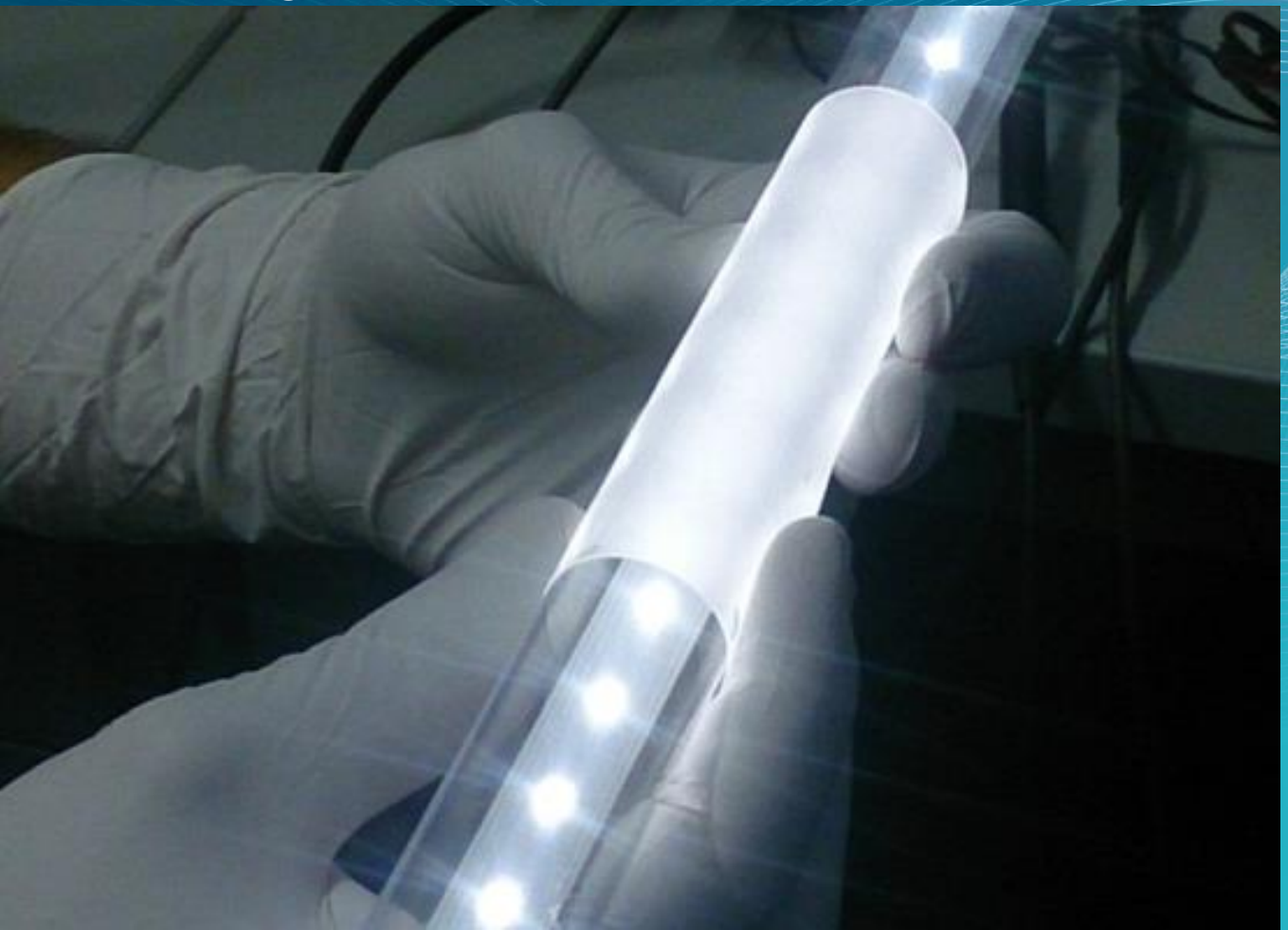
Deterministic Diffusers for Efficient Light-Shaping

Robert Leitel 12.05.2022
EPIC Meeting on Advanced Microoptics



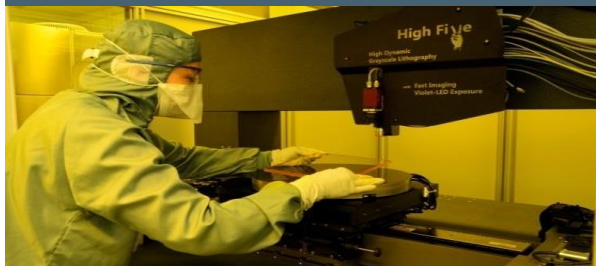
Outline

- Diffusers in general
- Designing of Deterministic Diffusers
- Making of Tailored Light Diffusers

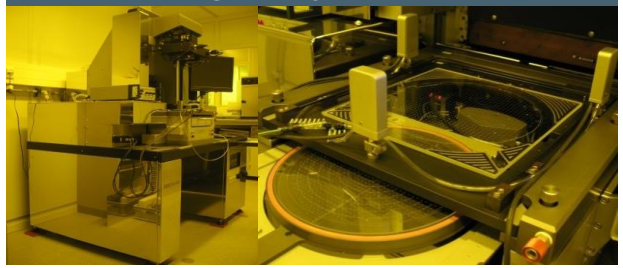
Micro- and Nanostructured Optics with Fraunhofer IOF…

