Grayscale photo-lithographic mastering for automotive lighting

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EPIC Meeting on Wafer Level Optics, Neuchâtel 2019

Outline

1. From a fly's eye condenser to micro array projectors
2. Irregular fly's eye condenser approach for head lamps
3. Direct writing grayscale photolithography as mastering technology

Funded by Fraunhofer society in WISA framework "SSL – StructuredSpotLight"

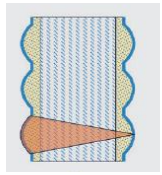
From fly's eye condenser to micro-array projection

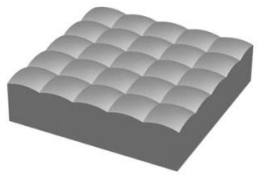
- Homogeneous illuminated far field [$-\theta_{out}$, θ_{out}]
- Maximum acceptance angle equals θ_{out}
- Far field shape = lenslet aperture shape
- Etendue conservation

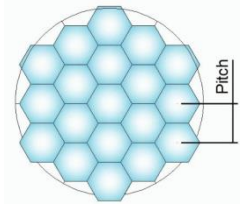
! High transmission requires large fill-factor arrays

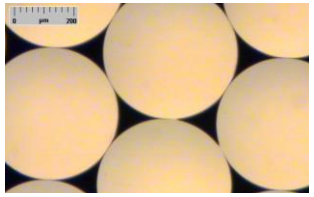
→ dense packaging

!



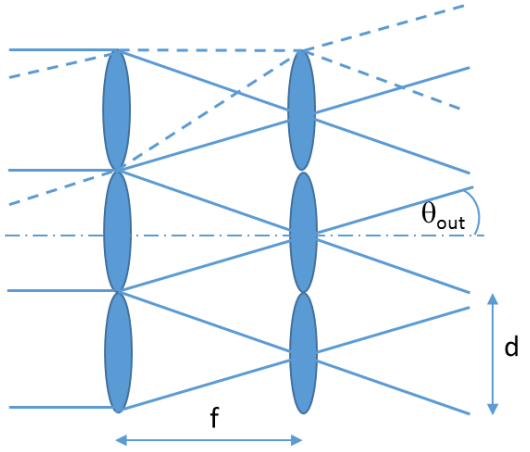


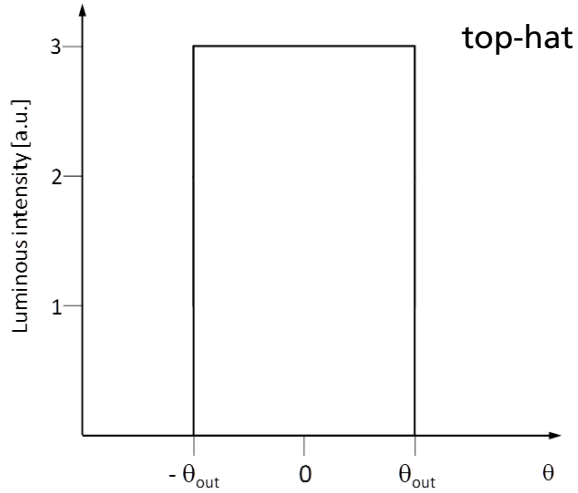


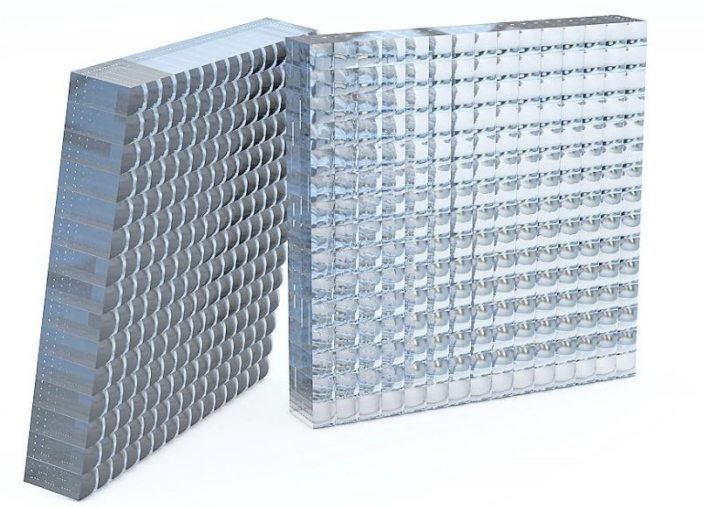


→ nowadays monolithic elements
(polymer on glass, or etched into substrate)

