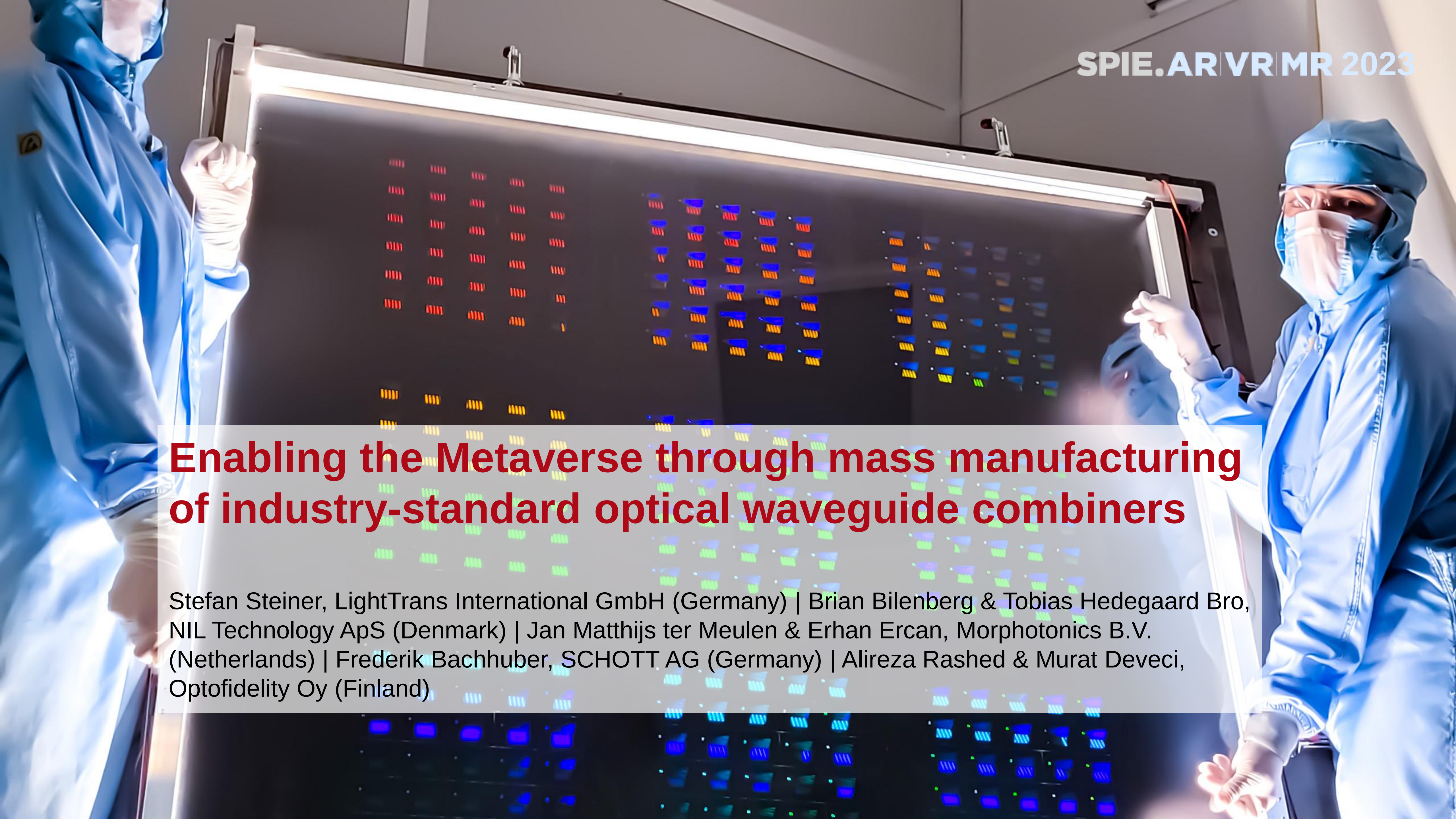


SPIE.AR|VR|MR 2023

Enabling the Metaverse through mass manufacturing of industry-standard optical waveguide combiners

Stefan Steiner, LightTrans International GmbH (Germany) | Brian Bilenberg & Tobias Hedegaard Bro, NIL Technology ApS (Denmark) | Jan Matthijs ter Meulen & Erhan Ercan, Morphotonics B.V. (Netherlands) | Frederik Bachhuber, SCHOTT AG (Germany) | Alireza Rashed & Murat Deveci, Optofidelity Oy (Finland)

Agenda

- Introduction
- Design
- Mastering
- Materials
- Nanoimprinting
- Metrology
- Summary

High Quality Waveguides Beyond Wafer Scale

- Quality and costs are essential if AR glasses want to be the ‘next big thing’
- In 2022, we presented a viable path beyond wafer-scale for AR waveguide optics mass manufacturing
- ‘basic’ proof-of-concept & entire value chain that can produce AR waveguide optics in high-volume via large scale nano-imprint, means low costs
- Now, replication and image quality are in the focus
- Goal: further establish the new approach towards high-volume and low-cost manufacturing of waveguides for enabling the Metaverse

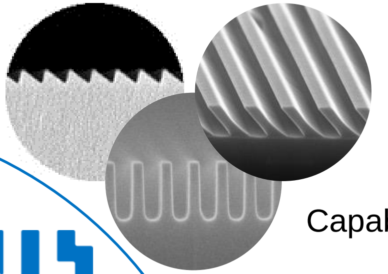
Complete Value Chain of Pioneers

Fast Physical Optics Modeling & Design Software

VirtualLab Fusion operates with a breakthrough technology for optical modeling & design based on physical optics

A powerful platform for innovative developments: LiDAR, AR/MR/VR Glasses, Laser Systems, Gratings, meta lenses, etc.

Large Area High-Precision Gratings



Accuracy in grating periodicity across large areas

Capable of designing & delivering non-periodic gratings

Leaders of Large-Area Nanoimprinting

World's largest-area, commercially available, fully integrated nanoimprinting machine

Cost-effective mass manufacturing of nano/micron structures via large-area nanoimprinting

Pioneering – responsibly – together

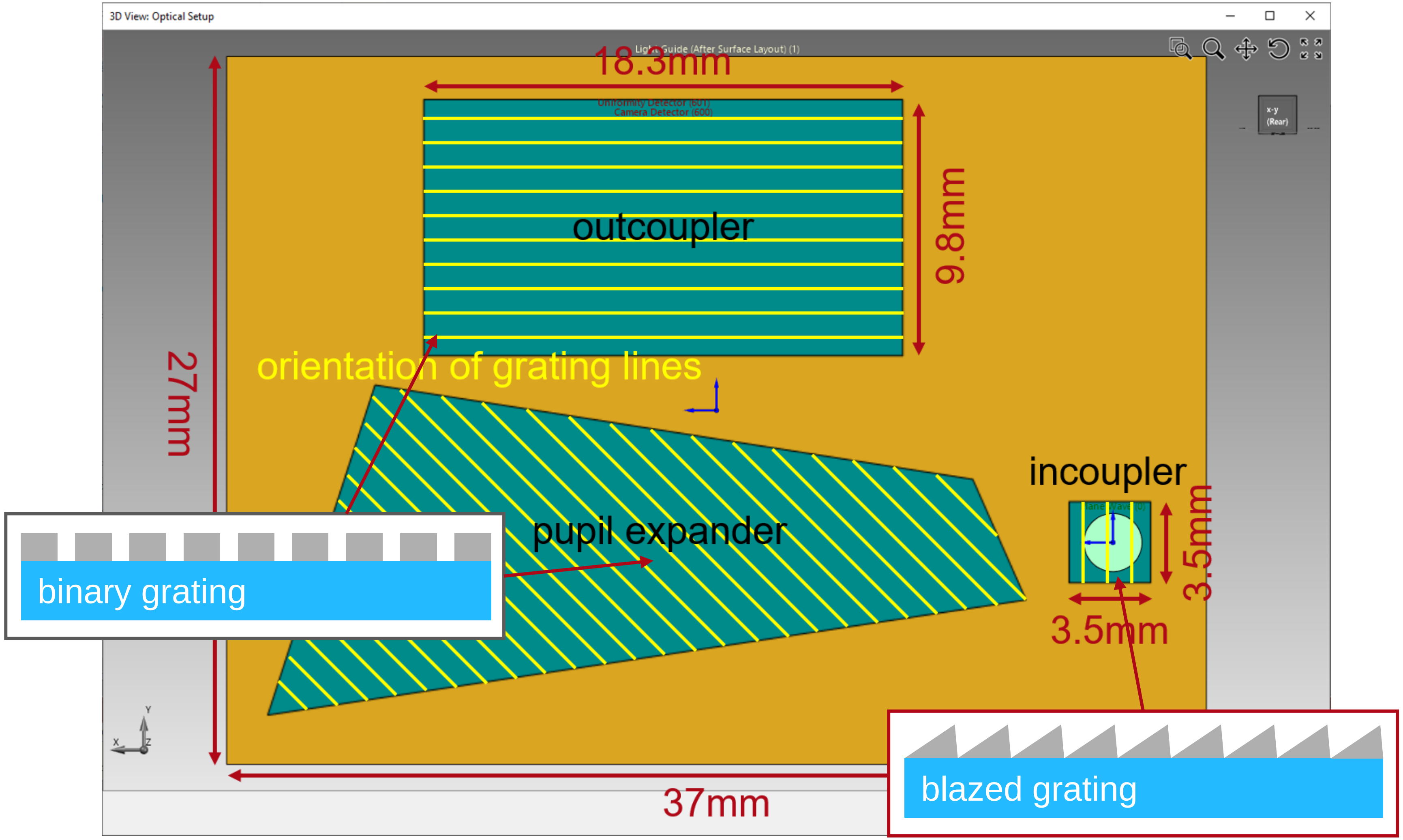
Founder Otto Schott is considered the inventor of optical glass and became the pioneer of an entire industry.

Always opening up new markets and applications with a pioneering spirit and passion – for more than 130 years.

