applied Sciences and Arts Northwestern Switzerland, 5210 Windisch, Switzerland

Refractive micro-optical elements are finding applications in high volume consumer electronic devices ranging from mobile gadgets to flat panel displays. The most convenient mastering technique for fabricating complex 3D pattern required for this application seems to be direct laser writing (DLW) with variable doses which results in different heights upon development. Using this grayscale approach, tall aspheric micro-lenses with deep sag are difficult to write as the resolution in lateral and vertical direction provided by single photon absorption is not high enough. A truly 3D capable approach boasting higher resolutions in lateral and vertical direction is 'two photon polymerization' (2PP)[1]. Even with higher resolutions, 2PP is not considered for mastering due to high inherent roughness and the inability to smoothen them out with post processing: Reflow is not possible in 2PP structures as it is primarily in negative cross linking resists.

Here we have established a mastering technique for micro-optical applications using a 2PP process and still get a smooth surface finish that is demanded. It is derived from the TASTE[2] process established for grayscale electron beam lithography but has now been advanced for surface selective modification of PMMA resists. For this purpose, master structures were replicated from the 2PP resist into PMMA through PDMS intermediate copy. UV-casted PDMS preserves the fine features present in the original and provides low energy surface for easy demolding after hot embossing into PMMA. To have surface selective reflow, while preserving the structural fidelity of a 3D pattern, one has to use high energy exposure (electrons, ions or photons) that modifies the polymer at a defined depth of the surface by chain scission followed by molecular weight dependent reflow at elevated temperatures. We have considered various high energy radiations and narrowed down to 172 nm UV exposure to be the ideal fit for this application. This provided high enough 'damage' in a 200 nm thick surface skin layer and negligible etching, which allowed smoothening out up to 100 nm roughness down to final roughness.

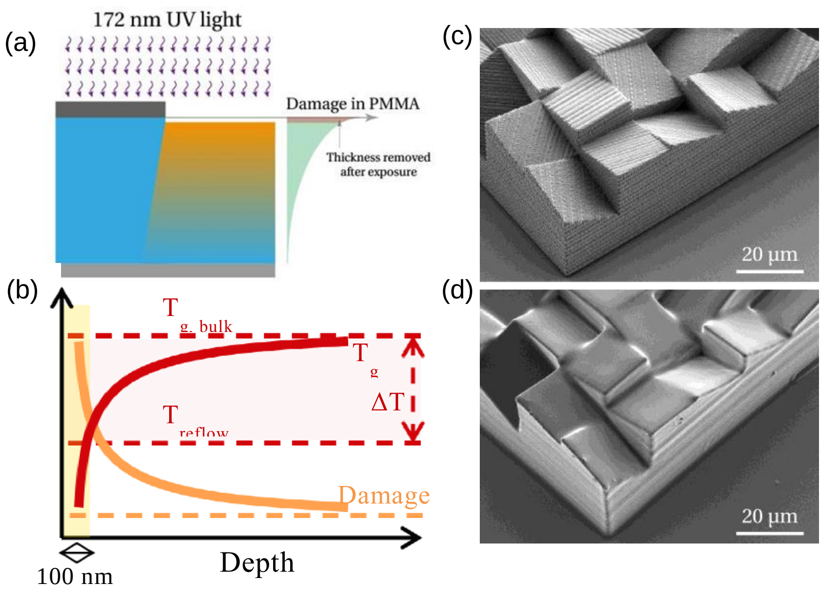

Figure 1: (a) Schematic of 172 nm UV exposure to PMMA film. (b) Expected depth profile of the damage in PMMA (orange) and corresponding glass transition temperature dependence (red) for a specific exposure dose. (c) As written microprism array with 2PP. (d) After transfer into PMMA with surface sensitive exposure and reflow for 15 mins at 115°C.

References

1. NanoScribe GmbH. http://www.nanoscribe.de/en/
2. A. Schleunitz, et al., *Nano Convergence*, ***1***, 7 (2014)

Free-form nanostructured tools for plastic injection moulding

Jan Kafka[1], Mads Sonne[2], Yee Cheong Lam[3], Maria Matschuk[1], Henrik Pranov[1], Rafael Taboryski[4], Guggi Kofod[1]

[1] Inmold A/S, Taastrup, Denmark
[2] DTU Department of Mechanical Engineering, Lyngby, Denmark
[3] School of Mechanical & Aerospace Engineering, Nanyang Technological University, Singapore
[4] DTU Department of Micro- and Nanotechnology, Lyngby, Denmark

We present results on a recently developed process to provide nanostructured surfaces on curved free-form injection moulding tools. The nanostructures are prepared using a sol-gel type coating, which can be applied by various means. Nanostructures are transferred from master structures originated typically by lithography. The nanostructures are imprinted by means of flexible stamps. After imprinting, nanostructures in the sol-gel are cured by baking, by which the material is converted to a quartz-like substance. Line patterns with depths up to about 500 nm and aspect ratio of up to 1 have been realized and successfully transferred to plastic parts during injection moulding.

As an example, we present theory and results regarding the imprint of pillar nanostructures on a semi-spherical mold surface, followed by injection molding of the same. The deformation of the flexible stamp is characterized by measurement of inter-pillar distance on various points on the sphere, and compared to predictions provided by a geometrical model. Moulded plastic parts show good replication of the pillar structure.

There are various practical advantages to the new process: the application of the coating is possible on both flat, single-curved and double-curved surfaces; the coating and the baking step is compatible with typical steel types in common usage for injection moulding; the coating is conformal with a relatively high surface roughness up to Ra ≈ 100 nm, accommodating several surface finishing methods such as fine milling and diamond polishing; the coating has slightly insulating properties, which improves the nanostructure transfer properties compared to metal nanostructures; several durability studies have shown that the nanostructures on the injection moulding tool surface are unaffected for at least 100.000 injection moulding cycles; the imprinting of nanostructures has been successfully attempted with several types of thermoplastic polymer, including PS, ABS, PE, PP, COC (Topaz), and PA (Nylon), showing that most polymers are compatible, while some may require an increase in mold temperature for full transfer of nanostructure depth.

In conclusion, the process for nanostructured surfaces on double-curved or free-form injection moulding tools relies on flexible stamps, giving rise to predictable deformation of the pattern. The sol-gel process provides for a durable tool with accommodation of imperfect injection tool surface.

Glassy Carbon Masters for Plastic Injection Molding

K. Prater[1], T. Scharf[1], H.P. Herzig[1], C. Rytka[2], P.M. Kristiansen[2]

[1] École Polytechnique Fédérale de Lausanne, OPT Laboratory, Neuchâtel, Switzerland
[2] FHNW University of Applied Sciences and Arts Northwestern Switzerland, School of Engineering, Institute of Polymer Nanotechnology (INKA), Windisch, Switzerland

In mass production of polymer parts with micro- and nanoscale functional features, Nickel shims are commonly employed in industry. The fabrication of such mold inserts is both expensive and time-consuming because of the various steps involved: lithography and etching of silicon, electroforming, machining, backside planarization and optional anti-sticking coating. In our previous studies, we used Glassy Carbon (GC) as mold material for precision glass molding [1,2] due to its extreme thermal resistance, low chemical reactivity, and high mechanical strength. In fact, we demonstrated micro-structuring of GC for diffractive optical elements (DOEs) [2]. The fabrication process consists of deposition of a hard mask layer (e.g. Ti, Si), conventional photolithography, and reactive ion etching (RIE). The entire process flow takes less than one week, which makes GC interesting for R&D purposes.

Recently, we experimentally verified the suitability of GC as mold insert material for injection molding, and observed exceptional stability thanks to the pronounced ductility and inherent anti-adhesive properties of GC. Figure 1 shows a fabricated 4” GC wafer with an etch depth of 1.34 µm and the results from injection molding replication into Cyclo-olefin copolymer (COC). The SEM pictures in Fig. 1 show the structures with critical dimension of 4µm on the GC mold, and the counterpart on the COC replica. Those structures are designed for DOEs, where the requirements are more demanding than what could be achieved in these preliminary trials.

In order to expand our approach to larger and more complex functional structures, higher etch depths in the range of 10-50 µm are sought after. Thus, process protocols need to be adopted particularly for fine structures. Microstructures with larger lateral dimensions could likely also be realized by direct laser writing of photoresist, which despite somewhat lower resolution compared to conventional lithography offers substantially more design flexibility and versatility from batch to batch.

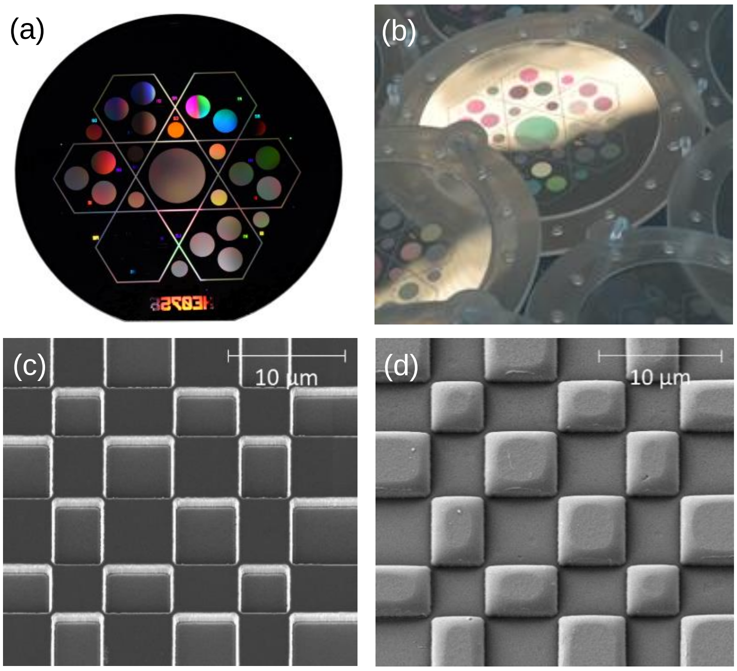

Figure 1: (a) 4” Glassy Carbon wafer as a master for plastic injection molding, (b) Cycloolefin copolymer (COC) replica prepared by standard injection molding. (c) SEM image of the GC mold and (d) the corresponding COC replica surface, where the scale bar indicates 10 µm.

References

1. K. Prater, J. Dukwen, T. Scharf, H.P. Herzig, S. Plöger, A. Hermerschmidt, “Multilevel micro-structuring of glassy carbon for precision glass molding of diffractive optical elements,” Proceedings of SPIE, 9374, 937410 (2015).
2. K. Prater, J. Dukwen, T. Scharf, H.P. Herzig, S. Plöger, A. Hermerschmidt, “Surface micro-structuring of glassy carbon for precision glass molding of diffractive optical elements,” Proceedings of SPIE, 9192, 919211 (2014).

Sophisticated Nanostructuring of Arbitrary Steel Grades and Geometries: Planar, Curved or Within Cavities

D. Kallweit, C. Schneider, M. Schnieper

CSEM SA, Muttenz, Switzerland

Micro and nano surface structuring is a technology domain with different processes and industrial applications that especially developed over the last years. The fabrication and tooling processes have improved in precision and decreased in cost, which allows the fabrication of smaller and more complex structures. In parallel, the choice of materials for surface micro- and nano-structuring is increasing opening up new opportunities and applications.

For several years CSEM has been working on a novel technology for transferring micro and nano-optical features on steel tools which can be used for injection molding or metal to metal embossing. The developed technology can be used to transfer visible features like holograms, logos, color effects, as well as hidden features like covert laser readable images, microtext or other encoded elements.

It is not only the vast variety of elements that CSEM can design and transfer into steel or glass, but also that we are able to treat every type of steel or metal our customers provide, which is important since depending on the type of product and the process parameters (pressure, temperature, dwelling time, (loaded) plastic material) each customer and application typically relies on a special type of steel, which is optimized for the given use.

The steel technology that we present is not limited to planar surfaces or a certain size of the mold insert. The size of the pieces treated at CSEM so far ranges from a few hundred micrometers up to half a meter. Furthermore the designed nanostructures, no matter what they are, cannot only be transferred into planar surfaces, but also into curved ones, on sidewalls or into cavities.

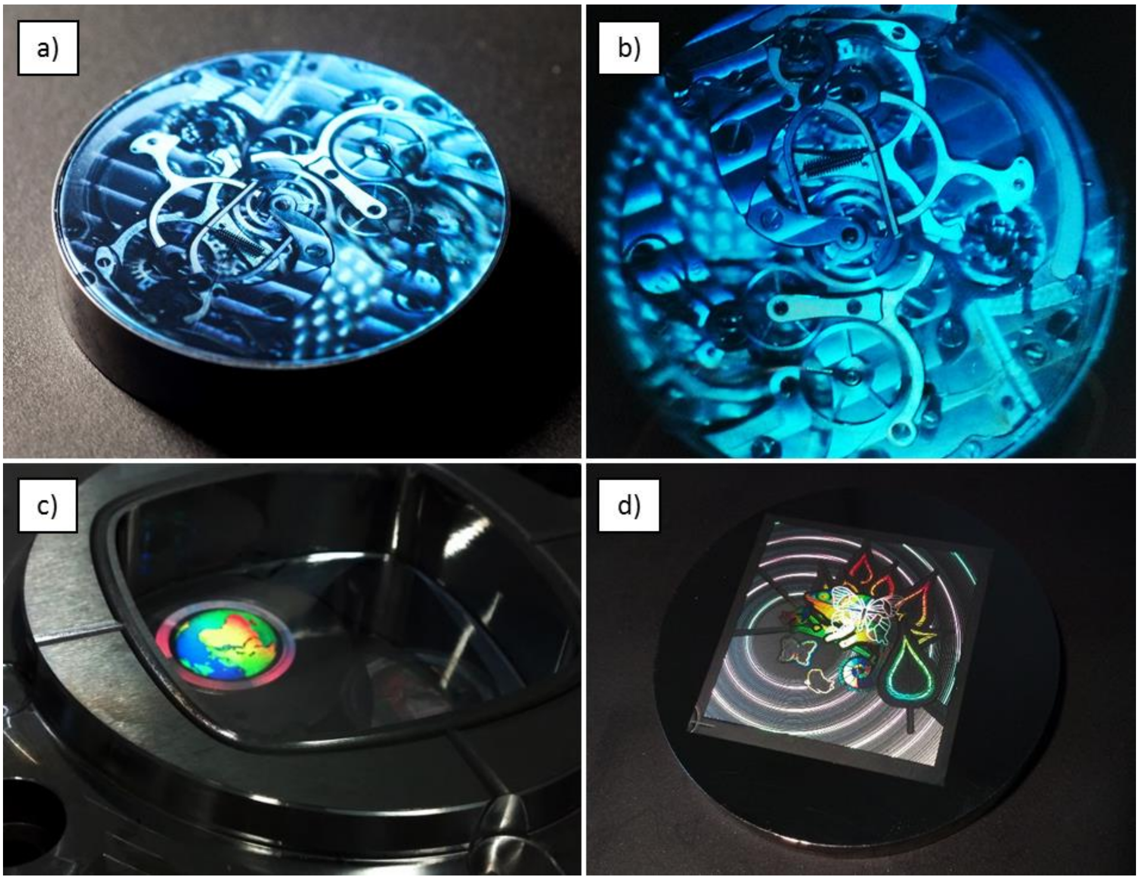

Figure 1: a) multilevel hologram in steel, b) hologram molded into black plastic, c) security hologram on the bottom of a steel cavity for injection molding, d) “alphagram” in steel (cooperation with Surys).

Nanoimprint Lithography

Chair: Helmut Schift (INKA PSI, Switzerland)

15:30-16:00 Flash presentations on poster contributions

16:00-16:20 Christoph Baum (Fraunhofer IPT, Germany)
"Comparison of drum production methods for roll-to-roll nano imprint lithography"

16:20-16:40 Angélique Luu-Dinh (CSEM, Switzerland)
"Applications of photocurable polymers for casting of micro- and nanostructures"

16:40-17:00 Michele Pianigiani (ThunderNIL, Italy)
"Pulsed nanoimprint lithography and its impact on elastic modulus"

17:00-17:20 Michael Haslinger (Profactor, Austria)
"Soft nanoimprint lithography on 3D-printed curved surfaces"

17:20-17:50 Invited: Jens Gobrecht (INKA FHNW/PSI, Switzerland)
"20 years of surface nanoreplication – from science to applications"

17:50-18:00 Closing by Clemens Dransfeld (FHNW, Switzerland)
"Polymers between fibres - learning from polymer replication"

Comparison of drum production methods for roll-to-roll nano imprint lithography

C. Brecher[1], M. Guttmann[2], A. Johansson [3], A. Gillner[4] , T. Bastuck[1], M. Priwisch[1], C. Baum[1]

[1] Fraunhofer Institute for Production Technology, Aachen, Germany
[2] Karlsruhe Institute of Technology, Institute for Microstructure Technology, Karlsruhe, Germany
[3] NIL Technology, Lyngby, Germany
[4] Fraunhofer Institute for Laser Technology ILT, Aachen, Germany

Roll-to-roll nano imprint technology can be used for the economic replication of micro and nanostructures in a cost efficient continuous process. Depending on the origination of the master drum even an endless production of nano patterned surfaces is possible. For the production of drums several technologies can be used. Most common methods are single point diamond machining, lithography and ultra short pulse laser machining.

Each of those technologies has its benefits and drawbacks. Therefore the technology for the production of master drums needs to be chosen with respect to the particular specifications of the nano and micro structured required. Within this paper the authors compares three types of mastering methods with respect to feature resolution, surface quality, and production efficiency. The results of the roll-to-roll replication using different structures will be presented by means of exemplarily replicated structures.

Single point diamond machining techniques can create seamless patterns on drums. The process bases on mechanical machining operation. A tool made of a single crystal diamond is used for cutting into a drum made of non-ferrous metal. The resulting surface roughness of diamond machined parts can be as little as 1 nm Ra. The shape of the structures can either be defined by the shape of the diamond tool only, or can be generated by the path of the tool. In the first case the geometry of the diamond tool is copied into the drum as negative during the turning operation. Since the minimum tool tip radius can be in the range of few 10-100 nm only, the resulting edge has very sharp edges. This machining method is typically used if a structure having a constant angle over the entire length of the drum should be generated. By the combination of circumferential grooves with lengthwise grooves or helixes also pyramid structures can be generated. If the structures to be generated have a variety of angles or complex shapes, the structures can be generated by using a tool with radius tip. The shape of the structures can be created highly flexible by programming the machine controller. Highly accurate simultaneous movement of the linear stages positions the tool relatively to the rotating drum. With this machining approach the machining time rises since the feed rate of the axes must be very low in order to create surfaces with little roughness. In addition a tool tip radius in the range of 5-20 µm needs to be used. Highly dynamic axes for controlling and changing the tool stroke with the respect to the angular position of the drum allow for 3-dimensional elements. Free-formed continuous micro patterns can be produced. However, the dynamic of the axes and the geometry of the tool limits the possibilities for the production of very steep structures and vertical flanks.

Lithographic processes can achieve even higher resolution than diamond machining. E.g. electron beam lithography can create structures in the range of few 10 nanometers. However, such mastering processes are suitable for the production of micro and nano patterns on relatively small areas. In order to produce drums suitable for the roll-to-roll production of micro structured and nano structured films a transfer of the structures to a bendable master is required. Electroforming therefore is often used in order to transfer the patterns of a flat master on a thin nickel shim which can be bent around a drum. Since the masters of most of the lithographic processes are relatively small and typically in wafer format, a transfer to a larger format is required. In order to transfer micro and nano patterns to masters of bigger dimensions a step&repeat embossing process can be used. Else multiple nickel shims can be used and can be welded together to form a sleeve for a drum. The author will present the full process chain consisting of electron beam writing, nickel electroforming for single patterns, step&repeat embossing on large polymeric areas and electroforming of larger nickel shims to be welded together as a sleeve for roll-to-roll nanoimprint lithography.

Laser patterning of drums is an alternative process which becomes more and more important due to the increasing possibilities of material processing by ultra-short pulse lasers. Such laser sources have pulse durations in the range of femto seconds which lead to very fine and highly reproducible ablation properties. The depth regulation can be in the range of 100 nm with lateral resolutions in the range of few micrometers. The process is suitable to ablate a very wide range of materials thus the drum can also be made of very corrosion resistant materials such as stainless steel or ceramics. Limitations result mainly from the surface roughness and the radius of edges.

Applications of Photocurable Polymers for Casting of micro- and nanostructures

Angélique Luu-Dinh, Guillaume Basset, Frédéric Zanella, Christian Schneider

Thin Film Optics, CSEM Muttenz

Micro- and nano-optical elements with feature sizes of around 100 nm to 10 µm play an important role in application fields like light management in electronic devices e.g. digital cameras, medical instruments, optical sensing, document security and brand protection [1]. Keeping the pace with the evolution of other technologies like e.g. semiconductors industry the shrinkage of such optical elements has to follow the same scaling. At CSEM intensive research and development has led to new materials [2] and processes [3] to provide high performance, low cost and up-scalable solutions for soft imprinting, casting and recombining.

Recent developments achieved in UV casting with new photopolymers and in particular hybrid polymers are presented. Key parameters in UV nano-patterning such as the kinetics of polymerization, the light source, functionalized photopolymers which influence the replicability of complex micro- and nano-structures have been studied. Based on these new developments replication of micro-optics at wafer scale (see Fig. 1) and on large area (see Fig. 2), utilizing a custom developed step-and-repeat robotic platform, have been realized for industrial customers.

On wafer scale micro-optics are replicated using an UV embossing process based on a modified mask-aligner, which allows a precise control of alignment and thickness of the replicated features.