electron beam lithography

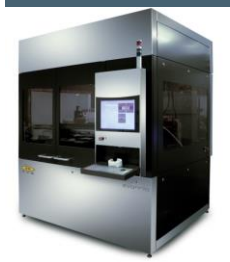
grayscale photo-lithography

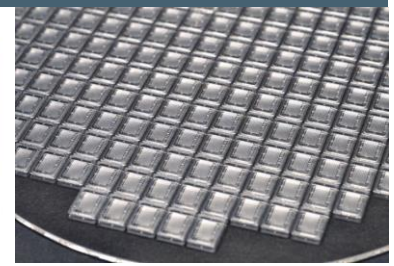


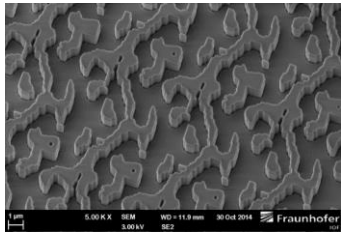
mask lithography & replication

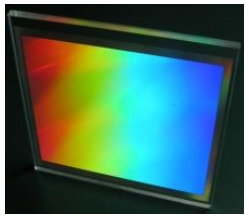


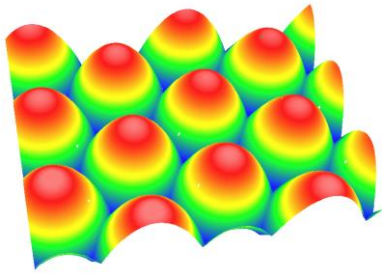
Step & Repeat replication

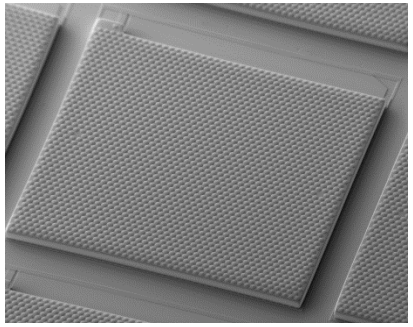


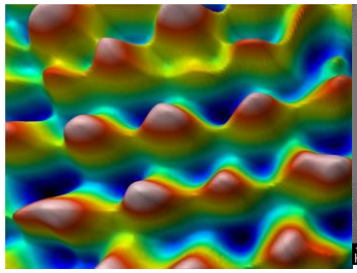


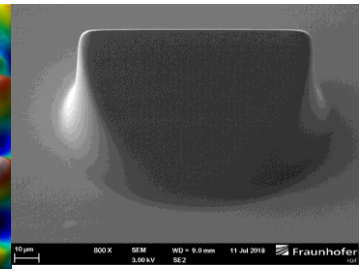


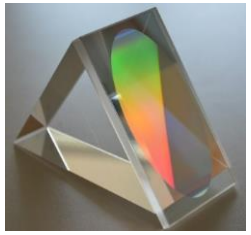


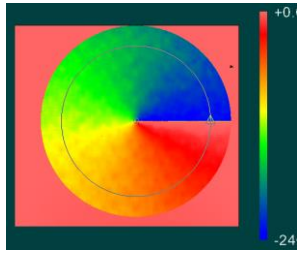


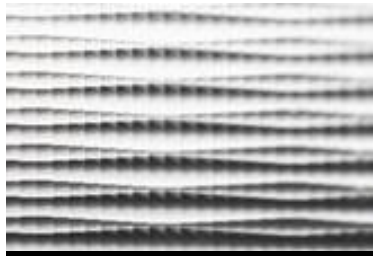


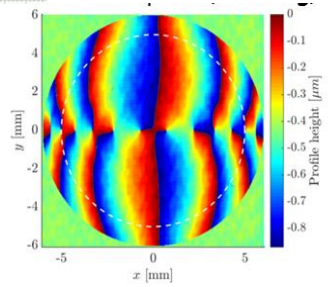


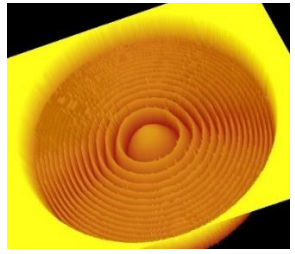


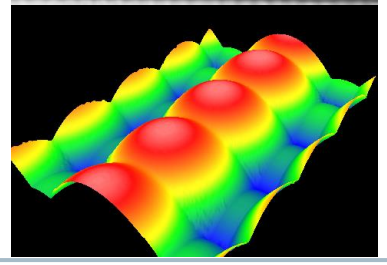


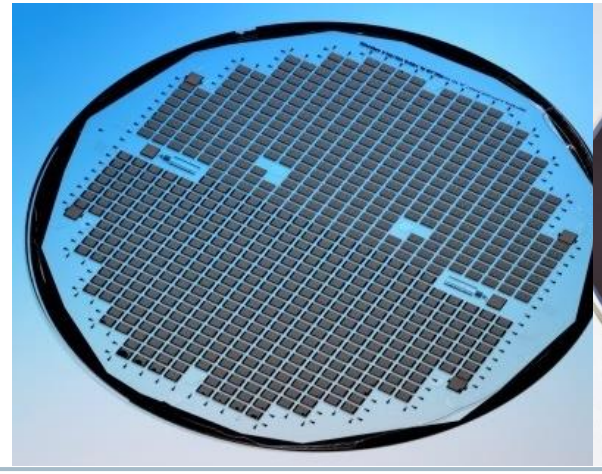


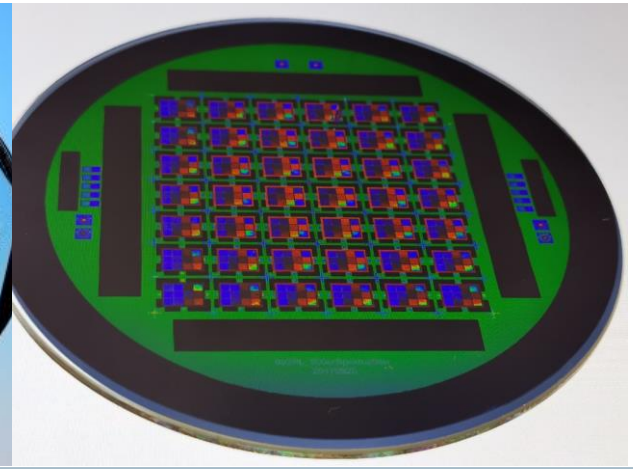






