Meta-surfaces Process Scale-up for Advanced Optical Applications

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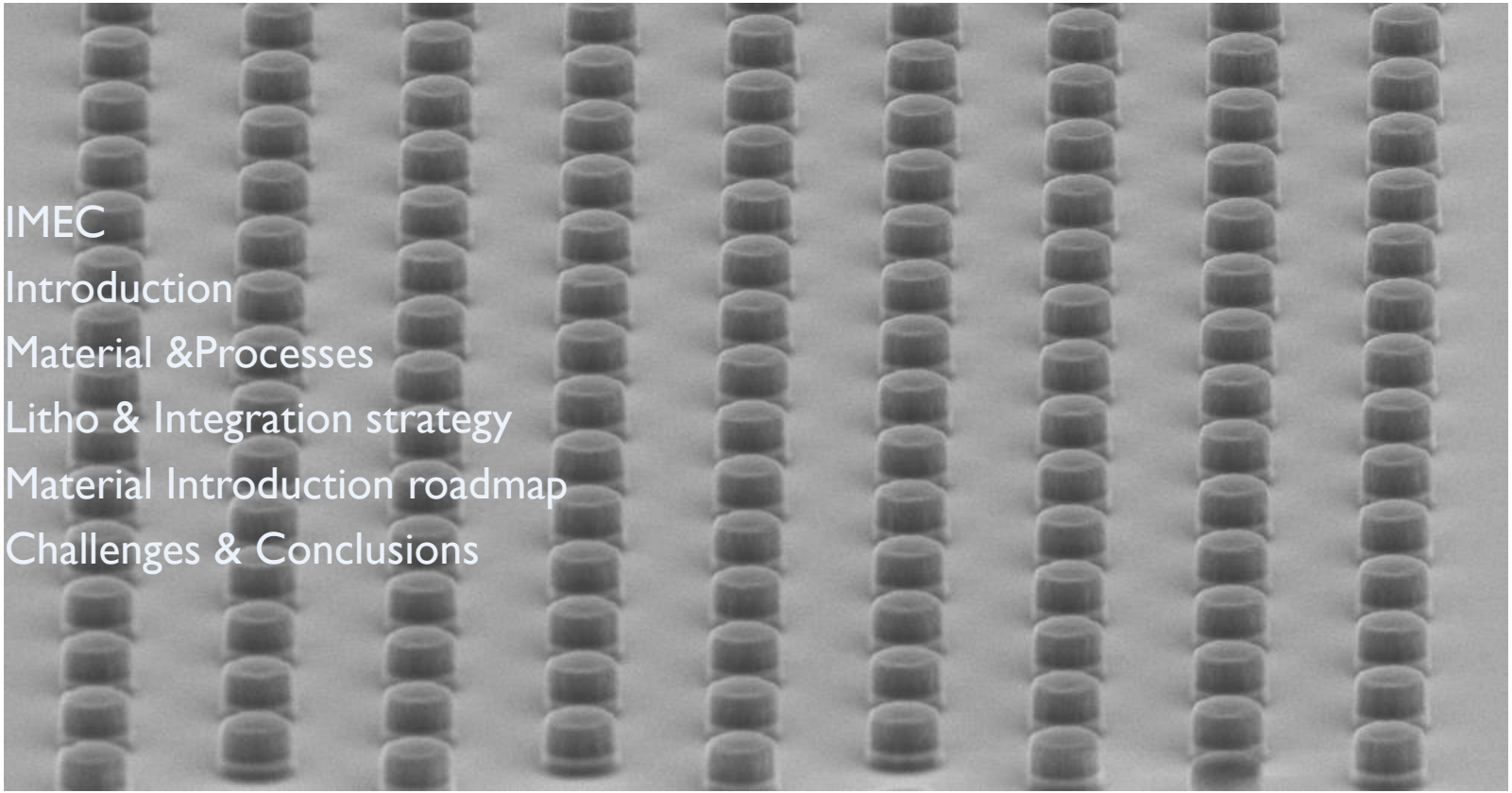
Overview

Example of NIR transparent amorphous-Si nano dots on Quartz



- IMEC
- Introduction
- Material &Processes
- Litho & Integration strategy
- Material Introduction roadmap
- Challenges & Conclusions

IMEC (founded in 1984)

- World-leading R&D in nano-technology & high-tech applications
- **>5000** international R&D top talents, >100 nationalities
- Unique **€ 2B leading-edge semiconductor fabs**
- Delivering industry relevant technology solutions serving semiconductor, ICT, IoT, healthcare and energy markets
- **2021: € 700M revenues: 70%** industry, **20%** regional gov't, **10 %** EU & regional programs
- Collaborating with 600+ industrial partners
- Created **118 spin-off** companies and incubated **200+ start ups**
- **8** sites worldwide

World-class infrastructure

1. 200mm pilot line
2. 300mm pilot line
3. Nano bio labs
4. NERF labs
5. Silicon solar cell line
6. Organic solar cell line

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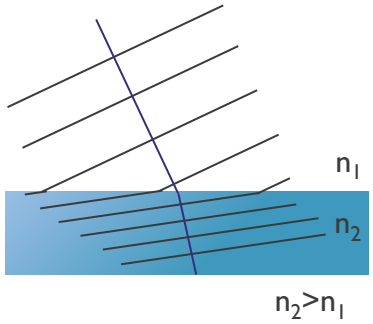
Why meta surfaces

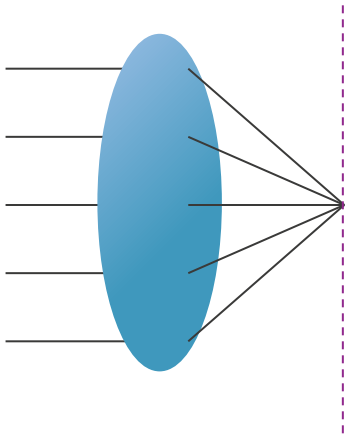
Key benefits
form factor
Manufacturing cost / scalability

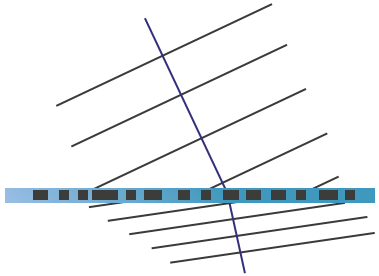
Bulk optics

Metasurface optics

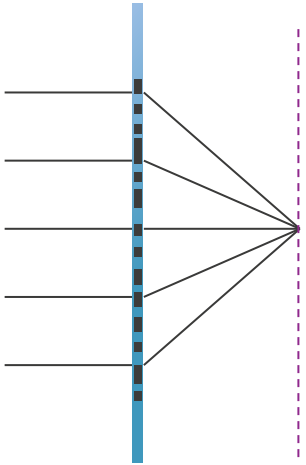


macroscopic lens





metasurface



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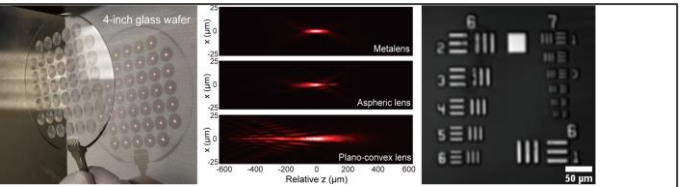
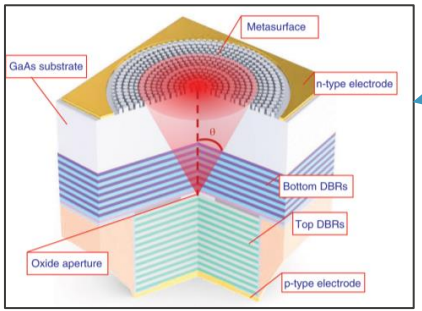
Possible applications



