



Lieven Penninck

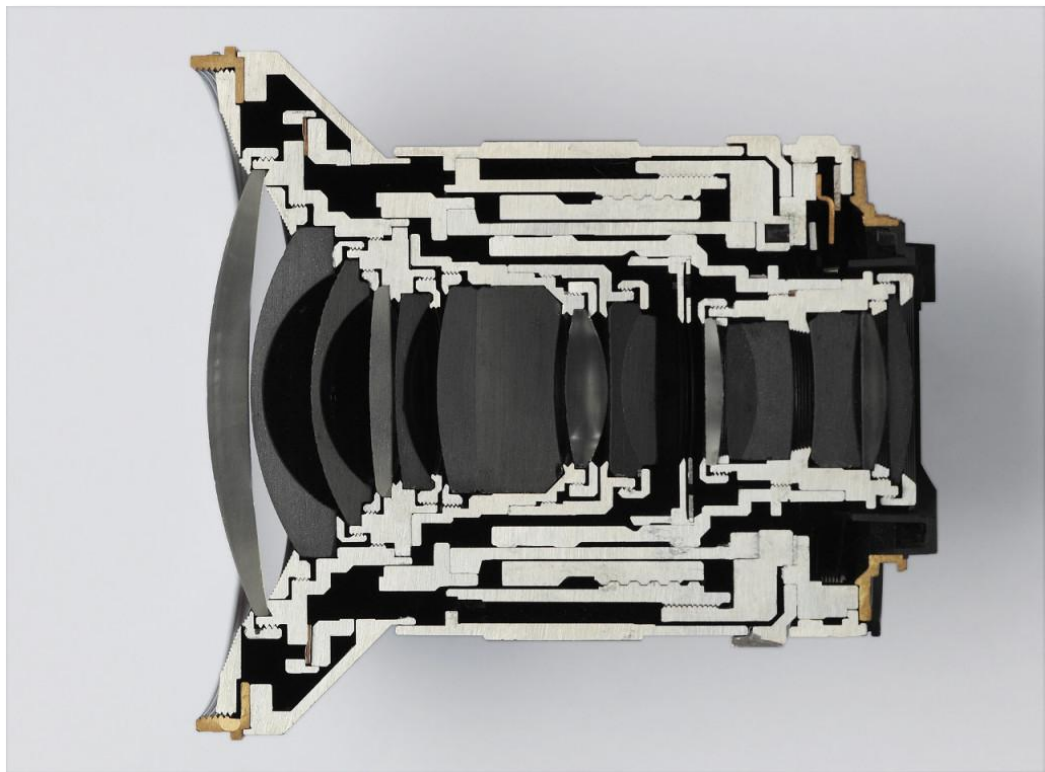
# Meta-surface Design Methods from the Nano- to Macro Level

EPIC Technology Meeting on Disruptive Technologies  
08/04/2025 Palaiseau, france



*PlanOpSim*  
Enlightened Planar Optics

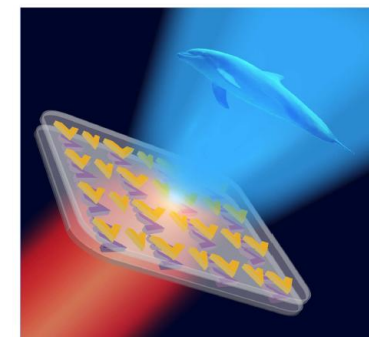
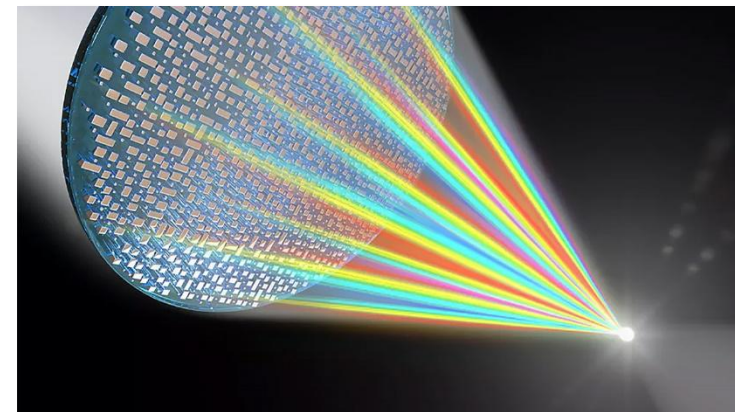
# Today



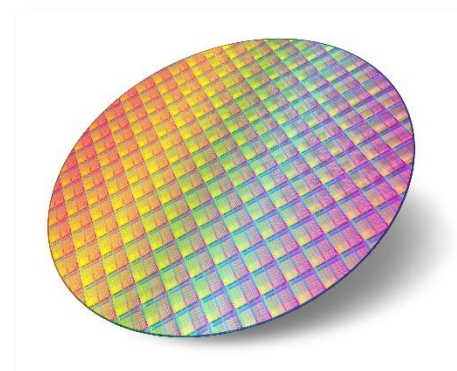
# Future: Nano-enabled



Higher Performance  
Simplified  
Miniaturized  
New Applications



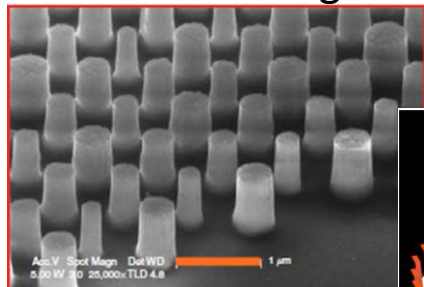
Art to Industry  
Lower Cost



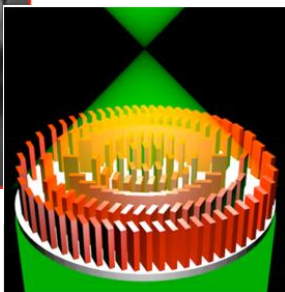
Lens Polishing —  
Hand-polishing spherical  
front lenses for microscopes.



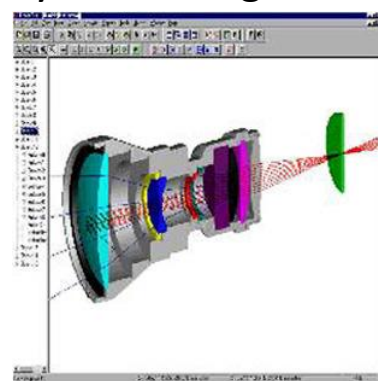
Nano-scale design



Component design



System Integration



**Planopsim's mission**  
Planopsim supplies R&D tools to engineers & scientists that allow to unlock the maximum benefit of flat optics in a user-friendly way.