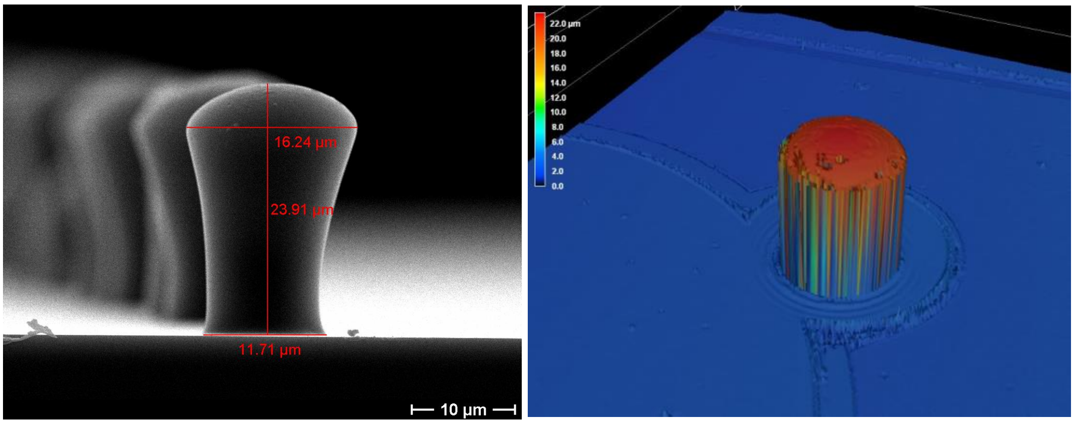

Figure 1: Replication on wafer scale of free-standing micro-lenses

Using the recently developed step-and-repeat platform at CSEM, UV replicated micro- and nanostructures have been produced on large area, enabling industrial applications.

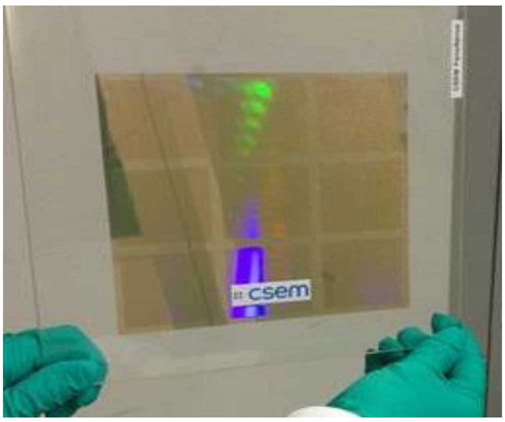

Figure 2: Nanostructures UV replicated by step and repeat process

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Pulsed Nanoimprint Lithography and its Impact on Elastic Modulus

Massimo Tormen[1,2], Michele Pianigiani[1,2,3,4], Alessandro Pozzato[1,2], Enrico Sovernigo[1,2], Alessandro Cian[1], Fabio Suran[2], Maurizio Tormen[1,5], Robert Kirchner [4], Helmut Schift [4]

[1] ThunderNIL srl, via Foscolo 8, Padova, I-35131, Italy
[2] IOM-CNR Area Science Park, Basovizza, S.S. 14,Km. 163.5, 34149 Trieste, Italy
[3] University of Trieste, Piazzale Europa,1 34127 Trieste, Italy
[4] Paul Scherrer Institut, Laboratory for Micro and Nanotechnology, 5232 Villigen PSI, Switzerland
[5] Ctr. Suisse d'Electronique et de Microtechnique SA, Switzerland

Nanoimprint lithography has been almost invariably presented as a high-resolution, low-cost, high-throughput technology for large-area parallel nanopatterning of surfaces. However, the throughput of conventional thermal NIL (T-NIL) is far from its physical limit. Pulsed Nanoimprint Lithography (Pulsed-NIL) is an ultrafast NIL technology which enables nanopatterning over large substrates in ultra-short thermal cycles [1-3]. This technique is based on the use of stamps with an integrated two-dimensional heating element buried below their nanostructured surfaces. A single, short (<100 µs) intense current pulse causes an abrupt increase of temperature at the stamp surface, resulting in the almost instantaneous melting of the resist film in contact with it. The rapidity of the thermal cycle brings key advantages with respect to the standard thermal NIL, such as the formation of very steep temperature gradients (of the order of 1000 °C/µm), enabling to confine the melting of thermoplastic resist to regions in direct contact with the stamp. The origination of large area nanostructures with seamless patterns (e.g. extended gratings of uninterrupted lines) in a Step & Repeat (SR) process or the formation of hierarchical nanostructures will benefit from this special feature of the Pulsed-NIL process, enabling cost effect origination of complex 3D hierarchical nanostructured shims for use in the industry of plastic products. Crucial for implementation of these replication processes, is selecting thermoplastic resists with well-suited thermomechanical properties [4]. In this work we examine, also, the effect of T-NIL and P-NIL on the mechanical properties of the surface of spin coated polymethyl-methacrylate (PMMA). By using the PeakForce QNM™ mode (quantitative nanomechanical property mapping) of the Bruker Dimension Icon AFM, the Young's modulus of resists as-coated and imprinted resist were investigated. The effect which the NIL process itself has on the properties of the imprinted polymer is important. The modification of different properties (mechanical, optoelectronic, chemical) would affect the final nanostructured polymer product, or play a role in the subsequent process steps if the material is used as a resist for pattern transfer.

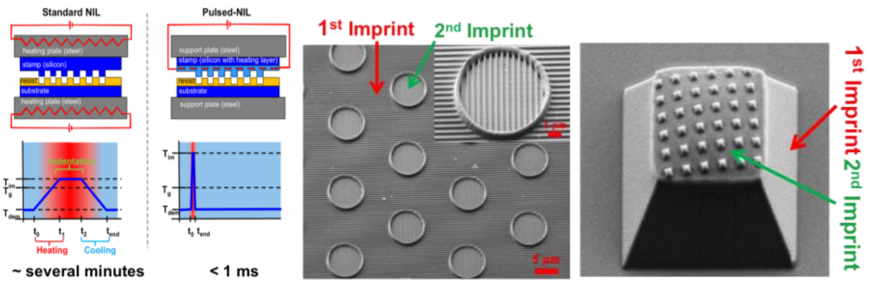

Figure 1: Concept difference between conventional thermal NIL. Demonstration of stitching capabilities and hyerarchical micro- nano-structuring by ultrafast NIL

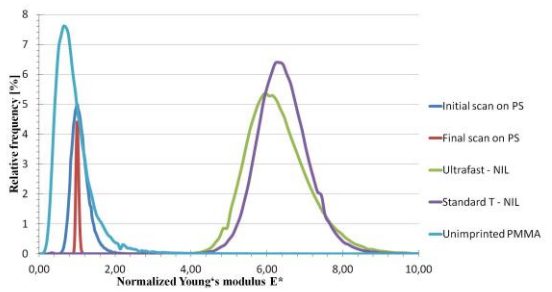

Figure 2: Relative modulus of PMMA with/without imprint. The two broad peaks on the right side are representing the normalized Young's modulus for ultrafast NIL and for standard T-NIL for PMMA while the group of peaks on the left side represents the pristine PMMA without imprinting as well as the PS reference measurements before and at the end of the measurements.

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Soft nanoimprint lithography on 3D-printed curved surfaces

M. J. Haslinger, T. Köpplmayr, T. Faury, T. Fischinger, L. Häusler and M. Mühlberger

PROFACTOR GmbH, Im Stadtgut A2, 4407 Steyr-Gleink, Austria

Around 20 years ago nanoimprint lithography (NIL) was develop by replicating hard stamps into polymer layers [1] and later by using flexible stamps [2] as well. Soft NIL with flexible stamps has the advantage that the stamps can easily compensate the unevenness of substrates (e.g. glass, Si-wafer) without the use of excessive forces and thus can perform conformal imprints over large areas. Even small defects or particles are easily compensated by soft NIL.

The combination of nanoimprint lithography with additive manufacturing [3] could open a new field of individualized products and new applications. With additive manufacturing or 3D-printing it is possible to fabricate objects which could not be made with standard subtractive methods. We are interested in performing soft UV-NIL on curved surfaces which could add functionality, like decorative coloring to the surface of such individualized 3D-printed parts. One other possible application could be the structuring of 3D-printed implants for a better integration and cell growth. The key is to figure out the limitations for bending of the stamp and the parameters for optimal imprinting on 3D curved surfaces.

We are investigating the effects that occur when soft NIL stamps deform over curved surfaces and the capability of performing NIL on curved objects in general. Especially, the macroscopic deformations of the stamp as well as imprinting on microscopically rough surfaces are of interest. Therefore, different stamp materials and stamp thicknesses as well as different imprinting patterns are tested and analyzed. Among others we show UV-NIL on 3D-printed curved objects fabricated with FDM 3D-printing.

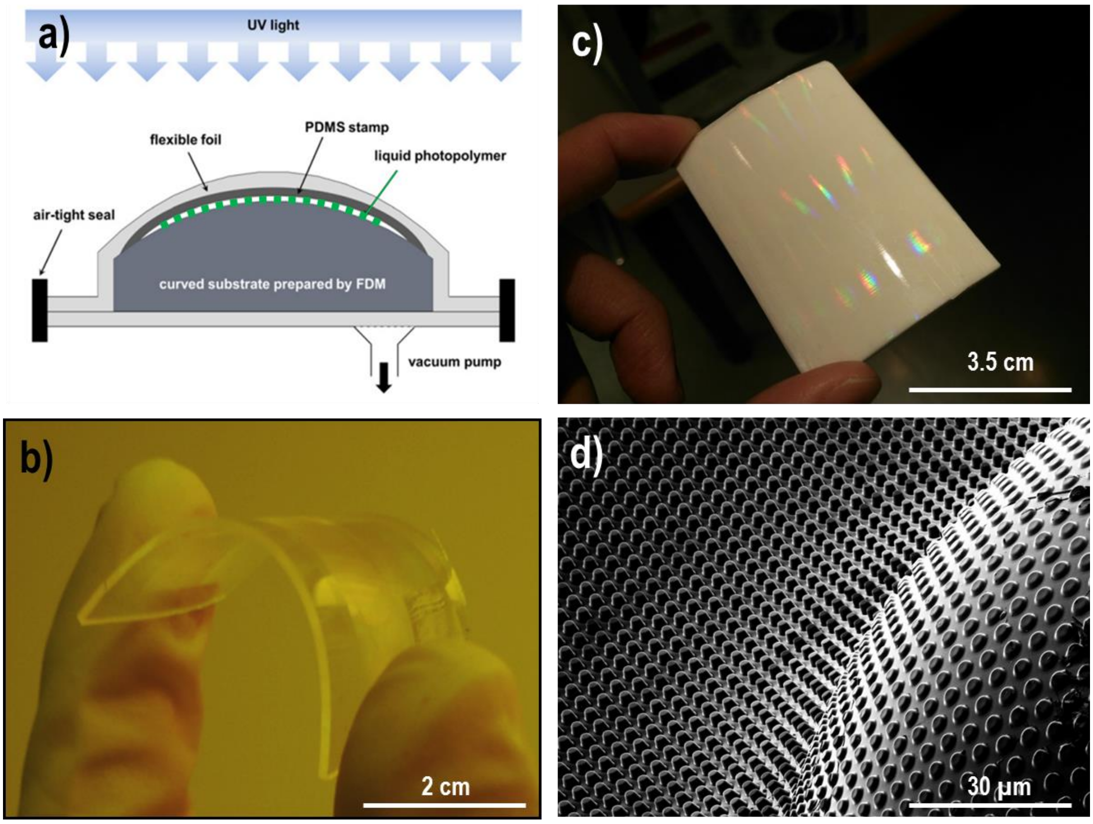

Figure 1: a) Schematic drawing showing our setup to perform imprints on curved surfaces. b) Flexible PDMS stamp. c) 3D-printed part curved in one direction with surface structured by nanoimprint lithography. d) Detail of an imprint over a half sphere with 160µm diameter demonstrating the deformation capability of a soft NIL stamp.

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20 Years of Surface Nanoreplication: From Science to Applications

Jens Gobrecht[1,2]

[1] Paul Scherrer Institut, 5232 Villigen, Switzerland
[2] Univ. of Applied Sciences and Arts of Northwestern Switzerland, 5210 Windisch, Switzerland

A large and important part of nanotechnology research is devoted to shaping a given material with nm precision in a controlled way. Since the pioneering work of St. Chou [(1)] it became clear that (thermoplastic) polmers are very suitable materials for controlled replication down to the single digit nm regime. We recognized at the Paul Scherrer Institute (PSI) in Switzerland early the potential of this method for the relatively easy, low cost and reproducible fabrication of nanopatterned polymer surfaces to be used in scientific research and in specific product applications [(2)]. PSI to a large part is focusing on basic scientific research, often involving large scale research facilities like a neutron source or a synchrotron for generating high brilliance x-rays (http://www.psi.ch). Part of our early work in nanoreplication thus e.g. dealt with understanding the thermal nanoimprint process in detail [(3)] but it also became apparent soon that for a successful transfer into real-world applications a close collaboration with groups being competent in polymer engineering would be highly beneficial. We therefore decided to join forces in this reaserach area with the polymer institute of the Univ. of Applied Sciences of Northwestern Switzerland (FHNW) by forming a new, joint organization, the “Institute of Polymer Nanotechnology” (http://www.fhnw.ch/INKA).

In the Talk several successful examples will be given for the combination of the scientific with the engineering approach. For example the surface grafting of polymers locally irradiated with soft x-rays from the SLS synchrotron started as a purely scientific endeavor in form of two PhD theses now became a focus of applied research at the FHNW together with local SMEs. Another PhD thesis in the area of biomolecule sensing using micro- injection molded cantilever arrays from various polymer materials revealed interesting insights about the detailed molecular arrangements in the IM micro parts using synchrotron based WAXS and SAXS techniques as shown in fig. 1 [(4)]. Other projects focused e.g. on the limits of the known replication processes concerning the minimum size of the features replicated. So far, it always turned out that the capability of machining the tool is the limiting factor (fig. 2), i.e. it is not yet clearly known, where the limits given by the material or the process can be found.

Looking at applications today, micro- and submicron replication of polymer surfaces is widely used in many fields in spite of the dramatic decline of optical data storage discs (CD, DVD, blue ray). Probably still the most important area is micro optics, for instance for diffractive security features in bank notes or on labels for brand protection. An application of particular interest at present are wire grid polarizers (fig. 3) for LCD flat screens which would substantially increase the energy efficiency of these devices [(5)]. The challenge here is the replication of defect free, ~300nm period gratings over a ~1m^2 area e.g. in a roll-to-roll process. Of special interest in micro-optical applications is a novel, partial reflow technique which takes advantage of the dependence of the melting point of e.g. pmma on the electron irradiation dose. This allows for example the creation of micro-prismatic surface structures for light guiding purposes (fig. 4).

Finally, some words on 3 D additive nano-printing of polymers: Will it become a serious competition for surface nanoreplication by NIL or IM? Probably not as long as mass production is considered due to the inherently slow process of serial 3D printing. But in areas where only one or a few samples are required like in prototyping, scientific research projects or for generating replication tools this method already is well established and will become more important if not dominant in the future. An example from our research is given in fig. 5[(6)].

In conclusion, it will be shown in the talk that for a successful research in the area of controlled replication of nanopatterns in polymer surfaces the whole chain is necessary from a basic scientific investigation and understanding of processes and materials up to the engineering approach to achieve reproducible quality, acceptable cost etc. The example of the “Institute of Polymer Nanotechnology” as a joint establishment between PSI and the FHNW is a proof of this successful approach. This institute thus is excellently positioned for the future challenges in research the area polymer nanoreplication.

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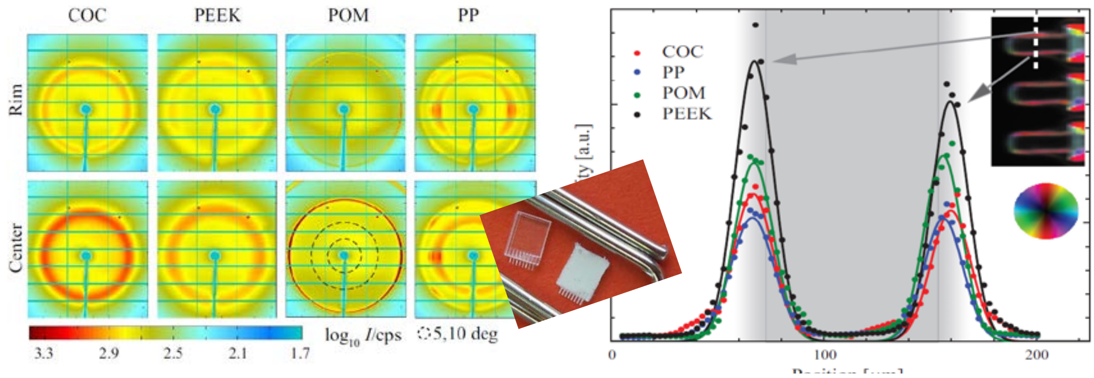

Fig. 1: WAXS patterns of micro-injection moulded cantilevers (left) and SAXS (right), taken at the “Swiss Light Source” (from Ref 4).

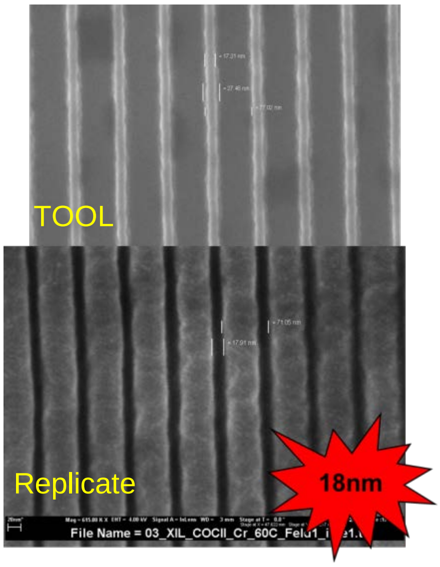

Fig. 2: 18nm wide, >20nm deep channels formed by micro-IM in PP. Tool: HSQ lines on Si, made by EUV-IL at PSI.

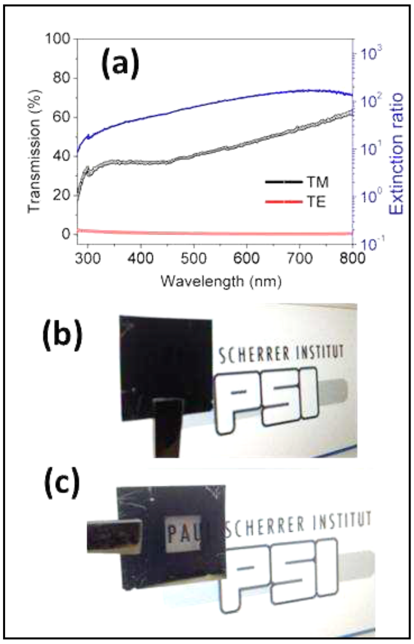

Fig. 3: Performance of a nanowire grid polarizer, taken from ref. 5.

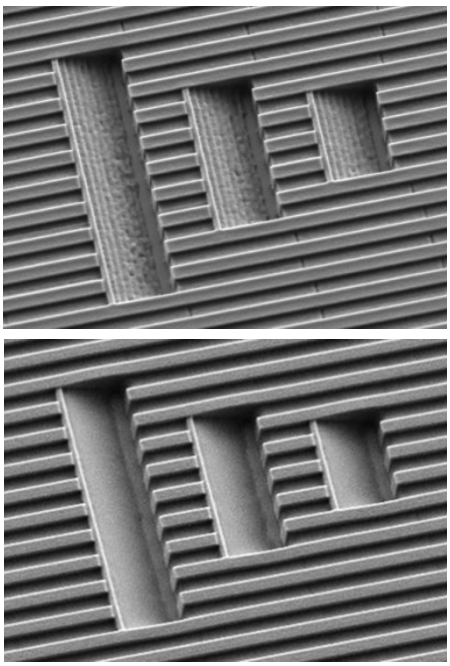

Fig 4: Array of inverted microprisms in pmma before (top) and after (bottom) reflow.

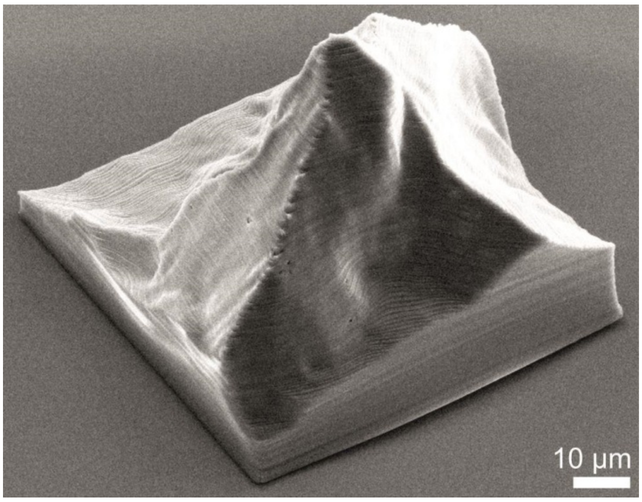

Fig. 5: 3D-printed “Micro-Matterhorn”, taken from ref. 6.

PRN 2016 Polymer Replication on Nanoscale

Industrial Replication Technologies I

Chair: Per Magnus Kristiansen (INKA FHNW, Switzerland)

09:00-09:30 Invited speaker: Oliver Humbach (temicon GmbH)

"Industrial replication of micro and nanostructured polymer films and components"

09:30-09:50 Mohammad S.M. Saifullah (A*STAR, Singapore)

"Fabrication of polycarbonate lens with double side anti-reflection structures via nanoinjection molding"

09:50-10:10 Werner Balika (Sony DADC, Austria)

"High precision injection molding for industrial manufacturing of MTP-sized microfluidic chips"

10:10-10:30 Veronica Savu (Morphotonix Sarl, Switzerland)

"Zero-added manufacturing cost and passport-grade security solution for rigid plastics"

10:30-10:50 Yu Jiang (University of Eastern Finland)

"Fabrication and applications of injection molded micro-micro hierarchical structures"

Industrial Replication of Micro and Nanostructured Polymer Films and Components

O. Humbach[1], M. Rawert[1], T. Ruhl[1], W. Schipper[1], J. Mick[2], V. Boerner[2]

[1] temicon GmbH, Dortmund, Germany,
[2] temicon GmbH, Freiburg, Germany

Surfaces on films and components are functionalized by micro and nanostructures to achieve new or improved performance in various application fields, like lighting, display, solar or life science. There is a strong demand in the industry to get structured films and components with different functionalities, large formats, high quality and economic prices.

