TECHNOLOGIEN FÜR MORGEN

JOANNEUM RESEARCH

Zukunftskonferenz

20.9.2022

messe congress graz

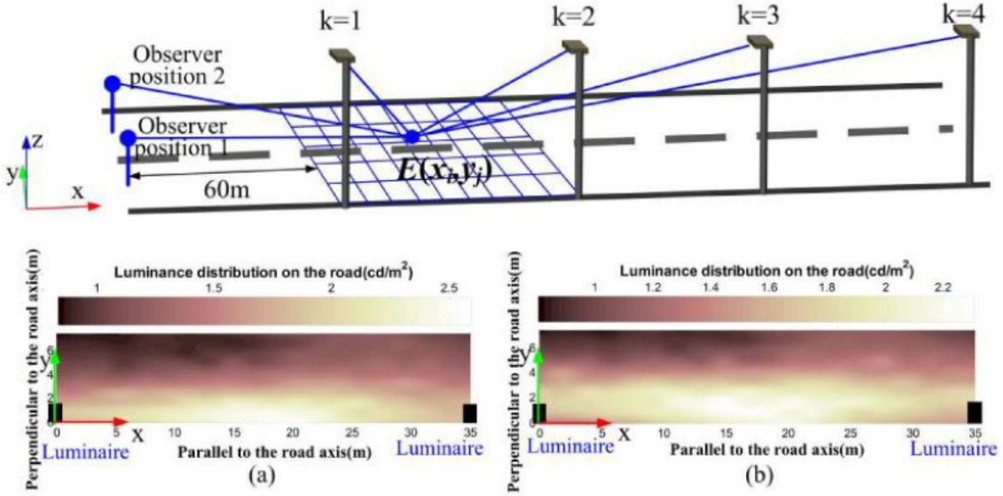
#zuko

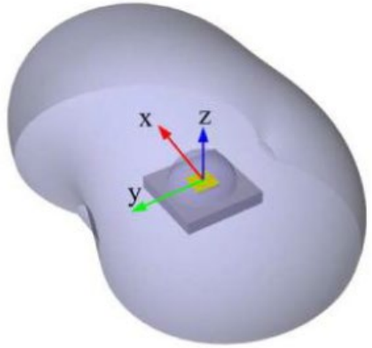
Motivation: Free-Form Optics

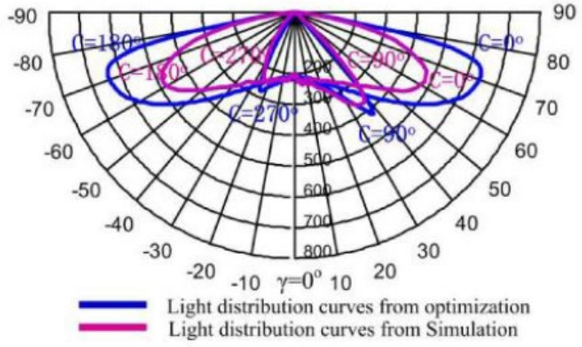
- Due to their nonrotational features, free-form optics can have almost an arbitrary surface and therefore offer incredibly high degrees of freedom compared to spherical optics.
- These high degrees of freedom e.g. allow the generation of tailored irradiance or radiant intensity distributions with a maximum of system performance or even combining the functionalities of different optical elements in one free-form surface.
- It’s not surprising that free-form optics has been a very hot topic of research and development over the last decades and has found wide application in many different fields.

Exemplary Application Fields

- Lighting







Feng, Z., Luo, Y., & Han, Y. (2010). Design of LED freeform optical system for road lighting with high luminance/illuminance ratio. *Optics express*, *18*(21), 22020-22031

Motivation: Free-Form Optics

- Due to their nonrotational features, free-form optics can have almost an arbitrary surface and therefore offer incredibly high degrees of freedom compared to spherical optics.
- These high degrees of freedom e.g. allow the generation of tailored irradiance or radiant intensity distributions with a maximum of system performance or even combining the functionalities of different optical elements in one free-form surface.
- It's not surprising that freeform optics has been a very hot topic of research and development over the last decades and has found wide application in many different fields.

Exemplary Application Fields

- Lighting
- Automotive
- VR and AR
- Imaging Systems
- Displays
- Optical Sensors
- Telescopes
- Projectors
- Photovoltaics

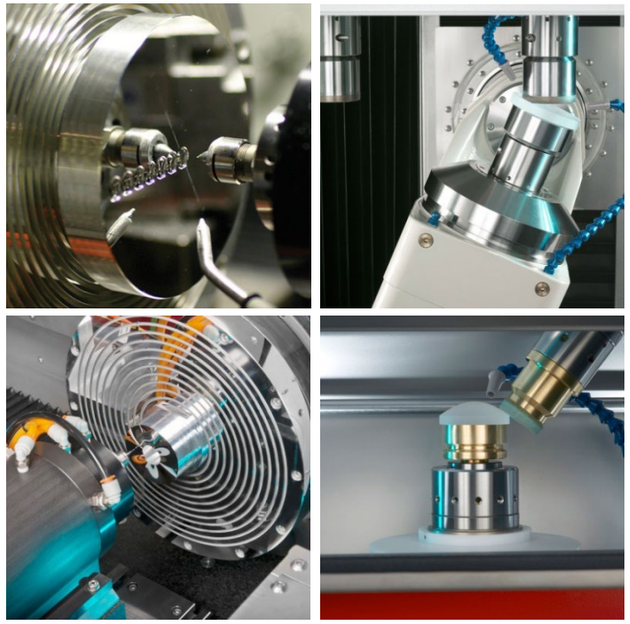
And Many More ….