Enabling Smarter Future

Global market leader in automated optical metrology & characterization solutions for AR waveguides and displays throughout the entire product life-cycle from R&D to high volume manufacturing

Design of Waveguide – Lateral Layout



Specifications:

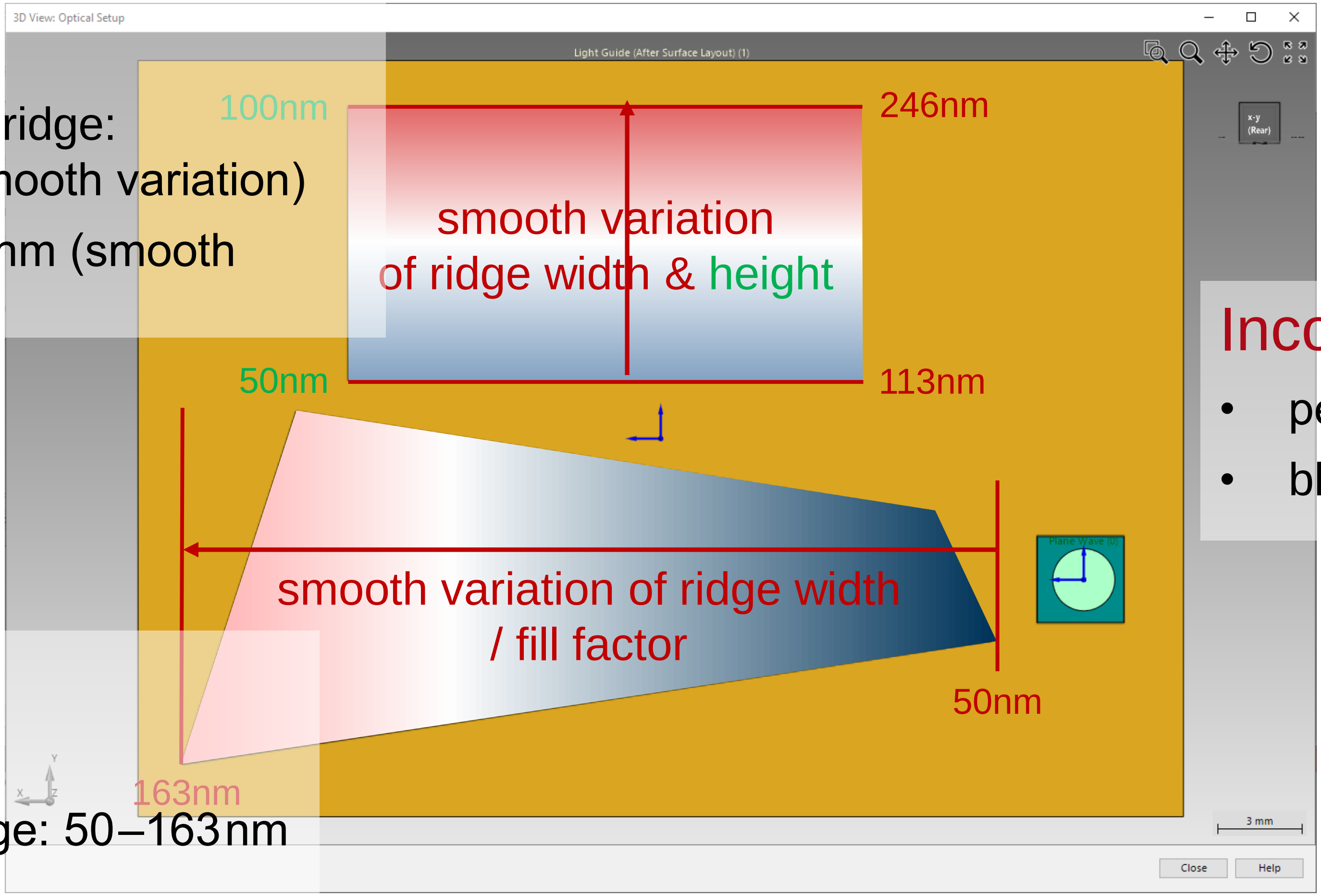
- 1D-1D pupil expansion
- FOV: 35°×18°
- eye-box: 15mm × 8mm
- eye-relief: 5mm

- substrate: Schott Realview 1.9
- 1D-periodic gratings
- index of grating material: 1.88

Design of Waveguide – Grating Parameters

Outcoupler:

- period: 415 nm
- width of grating ridge: 113–246 nm (smooth variation)
- Height: 50–100 nm (smooth variation)



Incoupler:

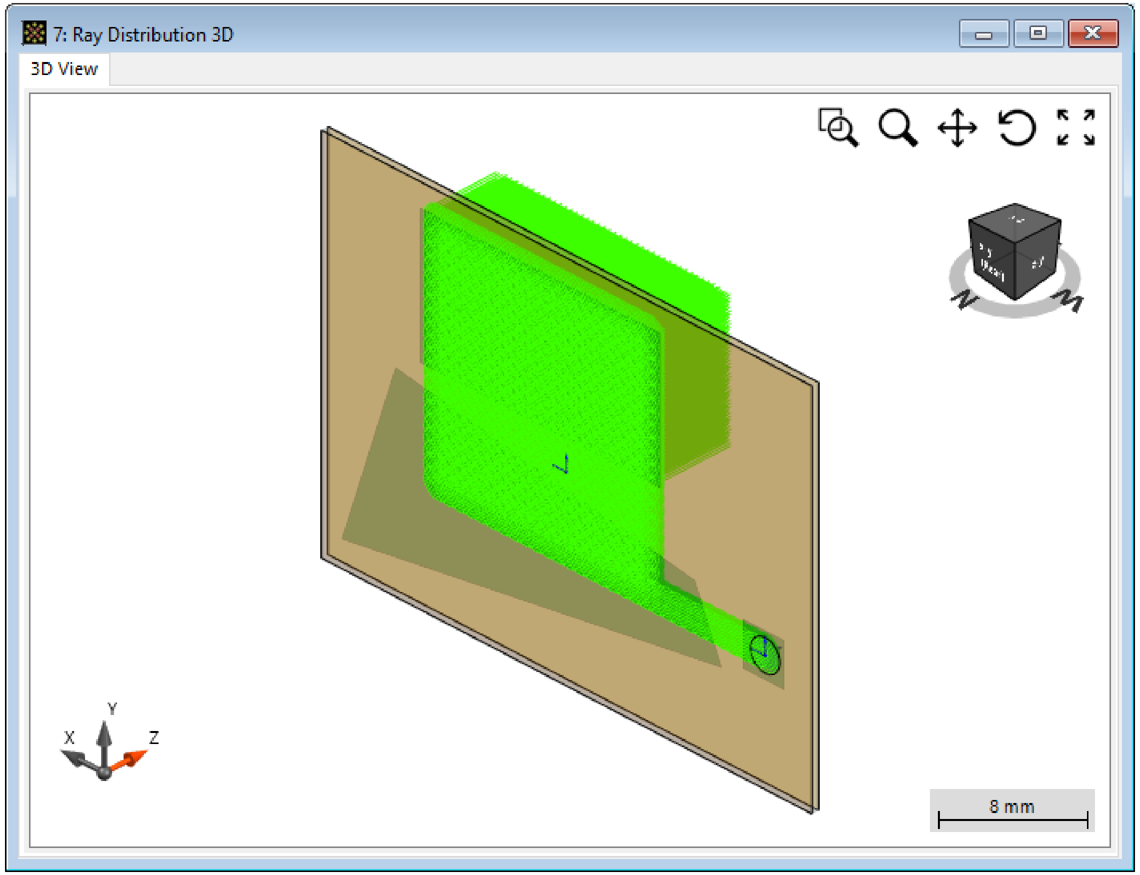
- period: 415 nm
- blaze angle: 29.9°

Pupil Expander:

- period: 293.45 nm
- width of grating ridge: 50–163 nm (smooth variation)
- Height: 50 nm (constant)

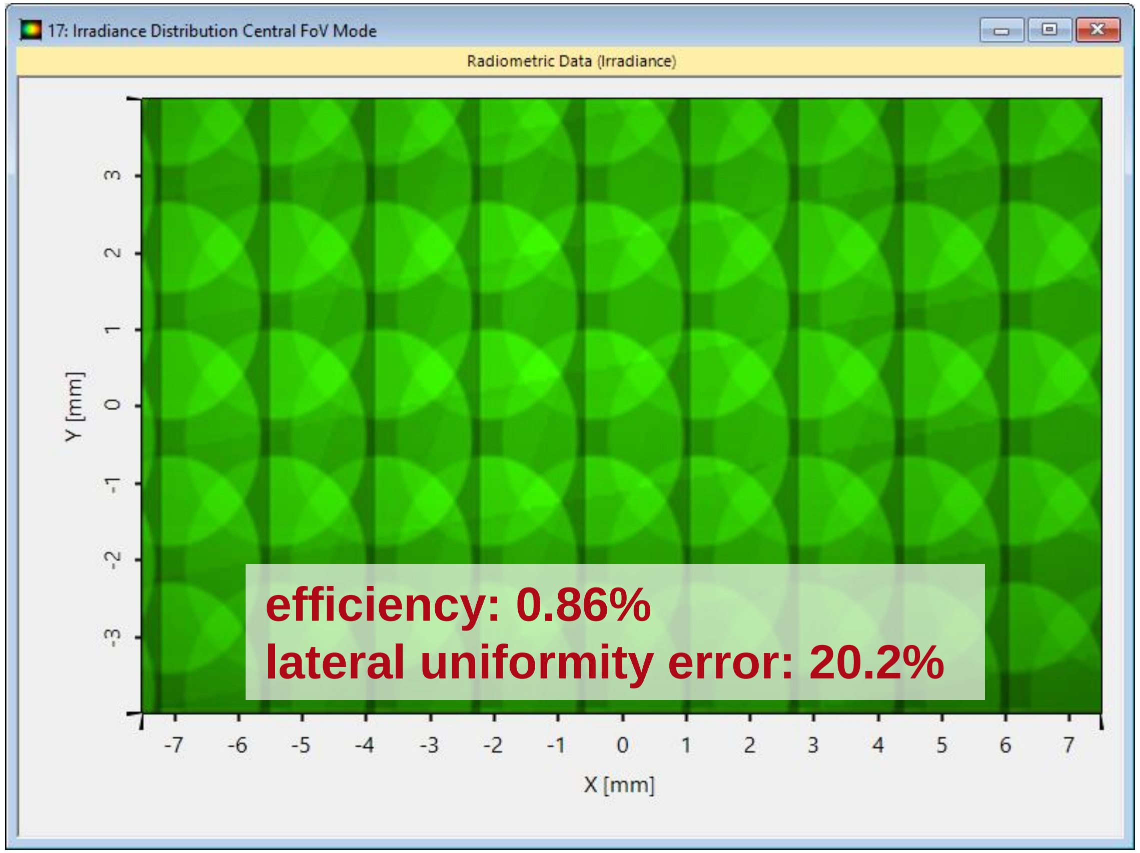
Simulation Results of Optimized Device

racing result for central direction of the FOV



(for illustration just light hitting the eyebox is shown)

