4 February 2020, Photonics West 2020

Modeling of High Contrast Metasurfaces and Their Performance in General Optical System

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Teams

LIGHTTRANS

LightTrans (since 1999)

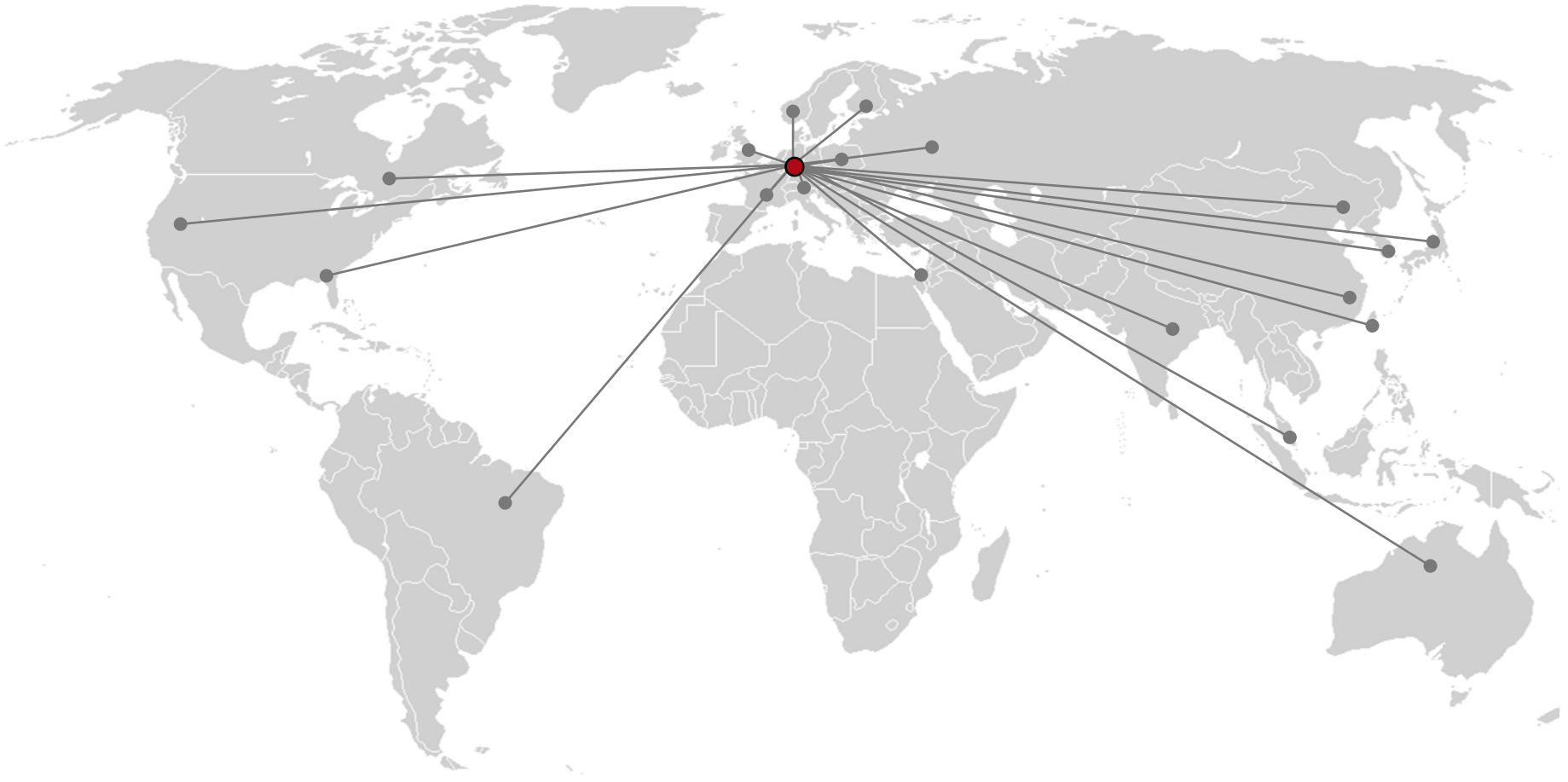
- Optical technologies development
- Technical support, seminars, and trainings
- Engineering projects
- Distribution of VirtualLab Fusion, together with distributors worldwide

WYROWSKI PHOTONICS

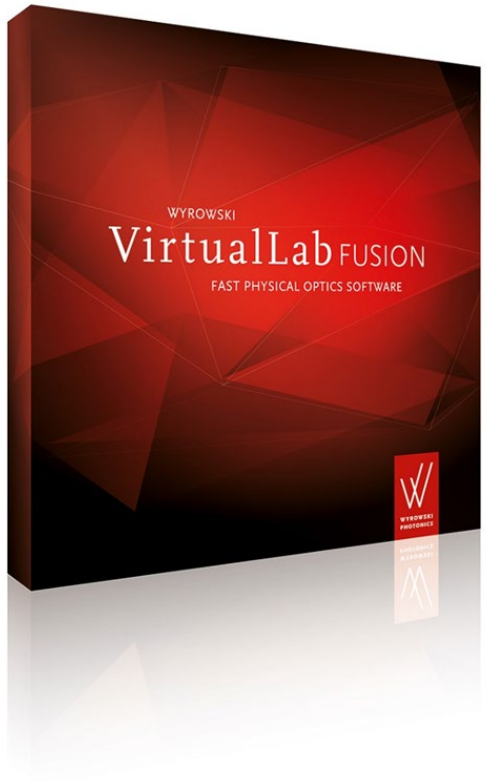
(since 2014)

photo from wikitravel

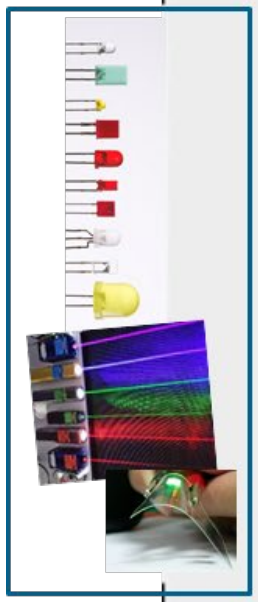
Optical Design Software and Services

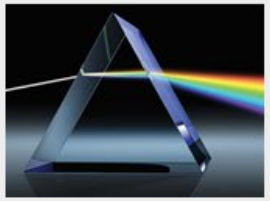


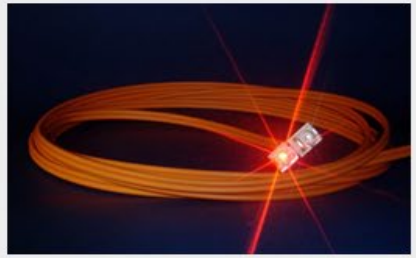
Booth #4545 (German pavilion)