- ❖ Computer Aided Design software for Planar Optics & metasurfaces
  - All-in-one design workflow
- ❖ Design service for metasurfaces and photonics
  - In-house and 3<sup>d</sup> party tools



# Meta-optics design flow

**PlanOpSim** Support solution

**PlanOpSim** Software solution

META CELL

META COMPONENT

LIBRARY

JOB OVERVIEW

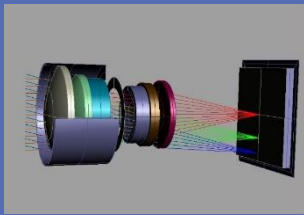
## Concept

- Feasibility
- Specs



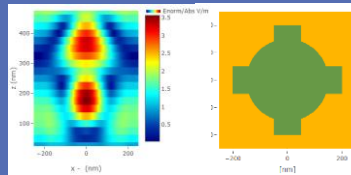
## System model

- Ray tracing



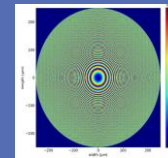
## Nanostructure

- Full wave RCWA
- Structure library



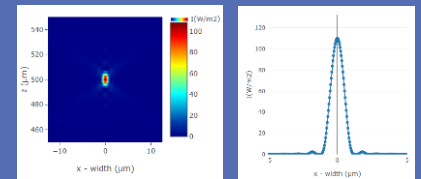
## Component design

- Propagation
- Wavefront design



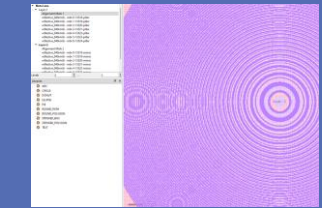
## Validation

- Propagation
- Non-idealities



## Fabrication

- gds export



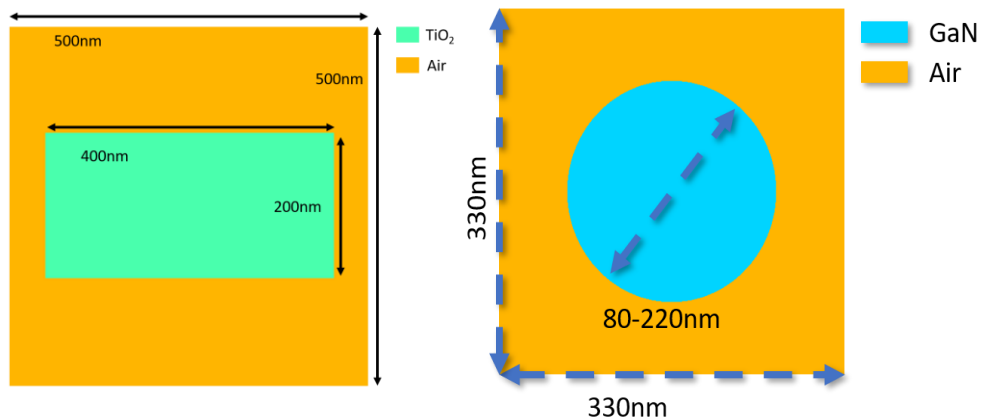
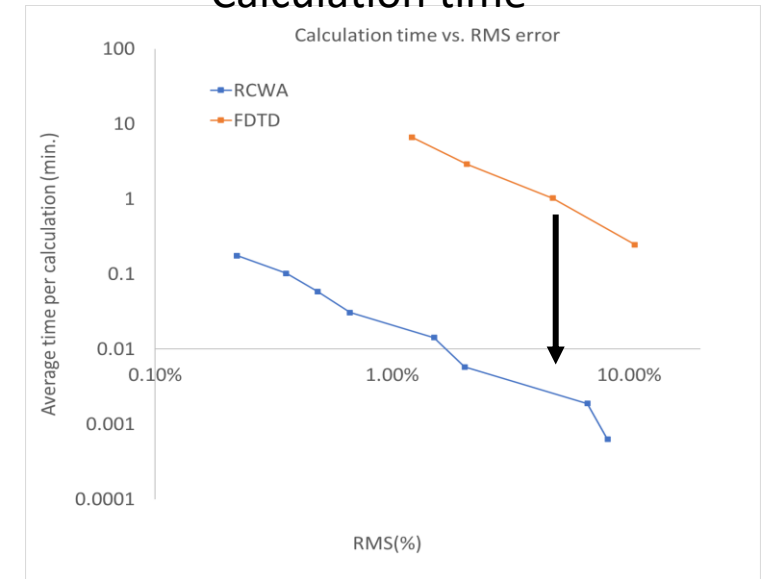
REPORT

MASK

# Meta-atom optimization

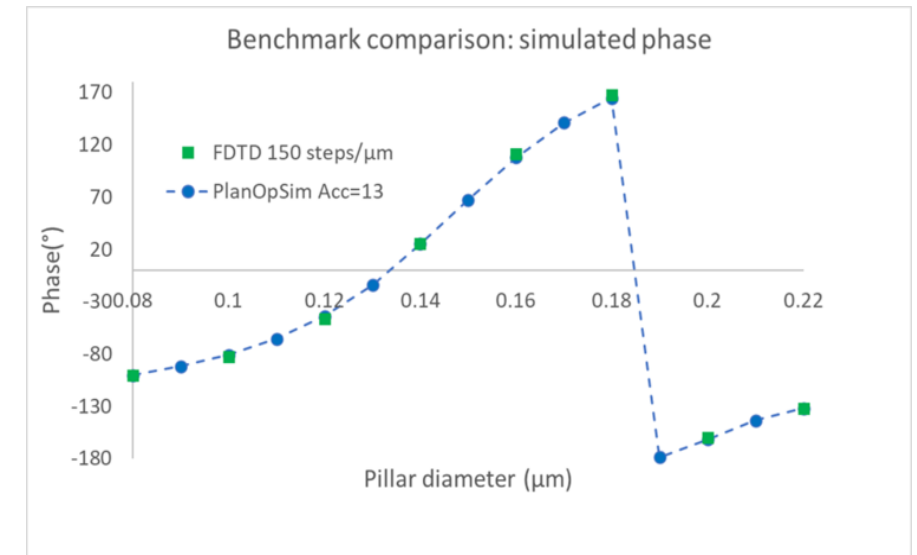
- ❖ Nano-structure calculation using **Rigorous Coupled Wave Analysis (Maxwell solver)**
- ❖ Thousands of nano-structures in parameter space
- ❖ Benchmark RCWA to FDTD
  - **RCWA is much faster** for meta-atom calculations
  - Meta-atom response same in RCWA and FDTD