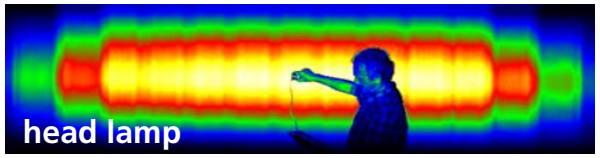


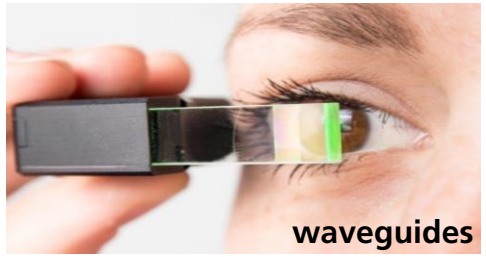


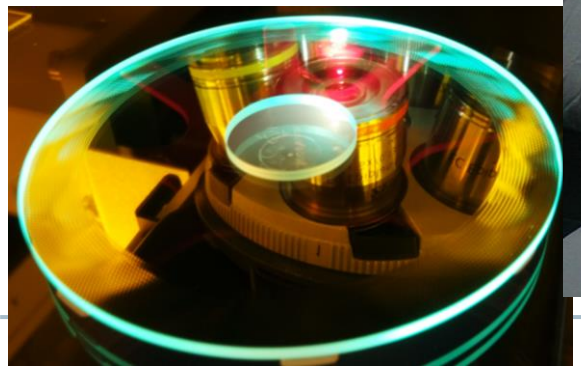


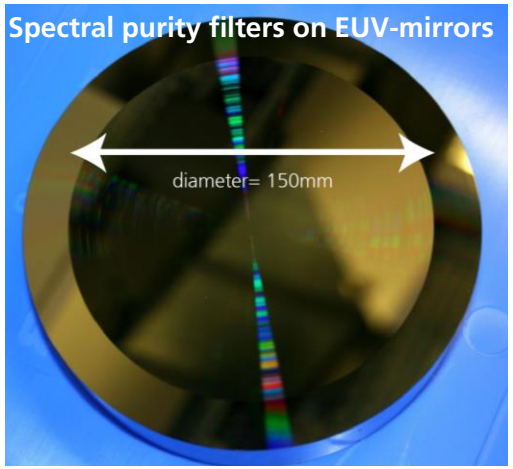
Fraunhofer IOF

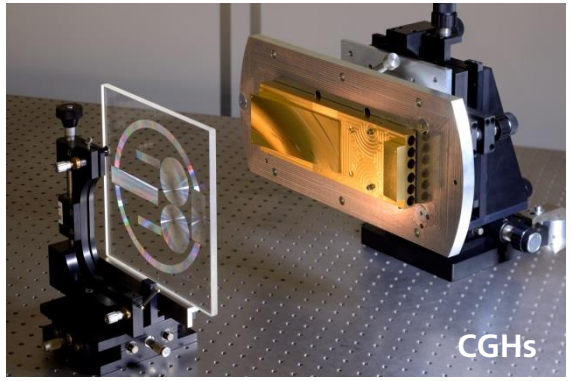
… and the applications thereof

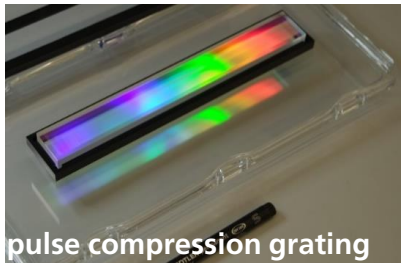


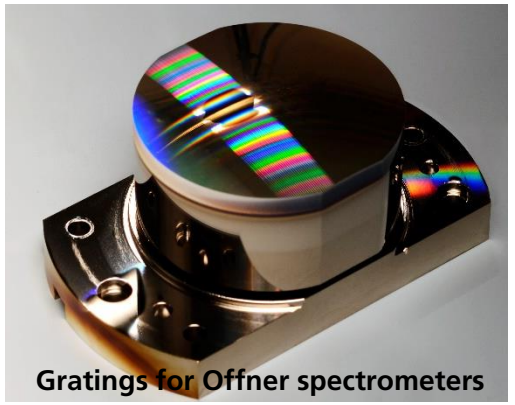


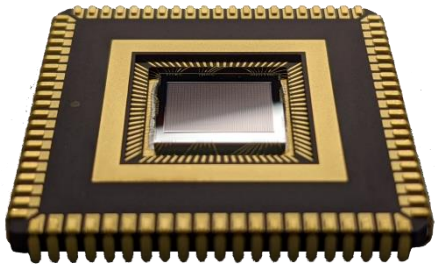


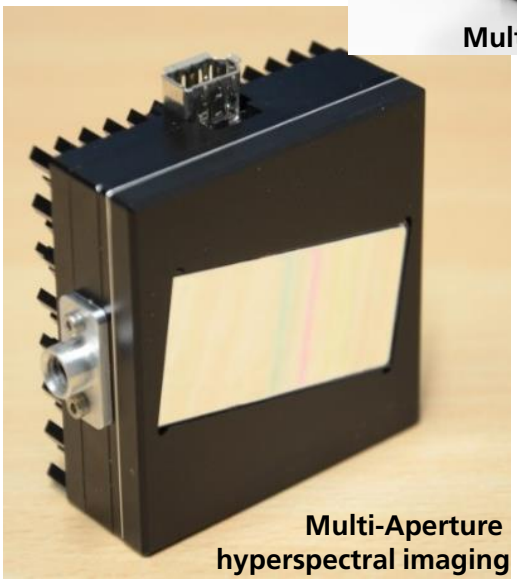


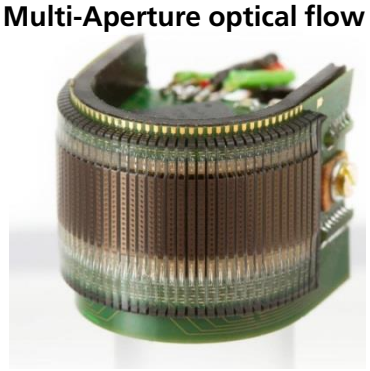






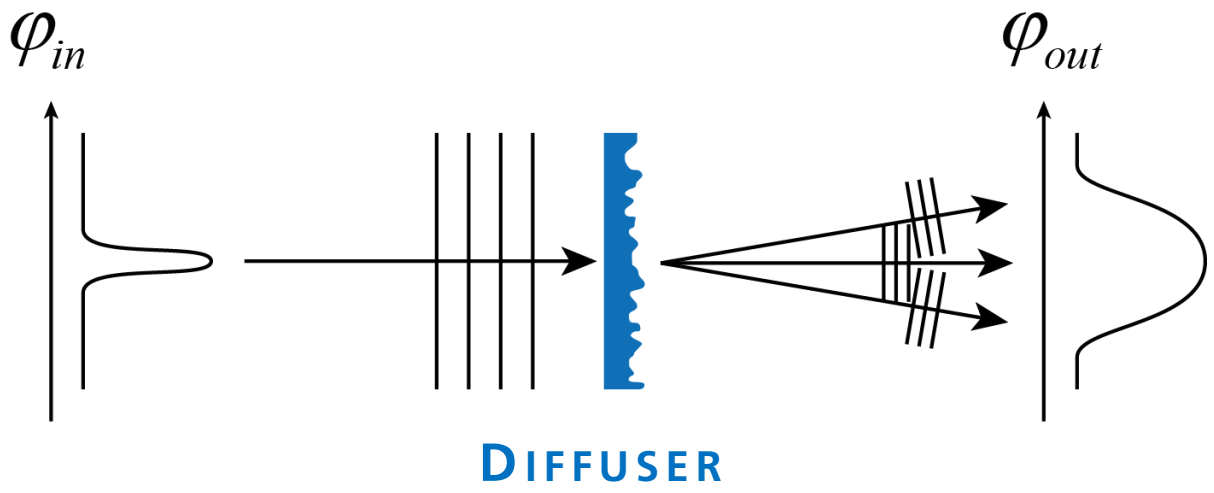


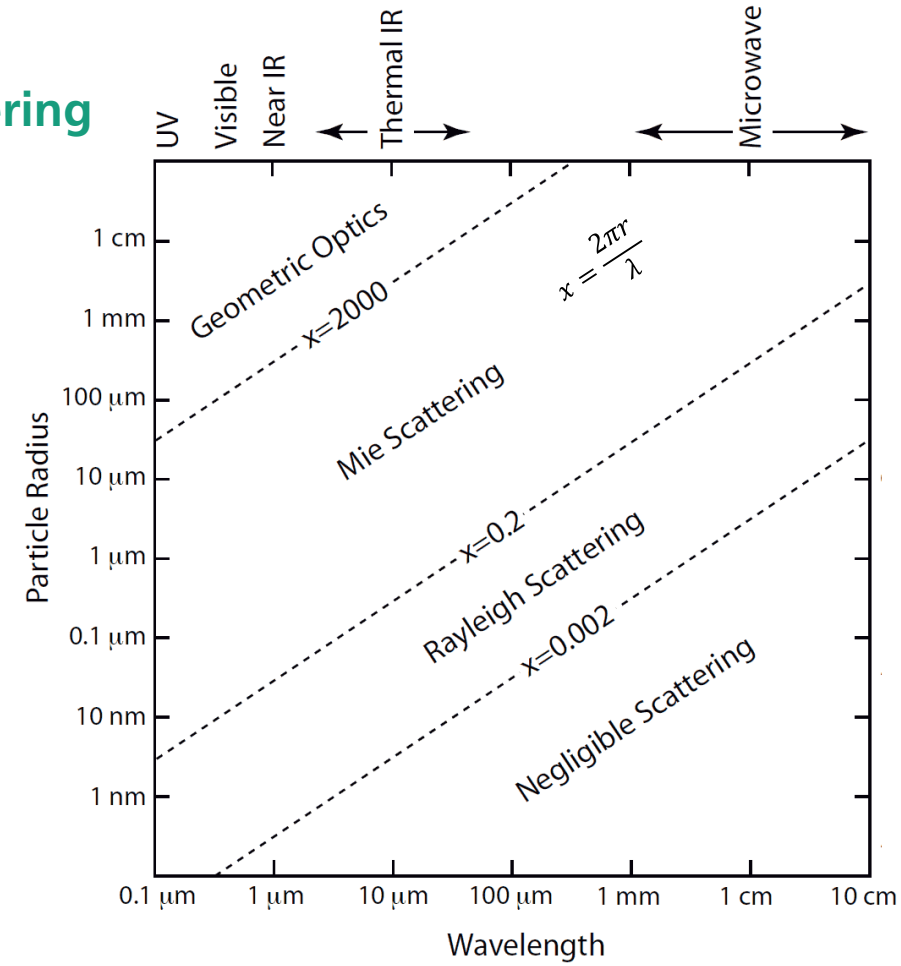




Diffusers in general use

Diffusers alter the divergence of incident light due to (elastic) scattering





Angular light distribution function behind optical element is convolution of incident light distribution and size distribution:

micro-roughness → mid-spatial frequency roughness → shape

Diffusers in general use: illumination

common diffusers exhibit stochastic or Gaussian (normal) distribution in:

- inclusions (volume), e.g. pigments, voids, interfaces, crystallites
- surface corrugations, e.g. grinding, sandblasting, etching, (laser) ablation

➔ Simple (no micromachining, no alignment)

➔ **Leads to Gaussian distribution in angular domain**

surface

Anti-Newton glass

Glare control film

screen

Roughness increases

volume

Tail light diffuser

Smart glass

Fluorescent lamp

Technical diffusers in general use: illumination + beam shaping

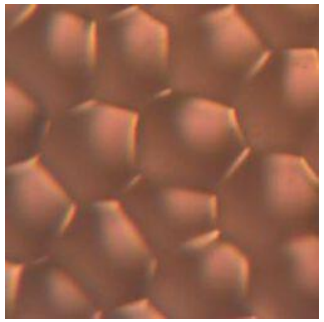
exhibit confined angular distribution due to or deterministic description of features

