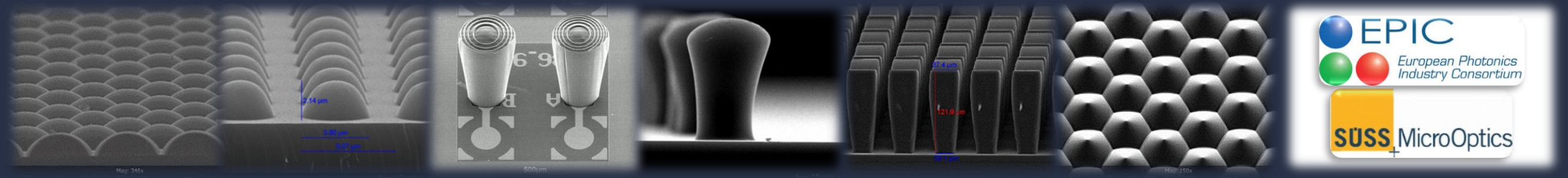
Micro-optics: the final frontier…

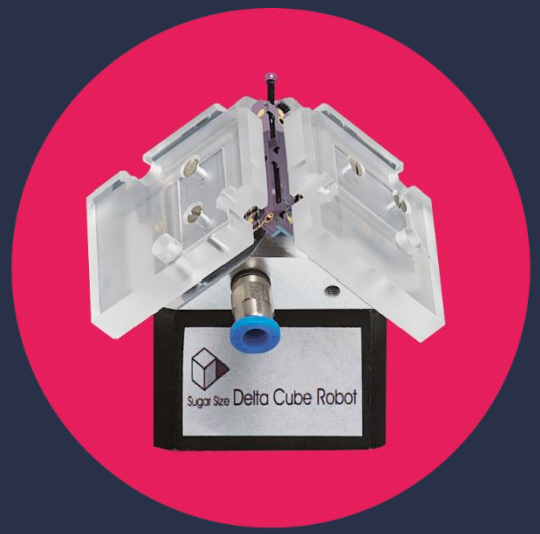
Wafer-scale fabrication of micro-optical interconnects

Dr. Rolando Ferrini

EPIC Meeting on Wafer Level Optics – SÜSS MicroOptics (Neuchâtel), 07-08.11.2019



Our mission



Development and transfer of world-class (micro-)technologies to the industrial sector – in Switzerland, as a priority – in order to reinforce its competitive advantage.

- Cooperation agreements with established companies
- Encouraging the creation of start-ups

CSEM at a glance

82.1
Turnover
(mio CHF)

43
Nationalities

470
Persons

44
New ventures

206
Industrial clients

210
Patent families

76
European
projects

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Close to industry, leveraging Swiss academic research

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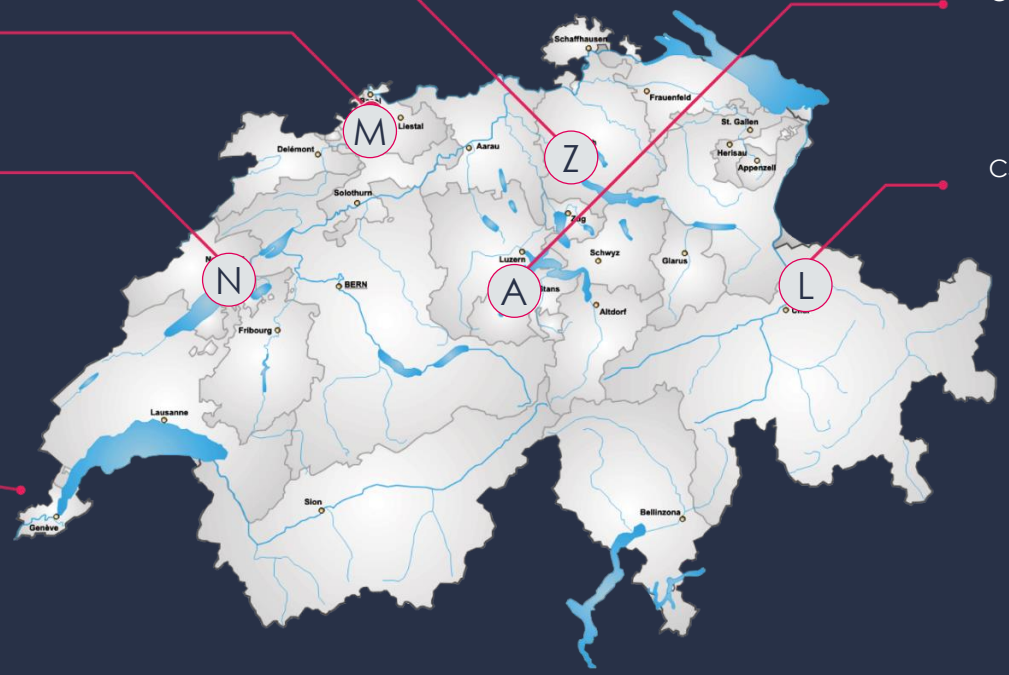

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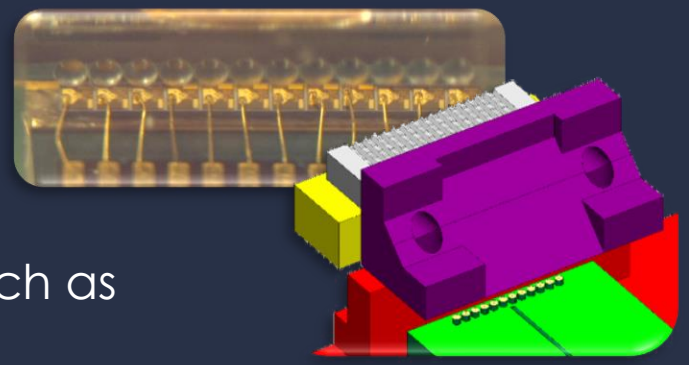
Outline

- Wafer-scale micro-optical components : folded interconnects
- High & Low refractive index materials for UV imprint
- Freeform micro-optics

