JOANNEUM RESEARCH

Imprint your future

Roll-to-Roll Structured Surface Coatings

We get it rolling from Nano to Macro

BIO BASED
RECYCLABLE FOILS
LIFE CYCLE ASSESSMENT

JOANNEUM RESEARCH MATERIALS

Roll-to-Roll based UV Nano-Imprint Lithography (R2R UV-NIL) for

Optics and Plasmonics

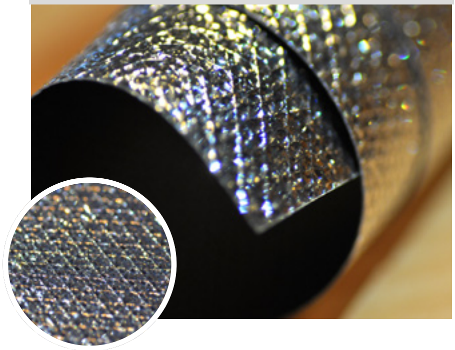
Our portfolio of UV-NIL fabricated optical structures covers:

- Refractive optical elements (ROE)
  - Flat free-form microoptics with structure height ≤ 50 µm
  - Flat waveguides with height ≤ 200 µm
  - Microlens arrays
  - Micro mirrors
- Diffractive optical elements (DOE) with critical dimensions down to 200nm
- Plasmonic metal nanostructures with critical dimensions down to 50nm

for applications like:

- Optical communication
- Optical sensing incl. biosensing
- Light management in Lighting
- Light management in Photovoltaics
- Backlit human-machine interfaces
- Decoration

OPTICS
PLASMONICS



Microfluidics

In microfluidics, we use UV-NIL to produce features such as

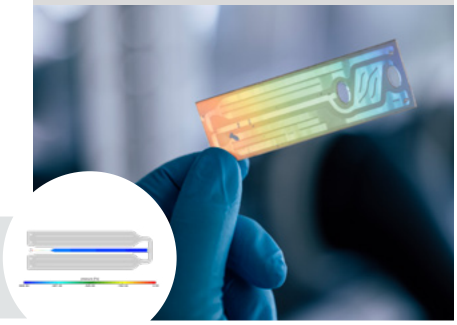
- microchannels,
- micropillars
- microvalves
- micromixers

which can be used for a variety of applications, including

- ab-on-a-chip devices
- biosensors
- bioreactors

We especially focus on foil-based chips that we can produce at high throughput and low cost.

MICROFLUIDICS



Biomimentics

In biomimetics, we generate structures that mimic the morphology and functions of natural materials such as insect wings, butterfly scales or lotus leaves. These bio-inspired structures can be used for a range of applications, including:

- self-cleaning surfaces
- anti-fogging coatings
- superhydrophobic surfaces

BIOMIMETICS

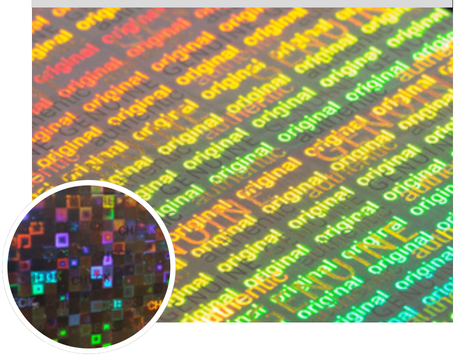
Security Features

For security features, we realise specific micro- and nanoscale structures, such as

- Holograms
- diffraction gratings
- freeform micro-optical elements.

These provide unique optical and physical properties that are difficult to copy or reproduce. These features are essential for anti-counterfeiting measures and ensure the authenticity of the product including ticketing and product labels.

SECURITY FEATURES



Advantages

Roll-to-Roll UV Nano-Imprint Lithography has become increasingly popular for fabricating micro or nano structures as it offers an enormous potential due to the following advantages:

- high production throughput (up to 30 m/min)
- nano to sub-mm structures on large area with high replication fidelity
- 2D- 2.5D structures with aspect ratio up to 5
- flexible polymer substrates
- multi-functional photo resins optimized to the targeted use case
- resource-efficient low temperature structuring

Environmental Sustainability

Environmental sustainability has clearly become an integral point of our development. We continuously shift towards more eco-friendly materials and processes.