Park J.-S. et al., Nano Letters, vol. 19, no. 12, 2019



Lenses, Prisms

Color/polarization filtering

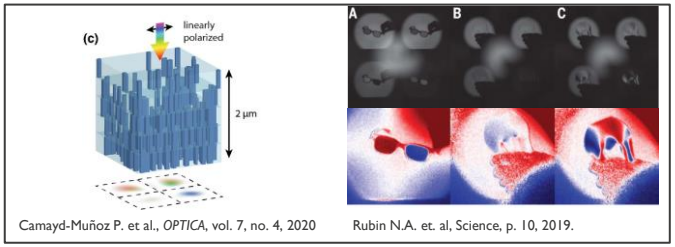
Miniaturization of free space optic systems,e.g. spectroscopy, imaging

Beam shaping

Display expanders

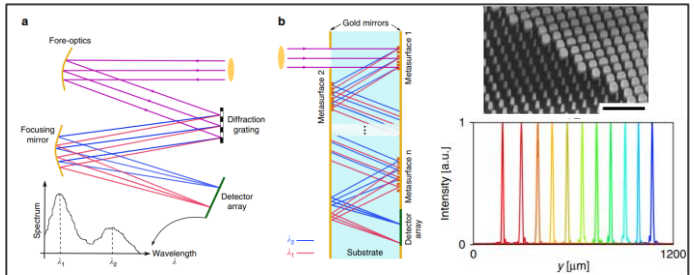
Reflectors

...

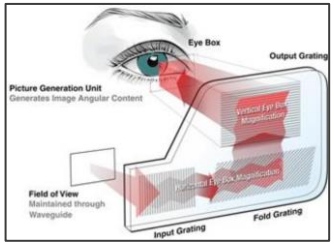


Camayd-Muñoz P. et al., *OPTICA*, vol. 7, no. 4, 2020

Rubin N.A. et. al, Science, p. 10, 2019.