## Calculation time



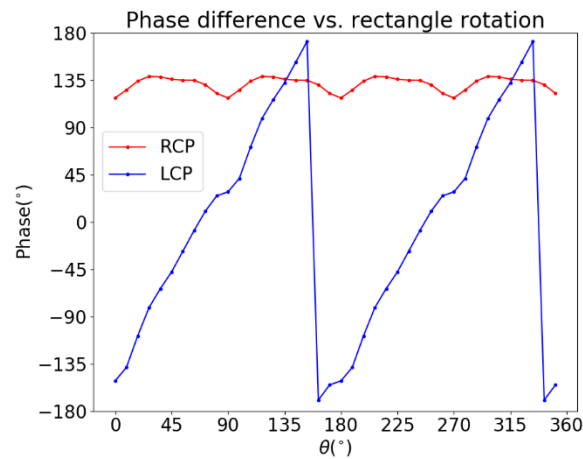
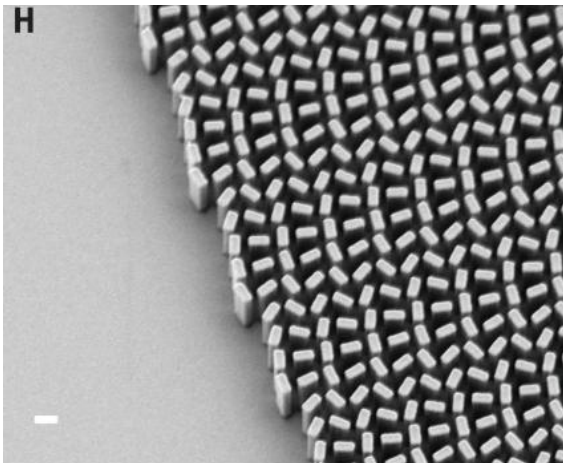
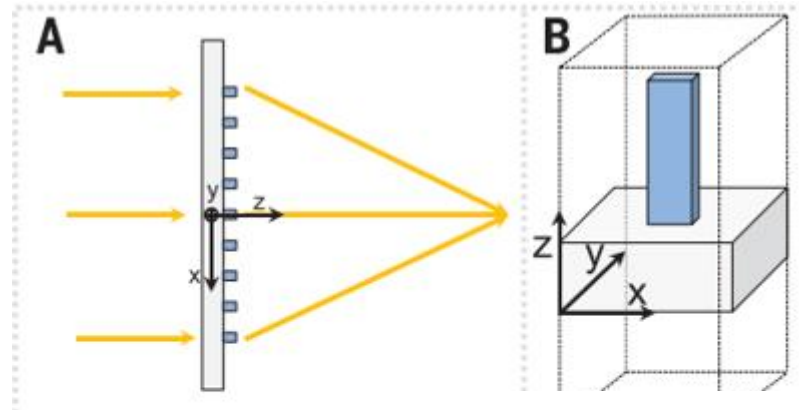
Test structures

## Calculated field response

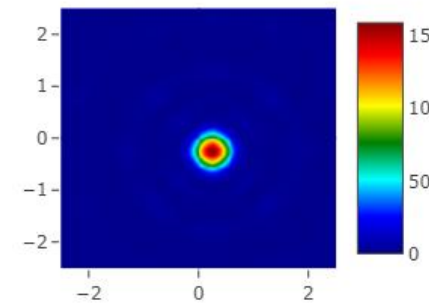


# Example: metalens design

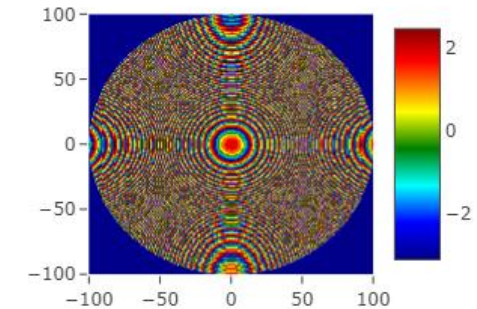
- ❖ Design of a metalens with diffraction limited focusing and NA 0.55 for 632nm
- ❖ Structures with TiO<sub>2</sub> on glass
- ❖ Integrated workflow:
  - Tuning of nano-pillars
  - Design of full metalens



Far-field wavefront



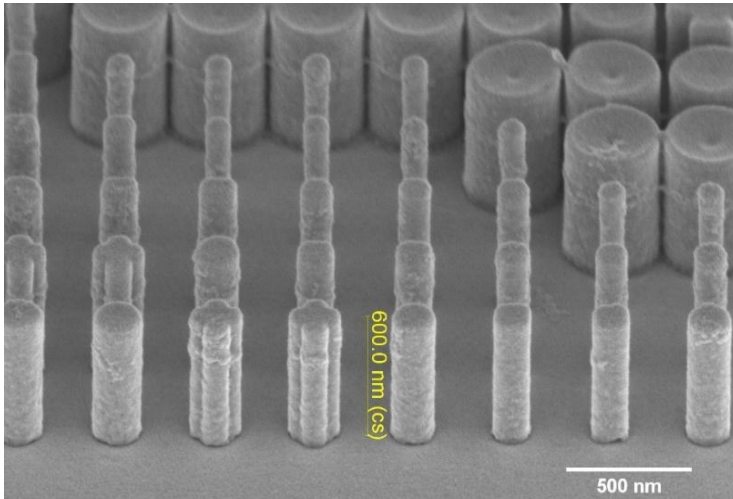
Near-field wavefront



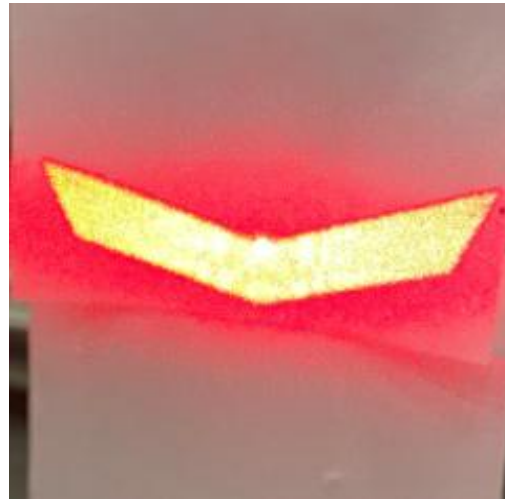
Focal spot and phasefront

# Application example

- ❖ Fabricated demonstrators of PlanOpSim: high opening angle phase only hologram
- ❖ Fabrication organised by PlanOpSim
- ❖ Wide full cone opening angle 40°