→ lithographic-based manufacturing with alignment precision (decentration) <1% of aperture diameter







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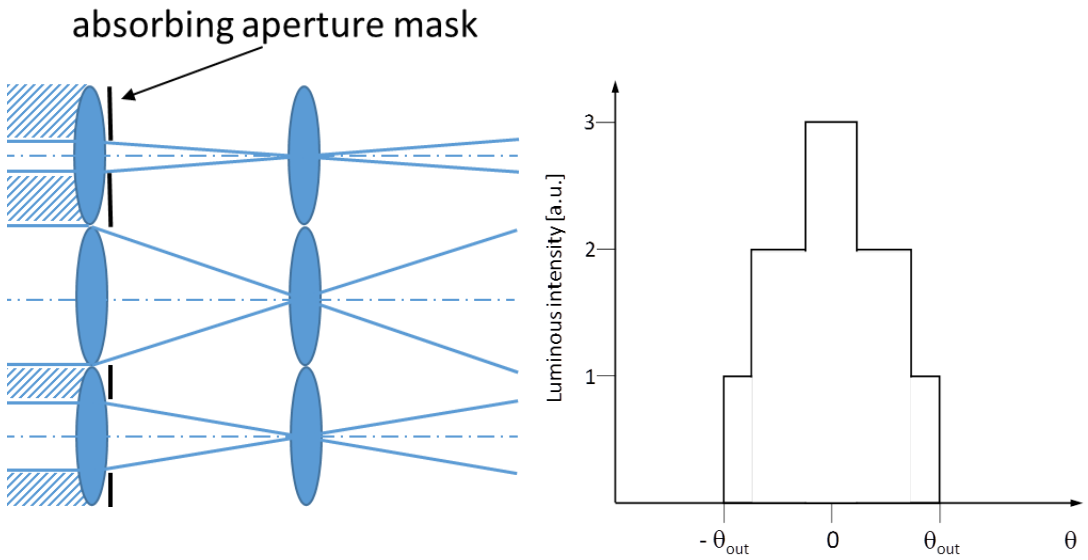
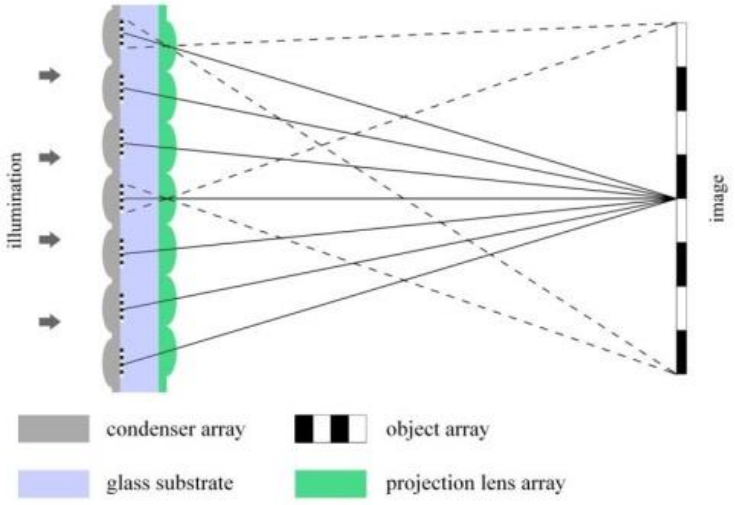
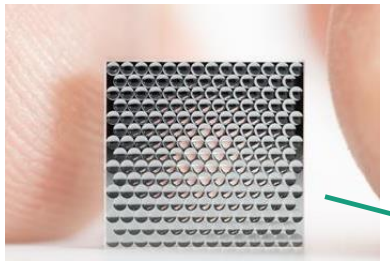
From fly's eye condenser to micro-array projection

- Add buried slide mask underneath entrance lenslets
- Still Etendue conserving
- Continuous far field within [- θ_{out} , θ_{out}], but this is paid by
  → lowered transmission / heating by absorbed light!
- Increment of flux by lateral scaling (channel number)
- Number of gray levels = array channel number







