Flat Optics for AR

Matt Traub

September 18, 2025

Enschede, NL

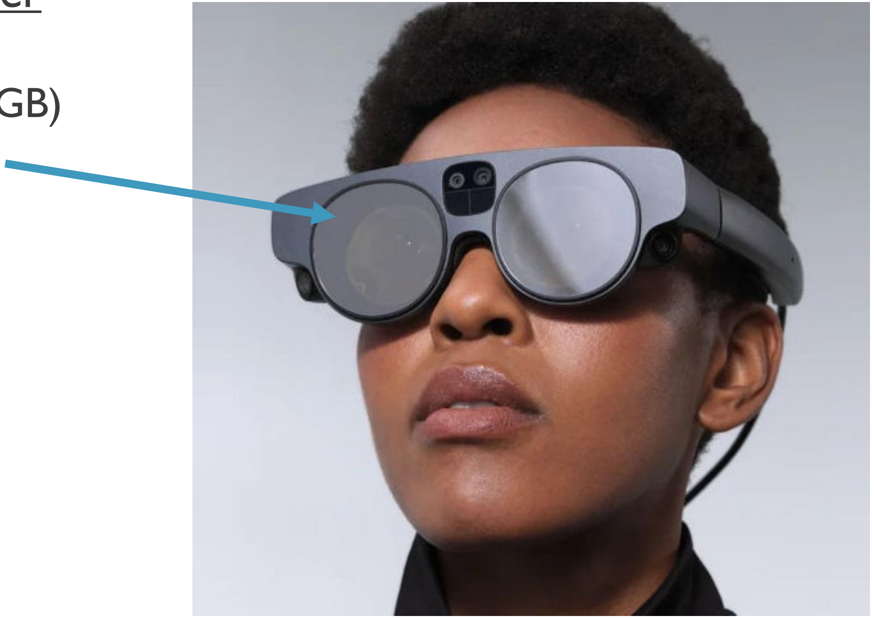
Optics for AR

Magic Leap ML2

Optics for AR

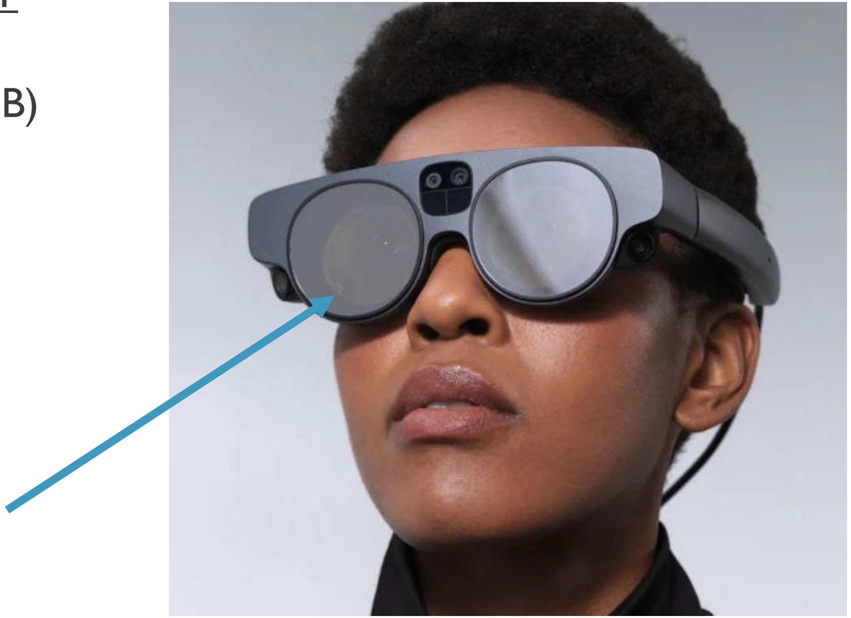
Optical Combiner

- Entire visible (RGB)
- Large area



Magic Leap ML2

Optics for AR



Optical Combiner

- Entire visible (RGB)
- Large area

Eye Tracking

- Near IR
- Small area

Magic Leap ML2

Optics for AR

Optical Combiner

- Entire visible (RGB)
- Large area

Light Engine

- Entire visible (RGB)
- Small area

Eye Tracking

- Near IR
- Small area

Magic Leap ML2

Optics for AR

Magic Leap ML2

Optical Combiner

- Entire visible (RGB)
- Large area

Eye Tracking

- Near IR
- Small area

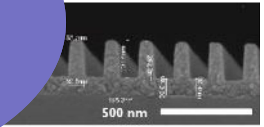
Light Engine

- Entire visible (RGB)
- Small area

World Sensors/Cameras

- Visible/Near IR
- Small area

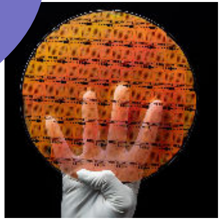
DUV, i-DUV, EUV,
NIL, IL, EBL



Advanced Patterning

Specialty Substrates

Silicon, (high RI) glass,
CMOS, flat panel



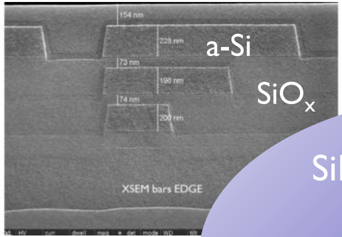
Imaging and sensing

AR/XR

Flat optics

Illumination and displays

Lens systems

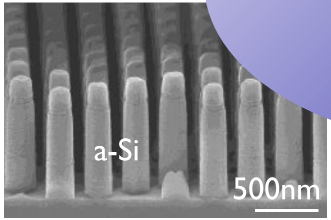


SiN_x, NbO_x, TiO_x, a-Si,
NIL resins
TCO: ITO, IGZO, ..
PCM: GST, SbS_x, ..
EOM: BTO, STO, …