Physical-Optics System Modeling





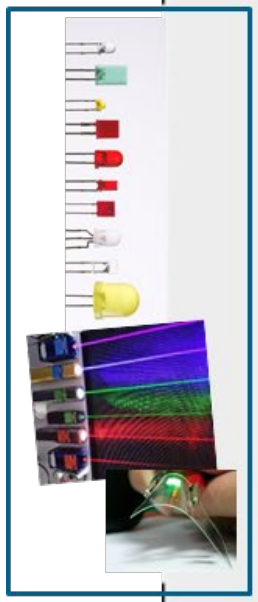


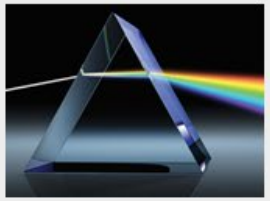
Name	Integral equations	Differential equations
Gauss's law	$\oiint_{\partial\Omega} \mathbf{E}\cdot\mathrm{d}\mathbf{S} = \frac{1}{\varepsilon_0}\iiint_{\Omega}\rho\,\mathrm{d}V$	$\nabla\cdot\mathbf{E} = \frac{\rho}{\varepsilon_0}$
Gauss's law for magnetism	$\oiint_{\partial\Omega} \mathbf{B}\cdot\mathrm{d}\mathbf{S} = 0$	$\nabla\cdot\mathbf{B} = 0$
Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial\Sigma} \mathbf{E}\cdot\mathrm{d}\boldsymbol{\ell} = -\frac{d}{dt}\iint_{\Sigma}\mathbf{B}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t}$
Ampère's circuital law (with Maxwell's addition)	$\oint_{\partial\Sigma} \mathbf{B}\cdot\mathrm{d}\boldsymbol{\ell} = \mu_0\iint_{\Sigma}\mathbf{J}\cdot\mathrm{d}\mathbf{S} + \mu_0\varepsilon_0\frac{d}{dt}\iint_{\Sigma}\mathbf{E}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times\mathbf{B} = \mu_0\left(\mathbf{J} + \varepsilon_0\frac{\partial\mathbf{E}}{\partial t}\right)$

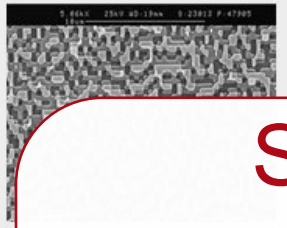
Homogeneous

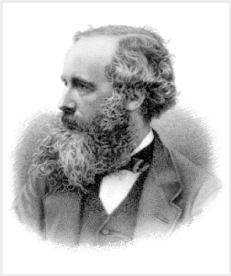
Solve Maxwell's equations for given source field and components.

Physical-Optics System Modeling









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Gauss's law	$\oiint_{\partial\Omega} \mathbf{E}\cdot\mathrm{d}\mathbf{S} = \frac{1}{\varepsilon_0}\iiint_{\Omega}\rho\,\mathrm{d}V$	∇
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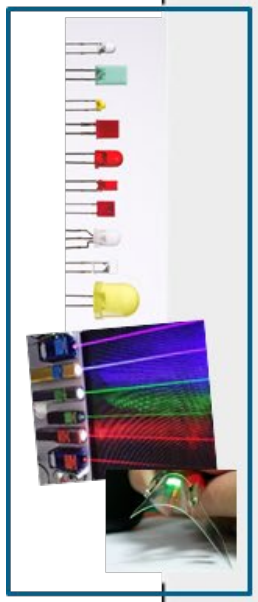
Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial\Sigma} \mathbf{E}\cdot\mathrm{d}\boldsymbol{\ell} = -\frac{d}{dt}\iint_{\Sigma}\mathbf{B}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times$
Ampère's circuital law (with Maxwell's addition)	$\oint_{\partial\Sigma} \mathbf{B}\cdot\mathrm{d}\boldsymbol{\ell} = \mu_0\iint_{\Sigma}\mathbf{J}\cdot\mathrm{d}\mathbf{S} + \mu_0\varepsilon_0\frac{d}{dt}\iint_{\Sigma}\mathbf{E}\cdot\mathrm{d}\mathbf{S}$	$\nabla\times\mathbf{B} =$

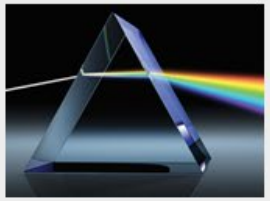
Homogen

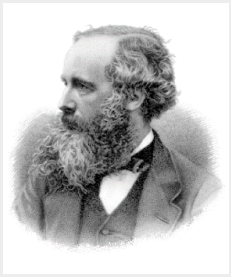
eous medium, like air or vacuum

Solution of Maxwell's equations with one field solver, e.g. FEM, FMM, or FDTD, for entire system not feasible because of numerical effort!

Physical-Optics System Modeling







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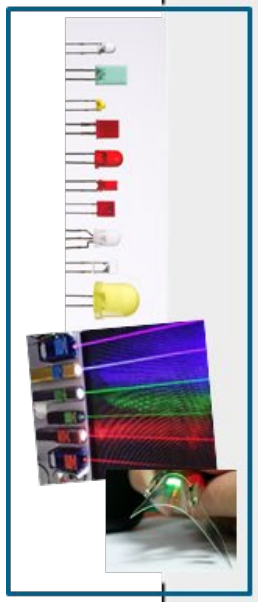
Homog

How to obtain a reliable and fast physical optics solution - whenever possible?

Connecting Optical Technologies / Maxwell Solvers



Field Solver Lenses, …

Field Solver Prisms, …

Field Solver Gratings, …

Field Solver micro- and nano-structures

Field Solver fibers, …

Homogeneous medium, like air or vacuum

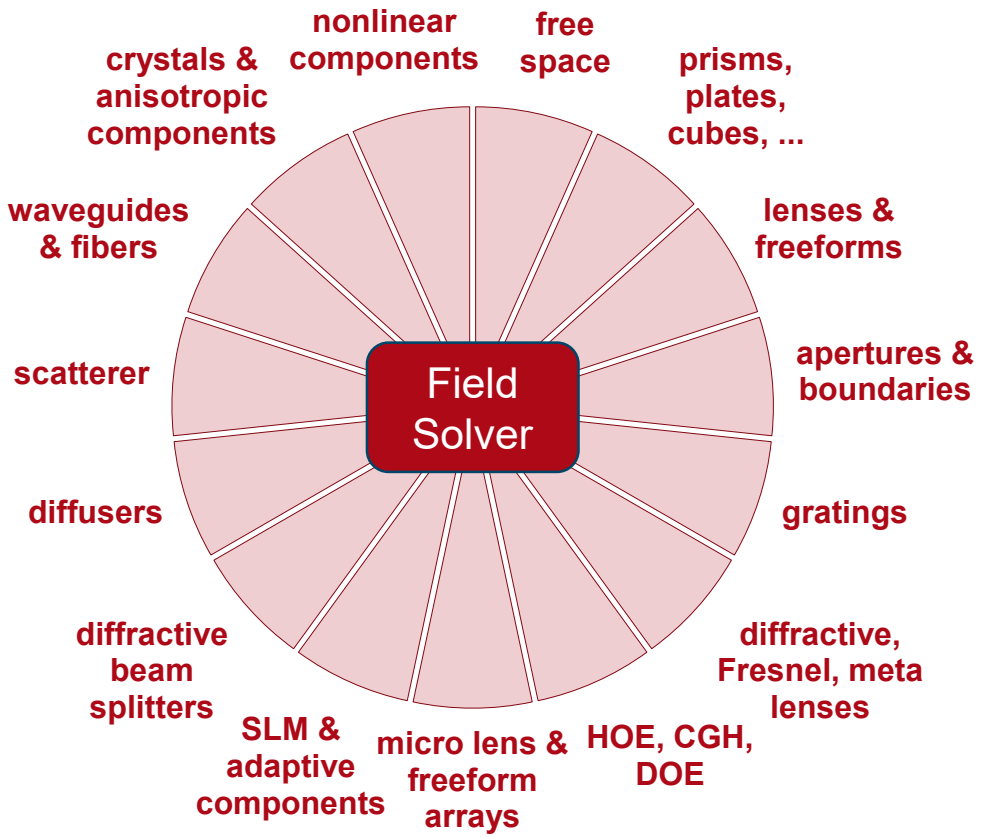
Connecting Optical Technologies / Maxwell Solvers