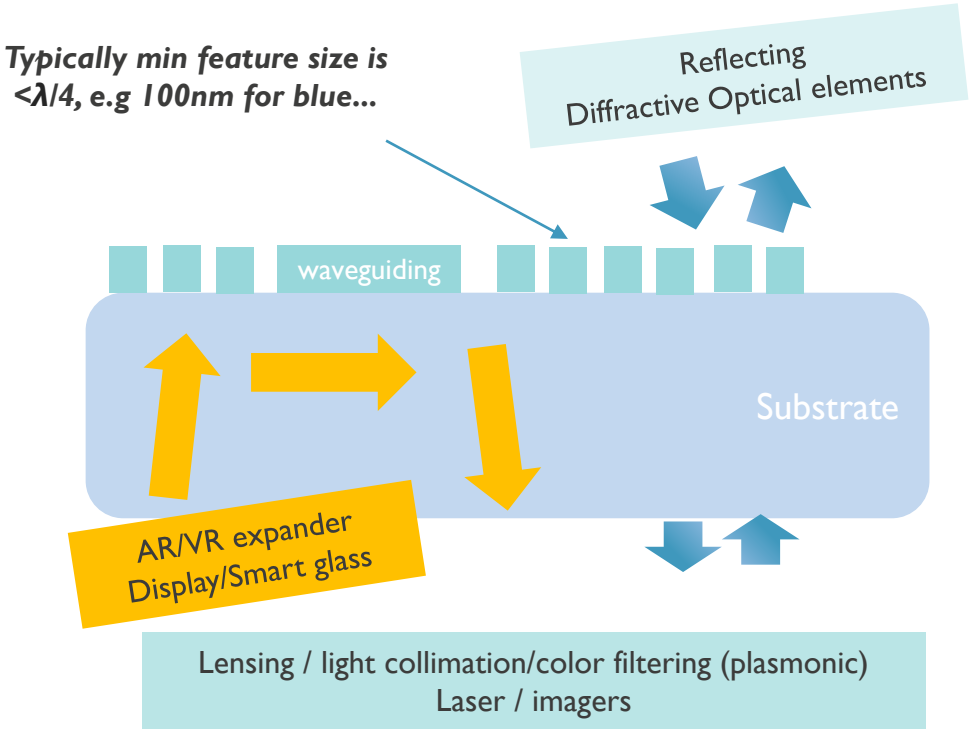


Faraji-Dana M. et al., Nat Commun, vol. 9, no. 1, 2018



The Material & Manufacturing angle

Manipulating light in/out of plane



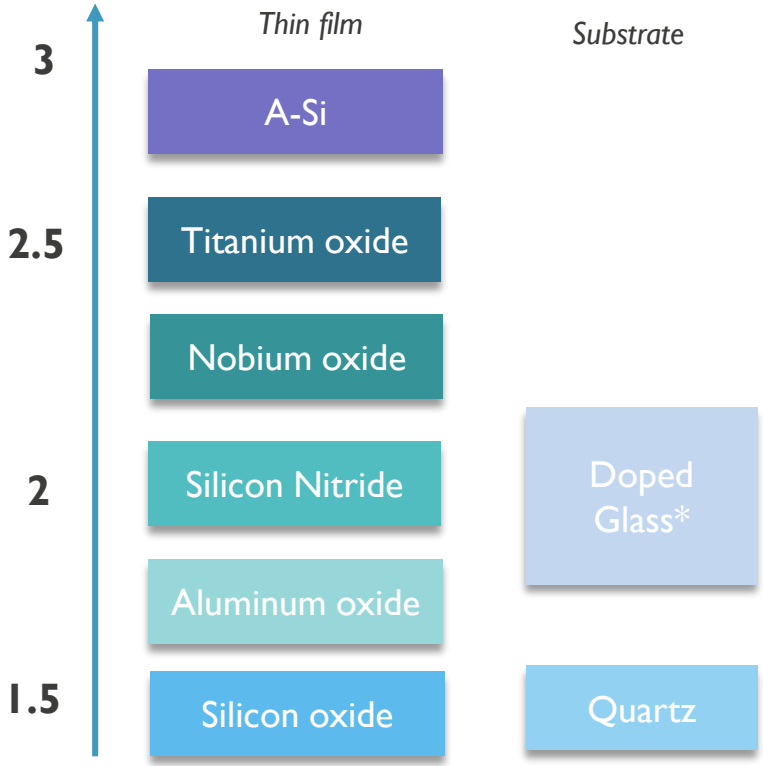
Key Material /Process specs

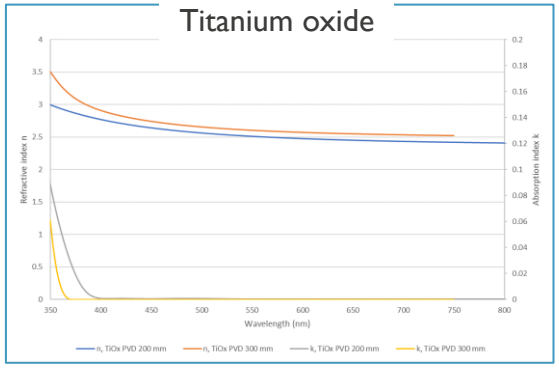
Period/ min feature size

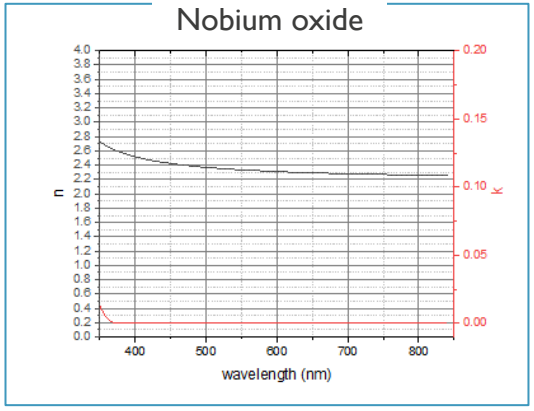
Refractive index / transparency

Line edge roughness for compact waveguiding

Materials





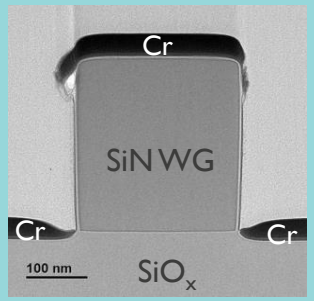


2 materials fully transparent in VIS/NIR/SWIR
T stability 400-450°

CMOS manufacturing capabilities

Silicon Nitride

Available trough different processes.
Transparent in full wave range

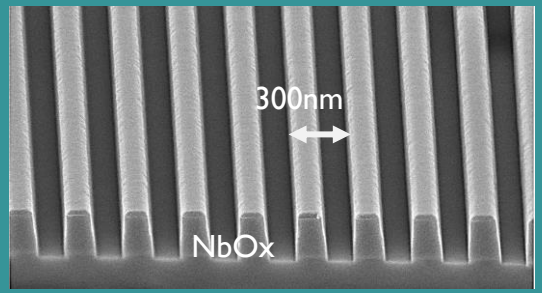


Si subtrate (300mm)

Large Maturity in integrated photonics
Deploying for meta surfaces

Nobium Oxide

Large experience in DBR mirrors in VIS

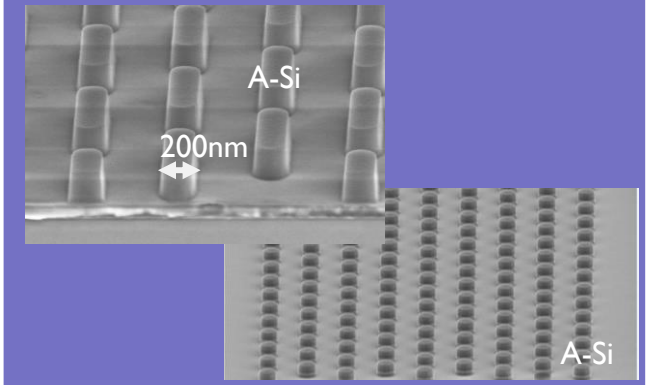


Quartz substrate

Deploying for waveguides & meta surfaces in VIS/NIR

Amorphous Silicon

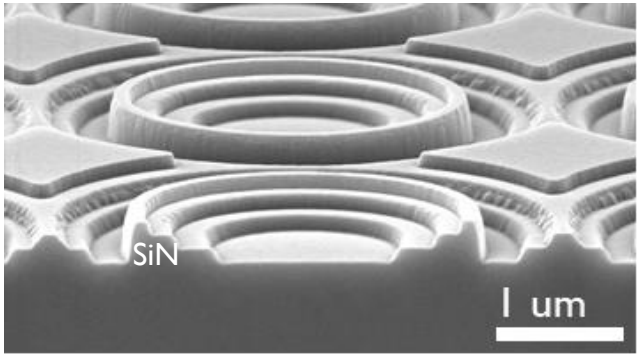
Large experience in DBR mirrors in NIR/ SWIR & waveguides



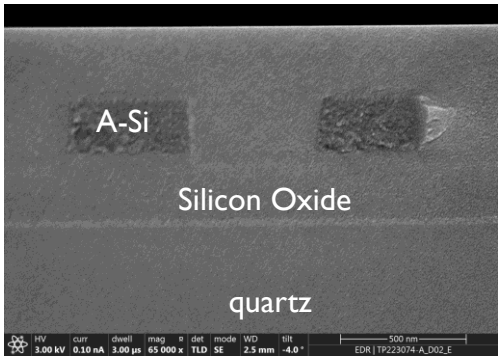
Quartz substrate

Deploying for meta surfaces in NIR/SWIR

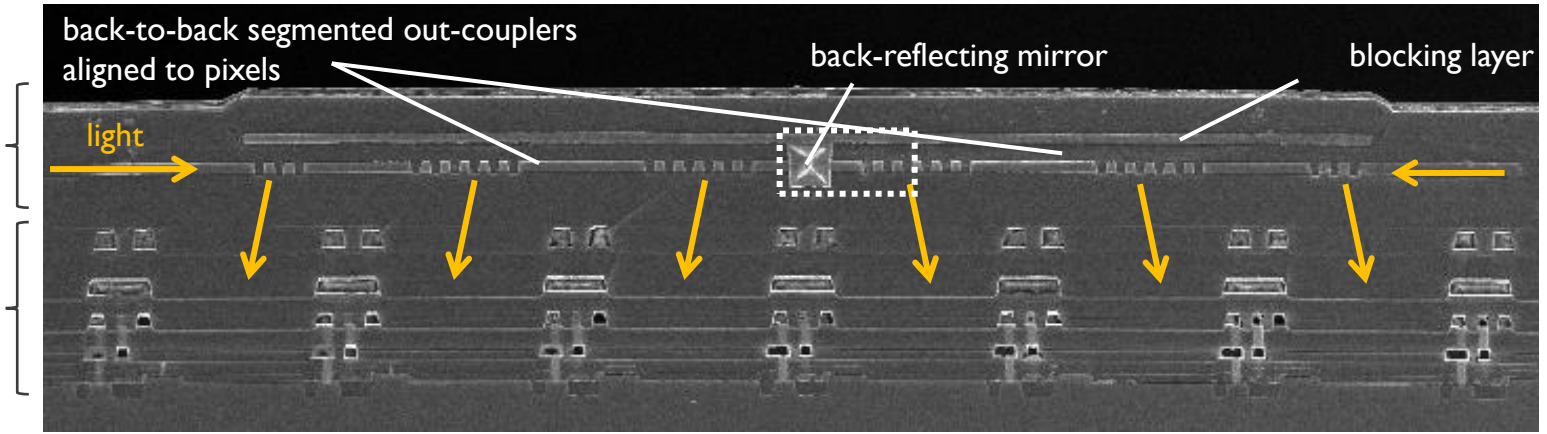
More complex shape/stack



Example of 3 levels staircase Fresnel lens



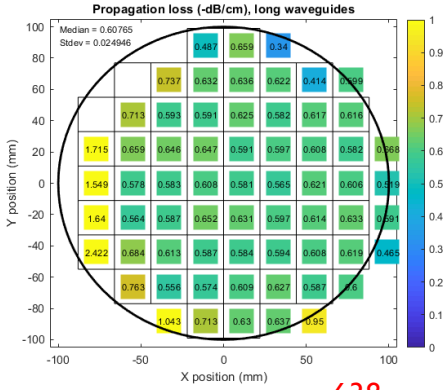
Example of gap fill & planarization



Example of Integration on chip

Layer Transfer

- Produce Patterns on Si then transfer bond onto transparent substrate
- Possible to produce Integrated photonics quality grade
- For early design de-risking or low volume production : Layer transfer
- For material processed at high temperature