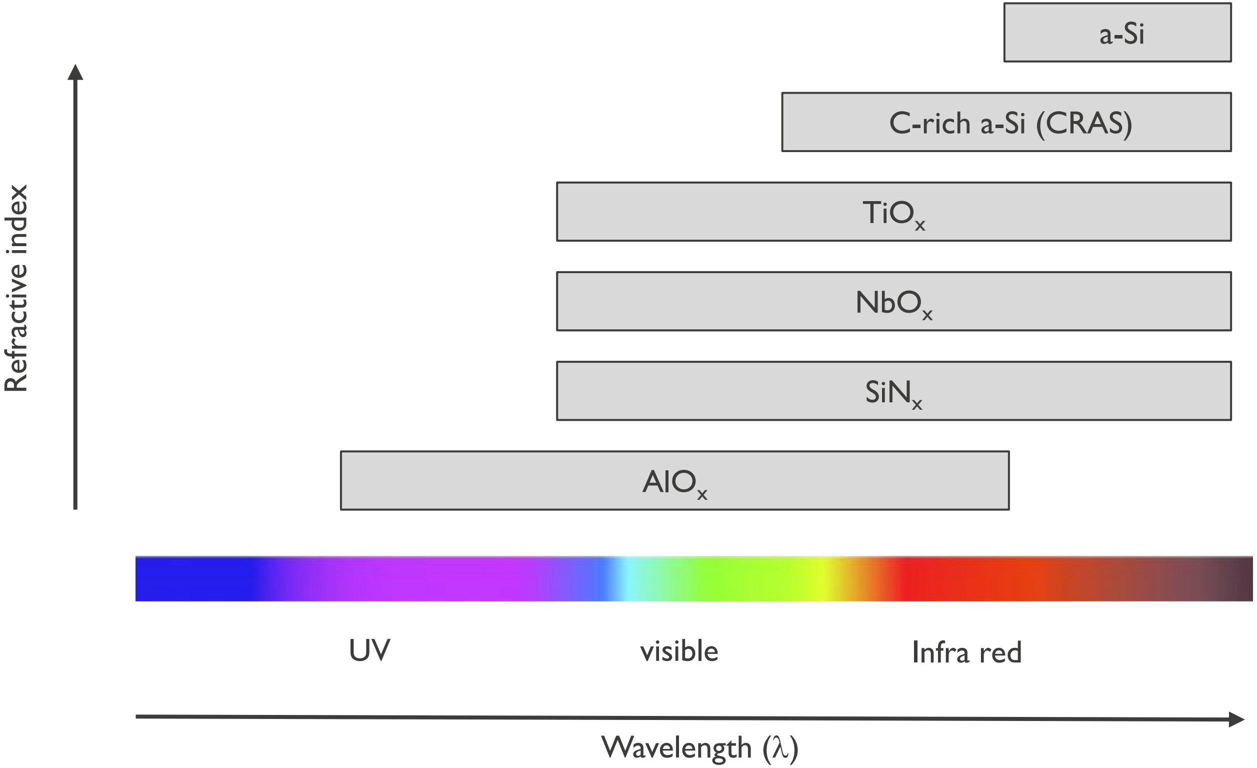
Optical Material Toolbox

Multilevel Technology

High AR etching &
refilling,
multilevel & double-sided processing



High refractive index material for flat lenses



a-Si

C-rich a-Si (CRAS)

