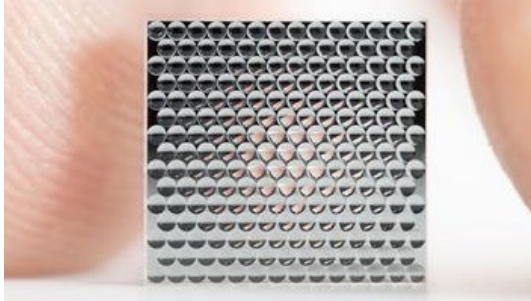Dr. Norbert Danz et al.

# Efficient, maskless pattern shaping for lighting and projection

Fraunhofer Institute for Applied Optics and Precision Engineering (IOF), Jena, Germany
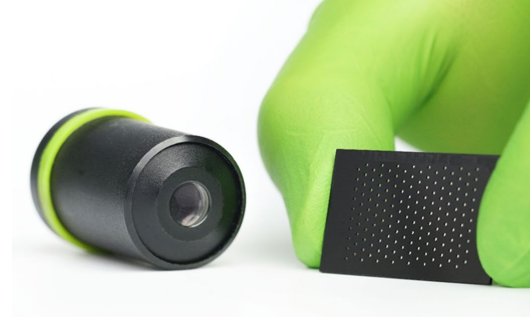
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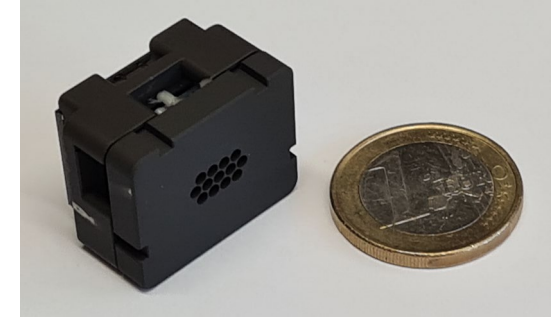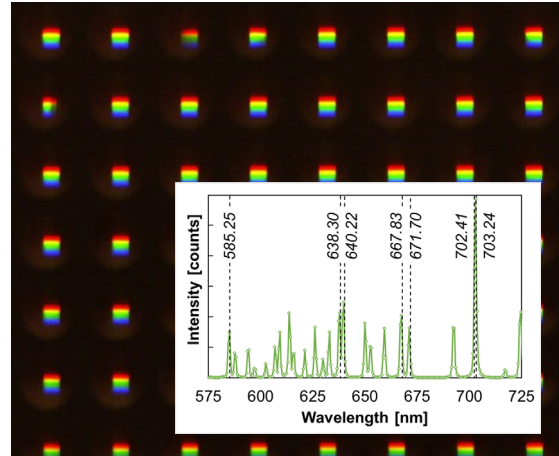# Micro-optical systems @ Fraunhofer IOF



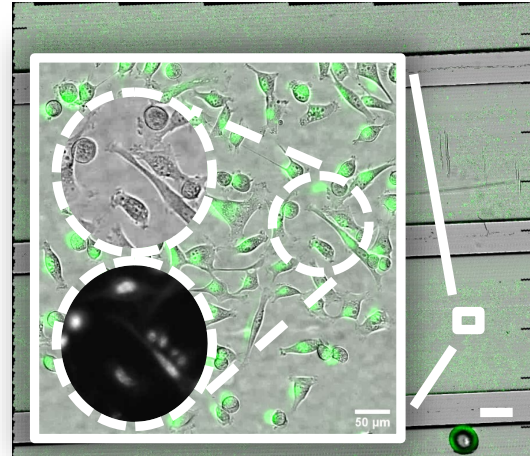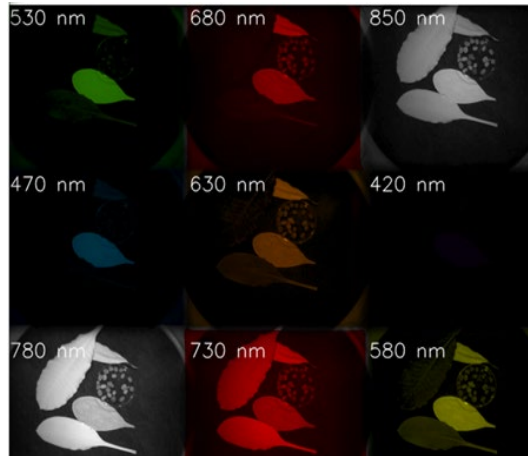**Illumination & Shaping**

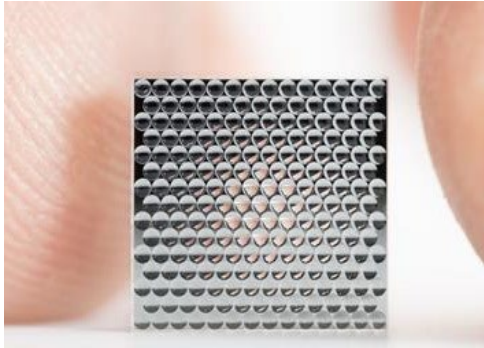**Multi-modal imaging**

**Miniaturized Microscopy**

**Integrated Spectroscopy**

# Light carpet approach

## From micro-optical projection to headlamps


Arrayed projector


BMW  Welcome Light Carpet (2015)

$$F_{IN} = F_{OUT}$$

$$F_{IN}$$

$$F_{OUT}$$


Lucid Air 2022


Hyundai Genesis 2022
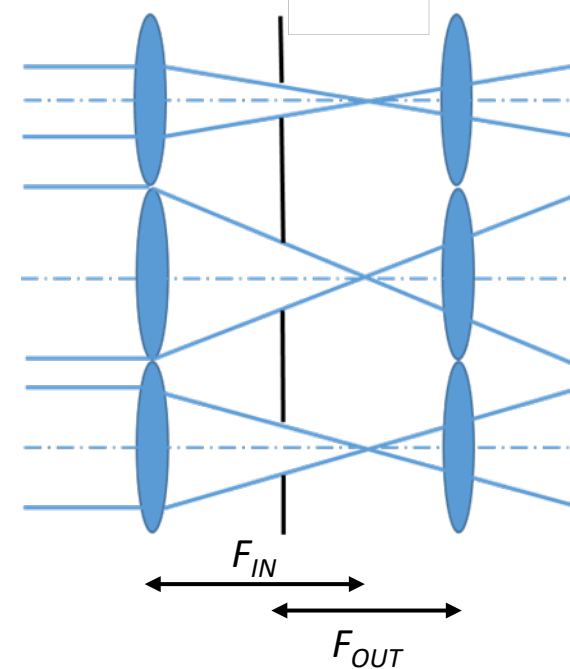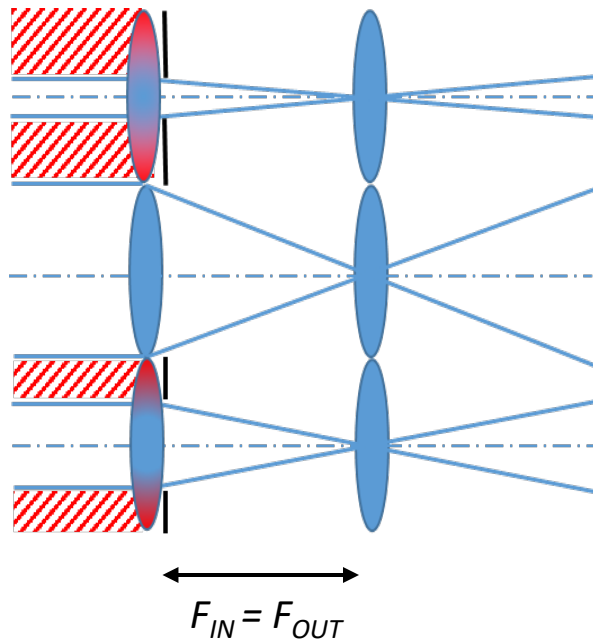
**Mask layer issues**