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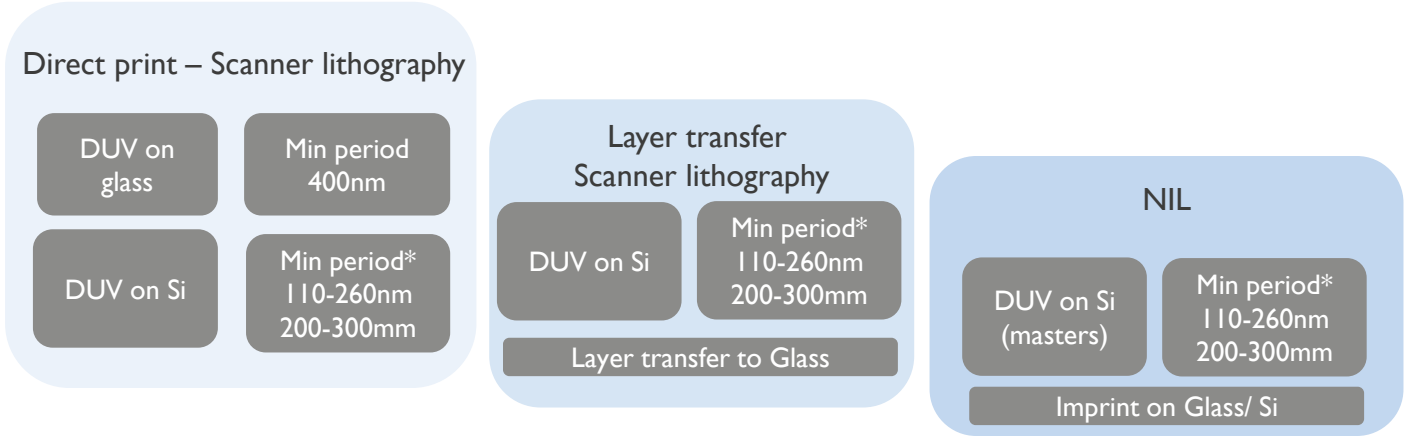
Lithography & Process Integration strategy

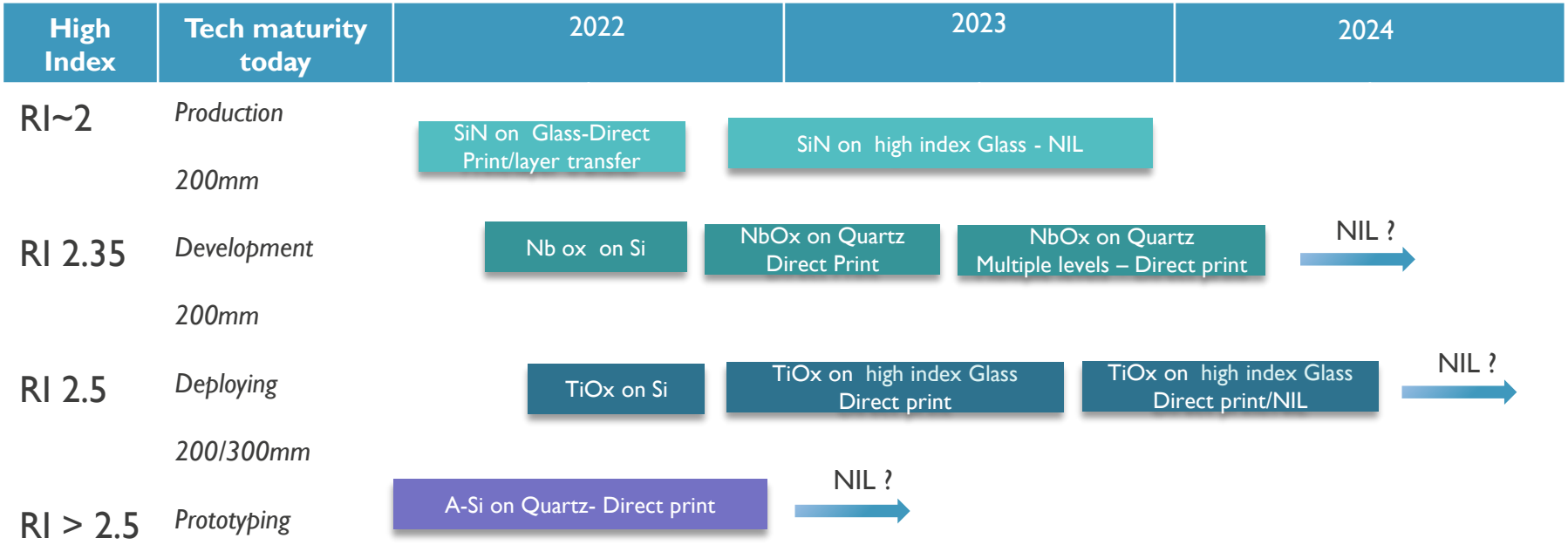


*Indicative value

	Direct Print on Glass/CMOS	Layer transfer on Glass/CMOS	NIL on Glass
Fidelity/Line edge roughness	*Excellent*	*Excellent, independent from bottom susbtrate*	*Fair but beyond 200mm litho capabilites*
Multi level design	*Possible*	*Possible*	*Pyramidal shapes*
Inter Pattern dependency	*Low*	*Low*	*fair*
Complexity/cost	*Low/Fair*	*fair*	*Very low*

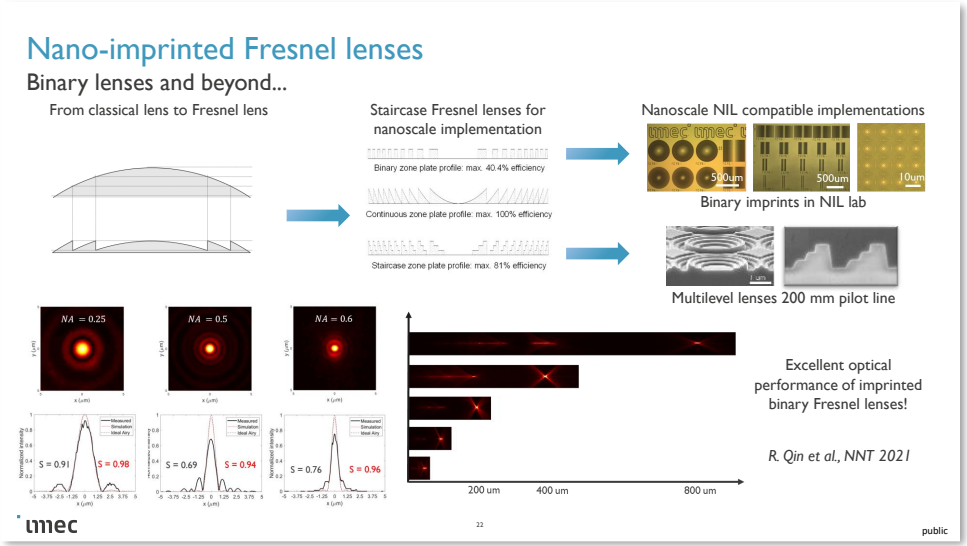
Roadmap for material Introduction in Pilot Line

200-300mm substrate



Scaling challenges

- Build right OPC model to optimize mask for shorter time to production
- Further maturing NIL technology for volume applications with high index material
- Establish proper waveguide processes for in-Plane light propagation & Inclined etching for more efficient grating couplers
- NEXT : Direct Integration of light source/detectors on the same substrate



Conclusions

- New class of components are emerging for different applications : Lensing, diffractive optics, waveguiding etc.. All relying on thin film processing for various photonics / flat optics applications

- It is possible to produce those objects using an advanced processing line on 200&300mm CMOS line, using different process implementation -DUV, NIL- depending on applications & volumes.