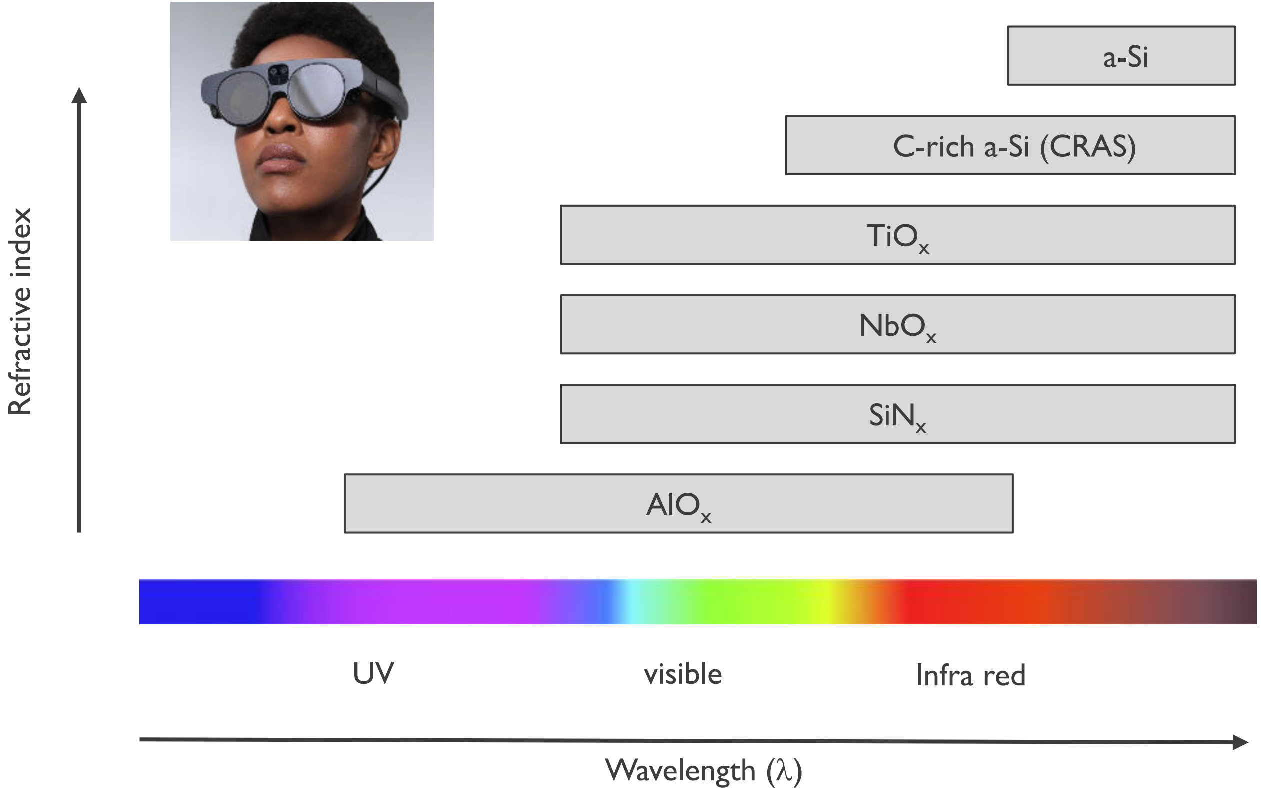
TiO_x

NbO_x

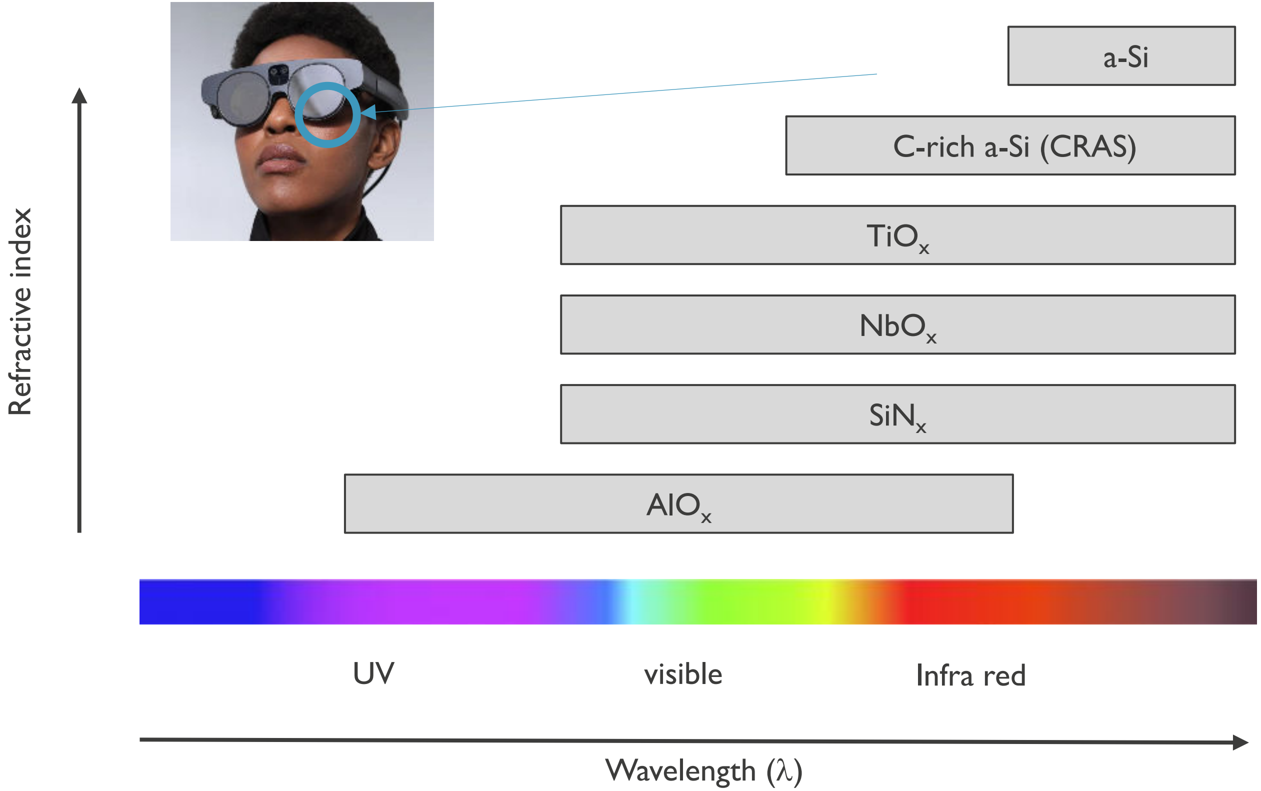
SiN_x

AlO_x

High refractive index material for flat lenses



High refractive index material for flat lenses



a-Si

C-rich a-Si (CRAS)

TiO_x

NbO_x

SiN_x

AlO_x

Refractive index

UV

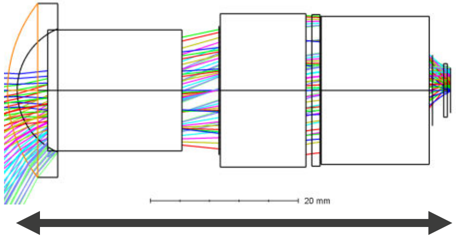
visible

Infra red

Wavelength (λ)

a-Si nanopillars for SWIR metasurfaces

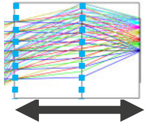
Reference lens system



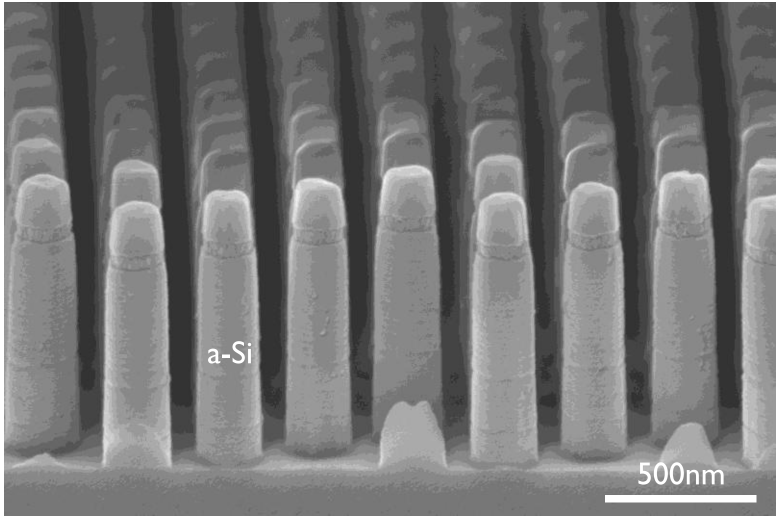
~ 65 mm

Equivalent optical system with two optical metasurfaces

Miniaturized compact lens system
Smaller by factor **x7**



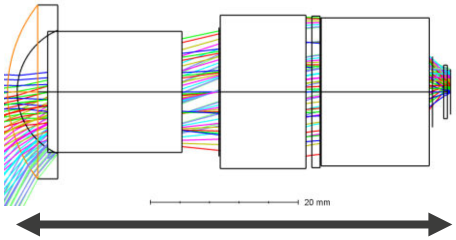
~12 mm



a-Si pillars for optical metasurface for $\lambda_0 = 940nm$

a-Si nanopillars for SWIR metasurfaces

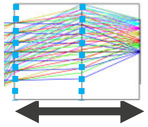
Reference lens system



~ 65 mm

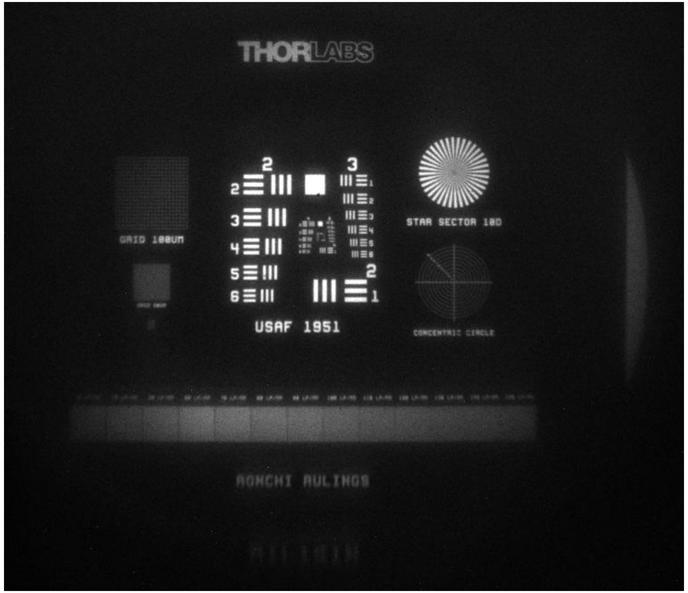
Equivalent optical system with two optical metasurfaces