M. Sieler *et al.*, Appl. Opt. **51** (2012) 64

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Irregular fly's eye condenser for head lamp beam shaping

- Continuous far field distribution and avoiding (absorbing) slide mask layer
- High transmission and keeping Etendue conservation
- Irregularity:

→ Entrance: variable aperture size, decentration

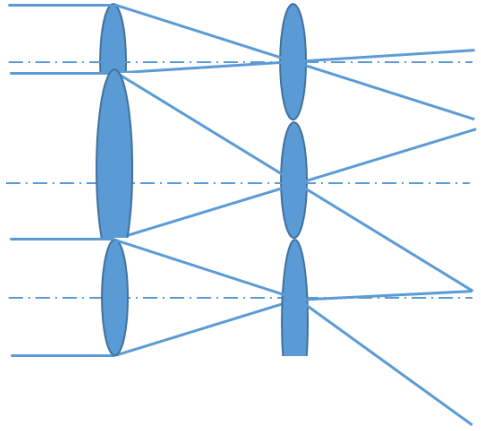
→ Exit: decentered lenslet vertices

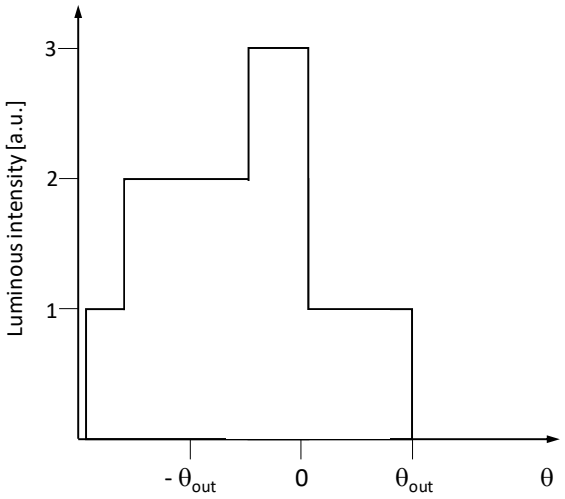
- Automotive far field distributions are challenging!