SEM of fabricated sample

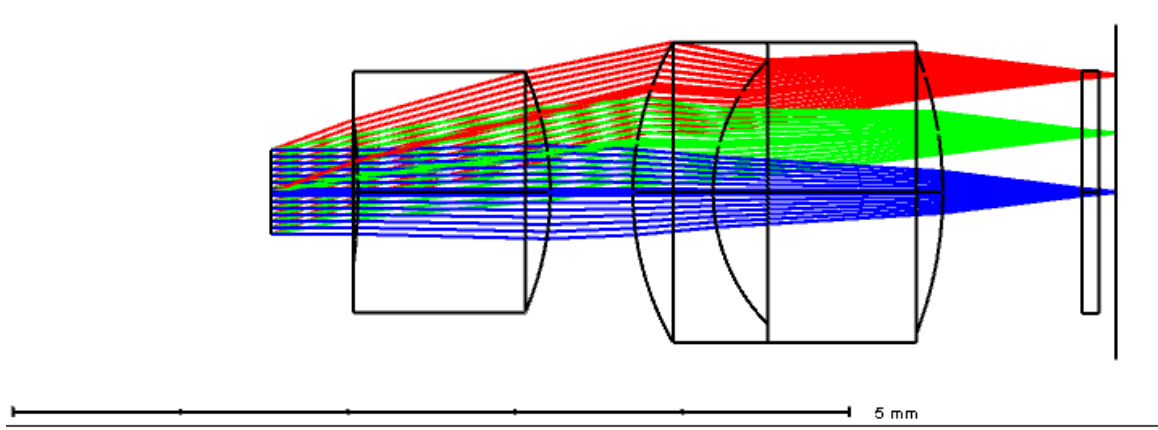


High brightness projection  
(hologram efficiency 70%)

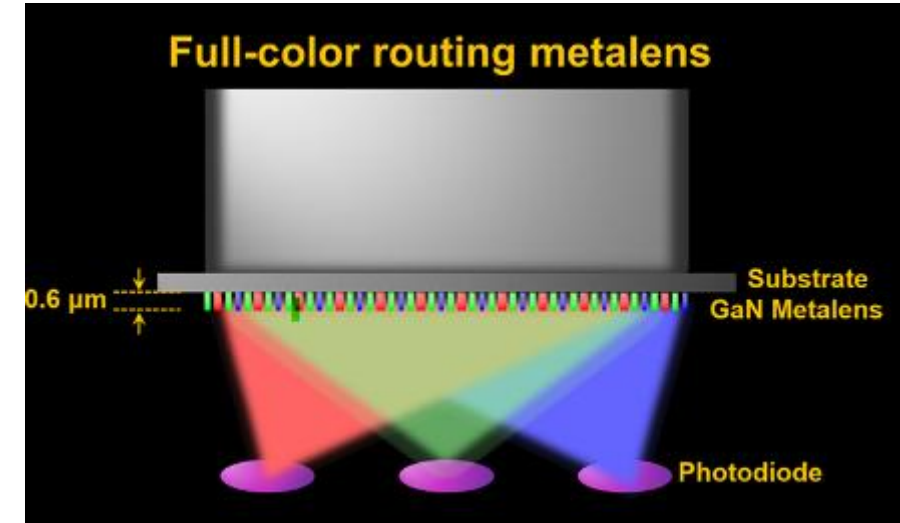


Application example

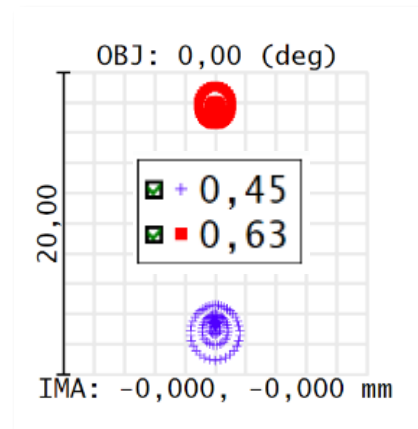
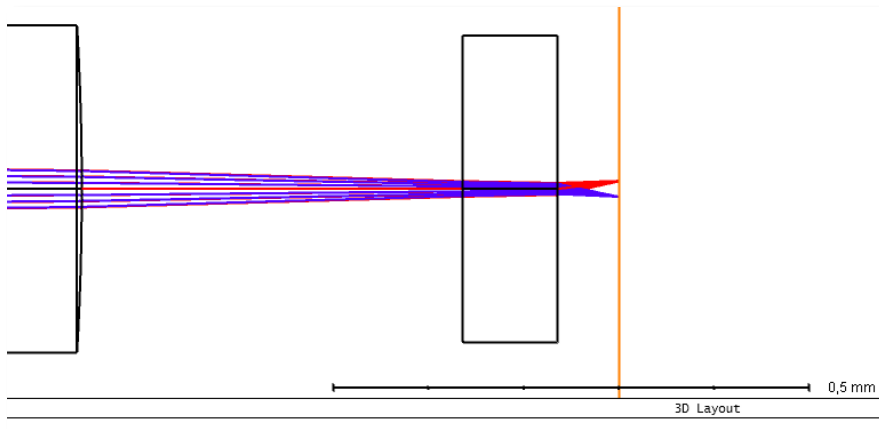
- ❖ Example: **Pixel level colour routing in system**  
Classical design: telecentric imaging system