Bio Based: Materials, which are derived from renewable resources such as plants, bacteria, and fungi, can replace petroleum-based materials. They can be designed to be easily recyclable, or they can biodegrade naturally without causing harm to the environment. This is especially important for our resins.

Recyclable Foils: We consider the recyclability of products and materials as an important task as well. By using recyclable components, we contribute to reduced waste, conserved resources, and reduce environmental impacts. Also we use lightweight foil substrates from recycled sources.

Sustainable UV-NIL Process:

- additive and therefore minimum resource consumption
- process temperatures below 50°C
- low water consumption, cooling is done in closed loop
- solvent-free materials

Life Cycle Assessment (LCA): To fully evaluate the sustainability of a product, we offer a LCA to customers. This LCA (based on our materials) assesses the environmental impacts of a product from its raw material extraction to its disposal. An LCA can identify potential of improvement, such as reducing energy consumption, minimizing waste, and using more sustainable materials.

JOANNEUM RESEARCH MATERIALS

From Idea to Prototype

For our customers, we offer a wide range of services to develop tailor-made processes and products - starting with a feasibility study up to the manufacturing of prototypes.

The value chain for Nano-Imprint Lithography (NIL) is a multi-stage process that involves several steps from the initial idea to the validation of the final product.

(i) Selection and Development of materials that are suitable for NIL. This includes materials for the substrate, the stamp (treatment) and the resins, which should have high fidelity, durability, and reproducibility and should be easy to mold and demold.

(ii) Simulation and Design of the desired pattern on the substrate. Computer-aided design (CAD) software is used to create the pattern, and diverse simulation tools like FEM, ray tracing and FDTF are used to optimize the design parameters and predict the behaviour of the material during the imprinting process.

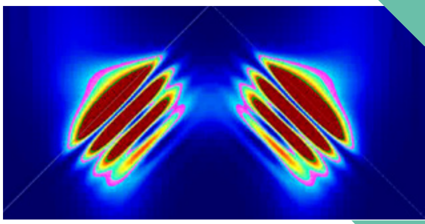
(iii) Origination of the master structure to create the stamp (or mold) needed for imprinting. Here we deploy e-beam lithography, photolithography or laser-based methods (greyscale laser lithography, two-photon absorption, laser ablation).

(iv) Upscaling for large area tooling to replicate the master structures onto a large area polymer substrate forming the flexible stamp for the R2R machine. This is done with our step-and-repeat UV imprinting equipment.

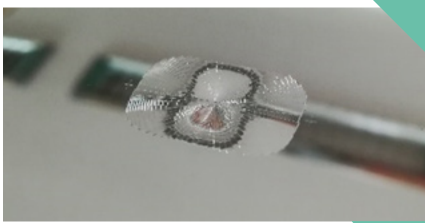
(v) Pre-series production stage with process development and optimization followed by roller-based fabrication of the product prototypes (up to a few kilometres of foil) with inline process control.

(vi) Validation stage for testing the functionality of the final product, including its performance, optical quality and durability. This step is usually performed by our customers for their particular application.