TECHNOLOGIEN FÜR MORGEN

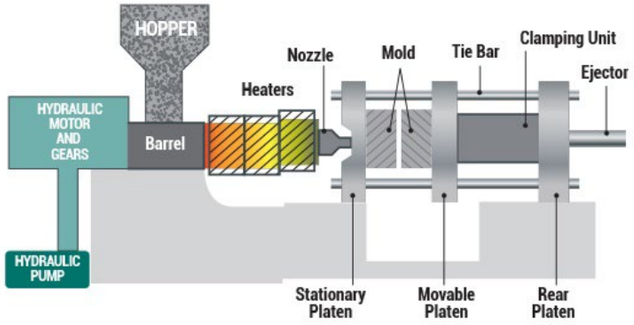
JOANNEUM RESEARCH

Origination methods of optics and freeform optics:

- Diamond Turning
- Milling
- Grinding
- Polishing



Replication of the optics with injection molding:



Our Vison:

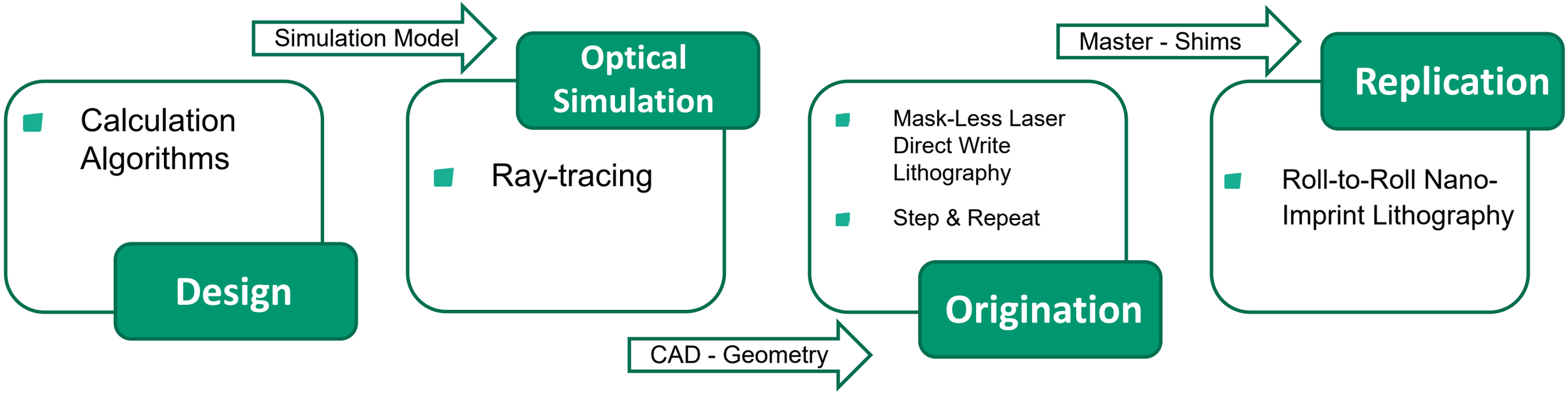
"Free-Form Micro Optical Elements"

Optical structures with a scalable height in the range of a few tens of µm with optical features comparable to voluminous free-form optics.

- Significantly lower material consumption
- Enabling new cost-effective fabrication methods like e.g.:
  - Laser writing processes for origination
  - Roll-to-Roll replication process for „Printing optics like newspapers"

Value Chain for Developing Free-Form Micro Optical Elements @ JR Materials

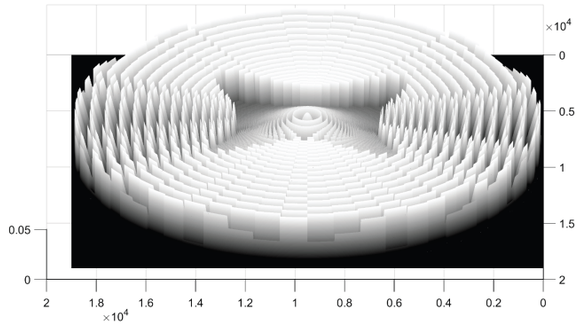
- Our Value Chain comprises all necessary steps from the idea to the manufactured structures on a foil. In detail, it can be subdived into the **Design**, the **Optical Simulation**, the **Origination** and the **Replication** process.