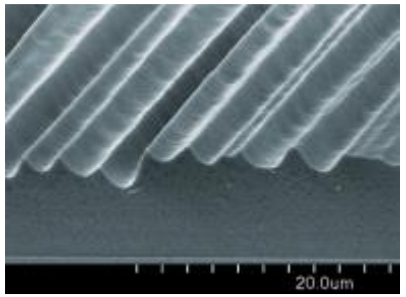
➔ Efforts needed in micromachining and alignment

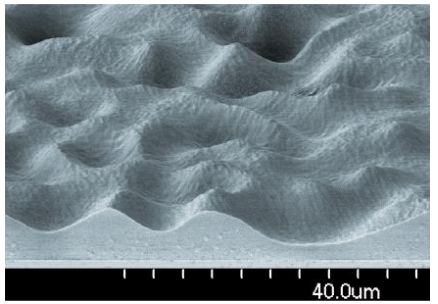
- **Using microlens arrays:**
  - shape according to footprint of lenslets
  - Gaussian distribution
- **Using holography:**
  - squared, rectangular, circular, elliptical, linear distributions
  - Top-hat distribution
- **Using direct writing lithography:**
  - quasi-arbitrary beam shaping
  - local variation in divergence
- **Most common: shaping laser beams using diffractive diffusers**
  - monochromatic, optimized for AOI, λ

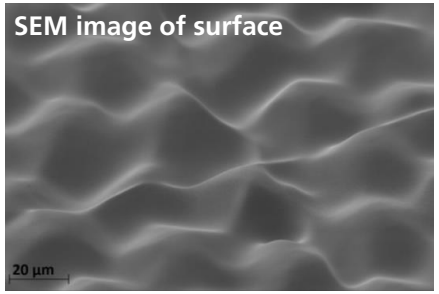
Fraunhofer IOF

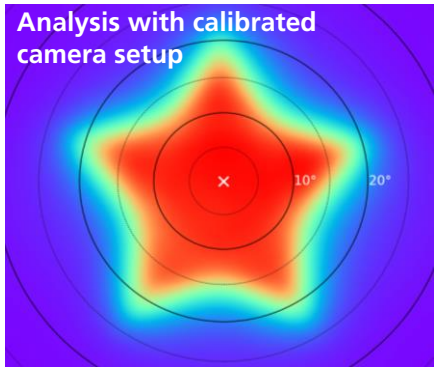
➔ Tailored-Light Diffusers









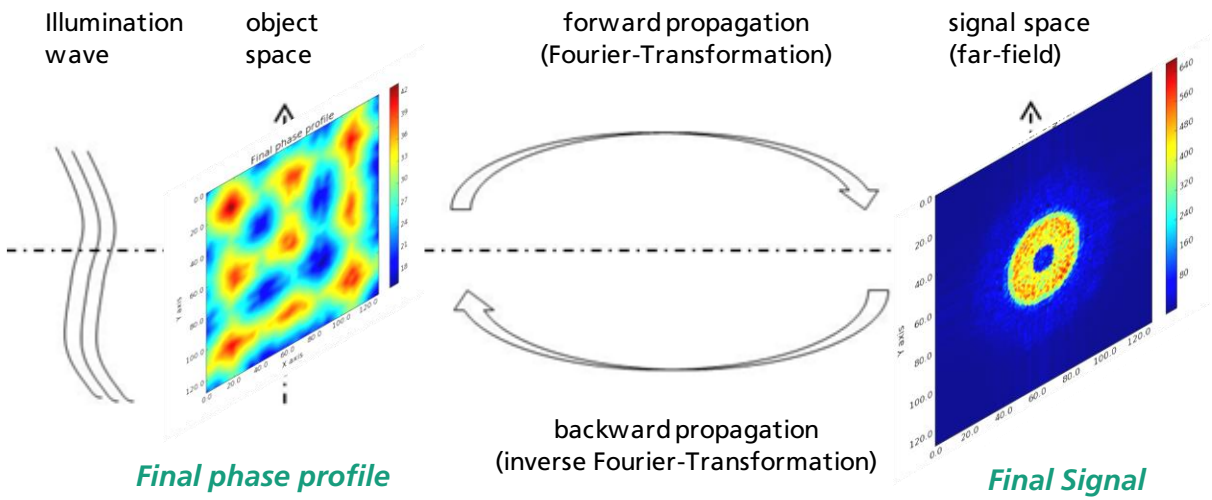


Examples: Rochester Photonics, Temicon, Jenoptik

Robert Leitel, © Fraunhofer 2022

Designing Tailored-Light Diffusers: Iterative Fourier-Transform Algorithm

Phase synthesis: Finding the phase pattern for a given far field light distribution → iterative phase optimization



1) Starting field:
   target amplitude arbitrary phase
2) Inverse FT
3) Replacement of amplitude by illumination function
4) FT
5) Replacement of amplitude by target function
6) Loop until condition fulfillment convergence!