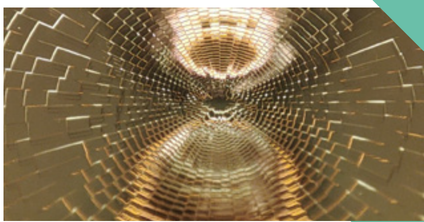
MATERIAL DEVELOPMENT



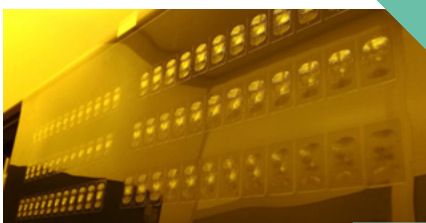
SIMULATION



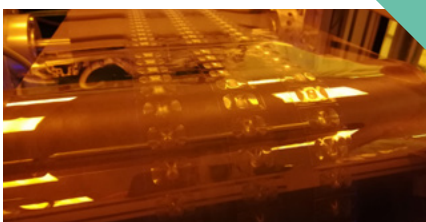
DESIGN OF STRUCTURE



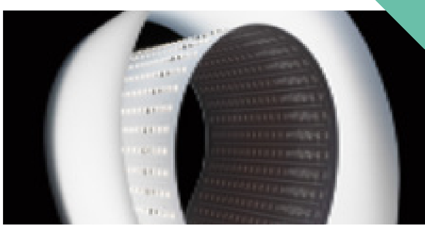
ORIGINATION OF MASTER



UPSCALING FOR LARGE AREA TOOLING



PRE-SERIES PRODUCTION



VALIDATION

MATERIAL DEVELOPMENT

NILcure® product line

Imprint resins for UV-NIL - perfect for any application

The NILcure® resin portfolio comprises in-house developed resins for UV-NIL.
The resins of this versatile product line can be tailored to your application regarding their mechanical, chemical and optical properties.

NILcure® characteristics

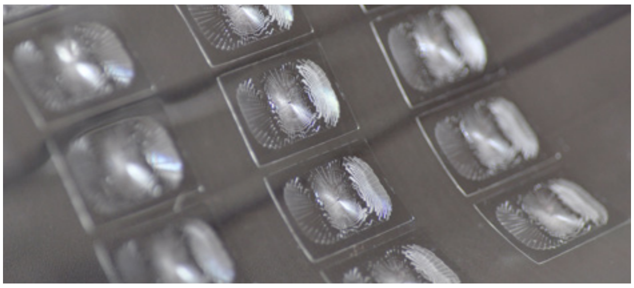
- Suitable for gravure printing, slot-die coating and inkjet printing
- Excellent adhesion to plastics, silicon, glass, metals and other substrates
- Exceptional anti-sticking properties
- Imprinting of high aspect ratio micro- and nanostructures
- Self-replicability: imprints usable as secondary stamps

Application examples

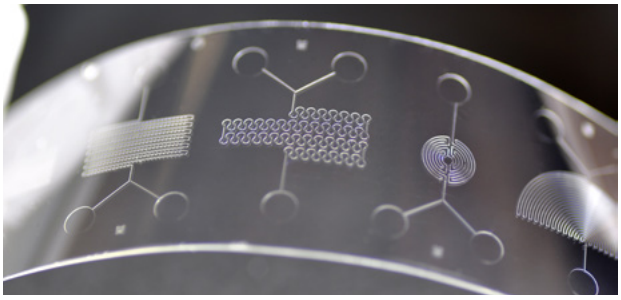
- Capillary flow control: wicking, microfluidic devices
- Superhydrophobicity: water and dirt repellency
- Scratch resistant surfaces with micro- and nano features
- Withstanding harsh artificial weathering tests and real-world applications
- Biobased, recyclable and compostable microfluidic chips

NILcure® resin for drag reducing riblet foils

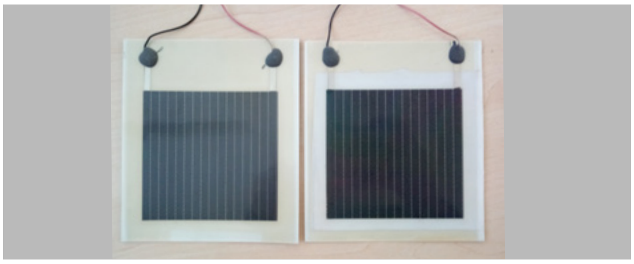
NILcure® resin for high refraction and high dispersion decorative foils