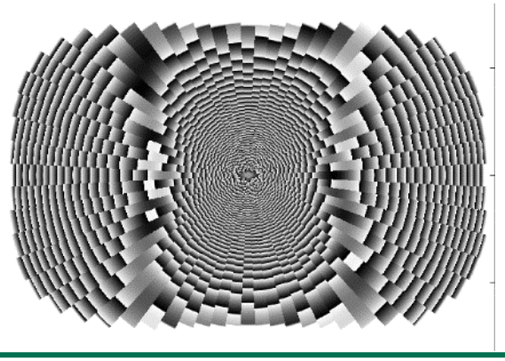


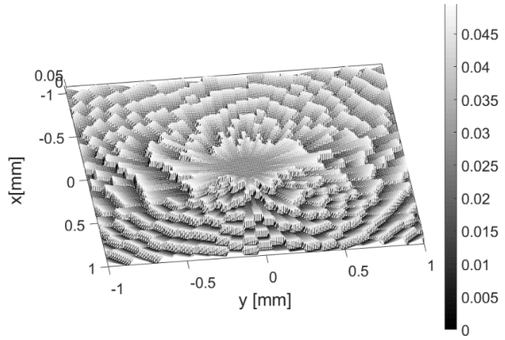
Value Chain for Developing Free-Form Micro Optical Elements @ JR Materials

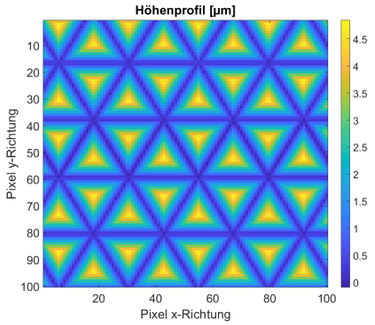
- During the **Design Process** the shape of the free-form micro optical elements is calculated using self-developed algorithms. Additionally a **Simulation Model** of all relevant optical parts of the system is build and is passed to the next process.

Design









Simulation Model

Design

- Calculation Algorithms

Optical Simulation

- Ray-tracing

Origination

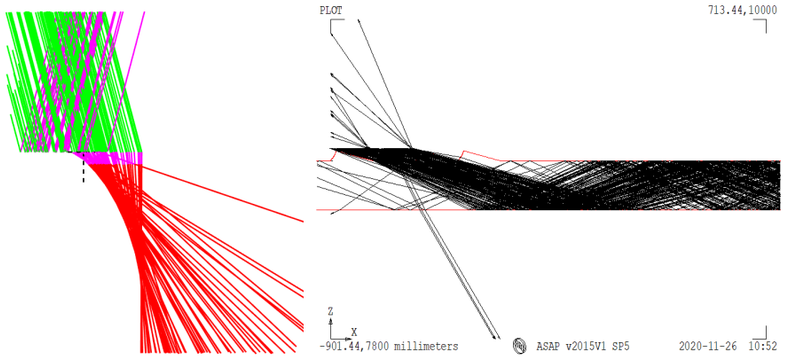
- Mask-Less Laser Direct Write Lithography
- Step & Repeat

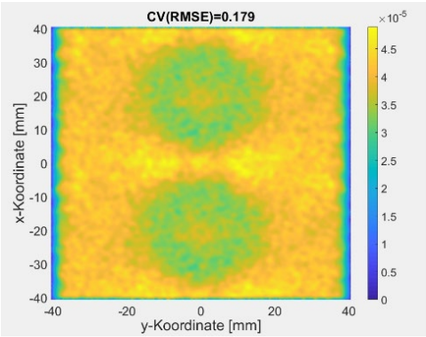
Replication

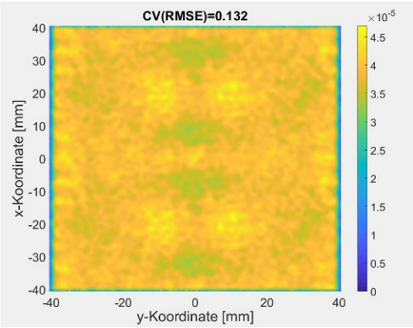
- Roll-to-Roll Nano-Imprint Lithography

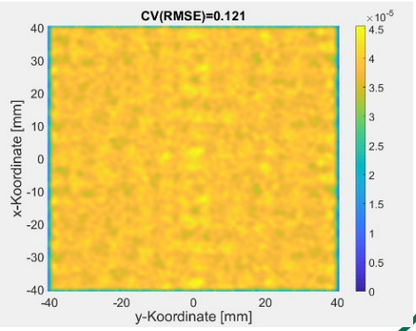
Value Chain for Developing Free-Form Micro Optical Elements @ JR Materials

- During the **Optical Simulation** process the optical functionality of the calculated free-form micro optical elements is verified by means of ray-tracing simulations. Furthermore a **Iterative Feedback Loop** between design and optical simulation is used to enhance the functionality of the structures. After completion of this step, a **CAD geometry** of the structures is transferred to the next process.