Two replication processes are of particular interest for the industry – injection molding and roll nanoimprint. However, several technical hurdles have to be addressed and solved: (a) the origination of demanding micro and nanostructures often on large formats, (b) the processing of mold inserts or even seamless sleeves and (c) the high-quality and cost-efficient industrial replication.

In this paper we describe latest developments in the process chain of industrial origination, tooling, injection molding as well as roll-to-roll (R2R) and roll-to-plate (R2P) imprinting.

A. Origination and Tooling

Interference lithography [1] and UV lithography are used to generate patterns between 50 nm and 500 µm on flat substrates. In order to generate these patterns uniformly on a cylinder surface it is necessary to achieve a precise exposure on curved (convex) surfaces. Step-and-repeat approaches have been investigated to result in homogeneous patterns without visible seams [2]. Due to the high depth of focus in case of laser-interference lithography, curved surfaces can be exposed with high quality. In the case of UV-lithography with a rather small depth of focus tiny exposure areas are exposed and stitched together. After the origination process the masters are transferred into metal nickel tools by electroforming processes – a flat electroforming unit for the flat masters and a cylindrical electroforming unit for the cylindrical masters. In case of injection molding the nickel shims are either mounted on a steel block or with a frame attachment directly into the mold. In case of roll-imprinting seamless sleeves are fabricated that are fixed on the imprint roll.

B. Injection Molding

One of the big challenges in industrial injection molding of micro and nanostructures is to keep the fidelity and thus the functionality of the patterns. High-quality replication of so-called moth-eye structures is certainly one of the most challenging tasks for industrial-compatible processes. Moth-eye structures as illustrated in Figure 1 are used for anti-reflective surfaces for example in the optical or display industry. With our laser interference lithography we fabricate these moth-eye structures with reflectivities as low as 0,2%. With the combination of a vario-thermal process and injection-compression molding we succeeded our developments in the replication of these high-aspect ratio moth-eye structures. The reflectivity of the replicated surface has also be reduced to 0,2% - exactly like in the original master pattern.

C. Roll-imprinting (R2R, R2P)

We use UV roll-imprinting processes to transfer patterns on the surface of different materials. A thin UV curable lacquer is coated on top of a polymer film and the micro and nanostructures are imprinted via UV embossing in the roll-to-roll process. A similar embossing process is applied in the roll-to-plate process. Here, a flexible master film with the pattern is imprinted into the UV curable lacquer on the plate. Different polymer films like PET, PMMA, PC, etc. can be used in case of roll-to-roll imprinting. In case of roll-to-plate imprinting even other materials like glass or opaque materials are possible. Several product lacquers have been developed in order to meet the requirements of the different applications, like transparency, UV stability or scratch resistance.

The above described new developments and advancements are a quantum leap in terms of micro/nano patterning and industrial replication. The new origination/tooling, injection molding and roll-imprinting methods allow high-quality and cost-effective production of micro and nanostructured films and components.

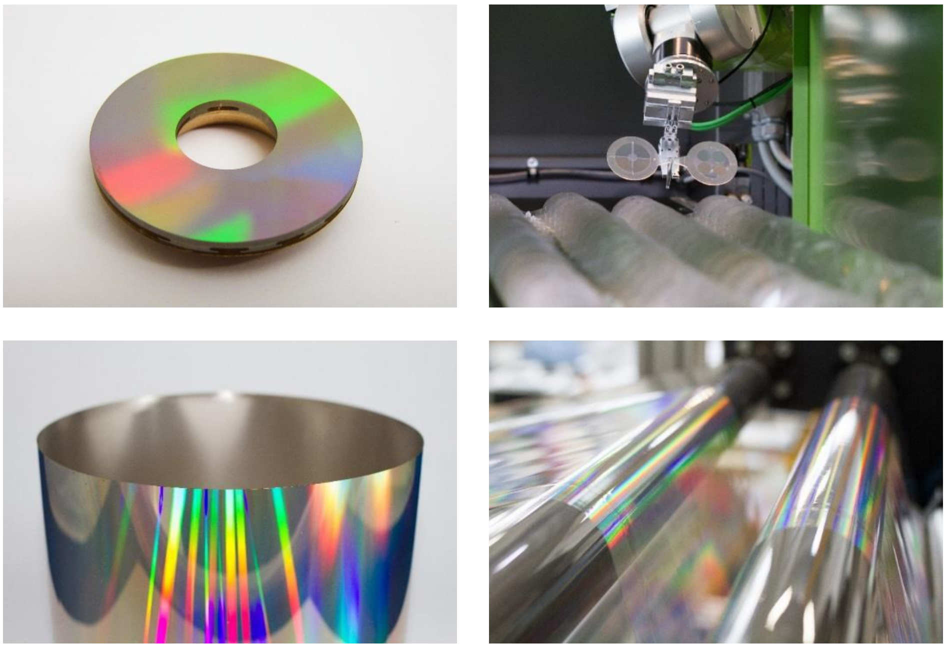

Figure 1: Industrial replication of micro and nanostructured films and components, (a) mold insert, (b) injection molding, (c) seamless sleeve, (d) roll-to-roll imprinting

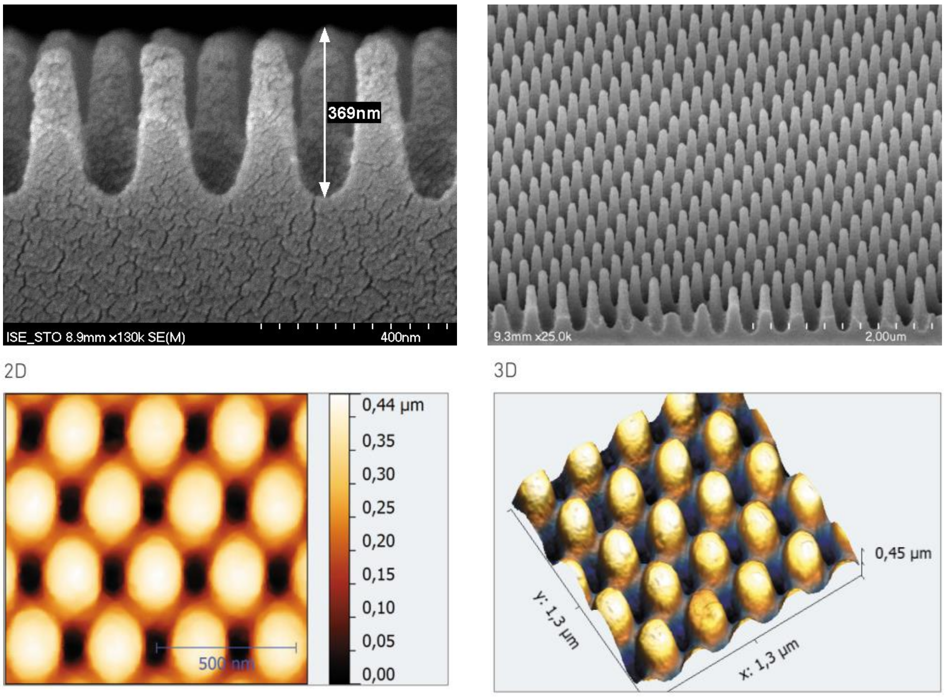

Figure 2: Nanostructure (moth-eye structure) with high fidelity after injection molding

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Fabrication of Polycarbonate Lens With Double Side Anti-Reflection Structures Via Nanoinjection Molding

M. S. M. Saifullah[1], Yee Chong Loke[1], Li Xue[1], Chang Sheng Lee[1], Ren Bin Yang[1], Ai Yu He[1], Christina Y. L. Tan[1], Alvin Cheng[2], Karen S. L. Chong[1]

[1] Institute of Materials Research and Engineering, A*STAR (Agency for Science, Technology and Research), 2 Fusionopolis Way, #08-03, Innovis, Singapore 138634, Republic of Singapore
[2] Banshing Industrial Co. (Pte) Ltd, 13 Serangoon North Ave 5, Singapore 554787, Republic of Singapore

ABSTRACT

Fresnel reflection is a major source of loss of incident light on optical components.[1,2] The reflection losses worsen when there is a stack of optical components involved. Typically, polycarbonate lenses transmit ~88% of the incident light in the visible range whilst the rest is lost by reflection losses. This loss of light is higher than what is observed in glass. Moth's eye anti-reflection structures are characterized by gradient refractive index and are very effective in reducing the Fresnel reflection losses at the air-plastic interface.

Here we demonstrate molding of a lens with double side anti-reflection structures fabricated by nanoinjection molding – a technique that synergistically combines the elements of nanoimprinting with traditional injection molding to enable access of sub-micro and nanoscale features onto macroscale three-dimensional free-form products. Inserts containing biomimetic moth's eye nanostructures were placed on both cavity and core side of the mold. After optimizing the molding conditions, that is, injection pressure, speed, holding time, temperature of mold and melt, the injection molding was carried out. It was observed that polycarbonate lens with a single side anti-reflection structures showed ~4% rise in transmission, whilst the double side moth's eye patterned lens lead to roughly 8% rise in transmission. Additionally, they also showed a red-shift in the transmission at lower wavelengths giving rise to an anti-UV effect.

Since this technique is relatively new, it also faces teething problems from different fronts. In my talk, I will discuss some of the exciting prospects as well as challenges associated with this technique.

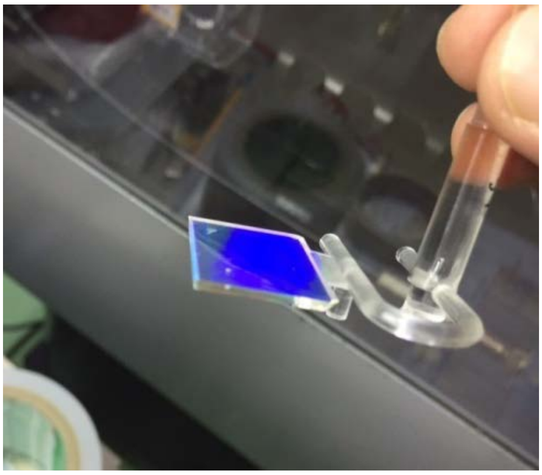

Figure 1: A nanoinjection molded lens with anti-reflection structures on both sides. When looked at glancing angles, it strongly reflects the blue and smaller wavelengths. The light transmission through the lens is >95% leading to high clarity, reduced UV transmission and lower stray reflection.

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High precision injection molding for industrial manufacturing of MTP-sized microfluidic chips

S. Brandstätter[1], S. Moderegger[1], R. Tornay[2], W. Balika[1]

[1]Sony DADC BioSciences GmbH, Sonystrasse 20, 5081 Anif, Austria
[2]MyCartis, VIB bio-incubator, Technologiepark 4, 9052 Zwijnaarde, Belgium

werner.balika@sonydadc.com

There are a lot of customer specific chip sizes in life science and diagnostic microfluidic systems. Some standardization in terms of footprint however exists in notably the microscope slide format (25 mm x 75 mm) or the larger scale microtiter plate (MTP). A recommendation for the latter footprint specification (127.76 mm×85.48 mm) was given by the Society for Biomolecular Screening (SBS) [1].

Within this work we demonstrate the fabrication of a polymeric MTP-sized microfluidic chip (Fig. 1) consisting of the following key features: (1) 16 structured microchannels connecting (2) 32 macroscopic sized ports acting as inlet and waste reservoirs, with (3) very well controlled macro to micro interfaces to connect ports to microchannels. The chip was designed by MyCartis as a key element of MyCartis' Evalution™ multiplex analysis platform [2] tailored to the development of clinical biomarkers.

The major challenges in terms of injection molding were the results of the following geometrical requirements: (a) Global flatness of ≤ 300 µm to ensure adequate interfacing with the optical, thermal and pressurization systems of the Evalution™ platform, (b) high channel density while achieving (c) local flatness of ≤ 20 µm/5 mm (together with avoiding burrs and sink marks) required to properly laminate a foil onto the molded chip and (d) very tight control over the channel width and height in a very narrow tolerance range over a total channel length of ≥ 100 mm. To realize all features mentioned above, a mold concept was developed based on moveable pins and a flexible mold insert (stamper). The latter was manufactured using lithographic and galvanic processes also used in a different project to manufacture nanostructured patterns for metal enhanced fluorescence (Fig. 2).

Using an optimized parameter set for injection molding such chips could be replicated successfully with high yield. The accuracy of the molded chips and the stability of the molding process were verified by statistical analyses of the geometry (topographic and microscopic methods) taking samples out of several production runs. Chip quality was then proven by manufacturing the functional chip via bonding and functional qualification at MyCartis.

We acknowledge partial funding by the Austrian funding agency FFG within the "Folien-Chips" Project No. 851017.

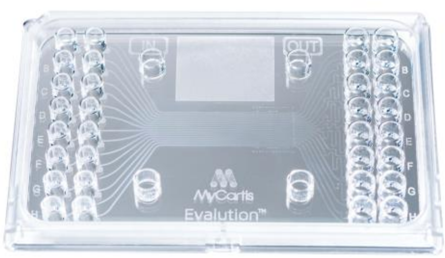

Fig. 1: Evalution™ chip.

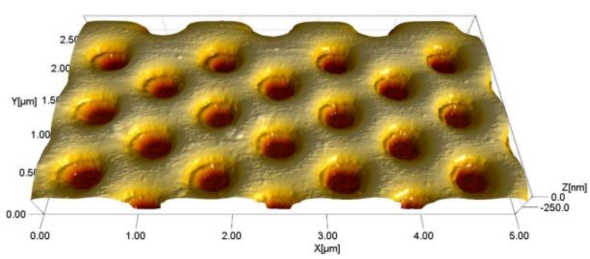

Fig. 2: Nanostructure pattern for metal enhanced fluorescence

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Zero-added manufacturing cost and passport-grade security solution for rigid plastics

V. Auzelyte[1,2], E. Marguet[3], D. Wyssen[3], V. Savu[1,2], J. Brugger[2]

[1] Morphotonix S.à.r.l., Chemin de la Raye 13, 1024 Ecublens, Switzerland
[2] EPFL, Microsystems Laboratory 1, 1015 Lausanne, Switzerland
[3] HES-SO, University of Applied Sciences and Arts Western Switzerland, 2610 Saint-Imier

Protecting products against counterfeits means raising the counterfeiting effort and cost barrier to physically replicate the original. For high-volume plastic items, security labels are complex to authenticate by the consumer and require energy consuming labelling processes. For functional molded parts in the medical, healthcare, and technical fields, additives like nano-taggants require extensive regulatory hurdles or are just simply altering the product's functionality. We present results of nano-patterning free-form steel tools for replication into plastic via molding with no additional production or energy cost, bringing additive-free product-embedded security.

State-of-the-Art technologies of nano-patterning steel tools are limited to semi-flat or cylindrical tool geometries. They are usually accompanied by dimensional constraints of the nano-features which require longer injection cycle times and too short a tool lifetime for industrial applications. We are presenting the most recent results of nano-patterning curved steel tools with complex diffractive patterns and tool life-times compatible with industrial conditions [1]. Four steel cavities were nano-patterned and then replicated in "pills" of various plastics for over 100,000 cycles [Figure 1]. The patterns' complexity ensures a high-security against replication and their dimensions allow a seamless integration in production [2].

The rigorous dimensional analysis of the replication quality and ageing rate will bring an additional data point to the scientific community, paving the way to a deeper understanding of molding at the nano-scale, with a wide range of applications based on various surface functionalities [3].

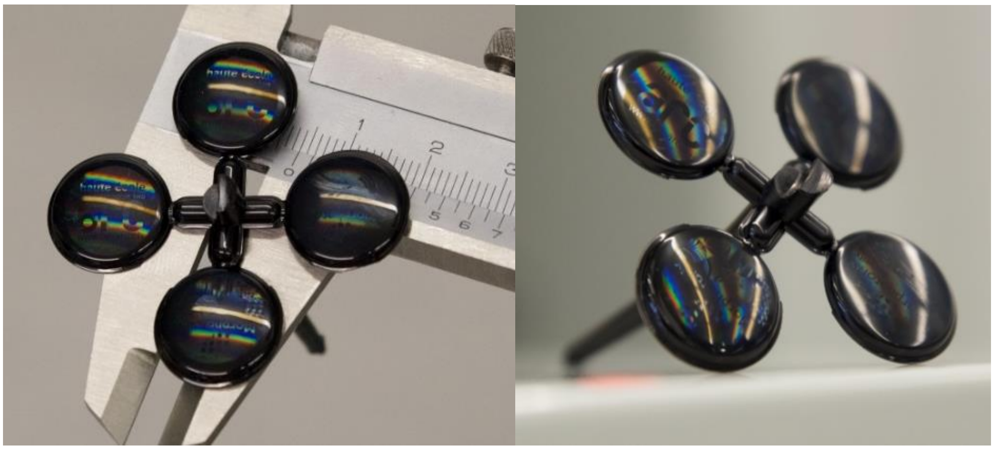

Figure 1: Injection molded curved "pills" with diffractive security elements replicated from nano-engraved steel tools

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3. http://www.innovaud.ch/fr/actualites/actualite-details/innovaud-connect-plastiques-plasturgie-et-composites/c69cf506ed0018d6e7a9b0a652e69852/

Fabrication and Applications of Injection Molded Micro-Micro Hierarchical Structures

Y. Jiang, L. Ammosova, K. Mielonen, M. Suvanto, T. A. Pakkanen

Department of Chemistry, University of Eastern Finland, Joensuu, Finland

Extensive studies have been performed in the aim of fabricating hierarchical surface structures inspired by nature. The synthetic hierarchical structures normally have to sacrifice the mechanical resistance to the functionality by introducing finer scaled, however, less durable structures. Surface pillars with micro-micro hierarchy has been proven to be effective in replacing micro-nano hierarchy in the sense of superhydrophobicity [1]. Nevertheless, less attention has been paid on the micro-micro hierarchies with surface pillars and pits incorporated together. The fabrication of this type of hierarchy may be less straightforward, with the possibility of being a complicated multistep process. Therefore, potential applications of the sophisticated surface structures are still quite uncertain.

Previously, a simple yet mass producible fabrication method were reported for hierarchical structures with different combinations of surface pillars and pits [2]. The prepared polymer structures exhibited enhanced mechanical durability and a relatively stable Cassie-Baxter state. Hence, horizontal water sliding tests are designed to explore the potentials of both half-pipe and half-cylinder shaped samples with different micro-micro hierarchical structures. In addition, with precisely controlled robot painting needles, various metal nanoparticle precursors are able to be selectively deposited on various geographies. Then low temperature sintering would generate metal nanoparticle micro-patterns on the polymer substrate *in situ*.

The water sliding tests of the micro-micro hierarchical structures give promising drag reduction results, which can be applied to practical applications such as types and skis. The metal nanoparticels introduce chemical variants, thus, add a fourth dimension to the 3D polymer surface structures. The 4D anisotropies on polymer surfaces would further expand the potential applications of the traditional polymer surfaces.

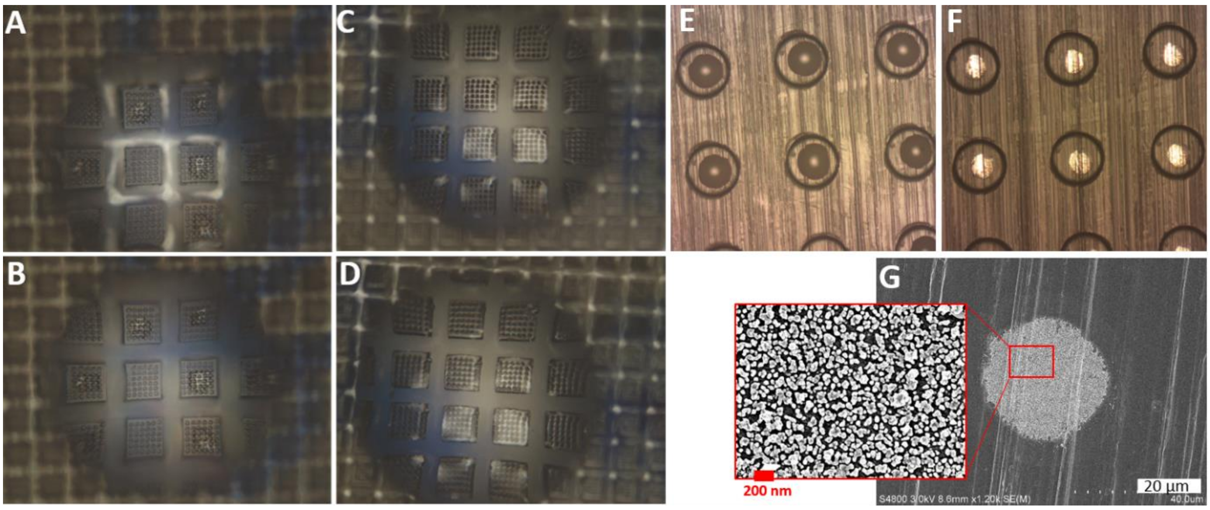

Figure 1: Comparison of optical microscopic images of a water droplet on different surface structures after (A and C) 30 s and (B and D) 5 min. Optical microscopic images of (E) deposited silver precursor and (F) sintered silver nanoparticle patterns. (G) SEM images of sintered silver nanoparticle pattern.