NILcure® resin for optical light guiding structures



NILcure® resin for microfluidic lab-on-a-chip applications

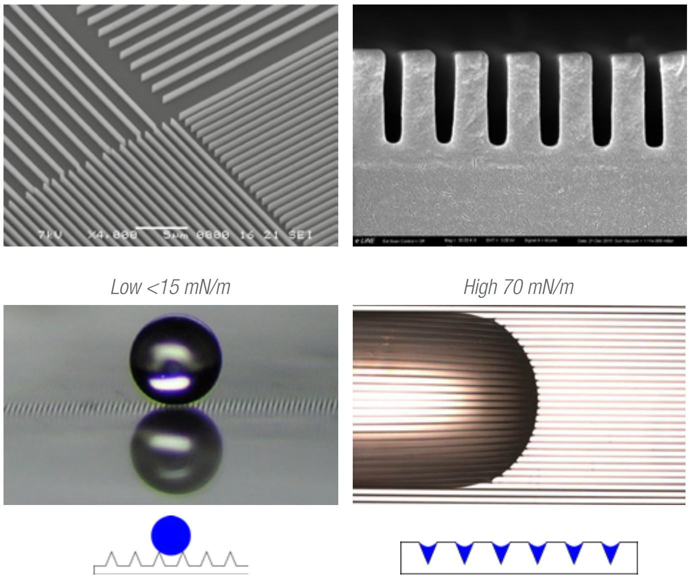


NILcure® resin for antireflective, dirt-repellent solar cell coatings

JOANNEUM RESEARCH MATERIALS

Basic resin properties

- Customized polymer matrix and additives
- Biobased UV curable resin product line
- Low cytotoxicity
- Low leakage of components
- Water soluble resins for lift-off processes (VOC free)
- Residual free imprinting (avoiding etching process)
- Self-replicability
- Resistant against UV radiation and weathering



Tunable properties

- Surface energy – from superhydrophobic to hydrophilic
- Mechanical properties – from stiff to elastic
- Optical properties – low / high refraction and dispersion
- Wide viscosity range of uncured resins

Property tuneable	from	to
Young's Modulus Elongation	5 MPa 100 %	1000 MPa 5 %
Surface energy	15 mN/m	70 mN/m
Refractive Index @589nm	1.4	1.8
Viscosity	10 mPas	10 Pas

Table 1: Resin properties can be adjusted independently

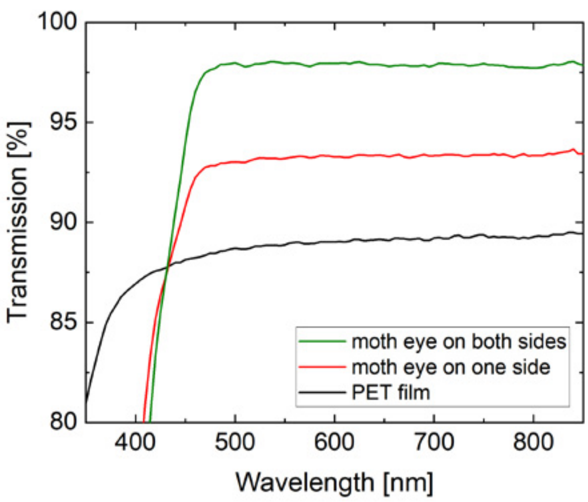


Figure 1: Transmission of pure PET film compared to one-sided and double-sided structuring with moth-eye structures

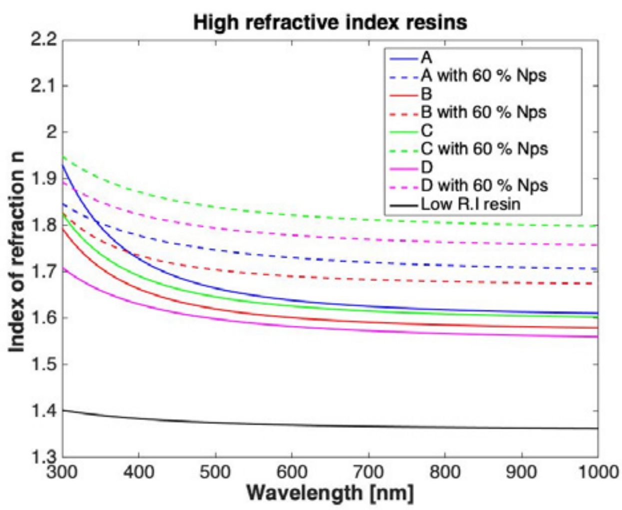


Figure 2: Refractive index ranges for different high refractive NILcure® resins with and without addition of nanoparticles and one comparison to a resin with a low refractive index

SIIMULATION AND DESIGN OF STRUCTURES

Design and simulation are critical steps in the development of Nano-Imprint Lithography (NIL) patterns.