Optical Simulation

Design

- Calculation Algorithms

Optical Simulation

- Ray-tracing

Origination

- Mask-Less Laser Direct Write Lithography
- Step & Repeat

Replication

- Roll-to-Roll Nano-Imprint Lithography

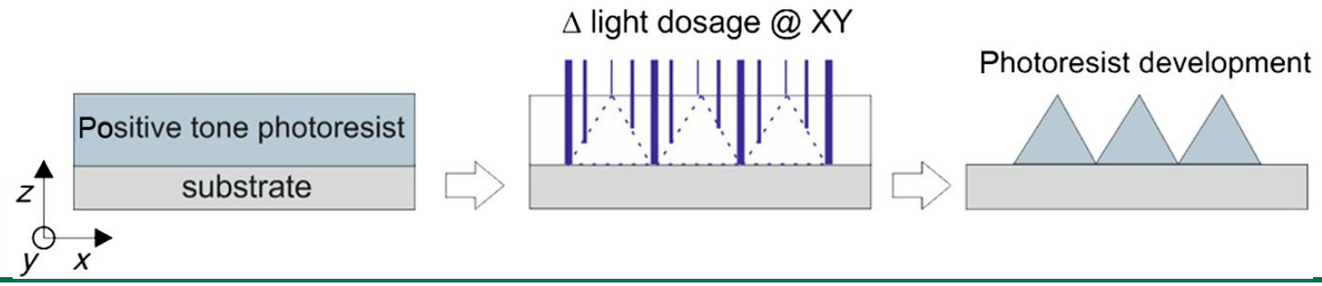
Iterative Feedback Loop

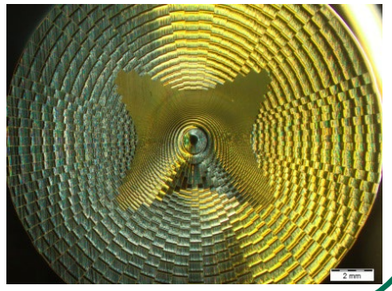
CAD - Geometry

Value Chain for Developing Free-Form Micro Optical Elements @ JR Materials

- During the **Origination** process the CAD geometry is converted into a virtual photomask, where every z-value of the geometry is represented by a corresponding light dosage. The laser applies these light doses at the corresponding x-y positions in a positive photoresist so that after a chemical development step the structures are formed by removing the exposed areas of the photoresist. The master structures produced in this way can be duplicated by a step & repeat system using the nano imprint lithography process to produce **Master Shims** for the next process step.

Origination





Design

- Calculation Algorithms

Optical Simulation

- Ray-tracing

Origination

- Mask-Less Laser Direct Write Lithography
- Step & Repeat

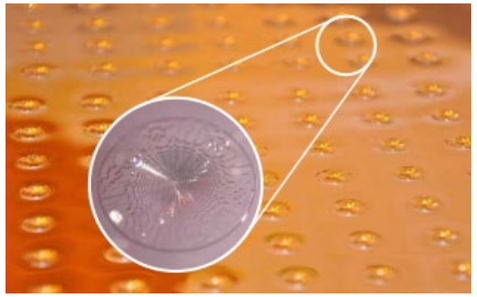
Master - Shims

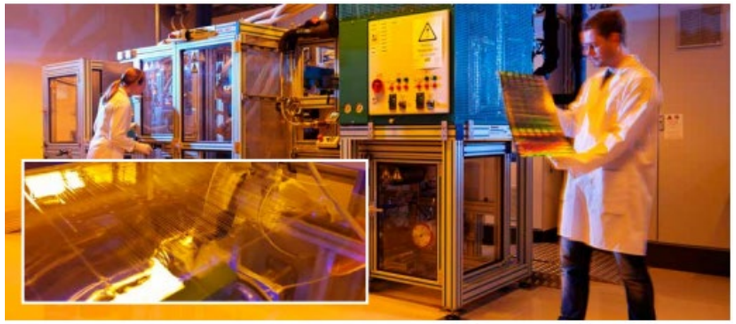
Replication

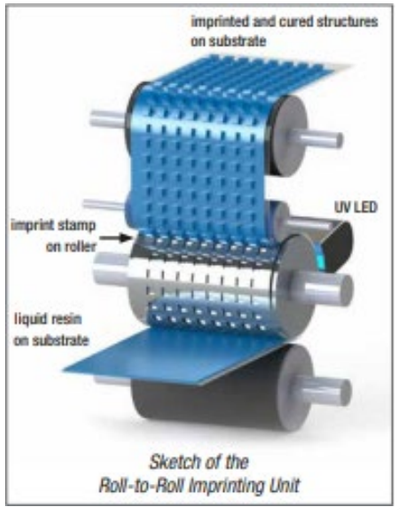
- Roll-to-Roll Nano-Imprint Lithography

Value Chain for Developing Free-Form Micro Optical Elements @ JR Materials

- The roll-to-roll nano imprint lithography method enables the mass fabrication of the developed optical micro structures in an continuous process: After unwinding, a flexible substrate plastic film is coated with the UV curable resin. The coated substrate is then guided to the imprinting station, where the master shim is pressed into the liquid resin. 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