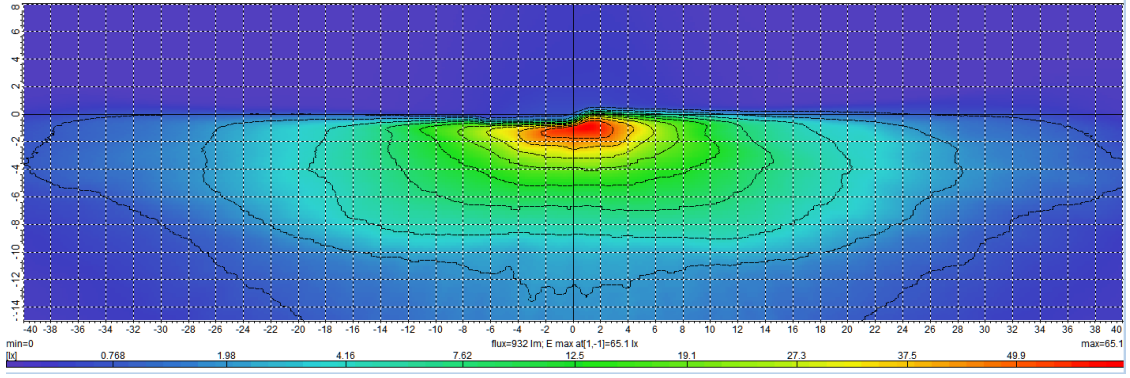
→ asymmetric

→ hot spot, steep gradients

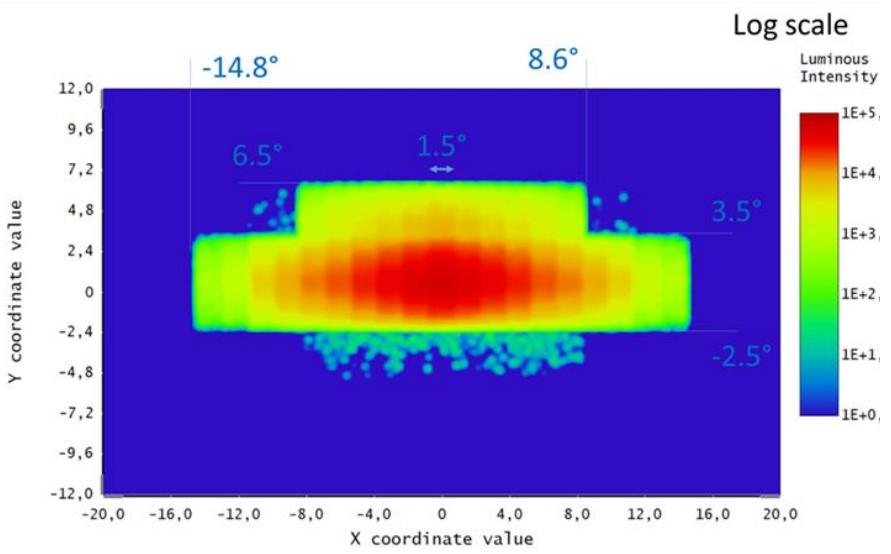
→ features (segmented high beam)







Low beam far field distribution



Targeted high beam far field distribution

Ch. Li, P. Schreiber, *et al.*, SPIE 10693 (2018) 1069304

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2. Irregular fly’s eye condenser approach for head lamps
3. **Direct writing grayscale photolithography as mastering technology**

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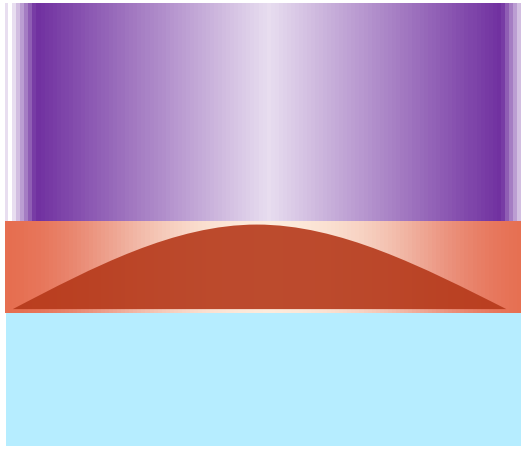
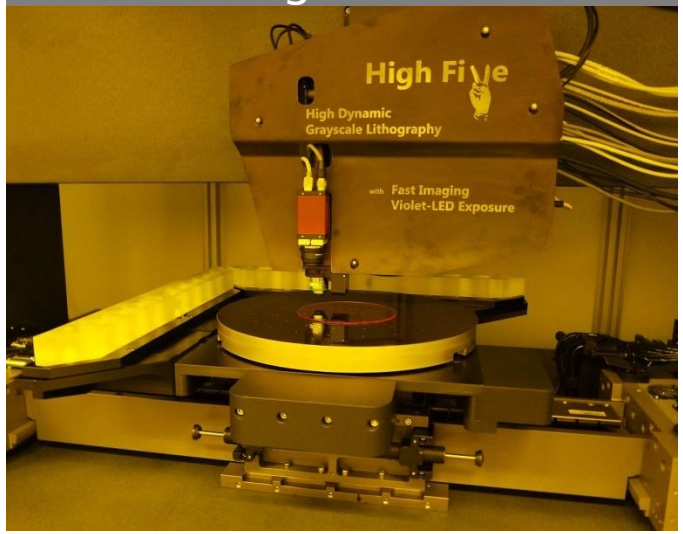
Direct-writing grayscale photo-lithography