Miniaturized compact lens system
Smaller by factor **x7**



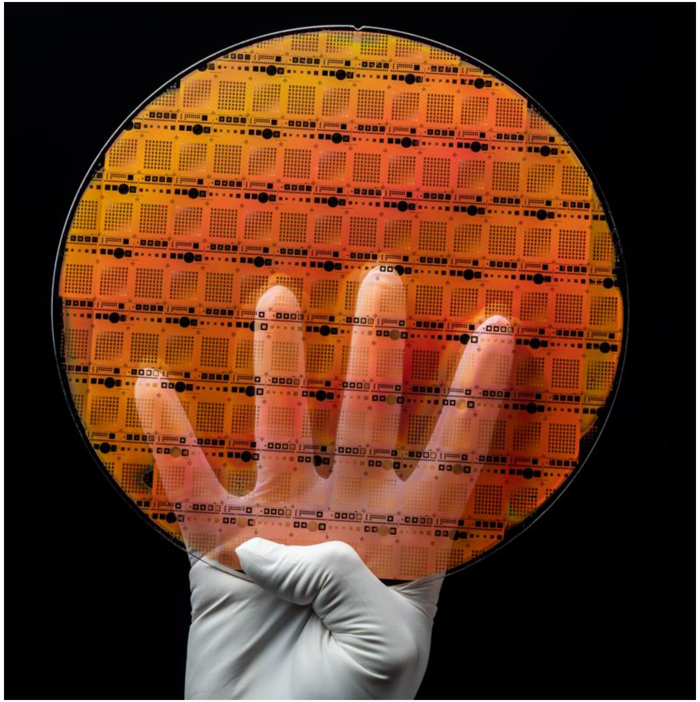
~12 mm

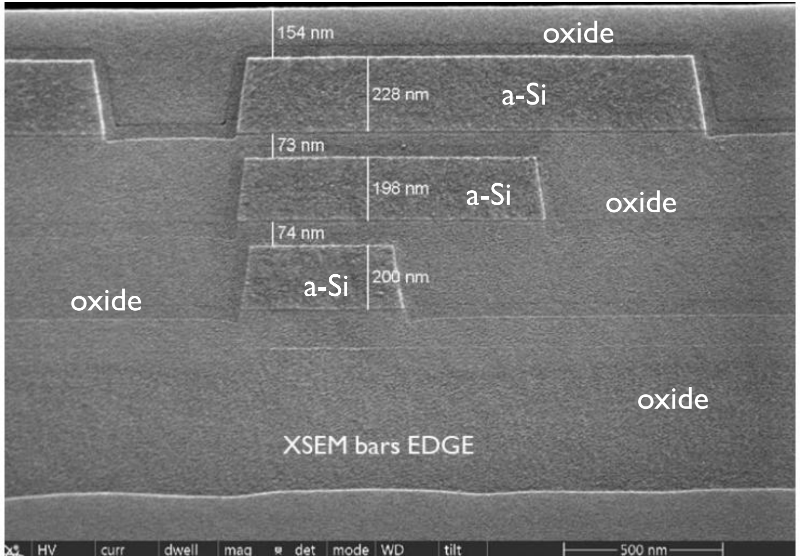
λ= 940 nm



First tests in limited FOV

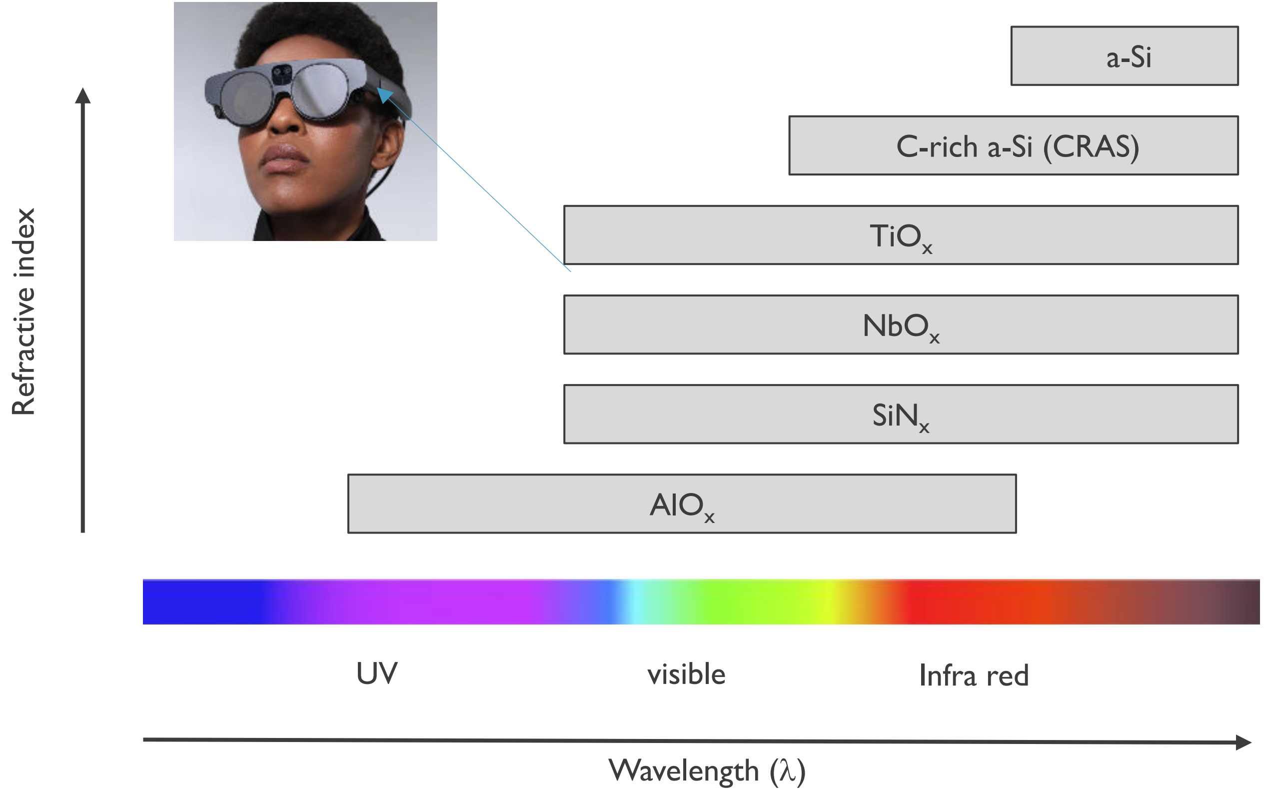
Multilevel flat optics on transparent substrates





DUV lithography technology for sub-wavelength patterning.
Transparent substrates for true replacement of lenses
Multilayer flat optic device

High refractive index material for flat lenses in imec fab



a-Si

C-rich a-Si (CRAS)

TiO_x

NbO_x

SiN_x

AlO_x

Refractive index

UV

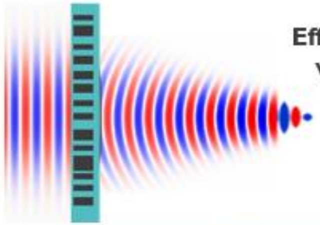
visible

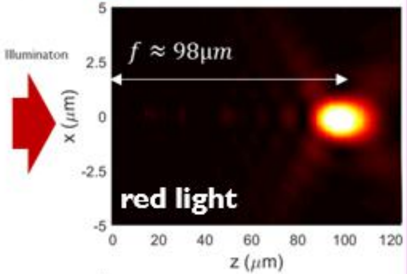
Infra red

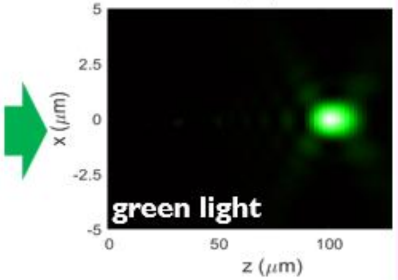
Wavelength (λ)