First we use computer-aided design (CAD) software to create a digital model of the desired pattern on the substrate. The design can include complex geometries, such as gratings, bumps, and trenches, that are difficult to achieve with other techniques.

After the design is complete, simulation tools help us to analyse the pattern and predict the behavior of the material during the imprinting process. Simulation tools enable us to identify areas where the pattern may fail, such as in the presence of defects or stresses, and can suggest changes to the design parameters to optimize the process.

Optics and Plasmonics

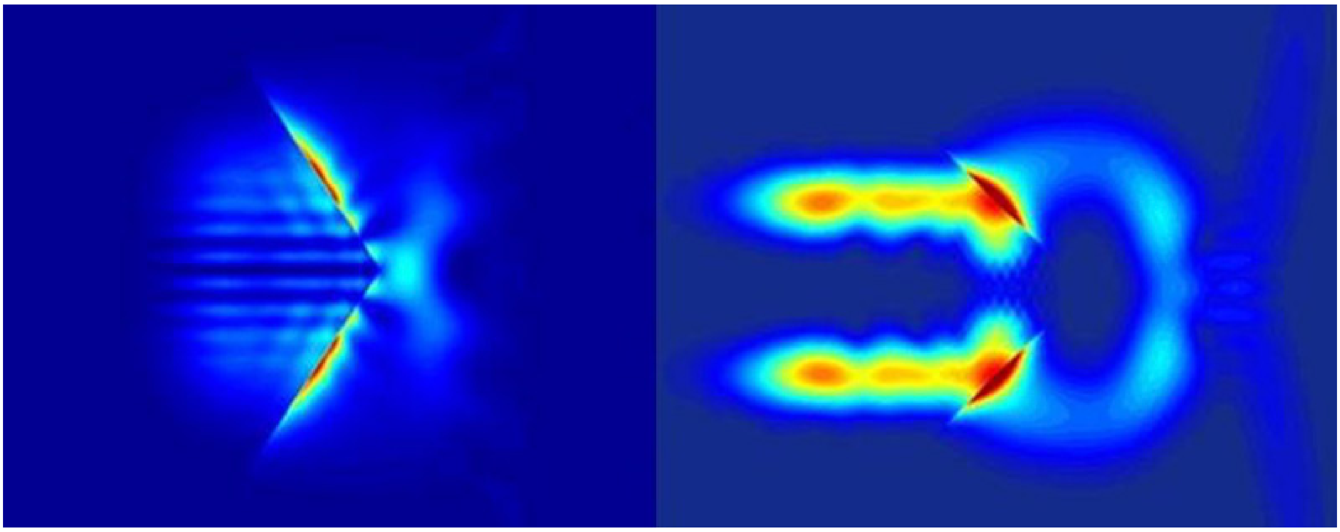
With our design and simulation methods customised optical elements and components can be designed, analysed and optimised in structure sizes both smaller and larger than the wavelength of light.

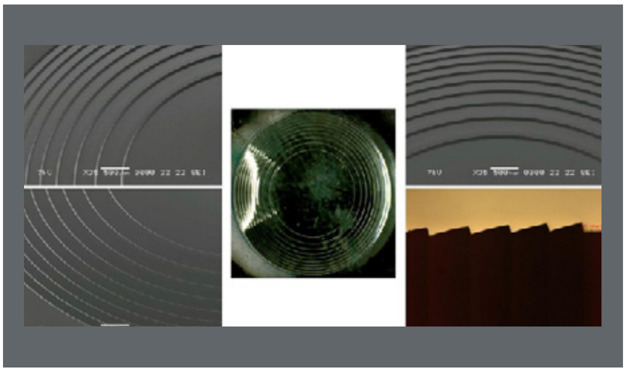
As a result of this virtual process in the course of optical simulation, geometric data of the (micro)optics are made available for production in the form of CAD files. These files can be used by customers for their in-house production.