Problem:

Application of a single field solver, e.g. FEM or FDTD, to the entire system:
Unrealistic numerical effort

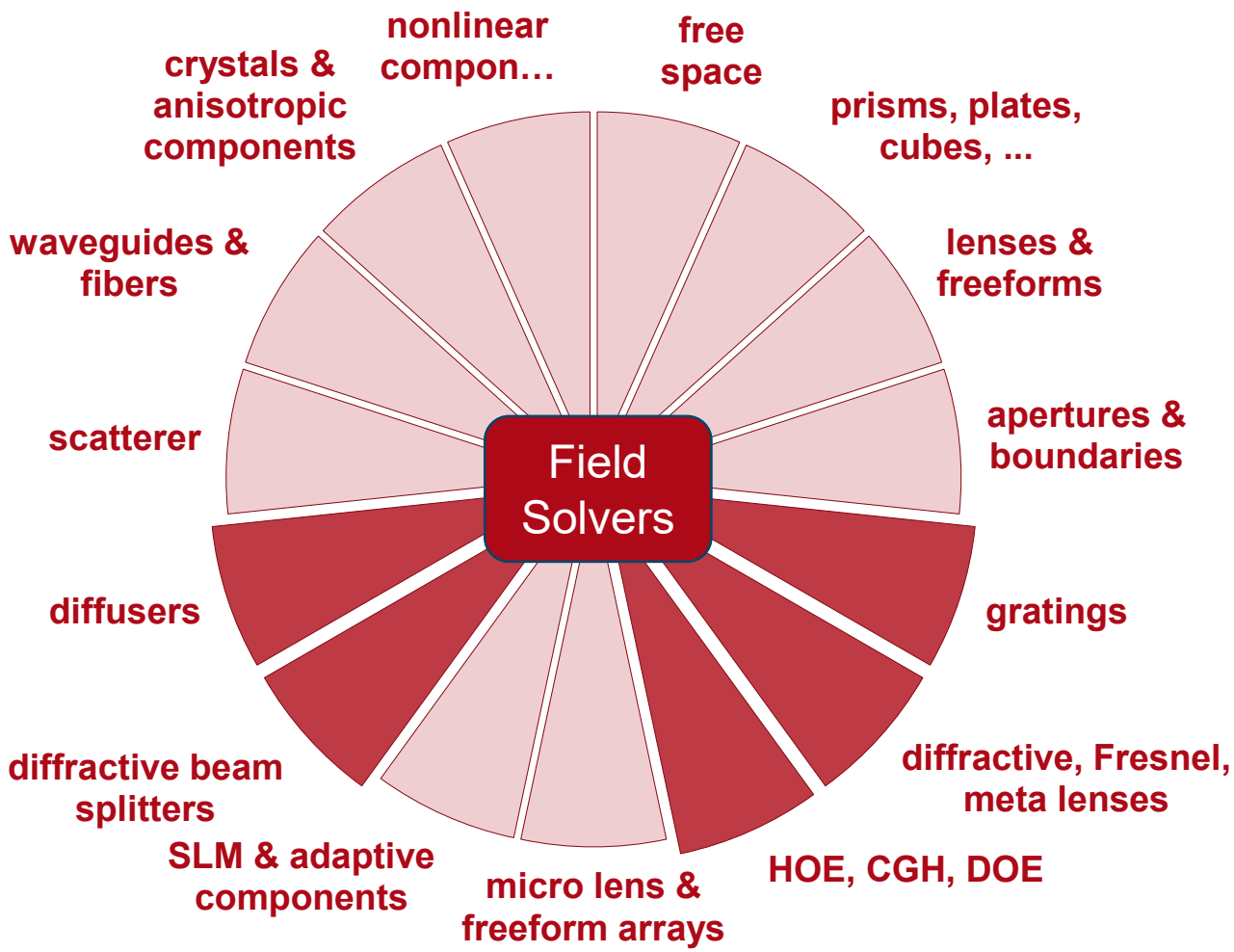
Solution:

- Decomposition of system and application of regional field solvers.
- Interconnection of different solvers and so to solve the complete system.