- Light losses → efficiency drop
- Heat dissipation, element aging
- Additional fabrications steps required

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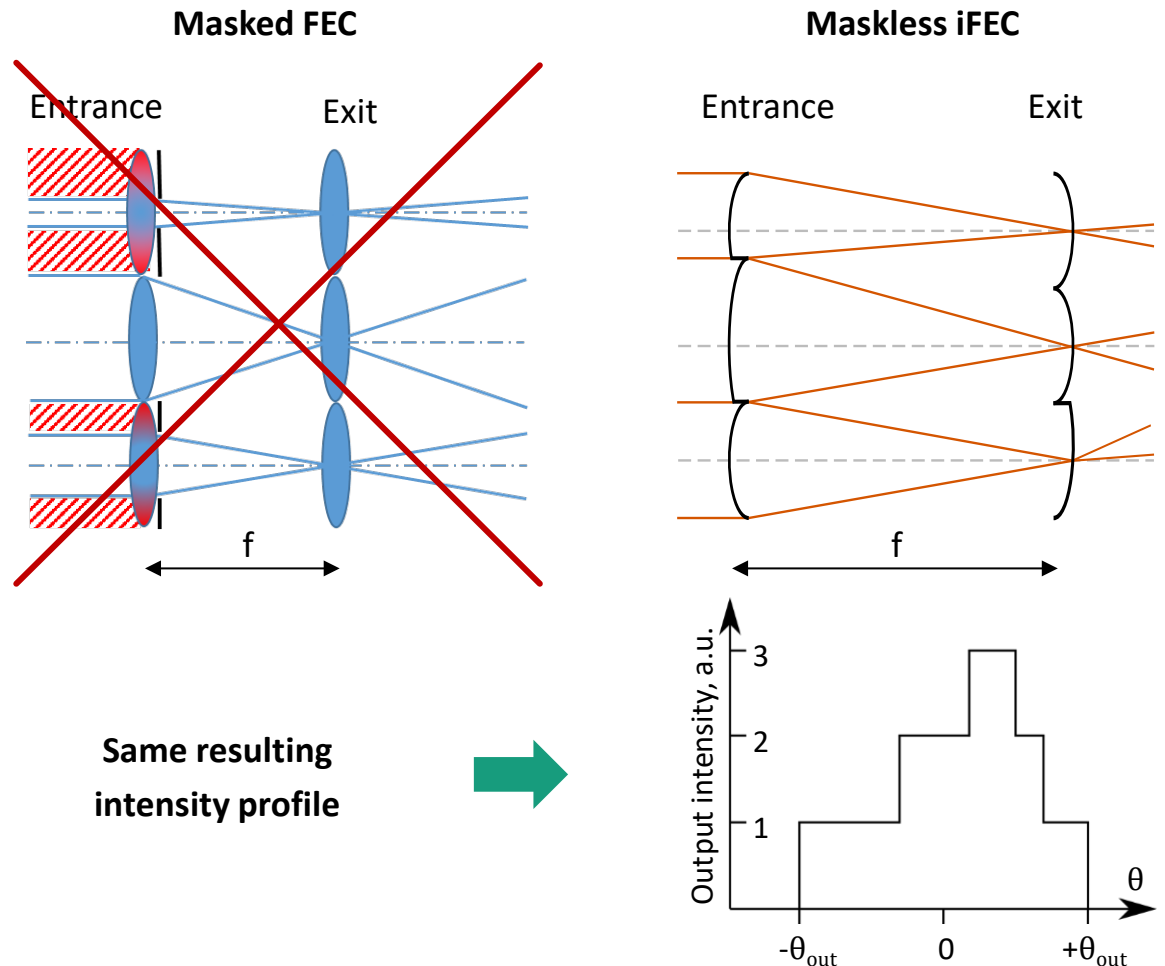IOF

# General design approach

## Irregular Fly's Eye Condenser (iFEC) for maskless shaping

**Masked FEC**

Entrance      Exit

f

**Same resulting intensity profile**

**Maskless iFEC**

Entrance      Exit

f

Output intensity, a.u.

3

2

1

$-\theta_{out}$    0    $+\theta_{out}$    $\theta$

### Goal(s)

- Flexibility → Arbitrary field distribution
- Efficiency → Without absorbing masks

### Solution: iFEC

- Variable pitch of entrance lenslets
  - ➢ Vertices on the channel's axis
  - ➢ Aperture might be decenterd
- Constant pitch of projection lenslets
  - ➢ Vertices might be decentered
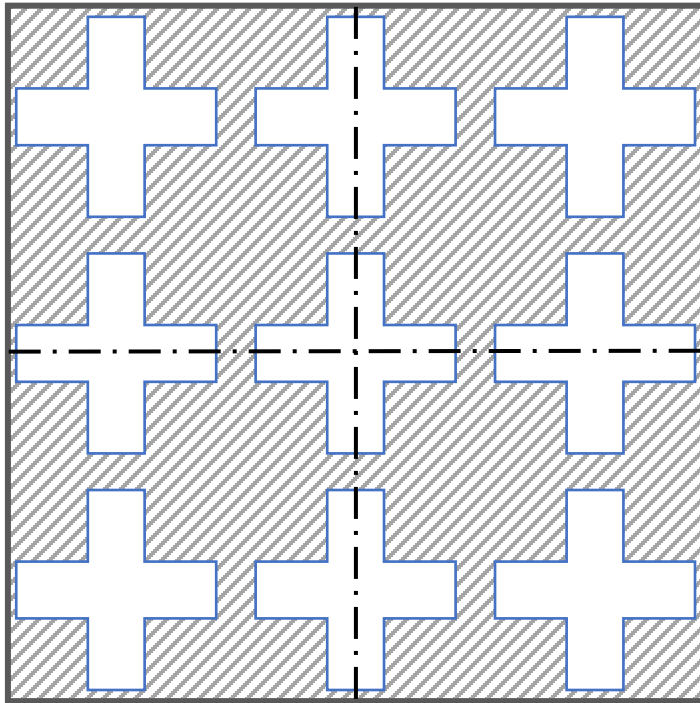
**Micro slides**      → **irregular lenslets**

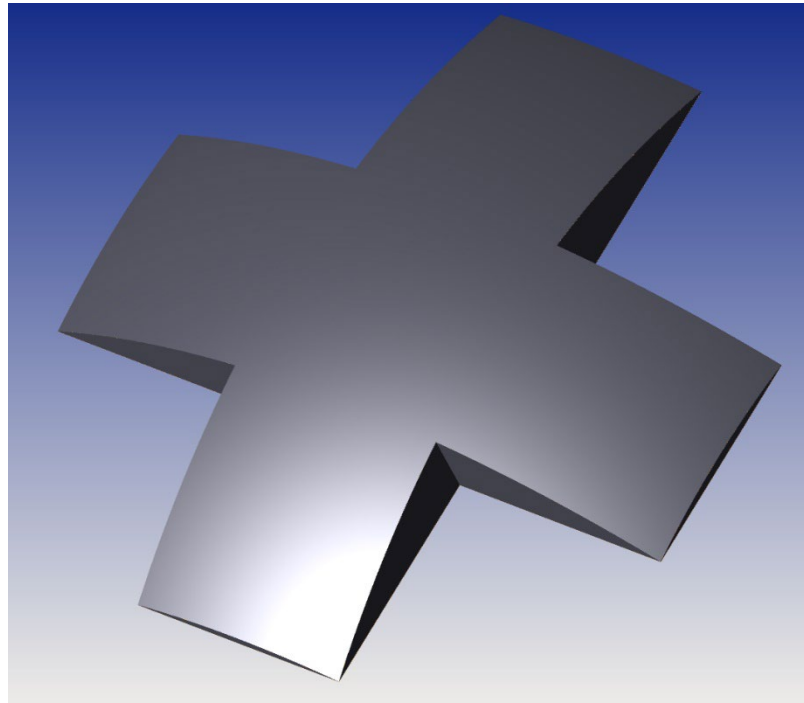**Max efficiency** ←      → **max entrance fill factor**