Folded interconnects

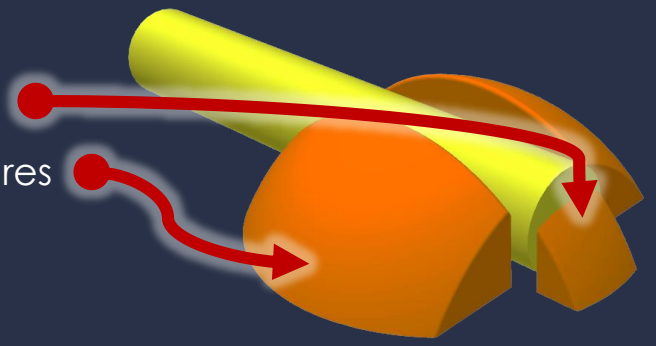


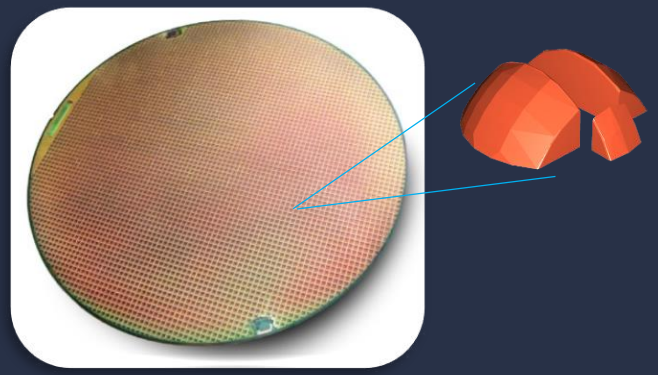
Current solutions

- Optical connectivity is based principally on collinear solutions
- Folded connectivity is manly done with additional components, such as parabolic mirrors, optical benches, lens mirror systems etc.

Our solution

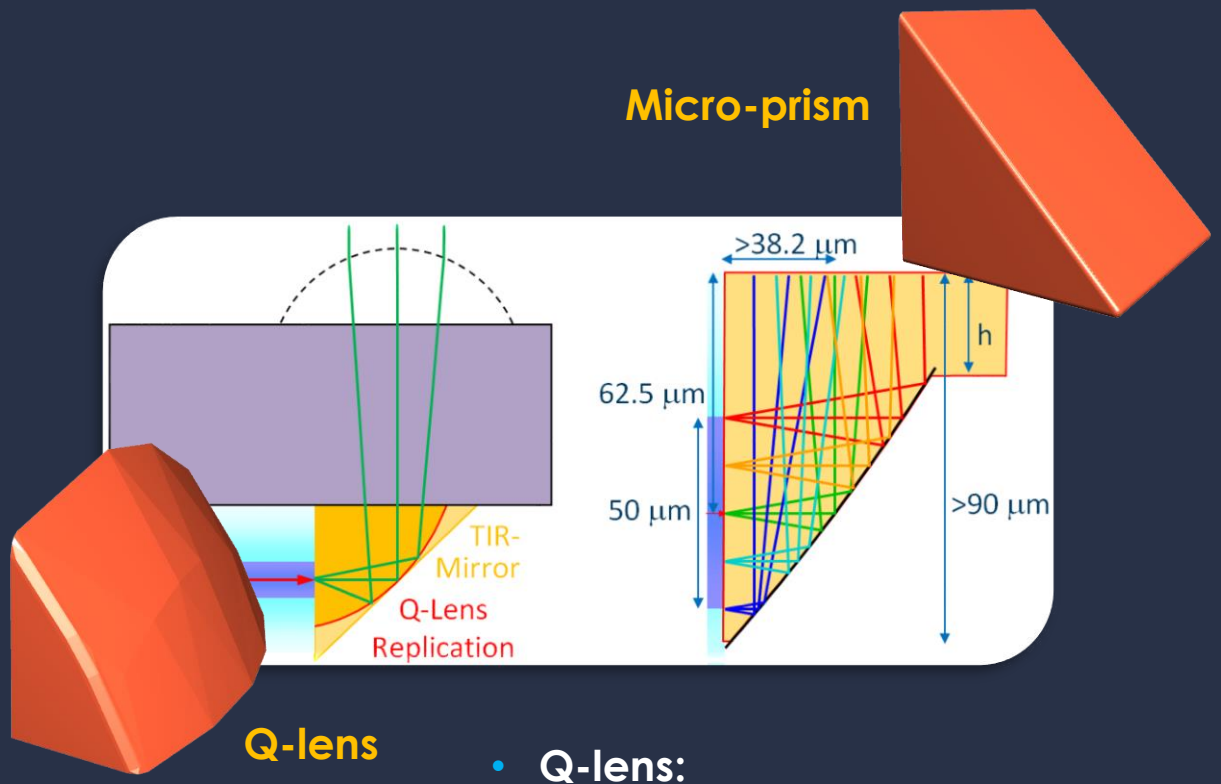
- Operational for all standard telecom optical fibers (SM & MM, 850-1650nm)
- Integrated micro-optical component:
  - Light bending ⇢ TIR (Total Internal Reflection)
  - Fiber coupling ⇢ Self-alignment micro-structures
- Wafer-scale compatible





Wafer-scale micro-optical components

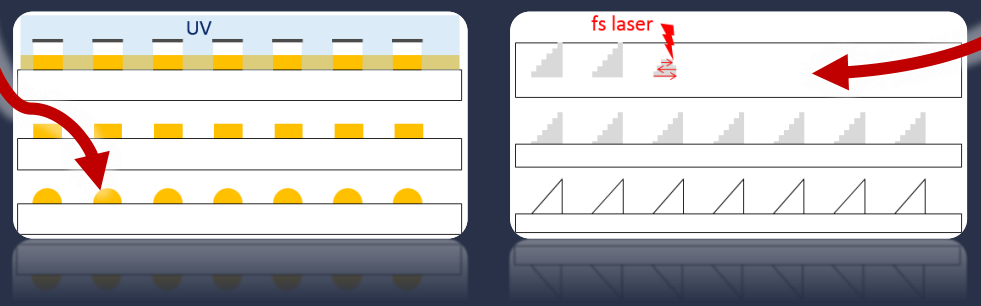
Design & Fabrication



- **Q-lens:**
  * r = 600µm
  * r = 780µm

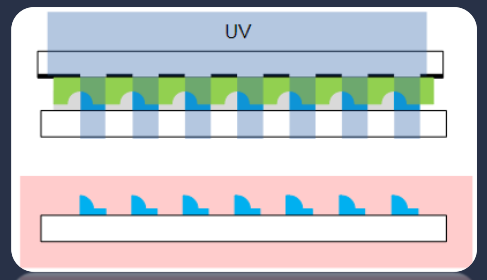
- **Micro-prism:**
  * α = 45 deg; h= 80µm