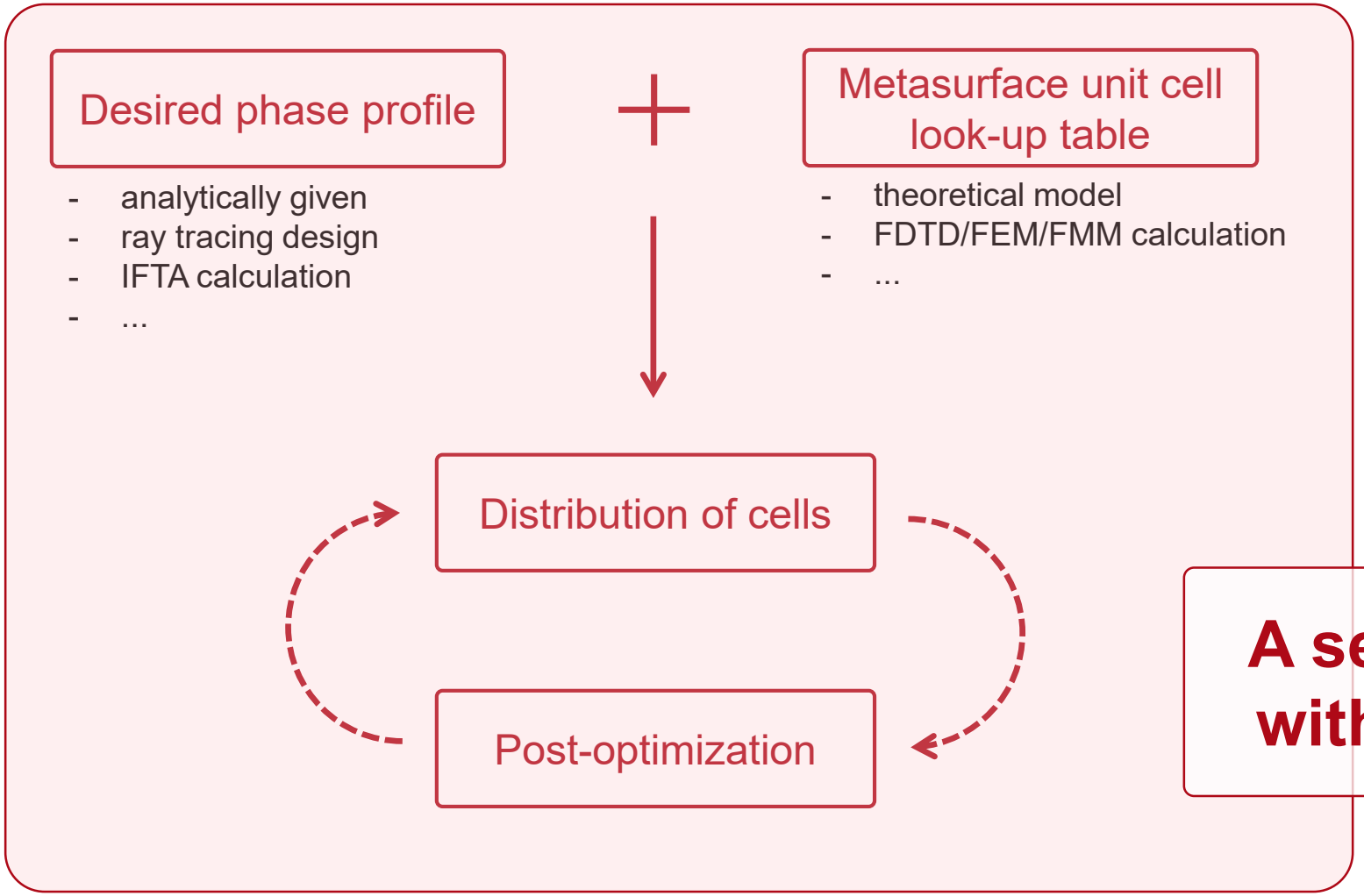


VirtualLab Fusion – Diffractive Optics Applications

Selection of VirtualLab Fusion applications for metasurfaces



General Design Procedure



State-of-the-art: exchange between several different software programms, e.g., ray tracer, FDTD solver, and Matlab ...

A seamless workflow within one platform?

Join our demo session tomorrow:
Date: Wednesday, 5 February 2020 | **13:30 – 14:45**
Location: Moscone Center West, 2nd level, **Room 2009**

Blazed Meta-Grating Composed of Square Pillars

P. Lalanne, *et al.*, "Blazed binary subwavelength gratings with efficiencies larger than those of conventional échelette gratings," Opt. Lett. 23, 1081-1083 (1998)

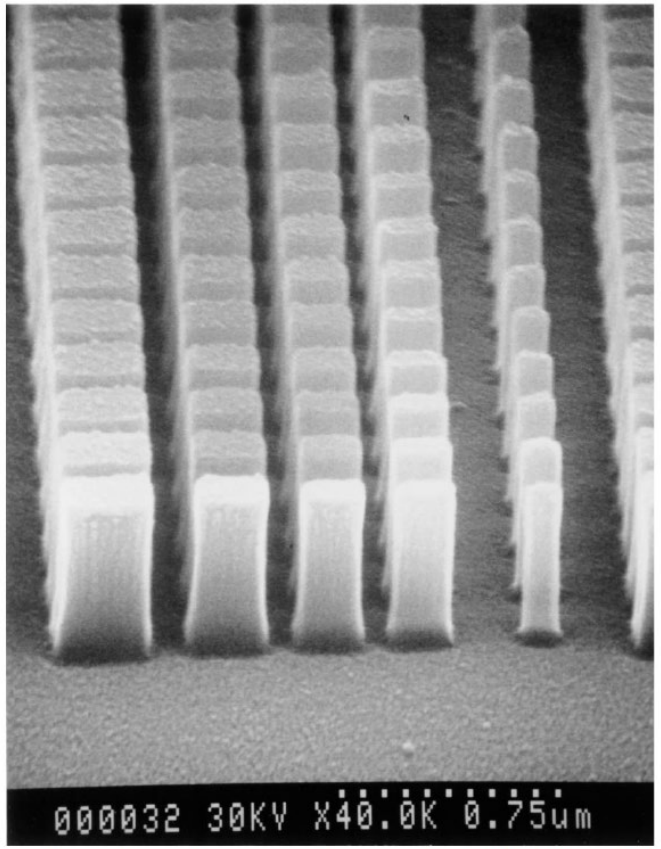
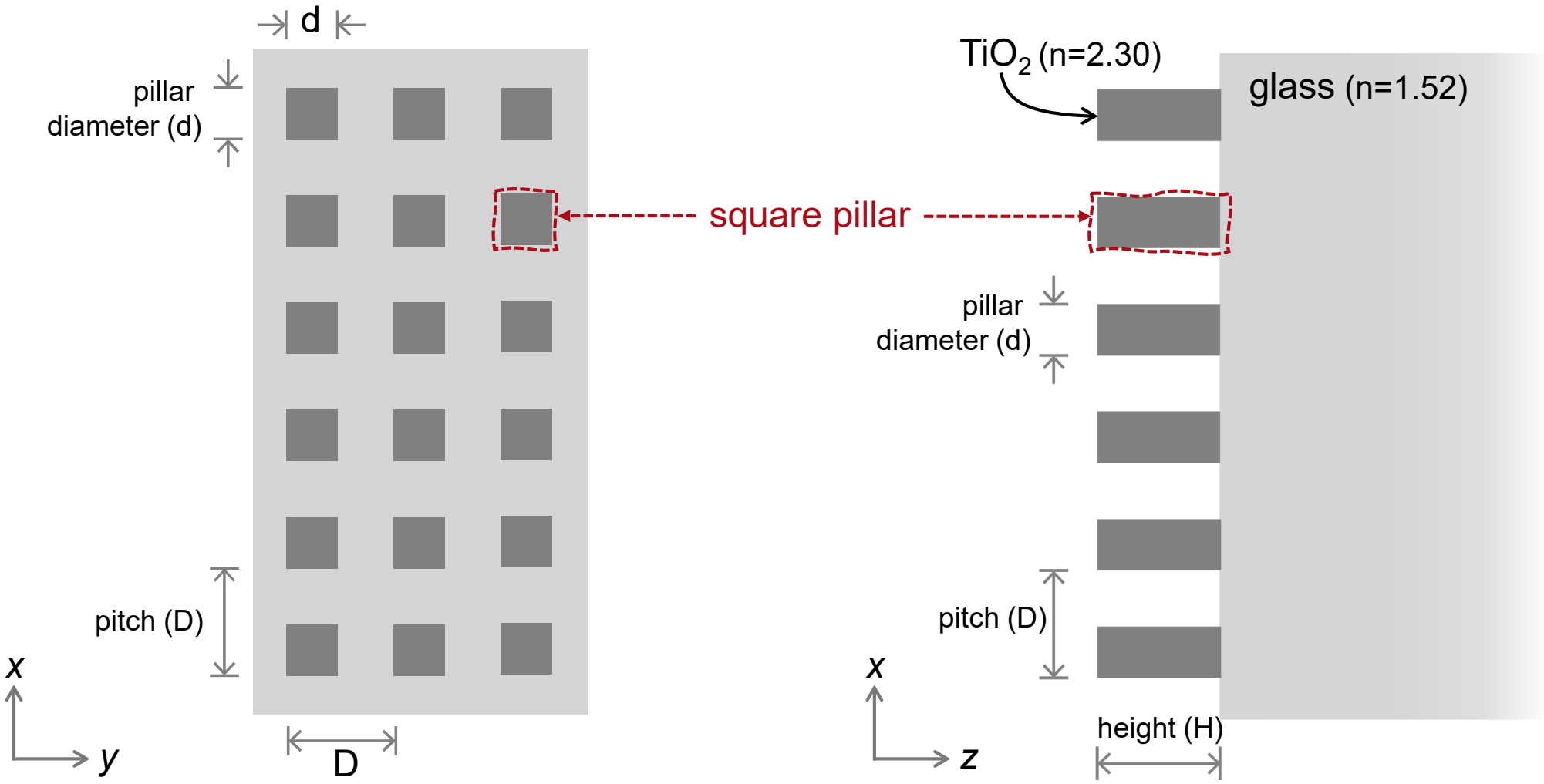


Fig. 2. Scanning-electron micrograph of the blazed binary subwavelength grating. The horizontal period (along the x axis) is 1.9 μm, and the period in the perpendicular direction (y axis) is equal to the sampling period (380 nm). The maximum pillar aspect ratio is 4.6.