Replication

Design

- Calculation Algorithms

Optical Simulation

- Ray-tracing

Origination

- Mask-Less Laser Direct Write Lithography
- Step & Repeat

Replication

- Roll-to-Roll Nano-Imprint Lithography

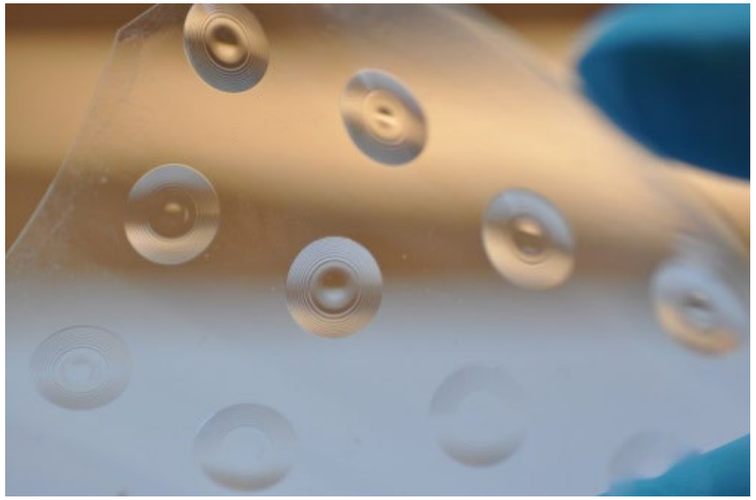
JOANNEUM RESEARCH

Free-Form Micro Optical Elements for complex light management

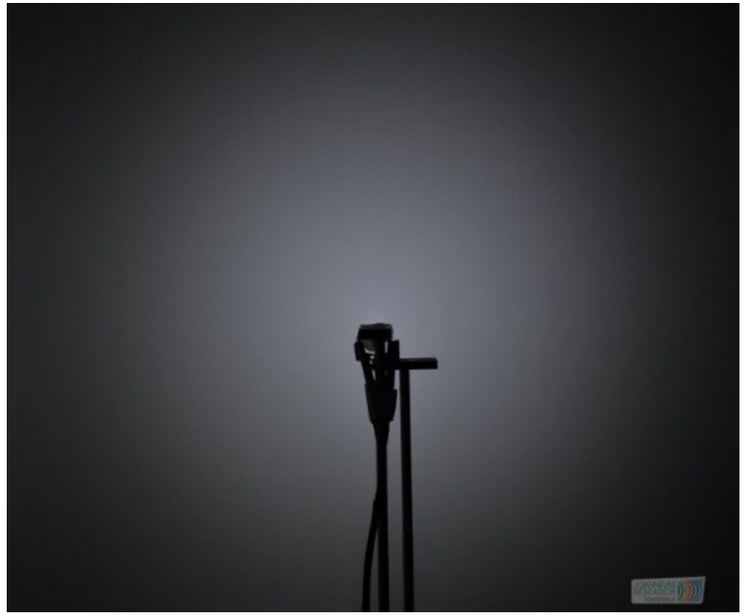
- So called Free-Form optics offer new opportunities to optical designers in many different fields as it can generate tailor-made radiation patterns or irradiance distributions in a target area in a very efficient way that cannot be achieved with conventional optics.
- Free-Form-Micro-Optical-Elements (FF-MOEs) developed at JR can reach comparable light management capabilities as convectional Free-Form optics but are notable for their low height in the range of a few 10s of µm.
- This low height emphasizes the use of cost-effective origination methods like mask-less laser direct write lithography and large scale reproduction methods like e.g. a roll-to roll (R2R) UV-NIL process.

Example: Realizing an optic which is homogenously redistributing the emitted light of an LED into a circular area.