- **Master origination**
  Q-lens: Wafer scale reflow (spherical only)
  Prism: Laser micro-fabrication (FEMTOprint©)



- **Mould tool on structured mask**

- **Lens replication and alignment structures**
  Single process step



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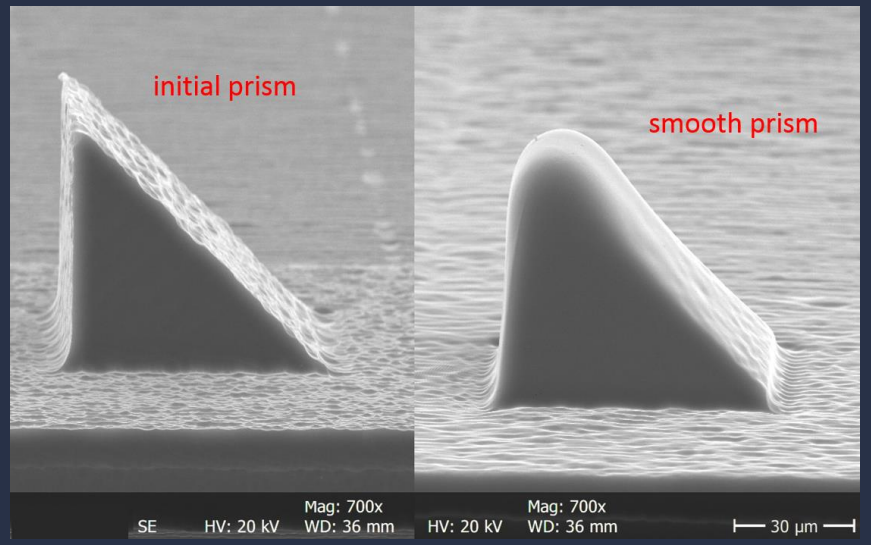
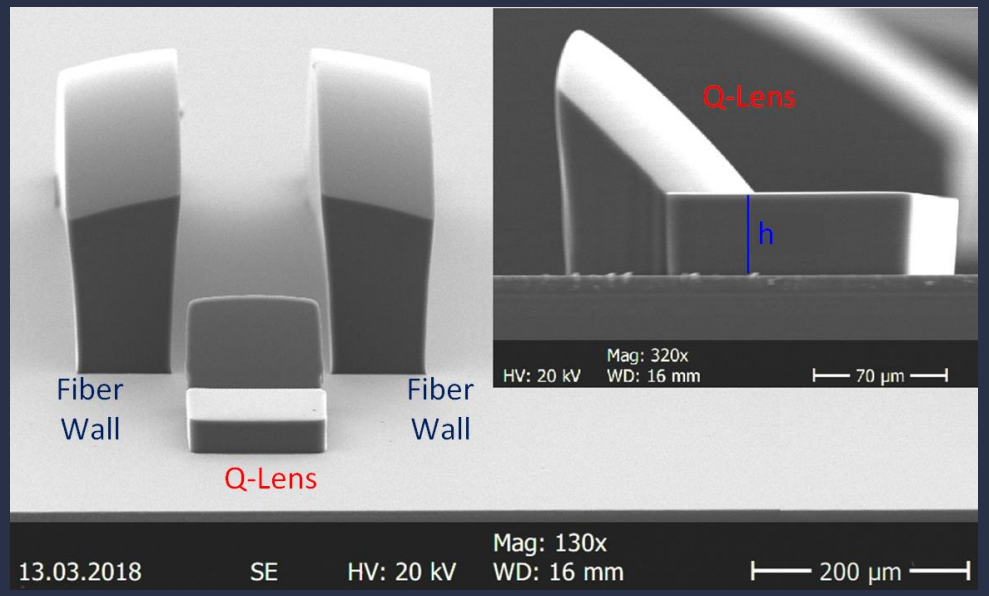
Fabricated folded interconnects

- **Replication of Micro-prisms**
  - without smoothened master ⇢ rough surface
  - with smoothened master ⇢ good surface / rounded edges

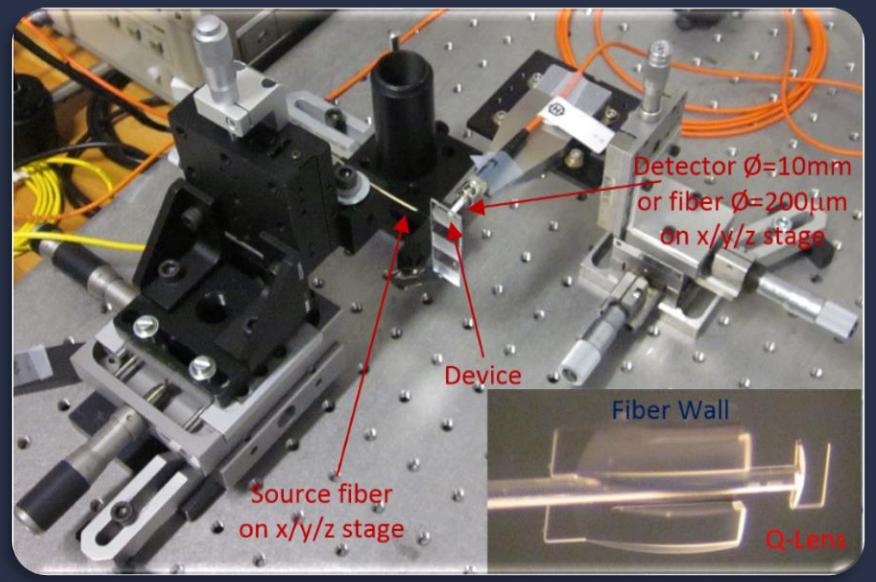
Commercial micro-prism as master benchmark