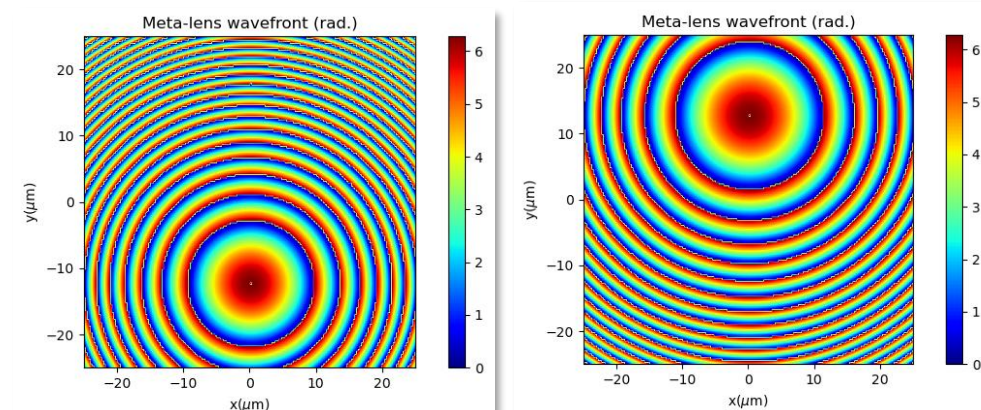
\*Based on: GaN Metalens for Pixel-Level Full-Color Routing at Visible Light. *Nano Letters*, 17(10), 6345–6352.



- ❖ Colour multiplexing meta-lens **designed and exported from PlanOpSim**



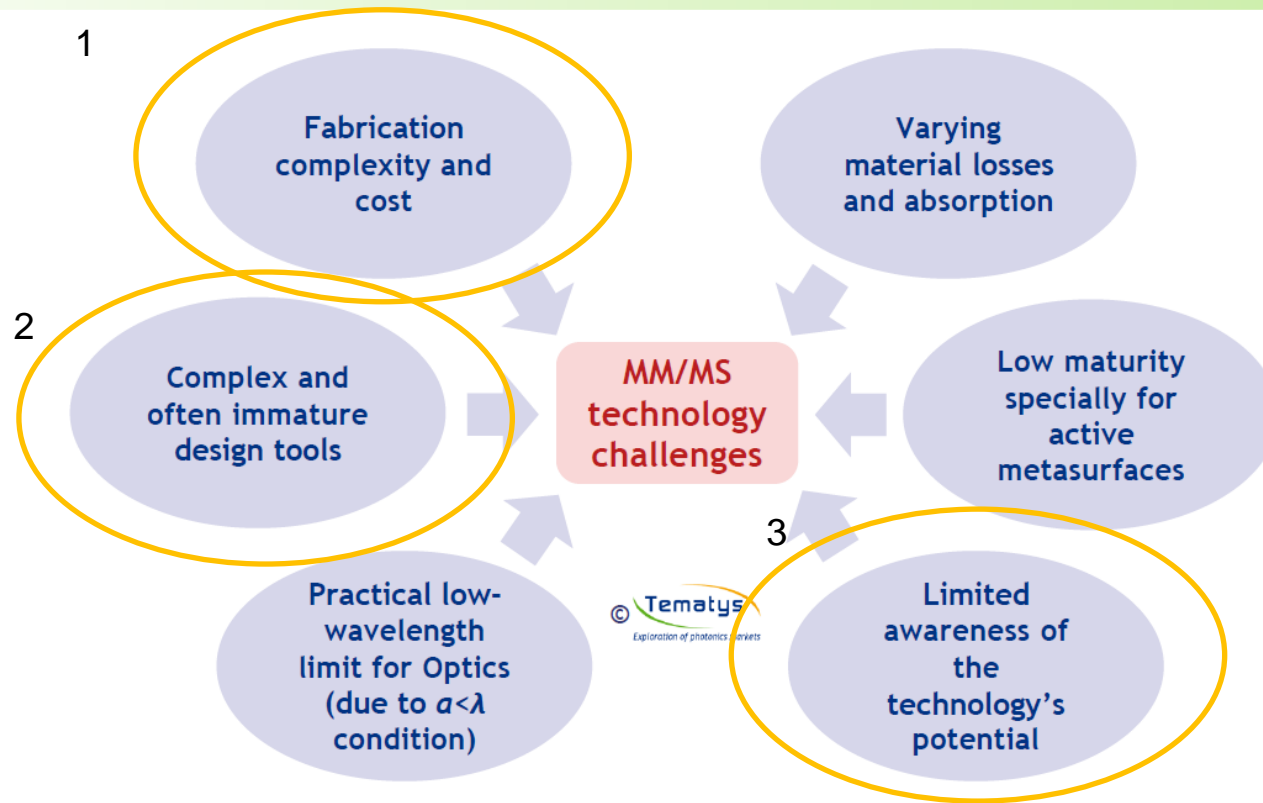
Wavelength multiplexed meta-lens





## CHALLENGES

### 2023 Metamaterials & Metasurfaces Technology - Challenges



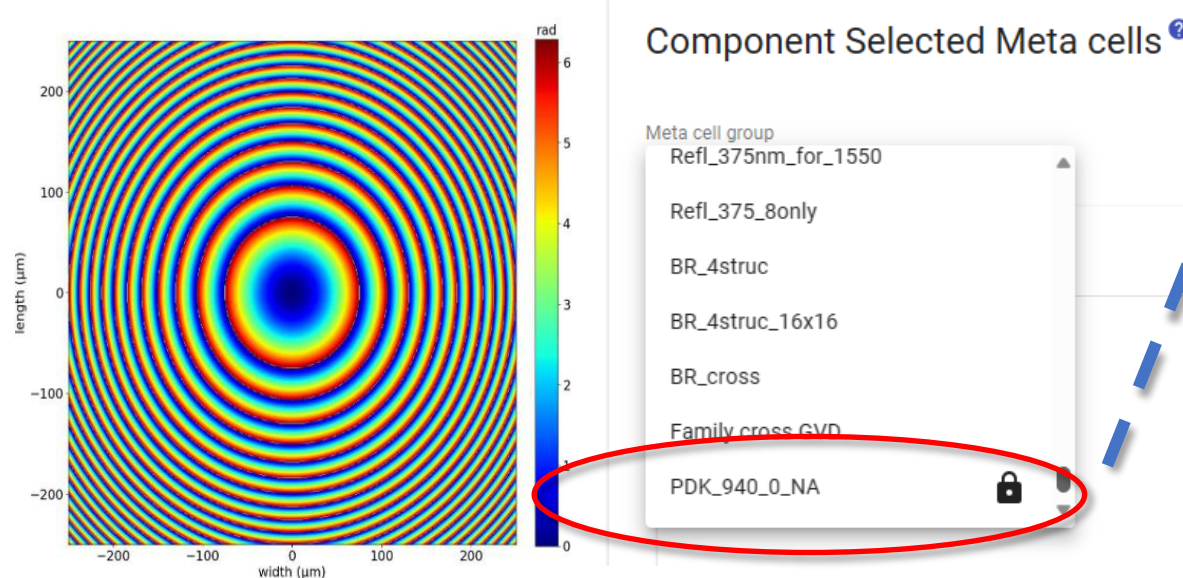
1. Fabrication complexity:
  - Robust design
  - streamlined workflow
2. Design methods & tools:
  - Accurate,
  - Integrated
  - Large area
3. Awareness
  - Enable rapid prototyping