calculated irradiance in eye-box for central direction



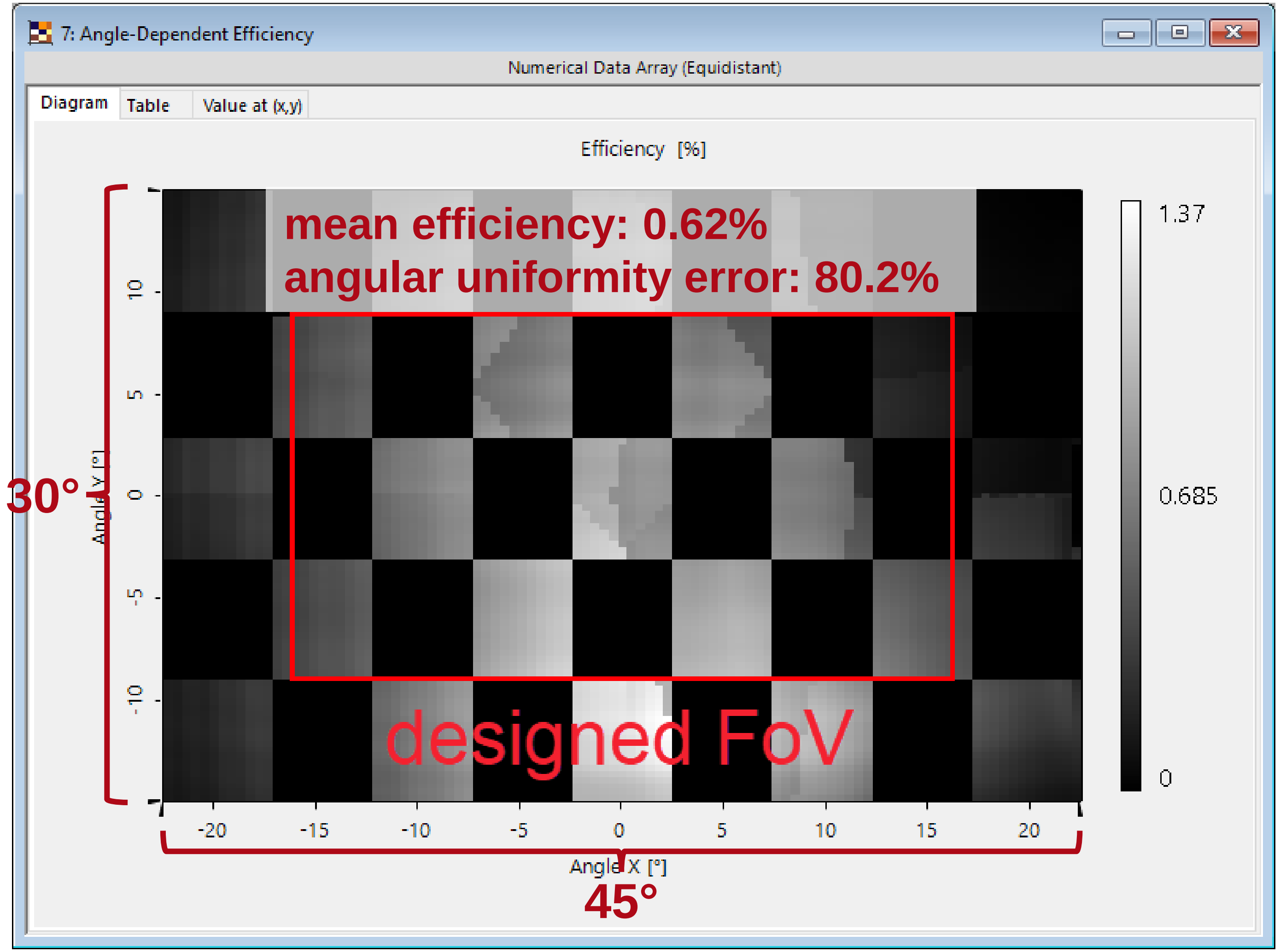
(including polarization effects & rigorously calculated grating responses)

Simulation Results of Optimized Device

analysis by using angular checkerboard:

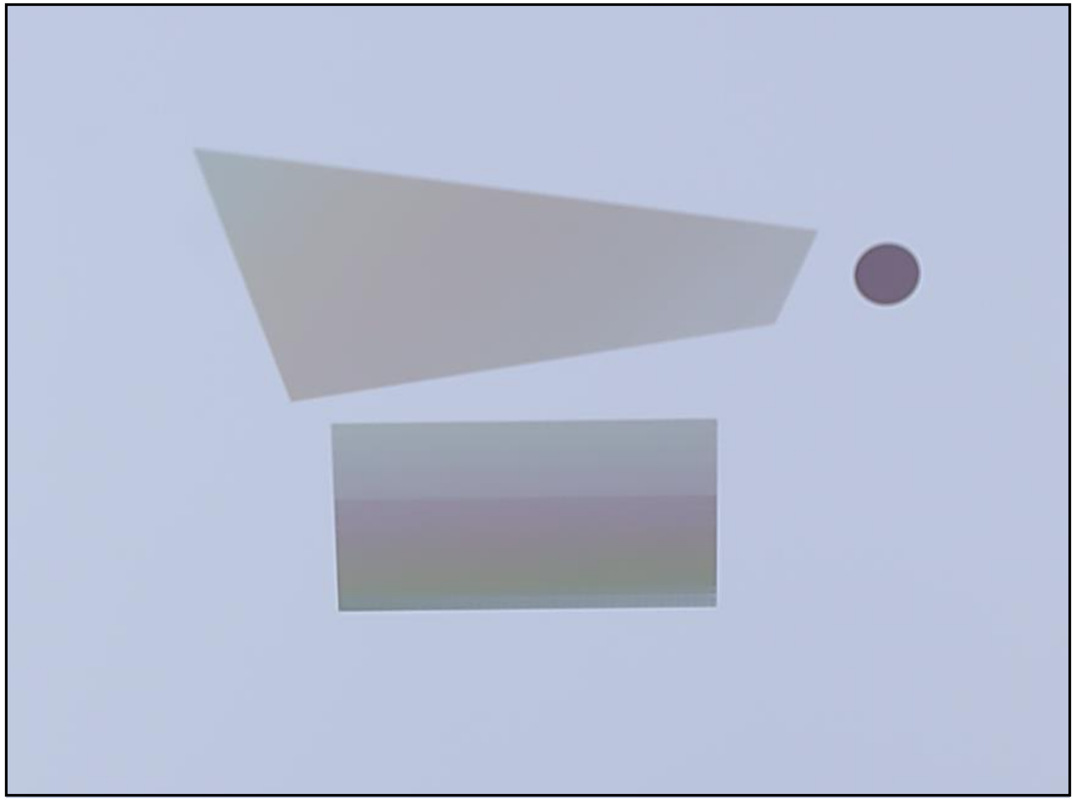
one box: 5°× 6°

whole range: 45°× 30°



Waveguide Optics Mastering

NIL TECHNOLOGY

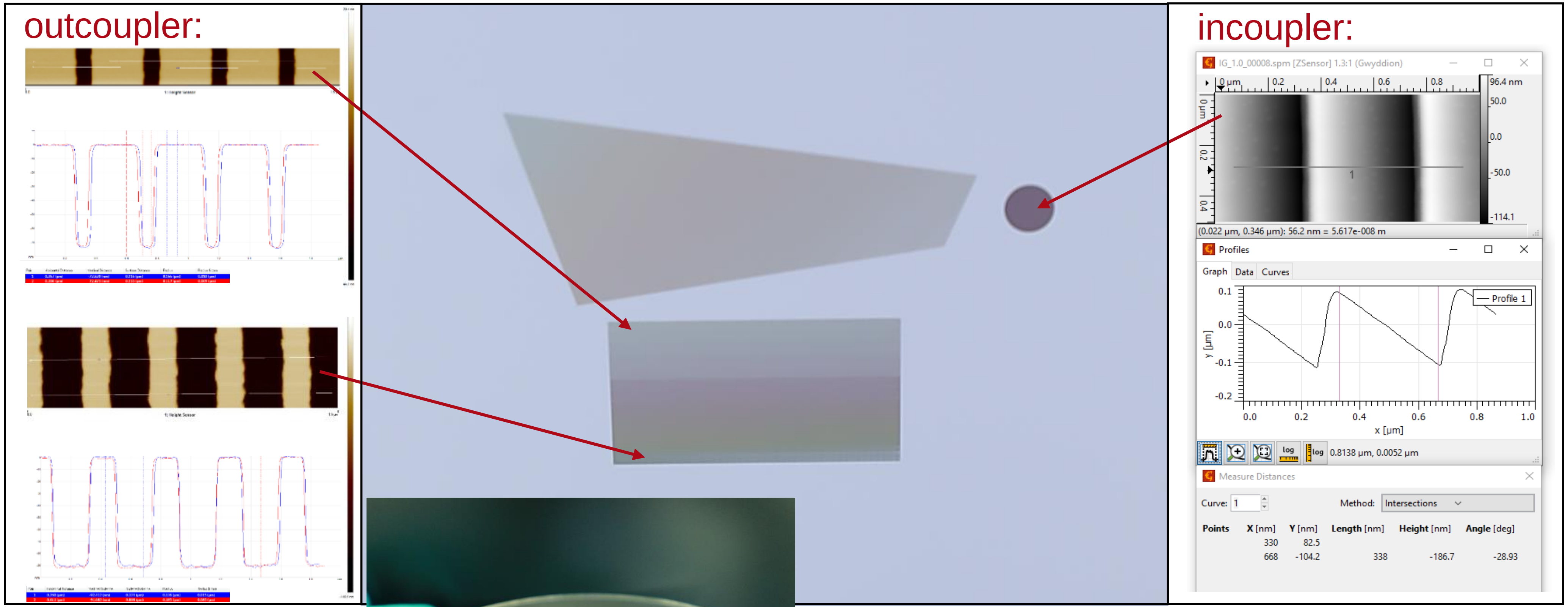


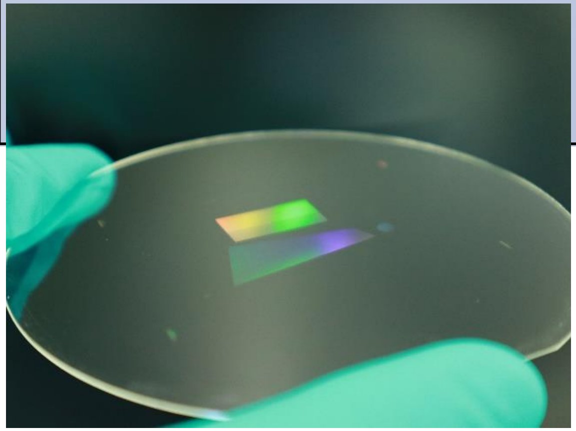
Complete AR master with:

- blazed input grating
- fill factor modulated expander grating
- depth and fill factor modulated output grating

Waveguide Optics Mastering

NIL TECHNOLOGY

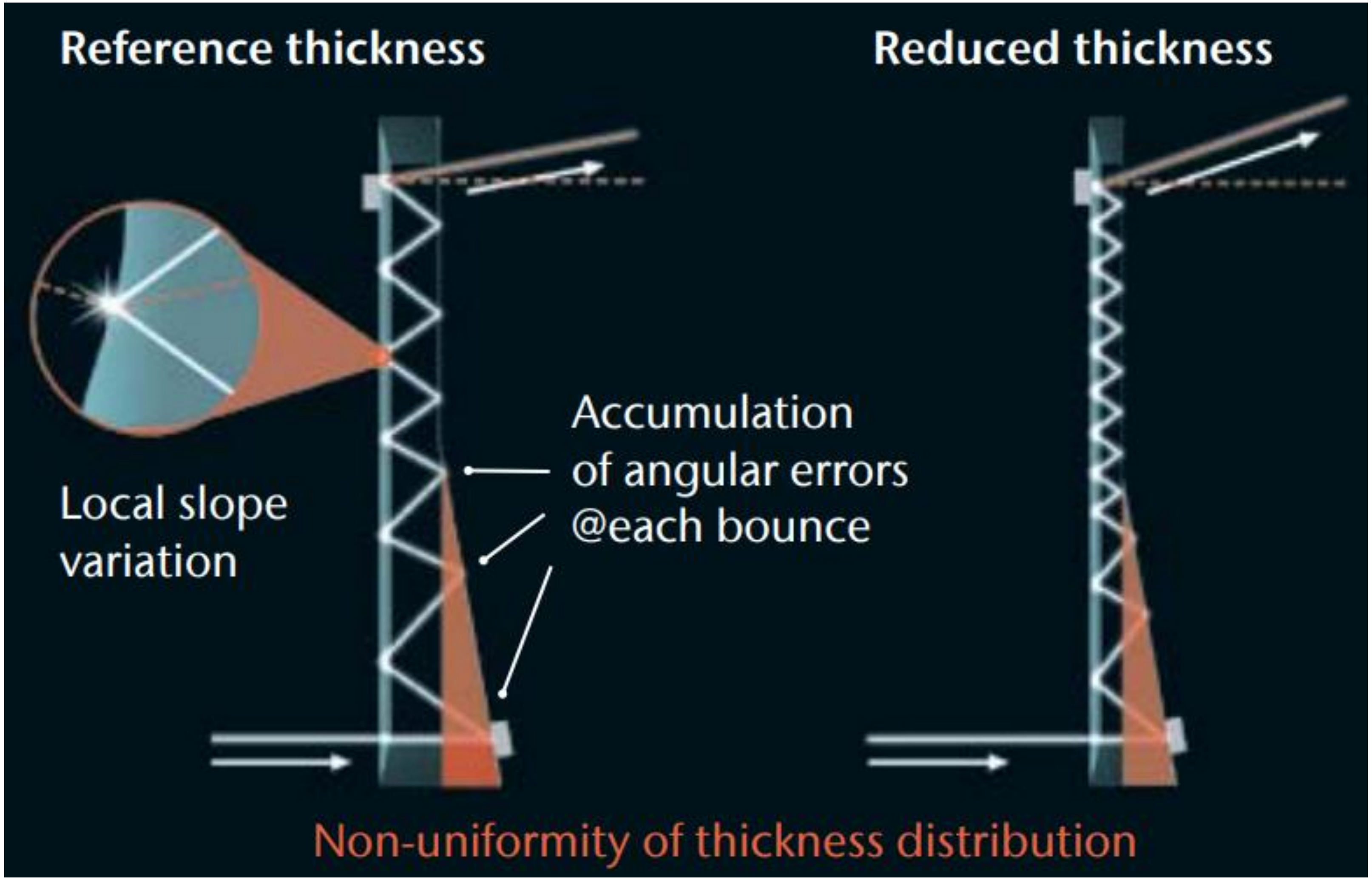


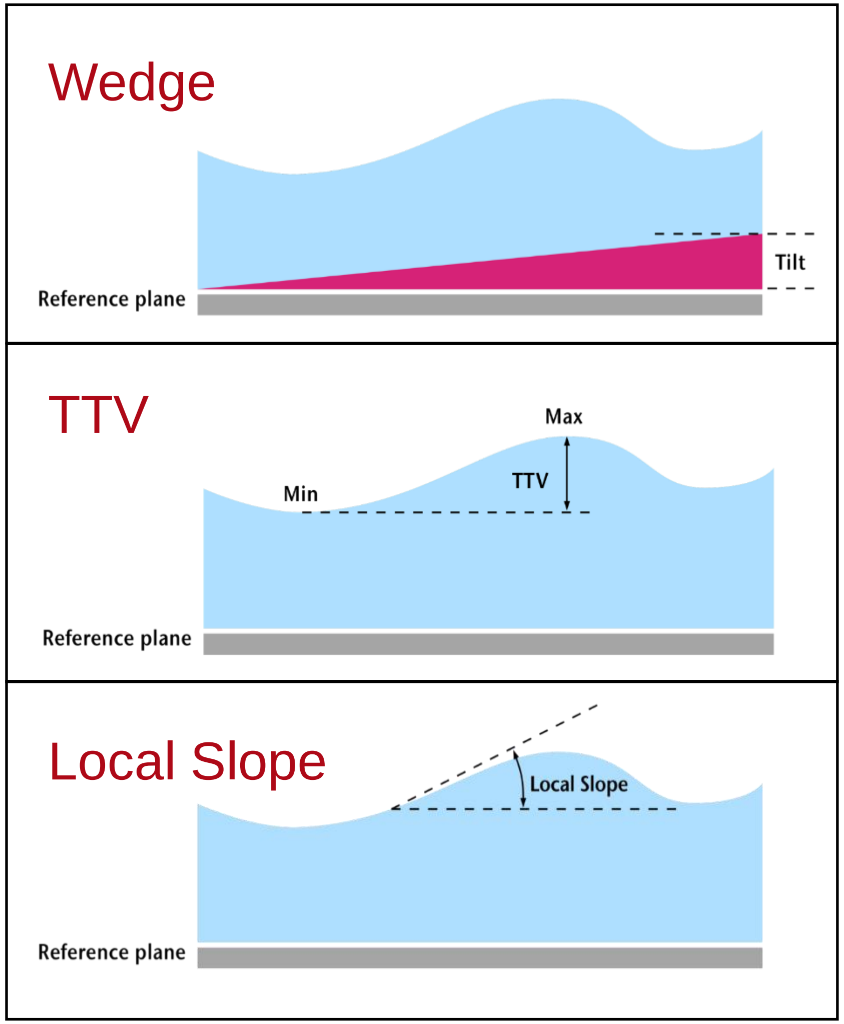


- fill factor modulation from 17% (top) to 56% (bottom)
- depth modulation from 72 nm (top) to 92 nm (bottom).

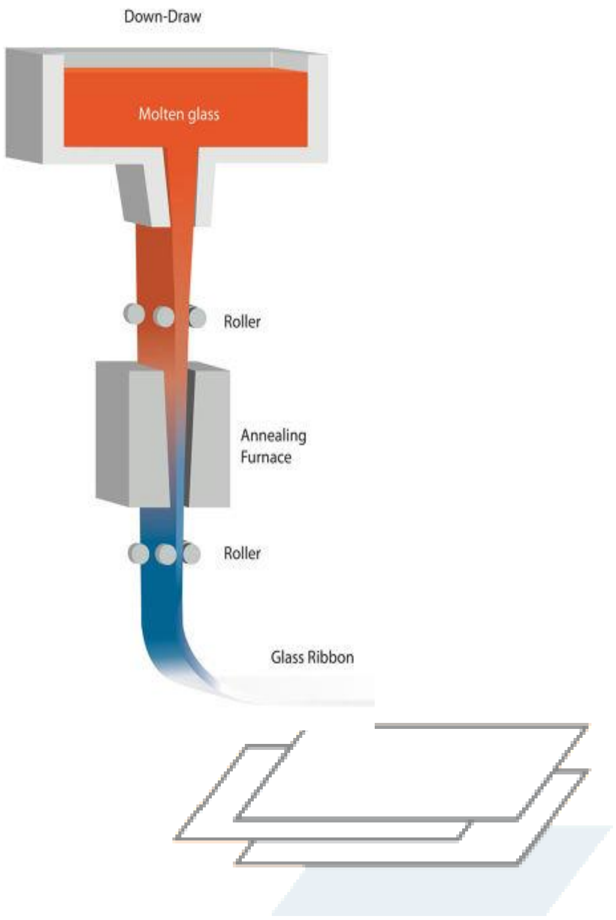
AFM scan of blazed input grating showing the sharp profile with 29 degrees blaze angle.