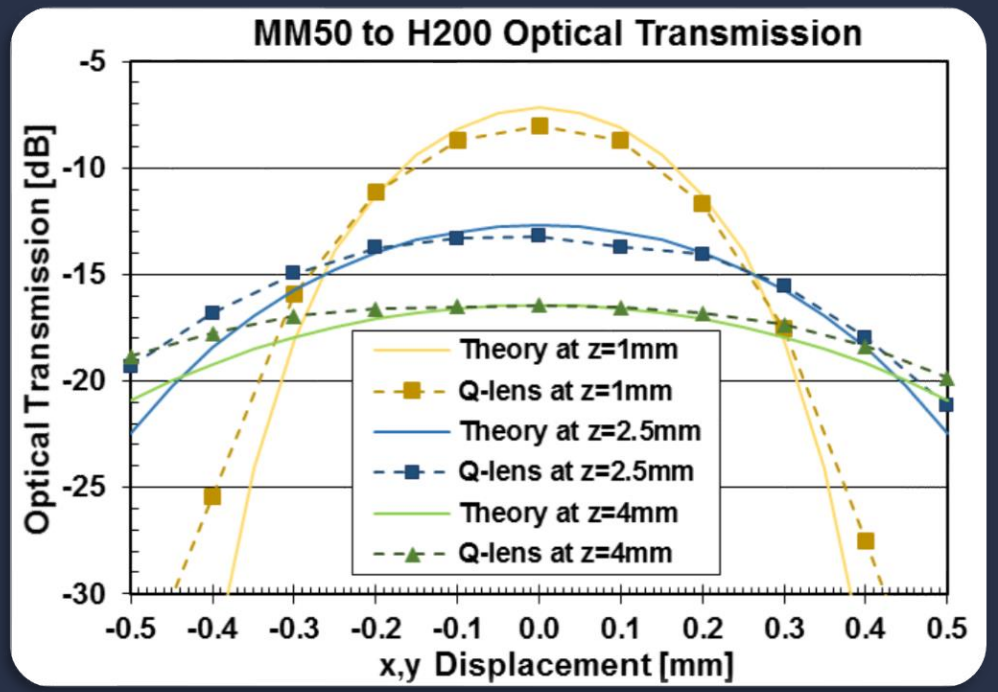
- **Replications of Q-lens**
  Nice surface & edges also for the alignment fiber walls



Folded interconnects: Optical losses & Mode profile



Device	SM loss [dB]	MM loss [dB]
45° Prism *(replicated from commercial µprism)*	0.35	0.42
Q-lens 600	0.42	0.48
Q-lens 780	0.36	0.38



Results of Q-lens (r=780 µm) with MM as input fiber at different z-distances in comparison to simulations

- **Optical losses below 0.5 dB**
- **The optical mode profile and the angular directivity are well maintained**

Perspectives

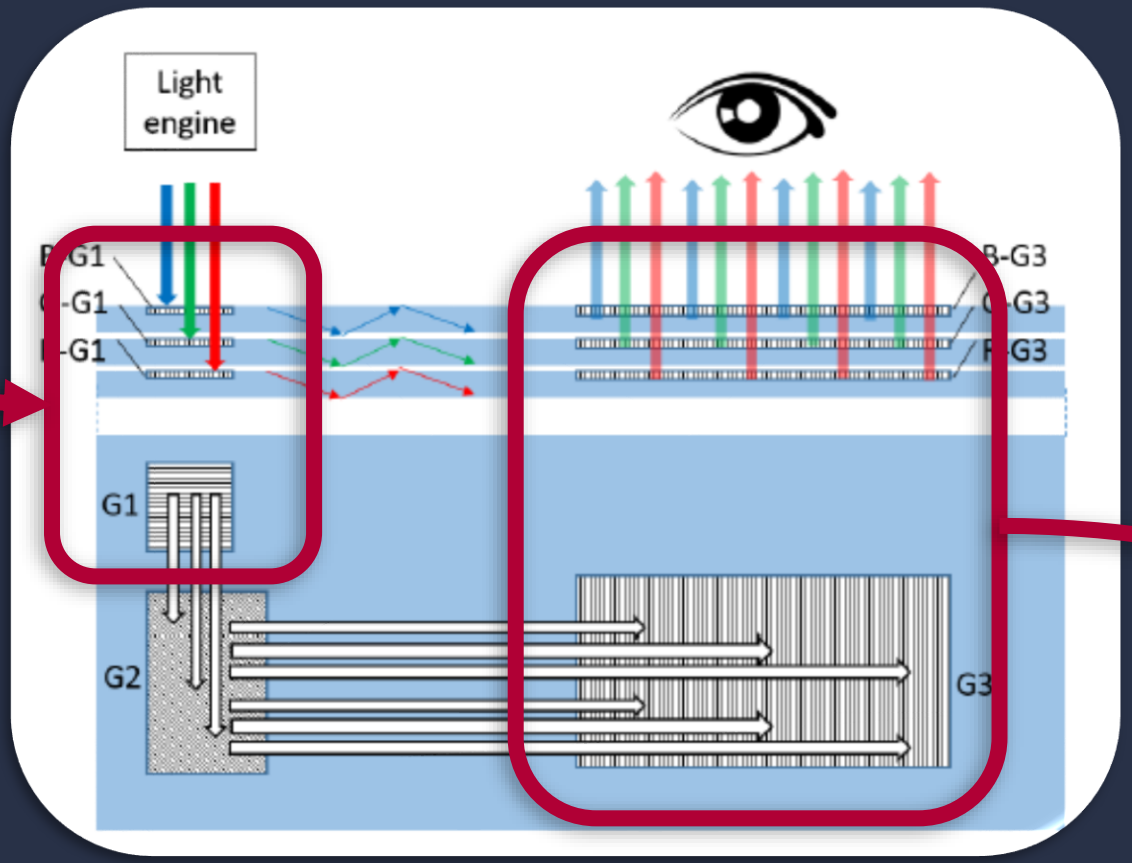
- Innovative **compact 90° optical interconnect** using TIR based Q-lenses or micro-prisms
  - **Packaging:** self-aligned fiber to chip (VCSEL, Photodiodes)
  - **Array structures:** ribbon fibers
  - **Angled fiber to fiber couplers:** backplane connector with enlarged alignment tolerances
  - **Integrated couplers:** coupling to planar waveguides using grating couplers
- Fabrication by **wafer-scale** UV-imprint
- **Losses as low as 0.34 dB** while **maintaining the optical profile**
- Integrated fiber **self-alignment structures**

This solution will facilitate chip integration & packaging of electro-optical components (LED, VCSELs, Photodetectors, PICs etc.) to standard glass fibers