# Meta-surface PDK

- ❖ **PDK:** Process development kit available since 2023
- ❖ **Manufacturer optimized and compatible** structure
- ❖ Multi-project wafer service: **rapid prototyping**, cost effective
- ❖ Supported wavelengths 940nm and 532nm

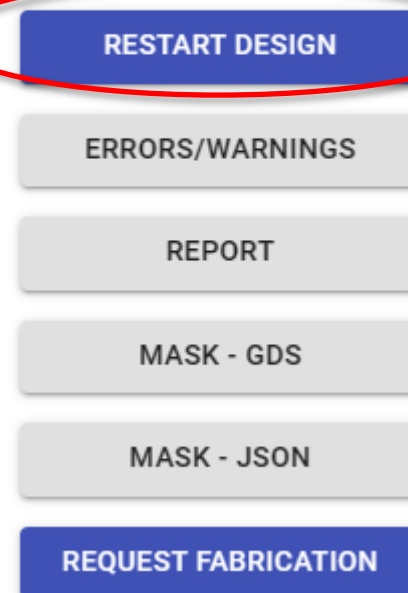


Step 1: select PDK and optical target



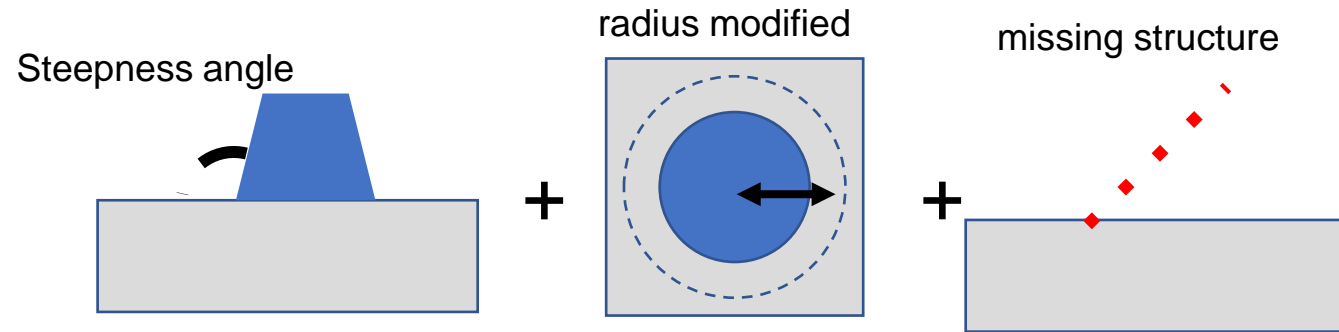
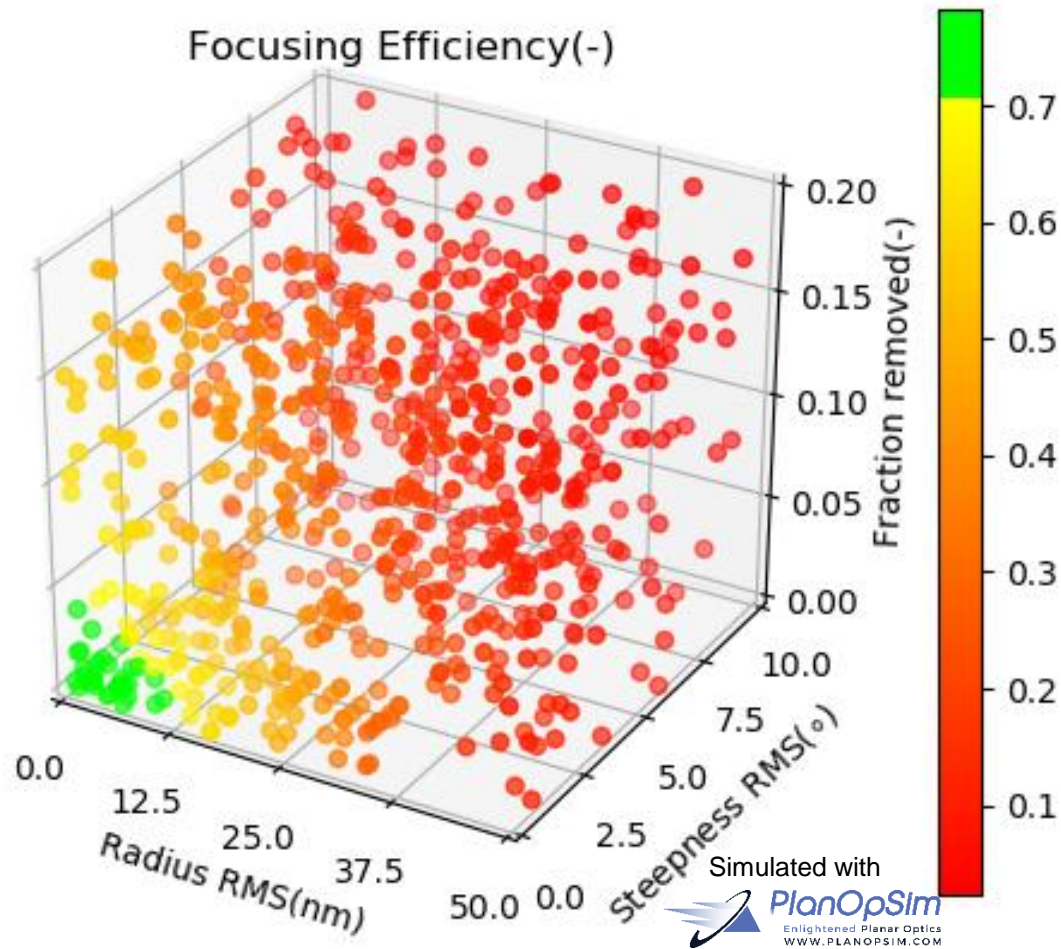
Step 2: run design