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# General design approach

## Arbitrary shaped entrance lenslets
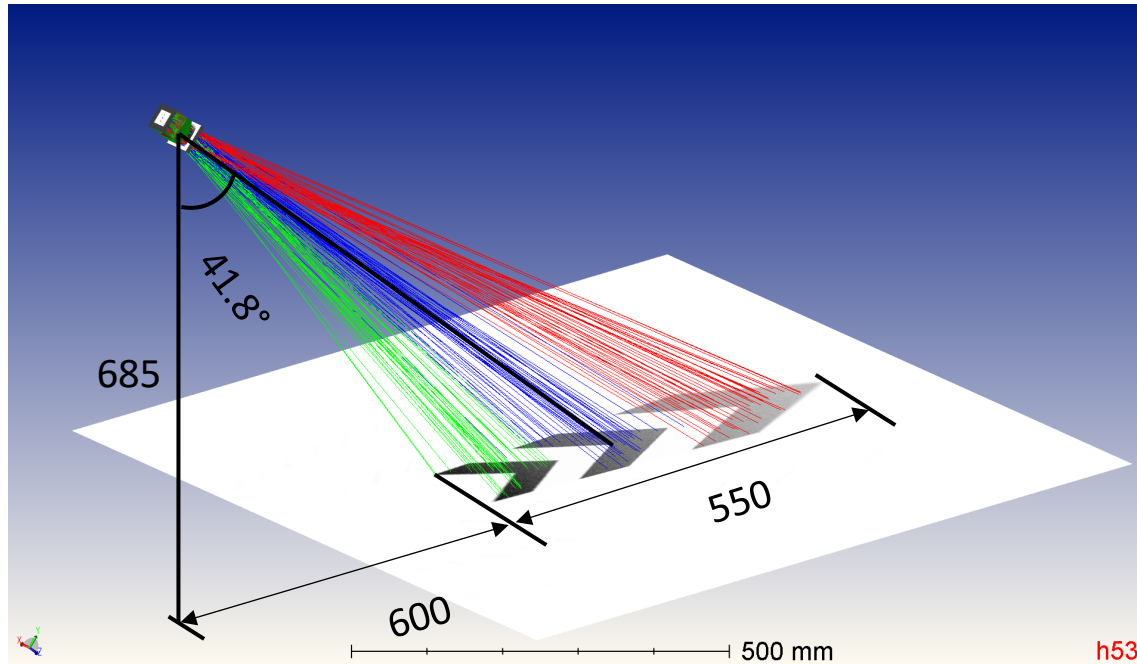
Masked MLA projector

Entrance lenslet as object

Maskless MLA projector
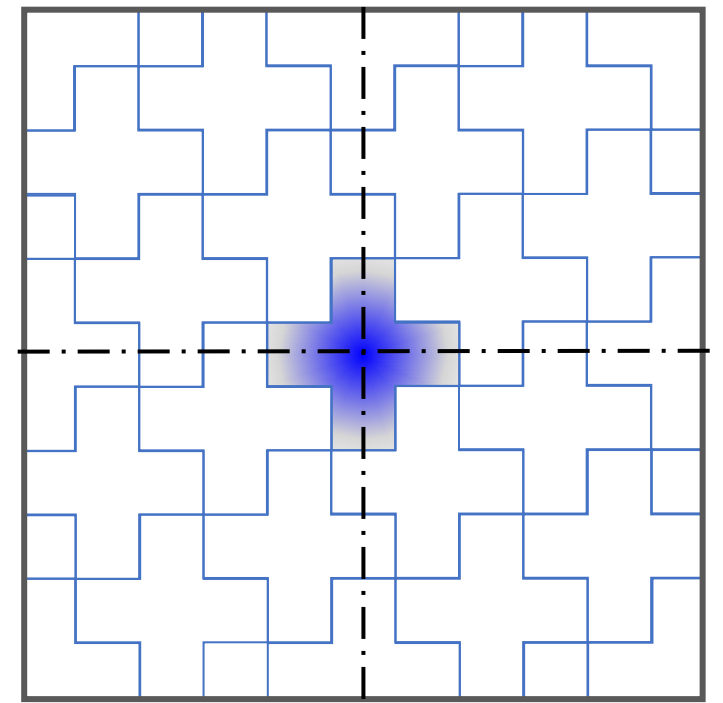


**Fill-factor < 55%**

**Fill-factor ≈ 100%**

# Application – Symbol ground projection
## Car-to-X communication: Turn indicator



41.8°

685

550

600

500 mm

h53

**Projection on tilted surface (road)**

**Challenges**

- Semi-dynamic projection desired

- Tradeoff between brightness & daylight visibility vs. aperture / projector size

**Approach**

- Size → One common projector for all chevrons

- Exploit 'crosstalk' to generate multiple chevrons

Kundu, Rohan, et al. "Multi-aperture pattern projection using arbitrary shaped microlenslets." Current Developments in Lens Design and Optical Engineering XXIV. Vol. 12666. SPIE, 2023

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# Application – Symbol ground projection

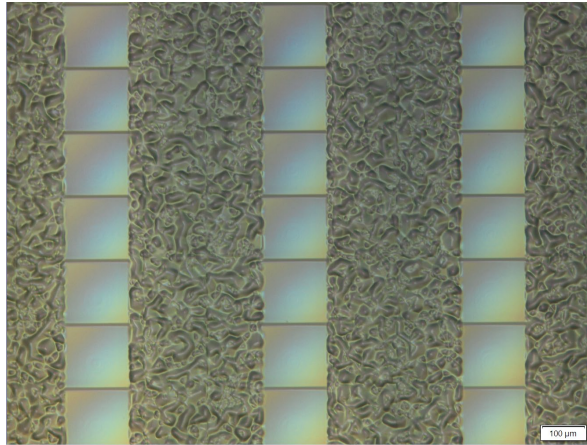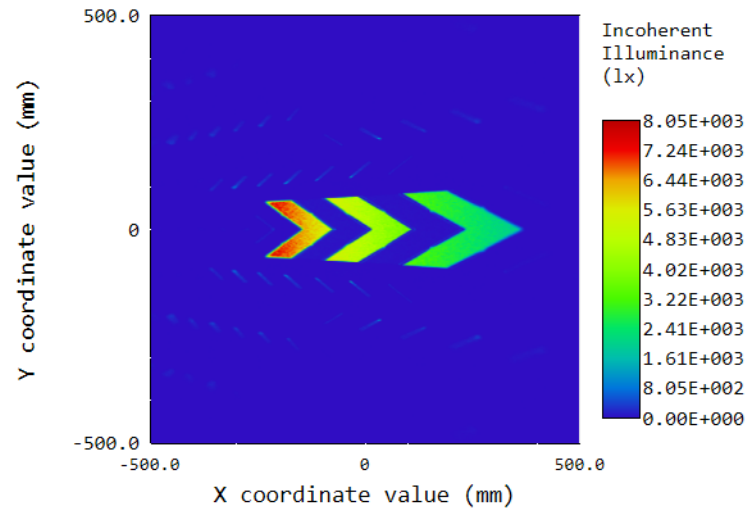## Symbol ground projection for turn indication