Building Block / Unit Cell Analysis



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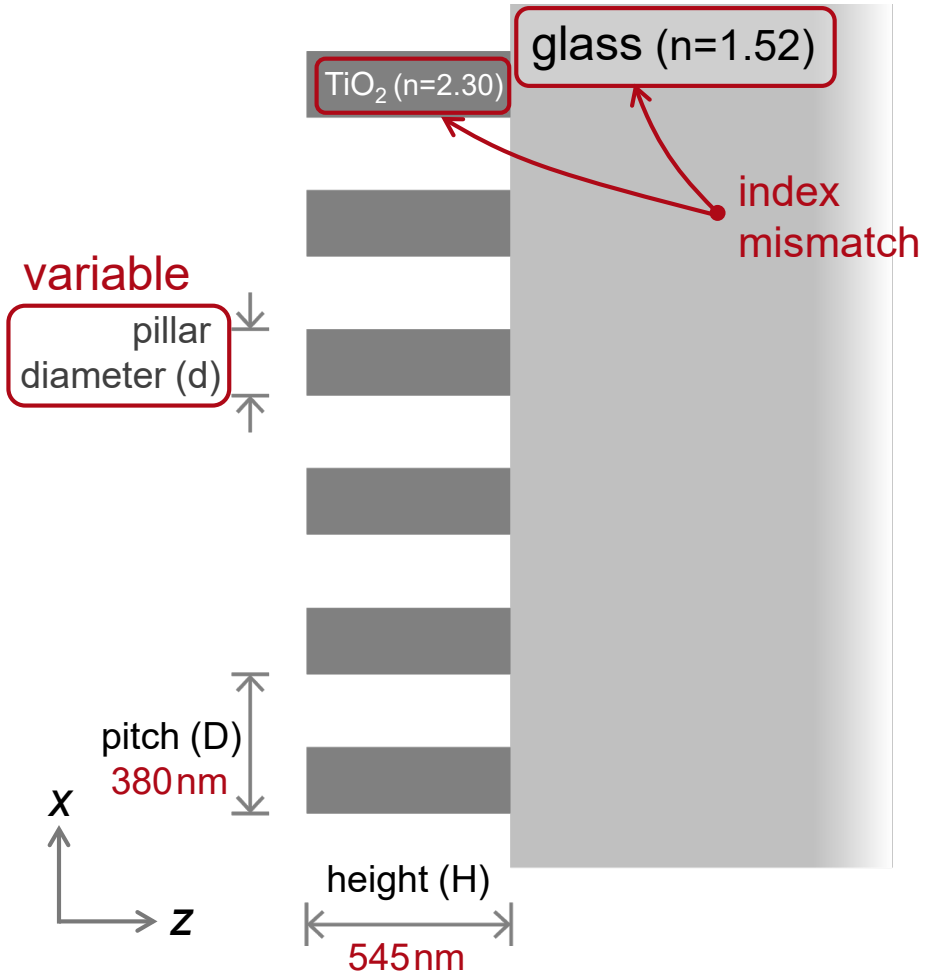
