

# Optical and Manufacturing Design Aware Flow for Metalenses

Dr. Maryvonne Chalony

EPIC Technology Meeting, April the 8<sup>th</sup> , Paris

# Legal Disclosure

## **CONFIDENTIAL INFORMATION**

The information contained in this presentation is the confidential and proprietary information of Synopsys. You are not permitted to disseminate or use any of the information provided to you in this presentation outside of Synopsys without prior written authorization.

## **IMPORTANT NOTICE**

This presentation may include information related to Synopsys' future product or business plans. Such plans are as of the date of this presentation and subject to change. Synopsys is not obligated to update this presentation or develop the products with the features and/or functionality discussed in this presentation. Additionally, Synopsys' products and services may only be offered and purchased pursuant to an authorized quote and purchase order or a mutually agreed upon written contract.

## **FORWARD LOOKING STATEMENTS**

This presentation may include certain statements including, but not limited to, Synopsys' financial targets, expectations and objectives; business and market outlook, business opportunities, strategies and technological trends; and more. These statements are made only as of the date hereof and subject to change. Actual results or events could differ materially from those anticipated in such statements due to a number of factors. Synopsys undertakes no duty to, and does not intend to, update any statement in this presentation, whether as a result of new information, future events or otherwise, unless required by law.

# Outline

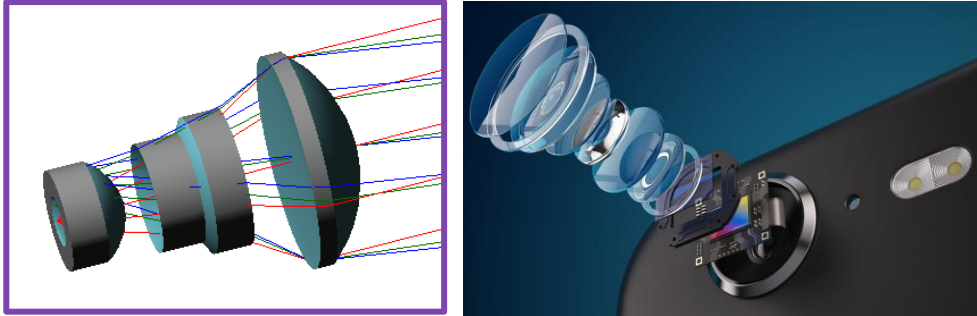
- Introduction
- Design flow for metasurfaces
  - Inverse Design of Metalens/Metasurface
  - Co-Design of Hybrid MetaOptic Systems
- Manufacturing impact on metasurfaces
- Conclusion

# Introduction

## Conventional lens

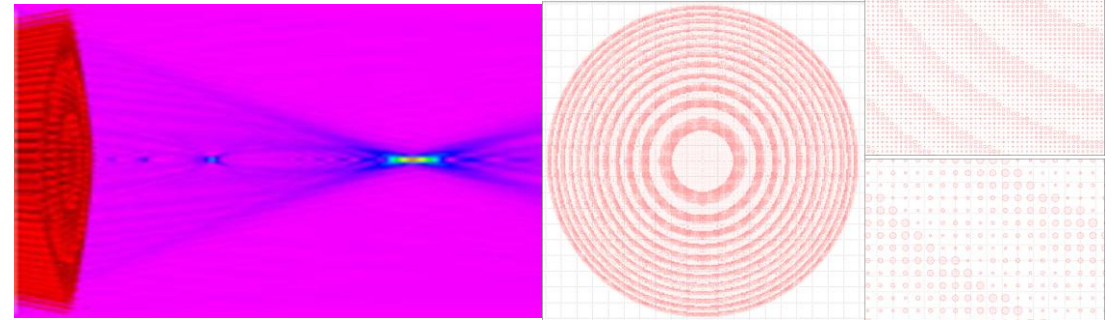
VS

## Metalens

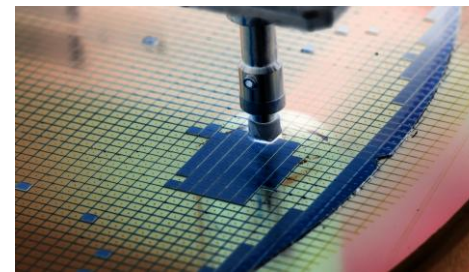


- Vary shape and material.
- Requires accurate shape control.

Metalens has the potential to be a powerful new tool for Optical Engineers!



- Subwavelength nanostructure
- Control transmission, phase, and polarization
- Manufacturing in foundry, potentially offers:

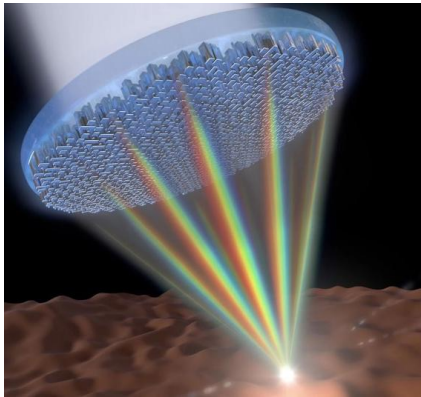


- ✓ Tolerance control
- ✓ Integration with sensor
- ✓ Reduced cost, especially for small lenses

# Metalens Applications

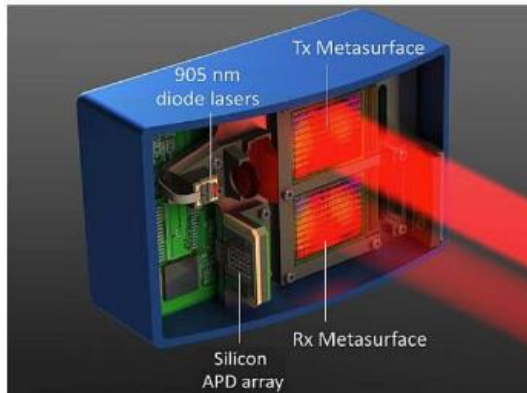
Metalenses can be used in many different application areas