Kundu, Rohan, et al. "Multi-aperture pattern projection using arbitrary shaped microlenslets." Current Developments in Lens Design and Optical Engineering XXIV. Vol. 12666. SPIE, 2023

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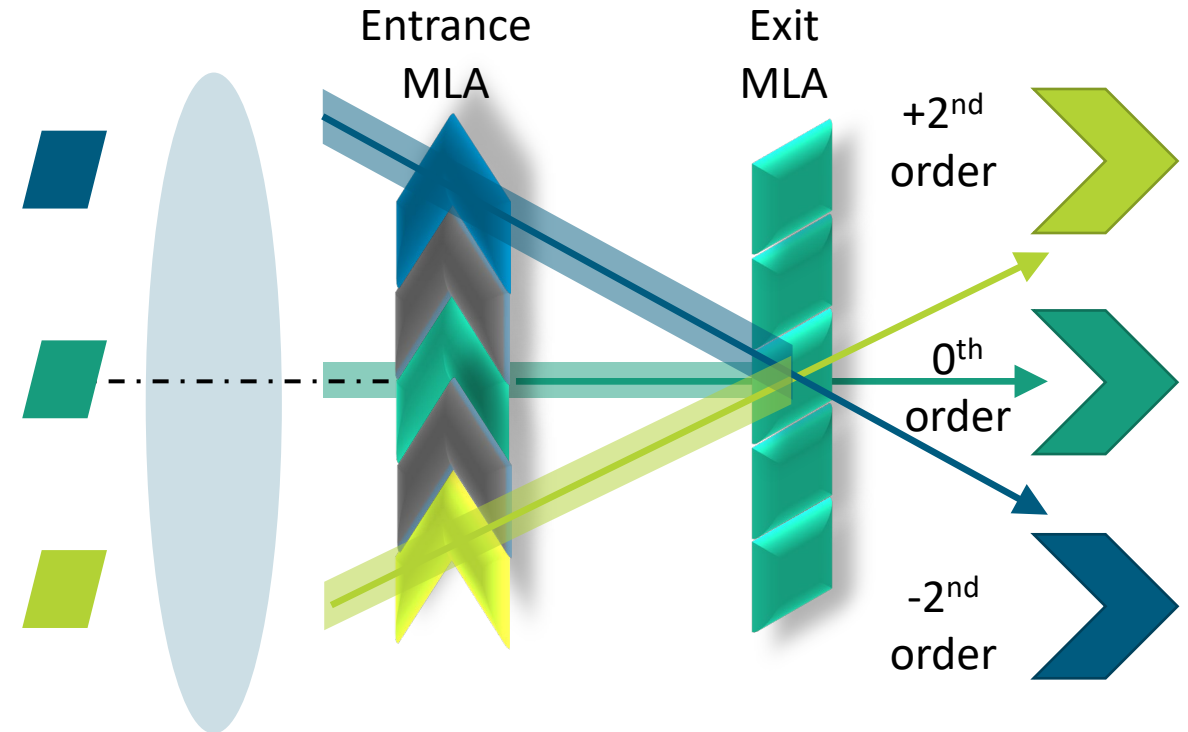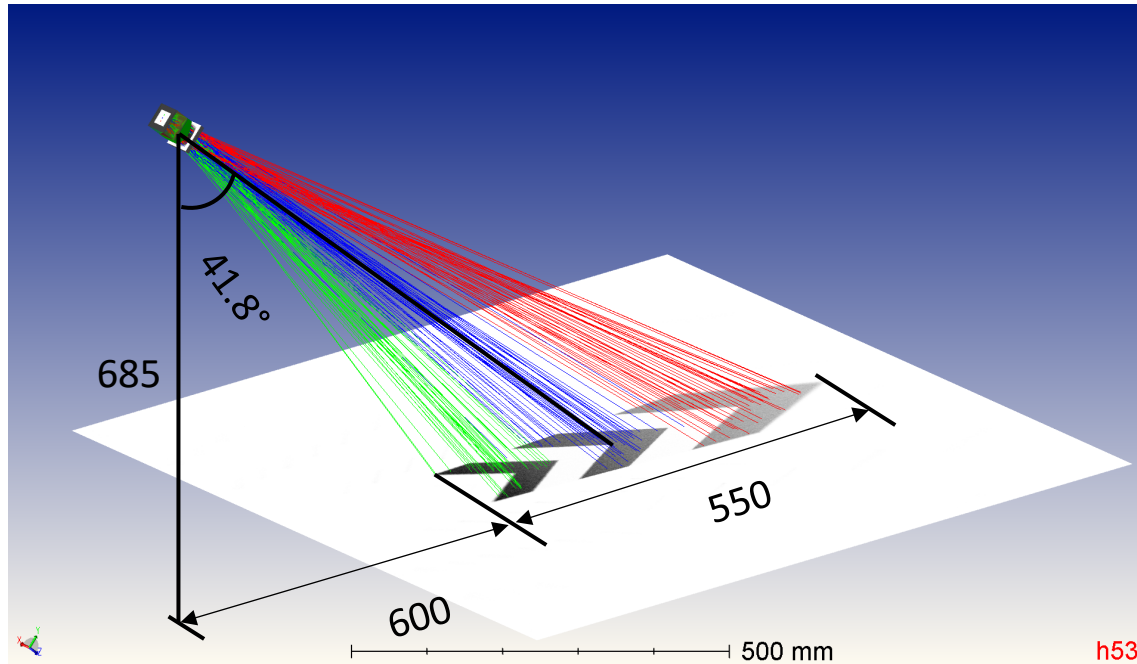
# Application – Symbol ground projection

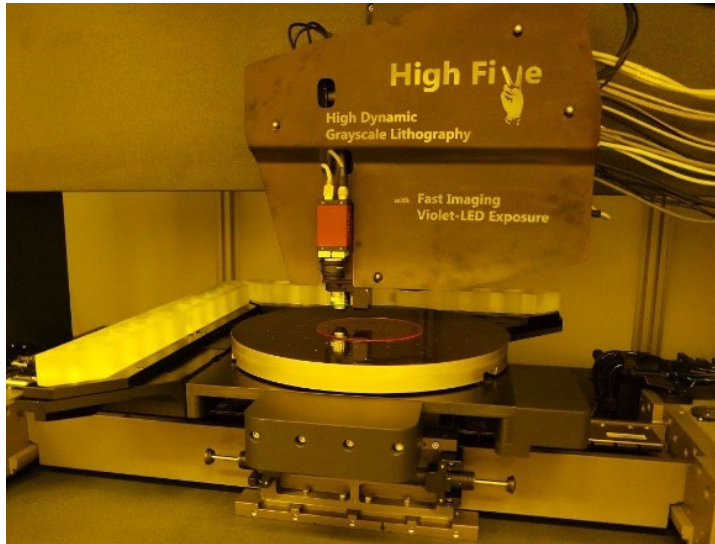## Symbol ground projection for turn indication
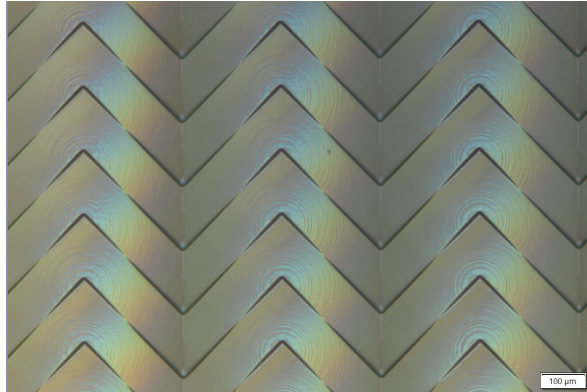