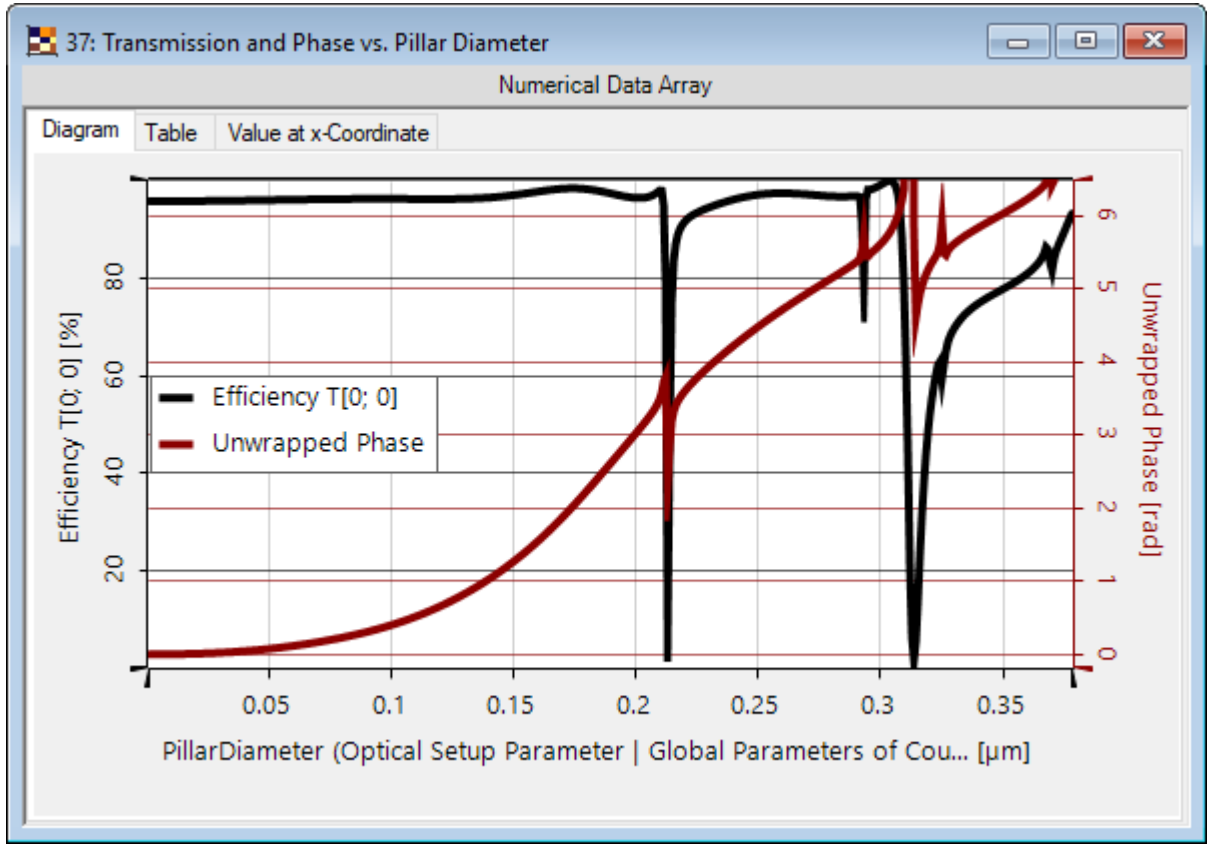
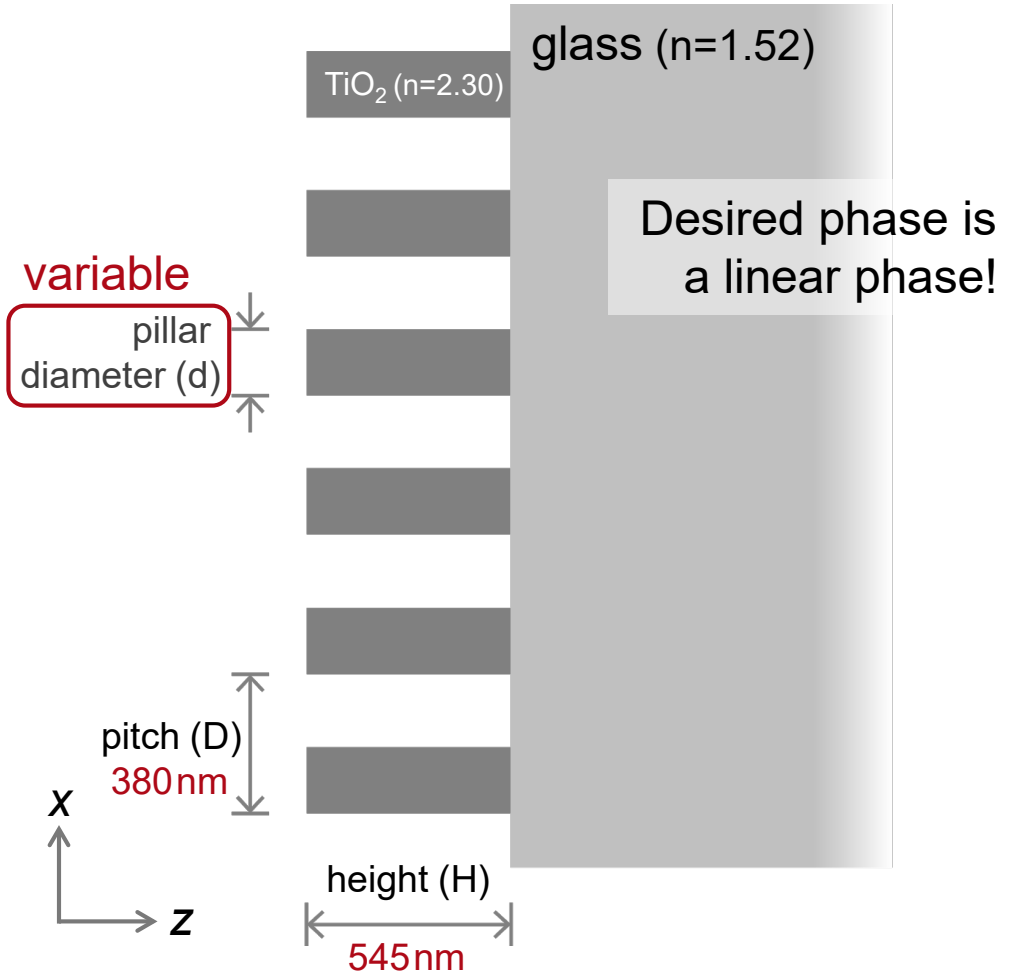
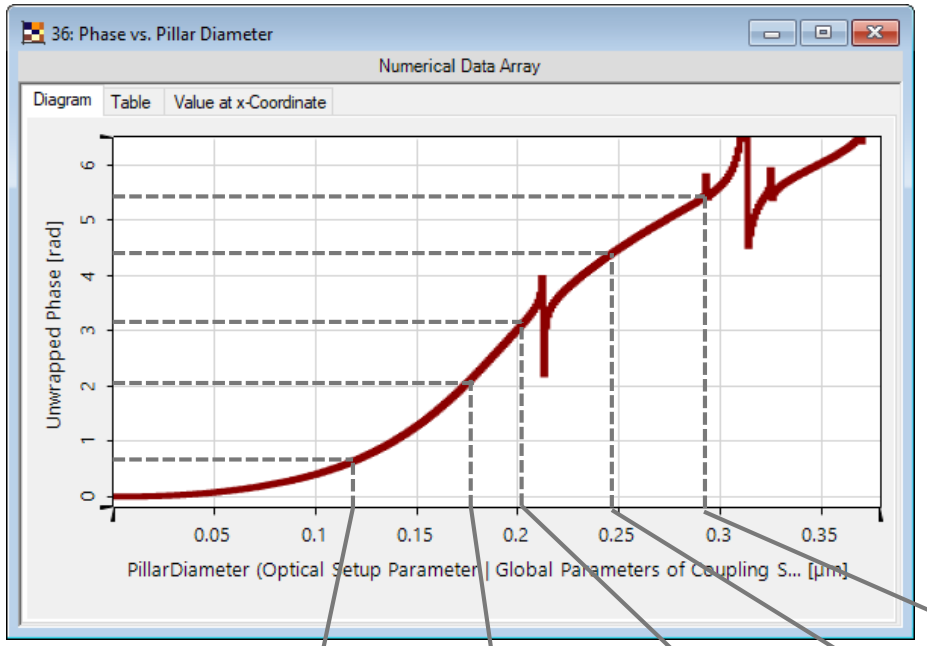