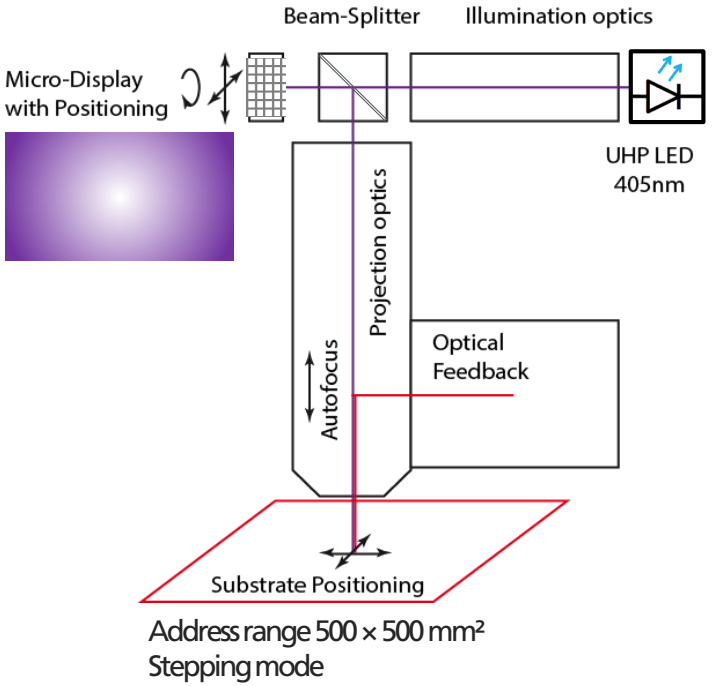
Local variation of UV-light dosage



(low contrast) positive tone resist

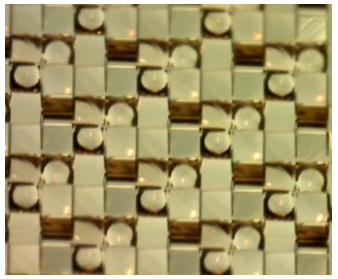
direct writing litho tool

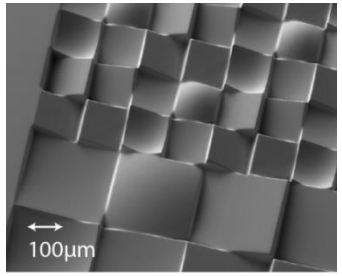


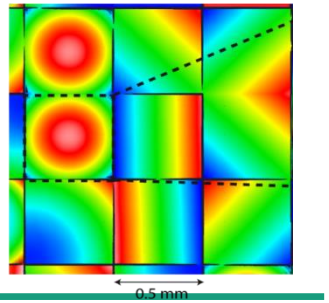


Address range 500 × 500 mm²
Stepping mode

- nearly arbitrary profiles → micro freeforms
- filling factor close to 100%
- ! limited structure height <~ 100 micron
- ! Writing artefacts / dosage calibration







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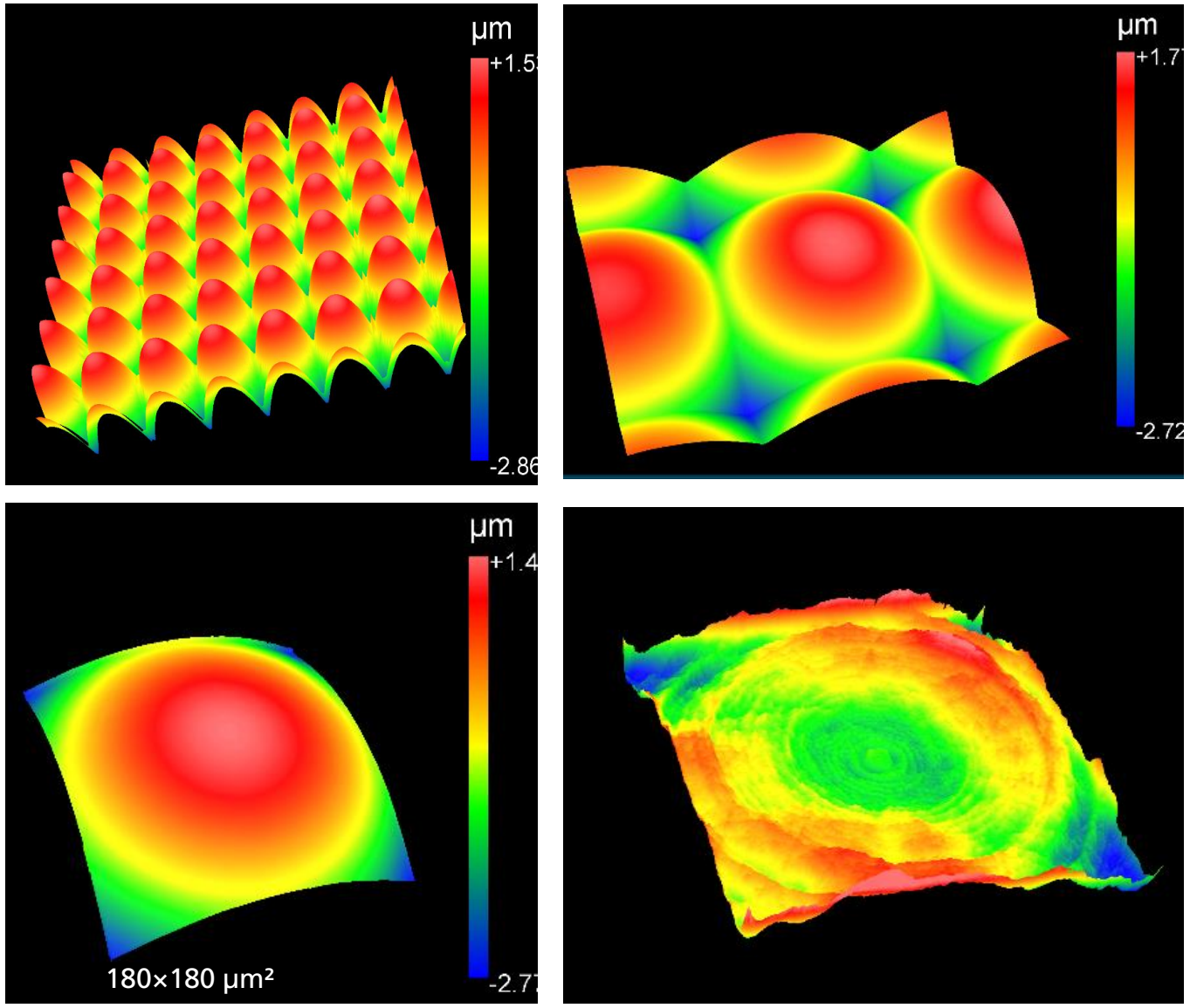
Grayscale lithographic mastering: High beam