Condenser lenslets (entrance)

Projection lenslets (exit)

≈ 7 klx

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# Manufacturing

## Mastering and Replication today



Well established by Fraunhofer IOF



Well established by Fraunhofer IOF & SUSS MicroOptics
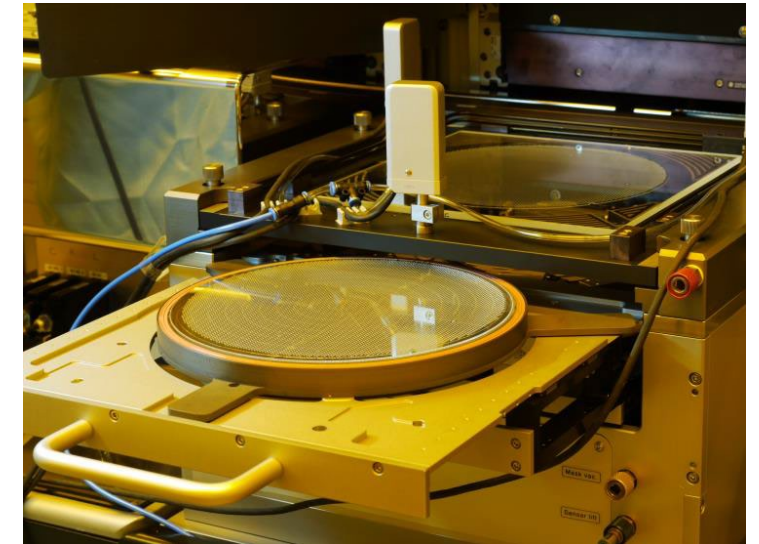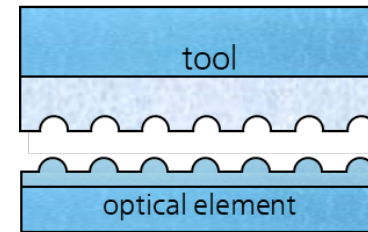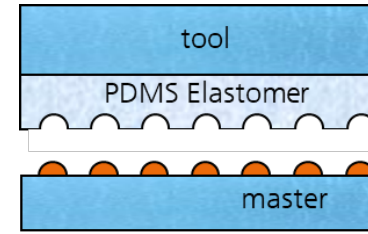
### MLA Mastering

- **Gray scale lithography**

- Alternatives: Diamond machining, 2P polym.

H.-Ch. Eckstein et al., "Direct write grayscale lithography for arbitrary shaped micro-optical surfaces", 20th MOC, Fukuoka 2015

### MLA Replication

- **UV molding in mask aligner** → Polymer-on-Glass element (POG)

- Alternatives: Injection molding → **Monolithic plastic element**

P. Dannberg et al., "Wafer-Level hybrid integration Integration of Complex Micro-Optical Modules", Micromachines 2014, No.5, 325-40.
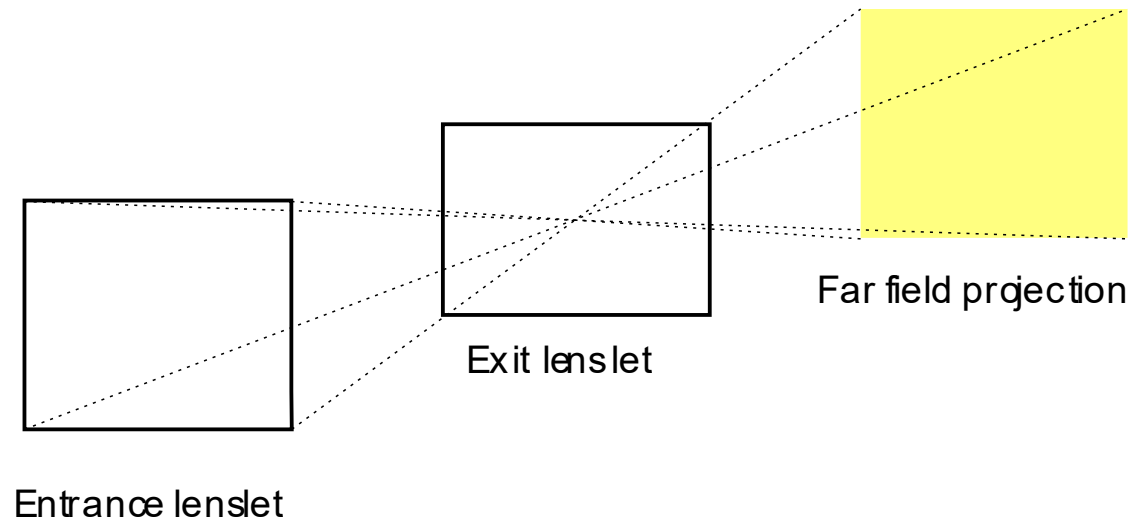
# Application – Low beam
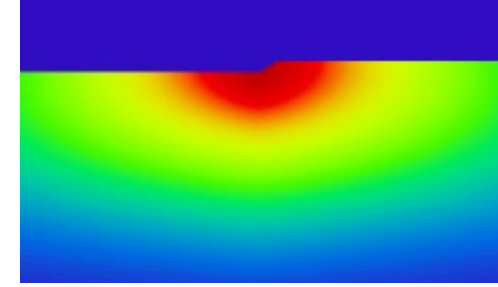
## Targeted intensity distribution

**Exemplary Target Distribution of an automotive low-beam**

**Radiant intensity [cd]**
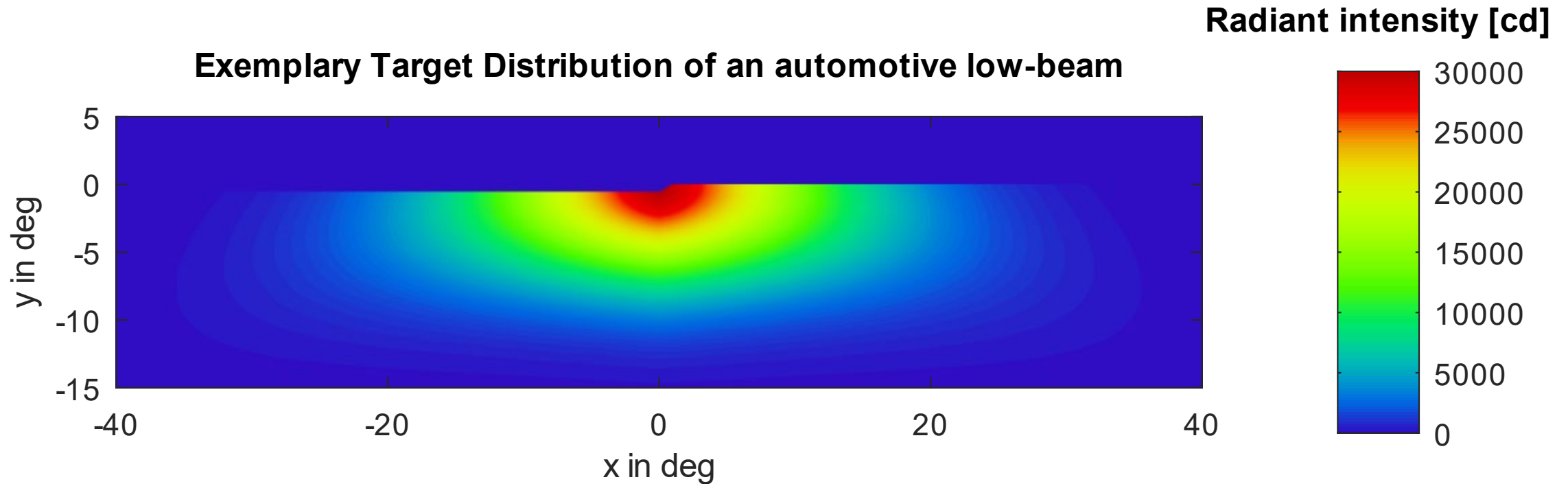


**Requirements**
- Vertical extent: -12° … 0° / Horizontal extent: -35° … 35°
- Peak intensity ca. 30 kcd
- Sharp and shaped cut-off at the top with smooth decrease downwards