The quest for new UV imprinting materials : Application pull

Diffractive WGs for AR : 2D exit pupil expansion ⇢ RI > 1.78 to enlarge the FOV

In-coupling gratings



Out-coupling gratings

High refractive index (HRI) imprintable materials

Approach 1

- **HRI nanoparticle doping** (SiO_2, TiO_2, ZrO_2, etc.) of **photoresist** (polymer) or **sol-gel material** (inorg.-org. hybrid polymer) for UV imprint
- *Applicable to both micro- & nano-imprint*

Approach 2

- UV imprint of **HRI hybrid sol-gel material** followed by calcination
- *Applicable <u>only</u> to nano-imprint*

HRI nanoparticle doping of photoresists for UV imprint

Approach 1

- **HRI nanoparticle doping** (SiO_2, TiO_2, ZrO_2, etc.) of **photoresist** (polymer) for UV imprint
- *Applicable to both micro- & nano-imprint*

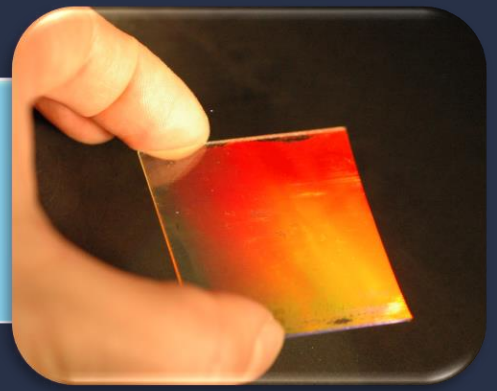
Refractive index measured by ellipsometry

ZrO_2 nano-particle loading	Fit refractive index @ λ = 600nm
2:1	1.68
3:1	1.75

HRI hybrid sol-gel materials for UV imprint

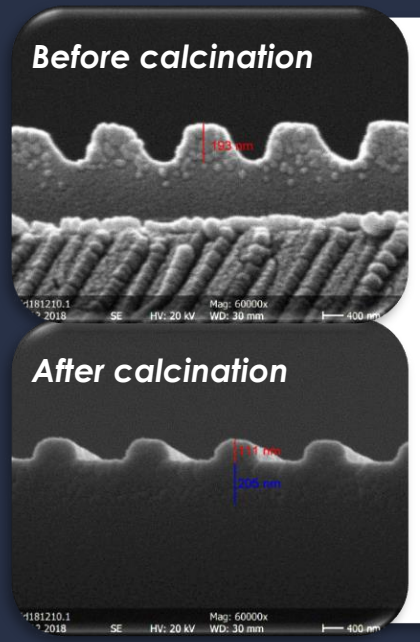
Approach 2

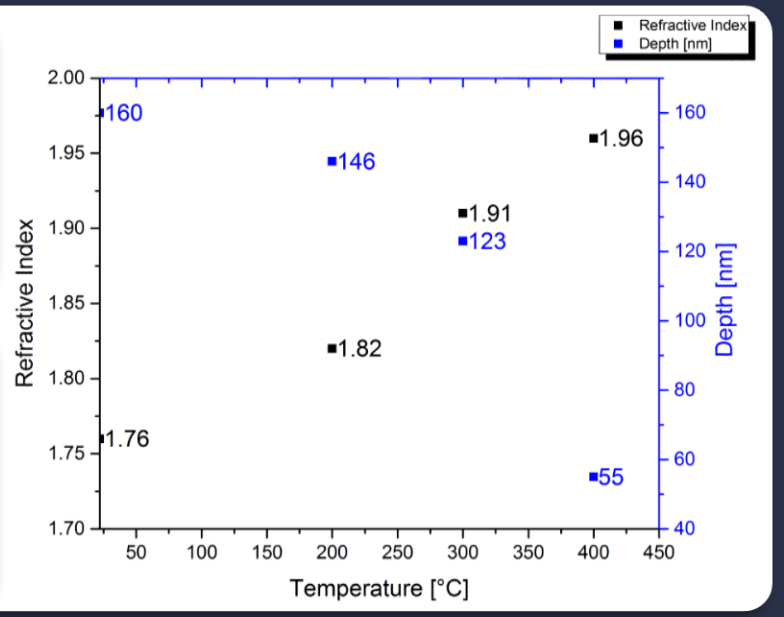
- UV imprint of **HRI hybrid sol-gel material** followed by calcination
- *Applicable only to nano-imprint*



Refractive index measured by ellipsometry

Calcination temperature	Fit refractive index @ λ = 600nm
RT	1.76
200°C	1.82
300°C	1.91
400°C	1.96



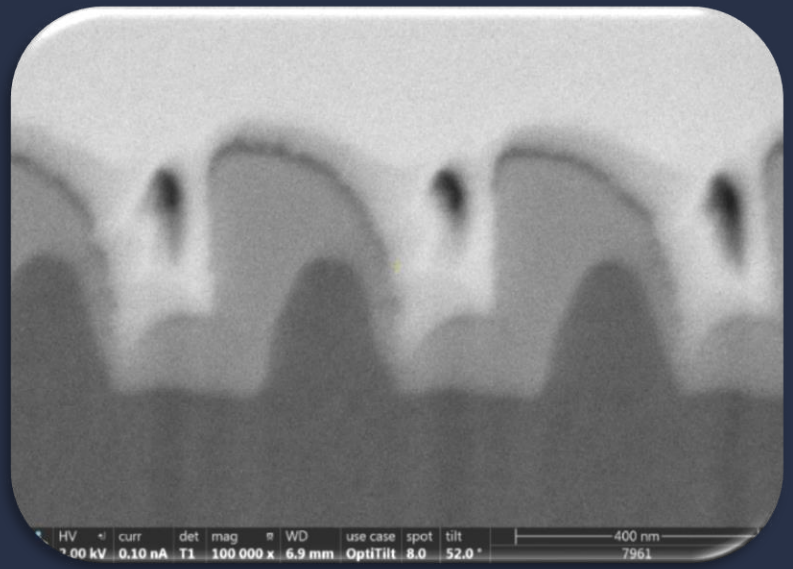


HRI materials for AR WG couplers: *In-coupling gratings*

- **UV nanoimprint** of photoresist doped with **HRI nanoparticles** → RI = 1.7

- **Coating** with (very) high refractive index material (> 2.0) at oblique incidence