Multilevel flat optics for SWIR and visible light

Efficient diffraction-limited flat lenses, with good match with simulations

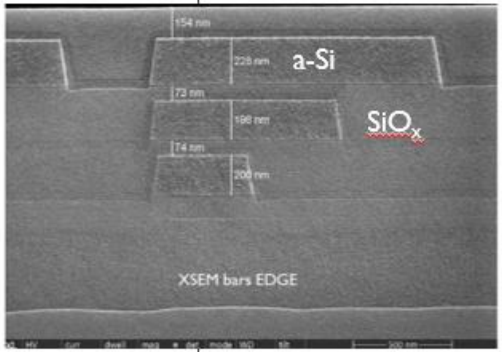




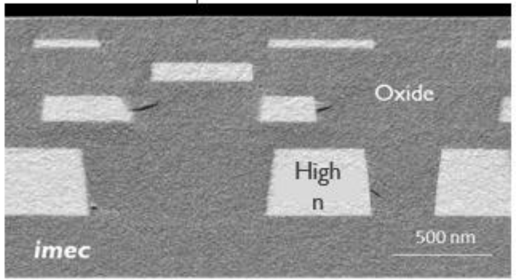


Diffractive optical elements

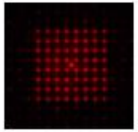
ideal for SWIR and red

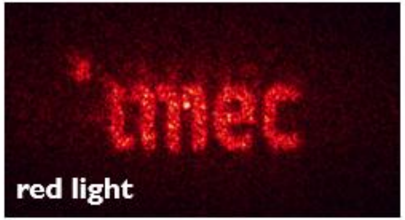


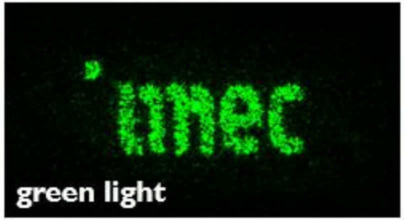
ideal for green and blue



Farfield diffraction pattern



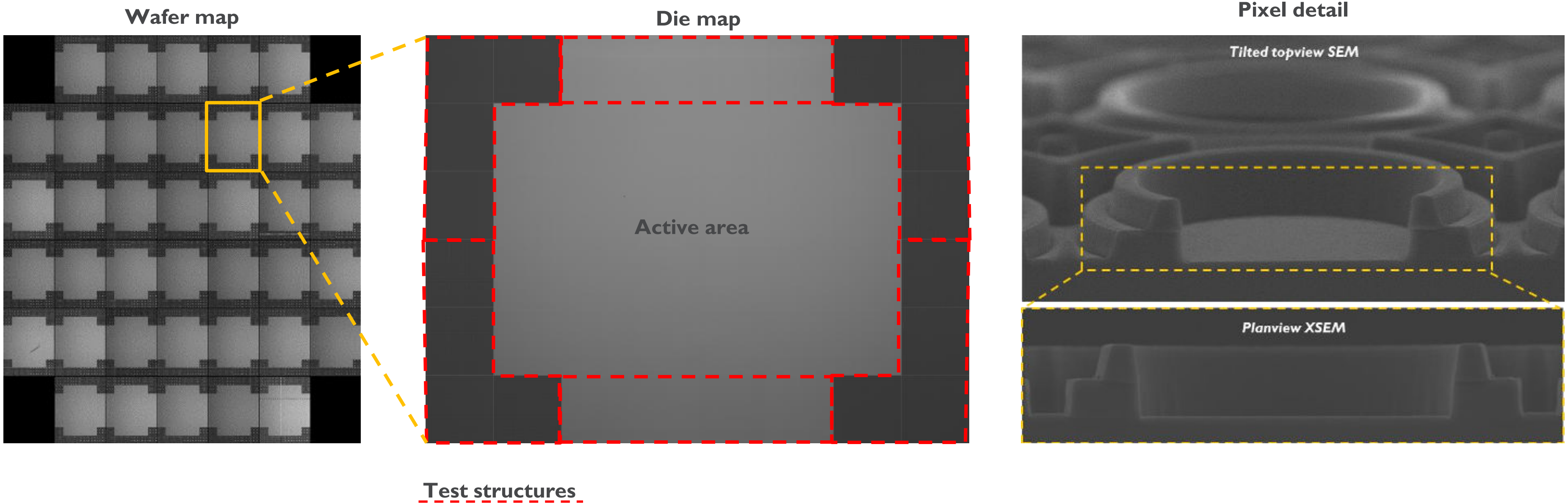




Imager enhancement enabled by flat optics

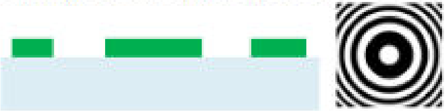
Fresnel phase plate lenses (FPPL)

- FPPL post-processed on imager wafer for QE boost
  - Pixel-level optimization by design
- Test infrastructure for on-wafer imager batch characterization developed, up and running

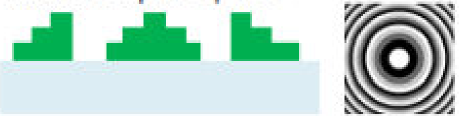


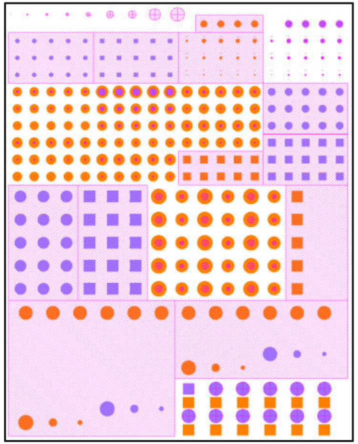
Multi-level optics designed for NIL fabrication