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Industrial Replication Technologies II

Chair: Christian Rytka (INKA FHNW, Switzerland)

11:20-11:40 Clemens Holzer (Montanuniversität Leoben, Austria)

"Instrumented injection mold for the measurement of demolding energies of micro-structured parts"

11:40-12:00 Kati Mielonen (University of Eastern Finland)

"Curved hierarchically micro–micro structured polypropylene surfaces by injection molding"

12:00-12:20 Swathi Murthy (DTU, Denmark)

"Systematic study of high throughput fabrication of nano holes and nano pillars in polymer foils by roll-to-roll-extrusion coating"

12:20-12:40 Henrik Pranov (Heliac A/S, Denmark)

"Large scale nano and microstructured polymer foil production for the Concentrated Solar Power industry"

Instrumented injection mold for the measurement of demolding energies of micro-structured parts

T. Struklec[1]*, T. Lucyshyn*[1]*, C. Holzer*[1]

[1] Montanuniversitaet Leoben, Leoben, Austria

Modern medical applications attempt to scale down entire diagnostic laboratories to a single polymer chip the size of a credit card [1]. This is an enormous challenge for the manufacturing process because very small structures have to be realized. The demolding of the polymer part containing these structures in the injection molding process is often the bottle neck for the part quality. Structures can be damaged and in some cases the continuous manufacturing process can be disturbed. Understanding the demolding is therefore essential for the final part quality. To analyze this step, a special measurement device (figure 1) has been developed [2]. Using this measurement tool, demolding forces can be measured in a reproducible way under process conditions. Demolding energies are calculated from this force. The demolding energy is shown to be an important indicator for the demolding step where lower energies mean better demolding and therefore less risk of damage to the part. The measurement device was used to investigate four influencing factors that affect the demolding step: polymer, geometry, mold surface and process conditions. Concerning the polymer, three thermoplastic polymers, one thermoplastic elastomer and two polymer blends were tested. To investigate the geometry, four different micro-structures in six configurations were tested. To look into the effect of the mold surface, several different coatings were tested to understand how different surface properties affect demolding. Finally, for the injection molding process, specifically the temperature management for the demolding step was emphasized. The investigations showed that there is not one coating ideal for all polymers but different suitable coatings for each investigated polymer. Poly(methyl methacrylate) (PMMA) works well with titanium nitride (TiN) while TiN does not improve the demolding of cyclo olofin polymers (COP). The placement of the micro-structure is also important, especially in combination with the process settings. High mold temperatures increase the demolding energy which can add to the effect of an unsuitable structure placement. Due to the complexity of the interactions improving the demoldability is not a straight forward process. Using this measurement device, suitable coatings for the application and polymer can be found easily. Additionally, an optimization of the processing parameters can be performed, reducing the number of substandard products.

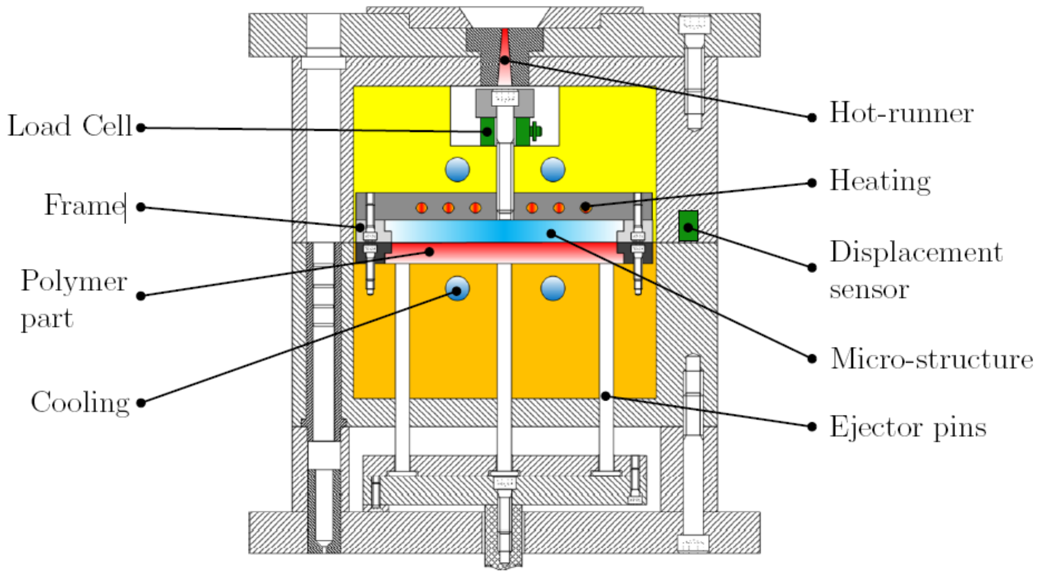

Figure 1: Schematic overview of the instrumented injection mold for the measurement of demolding energy [2].

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Curved Hierarchically Micro−Micro Structured Polypropylene Surfaces by Injection Molding

K. Mielonen, M. Suvanto, T. A. Pakkanen

Department of Chemistry, University of Eastern Finland, Joensuu, Finland

Structured superhydrophobic polymer surfaces have been widely studied and developed through several decades, but similarly functionalized curved surfaces have received less attention. The fabrication methods applicable to the planar surfaces can hardly be straightforwardly applied to corresponding curved surfaces. Additionally, micro−micro hierarchical surface structures have been demonstrated to withstand more pressure and wear than micro−nano structures, both still exhibiting superhydrophobicity.[1]

The fabrication method for curved hierarchically micro−micro structured polymer surfaces has been developed. The method is comprised of a precisely controlled mold structuration and polymer replication by injection molding, and it enables spherical and groove-shaped surfaces with various degrees of curvature. The wettability of the curved polymer surfaces can be adjusted by controlling the structure dimensions.

The capability of producing curved polymer surfaces with mechanically robust hierarchical structures may widen the field of surface research, and such surfaces may find use in yet unexpected applications.

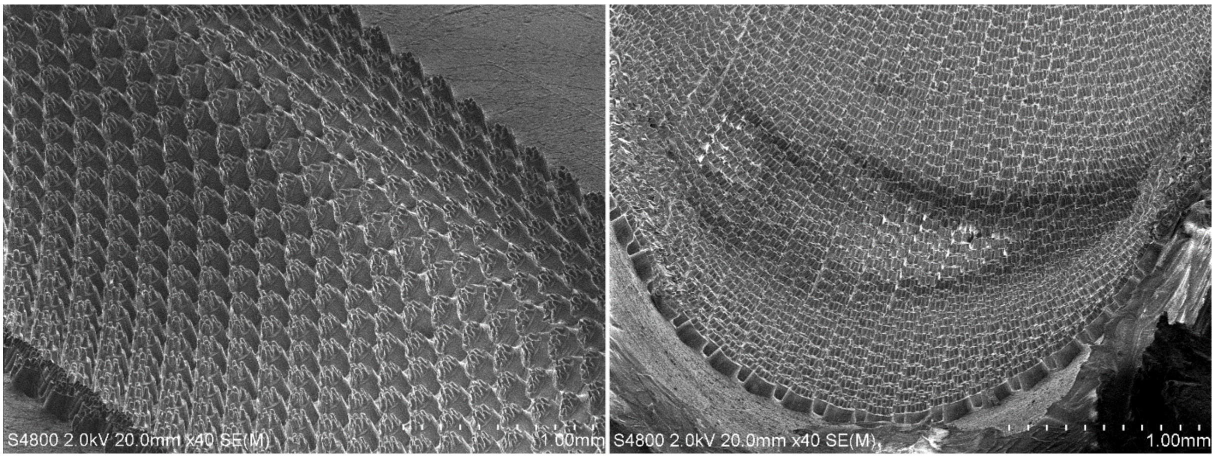

Figure 1: Groove-shaped hierarchically micro−micro structured polypropylene surface depicted from two different angles of view.

Reference

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Systematic study of high throughput fabrication of nano holes and nano pillars in polymer foils by roll-to-roll-extrusion coating.

S.Murthy[1,2], H. Pranov[1], H. Pedersen[2], R.Taboryski[3]
1. InMold A/S, Gregersensvej 6H, DK - 2630 Taastrup, Denmark
2. Department of Photonics Engineering, Technical University of Denmark
3. Department of Micro-Nanotechnology, Technical University of Denmark
E-mail: <smurthy@fotonik.dtu.dk>

Development of large area roll-to-roll (R2R) nanostructuring methods are driven by memory storage devices, hologram security stickers, flexible electronics, graphene electrodes, and organic solar cells. The most established technology is roll-to-roll UV-assisted nanoimprint lithography (R2R-UVNIL)[1]. This method is limited in the choice of materials due to the requirement of photo-curability. The throughput for current R2R-UV-NIL systems is ~0.2m^2 s^{-1}. Another widely used technology is R2R hot embossing (R2R-HE)[2]. Implementing R2R techniques, for large area nanostructuring of functional biomimetic surfaces such as superhydrophobic, anti-reflective, structural color effects is a challenge today due to the relatively low throughput of R2R-UVNIL and R2R-HE. This paper investigates a novel R2R process for nanostructuring, known as roll-to-roll extrusion coating (R2R-EC), having productivity rates, potentially, exceeding 5$m^2$$s^{-1}$ (Figure1)[3].

In this investigation, the structured roller was made by mounting a nano- structured Nickel (Ni) shim onto the cooling roller (Figure 1). The Ni shim was fabricated by standard DEEMO process[4], with the Si master fabricated by e-beam lithography and deep reactive ion etching. Here we report on the replication of both nano holes and nano pillars in different thermoplastic polymers. Different sets of processing parameters were studied to assess their influence on the replication fidelity, specifically, the influence of cooling roller temperature, line speed and counter roller force (example in figure 2). Our Initial studies indicate Polypropylene (PP) replicates the best for the parameter range used in the investigation. However, the process parameters had to be tightly optimized to achieve complete replication. So far, nanostructures down to 80nm have been successfully replicated, with high fidelity, by this process. The limiting factors for proper replication were found to be the surface tension induced radius of curvature of the polymer melt and the retardation time for crystallization of the polymer melt.

Figure 1

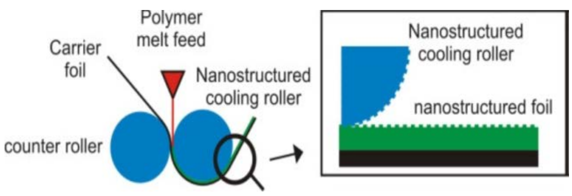

Figure 1: Schematic of R2R-EC. Polymer is heated to a high temperature, such that it achieves a desired low viscosity. Simultaneously, pressure is applied by the counter roller against the structured cooling roller, which is kept well below the solidification temperature of the polymer, forcing the polymer melt deeply into the nanostructures. The structured foil is subsequently wound up.

Figure 2

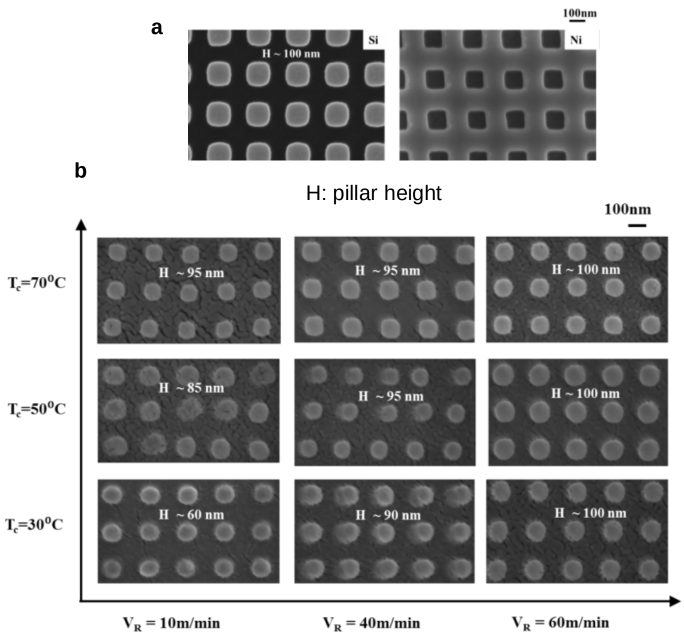

Figure 2: (a) SEM images (top view) of the Si master (e-beam lithography and deep reactive ion etching) and there after electroplated Ni shim. (b) SEM images (top view) of nano pillars replicated in PP by extrusion coating at different line speed (V_R) and cooling roll temperature (Tc), at counter roll force of 30 kN/m. An improvement in replication was observed by increasing Tc and V_R. Complete replication was achieved for V_R: 60m/min and Tc: 70^0 C.

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Large scale nano and microstructured polymer foil production for the Concentrated Solar Power industry

H. Pranov[1] , M. Matschuk[1], P. Johansen[2]

[1] Heliac Aps, Hørsholm, Denmark
[2]Danapak Flexibles A/S, Slagelse, Denmark

Micro and nanostructures can be used to efficiently guide light, which is the objective of Concentrated Solar Power (CSP). However, in order to make a feasible concept for the CSP industry, the cost needs to be low, the throughput high and the quality acceptable.

We have deployed extrusion coating using nanostructured rollers as prior reported [1] to create large area Fresnel microstructure reflective lenses and large areas of highly transparent, anti-reflective nanostructures, thereby demonstrating the ability of the extrusion coating process to fabricate several square meters of micro- and nanostructures per second.

By using micro and nanostructured planar surfaces to guide the light instead of a curved macroscopic geometry, we have shown that cost of CSP can be lowered significantly to a level where it can directly compete against power produced by fossil fuels.

The cost reduction mainly comes from the lower requirements for precision of components and the lower cost of planar components as compared to traditional CSP that relies on e.g. curved parabolic mirrors. Furthermore, the concept allows for easy 2D focusing of the light, further reducing the need for high precision focusing of the light in each dimension.

The first demonstration plants using the manufactured foil has been build using automated solar tracking, validating the technology as well as the current and potential cost reductions involved. Current cost of heat is around 300€/kWp installed, and short term reductions in the cost is estimated to bring this number below the 100€/kWp mark. As reference for traditional CSP installations cost is expected to be around €1000/kWp thermal installed over the next 5 years [2].

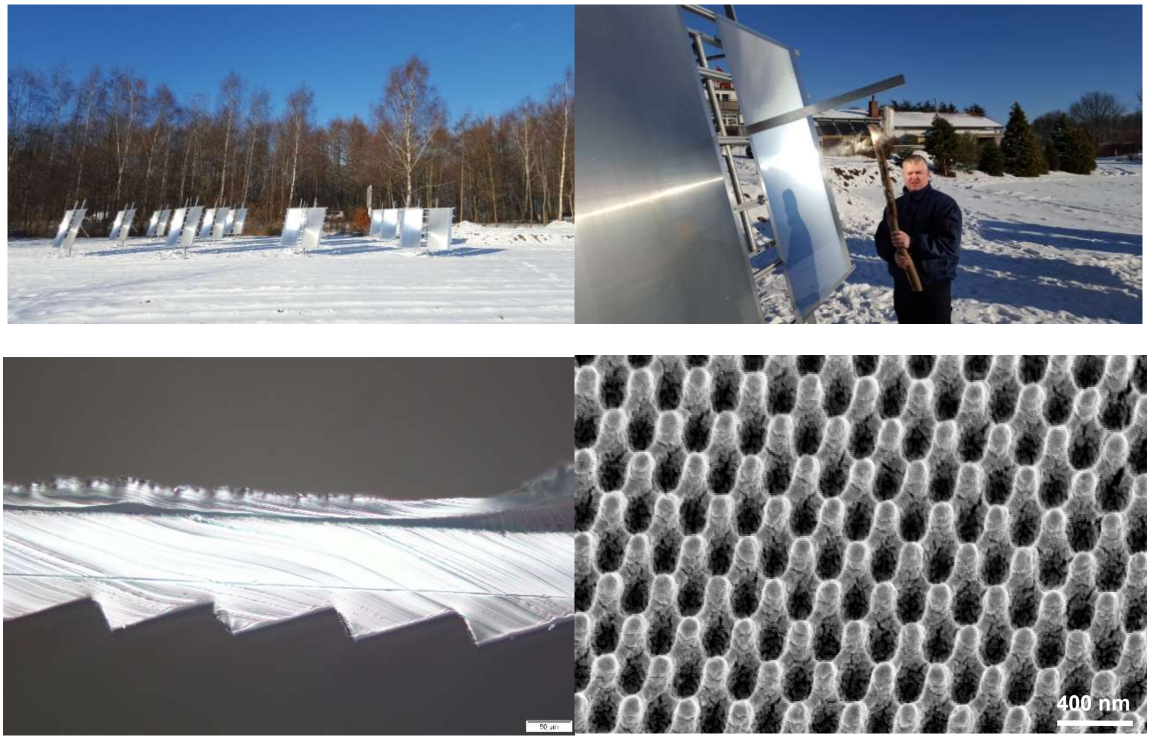

Figure 1: Top: First demonstration plant using micro and nanostructured polymer foil to concentrate sunlight. Bottom: Micrographs of the foil structures, Fresnel lens microstructures (left), Highly transparent index gradient nanostructures (right, masters made by Temicon GmbH).

References

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2. Cost projections from the Ouarzazate solar power station projects in Morocco

Simulation & Applied Nanostructures

Chair: Rafael Taborisky (DTU Nanotech, Denmark)

14:10-14:40 Invited: Hayden Taylor
(University of California, Berkeley USA)

"Computationally inexpensive, multi-scale simulation of polymeric embossing and imprinting"

14:40-15:10 Invited: Victor Cadarso (INKA PSI, Switzerland)

"Photonic nanofences: Fabrication challenges of high aspect ratio polymeric nanostructures"

15:10-15:30 An Eng Lim
(Nanyang Technological University, Singapore)

"Effects of nanostructured surfaces on electro-osmotic flow"

15:30-15:50 René Hensel (Leibniz INM, Germany)

"Engineering of bio-inspired fibrillar dry adhesives"

15:50-16:00 Closing by Per Magnus Kristiansen
(INKA FHNW, Switzerland)

"Polymer Replication on Nanoscale – quo vadis?"

Computationally inexpensive, multi-scale simulation of polymeric embossing and imprinting

Hayden Taylor

Department of Mechanical Engineering, University of California, Berkeley

We have developed a set of extremely fast computational techniques for simulating the imprinting and embossing of micro- and nano-scale patterns into layers of polymeric materials. The techniques are scalable to complex geometries containing many millions of features and can be used to guide the design of processes for manufacturing microfluidics, integrated circuits, photonics, and functional surfaces.

Conventional techniques for simulating imprinting and embossing include finite element modeling, which is excellent for studying feature-scale effects but not readily scaled to the complex patterns of complete integrated circuits, for example. Meanwhile, simplified solutions of the Navier-Stokes equations offer much faster simulation but have been demonstrated only for Newtonian resist models. Our method offers yet faster simulation speeds and the capability to model the embossing of any linear viscoelastic material.

We encapsulate the polymer's mechanical behavior using an analytical function for its surface deformation when loaded at a single location [1]. The stamp and substrate, meanwhile, are well modeled as linear-elastic and we distinguish between local stamp/substrate indentation and stamp bending, which we find to dominate when the spatial period of the pattern is more than about four times the stamp thickness. Our approach takes a discretized stamp design and finds polymer and stamp deflections in a series of steps. The compliance of the resist is gradually increased with each step, and the algorithm iteratively finds the distribution of stamp–polymer contact pressure that is consistent with the instantaneous compliances of the stamp and polymer. Incremental changes in polymer layer thicknesses are computed at each step by convolving the found pressure distribution with an appropriately scaled version of the polymer's point-load response. After each step, local polymer layer thicknesses and cavity-filling extents are re-evaluated, and the system is re-linearized for the next step. At the final step, the polymer's layer thickness distribution is reported along with the completeness of pattern replication.

We further accelerate the simulation of feature-rich patterns in the following way. We pre-compute relationships between the applied imprinting pressure–time profile and the completeness of pattern replication, for stamps patterned with uniform arrays of a variety of common feature shapes [2]. These relationships are encoded in a dimensionless form. We can then subdivide a given imprinting stamp into a coarse grid of regions, each of which is characterized as being patterned uniformly with features of a particular shape, size, and packing density. A spatially coarse simulation is then conducted.

The first application that I will describe is in the hot micro-embossing of highly entangled thermoplastics, for example for the production of microfluidic devices. Here, we use a Kelvin-Voigt model to approximate the viscoelastic behavior of the material in a rubbery state, and have experimentally calibrated models for three commonly used materials: PMMA, polycarbonate, and a cyclic olefin polymer, Zeonor 1060R [1].

The second application of the algorithms is in nanoimprint lithography (NIL) — in which a thermoplastic film or ultraviolet-curing resin is mechanically nanopatterned in contact with a solid template. NIL offers sub-10 nm patterning resolution with potentially lower capital and ownership costs than competing technologies such as extreme ultraviolet lithography. To be adopted widely in data storage and semiconductor manufacturing, however, NIL's throughput needs to increase and its defect rate needs to fall. Our model of the nanoimprint process can guide this optimization. We have extended the model to describe roller-based imprinting on continuous substrates, capturing substrate-speed and roller-load dependencies. By considering viscoelasticity of the imprinted material, we argue that there is an optimal substrate speed that maximizes the fidelity of imprinted patterns (Fig 1) [3].

Finally, we introduce recent work to model efficiently the directional spreading and coalescence of tens of thousands of picoliter-volume droplets of photocurable resin beneath a patterned imprint template [4]. In this extension of the model, we incorporate the mechanical work done by the surface tension of the resin droplets as they spread beneath the template. In this process, an important concern is to predict the locations of any incomplete coalescence of droplets and our analysis shows that the local curvature of the template at the location where droplets coalesce plays a crucial role in determining whether or not coalescing droplets will entrap gas bubbles (Fig 2). Simulations on a 1 mm grid take ~5 s to run on a standard personal computer; those using a 0.1 mm grid require $\lesssim$5 minutes. This simulation approach thus offers NIL users a rapid method for evaluating ways of achieving production throughput targets of $\lesssim$1 s/field spreading time.