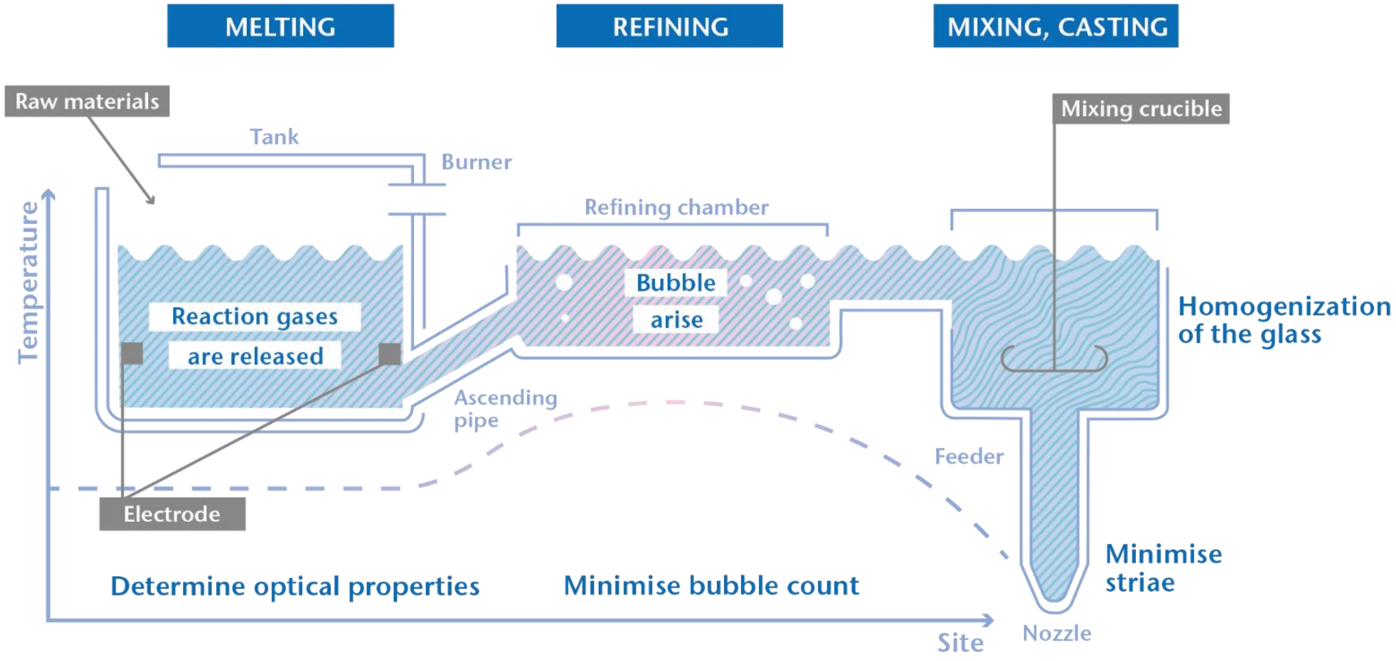
Surface topology impacts waveguide performance!

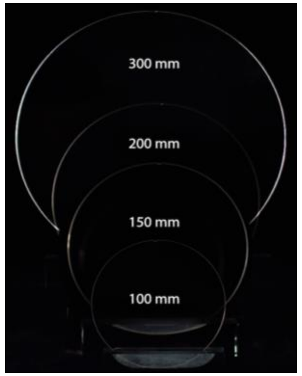


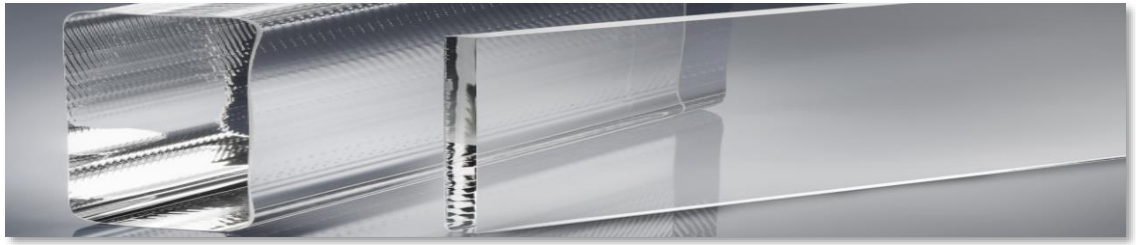


Technical vs. optical glass production for panels



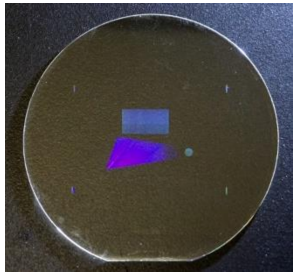


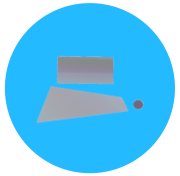


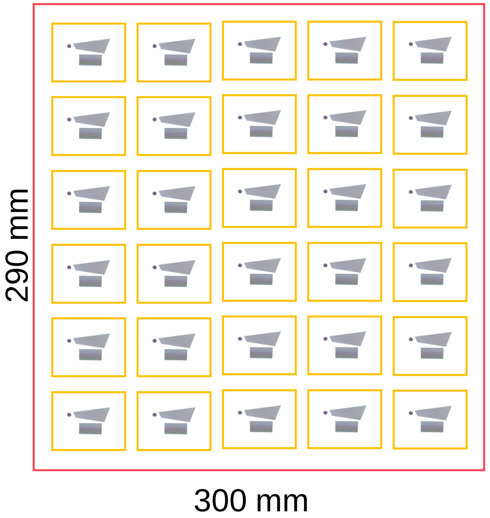


Manufacturing scaling advantage

Single eyepiece Master → **Master Upscaling (Morphotonics proprietary)**







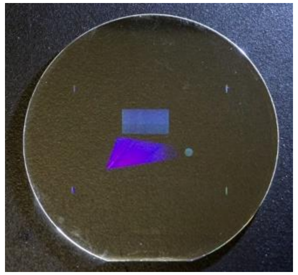
Upscaled Submaster

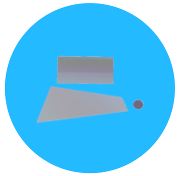
30 waveguides

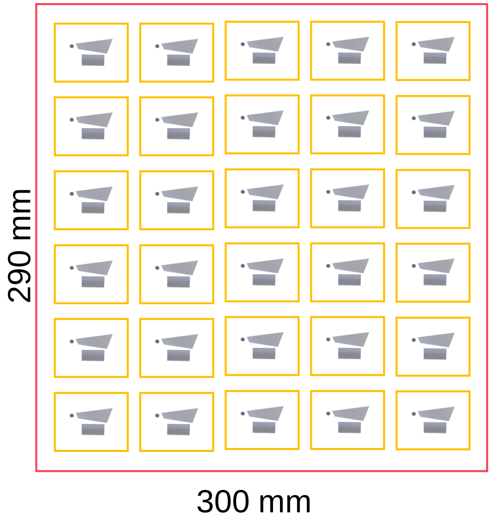
- Masters can be tedious & complex to originate, o de in wafer format
- Upscaling of masters is essential to increase throughput

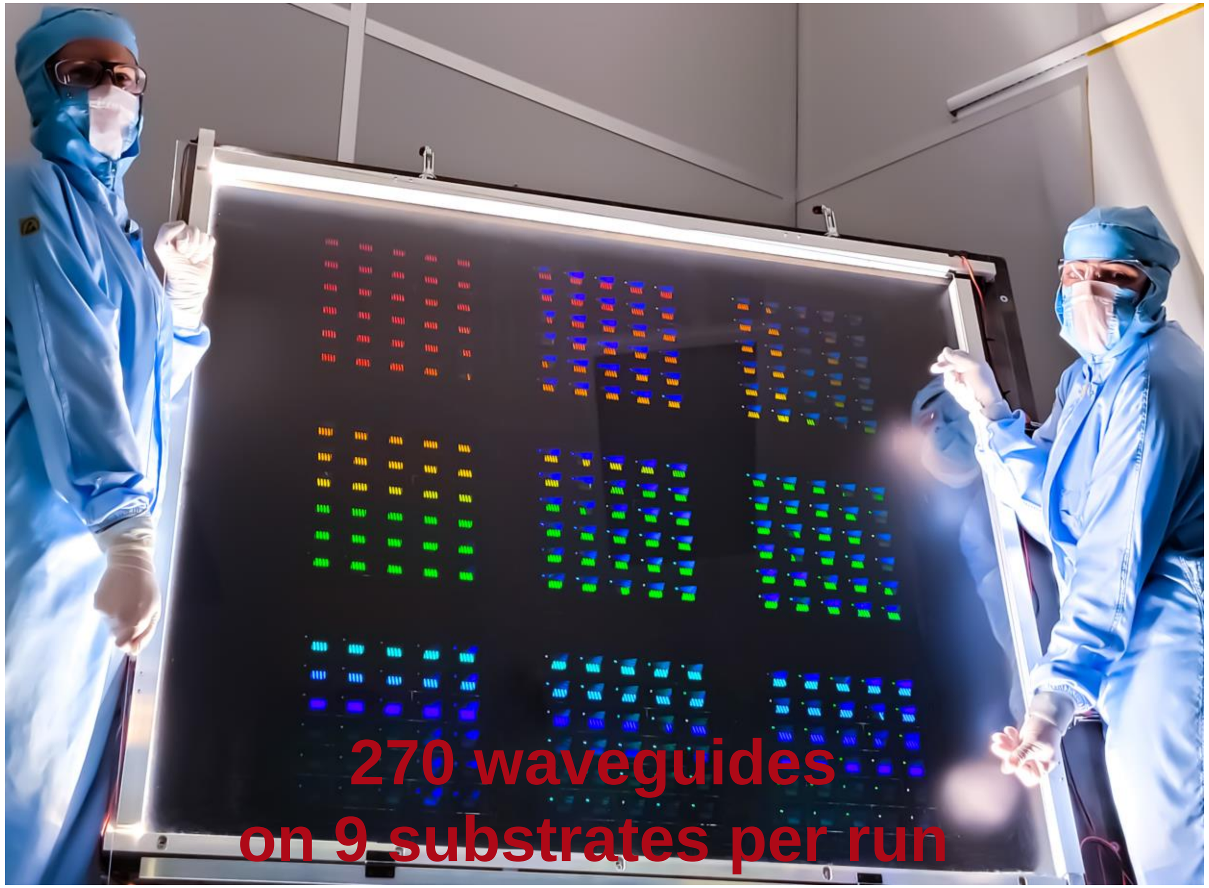
Manufacturing scaling advantage

Single eyepiece Master → **Master Upscaling (Morphotonics proprietary)** → **R2P Imprint**