Binary Fresnel phase plates



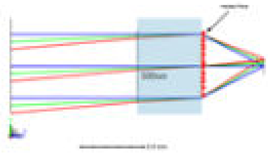
Multi level phase plates



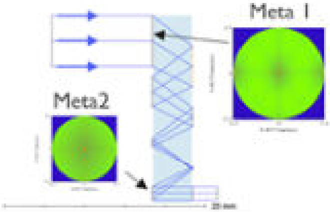


Reticle design for masters

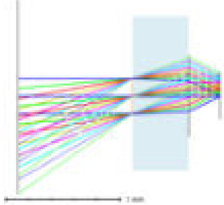
Focusing lenses
Diffraction gratings



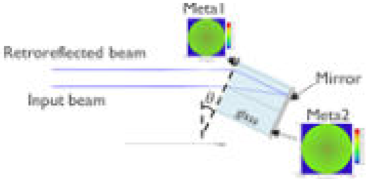
Flat optic telescope



Wide-field achromatic doublets



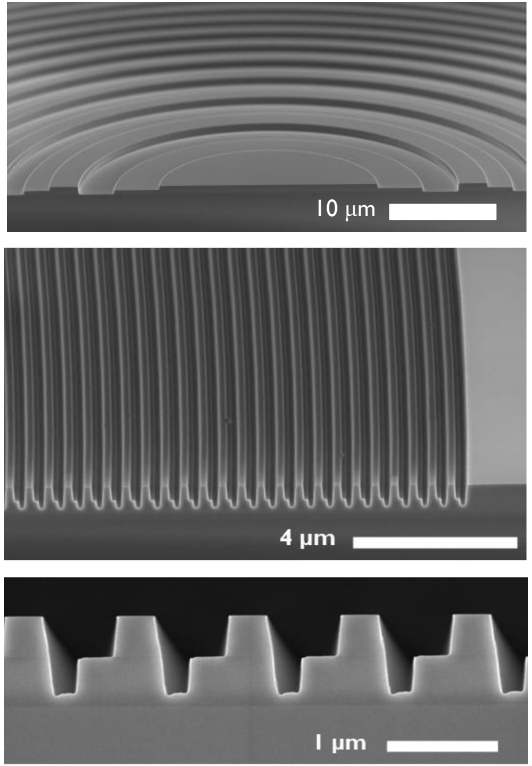
Retroreflector for sensing applications



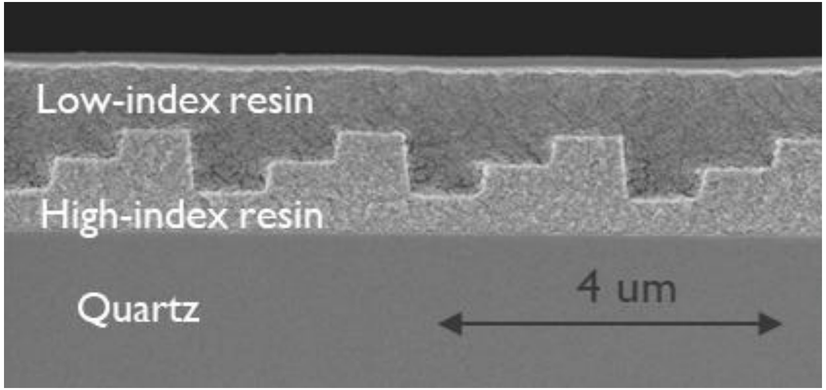
Concept and device design: Ugo Stella, Bruno Figeys

Double-sided patterning on a single transparent substrate

Two-level Si NIL master – 200 mm



NIL-based metalens fabrication

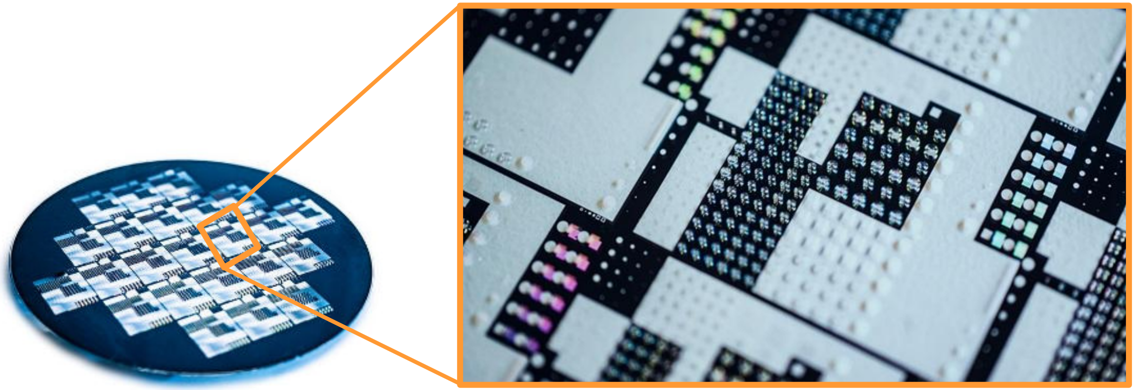


- Imprint levels are directly fabricated from high-index resin on both sides of the glass, combined with metal apertures

Master integration: Pau Guell, Jennifer Donohue

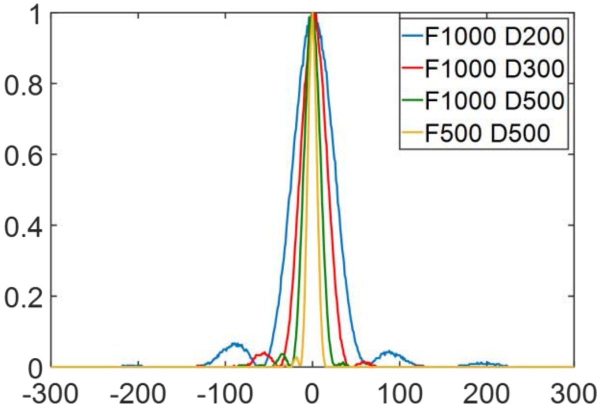
Double-sided patterning on a single transparent substrate