- **At λ = 460nm**
  - average in-coupling efficiency = 37%
  - incidence angle = +/- 18°
  - unpolarized light

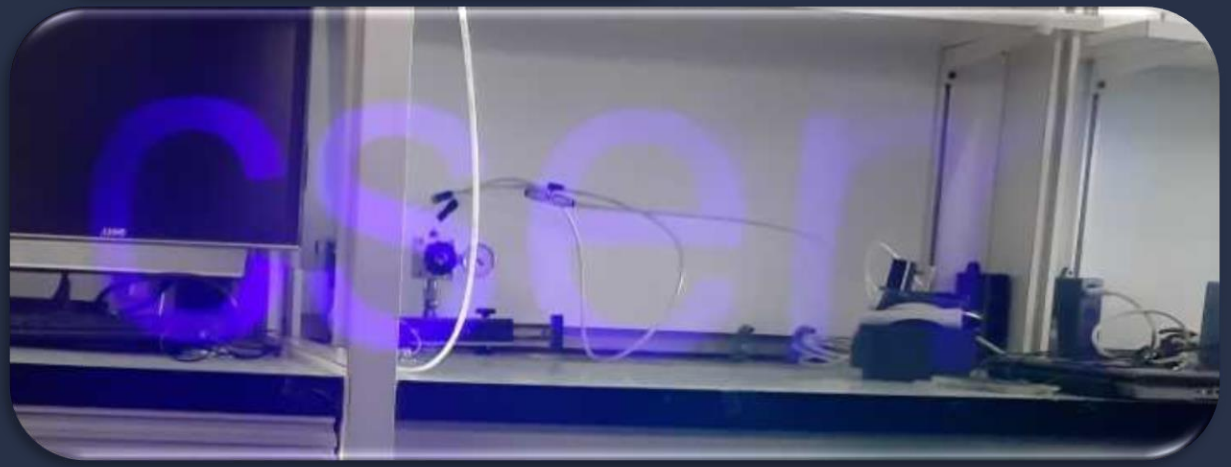


HRI materials for AR WG couplers : *Out-coupling gratings*

- **Approach 1 (HRI nanoparticle doping)**: large light scattering after propagation in the waveguide (losses, reduced image contrast)

- **Approach 2 (HRI hybrid sol-gel material)**: reduced surface roughness, lower light scattering, higher refractive index

Diffractive waveguide prototype



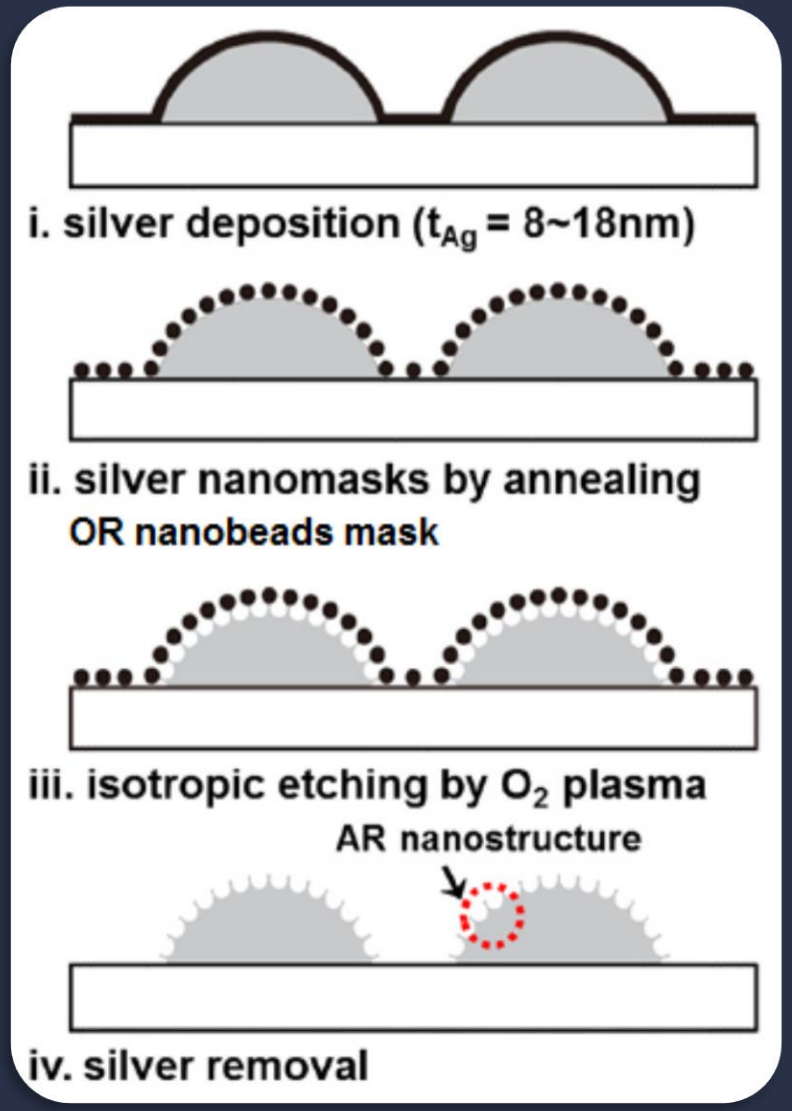
Test image outcoupled from waveguide

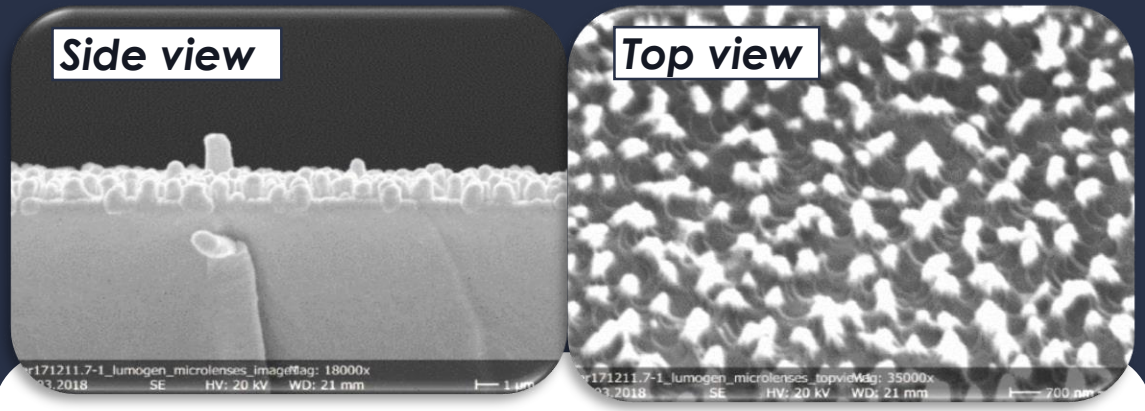
Low refractive index (LRI) nano-patterned interfaces