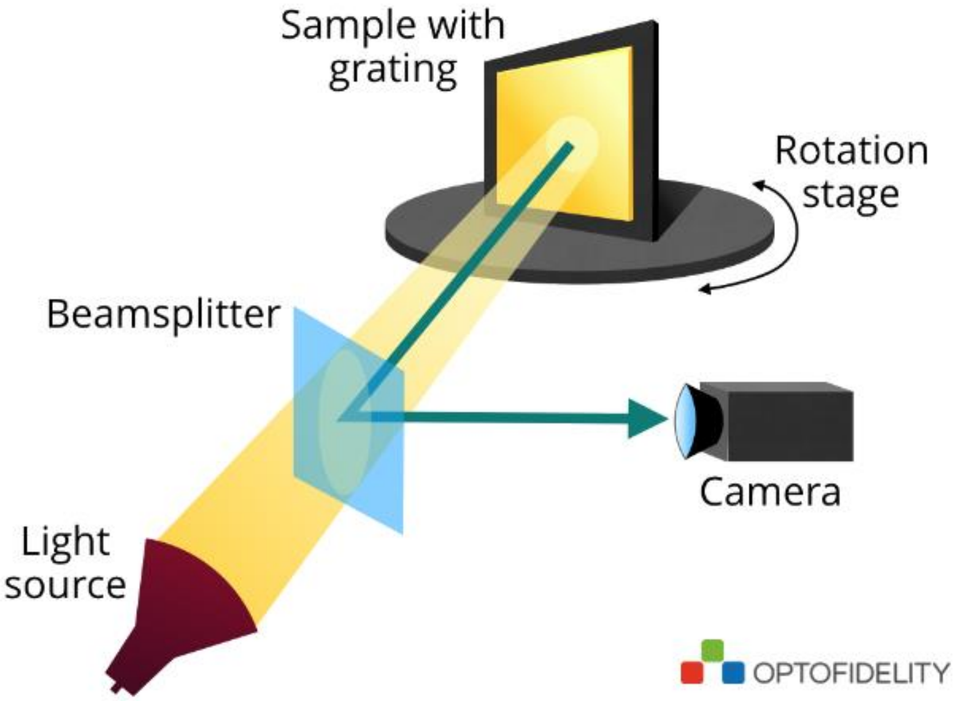


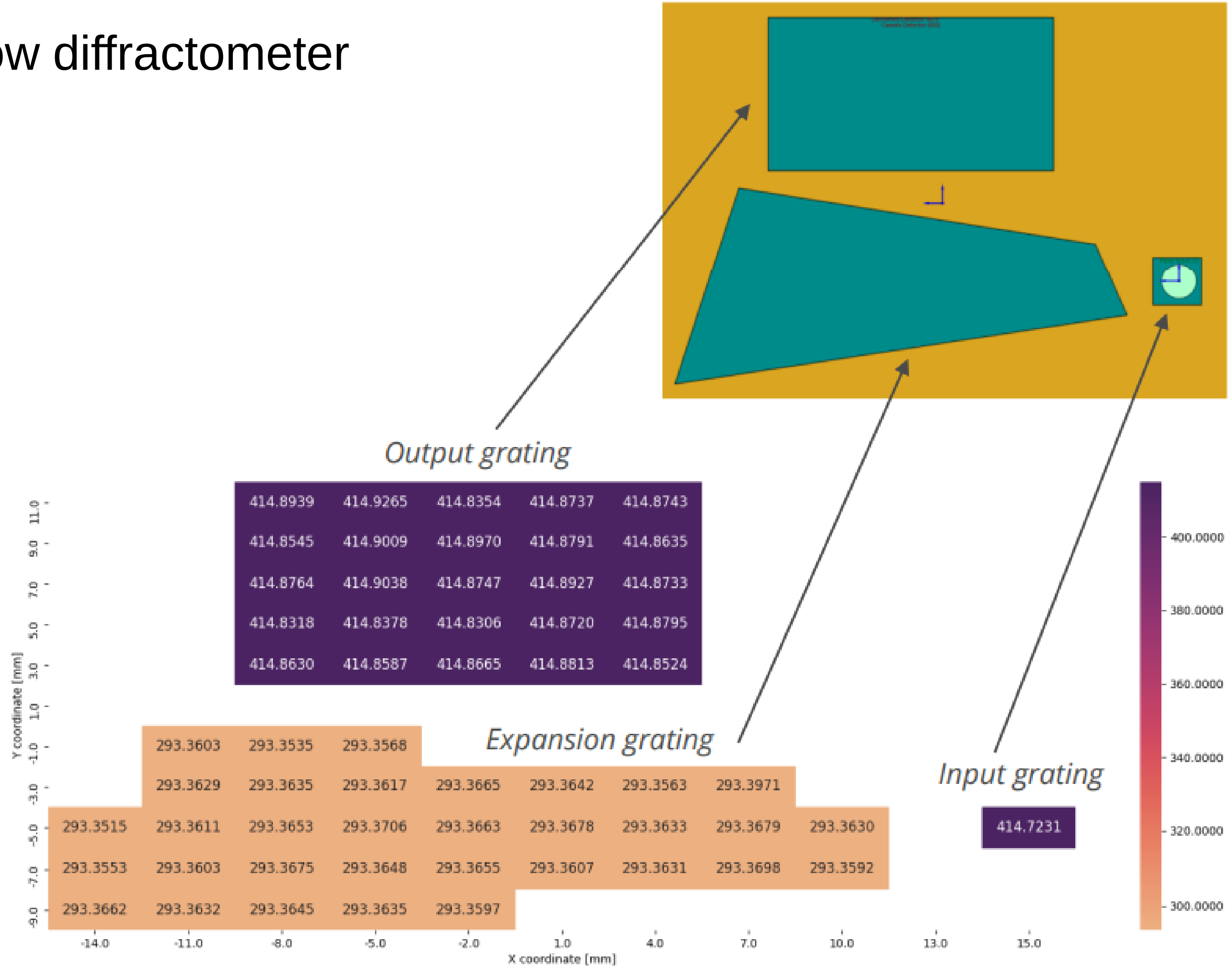
- Masters can be tedious & complex to originate, o
format
- Upscaling of masters is needed to increase throu
- Roll-to-Plate (R2P) NIL can replicate multiple sca
grouped together

Characterization of Imprinted Waveguides

Grating period determined by high-end Littrow diffractometer

1) single waveguide

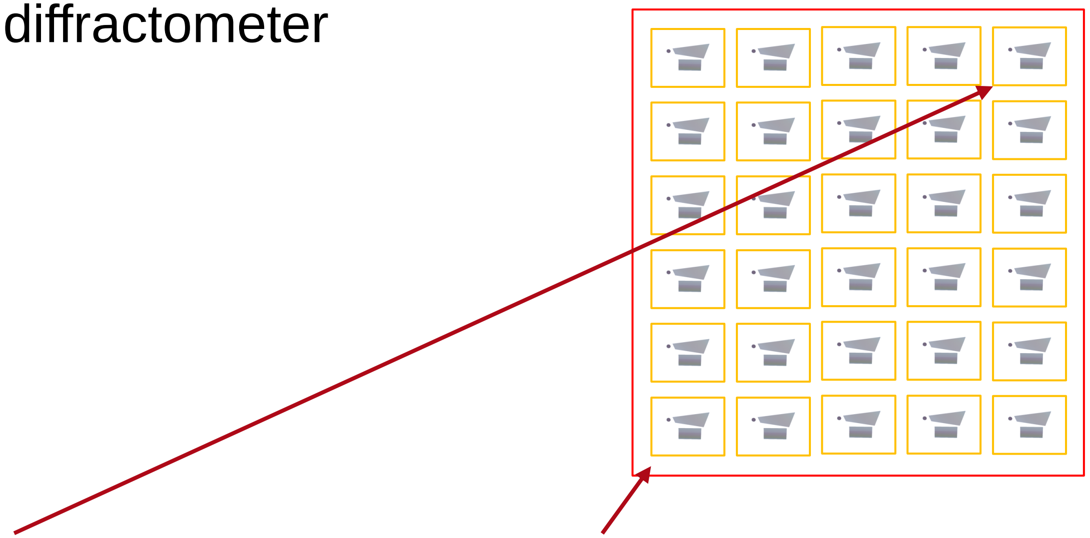




Homogeneity of Imprinted Waveguides

Grating period determined by high-end Littrow diffractometer

1) single waveguide
2) wafer (30 waveguides)



	Design	Master	Imprint sample 1 Upper right corner	Imprint sample 2 Lower left corner (same sample) 200×200 mm apart
Incoupler	415 nm	414.97 nm	414.8 nm	414.98 nm
Expander	293.45 nm	293.43 nm ± 2 pm (standard deviation)	293.35 nm ± 9 pm (standard deviation)	Not measured
Outcoupler	415 nm	415.01 nm ± 7 pm (standard deviation)	414.88 nm ± 47 pm (standard deviation)	414.88 nm ± 21 pm (standard deviation)