We use following simulation methods and tools for the design and optical simulation of different optics:

- Calculation of free-form micro-optics for targeted light guidance
- Ray-tracing (ASAP, Zemax) - Simulation tools based on geometric optics
- Finite Difference Time Domain (FDTD Solutions) - simulation tool based on wave optics
- Multiscale simulation - holistic optical simulation of complex systems that include both refractive and diffractive optical components
- CAD (Rhino, Autocad)
- Creation of algorithms (MATLAB)

Snapshot of the interaction of a plane wave (intensity) with a triangular outcoupling structure to demonstrate the size influence of the structure in relation to the wavelength of the light





Example of a flat free-form optic for generating homogeneous illumination of a circular surface with sharp edges at a defined distance using a light source (LED) that is as point-shaped as possible

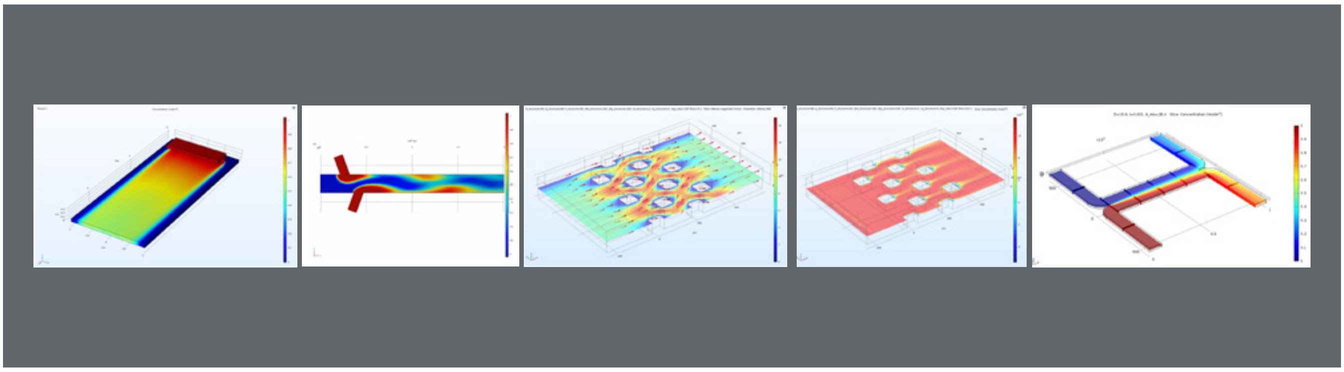
Example of foil optics with free-form micro-optic elements (structure height approx. 60 µm). Illumination of a white wall at a defined distance. The photos show the resulting illumination pattern and, in the foreground, the associated lighting setup

Microfluidics

After the design is complete, simulation tools are used to predict the behavior of the fluid flow in the microfluidic channels. This includes predicting pressure drop, flow rate, mixing, and diffusion.

We focus on

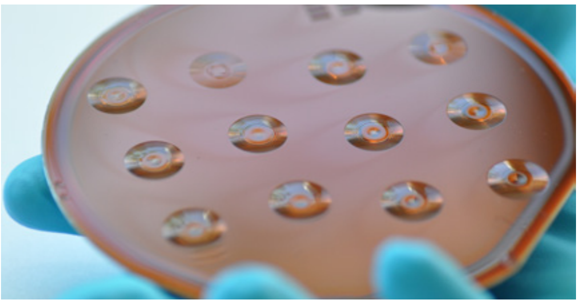
- Multiphysics simulation (flow, diffusion, species, particles,..)
- Simulation of fluid dynamics (CFD) to optimise design
- Optical simulations to increase S/N
- Layout for photomasks & imprinting tools