Exit lens array (projection)

- AZ 4562 resist by spin coating
- regular lens array
- Array size ~ 82 × 42 mm²
- Effective area (filling factor) >97%
- Sag height 4.3 µm
- ROC 1835 µm (± 1.5%)
- rms 28 nm (~ λ / 20)

- writing artefacts:
  - Stitching micro-images
  - Flat field inhomogeneity
  - Photoresist dose calibration



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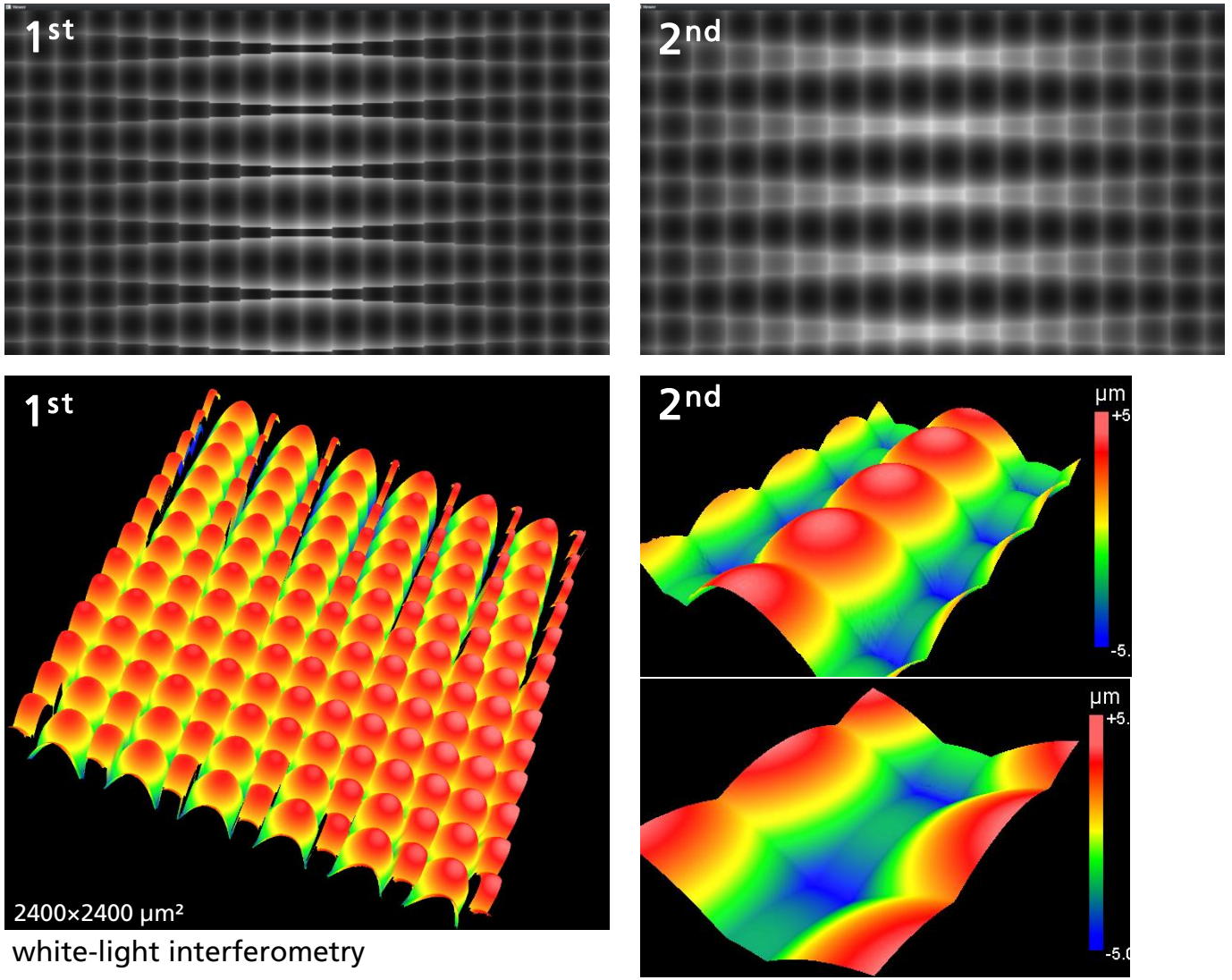
Grayscale lithographic mastering: High beam