02/11/2023 14:29:46 - DC

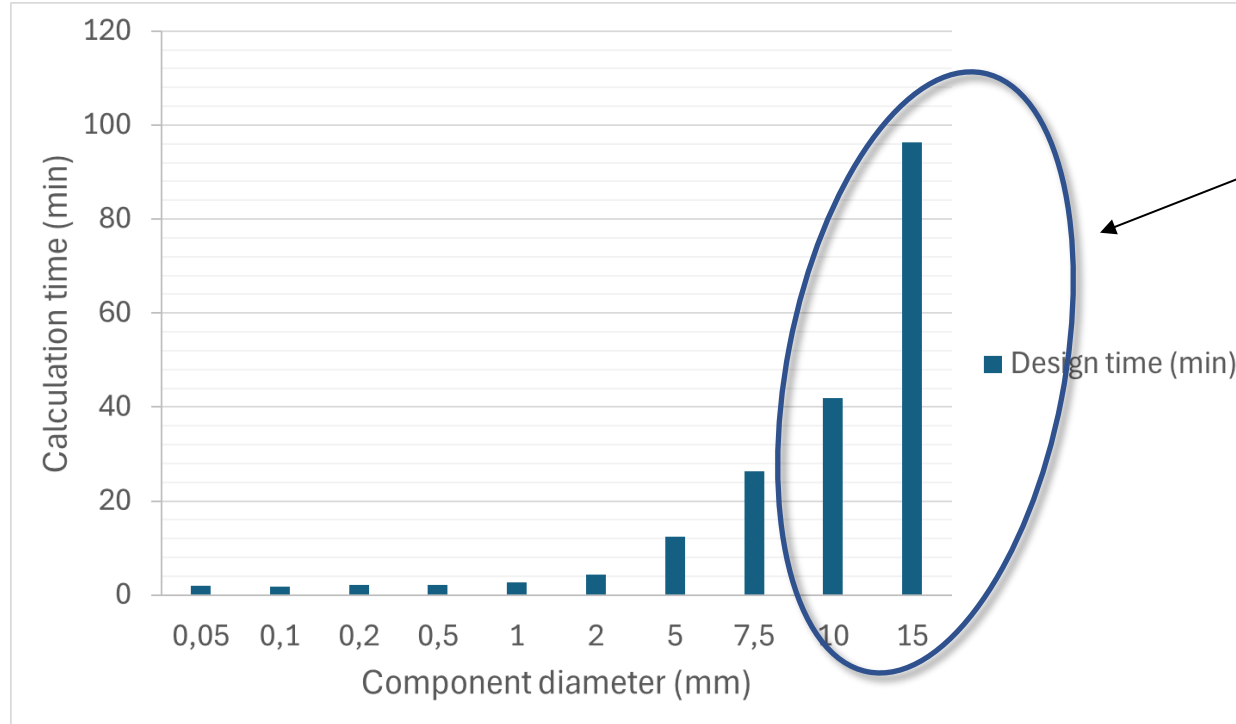


Step 3: submit design

A 'Request Fabrication' form with the following fields: '#Pieces\*' (50), 'Email\*' (lieven.penninck@planopsim.com), 'Expected Delivery\*' (in 3 months), and 'Comments' (Extra information or comments). At the bottom, there is a blue button labeled 'ASK FOR A QUOTATION' (circled in red) with a sub-link 'Talk to an expert'.



- ❖ Most designs work with nominal structure
- ❖ Effect of manufacturing error
  - Monte Carlo 25'230 metalenses simulated in this plot
  - Systematic errors can be compensated in design
- ❖ Integrate DFM into design process
  - Needs to be integrated into an out-of-the box solution



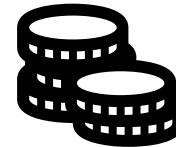
Up to cm scale in practical design times