Imaging metalens  
for cellphone camera



<https://www.nbcnews.com/mach/science/metalens-breakthrough-may-bring-revolution-camera-design-ncna834361>

Active metasurface for  
beam-steering on LIDAR



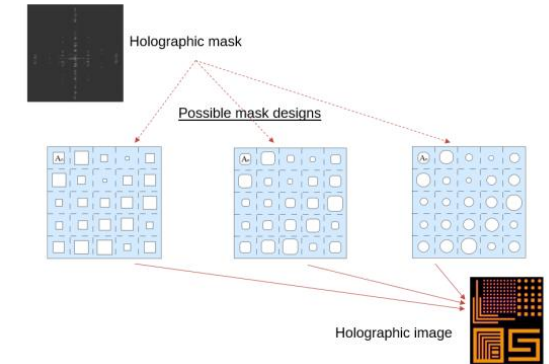
['Holy grail' of LiDAR leverages beam-steering metasurfaces ... \(eenewseurope.com\)](https://www.eenewseurope.com/news/2020/03/20/holy-grail-of-lidar-leverages-beam-steering-metasurfaces/)

Metaform combiner  
for AR application



<https://www.freethink.com/hard-tech/ar-optics>  
<https://www.nature.com/articles/s41467-020-15972-9>

Holographic mask  
for lithography

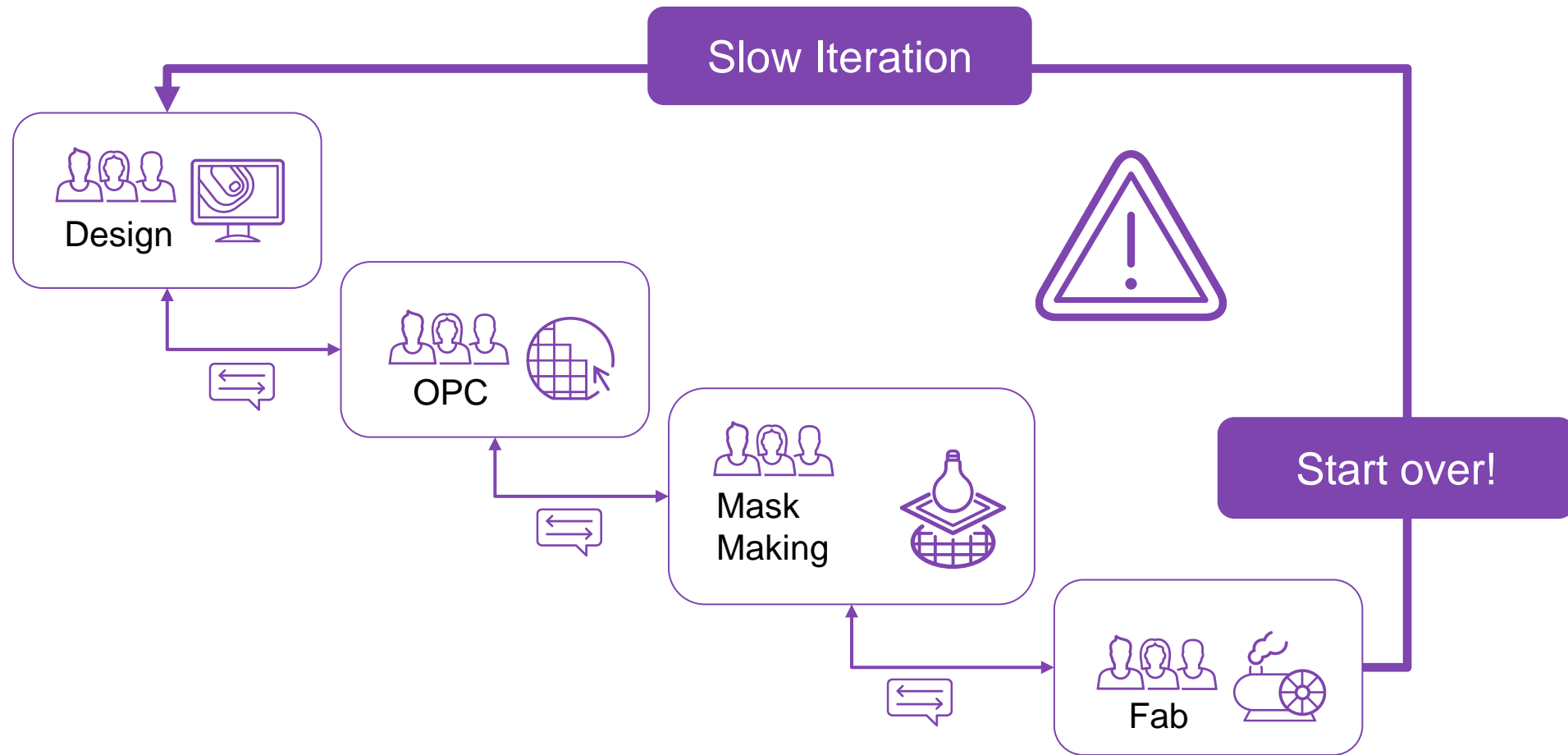


*Borisov, D. Chelubeev, V. Chernik, V. Rakhovskiy, A. Shamaev, "Subwavelength holographic lithography (SWHL)," Proc. SPIE 11324, Novel Patterning Technologies for Semiconductors, MEMS/NEMS and MOEMS 2020, 1132417 (23 March 2020); doi: 10.1117/12.2551936*