FF-MOEs on Substrate



Without FF-MOE



With FF-MOE

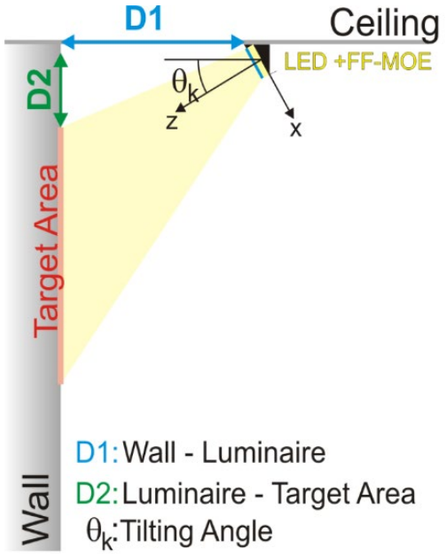
TECHNOLOGIEN FÜR MORGEN

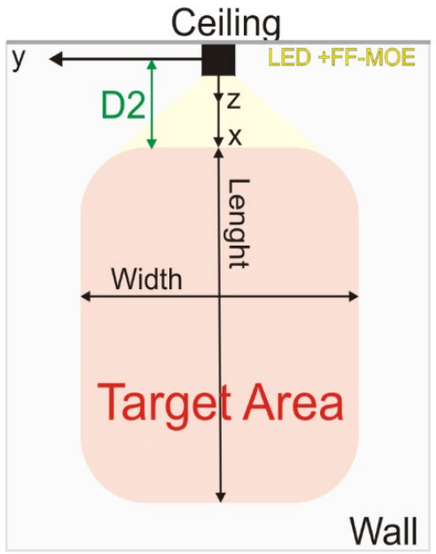
JOANNEUM RESEARCH

Free-Form Micro Optical Elements for complex light management

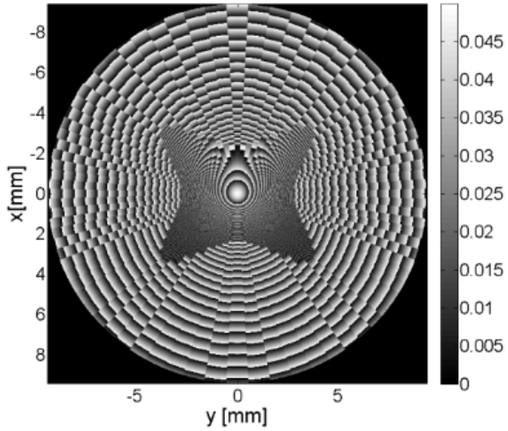
- So called Free-Form optics offer new opportunities to optical designers in many different fields as it can generate tailor-made radiation patterns or irradiance distributions in a target area in a very efficient way that cannot be achieved with conventional optics.
- Free-Form-Micro-Optical-Elements (FF-MOEs) developed at JR can reach comparable light management capabilities as convectional Free-Form optics but are notable for their low height in the range of a few 10s of µm.
- This low height emphasizes the use of cost-effective origination methods like mask-less laser direct write lithography and large scale reproduction methods like e.g. a roll-to roll (R2R) UV-NIL process.

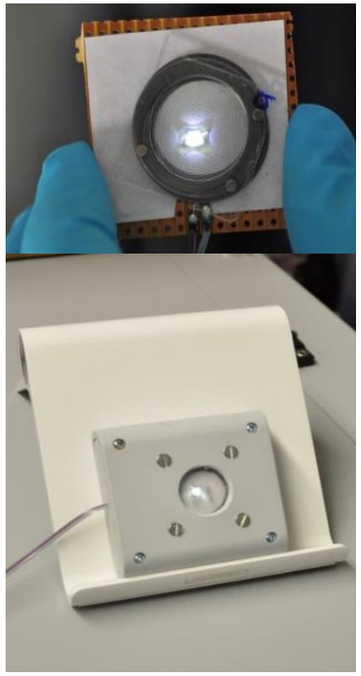
Example: Realizing a wall wash optic, which redistribute the light into an oval area on an adjacent wall.