transmission amplitude/phase vs. pillar diameter (@633nm)



Distribution of Cells ➔ Linear Phase

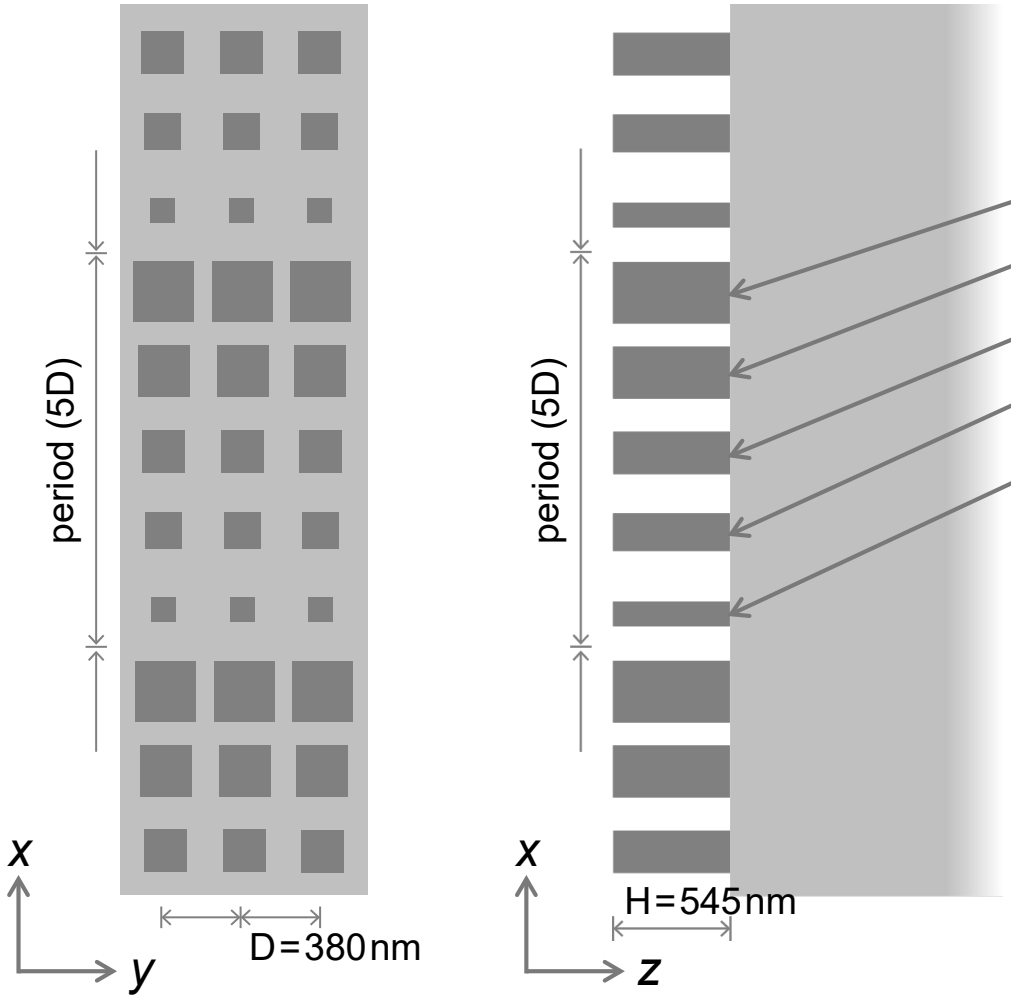


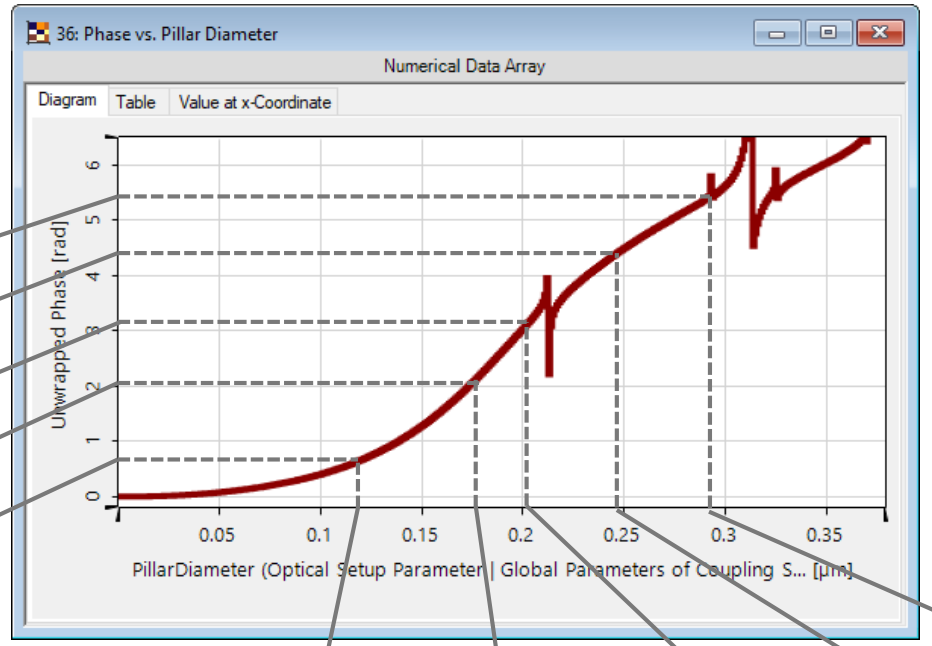


	#1	#2	#3	#4	#5
d	118 nm	179 nm	201 nm	247 nm	293 nm
f=d/D	0.31	0.47	0.53	0.65	0.77
$\Delta\psi$	0.20π	0.69π	0.98π	1.40π	1.73π

Selection of pillar diameters follows from P. Lalanne, *et al.*, Opt. Lett. 23, 1081-1083 (1998)