Designing metalenses is very challenging

# Production cycle

Time-consuming design-build-test cycles

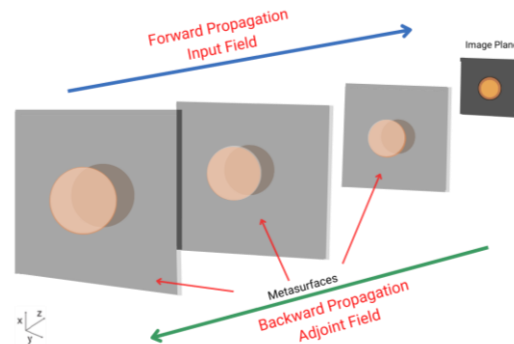
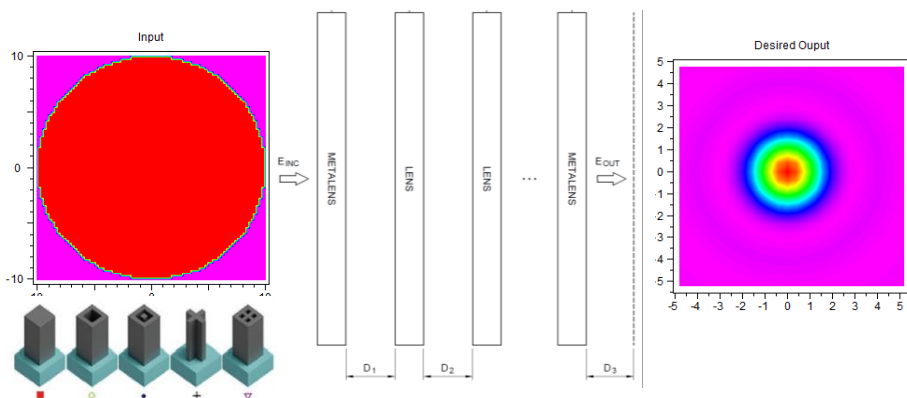


# Design flow for metasurfaces



# Wave-based Design Tool using inverse design

MetaOptic Designer automatically generates metalens/metasurface layouts, RSoft CAD files for simulation, and GDS/Oasis files for fabrication.



*Bos, J., Scarmozzino, R., Bahl, M., Heller, E., Xu, C., "A Design Automation and Simulation Flow for Lens Systems Containing Multiple Metasurfaces," META, July 2022, Torremolinos Spain.*

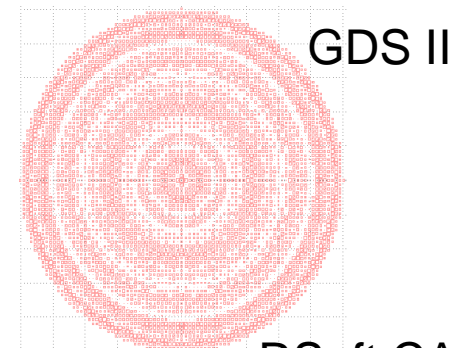
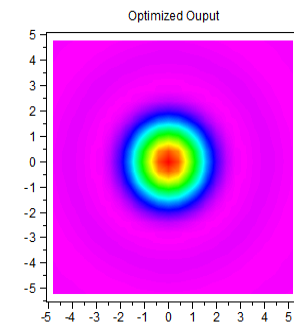
## Features:

- Efficient inverse design
- Accurate – validated, numerically and experimentally

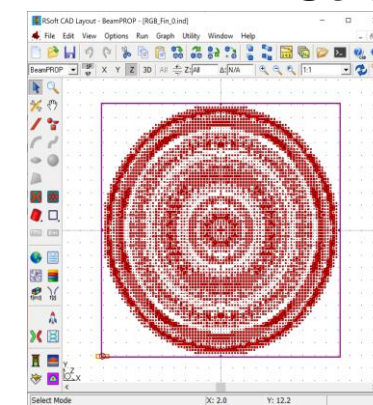
## Benefits:

- Reduces the level of knowledge and expertise required of users
- Shortens design cycle

Optimized Results

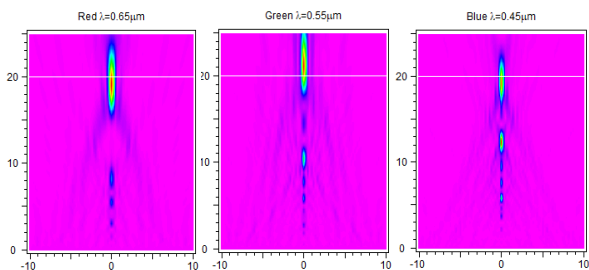
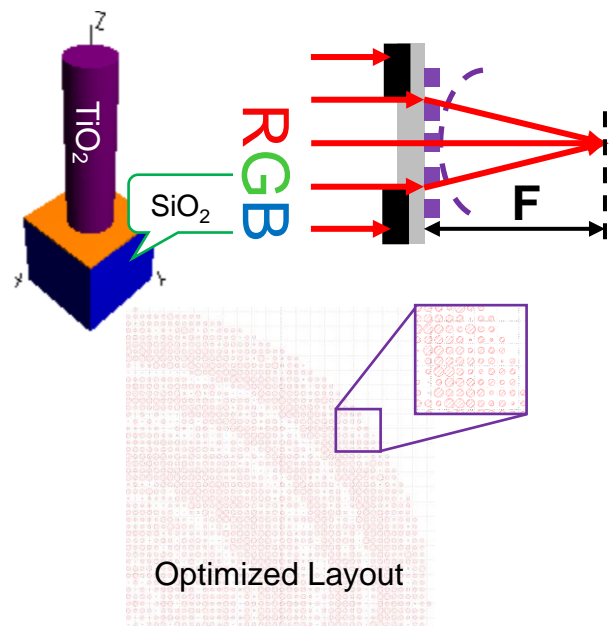