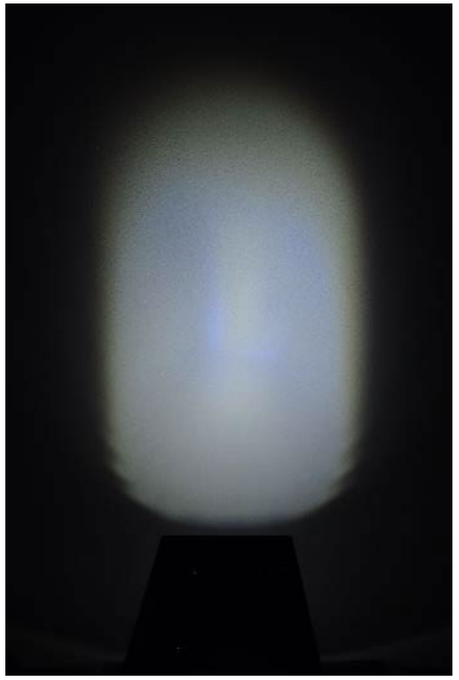
FF-MOE Structure





Without FF-MOE

With FF-MOE



TECHNOLOGIEN FÜR MORGEN

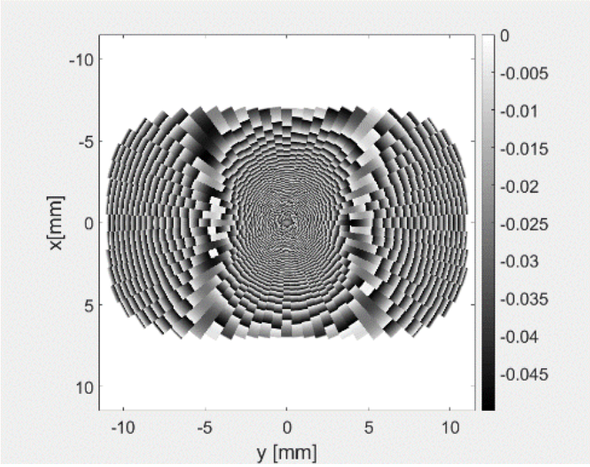
Phabulous

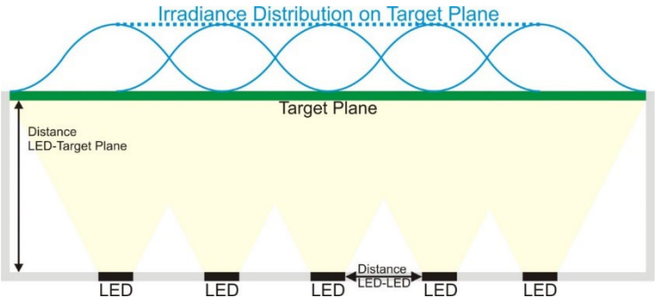
JOANNEUM RESEARCH

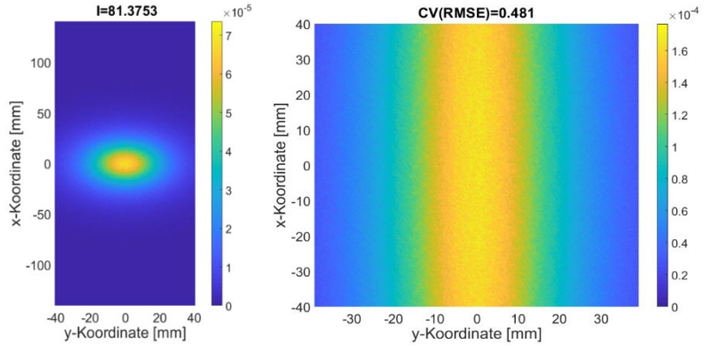
Free-Form Micro Optical Elements for complex light management

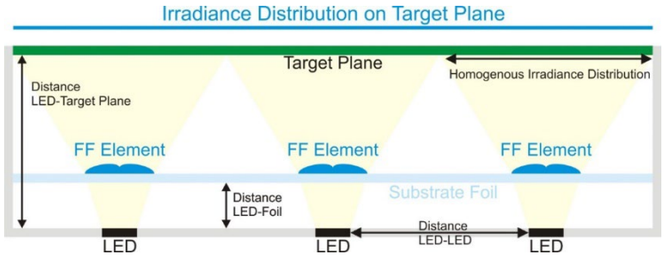
- So called Free-Form optics offer new opportunities to optical designers in many different fields as it can generate tailor-made radiation patterns or irradiance distributions in a target area in a very efficient way that cannot be achieved with conventional optics.
- Free-Form-Micro-Optical-Elements (FF-MOEs) developed at JR can reach comparable light management capabilities as convectional Free-Form optics but are notable for their low height in the range of a few 10s of µm.
- This low height emphasizes the use of cost-effective origination methods like mask-less laser direct write lithography and large scale reproduction methods like e.g. a roll-to roll (R2R) UV-NIL process.

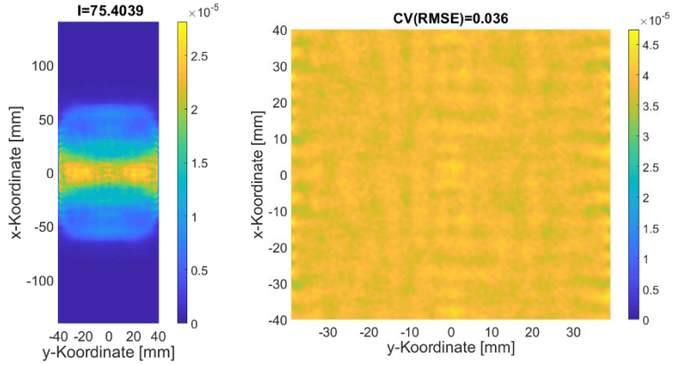
Example: Realizing an optic for a direct lit luminaire for interior lighting in trains, developed in the framework of the European Union's Horizon 2020 pilot line project Phabulous.