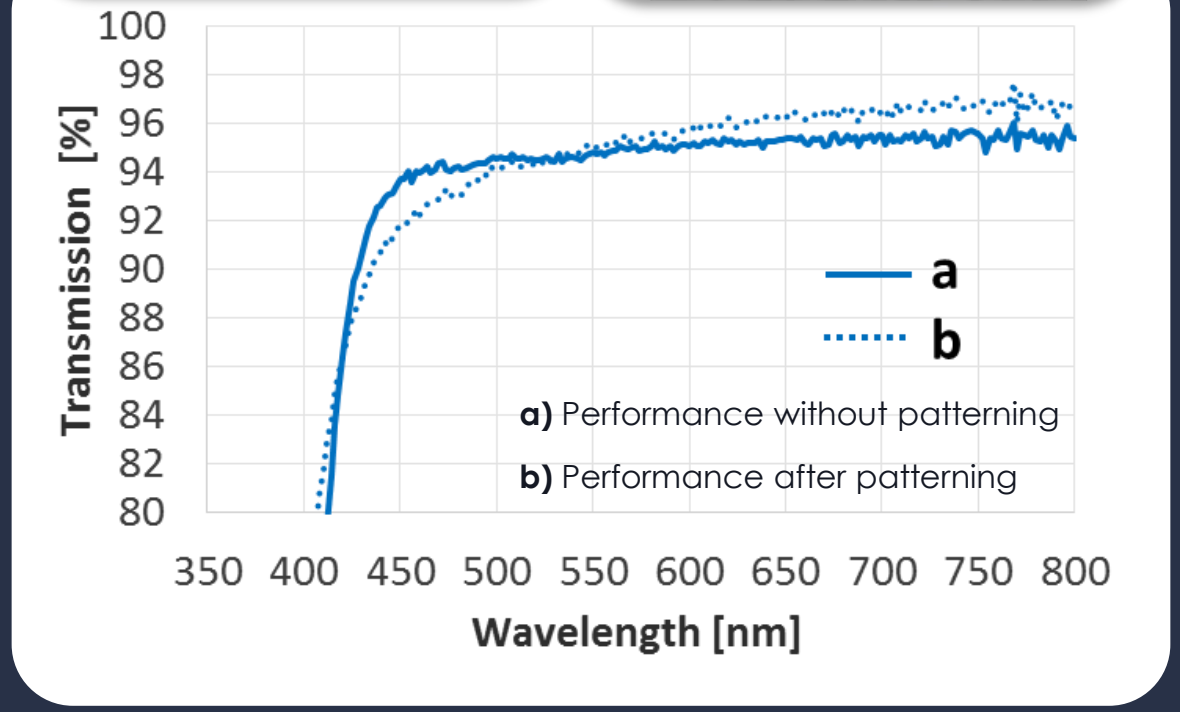
Nano-patterning of surfaces (LRI interface layer) through silver nano-island deposition

↓

UV imprint lithography of combined nano- & micro-structures







Future perspectives

- **Growing demand for UV imprinted nano-/micro-optical components**

- **Growing demand for freeform micro-optics**
  - Micro-optical surfaces with **no restrictions on symmetry**

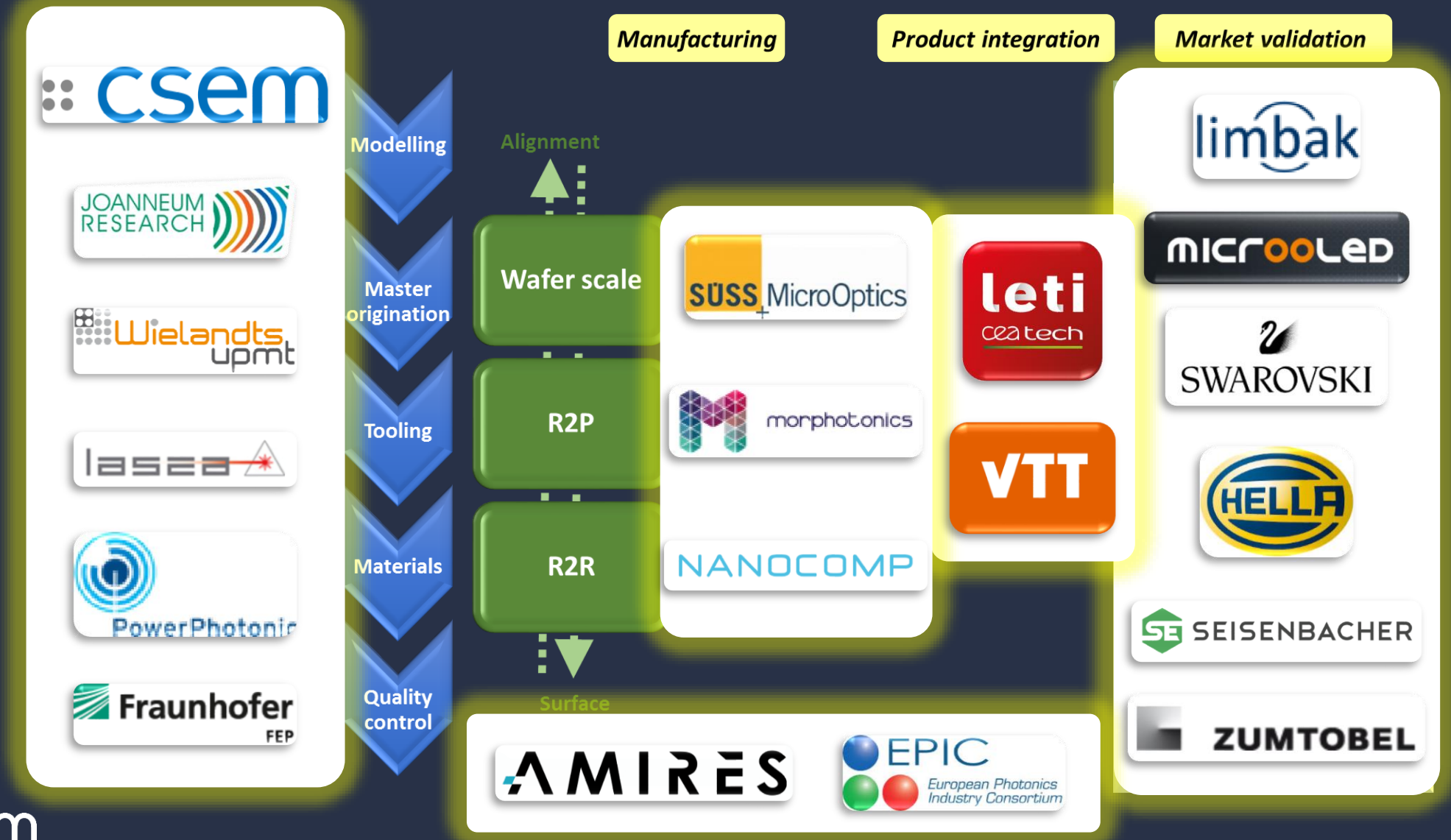
  - The **additional degrees of freedom** enable optimum lens design and hence
    - Aberration correction (*imaging*)
    - Non-symmetrical light distributions (*non-imaging*)
    - Fewer and/or smaller optical components → Miniaturization & Integration