RSoft CAD

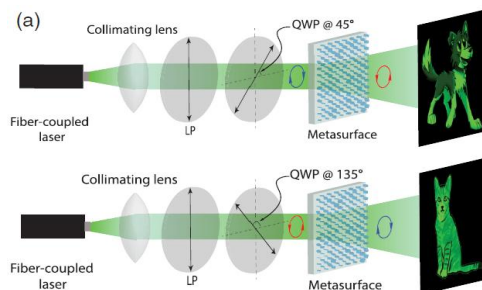


# Design cases

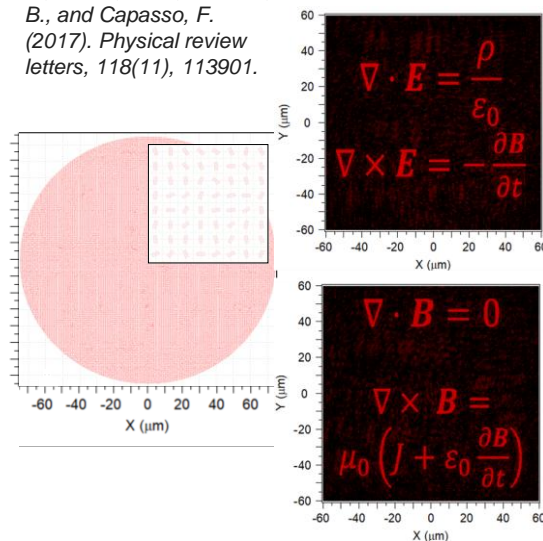
- Achromatic Metalens



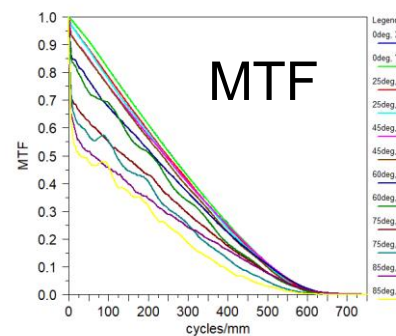
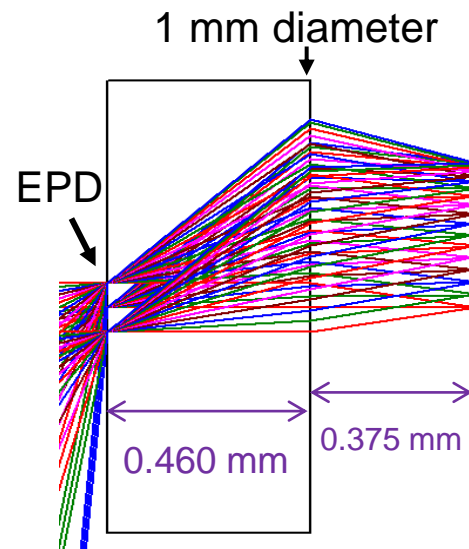
- Polarization Sensitive Hologram



Mueller, J. B., Rubin, N. A., Devlin, R. C., Groever, B., and Capasso, F. (2017). *Physical review letters*, 118(11), 113901.

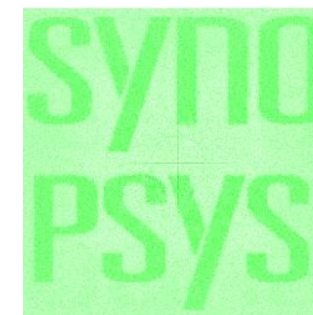


- Ultra-Wide angle metalens



- Holographic display (farfield optimization)

Simulation



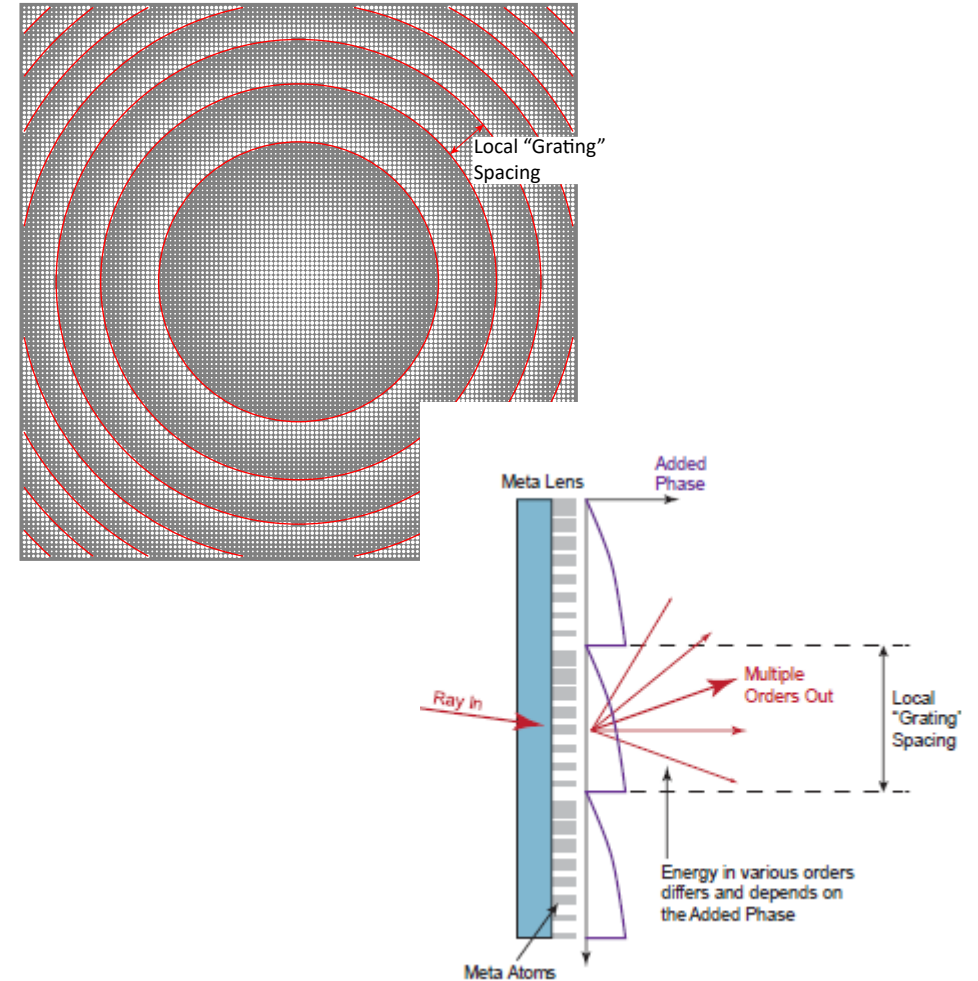
Measurement



H. L. Liu, T. K. Yang, and P. Yu, "Design and Fabrication of Meta-Optical Elements for Beam Shaping," *META 2024, Toyama, Japan, July 2024*