- Those implementations are compatible with different type of substrate : Glass, CMOS wafers, Photonic circuits.

- A new generation of high refractive index material is being deployed such as Nobium oxide & Titanium oxide , doped glass substrate.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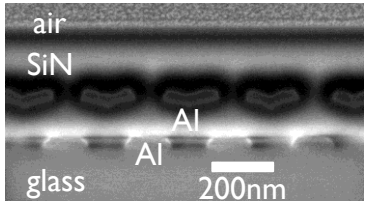
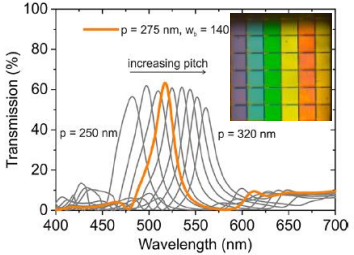
embracing a better life

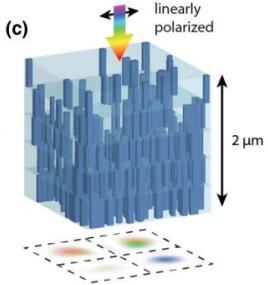
Color/polarization filtering



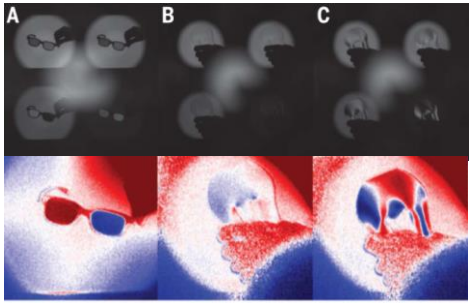


De Proft A. *et al.*, *ACS Photonics*, vol. 9, no. 4, 2022

Color/polarization splitting

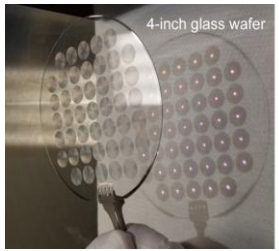


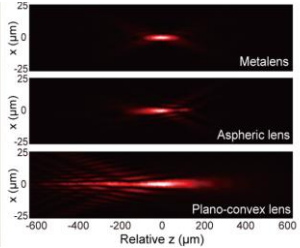
Camayd-Muñoz P. et al., *OPTICA*, vol. 7, no. 4, 2020

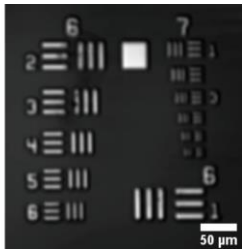


Rubin N.A. et. al, Science, p. 10, 2019.

Optical components
e.g. lenses, prisms

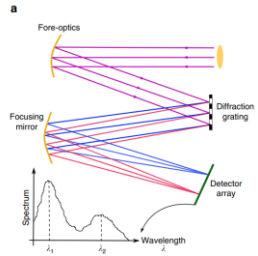


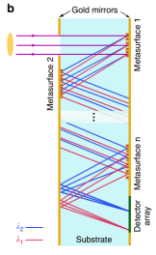


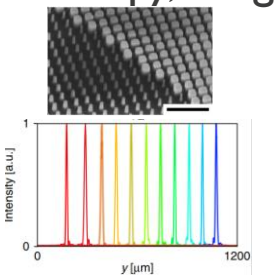


Park J.-S. et al., Nano Letters, vol. 19, no. 12, 2019

Miniaturization of free space optic systems,
e.g. spectroscopy, imaging



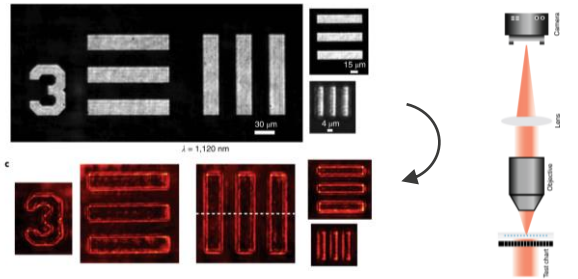




Faraji-Dana M. et al., Nat Commun, vol. 9, no. 1, 2018

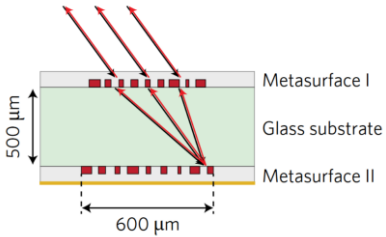
Metasurfaces

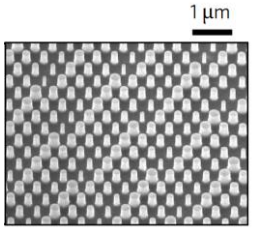
Specialized optical targets, differentiation



Zhou, Y. et. Al, *Nat. Photonics*, vol. 14, no. 5, 2020

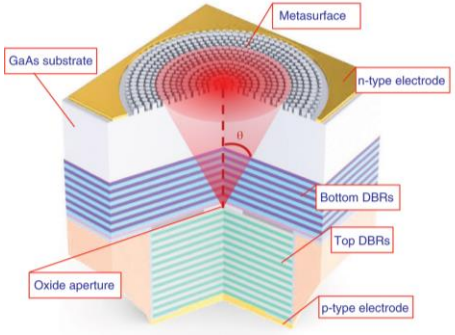
retroreflection

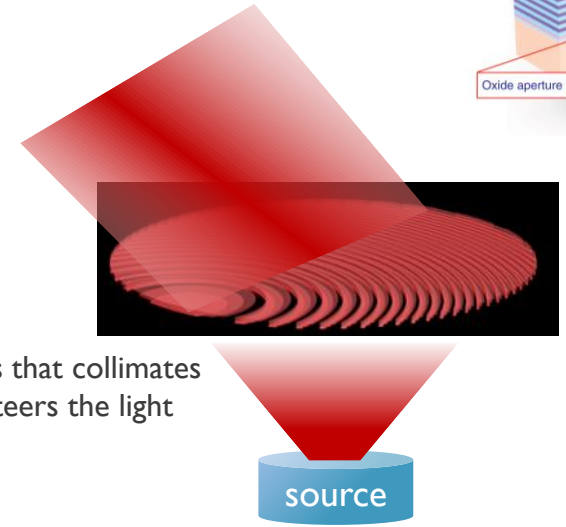




Arbabi A. et al., *Nature Photon*, vol. 11, no. 7, 2017

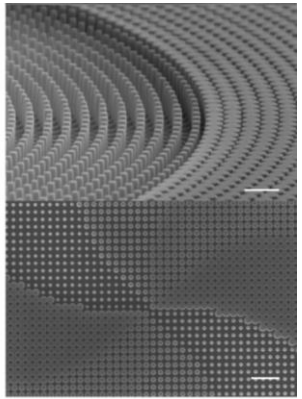
Flat optics on top of light sources





Flat lens that collimates and steers the light

Light source beam shaping VCSELs, uLEDs, ...