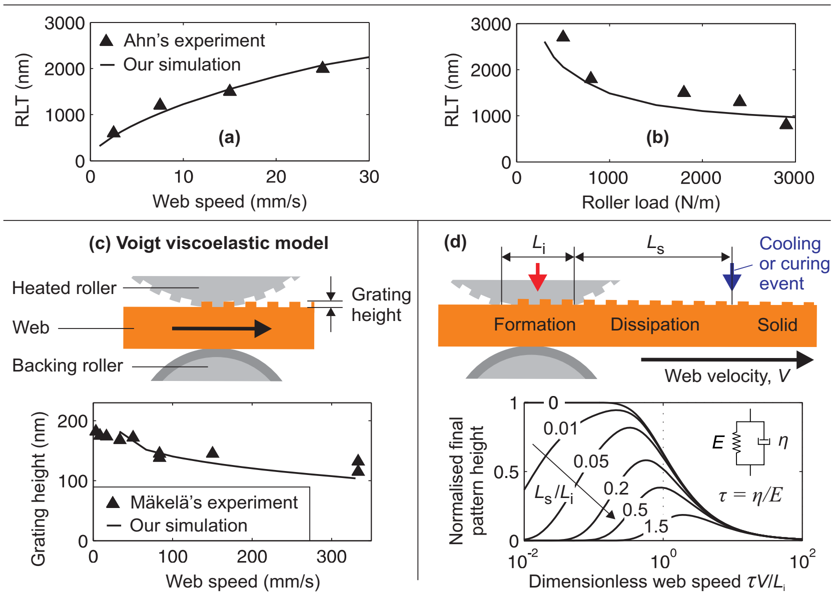

Figure 1: Our technique captures the dependencies of residual polymer layer thickness (RLT) on (a) web speed and (b) roller load seen experimentally by Ahn [5] using a polymeric roller, a solid backing plate and epoxysilicone resist. A Newtonian resist with viscosity 0.8 Pa.s is assumed. Meanwhile, by adopting a Voigt viscoelastic model (c), the technique captures the dependence of an imprinted grating's height on web speed as measured by Mäkelä [6] for a cellulose acetate web heated on one side by a metallic roller. If solidification of the imprinted material finishes after the load is removed (d), pattern dissipation can occur, implying an optimal web speed.

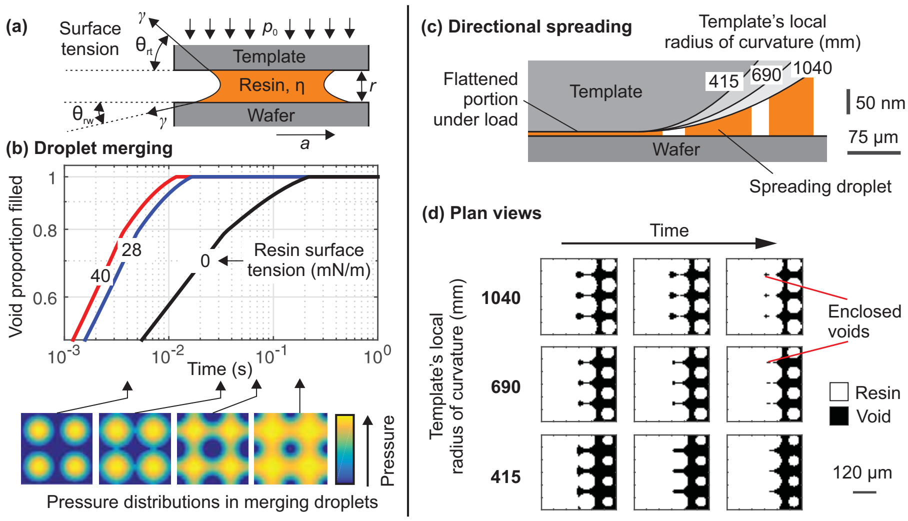

Figure 2. Model for spreading and coalescence of resin droplets beneath a template. Resin deformation (a) is driven by externally applied loads, p_0, and surface tension. For a typical square array (b) of 1 pL, 10 cP-viscosity droplets on a 120 µm pitch, merging beneath a flat template under a load of 40 kPa, capillary pressures are a major contributor to coalescence speed. Directional resin spreading is commonly practiced by inducing elastic template curvature (c). For typical droplet parameters, simulations (d) suggest that a local radius of template curvature of at most ~500 mm is needed at the propagating fluid front in order for droplets to merge without enclosing voids of gas.

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Photonic Nanofences: Fabrication challenges of high aspect ratio polymeric nanostructures

V.J. Cadarso[1], A. Llobera[2], M. Puyol[3], H. Schift[1]

[1] Laboratory for Micro- and Nanotechnology, Paul Scherrer Institut (PSI), 5232 Villigen PSI, Switzerland

[2] Chemical Transducers Group, Institut de Microelectrònica de Barcelona (IMB-CNM, CSIC), 08193 Bellaterra, Spain

[3] Sensors & Biosensors Group, Department of Chemistry, Autonomous University of Barcelona, Edifici Cn, 08193 Bellaterra, Spain

Various applications are requiring and demanding the development of structures that are challenging for classical MEMS technologies. High aspect ratio nanosized structures and three-dimensional (3D) arrangements are among the most challenging. Development of technologies which allow fabricating such structures in a cost-efficient way and potentially for high-throughput replication processes are the key for the applications of tomorrow [1]. In this work we present the development of a novel photonic nanostructure that is based in the use of high aspect ratio (HAR) subwavelength structures to generate large evanescent fields for sensing applications [2]. These structures, labeled as photonic nanofences (PNF), can be arranged in small arrays with each individual PNF separated up to few microns (Fig 1A) to generate an effective optical waveguide (Fig 1B). Such waveguide will allow the confinement of the light in the region of the PNFs, but a large percentage of the light will be in the form of the evanescent field (Fig 1C). This allows an exceptional high interaction between the light coupled to the waveguide and the environment.

PNFs exhibit geometrical requirements to achieve the expected optical performance, optical coupling and confinement. Hence, development of PNFs with widths below 400 nm (for optical wavelengths) and heights above 2 µm is necessary. Fabrication of such HAR nanostructures combined presents a number of challenges that need to be addressed. In order to do this, we have developed two different technologies: i) A fast prototyping method that allows the direct fabrication of the polymeric nanostructures by means of UV lithography and 3D printing by 2 photon polymerization. ii) A high throughput approach, based on nanoimprint lithography (NIL) using very low roughness silicon stamps fabricated by e-beam and cryo-etch and by performing the demolding of the polymeric structures at low temperatures (between -8°C and -15°C) [3]. The former method has allowed the fabrication of PNFs with 200 nm resolution and HAR up to ~40 (Fig 2A). The later has achieved resolutions down to ~45 nm with high yield HAR of up to 8.5 and a maximum of ~17.5. Final devices developed by both methods combined micro and nanostructures made out of Ormocers® materials (micro resist technology GmbH).

Fabricated PNFs were characterized optically considering different array arrangements. Light was effectively in- and outcoupled from the PNFs using micro-sized optical waveguides, as shown in Fig 2B for two bent PNF. The expected high evanescent field generated by the PNF was measured and applied in the development of a sensor for the detection of lead (Pb^{2+}) ions in contaminated water samples. Such sensor was composed of a 7 PNF array embedded in an optical membrane (or optode) formed by a polyvinyl chloride (PVC) matrix that contained a chromo ionophore and an ion sensitive ionophore. This optode is permeable to water and engineered to have maximum absorption for the working wavelength (780 nm) when there is no Pb^{2+} in the samples. Once Pb^{2+} ions are diffused into the optode, the absorbance spectra changes and the optode becomes gradually more transparent resulting in a reduction of the absorbance that is directly related to the concentration of Pb^{2+} in the sample (Fig 2C). This method allowed for the detection of Pb^{2+} with a limit of detection of 7.3 nM using a sensing region of only 500 µm length instead of the centimeters range sensing region typically required for such sensors.

These results demonstrated not only the validity of the proposed nanostructures for sensing applications, but also the capacity of the proposed technologies for both fast prototyping and high throughput fabrication of future polymeric micro and nanosystems requiring high aspect ratio structures.

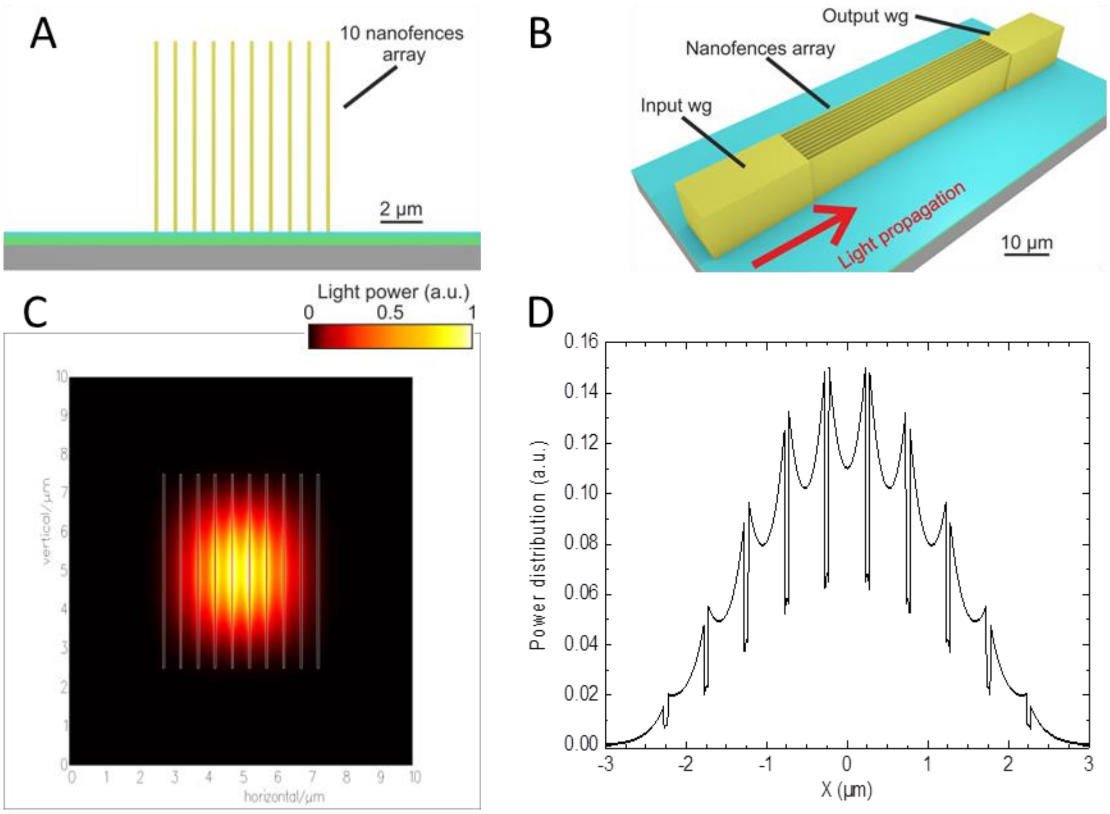

Figure 1: (A) Cross-section of a high aspect ratio nanofences array at scale. (B) Schematic of a PNF array connected to micro-sized input and output waveguides. (C) Simulated fundamental mode (TE00) power distribution. (D) Section of the TE00 power distribution in the array.

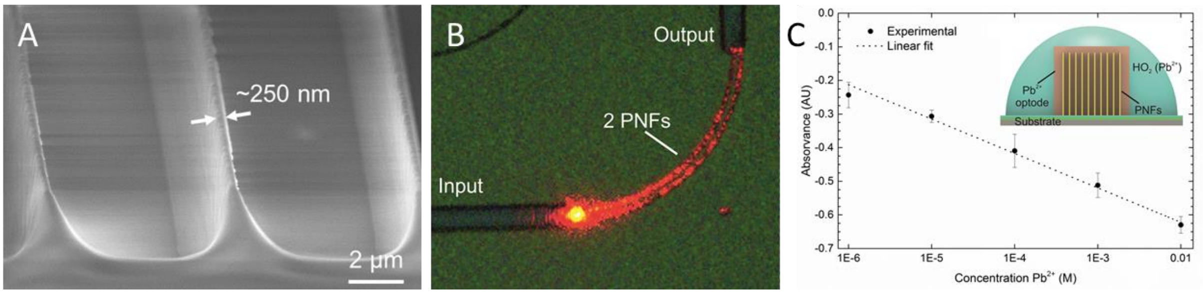

Figure 2: (A) SEM image of a photonic nanofence with HAR ~40. (B) Picture of the light coupling from an input waveguide into a 2 PNFs array with bent shape. (C) Calibration curve of a PNF-based lead (Pb) sensor. The inset shows a cross-section schema of the sensor.

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Effects of Nanostructured Surfaces on Electro-osmotic Flow

An Eng Lim[1], Chun Yee Lim[1], Rafael Taboryski[2], Yee Cheong Lam[1]

[1] School of Mechanical and Aerospace Engineering, Nanyang Technological University, Nanyang Avenue 50, Singapore 639798

[2] Department of Micro- and Nanotechnology, Technical University of Denmark, 2800 Kongens Lyngby, Denmark

Electro-osmotic flow (EOF) is the flow of fluid in a microchannel which is induced by an external electric field. EOF originates from electrical double layer (EDL) formed spontaneously at the channel-fluid interface. The electrostatic potential at the channel wall is called the zeta potential. Nanostructures have been employed in microfluidic channels for electrophoretic separation of biomolecules [1] and catalytic reaction which yields higher reaction efficiency due to the increased surface area [2]. However, the effect of nanostructured surfaces on EOF has yet to be fully understood. In this preliminary investigation, we demonstrate experimentally that the presence of nanostructured surfaces affects EOF significantly.

Microchannels (cross section of 3.9/6.5/33µm x 100µm and length of 5cm) with nanostructures on the bottom wall were fabricated by a series of steps that can be divided into three phases; fabrication of the master structures on a silicon (Si) wafer, creating of mold insert via electroplating and injection molding with Cyclic Olefin Copolymer (COC). The two types of nanostructures employed in our investigation are prolate hemispheroid-like structures (diameter of 130-370nm, height of 100-420nm and spatial distance of 160-560nm) and indented lines (period of 330nm, line width of 180nm and height of 170nm) which are perpendicular or parallel to the EOF direction. Current monitoring experiments were conducted to study the effects of these nanostructured surfaces on EOF behavior.

Zeta potential is an important parameter that dictates the direction and velocity of EOF. The zeta potentials of 1mM sodium bicarbonate ($NaHCO_3$) in microchannels with different nanostructured surfaces were measured with current monitoring method and shown in Fig. 1, and compared to a smooth microchannel. For prolate hemispheroid-like structures, the magnitude of zeta potential is reduced by ~10%. The reduction in the magnitude of zeta potential for perpendicular indented lines is even larger (~30%). However, no significant difference is observed for the case of parallel indented lines. These results reveal that EOF velocity is lowered by the introduction of nanostructured surfaces in certain orientations. EOF originates from the interaction between EDL (nanometer thickness) and the applied electric field. The presence of nanostructures distorts the local electric field at the wall and thus affecting the overall flow velocity.

Precise control of fluid flow is critical in microfluidic lab-on-a-chip devices. Our investigation contributes to the fundamental understanding of EOF behavior in devices which utilize nanostructured surfaces for chemical and biological analyses.

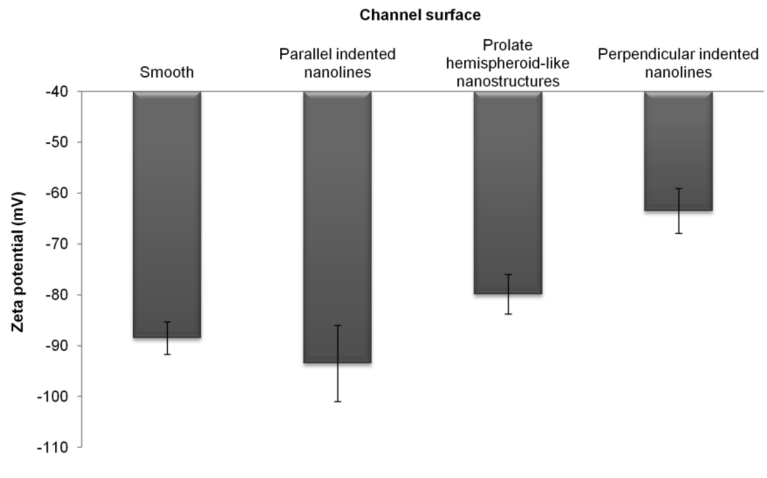

Figure 1: Zeta potential of 1mM sodium bicarbonate ($NaHCO_3$) for microchannels with different nanostructured surfaces, in comparison to smooth microchannel.

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Engineering of bio-inspired fibrillar dry adhesives

René Hensel[1] , *Karsten Moh*[1], *Eduard Arzt*[1,2]

[1] INM – Leibniz Institute for New Materials, Campus D2 2, 66123 Saarbrücken, Germany
[2] Department of Materials Science and Engineering, Saarland University, 66123 Saarbrücken, Germany

INM's Gecomer technology is result of our long-term research, allowing for reliable and reversible adhesion on a wide range of substrate materials. Our solution provides a novel, noise-free system for handling delicate objects even in vacuum. The present work will focus on design principles for fibrillar adhesives obtained from results of numerical and experimental studies. Based on that, demands on large-scale fabrication of those adhesives and their potential for emerging applications will be discussed.

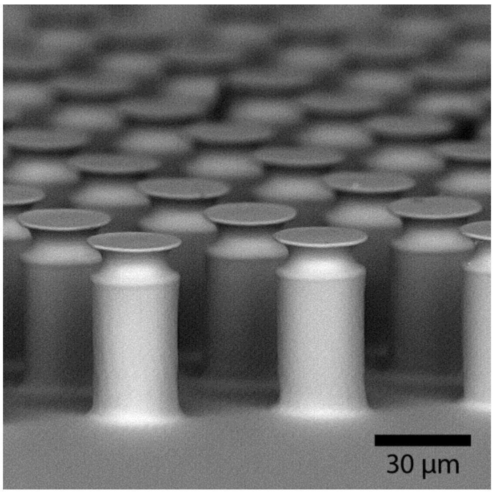

Figure 1: Scanning electron micrograph of fibrillar dry adhesive fabricated via two-photon lithography and subsequent replication into elastomeric material.

Agneszieka Telecka (DTU Nanotech, Denmark)
Superhydrophopic nanostructured polypropylene foils fabricated by roll-to-roll extrusion coating

Maria Matschuk (Inmold S/A, Denmark)
Large-scale fabrication of single and multilayer polymer foils with nano- and microstructures

Robert Kirchner (INKA PSI, Switzerland)
High resolution 3D topographic patterns using grayscale electron beam lithography and thermal reflow

Nicolas Feidenhans (Danish Fundamental Metrology Ltd and DTU Nanotech, Denmark)
Characterization of nanostructures from visual color

Danilo Quagliotti (DTU MEK, Denmark)
Metrology of sub-micro structured polymer surfaces

Matteo Calaon, represented by Danilo Quagliotti (DTU MEK, Denmark)
High throughput polymer micro replication quality assurance using 3D optical high-speed metrology

Nis Korsgaard Andersen (DTU Nanotech, Denmark)
Super hydrophobic microstructures by isothermal injection molding

Celestino Padeste (INKA PSI, Switzerland)
Functionalization of polymer films using lithographic radiation-induced grafting

Jonathan Schmidli (INKA FHNW, Switzerland)
Replication of microstructures in thermoplastic films using wire-cloth as stamp for hot embossing and R2R embossing

Alexandra Kämpfer-Homsy (Univ. Appl. Sci. Western Switzerland)
Fabrication of high transmission microporous membranes by proton beam writing and soft lithography

Jordi Pina-Estany, represented by Andrés-Amador García Granada (IQS Universitat Ramon Llull, Spain)
Fluent solver expanded to the nano-world

Nastasia Okulova (Danapak Flexibles A/S & DTU, Denmark)
Investigating the micro-replication regime for structures produced by an extrusion coating process

Calypso Beloli (Roctool, France)
High Definition Plastics™ Molding by Dynamic Heating

Victoria Manzi-Orezzoli (Paul Scherrer Institute, Switzerland)
Tunable patterned wettability in porous media: Gas diffusion layers for PEFCs

Superhydrophobic nanostructured polypropylene foils fabricated by roll-to-roll extrusion coating

A. Telecka , L. Sun, R. Taboryski[1]

[1] DTU Nanotech, Kongens Lyngby, Denmark

Technologies based on superhydrophobic treatments of artificial surfaces are under a great deal of attention, in both scientific research and manufactory, due to their broad potential applications in industry such as self – cleaning and antifogging materials[1]. Fabrication of superhydrophobic surfaces usually follows two conventions: initial structuring the micro/nanopattern to increase surface roughness and then covering a low surface – energy coating to decrease surface free energy of material.

However, the coating treatment can lead to problems in some practical aspects due to the degradation of organic compounds caused by UV radiation, abrasion or mechanical expenditure. Nowadays commercially available polymers like polypropylenes (PP), polyethylenes (PE) or cyclic olefin copolymers (COC) are widely used for direct patterning as low surface free energy materials with advantages of good functionality, flexibility, chemical stability and ease of processing.

In this paper we present systematic wetting properties study of nanostructured polypropylene (PP), functional foils, fabricated by roll – to – roll extrusion coating process (R2R EC). It is a fast and effective manufacture method, widely uses for smooth polymer films, which allows to large – scale replication of micro – and nanometric scale arrays onto polymer substrates[2]. Metal templates used for patterns imprint were prepared through a one step, maskless, black silicon etching process[3], what led to covering of the whole 4 inch silicon wafer area, and consequent NiV electroplating. By the manipulation of reactive SF_6 and O_2 gas steams, diverse nanograss topographies were generated. Figure 1 presents detailed process flow with images. R2R extrusion was performed under varied imprinting temperatures and extrusion speeds to control nanostructures replication quality. Wetting properties of fabricated PP foils were characterized by contact angle measurements of water sessile drop in static and dynamic method. We recorded values of static contact angles above 150˚ and roll – off angle in a range of 10 - 20˚ what indicates on superhydrophobic surfaces with self – cleaning potential applications.