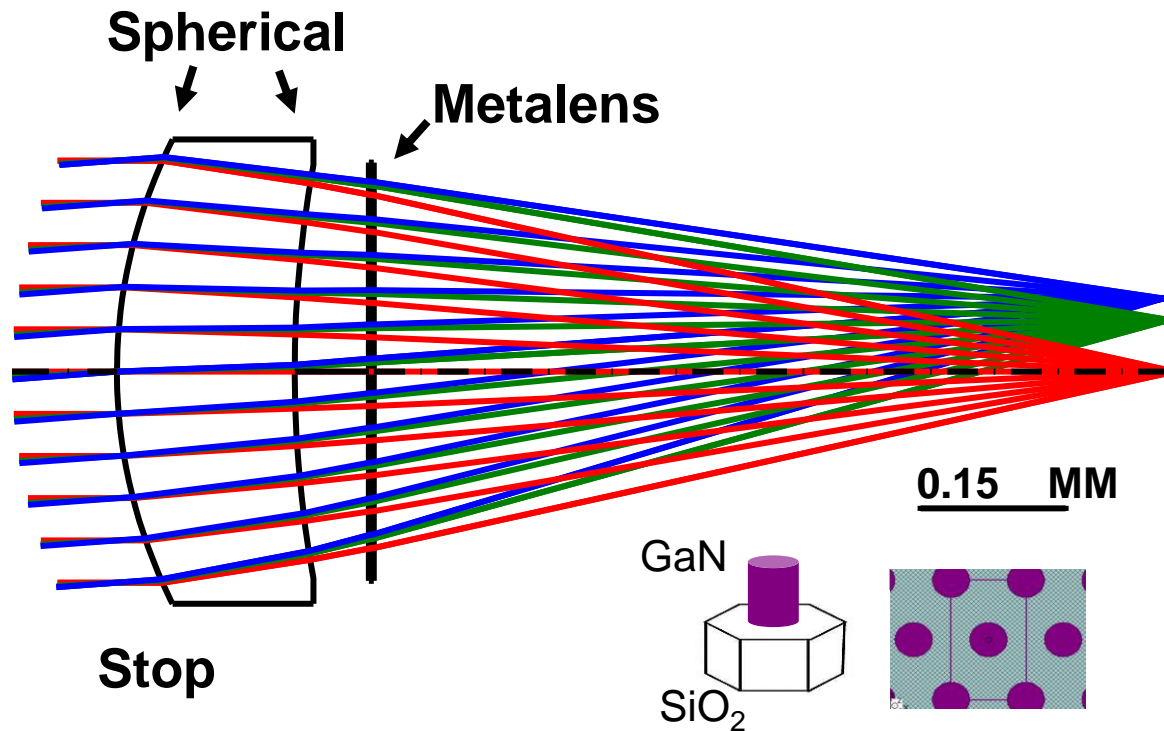
# Ray-Based Design Tool

- Ray directions of the various “diffracted” orders
  - Discontinuities in the meta-atom parameter(s)
- Energy in each “diffracted” order
  - Estimated from the meta-atom parameter arrangement within a period
  - Meta-atom transfer function is computed from RCWA or FDTD over a range of incident angles and wavelengths.



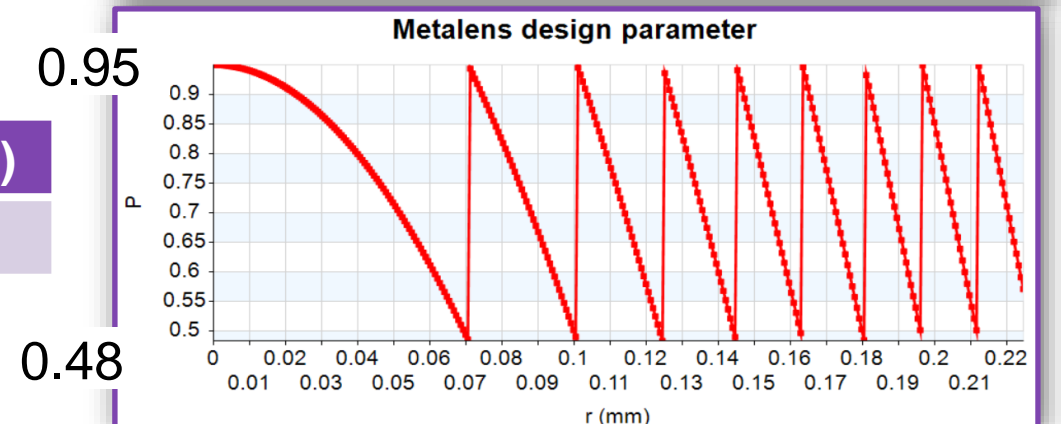
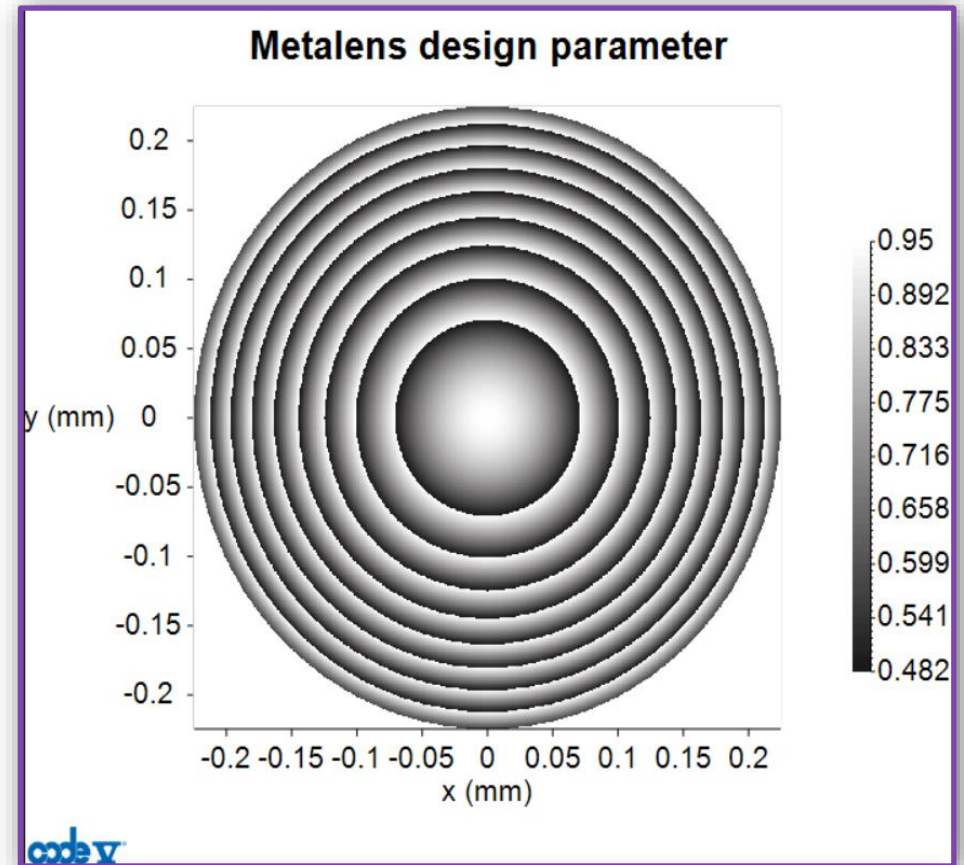
Stone, B. D., and Ding, Y., “Foundations for ray-based design of metalenses,” presented at IOBC 2023, Quebec City, Canada.