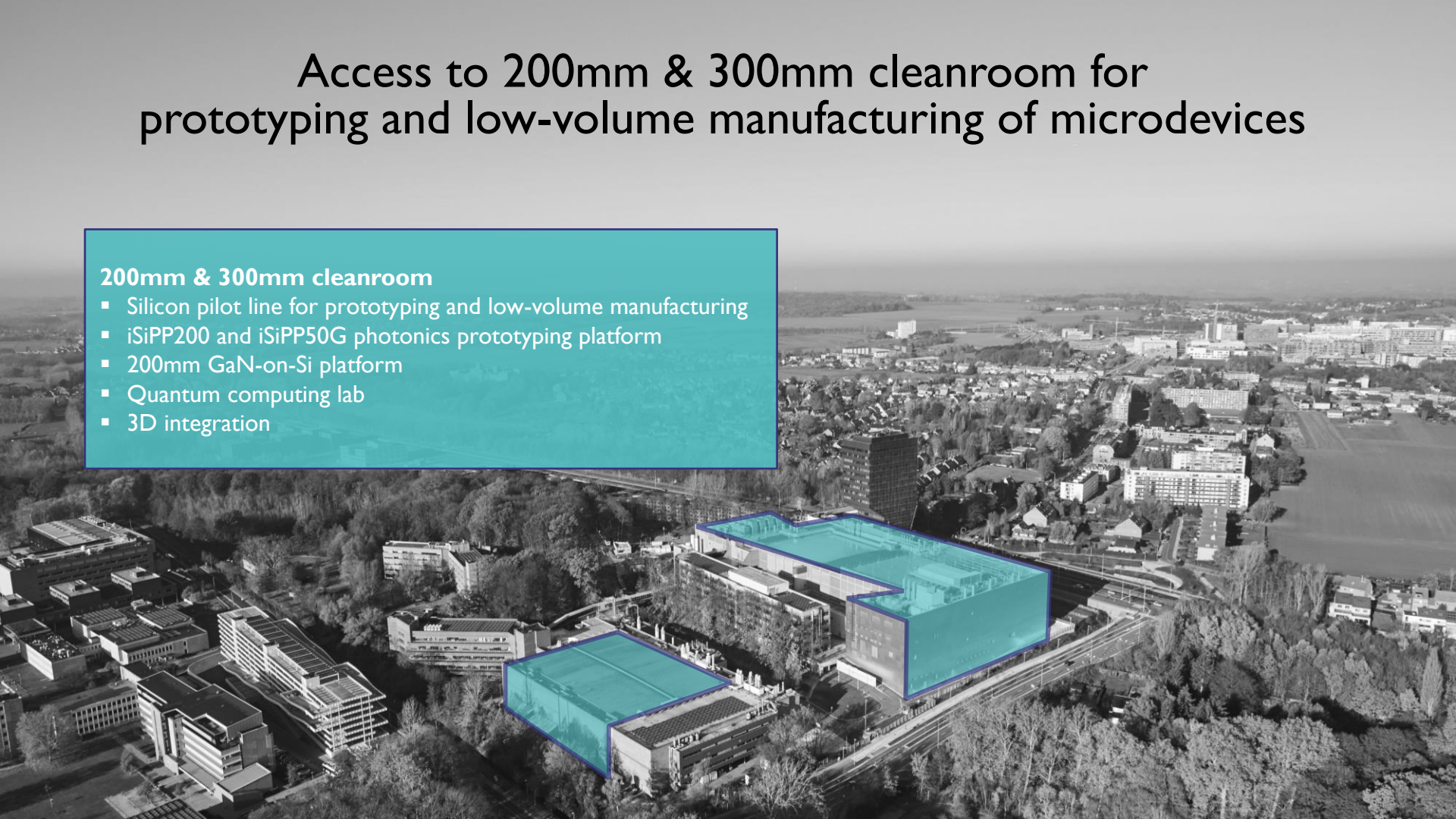


Xie, YY., Ni, PN., Wang, QH. *et al. Nat. Nanotechnol.* **15**, 125–130

Access to 200mm & 300mm cleanroom for prototyping and low-volume manufacturing of microdevices

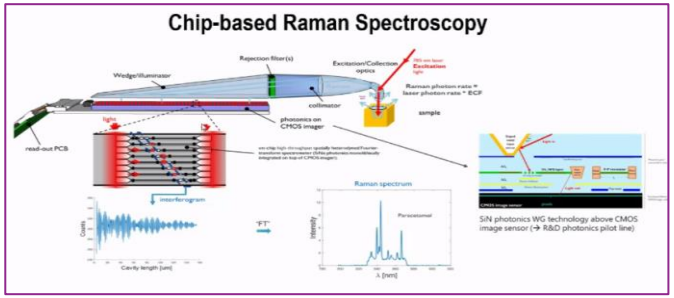
200mm & 300mm cleanroom

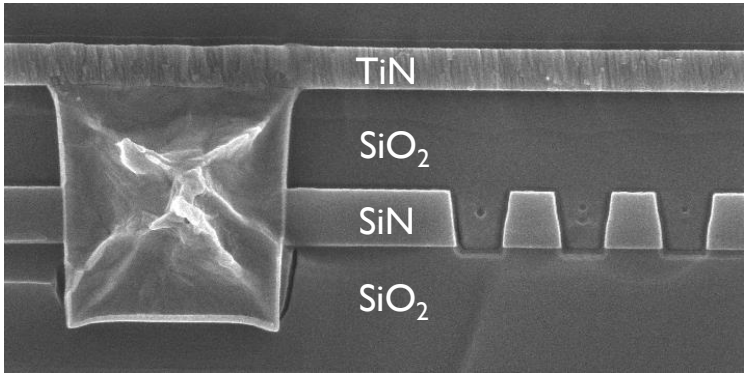
- Silicon pilot line for prototyping and low-volume manufacturing
- iSiPP200 and iSiPP50G photonics prototyping platform
- 200mm GaN-on-Si platform
- Quantum computing lab
- 3D integration