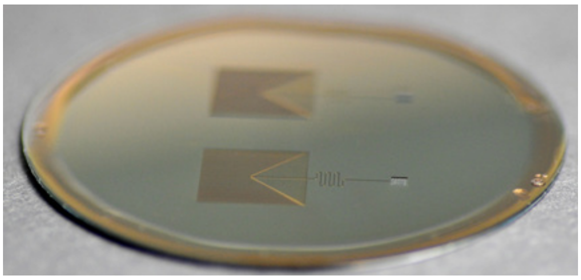


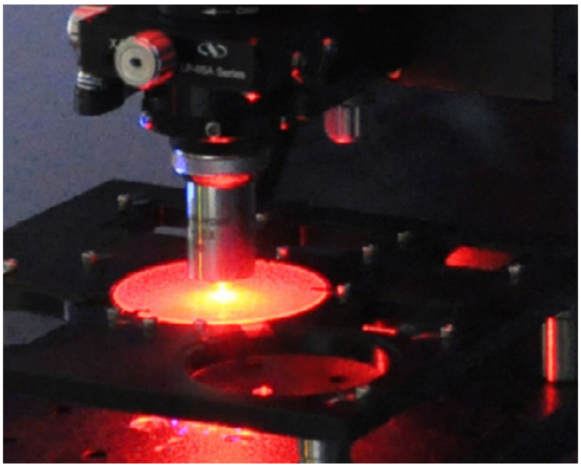
ORIGINATION OF MASTER STRUCTURE

Our unique mask-less laser lithography enables the low-cost production of novel and complex high-resolution sub-micro and micro-structures:

MALA
MASKLESS LASER LITHOGRAPHY







- Master fabrication e.g. for UV-NIL, hot-embossing, high precision optical injection moulding, vacuum resin casting
- Rapid prototyping in Micro-Optics, Photonics, Microfluidics, Electronics and others

Several advantages can be realised:

- Reduction of process time
- Digital, non-photomask-based production
- quick and flexible to test and implement design changes
- fabrication of microstructures on flat and curved substrates via 5-axes nano-positioning system

Our technology allows high quality fabrication of sub-micro and micro-structures on large area formats
(2", 4", possibly 6" substrate). The structures can have a one-(1D), two-dimensional (2D), or stepless (2.5 D) relief shape.

The minimum structure size achieved in the lateral direction (critical dimension) of our system is in the range of 200 nm. The maximum structure depth for 2.5D microstructures is in the range of 60 µm. An aspect ratio of 4 is possible.

Depending on the complexity of the designed microstructure, the processing time is approx. 1 hour per cm^2.

Applications can be found in

- Free form micro optics for innovative illumination designs
- Diffractive and refractive micro optical elements
- Bionic surfaces in aviation for reduction of drag to reduce fuel consumption
- Microfluidic Lab-on-Chip systems for molecular diagnostics
- Micro-Electronics

UPSCALING FOR LARGE AREA TOOLING – STEP AND REPEAT

Step & repeat imprint solutions for the large-scale production of flexible shims and innovative prototypes

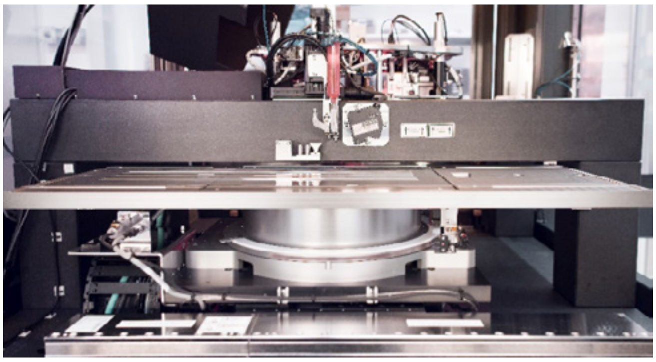
We use a specially modified EVG770 Nano-Imprint Lithography (NIL) stepper for the production of flexible embossing tools for roller-based NIL in the fields of photonics, functional surfaces and microfluidic systems.

Nano-Imprint Lithography is, compared to other lithographic methods, a cost-effective structuring technology and therefore ideally suited for the use in high volume manufacturing processes. However, the associated time for the production of working stamps (shims) for industrial roll-to-roll imprinting as well as their cost is still significant.

By the development of the step+repeat technology for large-area foil substrates we were able to close the gap between small format masters and large-area shims.

This enables a remarkably higher process flexibility and further **reduction of process costs** in the field of nanoimprint technology. The adaptation of the EVG770 system together with EV Group included a sample intake extension for wafer geometries on large-area foil substrates. Using UV-NIL step+repeat technology, flexible polymer-based shims are created for the use in roll-to-roll imprinting processes. The new approach combines the **very high positioning accuracy** known from semiconductor technology with foil-based high-throughput methods and offers a cost-effective and industry-compatible alternative to the direct use of conventional time consuming nanostructuring methods.