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# Application – Low beam
## Shaping of the cut-off line

Far field projection

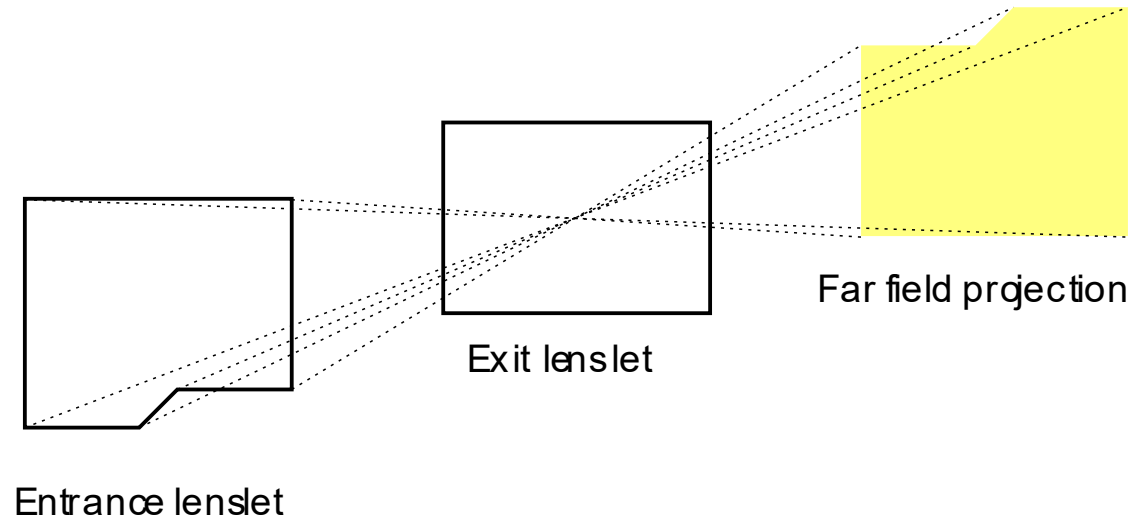Exit lenslet

Entrance lenslet

- Entrance lenslet's aperture shape is imaged into the far field by exit lenslets

- Shape of the entrance lenslets according to the required cut-off line

- Arrange entrance lenslets in space filling geometry → repetition of the cut-off

- Smooth lower part of the distribution
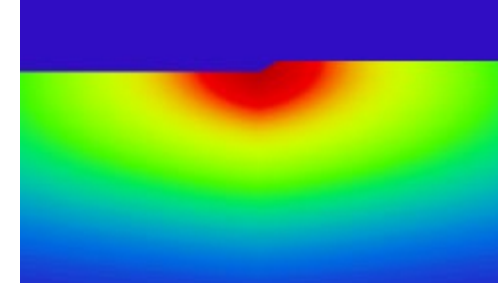  → vary entrance lens heights
  → vary lateral position

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# Application – Low beam
## Shaping of the cut-off line

Far field projection

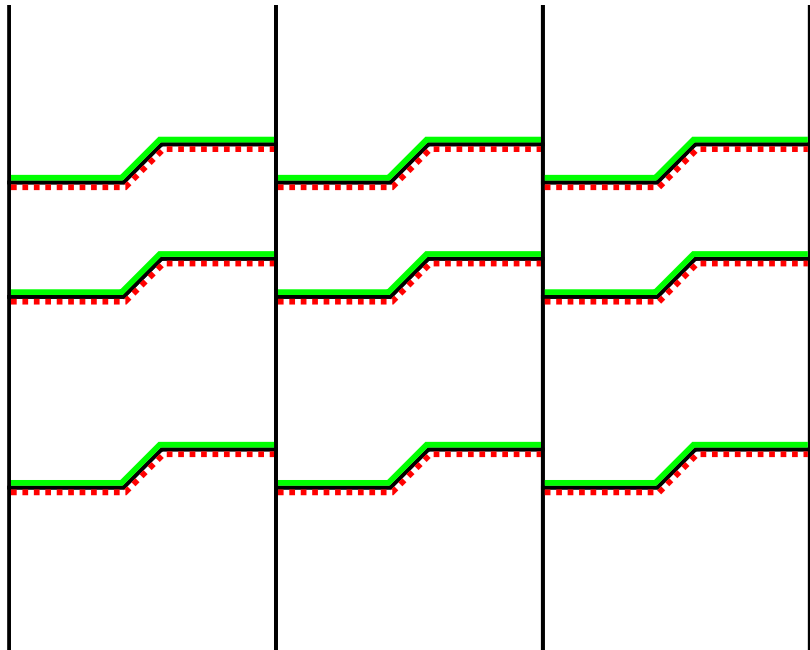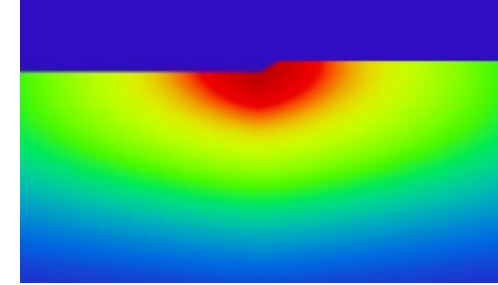Exit lenslet

Entrance lenslet

- Entrance lenslet's aperture shape
  is imaged into the far field by exit lenslets

- Shape of the entrance lenslets
  according to the required cut-off line

- Arrange entrance lenslets in space filling
  geometry → repetition of the cut-off

- Smooth lower part of the distribution
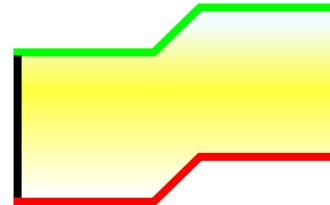  → vary entrance lens heights
  → vary lateral position

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# Application – Low beam
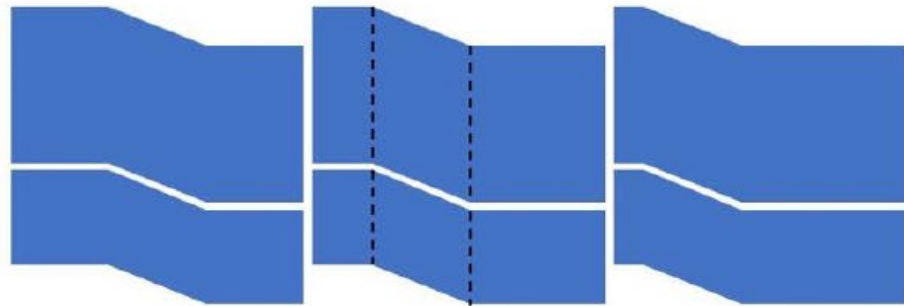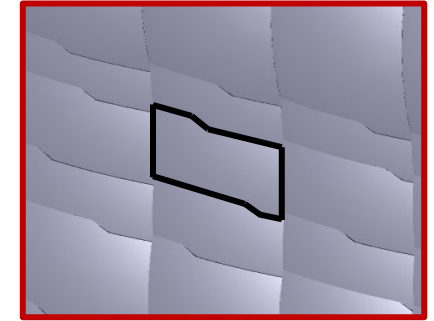
## Shaping of the cut-off line