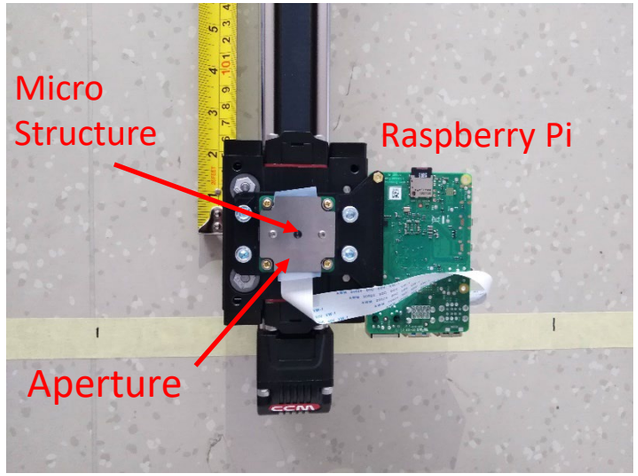


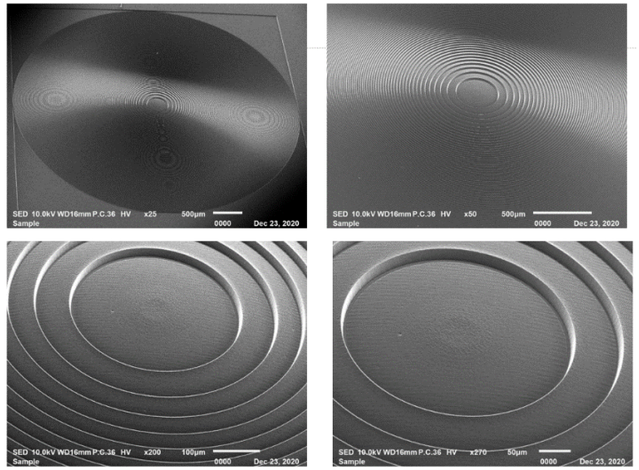
57 WW LEDs/m → 25 WW LEDs/m

57 KW LEDs/m → 25 KW LEDs/m

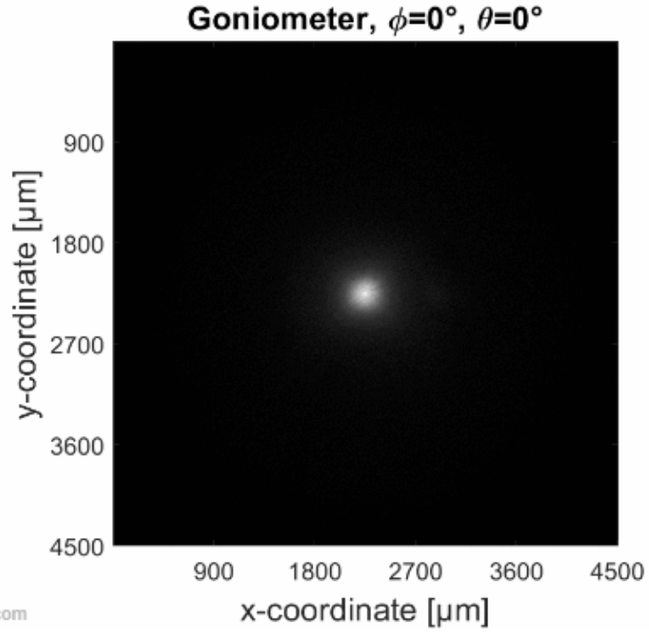
Free-Form Micro Optical Elements for Sensor Applications

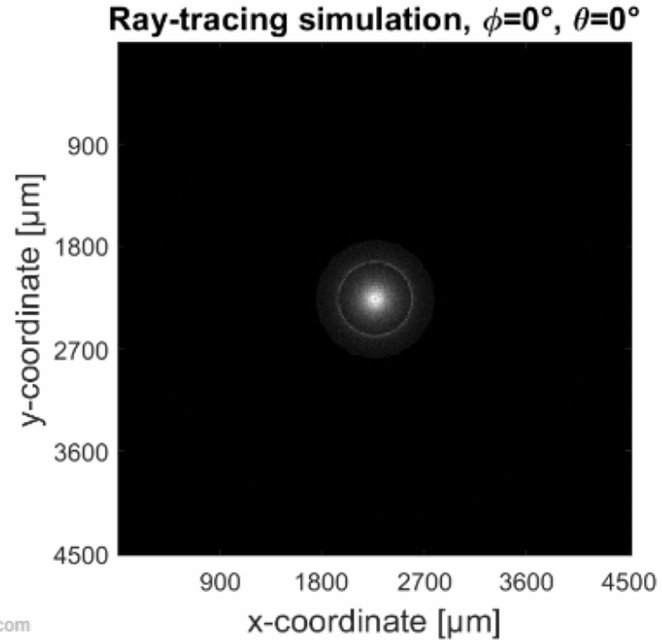
- System to determine the position of a device in indoor environments using the room light as signal beacons .
- The optical micro structure is used to refract incident light on different positions on the underlying CMOS chip, whereby these positions directly correlate to the angles of incidence.
- The pictures taken with the CMOS chip are pure light distributions so that the abuse of privacy rights is excluded.
- By means of a special evaluation algorithm of the images taken, the positions of the light sources relative to the device can be determined.
- The use of optical micro structures with an diameter of 5 mm and a maximal hight of 20 µm allows for a very compact receiver design with an height less than 2 mm and a very high field of view of 140°.





Comparison between experiment and optical simulation of the generated light distributions on the CMOS chip for different angles of incidence





Conclusio

- FF-MOEs for light management are proving to very promising for the future as they have
  - similar optical functionalities like free-form optics in terms of generation of tailored irradiance or radiant intensity distributions with a maximum of system performance or combining the functionalities of different optical elements into one structured surface,
  - many different application fields,
  - the potential to save materials in comparison to voluminous optics,
  - and the advantage to be originated and manufactured cost-effectively with alternative approaches like the mask-less grayscale laser lithography and the nano-imprint lithography roll-to-roll processes.

Danke für Ihre Aufmerksamkeit!

JOANNEUM RESEARCH
Forschungsgesellschaft mbH

Leonhardstraße 59
8010 Graz

Tel. +43 316 876-0
prm@joanneum.at

www.joanneum.at

JOANNEUM RESEARCH