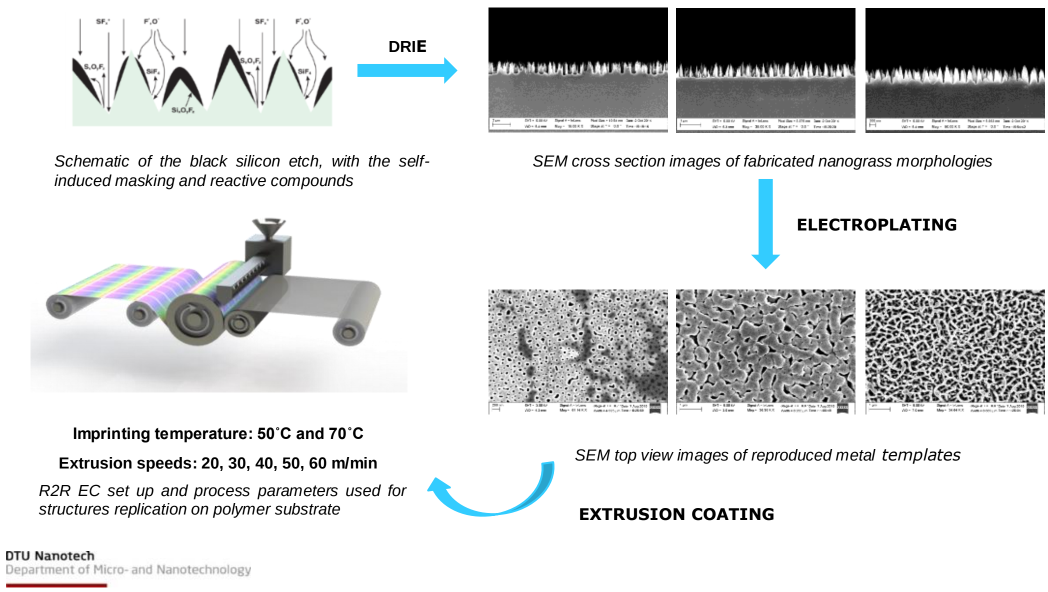

Fig. 1 Process flow

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Large-scale Fabrication of Single and Multilayers Polymer Foils with Nano- and Microstructures

M. Matschuk[1,2], H. Pranov[2], P. Johansen[3]

[1]Inmold A/S, Gregersensvej 6H, DK-2
[2]Heliac Aps, Hørsholm, Denmark
[3]Danapak Flexibles A/S, Slagelse, Denmark

Roll-2-Roll extrusion coating is a versatile technique that allows coating of polymers on various substrate materials such as plastic films, paper, aluminum foil, or non-wovens. Over the last few years, Inmold A/S, Heliac ApS and Danapak flexibles have optimized extrusion coating for the production of single and multilayer films containing nano- and microstructures introducing new functionalities into industrial standard packaging products.

We have previously demonstrated the fabrication of arbitrary nanostructures such as pillars, holes, lines, and spirals with an aspect ratio above unity at a speed of 1 m/s, but also creating functional surfaces such as tactile, superhydrophobic, and omniphobic (with post-functionalization), antireflective, light guiding surfaces, or structural and plasmonic colors. We recently published our results [1] showing that extrusion coating enables the replication of nano- and microstructures using semi-crystalline polymers with appropriate crystallization rate while amorphous polymers such as polystyrene showed no significant replication.

Here we would like to present recent results regarding the replication of surface and embedded nano- and microstructures in single and multilayer polymer films. The simultaneous replication of structures with dimensions varying between several tens of nanometers to several tens or hundreds of micrometers can be challenging for injection molding or nanoimprint lithography. Such structures can be replicated by extrusion coating though the height of microstructures is limited by the available film thickness of the extruded polymer, currently up to 100 µm. Besides, we will also show that nano- and microstructures can be replicated consecutively to create multilayer polymer foils with embedded microstructures and surface nanostructures and their application for Concentrated Solar Power (CSP).

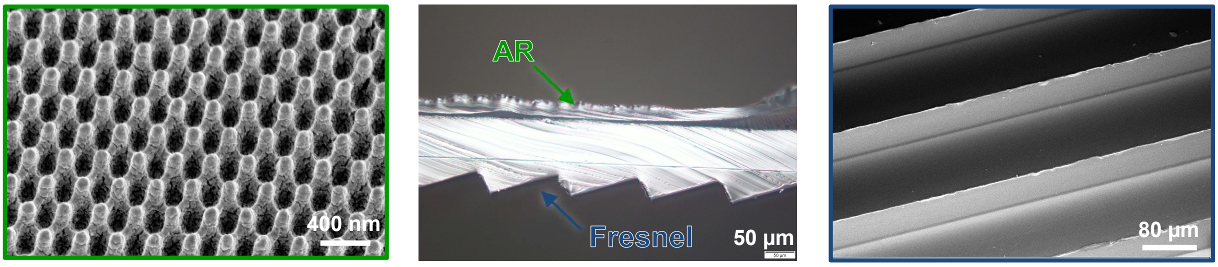

Figure 1: SEM of an antireflective structure in polypropylene (PP) (left, masters made by Temicon GmbH), light microscope image of a multilayer foil consisting of PP/PET/PP (center), and SEM of Fresnel lens microstructures (right).

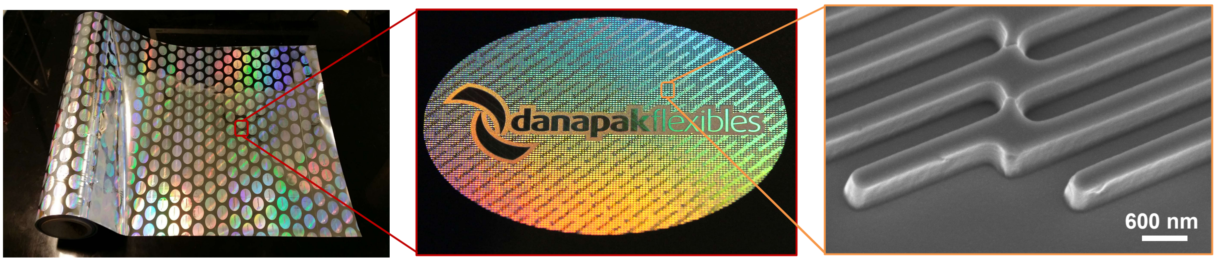

Figure 2: Photo of a single layer foil presenting a holographic logo for Danapak flexibles A/S (left), a magnified photo (center), and a respective SEM showing an about 500 nm wide and 650 nm high line grating in PP (right).

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High resolution 3D topographic patterns using grayscale electron beam lithography and thermal reflow

R. Kirchner and H. Schift

Paul Scherrer Institut, Laboratory for Micro- and Nanotechnology, 5232 Villigen PSI, Switzerland

Techniques such as nanoimprint lithography or injection molding are ideal to replicate complex original 3D polymer patterns with unchallenged resolution for high volume manufacturing [1]. Promising applications are optics, photonics, fluidics and bio-mimetics. The major challenge is the fabrication of the 3D replication masters with a high fidelity.

We propose a high resolution electron beam grayscale lithography approach combined with an efficient thermal post-processing to fabricate high-precision topographic patterns [2]. We realized 3D patterns down to 200 nm resolution in poly(methyl methacrylate) (PMMA) and in two similar commercial resists: ZEP520A (ZEON Corp.) and mr-PosEBR (micro resist technology GmbH). We show that electron beam grayscale pattern profiles are independent of the used resist. However, to better control pattern precision, a low-contrast resist is favored. The realized structures range from the micro- to nano-regime (Fig. 1). Thermal post-processing is based on the energetic self-optimization of a polymer topographic feature while being held above its glass transition temperature [2,3]. By carefully controlling the post-processing temperature and time, the polymer re-shaping can be precisely tuned (Fig. 2). Compared to PMMA, ZEP520A demonstrated a similar grayscale patterning performance. However, its major advantage is the higher sensitivity allowing for at least two times faster electron beam writing. Reflow temperatures of ZEP520A are much higher (140-150°C) than for PMMA (110-120°C) yielding improved temperature stability of resist patterns. ZEP520A behaves similar to PMMA during electron beam exposure: the molecular weight and thus the glass transition temperature are reduced due to electron induced chain-scission. This helps reflowing selectively only certain exposed regions.

ZEP 520A is a very promising material for combined grayscale patterning and selective thermal reflow. It offers important advantages over PMMA resists. The described grayscale and reflow method is an efficient route to make original polymer patterns for replication of final mass-replicated products.

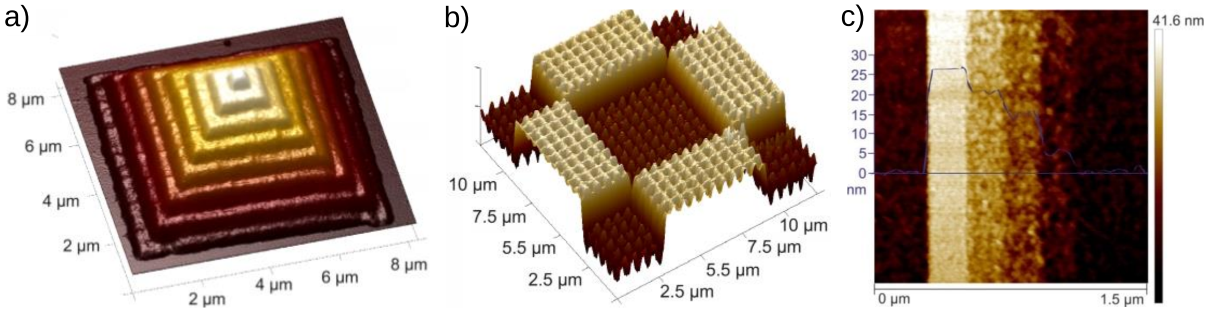

Figure 1: Atom force microscopies of grayscale patterns: a) 9-level pattern for diffractive optics, b) hierarchical structure for bio-mimetics, c) 6-level patterns with 6 nm steps.

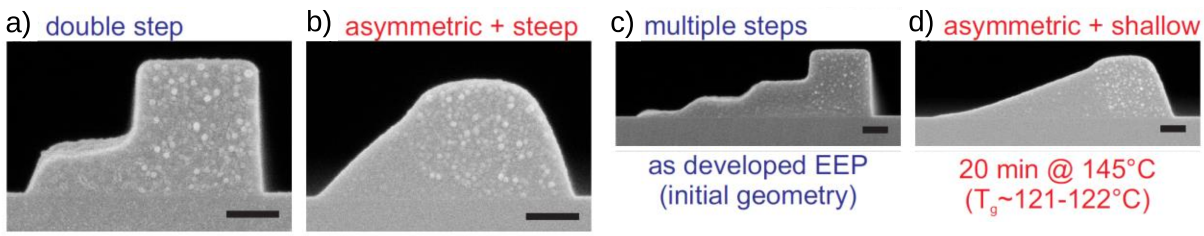

Figure 2: a),c): Grayscale topographies after exposure and development. b),d): the same topographies after reflow and re-shaping due to energy self-optimization. (all scale bars 200 nm)

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Characterization of nanostructures from visual color

N.A. Feidenhans'l[1,2], M.H. Madsen[1], P.-E. Hansen[1], J.C. Petersen[1], R. Taboryski[2]

[1] Danish Fundamental Metrology Ltd., Kgs. Lyngby, Denmark
[2] Technical University of Denmark, DTU Nanotech, Kgs. Lyngby, Denmark

Characterization of micro and nanoscale structures is often time consuming, as it requires inspection with rather slow tools such as AFM or SEM. Consequently, when optimizing manufacturing processes, the characterization time is often the limiting factor for the number of evaluated process parameters. This work presents a fast and simple inspection method based on scatterometry.

In scatterometry, the reflection spectrum from a sample is compared with a set of simulations by inverse modeling. By simulating many variations of structure dimensions, the actual values can be determined with nanometer precision [1]. Typically a spectrometer is used to obtain the average spectrum from a larger area of homogeneous structures, where the area is defined by the illumination spot size. We present a new method, where only the reflected color is evaluated with a standard CMOS color camera, compared to capturing the entire spectrum. This provides an overview image of the sample, from which smaller areas later can be extracted, and each area analyzed separately by fitting to the simulated colors. The technique provides a fast and easy quality control of periodic micro and nanoscale structures, with precisions in the nanometer range.

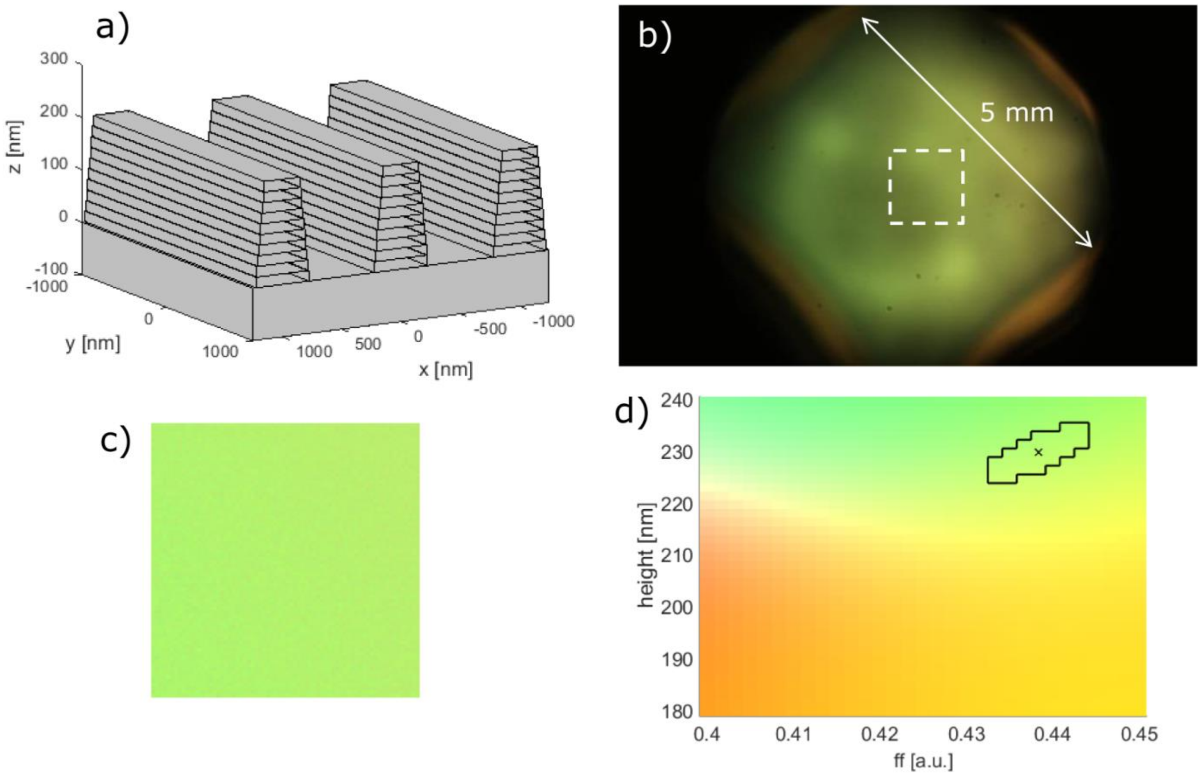

Figure 1: a) Illustration of the simulation setup for a line grating. **b)** Color image of sample with line gratings, white square represent analyzed region. **c)** Cropped region from b), with colors scaled to correct non-uniform light intensities. **d)** Output from the fitting process. Each color corresponds to a simulation with different heights and filling factors. The black cross is the optimum fit, while the surrounding black lines indicate the 95% confidence limits.

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Metrology of sub-micro structured polymer surfaces

D. Quagliotti[1], G. Tosello[1], J. Salaga[1], F. Baruffi[1,3], H. N. Hansen[1], S. Gasparin[2]

[1] Technical University of Denmark, Department of Mechanical Engineering, Kgs. Lyngby, Denmark
[2] The LEGO Group, Billund, Denmark
[3] Politecnico di Milano, Dipartimento di Ingegneria Meccanica, Milano, Italy

Precision moulding is an essential technology for the miniaturisation of moulded parts and it is continuously needing for specially developed solutions to face new challenges in injection moulding (IM) processes.

One of the key challenges in advanced IM technology is the achievement of a full surface replication of the tool insert component when moulding the polymer melt [1]. This aspect is particularly critical when dealing with increasingly small dimensional scales in micro- and nano-structured surfaces [2, 3].

In this context, a metrological investigation of polymer replicated surfaces using metal masters with different types of finish has been carried out.

Four types of surface finish were considered: a) Diamond buff polishing. b) Grit paper polishing. c) Stone polishing. d) Dry blast polishing (see Fig. 1). Both master and replicated surfaces were measured using a laser scanning confocal microscope. Hence, the replication fidelity was evaluated comparing the measurements of the polymer surfaces against the ones of the masters. The amplitude and the slope replications were considered calculating respectively *Sq* and *Sdq* areal surface texture parameters. The expanded uncertainty was also evaluated according to ISO 15530-3:2011, adapted to optical measurements, and propagated to the replication fidelity.

A good amplitude replication was achieved for stone polished surfaces with a replication fidelity larger than 90 %. The dry blast ones were evaluated with an amplitude replication fidelity of about 70 %. The worst amplitude replication was achieved for both diamond buff and grit paper polished surfaces with a replication fidelity around 50 %.

The tendency is almost the same for slope replication but the replication fidelity values are lower: 70 % for stone polished surfaces. 50 % for dry blast and grit paper polished surfaces. 30 % for diamond buff polished surfaces.

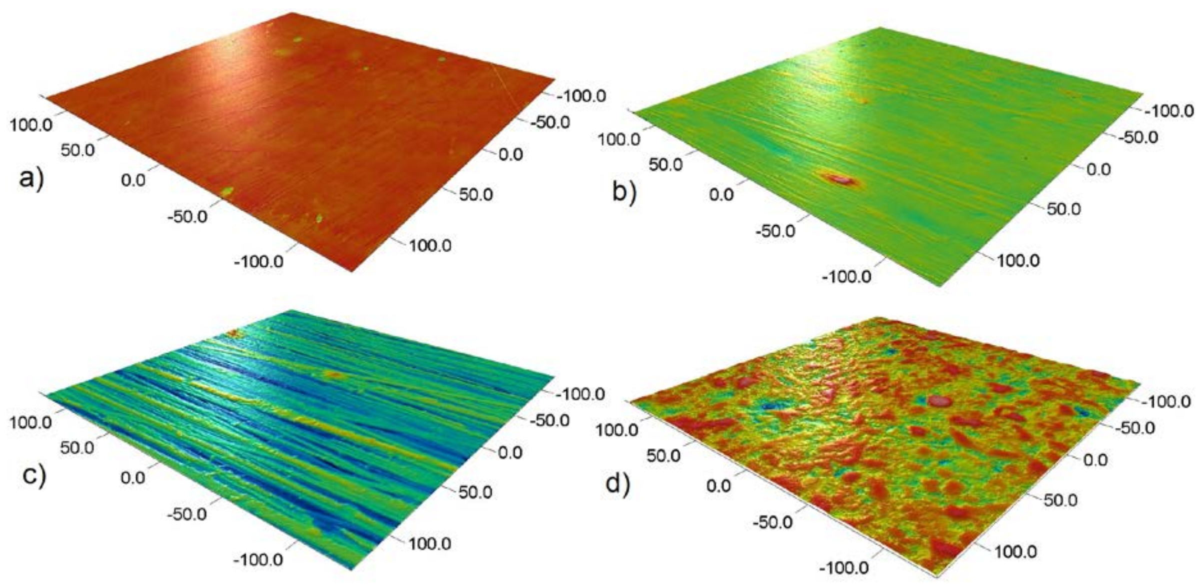

Figure 1: Examples of replicated surfaces using different surface finish of the masters. a): Diamond buff polishing. b): Grit paper polishing. c): Stone polishing. d): Dry blast polishing.

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High throughput polymer micro replication quality assurance using 3D optical high-speed metrology

Matteo Calaon[1], Guido Tosello[1], Hans N. Hansen[1], Manfred Prantl[2], Stéphane Dessors[3], Tobias Mueller[4], Steffen G. Scholz[4], Nathan Miller[5]

[1] Technical University of Denmark, Department of Mechanical Engineering, Denmark.
[2] Alicona Imaging GmbH, Raaba, Austria.
[3] IPC, Innovation Plasturgie Composites, Bellignat, France.
[4]Karlsruhe Institute of Technology, Karlsruhe, Germany.
[5]Flann Microwave Limited, Cornwall, United Kingdom.

Mass fabricated products either in the form of micro three-dimensional parts or for larger components with micro/sub-micro structured surfaces have been developed, produced and implemented into many products in different sectors [1,2]. The present study applies ultimate focus variation optical technique for injection-molded process and part micro/sub-µm repeatability evaluation. The system design integrates data acquisition and analysis for each measurement location establishing the base ground for non-contact in-line measuring capabilities.

The approach is used to assure critical features dimensional conformance within product design tolerance specification. Design of experiment was adopted to design injection molding runs aimed to identify most effective process parameters responsible to geometrical part dimensional variation. Different sub-mm critical geometries in the form of waveguides flanges, splitting junction and filter sections integrated in passive micro microwave components for point-to-point communications for short-range high capacity urban mobile backhaul were dimensionally characterized.

Results of more than 3000 semi-automated measures covering the total number of sample produced within the DOE are collected and analyzed. For each measurement location two 3D geometries reconstructions are performed with 50% scan overlapping to ensure high image resolution. The optical acquisitions for every single location (< 10 s) are processed and results stored for final data analysis. Measurements results expressed as deviation from calibrated mold master geometries were statistically evaluated. The analysis allows for quantification of injection molding process capability verification in terms of product dimensional variation within a range of ± 10 µm. Finally, the study quantifies different polymer behavior on the final structured frame quality/dimension of the microwave component as a function of mold absolute position, distance from the gate and structure orientation in respect of the polymer flow direction.

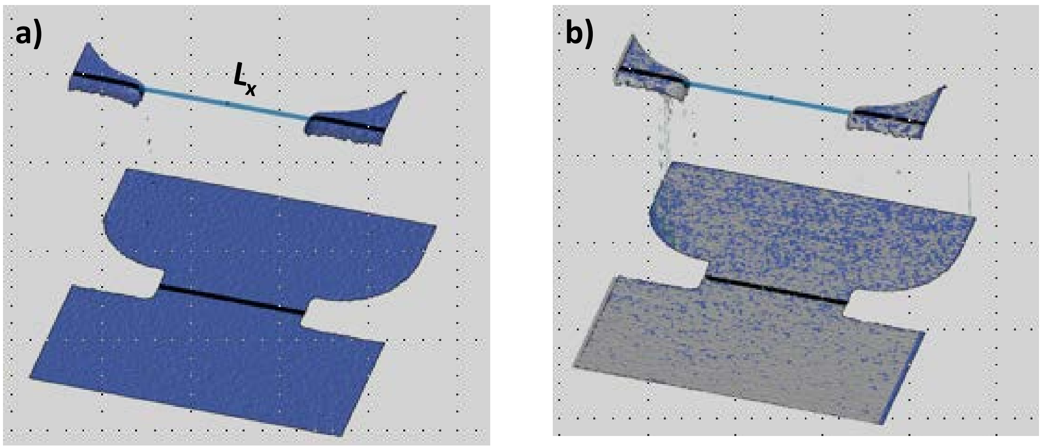

Figure 1: 3D data acquisition (Nominal L_x = 1,105 mm) example of reference part, different for each measurement location; b) actual measurement data automatically aligned to the reference part.