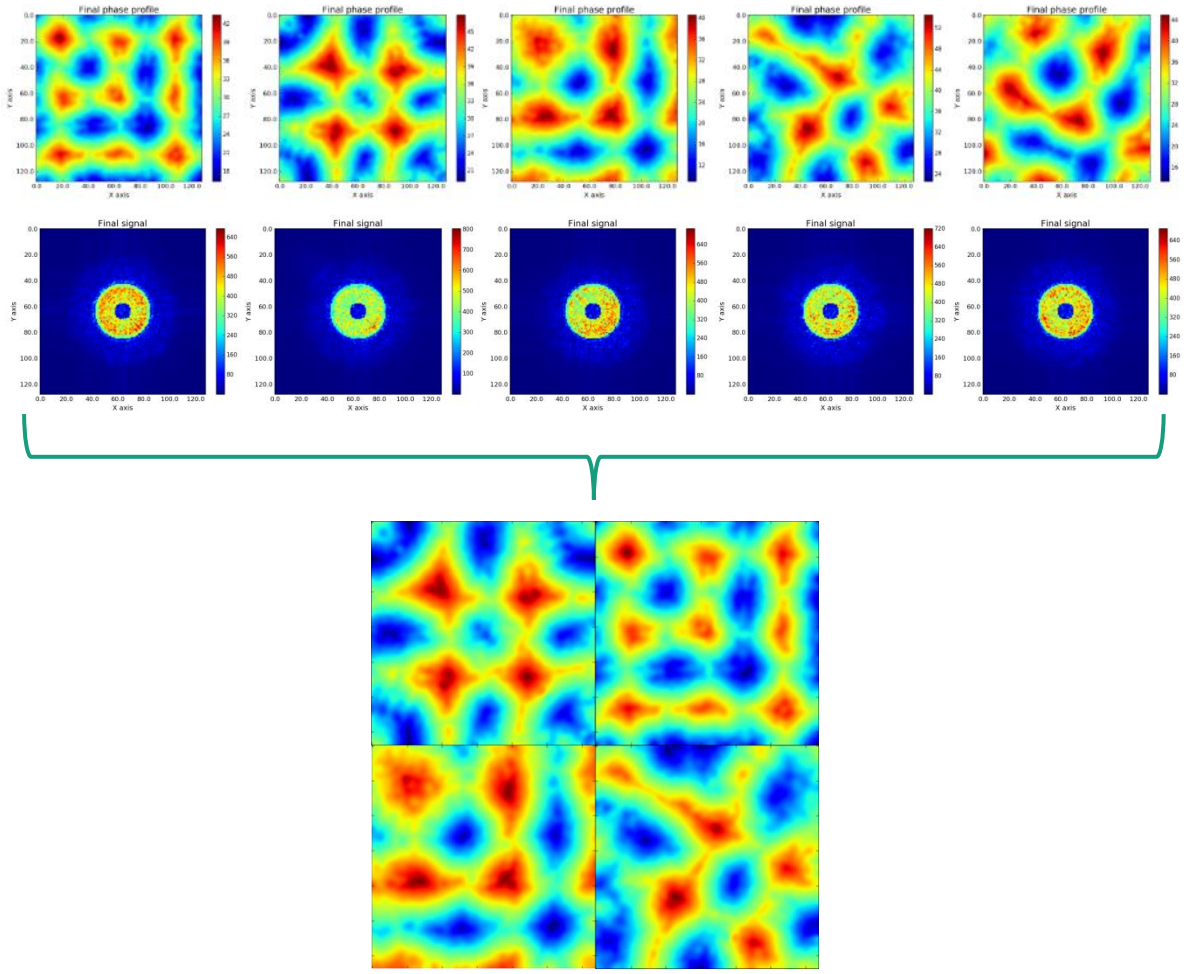
Modifications (not only) for diffusers:

- educated guess for starting field → no discontinuities in phase
- Amplitude freedom in signal space → SNR improvement
- Smooth phase profiles: → Adding the phase / unwrapping instead of [0,2π]
- Consider manufacturing characteristics → low-pass filtering
- Pre-distortion of target

Gerchberg, Saxton, Optik 32 (1972)

Designing Tailored-Light Diffusers: Modified Iterative Transform Algorithm

Large area: segmentation of the diffuser



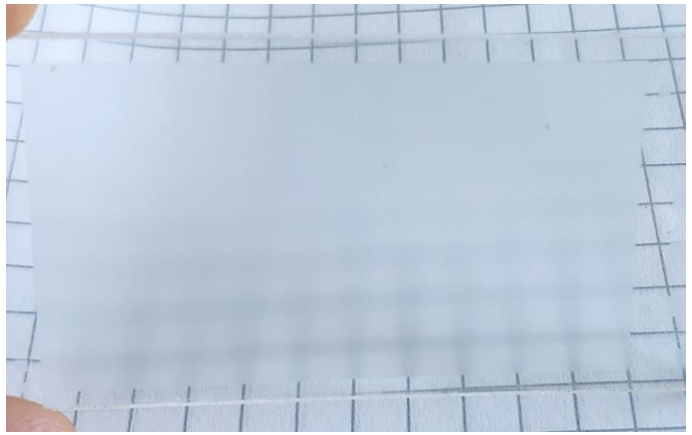
Introduction of large set of small tiles

- IFTA: (i)FFT much faster and less memory consuming
- variation to prevent diffraction effects
- Local variation of design targets
  → different angular distribution
- Allows adding of local different prism terms
  → **local chief ray deflection angle**
  → superposition of **moderate lens characteristics** on large scale
  → **divergent sources**

Incorporation into System Design

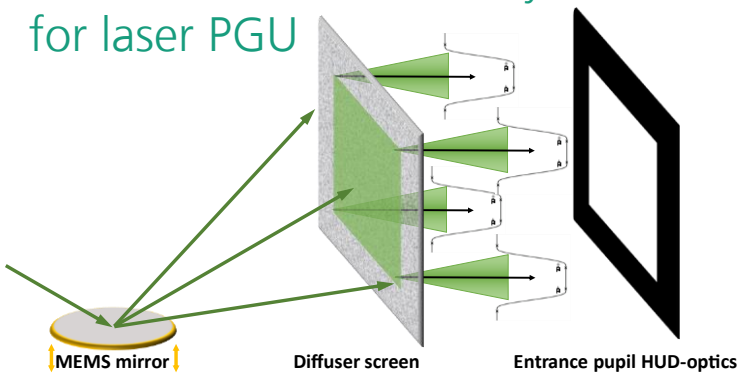
- Interface to Zemax® OpticStudio
- Parametrization with low count of variables

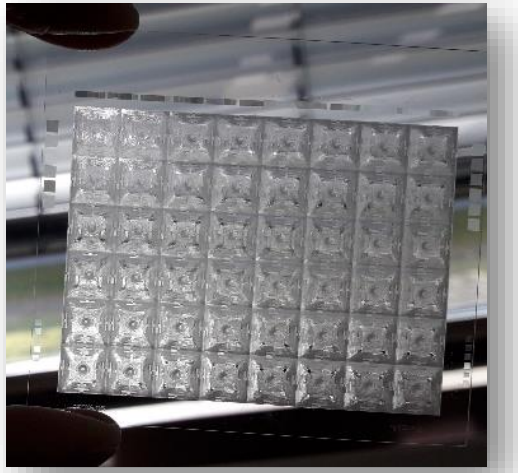
Tailored-Light Diffusers for divergent light sources