Rapid iteration

Faster design times for larger areas

Up to **22'500x** larger

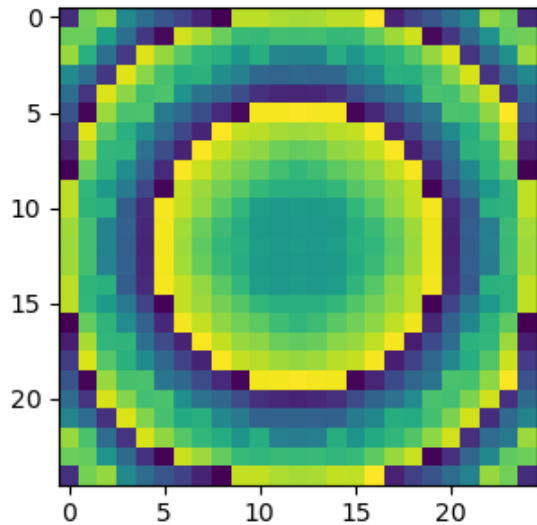


Reduced development cost

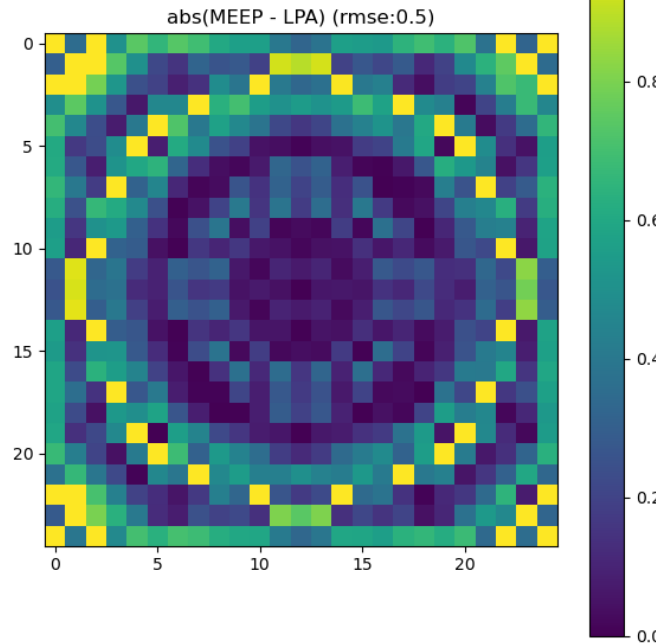
Cheaper R&D cycles

Design iteration in **1h**

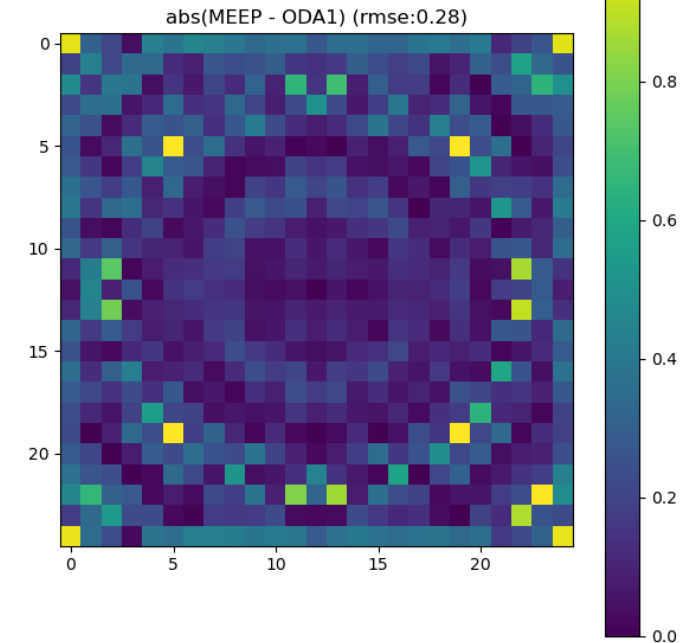
## Full wave 'ground truth'



## LPA error map



## ODA error map

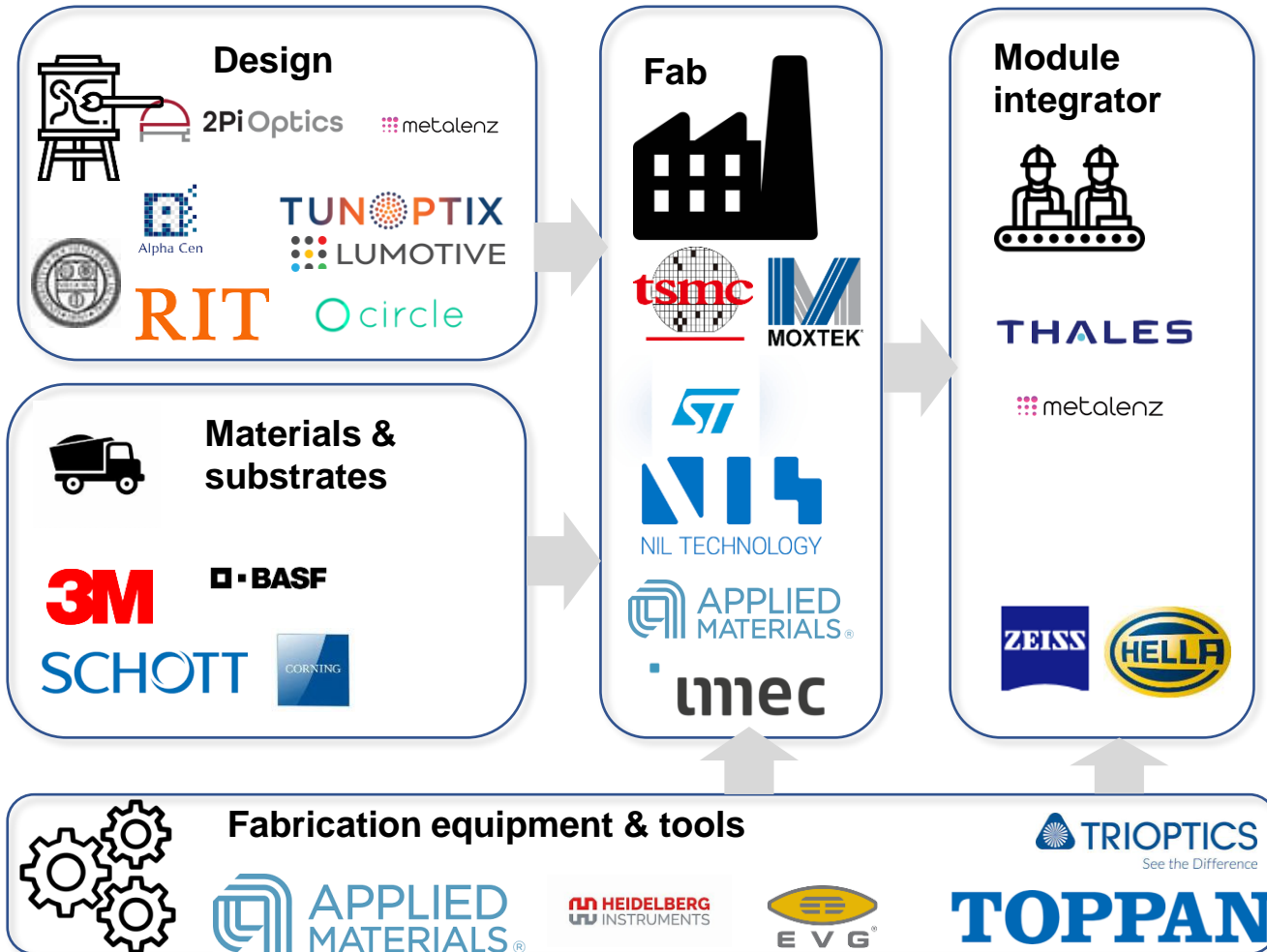


There are fast & approximative methods, there are slow & accurate methods. **We need fast & accurate methods!**

	Calculation time*	Memory usage	rmse	Max. diameter*
LPA	1 minute	<1Gb	0,5	6000 $\mu\text{m}$
ODA	20 minutes	8Gb	0,28	120 $\mu\text{m}$ **
Full wave (meep)	6 hours	32Gb		10 $\mu\text{m}$

\*10 $\mu\text{m}$  diameter metalens  
Core i9, 64Gb RAM PC  
\*\* Time limited to 24h  
calculation

## PlanOpSim Meta-surfaces challenges & opportunities



- ❖ Technology needs an eco-system
- ❖ Looking for partners on:
  - Enable new applications: reduce NRE and prototyping cost
  - Design & integration methods
  - Design for manufacture + QA



Contact us to discuss your application!

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