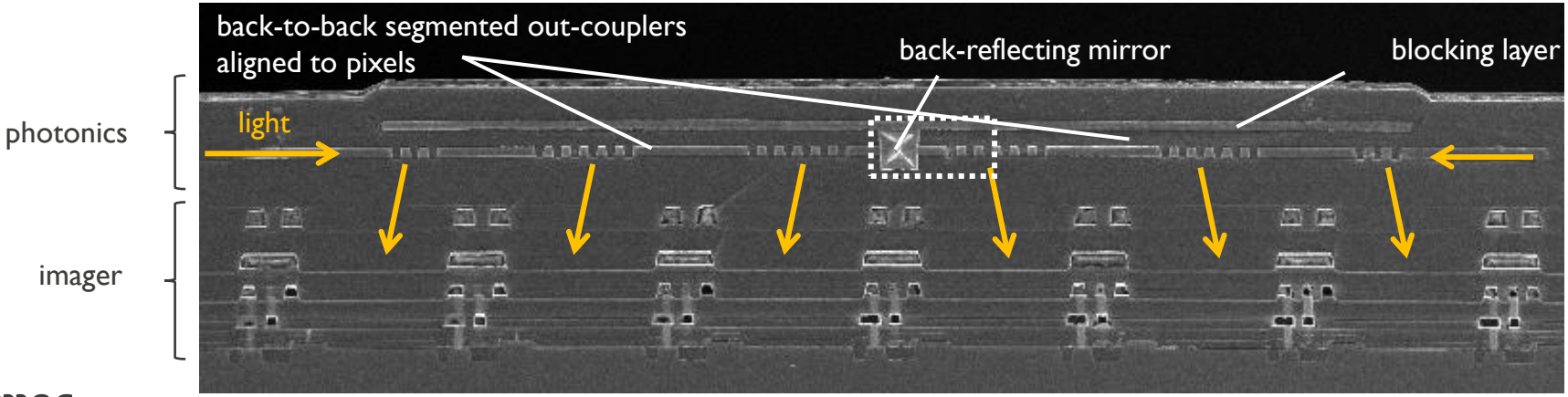


SiN photonics integration on CMOS

Integrated on top of CMOS imager wafer

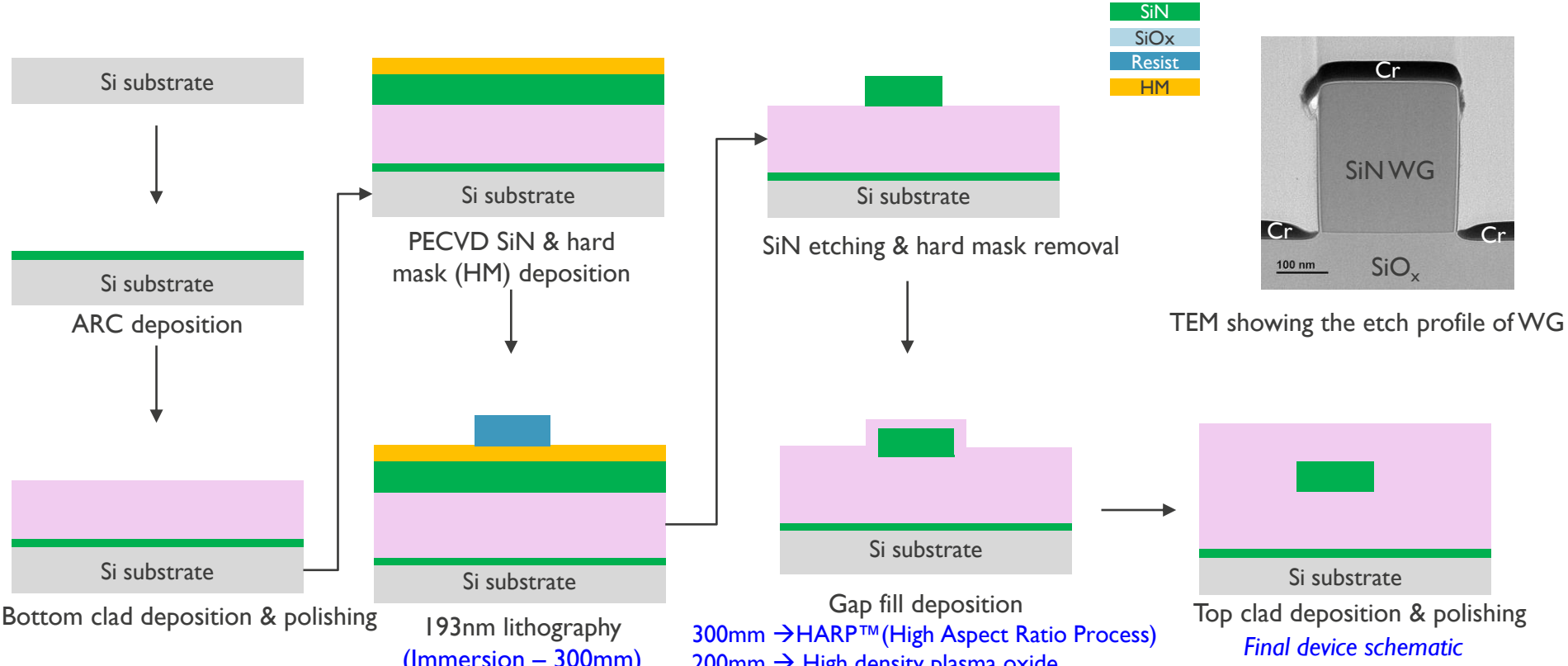




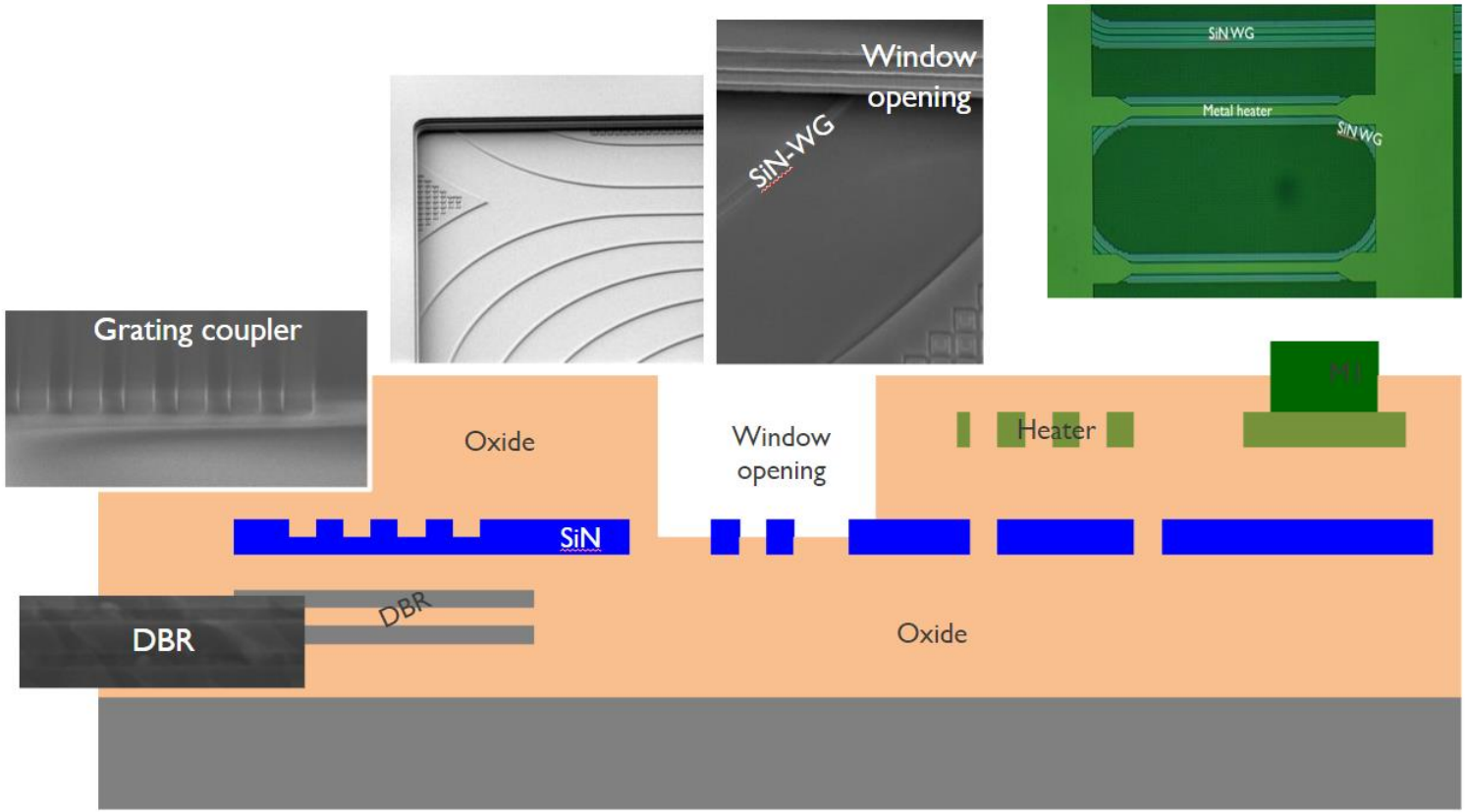


PROCESS FLOW

WAFER FABRICATION FLOW FOR PECVD SIN WAVEGUIDES



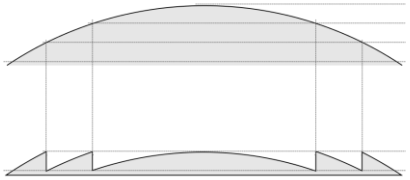
Process example (1)



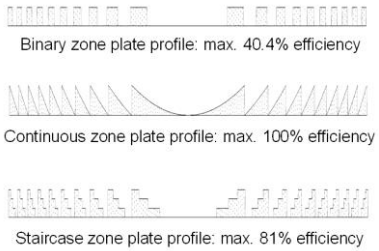
Nano-imprinted Fresnel lenses

Binary lenses and beyond...