(intermediate) image plane for car HUD

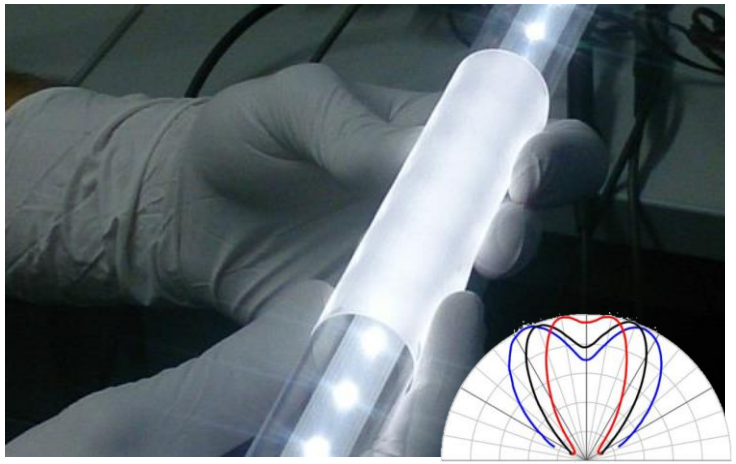
- Off-axis lens functionality for laser PGU





Thin display direct-lit backlight

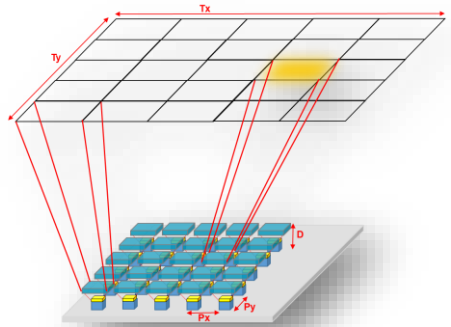
- Total stack 3 mm, pitch 8 mm
- Introduction of TLD into stack homogeneity 85% (+10%)