Homogeneity of Imprinted Waveguides

OPTOFIDELITY

Grating period determined by high-end

1) single waveguide
2) wafer (30 waveguides)
3) R2P imprint (270 waveguides)

	Design	Master	H1	H2	H3	R1	R2	R3	R4	R5	R6
Incoupler	415	414.97	414.98	414.97	414.96	414.97	414.98	414.95	414.96	414.96	414.91
Expander	293.45	293.43 ± 2 pm	293.47 ± 9 pm	293.46 ± 9 pm	293.44 ± 7 pm	293.44 ± 7 pm	293.44 ± 6 pm	293.44 ± 6 pm	293.44 ± 6 pm	293.45 ± 6 pm	293.46 ± 9 pm
Outcoupler	415	415.01 ± 7 pm	415.00 ± 17 pm	415.00 ± 15 pm	415.02 ± 20 pm	414.99 ± 16 pm	414.98 ± 26 pm	414.99 ± 19 pm	414.99 ± 20 pm	414.99 ± 18 pm	415.00 ± 24 pm

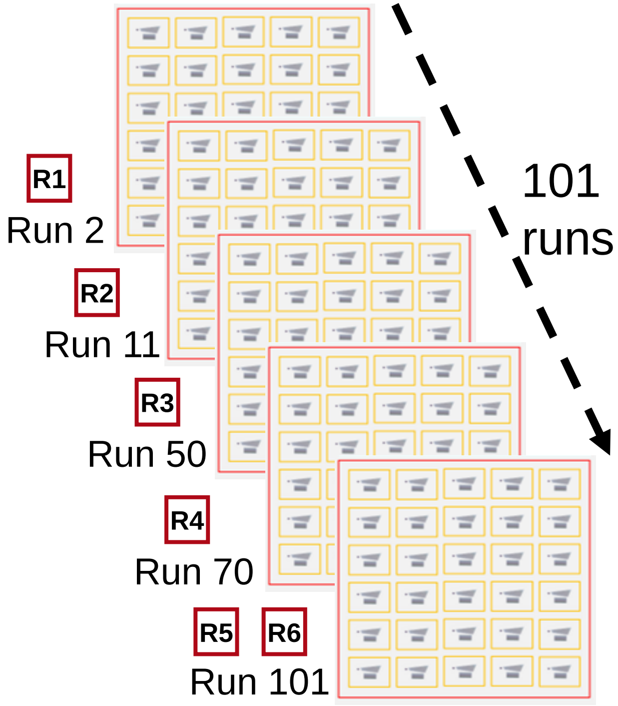
(all values in nm unless denoted differently)

Repetition Quality of Imprinted Waveguides

OPTOFIDELITY

Grating period determined by high-end

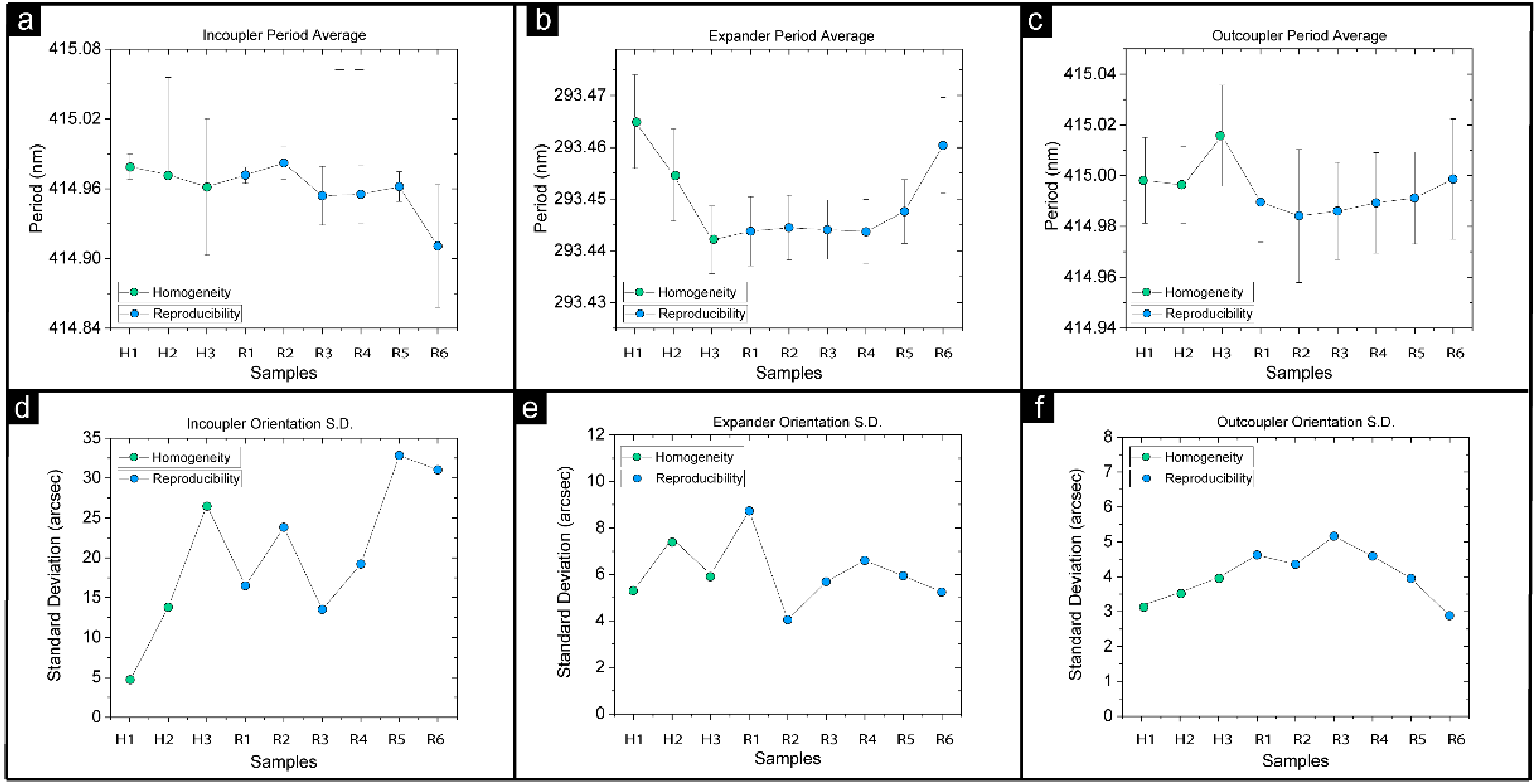
1) single waveguide
2) wafer (30 waveguides)
3) R2P imprint (270 waveguides)
4) 101 repetitions

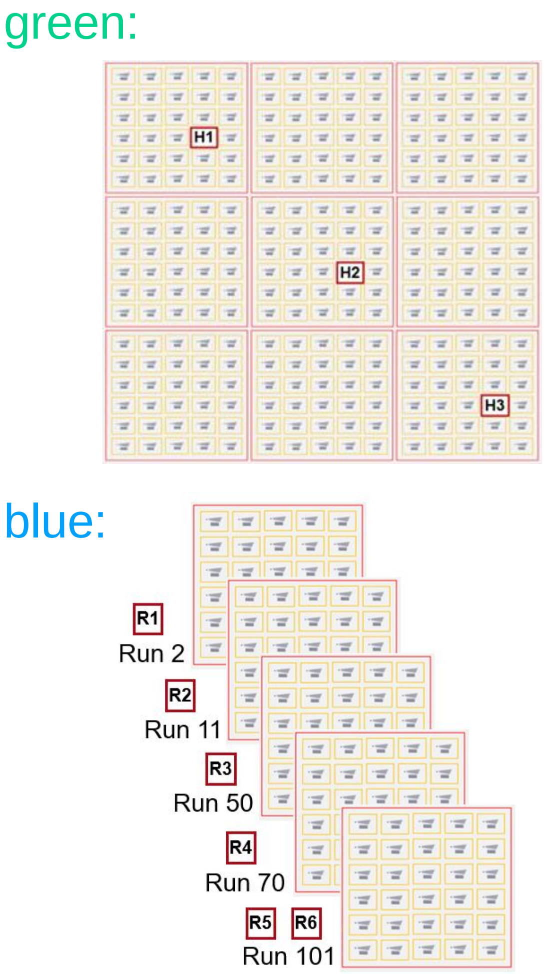


	Design	Master	H1	H2	H3	R1	R2	R3	R4	R5	R6
Incoupler	415	414.97	414.98	414.97	414.96	414.97	414.98	414.95	414.96	414.96	414.91
Expander	293.45	293.43 ± 2 pm	293.47 ± 9 pm	293.46 ± 9 pm	293.44 ± 7 pm	293.44 ± 7 pm	293.44 ± 6 pm	293.44 ± 6 pm	293.44 ± 6 pm	293.45 ± 6 pm	293.46 ± 9 pm
Outcoupler	415	415.01 ± 7 pm	415.00 ± 17 pm	415.00 ± 15 pm	415.02 ± 20 pm	414.99 ± 16 pm	414.98 ± 26 pm	414.99 ± 19 pm	414.99 ± 20 pm	414.99 ± 18 pm	415.00 ± 24 pm

(all values in nm unless denoted differently)