**Resulting beam**

- Entrance lenslet's aperture shape is imaged into the far field by exit lenslets

- Shape of the entrance lenslets according to the required cut-off line

- Arrange entrance lenslets in space filling geometry → repetition of the cut-off

- Smooth lower part of the distribution
  → vary entrance lens heights
  → vary lateral position

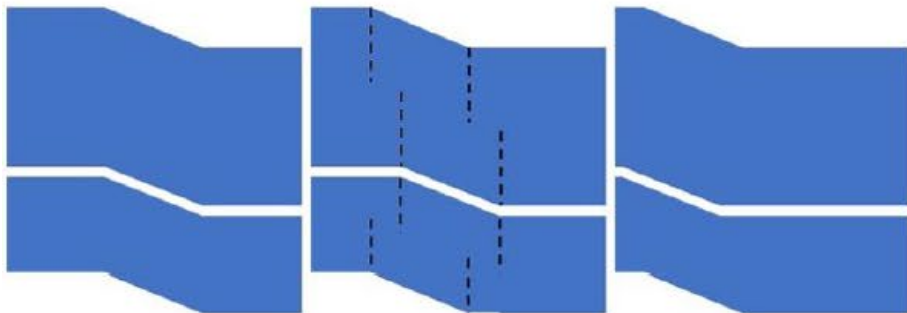Fraunhofer
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# Application – Low beam

## Shaping of the cut-off line
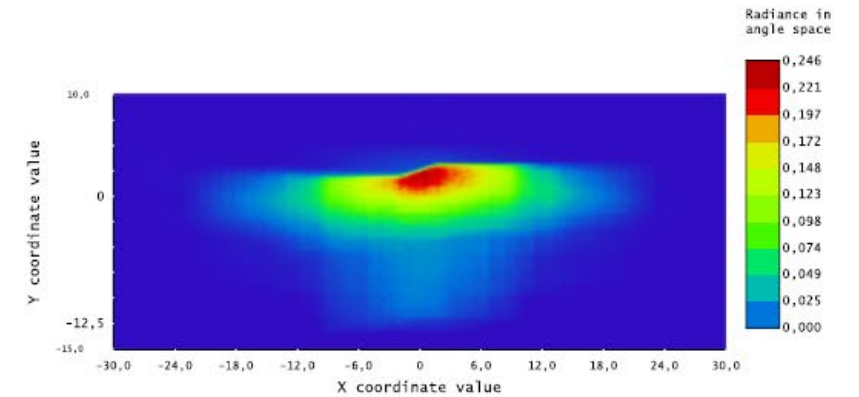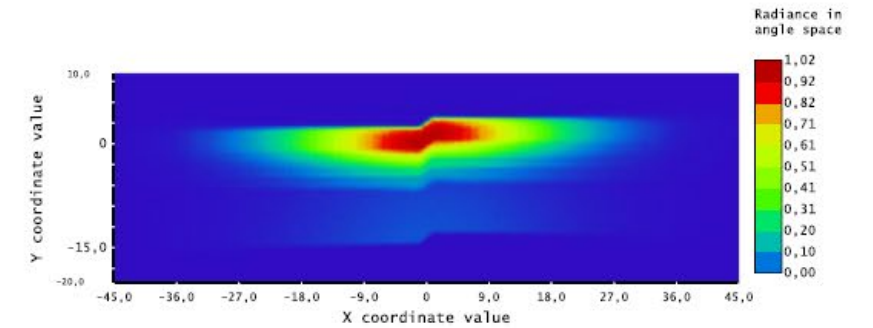
# Application – Low beam