References

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Super hydrophobic microstructures by isothermal injection moulding

Nis Korsgaard Andersen[1], Carl Esben Poulsen[1], Kasper Kistrup[2], Anders Wolf[1],

Rafael Taboryski[1]

[1] Technical university of Denmark, DTU Nanotech, Denmark
[2] Novo Nordisk, Bagsværd, Denmark

In the past decades, there has been an extensive research in the fabrication of super hydrophobic surfaces. The super hydrophobic effect arises from an interplay between surface structures and surface chemistry. Despite many promising results in academia, the adoption of super hydrophobic surfaces in industry is rather limited. To meet the industry needs we present a technique for easy incorporation of super hydrophobic surfaces on injection-moulded parts.

Common design for super hydrophobic structures are hierarchical structures [1], combining micro and nanostructures, inspired by the lotus leaf. These types of structures are unfavourable for injection moulding since the formation of skin layer prohibits the filling of nanostructures on top of microstructures. Here we present injection moulded super hydrophobic surfaces realized only with microstructures by an isothermal moulding process. We use a fast stochastic laser-based process capable of structuring hardened tool steel to define the structures in the mould. The laser process creates hole-like structures in the mould surface resulting in pillar like structures on the surface.

The implementation of microstructures in commercial injection moulding processes requires the production line to optimize for different parameters than previously, not only the filling of microstructures but also evaluation of their effect is very important. This is due to the super hydrophobic effect arising from a drop on the surface being in the so-called Cassie Baxter state. For instance, when gradually increasing the mould temperature we get a nonlinear but gradually increased filling of microstructures. This increased roughness enables the support of the drop in the Cassie Baxter state resulting in an abrupt reduction in the contact angle hysteresis, as seen in Figure 1.

To conclude, we present the fabrication of injection moulded super hydrophobic surfaces realized only with microstructures by an isothermal moulding process and discuss important steps in commercial implementation.

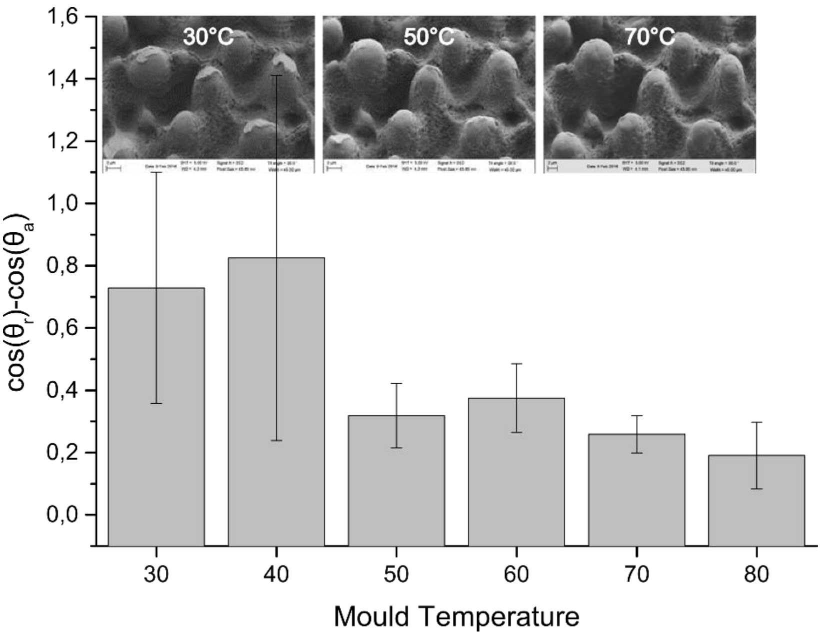

Figure 1: Contact angle hysteresis of surfaces for different moulding temperatures. At 50°C degrees, moulding temperature there is a drastic drop in hysteresis indicating the Cassie Baxter state

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Functionalization of polymer films using lithographic radiation-induced grafting

Celestino Padeste[1], Matthias Dübner[1,2], Sonja Neuhaus[3]

[1] Paul Scherrer Institut, 5232 Villigen PSI, Switzerland, [2] ETHZ, 8093 Zürich, Switzerland,
[3] University of Applied Sciences and Arts Northwestern Switzerland (FHNW), School of Engineering, Institute of Polymer Nanotechnology (INKA), 5210 Windisch, Switzerland.

Radiation-induced grafting is a simple and elegant method to adapt the properties of polymeric substrates via introducing functionalities at their surface or in the bulk. Beams of electrons, photons or ions of sufficient energy may be used to break chemical bonds in a polymer substrate or at its surface in order to create radicals, which act as initiators in a subsequent graft polymerization.

We are combining radiation-induced grafting with structuring technologies in order to chemically modify specific areas on the substrate [1]. While micro- to millimeter sized structures are achieved with large-area activation tools and masking techniques, structures with sub-micrometer resolution can be obtained using extreme ultraviolet (EUV)-interference or electron-beam lithography.

The grafting process is schematically shown in Fig. 1. Samples made from fluoropolymers such as ETFE or Teflon or polyolefins such as polyethylene can selectively be activated to create defined radical patterns. Subsequent exposure to ambient air leads to the stabilization of the radicals as peroxide species, which are stable over weeks to months when stored at low temperatures (-80 °C). Samples are immersed into degassed solutions of monomers (typically methacrylates or other vinyl monomers), which are then heated to 50-80 °C to cleave the peroxides and to start the grafting reactions yielding patterned surface-anchored polymer brushes. The selection of the monomers allows defining the properties of the grafted areas in a wide range [2]. Furthermore, chemical modification of the grafted chains enables further adaptation of properties and the introduction of specific functionalities [3]. Using a series of recent examples, we will demonstrate the high versatility of the lithographic grafting process, which is also applicable to topographically pre-structured surfaces for the creation of functional polymer structures.

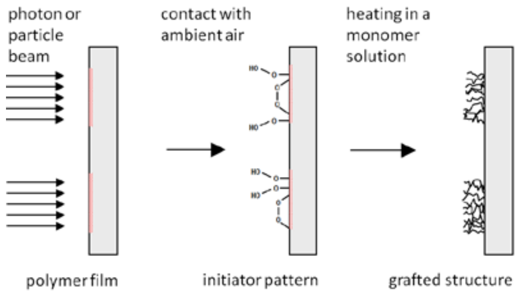

Fig.1: Scheme of lithographic radiation grafting

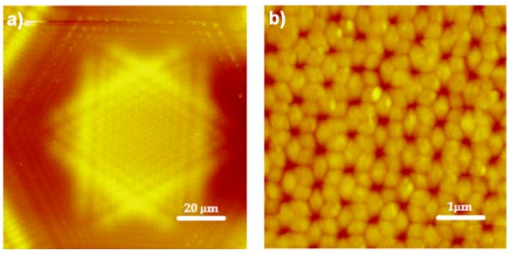

Fig. 2: High-resolution structures obtained with 6-beam EUV-interference exposures

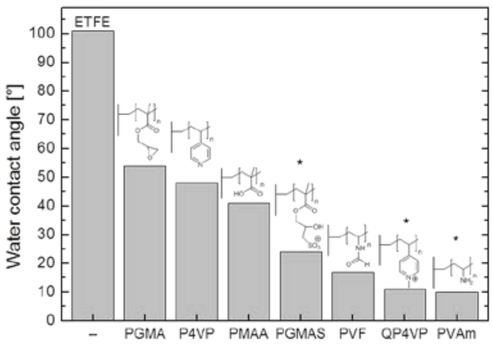

Fig. 3: Adaptation of surface properties of polymers by grafting of polyelectrolytes

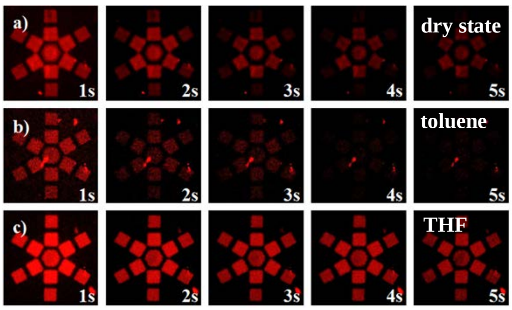

Fig. 4: Fluorescence decay of spiropyran-functionalized structures in different solvents after initial activation with UV-light

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Replication of microstructures in thermoplastic films using wire-cloth as stamp for hot embossing and R2R embossing

J. Schmidli[1], M. Grob[1], A. Stumpp[2], P.M. Kristiansen[1], S. Neuhaus[1]

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

[2] FHNW University of Applied Sciences and Arts Northwestern Switzerland, School of Engineering, Institute of Product and Process Engineering (IPPE), Windisch, Switzerland

In this study, woven stainless steel wirecloths (Fig. 1a) were used to texture thermoplastic films, aiming to create superhydrophobic surface topographies. A broad range of thermoplastic materials were studied with respect to their wetting behavior before and after structuring by hot embossing and roll-to-roll thermal embossing, respectively. Furthermore, picosecond pulse laser ablation was used to additionally modify the surface structure of steel wirecloths. Lastly, structured polyolefin films were modified by swelling in alkanes, which in some cases significantly changed the surface topography due to partial dissolution and subsequent recrystallization.

The fabricated polymer surfaces were analyzed by confocal laser scanning microscopy (CLSM) and scanning electron microscopy (SEM), respectively, which revealed well-defined surface topographies with high aspect ratios, created under appropriate replication conditions (Fig. 1b). Treatment of metal cloths with picosecond pulsed laser ablation created grooves along the warp wire, giving the surface an additional level of roughness (Fig 1c). Swelling in alkanes resulted in a variety of changes ranging from formation of submicron protuberances to generation of open porous structures with pore sizes between nanometers and several micrometers (Fig 1d), depending on the swelling parameters.

Wetting characteristics were analyzed by static contact angle and roll-off angle measurements. Similar results were obtained for hot embossed samples and roll-to-roll thermal embossing. For most of the tested materials, static contact angles reached values in excess of 150° and, in some cases, roll-off angles were reduced to less than 25°.

The application of simple methods which have the potential of being used on an industrial scale combined with the promising results show that even with comparably cheap approaches interesting surface structuring effects can be achieved.

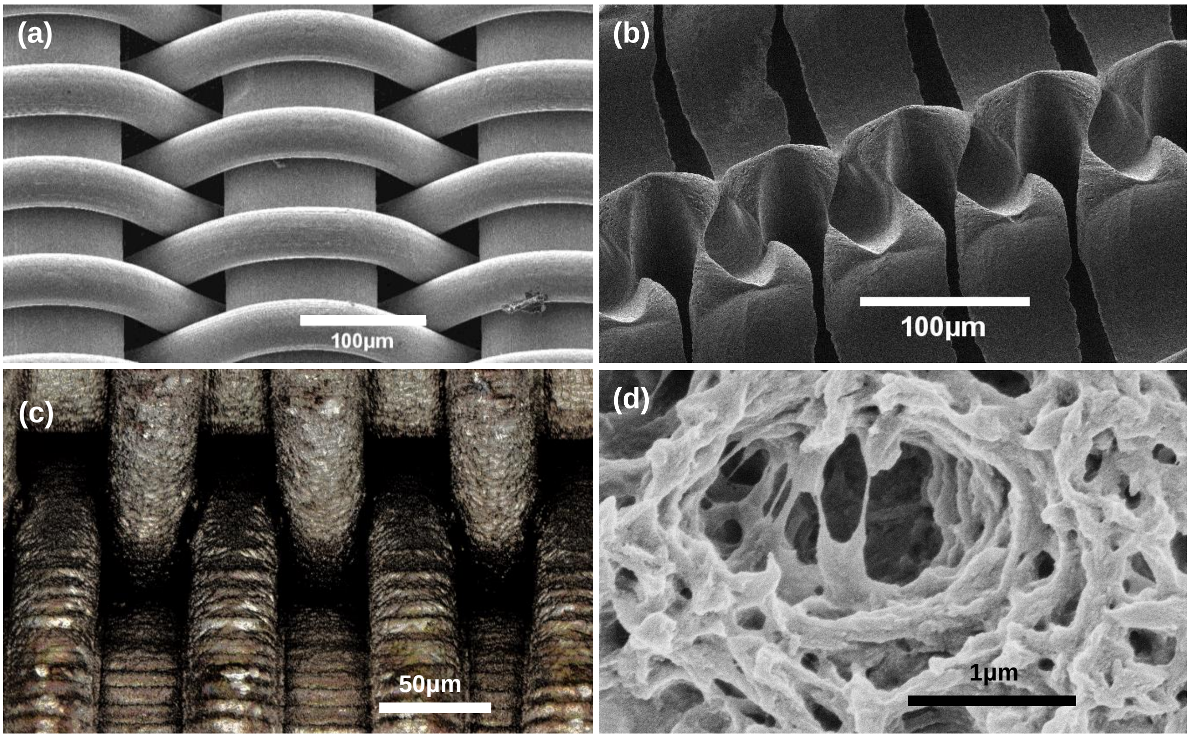

Figure 1: SEM pictures of a) wirecloth used as embossing stamp, b) surface structure after hot embossing wirecloth in PP, c) CLSM image of laser treated wirecloth and d) SEM image of PP after swelling in Heptane/Cyclohexane solution

Fabrication of high transmission microporous membranes by proton beam writing and soft lithography

C. Meyer[1,2], L.P Wang[1], E. Guibert[1], A. Homsy[1], H.J. Whitlow[1]

[1] University of Applied Sciences of Western Switzerland, Haute Ecole Arc Ingénierie, La Chaux-de-Fonds, Switzerland

[2] Institut für Physik, Universität Augsburg, Augsburg, Germany

Porous membranes are widely used as filters for a wide range of applications in micro- and nanotechnology, (e.g. organelle sorters, permeable cell growth substrates, virus filters etc). Filters inhibit geometrically particle flow in a multi-phase fluid when the smallest geometrical dimension is larger than the largest dimension of the aperture. The optimal, a harp geometry, is impractical because of rigidity considerations. In order to achieve an enhanced flow we have studied fabrication and flow in elliptical pores. These will have a lower flow resistance and reduced clogging rate than for round holes.

Conventional membrane fabrication approaches are quite restricting because the mechanical stability of the thin film in which the pores are produced. Ion track etching is limited to random distributions of round pores, some of which overlap, laser machining gives conical pore walls, plasma etching is difficult to control for high aspect ratios and needs a complex mask deposition process.

In order to overcome these difficulties we have been developing microporous membranes produced by a spin-casting method where the mold is produced by proton beam writing (PBW) Fig. 1 (left). In this approach the focused energetic (1–2 MeV) protons are used to lithographically write a pattern of elliptical pillars that are used as mold for soft lithography[1]. The PBW lithography technique is similar to electron beam lithography (EBL). The much higher momentum of the protons and much longer penetration depth in PBW compared to EBL allows the writing of patterns with straight vertical sidewalls with height to wall thickness aspect ratios exceeding 100:1 in conventional resist materials (SU-8, PMMA etc.) [2]. PBW was used to write a mould consisting of hexagonal arrays of 4×8.5 µm and 20 µm high pillars in SU-8 on Si. After development the pillars were conformably coated by CVD with 100 nm of Parylene-C which is used as a release agent. Subsequently, ~20 µm of PDMS was spin coated. To facilitate delamination a special procedure based on laser-cut sealing tape rings was developed (Fig.1 middle).

The membranes were characterized by cross-sectional microscopy and by measurement of the pressure induced flow. The microscopy results show a high fraction of open pores (Fig. 1). In order to test the fluid flow the membrane a microfluidic flow cell device was used with fluorescent nanoparticles .

The procedure allowed fabrication of micro-porous membranes with elliptical pores with few µm widths. Others have demonstrated PBW with 20 nm line width resolution which indicates that smaller elliptical should be possible by direct writing in PMMA membranes.

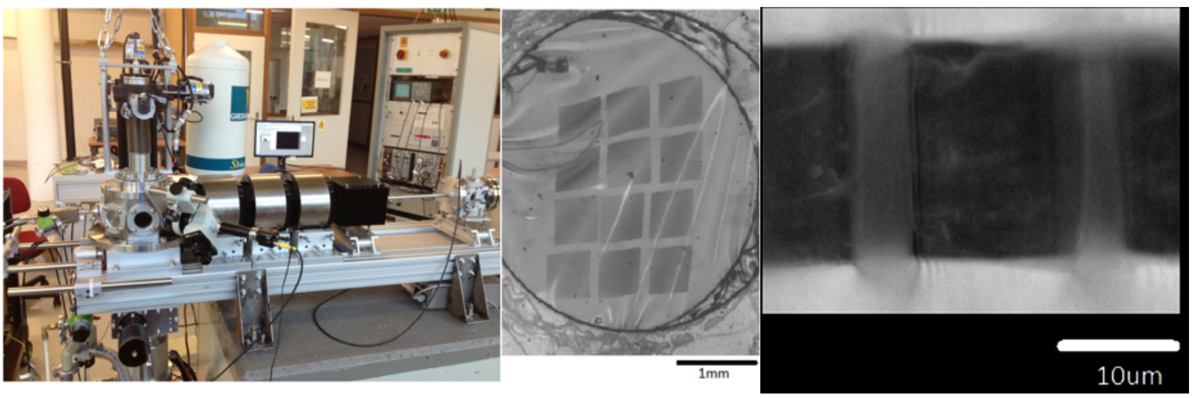

Figure 1: Left: PBW system. Middle: Membrane with two 60 µm tape rings for delamination. Right: Cross-sectional micrograph of the membrane.

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Fluent solver expanded to the nano-world

J.Pina-Estany[1], J.Fraxedas[3], F.Perez-Murano[3], C.Colominas[2], J.M.Puigoriol-Forcada[1], A.A.Garcia-Granada[1]

[1]IQS-Universitat Ramon Llull; [2]Flubetech SL; [3]ICN2-CNM-CSIC Barcelona;

Within the www.aim4np.eu project, a metrology platform hosting an Atomic Force Microscope [AFM] will be used for the determination of the nanomechanical objects' surfaces at production sites enabling inline process control (fig. 1).

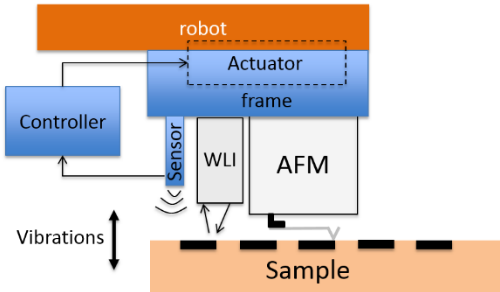

Figure 1: aim4np actuator diagram

Plastic injection was chosen as a case system for the validation-study. The goal is to determine the influence of the micro/nano roughness of a mould and the roughness of the resulting part. The determination of the link between the nanomechanical properties mould's surface and the functionality of the mould is addressed both by means of experimental and simulation techniques. Moulds and moulded plastic parts (view figure 2) have been characterized by AFM and other techniques, and computer models have been developed to simulate the effect of mould surface roughness on the appearance of the final plastic piece.

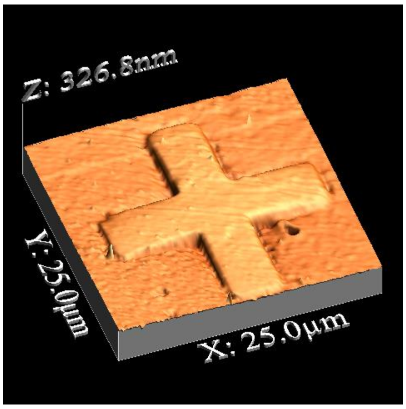

Figure 2: AFM measuring of a nano-mark

All available simulation codes devoted to plastic injection have so far been conceived for large pieces in industrial applications (e.g. automotive) with dimensions well above the millimetre range. Thus, it was foreseeable that the extension of such codes down to the nanometre range would be challenging. Therefore, we were driven to develop the necessary code to carry out nano-simulations: **ANSYS Fluent** capabilities are expanded with own-developed User Defined Functions. The aim is to obtain a model able to forecast the relationship between the depth of the mould's marks (blue line) and how much they are replicated by the polymer (red line).

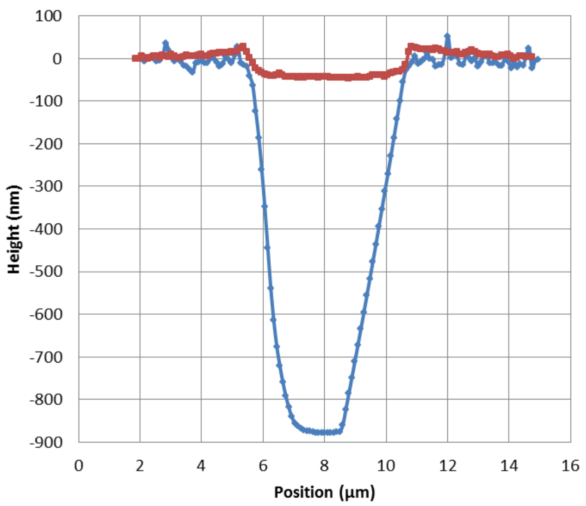

Figure 3: AFM measurement of a mould mark (blue) and how the mark was

Investigating the micro-replication regime for structures produced by an extrusion coating process

N. Okulova[1,2], L. Christensen[1], P. Johansen[1], R. Taboryski [2]

[1] Danapak Flexibles A/S, Slagelse, Denmark
[2] Technical University of Denmark, Copenhagen, Denmark

A recently developed method for producing micro-/nano-structures using roll-to-roll extrusion coating shows great promises in terms of implementing the technology into the packaging industry. The method has been proven to produce various structures and in this study a more systematic approach is chosen, in order to support further development of this technique.