# Hybrid Refractive-Metalens System



EPD (mm)	EFL (mm)	WL (nm)	Field (degs)
0.5	2	(470,532,650)	(0, 3.5, 5)

Yijun Ding, Bryan D. Stone, "Validation of a ray-based tool for metalens design and analysis," Proc. SPIE 12798, International Optical Design Conference 2023, 1279807

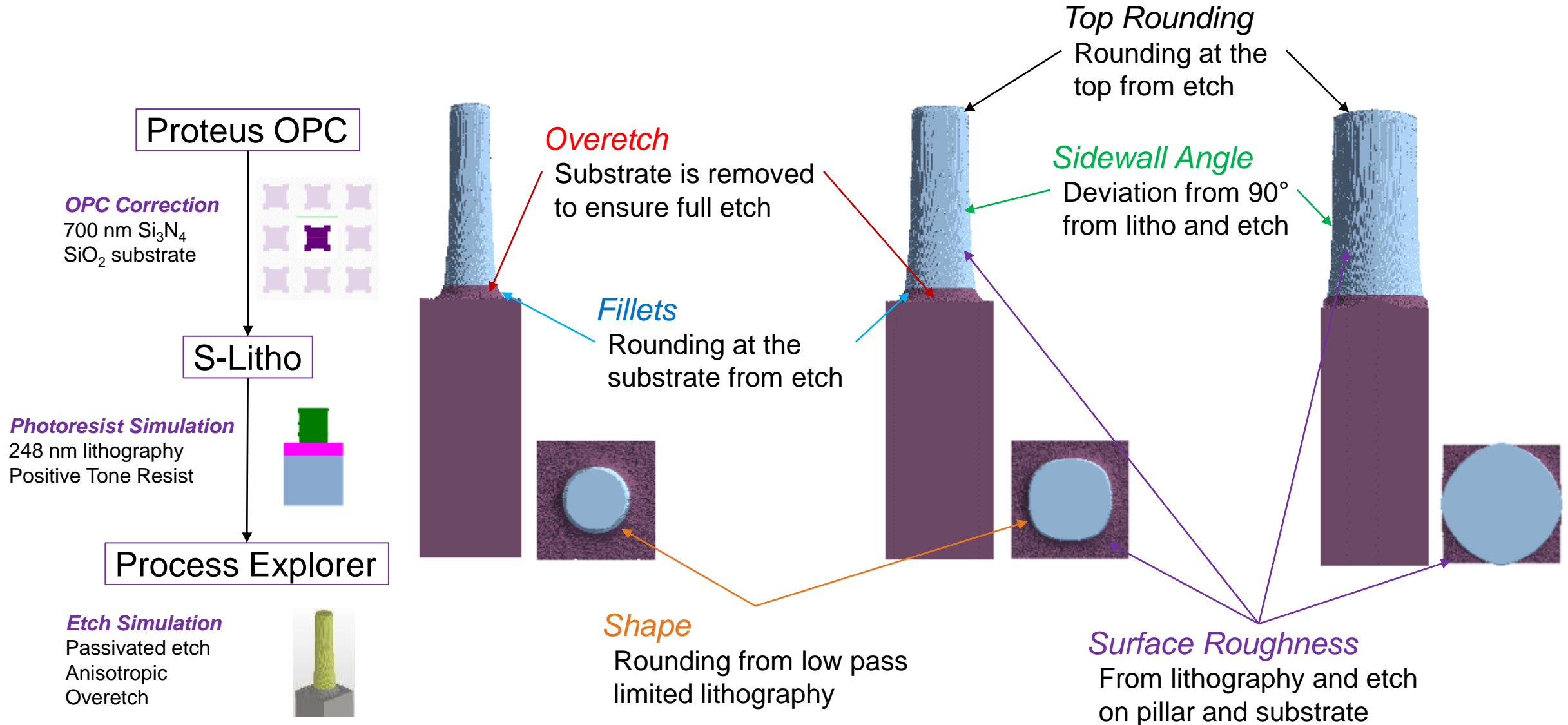


# Manufacturing impact on metasurface



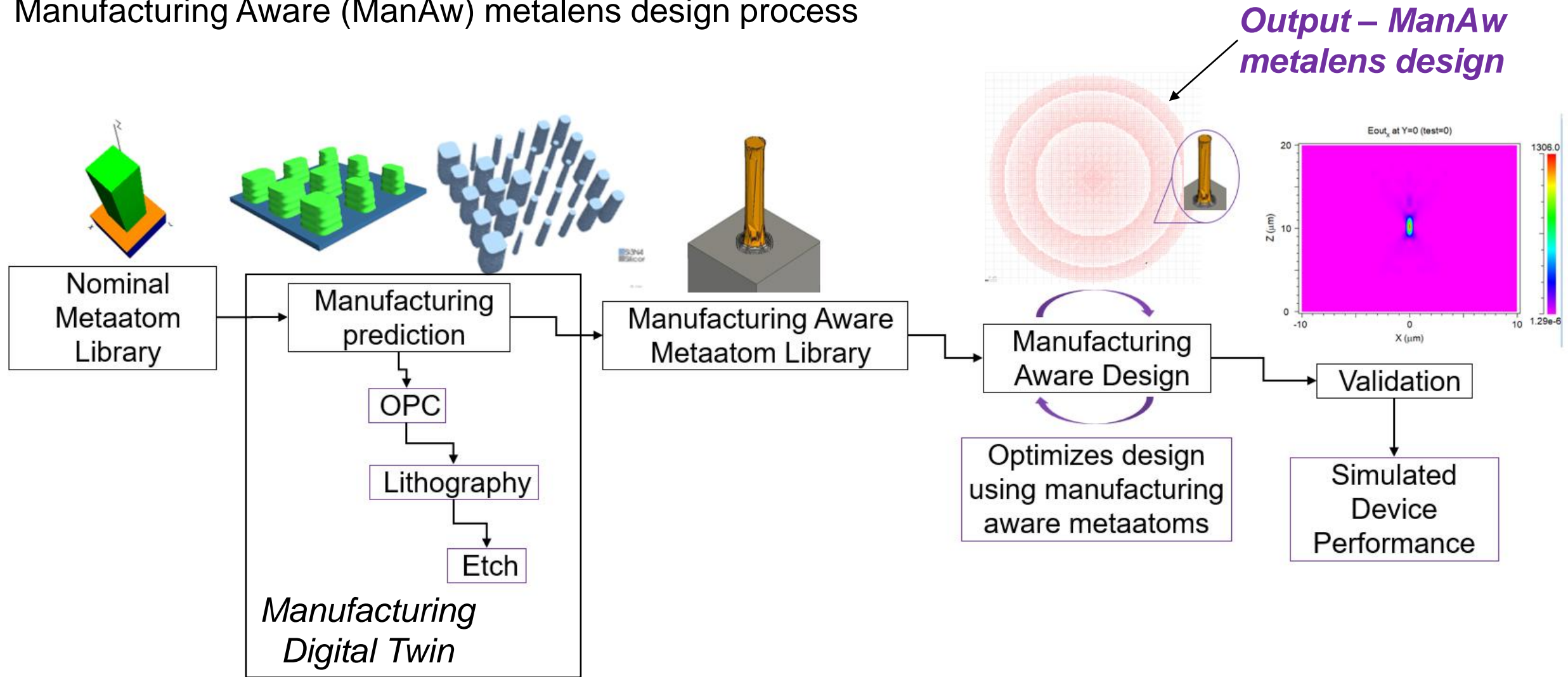
# Manufacturing Impact on MetaAtoms

Manufactured MA are never shaped like in the ideal design



# Virtual Fab workflow

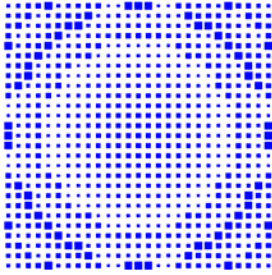
Manufacturing Aware (ManAw) metalens design process



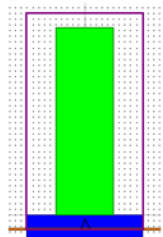
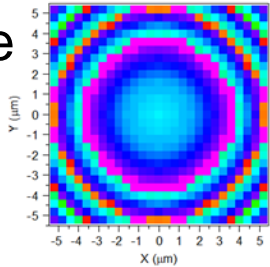
Used to optimize a metalens design to a manufacturing process → Manufacturing Aware (ManAw)