Entrance lens array

- AZ 4562 resist by spin coating
- vertically irregular entrance MLA
- Effective area (filling factor) >97%
- Sag height: 2 µm … 8.1 µm
- 1st run: discontinuities up to 6.2 µm
  → cause stray-light, esp. into vertical direction
- 2nd run: height adaptation of individual lenslets

exposure dosage: the whiter, the deeper



white-light interferometry

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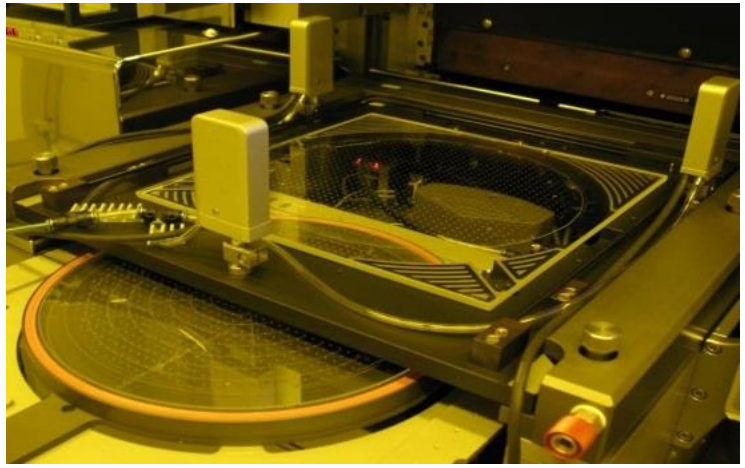
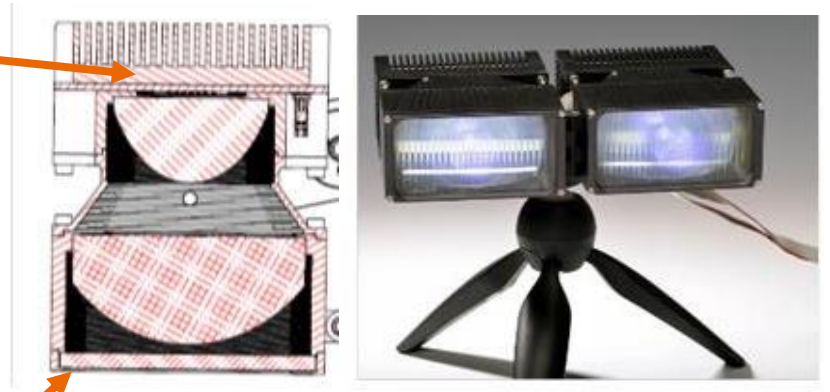
Replication by UV-molding using a mask aligner