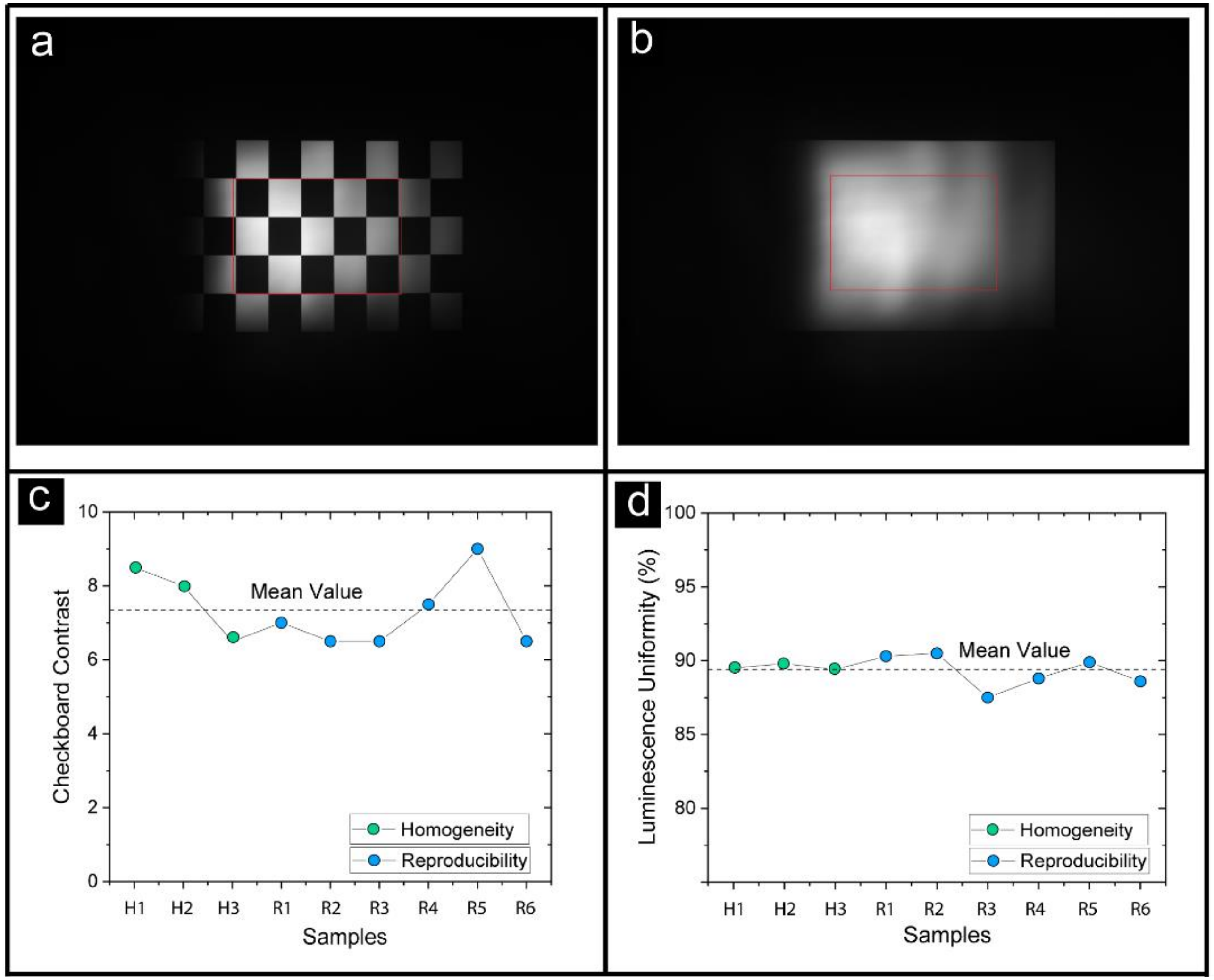
Homogeneity and Reproducibility of Waveguides



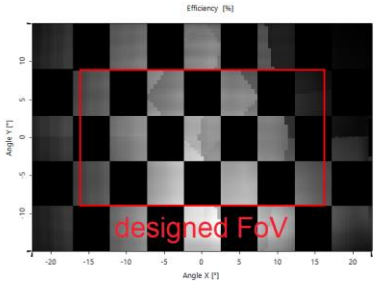


Angular Uniformity Measurements

checkerboard contrast and luminance uniformity measured on IEC63145 standard with OptoProjector:

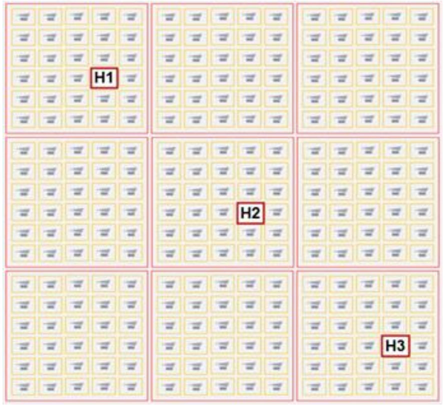


simulation result:

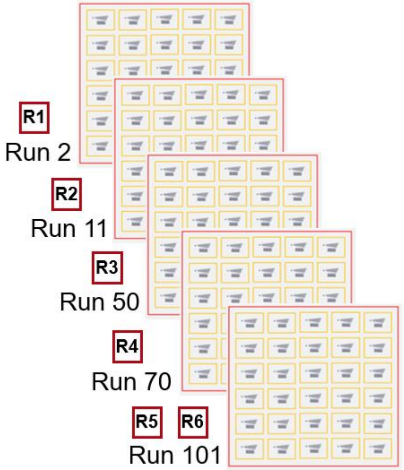


- very high homogeneity and reproducibility
- just negligible fluctuations
- good agreement with simulation result

green:

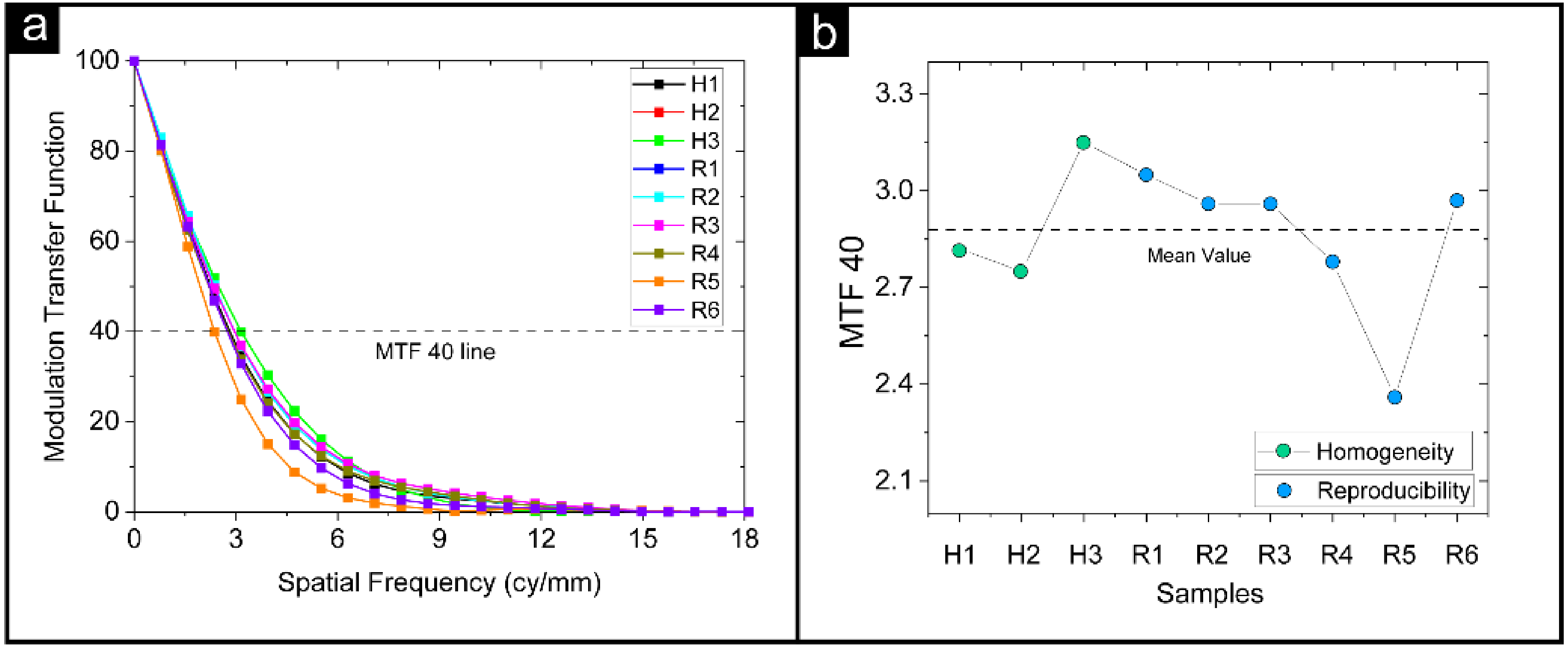


blue:



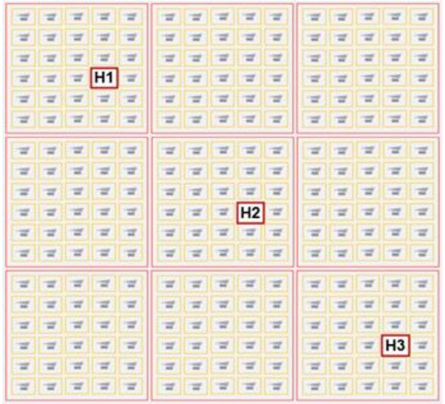
Measured MTF

MTF measured with camera and telescope objective:

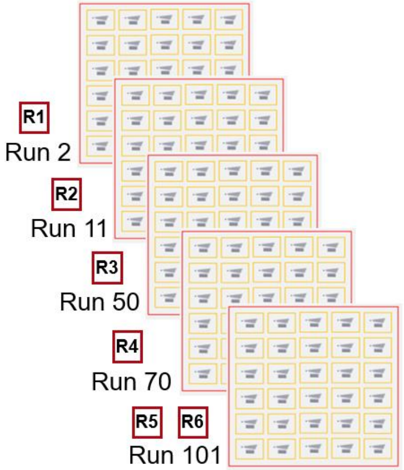


imprinted waveguide exhibit a comparable MTF (a) and a decent MTF 40 value

green:



blue:



Summary

Will the shown high-volume manufacturing of AR waveguides help to trigger the adoption of smart glasses towards the metaverse?

- successful transition to high-volume manufacturing or AR waveguides, display-oriented, high-quality focused
- high-index squared glass enable the increase the production volume
- together with complex design, high-end mastering and in-depth quality inspection, large area nanoimprint proves that mass production is feasible
- end-to-end supply chain and cooperation of different disciplines is key