Double side patterned device wafer



Fabrication: Mahyar Mazloumi

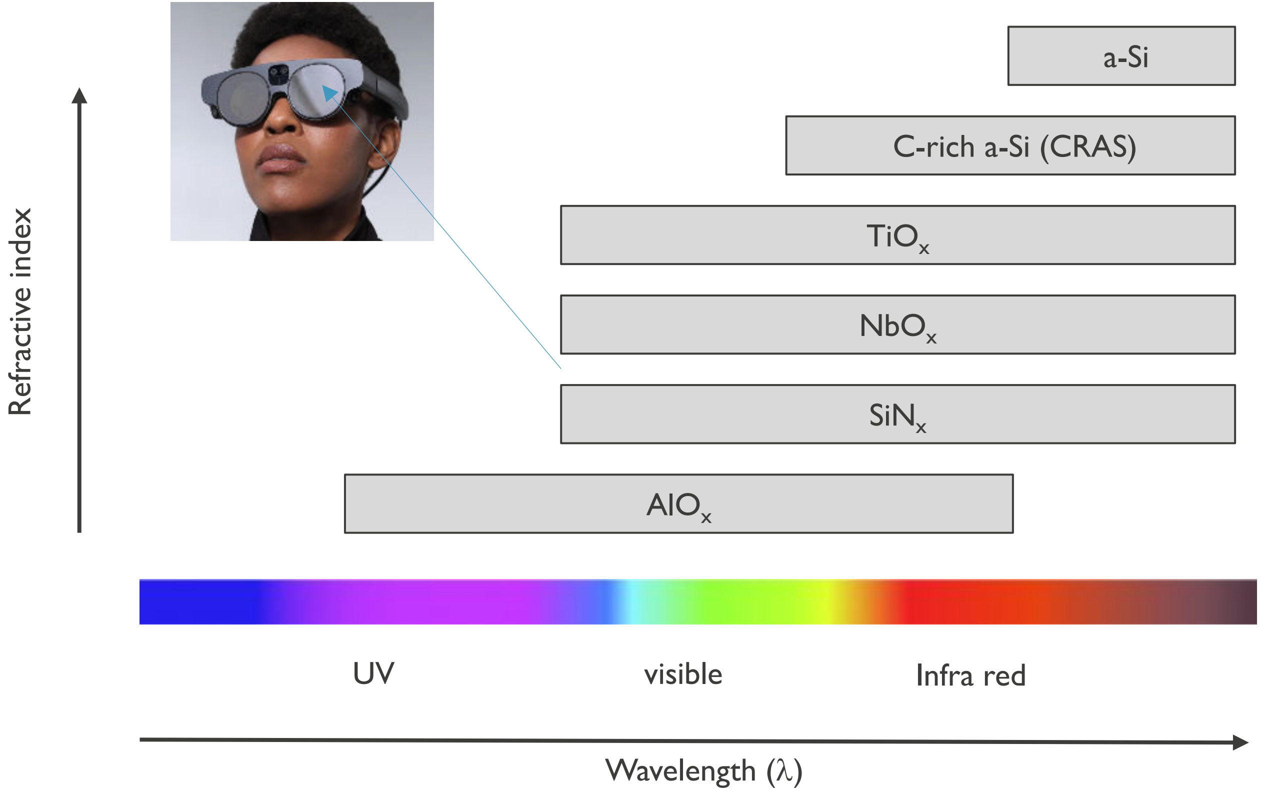
Metalens focusing



Measurement: Vladimir Pejovic

- First device measurements show diffraction limited lens performance.

High refractive index material for flat lenses



a-Si

C-rich a-Si (CRAS)

TiO_x

NbO_x

SiN_x

AlO_x

Refractive index

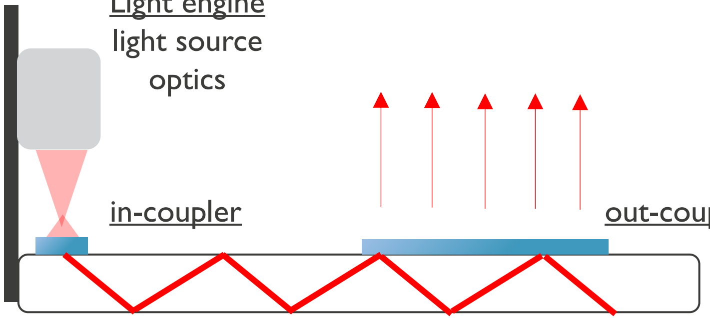
UV

visible

Infra red

Wavelength (λ)

TIR-based optical combiners



Light engine
light source
optics

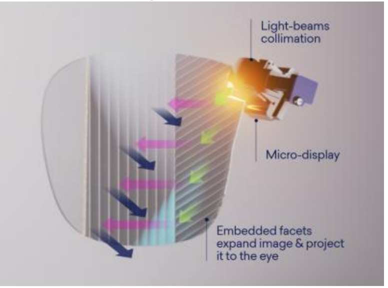
in-coupler

out-coupler

Substrate

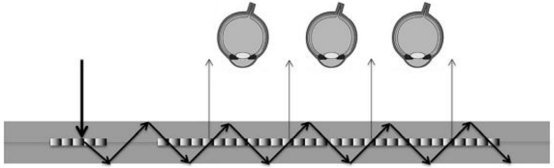
Reflective waveguides

Lumus waveguide[1]

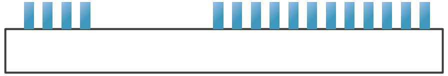


Prism in-coupling
Embedded mirror out-coupling

Diffractive waveguides



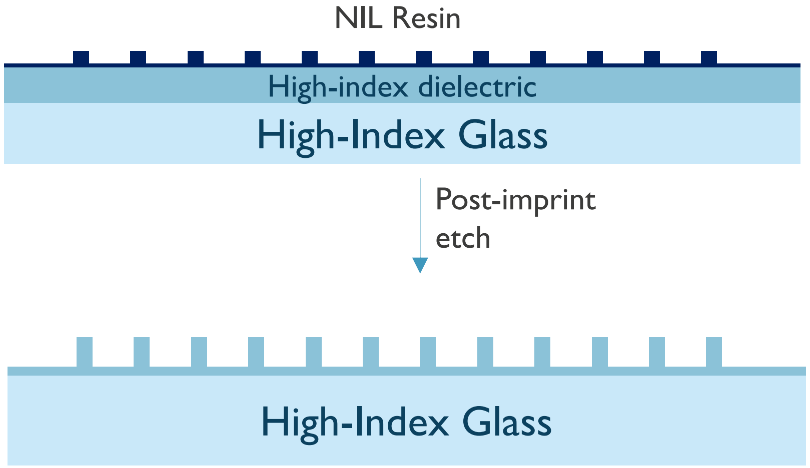
Volume holograms



Surface features

Surface Relief Patterning on High-Index Substrates

Dry Etch Pattern Transfer


NIL Resin

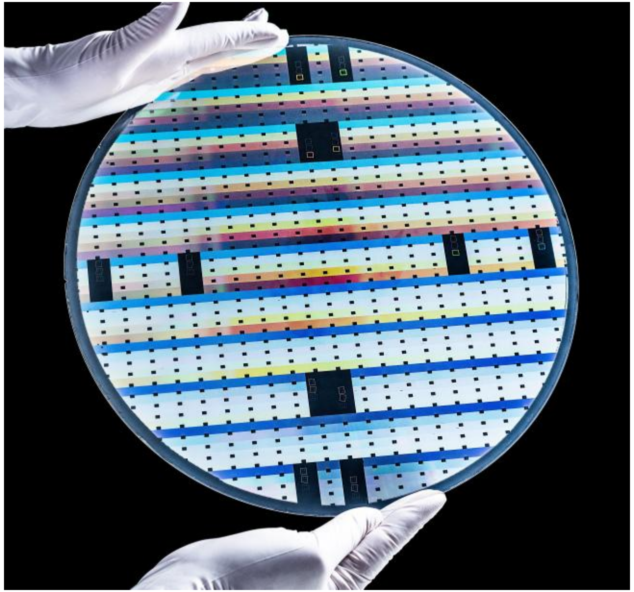
High-index dielectric

High-Index Glass

Post-imprint etch

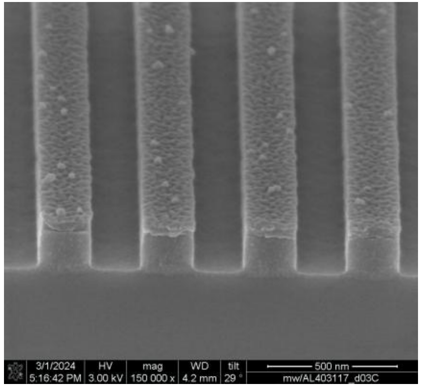
High-Index Glass

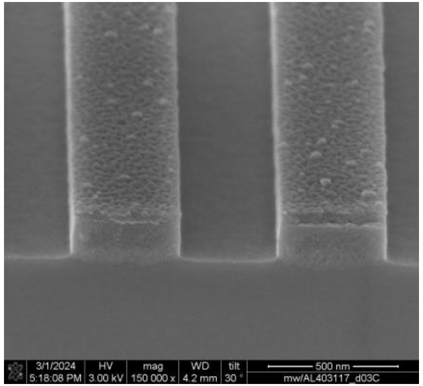
Process to access the higher optical performance achievable from high-index inorganic dielectrics (lower losses, higher refractive index).