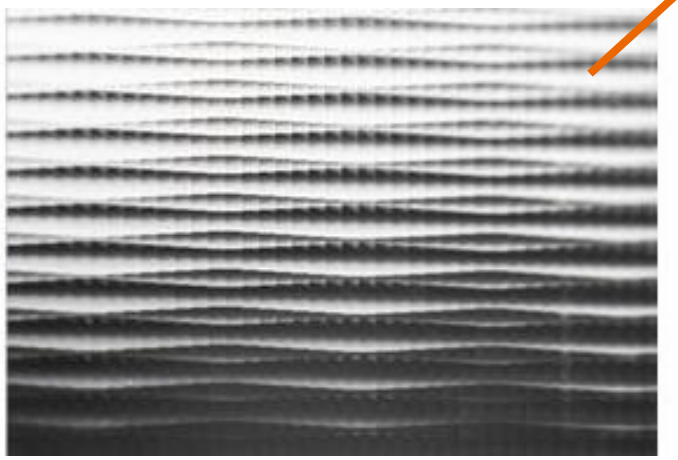
- PDMS mold from resist master
- Substrate: Schott B33: *d* = 5.0 mm
- Lens material: 1K Epoxy (DELO) aligned double-side processing

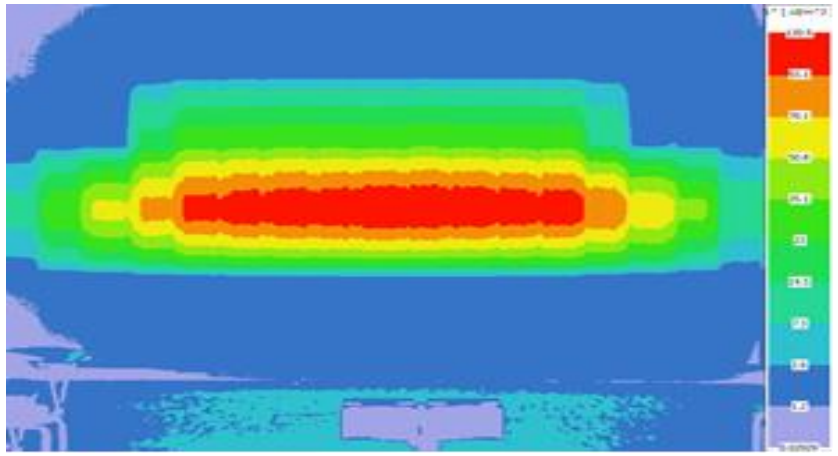


- Antireflection coating
- Next step: transfer to Injection compression molding

LEDs
(7 columns)







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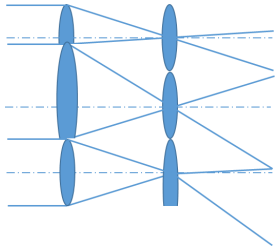
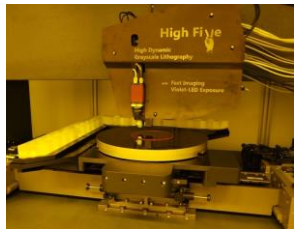
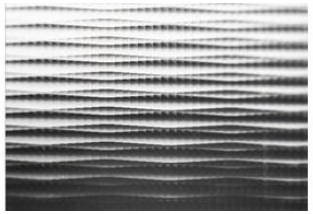
Conclusions



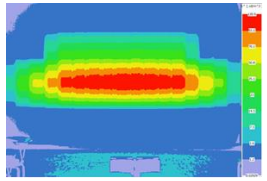
Irregular Fly's eye condenser enable continuous far field distribution while conserving Etendue



Arrangements of dense-packed (segmented) microlenses have been mastered by direct-writing grayscale photolithography



Monolithic micro-optical refractive elements have been generated by replication using UV-molding



Continuous far field patterns have been optimized for a segmented high beam and a low beam application

Funded by Fraunhofer society in WISA framework "SSL – StructuredSpotLight"

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