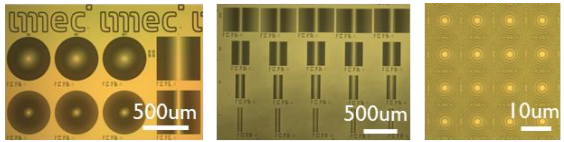
From classical lens to Fresnel lens



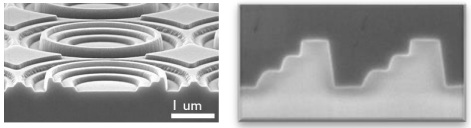
Staircase Fresnel lenses for nanoscale implementation



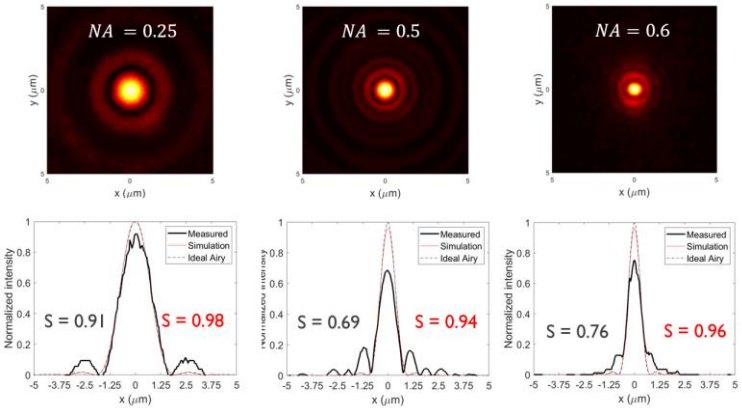
Nanoscale NIL compatible implementations

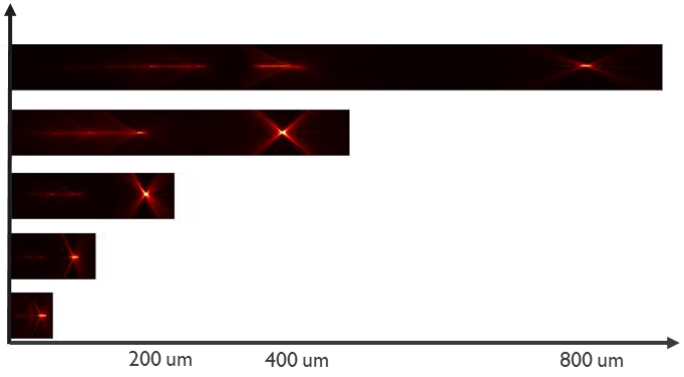


Binary imprints in NIL lab



Multilevel lenses 200 mm pilot line

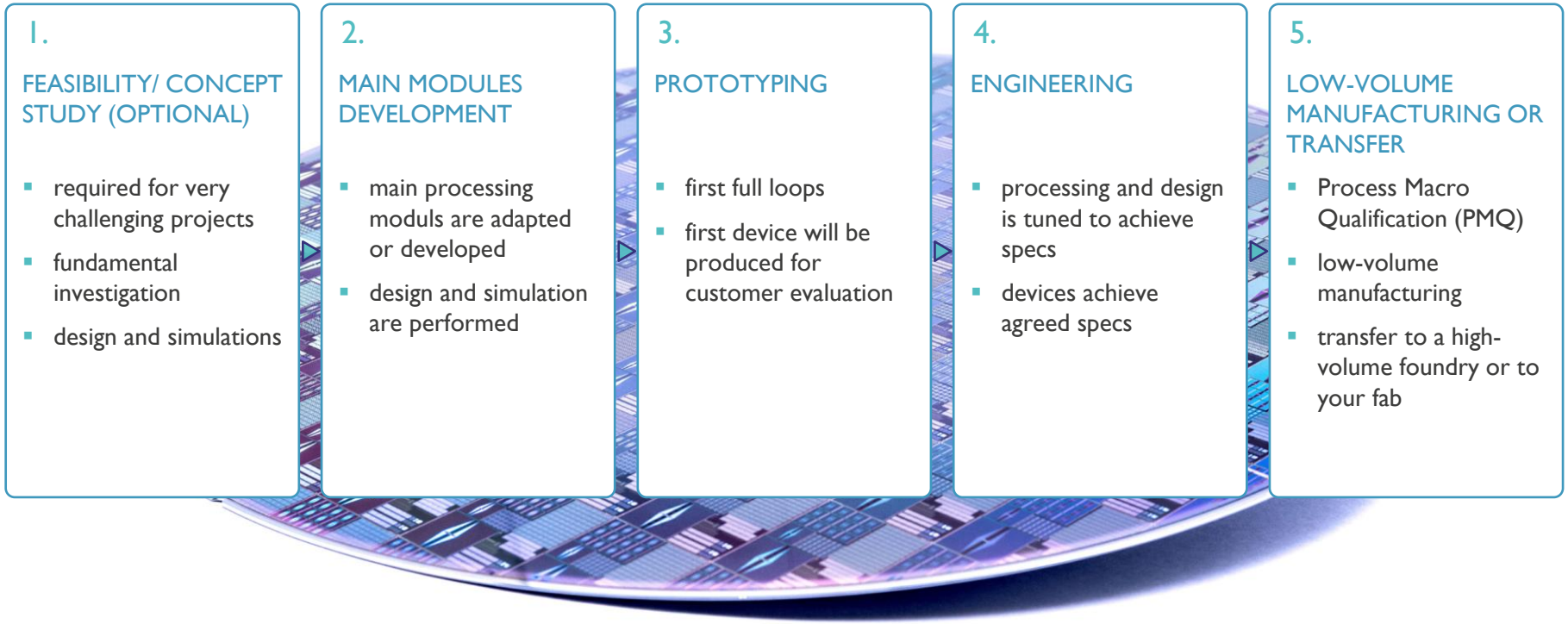




Excellent optical performance of imprinted binary Fresnel lenses!

R. Qin et al., NNT 2021

Imec guides companies through all the steps to a functional product



1. FEASIBILITY/ CONCEPT STUDY (OPTIONAL)

- required for very challenging projects
- fundamental investigation
- design and simulations

2. MAIN MODULES DEVELOPMENT

- main processing moduls are adapted or developed
- design and simulation are performed

3. PROTOTYPING

- first full loops
- first device will be produced for customer evaluation

4. ENGINEERING

- processing and design is tuned to achieve specs
- devices achieve agreed specs

5. LOW-VOLUME MANUFACTURING OR TRANSFER

- Process Macro Qualification (PMQ)
- low-volume manufacturing
- transfer to a high-volume foundry or to your fab