Dry Etch Pattern Transfer – Silicon to Glass to High-Index Glass

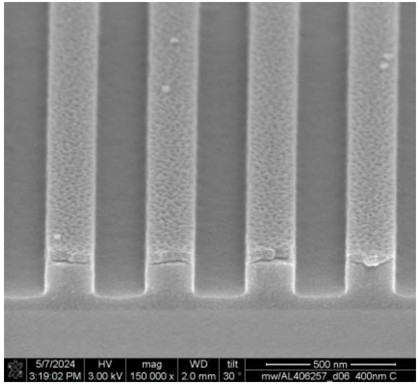
Silicon Substrate

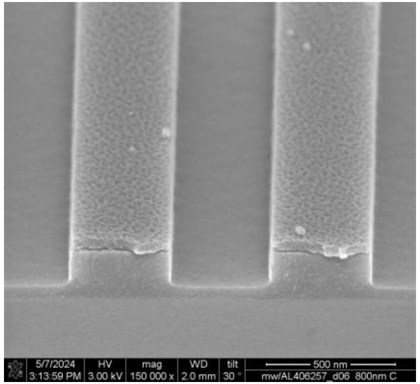




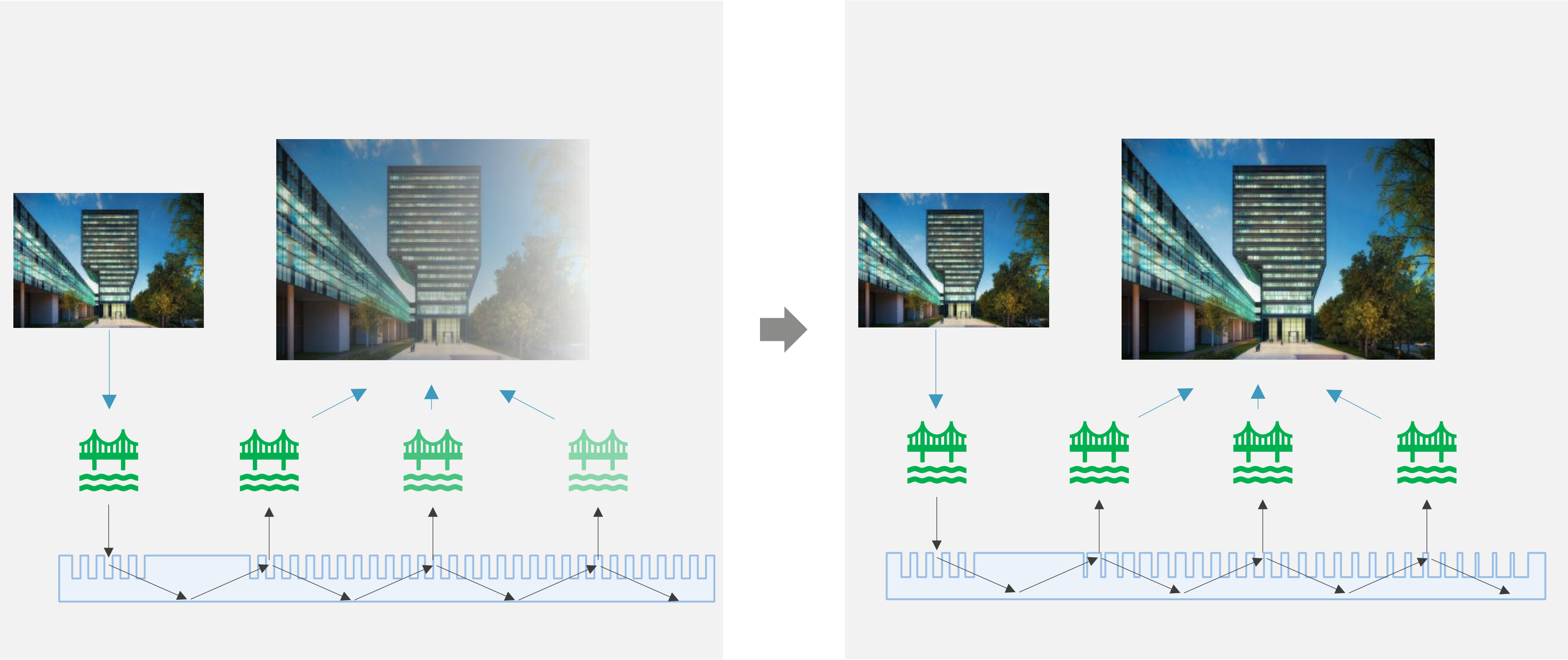
	Silicon	**1.9 Glass**
Density (g/cm^3)	2.33	3.62
Thermal conductivity (W/(m•K))	148	1.03
Coefficient of thermal expansion (ppm/K)	2.6	8.5 – 9.5

1.9 Glass Substrate





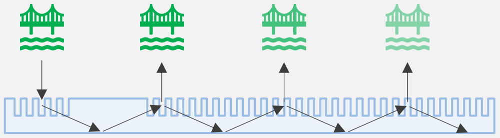
Improving uniformity of the eye-box

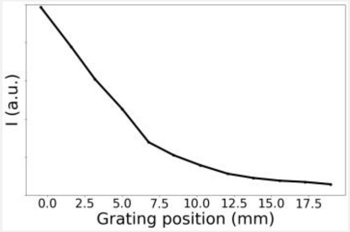


Reference Design – 1D Pupil Expander

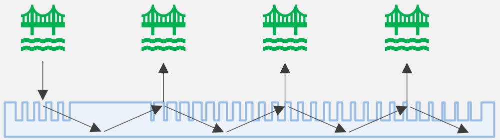
Output Uniformity (simulated)

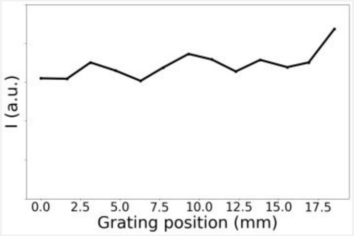
FIXED DUTY-CYCLE



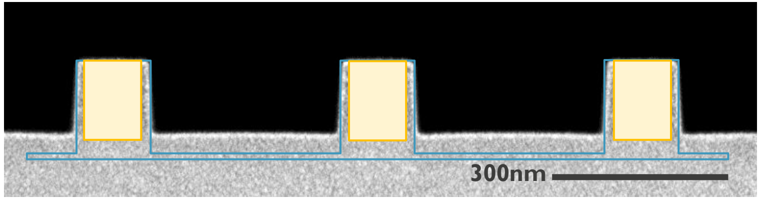


VARIABLE DUTY-CYCLE





OPC-Guided Imprint Master Design



Target line width: 125nm

Measured line width: 124.6 nm

Design: Florian Maudet; Integration: Carine Gerets imec

embracing a better life

Thank you