# Why the perfect metaatom may not need to exist

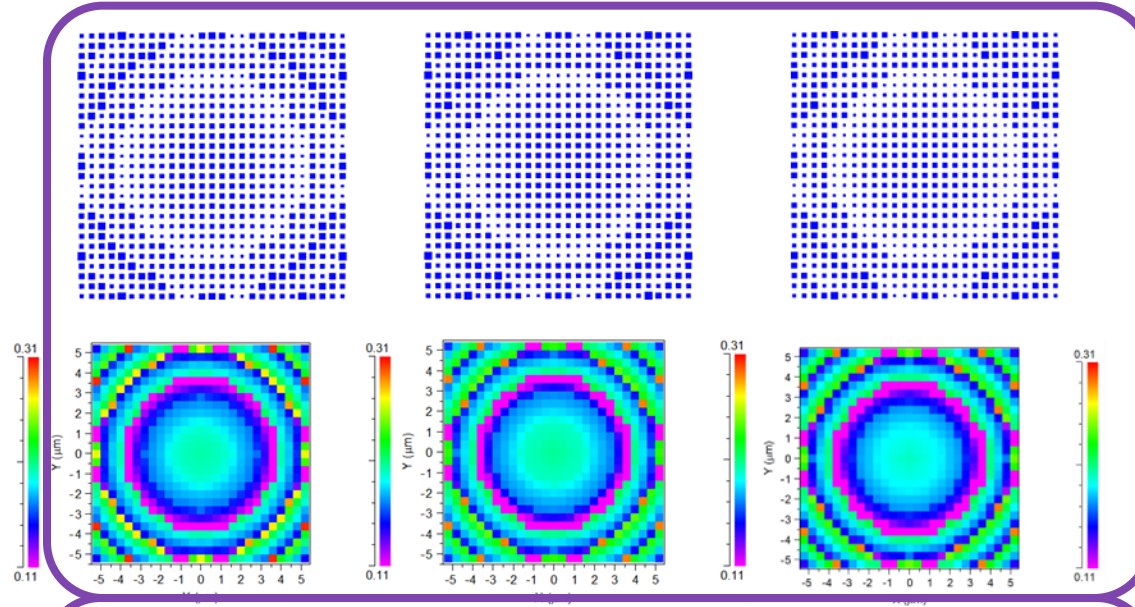
Designed GDS using ideal metaatoms



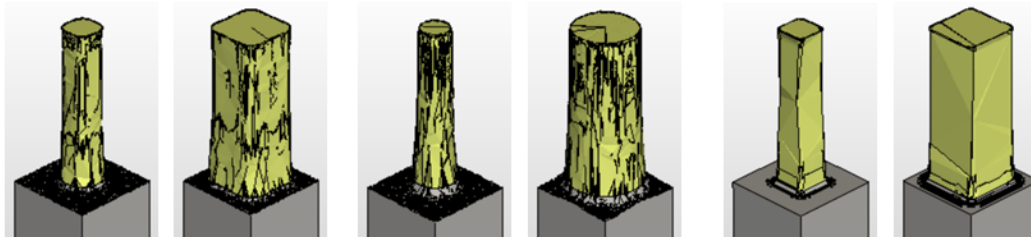
Color = pillar size



Ideal



Modified GDS using manufacturing-aware metaatoms



193 nm

248 nm

e-beam

Manufacture

Design

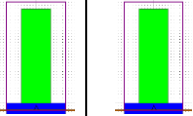
Verify

L. S. Melvin III, M. Chalony, A. M.C. Dawes, B. Kuechler, R. Zimmermann, E. Viasnoff, Y. Zhou, A. Blais, "Metalens manufacturing complexities and costs," *Proc. SPIE* 12958, 129580A (9 April 2024) <https://doi.org/10.1117/12.3010491>



# Manufacturing Aware Design for Two Scanner Processes

Metalens Manufactured on 193 nm and 248 nm achieve similar simulated results

Focal distance	107 $\mu$ m	<b>Ideal</b> (range 110-340nm)/ 400 nm pitch							
Diameter	150 $\mu$ m								
F/# (N.A.)	0.7(0.7)								
$\lambda$	445 nm								
<b>Pout/Pin</b>		86.9%							
<b>Overlap</b> Overlap( Eout , Edes )^2		91.4%							
<b>AFE</b>		75.6%							
<b>Fidelity loss</b>		-							
<b>Design/Simulation</b>									

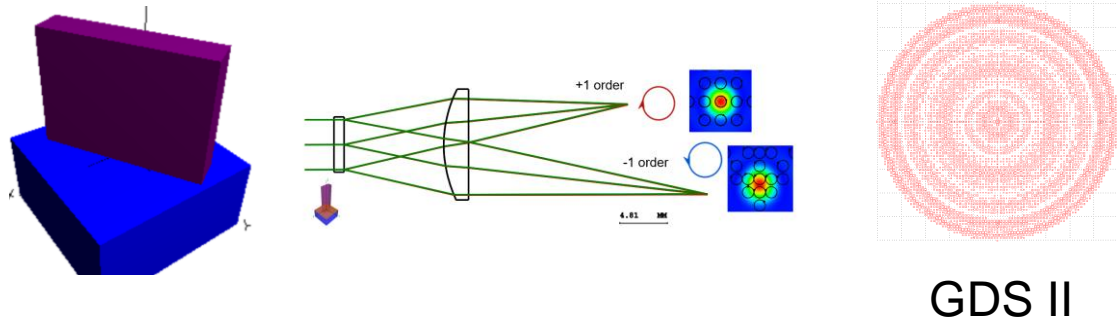
193 nm process uses a hard mask, 248 does not. (Extra processing steps)

Optimized manufacturing aware metalenses designs achieve similar results using vastly different fabrication technology

# First Time Right: Virtual Design and Manufacturing Flow

Reduce time to market by bringing manufacturing data to optical design.

## Design

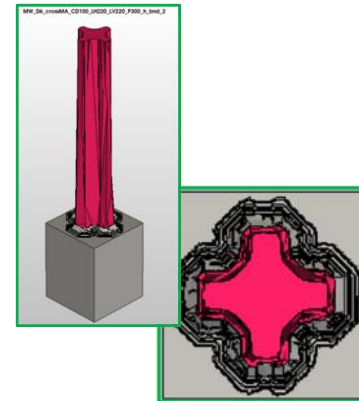


Optimize meta-optics using inverse design technique and/or ray-based design tools.

Process Aware Library

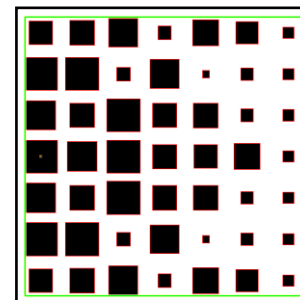
(MetaOptic Designer, RSoft Photonic Device Tools)  
(CodeV MOD add-On, CodeV)

## Manufacturing Prediction



### Virtual Fab: Rigorous Simulation of Process Variability and Skew

- e.g., Corner Rounding
- SideWallAngle
- Min/Max pillar size



### Lithograph- and Etch-Aware Layout Correction to print on target design

- OPC
- Retargeting

(ILT, Proteus, SMO)

**SYNOPSYS®**

Thank you