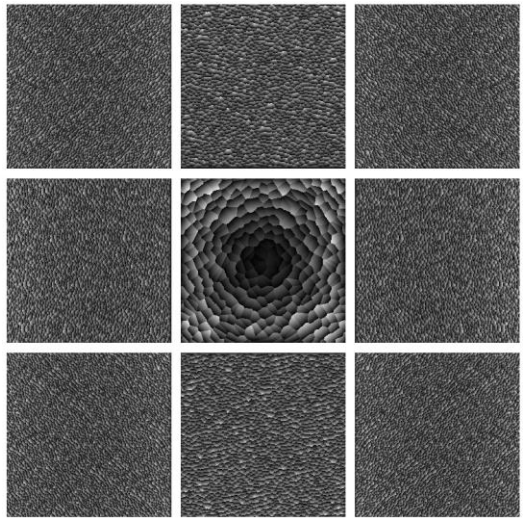


F. tube replacement with batwing distribution

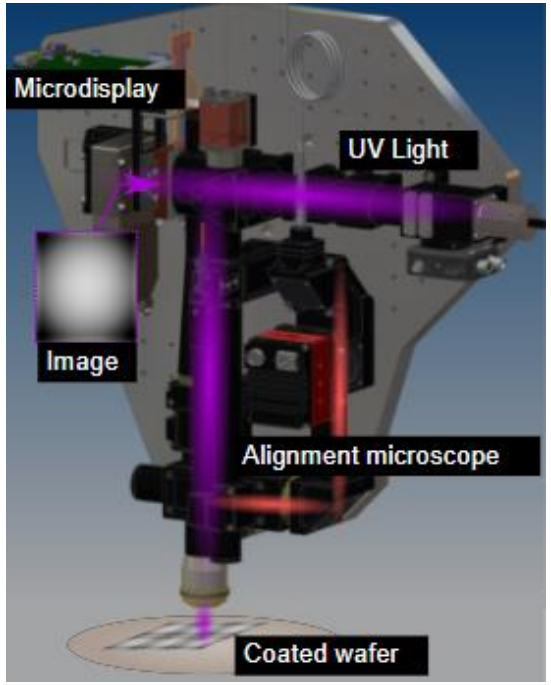
Adaptive flashlight

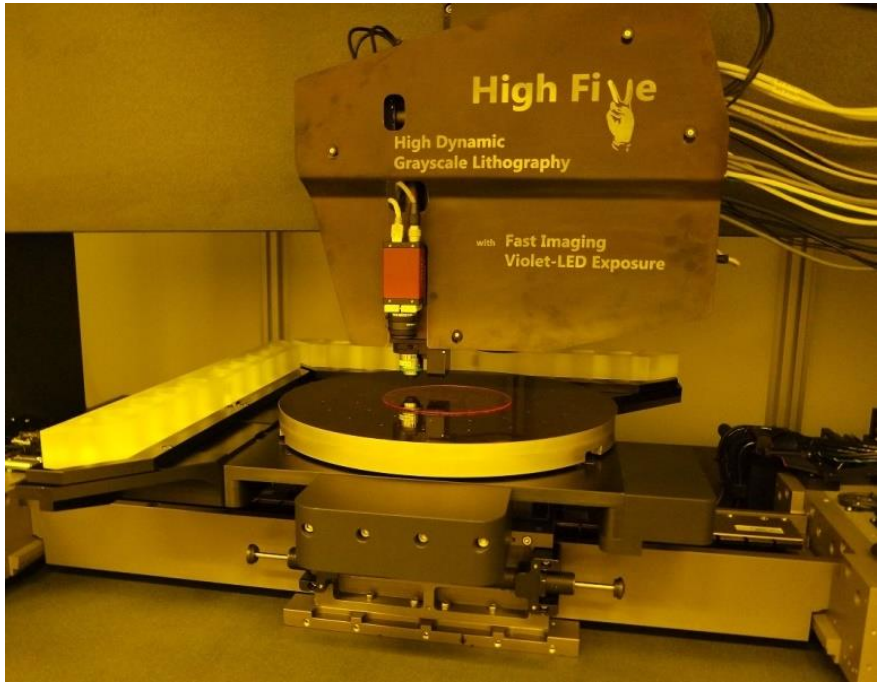
- segmented source e.g. color mixing

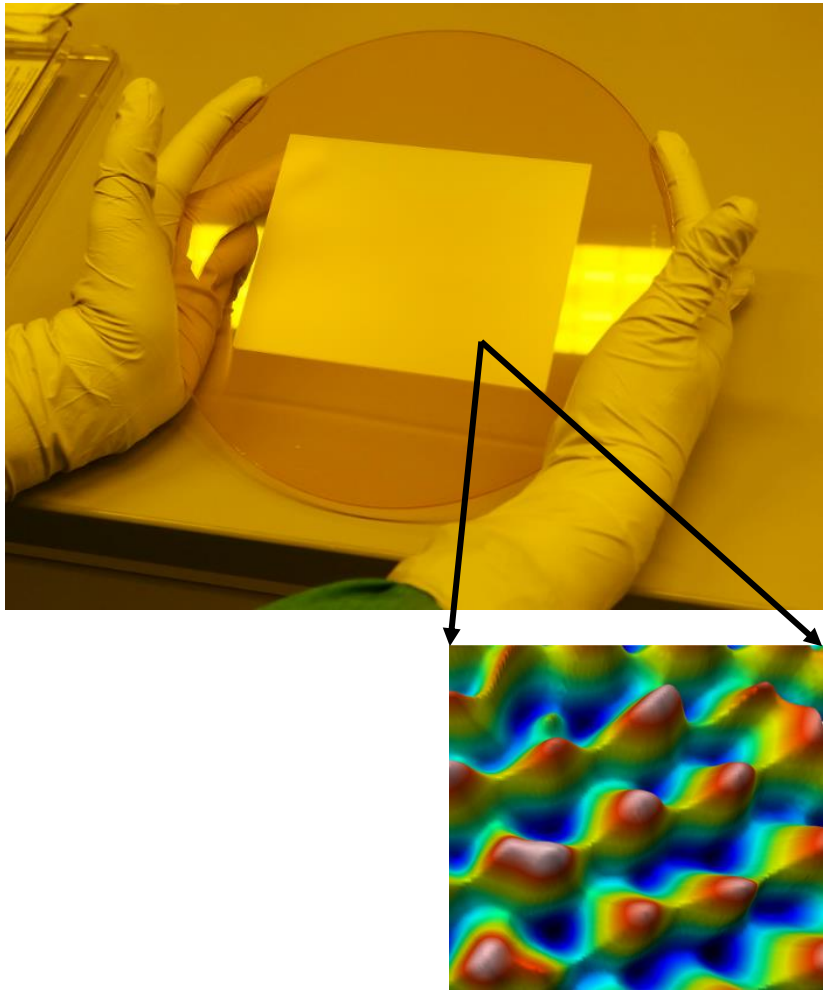


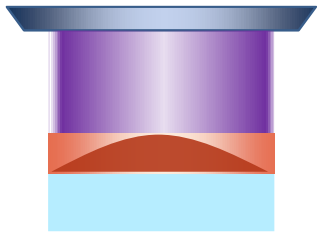


Mastering Tailored-Light Diffusers with grayscale photolithography







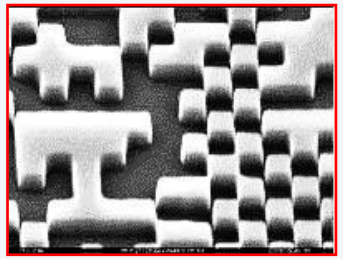
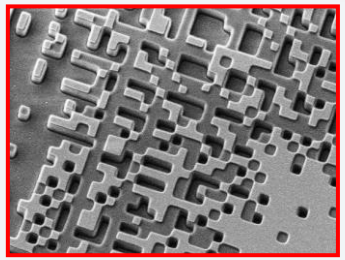
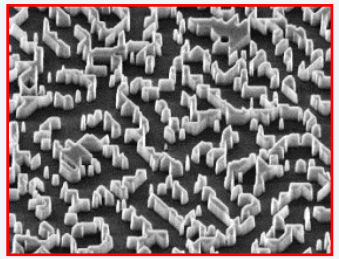
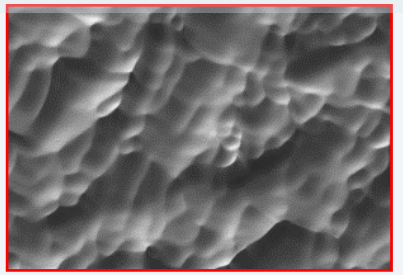
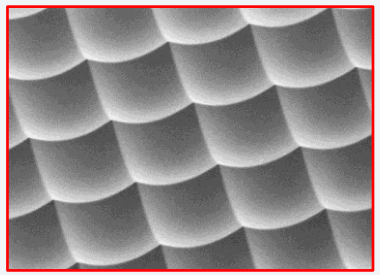


positive tone resist

- nearly arbitrary profiles:
  → prisms, (a)spheres, freeforms
- structure height up to ~120 microns
- Process chain for Ø 300 mm

C. Eckstein *et al.*, Proc. SPIE 9780, Optical Microlithography XXIX, 97800T (2016)

Tailored-Light Diffusers compared to others

	Diffractive Elements			Tailored-Light Diffuser	Refractive Element (Microlens Array)
	binary	multilevel	effective medium		
					
Design	easy	easy	demanding	moderate	easy
Flexibility	+	++	+	+	–
Maximum angle	+	–	++	++	+
Achromatism	–	–	–	++	+
Fabrication	easy	moderate	demanding	moderate	easy
Efficiency	–	+ … ++	++	++	–
0th-order	some %	~1%	<0.1%	<0.01%	~ filling factor

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Thank you for your attention

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w: www.microoptics.org

funded by BMBF within IBELIVE-Project: FKZ 13N14613