Freeform micro-optics

Application cases

Freeform micro-optics

Complex manufacturing eco-system



PHABULμOS: Pilot line for free-form micro-optics

Who

- **19 partners: Research & Technology Organizations (RTOs)** and **Companies** along the manufacturing value chain

What

- **European pilot line for the manufacturing of freeform micro-optical components** with a clear roadmap for high volume production in Europe at competitive cost

How

- **3 UV replication technologies** (wafer scale, R2P, R2R)
- **Accelerated innovation cycles** from prototypes to large volume production
- Boost in **new product developments**
- A manufacturing **one-stop shop** for SMEs up to LMEs
- An **European ecosystem** for free form micro-optics

Freeform micro-optics

PHABULμOS: The consortium

We are …

PHABULOμS

January 1st, 2020

Photonics Public Private Partnership
www.photonics21.org

Thank you for your attention!

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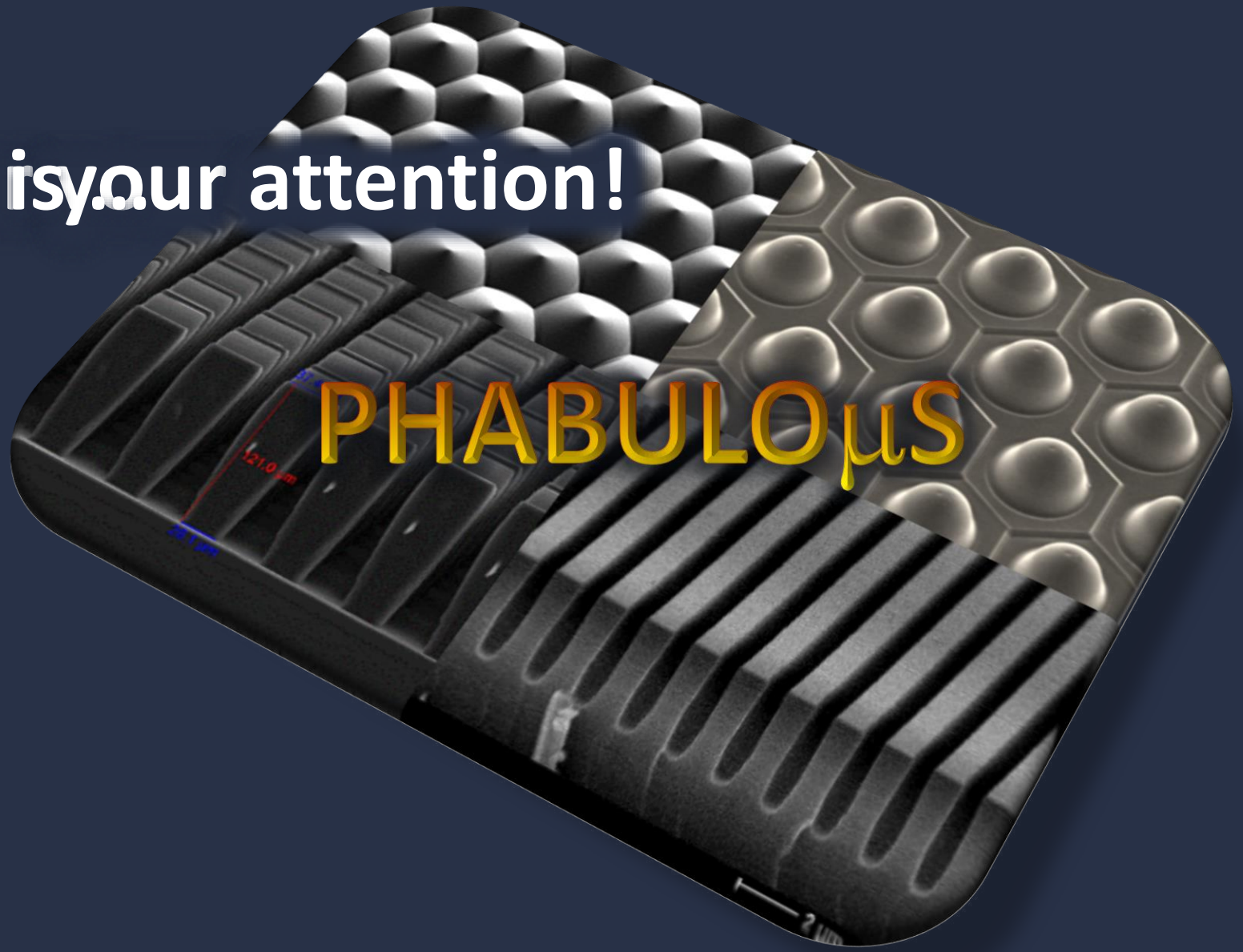

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