The replication regime for nano-sized structures is described in Murthy's article[1], where the structures are filled up simply due to the surface tension and the best replication is reached at the higher speeds. The micro-scaled structures, however, are too large to be filled up using the surface tension and a different regime applies. In this study the replication fidelity is tested using micro-sized pillars in different aspect ratios: 1:2, 1:1 and 2:1. The silicon master for pillars is produced by UV photolithography and DRIE etching. The pattern from the Si master is then covered with NiV and Ni is electroformed on top of the wafer. The excess silicon is then etched away using KOH. The produced nickel replica of the Si master is coated with FDTS and attached onto the cooling roll of the extrusion coater.

During the extrusion coating process the melted polymer is extruded through a flat nozzle directly onto the carrier foil. The polymer is then pressed against the cooling roll, where it solidifies and sticks to the surface of the carrier foil. In the case of semi-crystalline polymers, during the replication process due to the supercooling the polymer can fill in the structures before it solidifies. The important parameters for good replication fidelity are the crystallinity of the extruded polymer, the output, and the line speed, the temperature of the cooling roll and the pressure on the cooling roll. In this study polypropylene is used as extruded material.

The aim for the future studies is to examine the replication fidelity for various polymers and to build up a database of possible candidates for further development for combining the micro- and nano-structures into hierarchical structures for superhydrophobic surfaces.

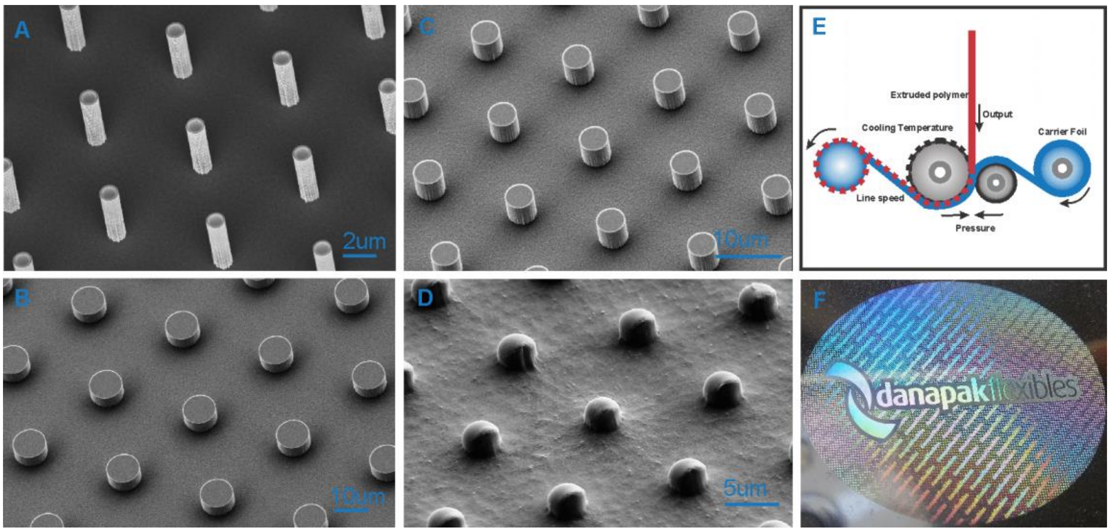

Figure 1 A-C: The Si masters for replication. D: Structures replicated in polypropylene. E: The schematics of the extrusion coating process and the important parameters. F: Diffractional gratings of ½ µm that reflect light in a holograffic manner, replicated in polypropylene.

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High Definition Plastics™ Molding by Dynamic Heating [1]

C.Beloli[1], J.Feigenblum[1], Y.Mocellin[1], Lucia Dominguez Varela[2]

[1] RocTool SA, France
[2] GF Machining Solutions, Switzerland

RocTool induction process is fully adapted to plastic injection, including multiple configurations to fit with tier manufacturers requirements [2]. RocTool's Research and Development team is constantly adapting the technologies to new materials and technologies.
As a Heat and Cool technology leader, RocTool now offers High Definition Plastics™ capabilities to plastic molders. The processes developed by RocTool are used in production by major brands in innovative industries such as automotive, aerospace, consumer products & electronics. They hold many advantages including reduced cycle times, surface quality, light weighting and performance, therefore resulting in an overall cost reduction of the produced parts for manufacturers.

Over the last few years a number of studies have been made to improve mold texturing replication. The target of our study is to quantify mold replication benefits using induction heating system. The most used and innovative materials will be selected, then tested to compare with conventional injection molding.

It was clearly observed that using Heat&Cool technology, polymer is in molten state for a few seconds, allowing an excellent replication of the textured surface [3]. In conventional, this phenomena is not observed, this is due to the thin frozen layer formation upon contact with the cold mold.

Moreover, topographic analysis of the injected parts surfaces were carried out using optical rugosimeter. Study was focused on grain replication according to the injection processes. For an ABS/PC, the laser surface replication of the tool (VDI 22) is improved up to 52.5 % with RocTool dynamic heating system.

This research will be an important investigation on various polymers (amorphous or semi-crystalline) and also on different kinds of texturing. A specific mold was designed, in collaboration with +GF+, which will contribute to the understanding of polymer replication. We will go into detail, looking at the relationship between replication rates, polymers and texturing.

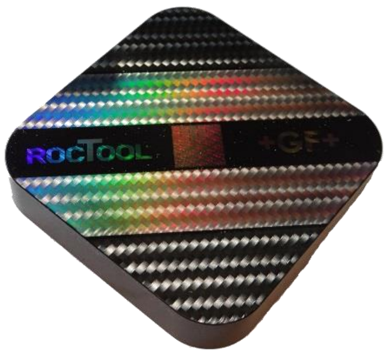

Figure 1: Nano-replication of laser texturing with RocTool's Dynamic heating solution

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Tunable patterned wettability in porous media: Gas diffusion layer for PEFCs

V. Manzi-Orezzoli[1], A. Forner-Cuenca[1], L. Gubler[1], P.M. Kristiansen[2], T.J. Schmidt[1, 3], P. Boillat [1, 4]

[1] Electrochemistry Laboratory, Paul Scherrer Institute, 5232 Villigen, Switzerland
[2] Institute of Polymer Nanotechnology, University of Applied Sciences and Arts Northwestern Switzerland, 5210 Windisch, Switzerland
[3] Laboratory of Physical Chemistry, Department of Chemistry & Applied Biosciences, ETH Zurich, 8093 Zurich, Switzerland
[4] Neutron Imaging and Activation Group, Paul Scherrer Institute, 5232 Villigen, Switzerland

Polymer electrolyte fuel cells (PEFCs) are intended to play a key role on the quest to switch to renewal energies. PEFCs generate electrical energy by reacting H_2 on one side of the cell and O_2 on the other side, producing water. They are based on a central ion conducting polymer electrolyte membrane. The membrane separates two catalyst layers (CL), generally consisting of thin layers of Pt nanoparticles supported on carbon. Adjacent to the CLs, the gas diffusion layers (GDL) are placed, through which gases are supplied and water is removed, among other functions. The water and the reagent gases use the same GDL pathways; therefore, if water accumulates near the CL, it can block the access of the reactants to the catalyst, diminishing the performance. Contrary to this, the membrane needs to be hydrated in order to be conductive, what leaves the system in need of a well balance water management. Normal GDLs are highly porous carbon papers or carbon cloths with a thickness around 200 µm. The carbon layer is generally coated by a fluoropolymer, FEP or PTFE, to enhance hydrophobicity and help water removal.

In our investigation, we tackle the problem of water management in fuel cells by creating a custom GDL with hydrophilic and hydrophobic pathways employing radiation grafting [1]. By modifying the water affinity of selected regions, water transport may be separated from gas transport within the same material, helping to improve the performance at high current densities where large amounts of water are produced and important gradients of concentration can be induced due to the large mass flow of oxygen. These different pathways are generated by electron induced radiation grafting, employing masks with the desired pattern to partially block the electron beam. Afterwards, a more hydrophilic polymer is grafted onto the coating generating preferential pathways for the water throughout the whole porous media [2].

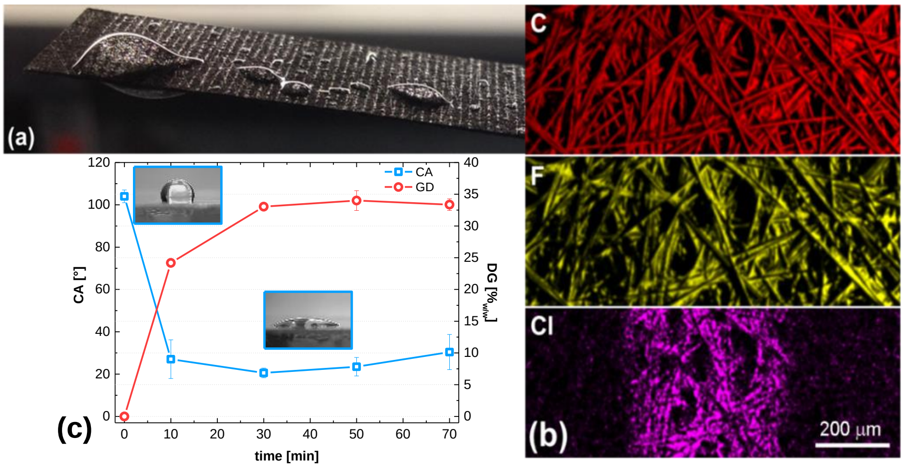

Figure 1: (a) Picture of modified carbon paper with pattern wettability. (b) EDX elemental mapping of modified carbon paper (c) Kinetic curve for grafted polymer films showing contact angle (CA) and degree of grafting (DG) versus time.

In this presentation, we will discuss our results on surface wettability modifications (Figure 1c) using two different monomer systems (acrylic acid and N-vinylformamide) in model polymer films, as well as in porous materials including samples with patterned wettability. The characterization is done by sessile drop measurements as well as by capillary imbibition experiments.

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Polymer Replication on Nanoscale

Funktionelle Oberflächenstrukturen im Fokus

Die Herstellung von Kunststoffbauteilen mit Oberflächenstrukturen im Mikro- und Nanometerbereich birgt Potential für viele Anwendungsgebiete. Den damit verbundenen Herausforderungen an die gesamte Wertschöpfungskette widmet sich die dritte Internationale Konferenz «Polymer Replication on Nanoscale» (PRN2016), welche am 19./20. Mai 2016 erstmals an der Fachhochschule Nordwestschweiz (FHNW) durchgeführt wird.

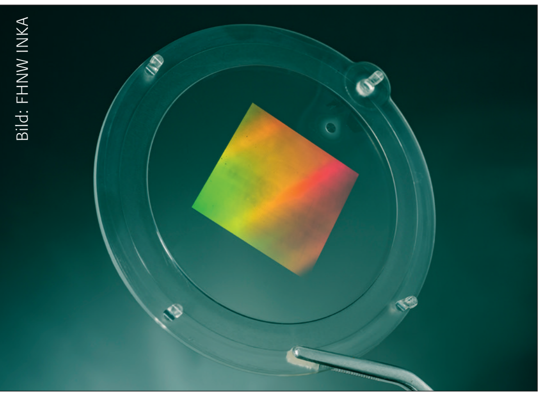

Bild: FHNW INKA

Spritzgegossene Nanostrukturen (hier 200 nm Säulen auf 44 × 44 mm) dank variothermer Werkzeugtemperierung.

Prof. Dr. Per Magnus Kristiansen[1]

Die Funktionalisierung von Kunststoffbauteilen durch Modifikation der Oberfläche gewinnt zunehmend an Bedeutung und ermöglicht laufend neue Anwendungen in verschiedenen Industriezweigen. Dabei kommt der Strukturierung von Oberflächen auf der Mikro- und Nanometerskala eine wichtige Rolle zu. Denn auf diese Weise lassen sich Kunststoffoberflächen funktionalisieren, ohne dabei das Material in seiner Zusammensetzung zu verändern. Dies ist insbesondere in den Bereichen der Life Sciences generell und speziell in der Medizintechnik von grosser Bedeutung, wo eine chemische Veränderung des Materials oftmals zeitraubende und kostenintensive Neuzertifizierungen nötig macht. Im Bereich optischer Anwendungen ermöglichen funktionelle Oberflächenstrukturen in Kombination mit der inhärenten Flexibilität hinsichtlich Formgebung die Realisierung komplexer optischer Bauteile. Aber auch das Interesse anderer Industriezweige für die Oberflächenstrukturierung steigt stetig. So lassen sich Adhäsion und Benetzbarkeit beeinflussen, haptische oder tribologische Eigenschaften modifizieren, neuartige sicherheitstechnische Merkmale wie auch dekorative Effekte erzeugen oder gar gänzlich neue Funktionalitäten sowie Kombinationen davon realisieren.

Interdisziplinäre Synergien trotz Zwangsheirat

Das Institut für nanotechnische Kunststoff-Anwendungen (INKA) – eine gemeinsame Einrichtung der Fachhochschule Nordwestschweiz und des Paul Scherrer Instituts – gehört im Bereich der Strukturabformung zu den führenden Instituten in Europa. Was seinen Ursprung quasi in einer Zwangsheirat zweier auf den ersten Blick inkompatibler Einrichtungen der Schweizer Hochschullandschaft nahm, hat sich über die letzten zehn Jahre zu einem erfolgreichen Joint Venture entwickelt, das seinesgleichen sucht. Möglich geworden ist dies durch die gezielte Nutzung von Synergien zwischen den zwei beteiligten Institutionen. Konsequenter Kompetenzaufbau entlang der gesamten Wertschöpfungskette, zielgerichtete Infrastrukturentwicklung und anwendungsorientierte Forschungsprojekte mit Industriepartnern aus unterschiedlichen Branchen wurden über Jahre intensiv vorangetrieben. Dabei kam die wissenschaftliche Auseinandersetzung mit dem Thema der Strukturabformung nicht zu kurz, so dass sich das INKA trotz ausgeprägtem Industriefokus einen ansprechenden Leistungsausweis erarbeiten konnte, der zunehmend über die Grenzen des eigenen Landes hinaus gewürdigt und nachgefragt wird. Zu verdanken ist dieser anhaltende Erfolg einem hochgradig interdisziplinären Team aus Ingenieuren, Physikern, Elektrotechnikern, Materialwissenschaftlern und Kunststoffexperten aus der Praxis, das sich in vorbildlicher Konsequenz einem zukunftsträchtigen Thema angenommen hat. Diesem Engagement ist es auch zu verdanken, dass die FHNW in diesem Jahr als Gastgeber der PRN2016 auftreten darf.

Austausch auf hohem Niveau

Ursprünglich durch die Dänische Technische Universität Kopenhagen ins Leben gerufen, wird die Konferenz «Polymer Replication on Nanoscale» – die PRN2016 – dieses Jahr nun zum dritten Mal durchgeführt. Am ursprünglichen Ziel hat sich dabei nichts verändert: Gleichgesinnte aus Akademie und Industrie treffen sich zum Dialog über die neusten Erkenntnisse aus Forschung und Entwicklung im Bereich der Oberflächenstrukturierung. Behandelt werden dabei folgende Themen: Herstellung von Masterstrukturen und deren Integration in Werkzeuge, Replikation mittels industrieller Fertigungsprozesse, Materialien für funktionelle Oberflächen, Anwendungen strukturierter Polymere sowie Messtechnik, Qualitätskontrolle und Simulation.
Die PRN2016 soll dabei keine Leistungsschau akademischer Koryphäen sein, sondern vielmehr ein möglichst informelles Treffen Interessierter zum fruchtbaren Austausch, zu dem in diesem Jahr ungefähr 100 Teilnehmer aus ganz Europa erwartet werden. Mit ihrem thematisch eng eingegrenzten Fokus orientiert sich die Konferenz am Puls der Zeit.

[1] *Prof. Dr. Per Magnus Kristiansen, stv. Leiter des Instituts für Nanotechnische Kunststoff-Anwendungen (INKA) an der Fachhochschule Nordwestschweiz, Hochschule für Technik, Windisch.*

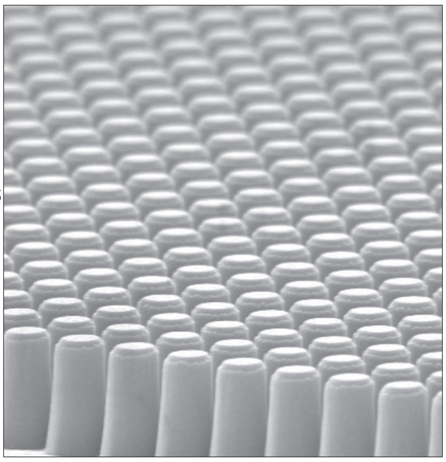

Bild: Weidmann Medical Technology AG

Perfekte Strukturabformung gewährleistet Funktion (Säulenhöhe 2.5 Mikrometer).

Inspiration aus der Natur

Die Natur liefert zahlreiche Beispiele für hochentwickelte funktionelle Oberflächen. Bestens bekannt ist die selbstreinigende Eigenschaft von Blättern der Lotuspflanze oder die wasserabstossende (superhydrophobe) Wirkung von Entenfedern. Auch die schillernden Farben von Schmetterlingsflügeln und Pfauenfedern basieren auf komplizierten geometrischen Formen, die aus dem auftreffenden Licht wahre Kunstwerke hervorbringen. Die Haut des Haifischs ist mit feinen Finnenstrukturen von wenigen Tausendstel Millimeter übersäht, die den Strömungswiderstand minimieren. Einen ähnlichen Effekt nutzt der weniger bekannte Sandfisch, um sich praktisch reibungslos im Sand zu bewegen. Der Gecko hingegen läuft selbst die glattesten Wände hoch, weil ihm Abertausende feinster Härchen an den Füssen ausreichend Haftung verleihen. Beispiele wie diese liessen sich noch viele mehr aufzählen. Denn der Erfindergeist der Natur kennt praktisch keine Grenzen.

Viel Potenzial für die Schweizer Kunststoffindustrie

Der Erfolg der Schweizer Kunststoffindustrie hängt – nicht zuletzt aufgrund der anhaltenden Frankenstärke – massgeblich von Innovationen entlang der gesamten Wertschöpfungskette ab. Mit der Schaffung der national thematischen Netzwerke (NTN) hatte der Bund bereits vor vier Jahren übergeordnete Gefässe für übergreifende Themengebiete geschaffen. Von den acht durch die KTI für vier Jahre finanzierten Netzwerken haben mindestens drei einen engen Bezug zur Kunststoffindustrie. Das NTN Carbon Composites Schweiz verfolgt den industriellen Durchbruch der Hochleistungsfaserverbundwerkstoffe. Das NTN Swissphotonics befasst sich im Schwerpunkt mit optischen Anwendungen und der Lasermaterialbearbeitung und das NTN Innovative Oberflächen spricht für sich.

Anwendungsgebiete sind vielfältig

Die Diagnose von Infektionen und Krankheiten wird zunehmend revolutioniert durch die sogenannte Point-of-Care Diagnostik. Nimmt heute der Arzt noch venös bis zu 50 ml Blut ab, um dieses in ein zentralisiertes Labor zu schicken, soll zukünftig mit nur wenigen Tropfen Blut innerhalb von 10 bis 15 Minuten eine Diagnose vor Ort machbar werden. Ermöglicht wird dies durch massgeschneiderte Mikrofluidik-Chips, die vom Prinzip her ähnlich funktionieren wie der Blutzuckertest – ein Glasplättchen mit einem Kapillarkanalsystem und einem Auslesegerät. Moderne Mikrofluidik-Chips erfordern jedoch deutlich komplexere Strukturen und erschweren damit deren Herstellung in der Massenfertigung. Hinzu kommt, dass eine Reihe von Prozessschritten aufeinander abgestimmt werden müssen.

Im Bereich optischer Anwendungen bringt der anhaltende Siegeszug der LEDs eine Fülle von neuen Herausforderungen und Möglichkeiten mit sich. Bei der Realisierung ausgeklügelter Systeme zur Leitung, Lenkung und Auskopplung von (sichtbarem) Licht spielt die Strukturierung von Kunststoffoberflächen eine zentrale Rolle. Auch hier ist interdisziplinäre Zusammenarbeit gefragt. Denn komplexe optische Bauteile lassen sich zwar am Computer simulieren und hinsichtlich ihrer Funktion optimieren. Das resultierende Design ist allerdings oft nicht kunststoffgerecht und muss im engen Dialog mit Spezialisten aus dem Werkzeugbau und der Kunststoffverarbeitung angepasst werden, um eine Massenfertigung erst möglich zu machen. Eindrückliche Beispiele gab es im

Nicht bloss Zukunftsmusik – Mikrofluidikchip für die Blutdiagnostik von morgen.

vergangenen Jahr des Lichts an einer Vielzahl von Veranstaltungen nicht nur in der Schweiz sondern in ganz Europa zu bestaunen.

Fruchtbarer Nährboden für Innovation gefragt

Am diesjährigen Swiss Plastics Innovationsforum in Luzern wurde die Innovation in all ihren Facetten beleuchtet und die Innovationskraft der Schweizer Kunststoffindustrie anhand zahlreicher hervorragender Beispiele aufgezeigt. Innovation braucht, so der Grundtenor, die richtigen Randbedingungen, Offenheit und Akzeptanz gegenüber neuen Ideen, interdisziplinäre Ansätze und vernetztes Denken – gepaart mit Entrepreneurship, Mut zur Exposition und solider Ausdrucksfähigkeit in Wort und Schrift.
Auch die PRN2016 bildet einen thematisch fokussierten Schmelztiegel zur Inspiration für neue Vorhaben zum Nutzen aller Teilnehmenden. Um dies zu gewährleisten, werden alle eingereichten Abstracts durch ein internationales Advisory Board begutachtet und auf dieser Basis ein entsprechendes Programm für die beiden Konferenztage zusammengestellt.

Weitere Informationen zur PRN2016 unter www.prn-conference.com

Kontakt
Fachhochschule Nordwestschweiz
Hochschule für Technik
Institut für nanotechnische
Kunststoff-Anwendungen (INKA)
Klosterzelgstrasse 2
CH-5210 Windisch
Telefon +41 (0)56 202 73 86
magnus.kristiansen@fhnw.ch
www.fhnw.ch/technik/inka