## Demo
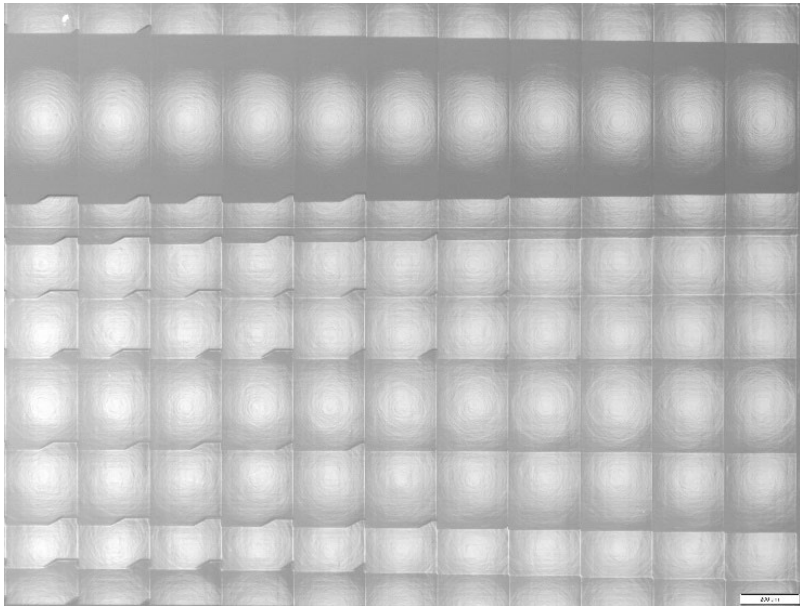


**Entrance array**
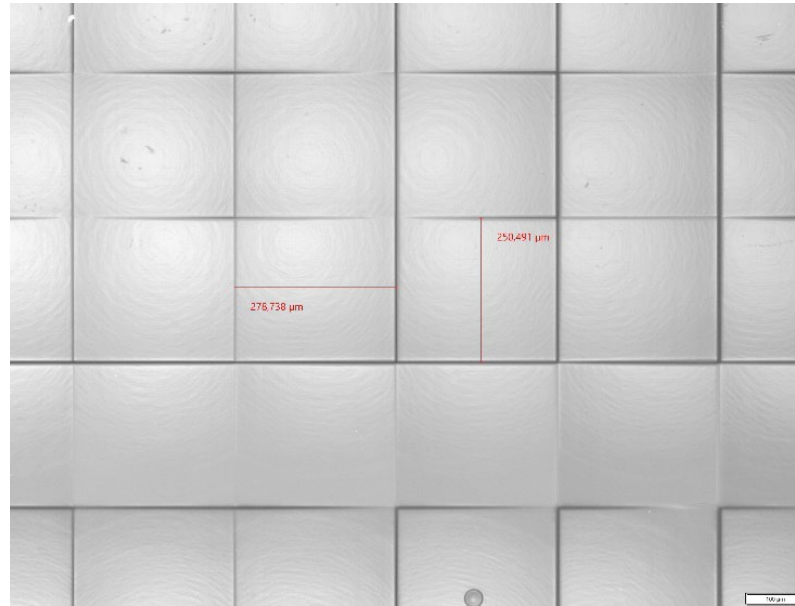


**Exit array**
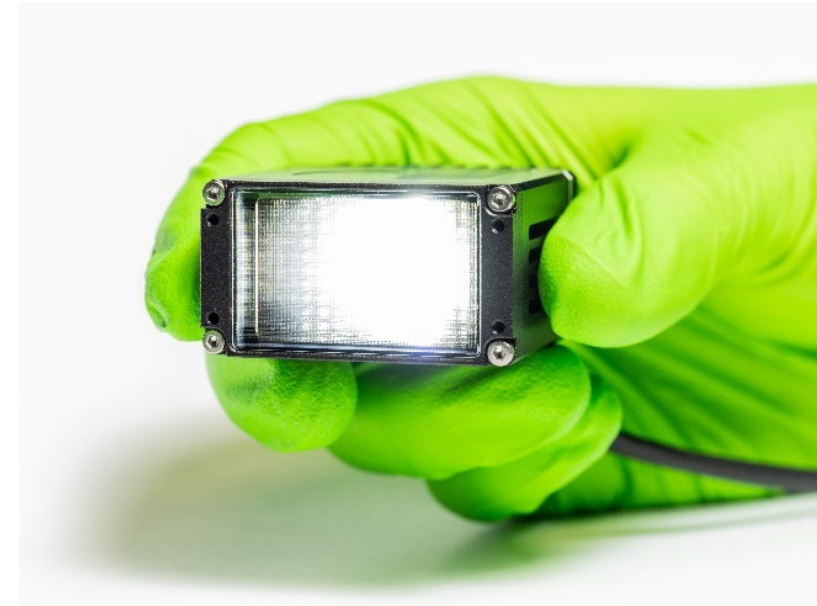


**20** x 35 x 60 mm³ (**H** x W x L).

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# Applications – Low beam

## Resulting distribution

**Radiant intensity [cd]**

**measured far field of single module linear scale**



**Radiant intensity [cd]**

**measured far field of single module log-2 scale**
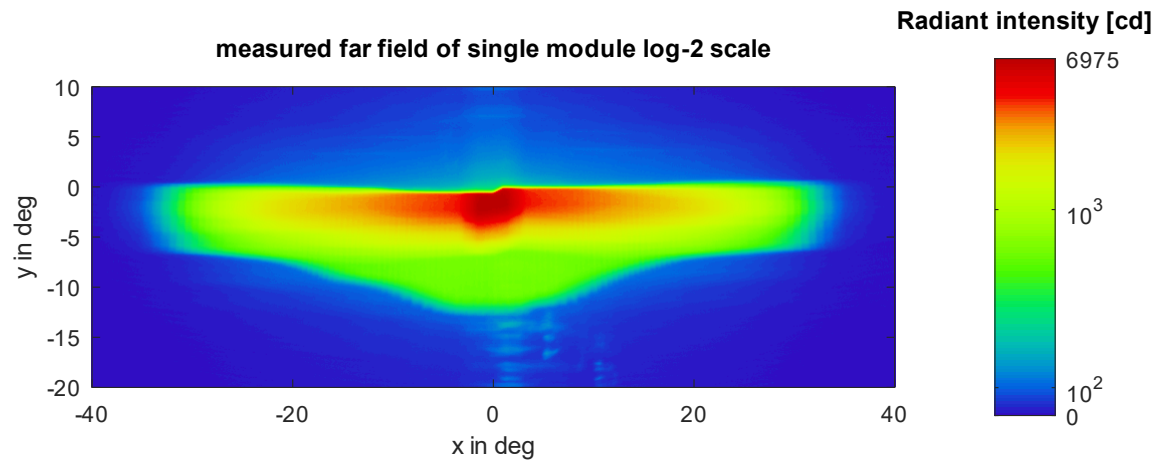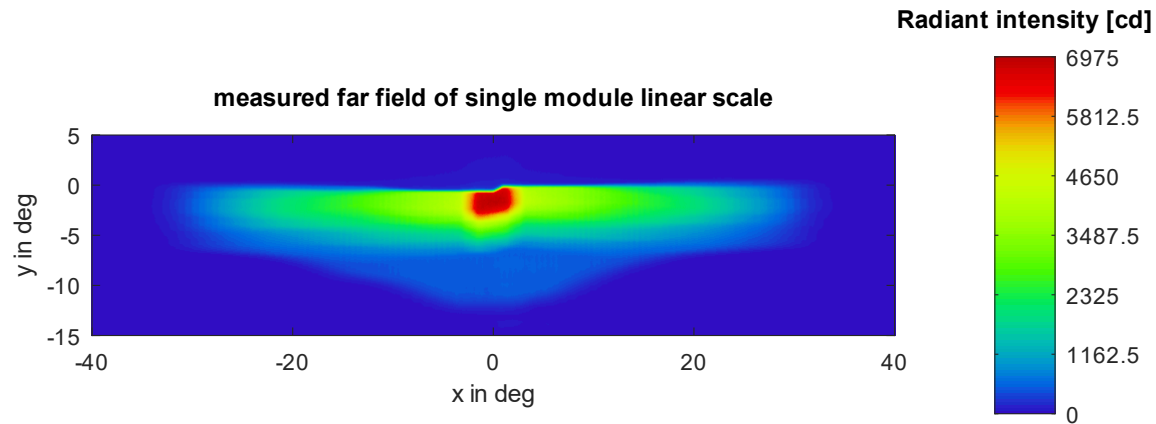




385 lm LED (lowest bin)  → ~7 kcd from one module

585 lm LED (highest bin)  → **~10.5 kcd expected**

→ **~ 42 kcd expected
with 4 modules**

Sharp cut-off, no color, **~ 75% total transmission
(incl. stray light)**

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# Efficient, maskless pattern shaping for lighting and projection
## Conclusions & Outlook

**Maskless irregular fly´s eye condenser (iFEC)**
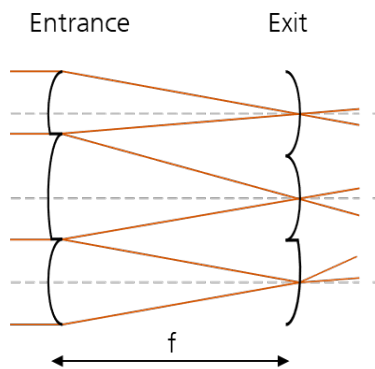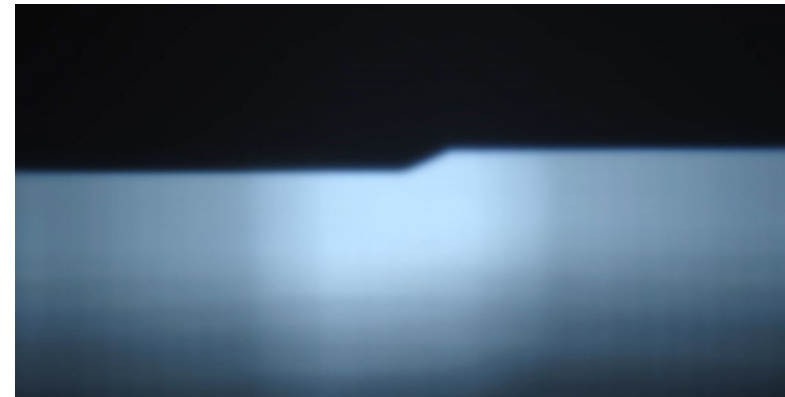
**for generating variable patterns with low loss**

→ no lithographic pattering

→ one-step replication of monolithic elements

→ decreased costs (molding, embossing)

→ large area, potentially curved elements …



**Low beam and blinker modules demonstrated**

→ improved brightness & extended lifetime expected due to reduced losses

→ ongoing condenser design (sag height jumps) to reduce stray light,

   to ease replication, and to adapt to non-ideal collimation

→ similar patterns for all channels → combined distributions

→ add functionalities (3D light-fields, daytime running lights, …)

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**μo Designs by**

Dr. Peter Schreiber
Dmitrii Stefanidi
Rohan Kundu
Dr. Dirk Michaelis
Leo M. Wilhelm

**μo Technology by**

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Dr. Peter Dannberg
Sylke Kleinle
Philipp Schleicher
Anja Schöneberg

**Set-up by**

Ralf Rosenberger
Felix Kraze
Thomas Dietrich

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# Thanks for your kind attention