We offer research pilot lines for the development and implementation of new product ideas and manufacturing processes to its customers and partners, from the idea to the prototype. The **pilot line for roll-to-roll micro- and nanostructuring** covers simulation, design and material development (coatings, imprint resins) and offers large-scale structuring and structure replication from mastering to roller-based manufacturing. The EVG770 NIL stepper completes this pilot line with regard to the production of large-area working stamps.



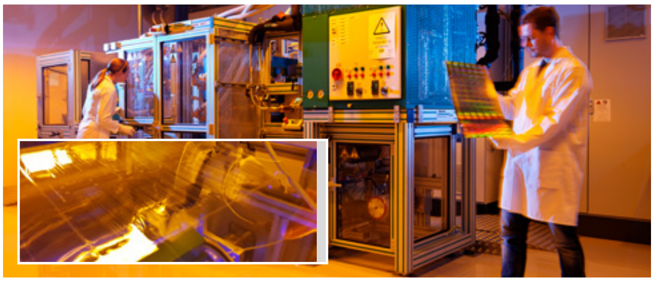
Advantages:

- cost-effective
- industry-compatible
- flexible
- accurate positioning

Technical data:
Technology: ■ UV nanoimprinting
Maximum substrate surface: ■ Width: 270 mm Length: 700 mm
Position accuracy Stage: ■ 1 µm

PRE SERIES PRODUCTION – ROLL-TO-ROLL – R2R

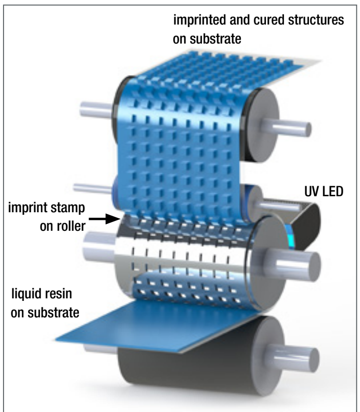
Large area micro- and nanostructuring of foil-based materials for industrial production



We have been involved in the development of manufacturing processes for optical, optoelectronic and electronic components for more than 10 years. The established knowledge in design, fabrication, characterization and optimization is now available to industry in combination with the roll-to-roll pilot line for the development of sustainable industry compatible manufacturing processes.

The utilization of roll-based imprinting processes enables the mass fabrication of micro- and nanostructures on large and flexible substrate materials. These can be used in optical, electronic, sensory or bionic applications. Roll-to-roll micro- and nanostructuring thus forms the basis for the development of novel and cost effective products in Key Enabling Technology fields such as biotechnology, nanotechnology, as well as advanced materials or advanced manufacturing and production technologies.

This continuous roll-to-roll process relies on a number of steps: (i) After unwinding, a flexible substrate plastic film is coated with the UV curable resin. Our NILcure® imprint resin portfolio offers a wide range of possibilities and the resin can be tailored in terms of mechanical, chemical and optical properties. (ii) The coated substrate is then guided to the imprinting station, where a stamp with the desired surface pattern is pressed into the liquid resin. The stamp is usually a nickel or polymer sheet with excellent anti-sticking properties wrapped around the imprinting roller. (iii) While in contact with the stamp, the resin is cured by UV light. Afterwards the imprint is demolded and wound up.



Sketch of the Roll-to-Roll Imprinting Unit

Specification:

Resist coating by means of gravure printing or slot die coating	Coating thickness range	200 nm – 200 µm
UV imprinting and hot embossing	UV LED irradiance Mercury vapour lamp	max. 14 W/cm², 365 or 395 nm max. 18 W/cm², broadband
	Line pressure UV imprinting	max. 60 kN/m
	Line pressure hot embossing	max. 330 kN/m
	Temperature hot embossing	max. 200°C
Lamination	UV lamination	
Substrate	Transparent films	width 250 mm
Throughput	Web speed	0.5 – 30 m/min
Pre-treatment	Corona	max. 1000 W
In-line characterisation	Line scan camera	Resolution 5 µm
	White light interferometry	200 nm – 200 µm

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