Distribution of Cells ➔ Linear Phase





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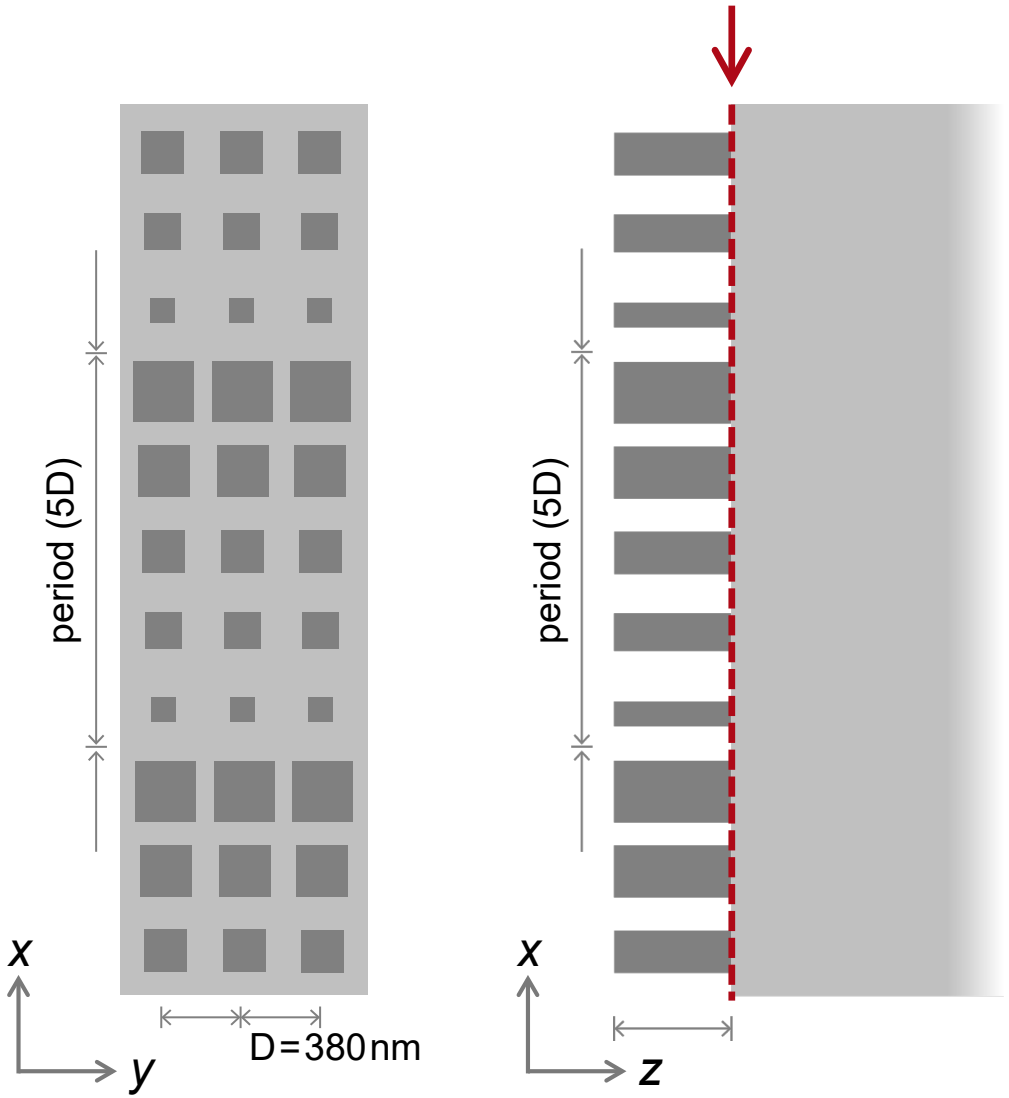
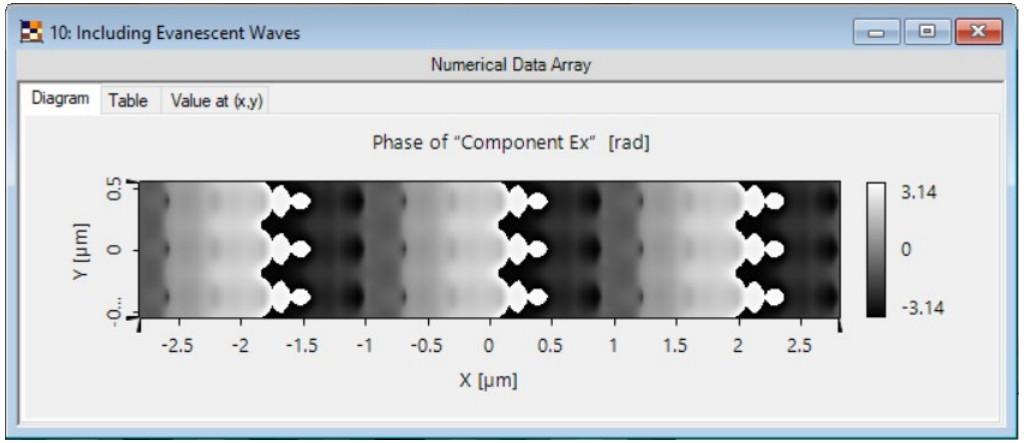
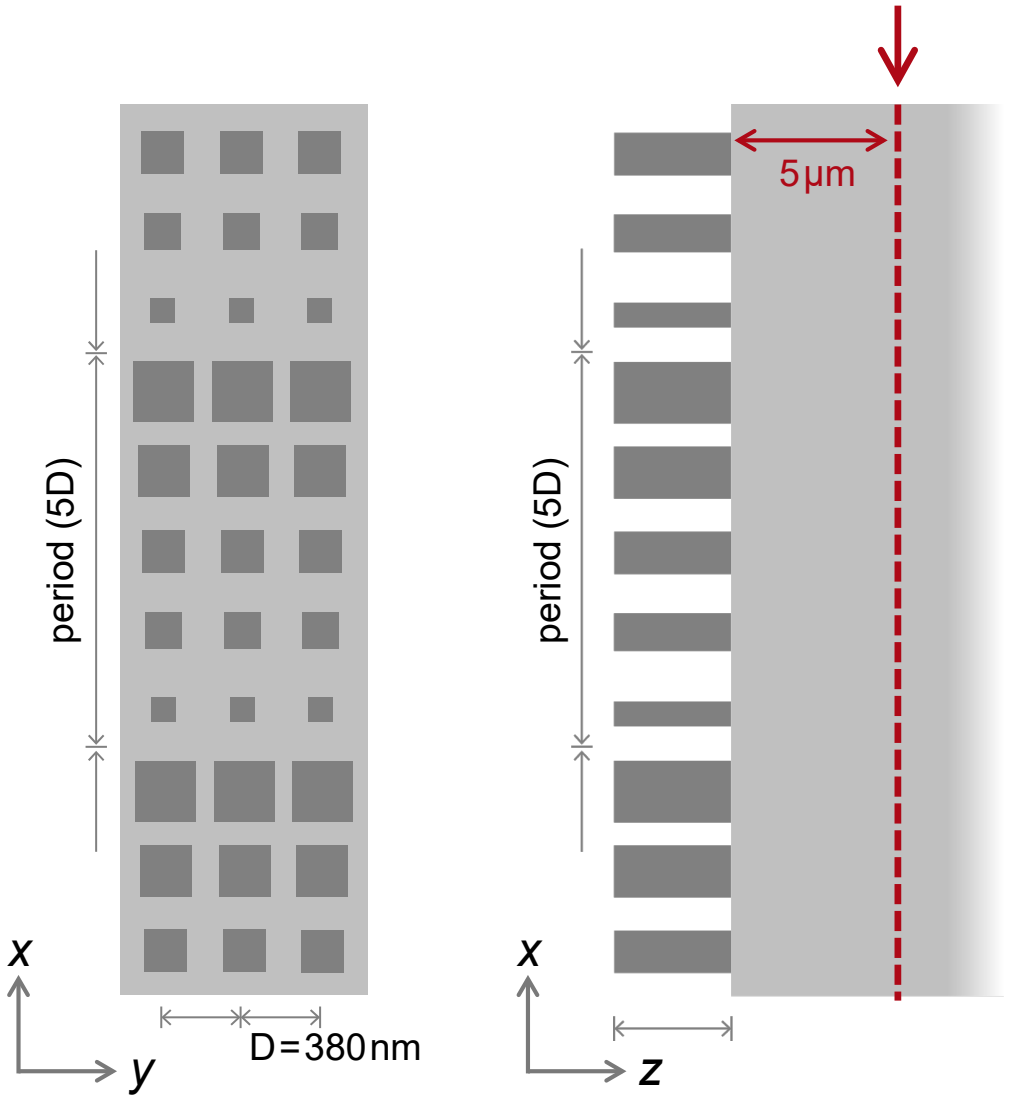
Performance Evaluation: Transmitted Phase Distribution



directly behind the grating

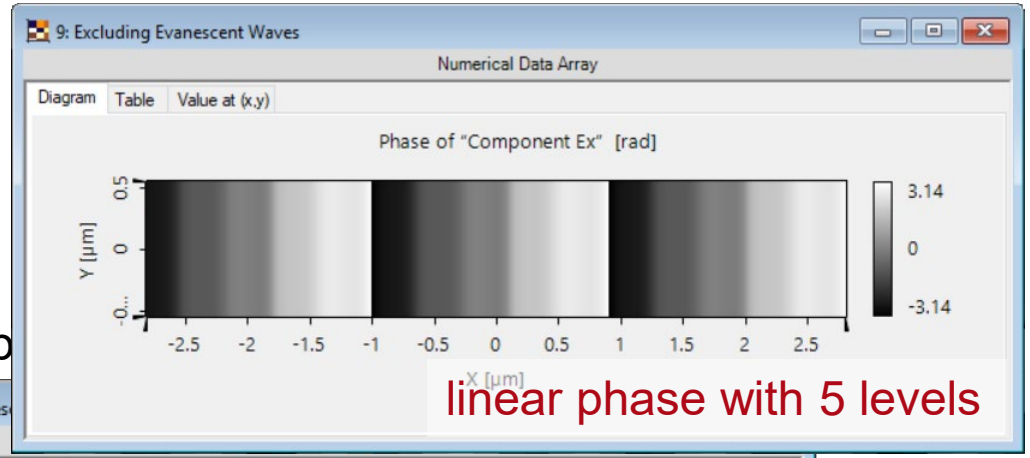


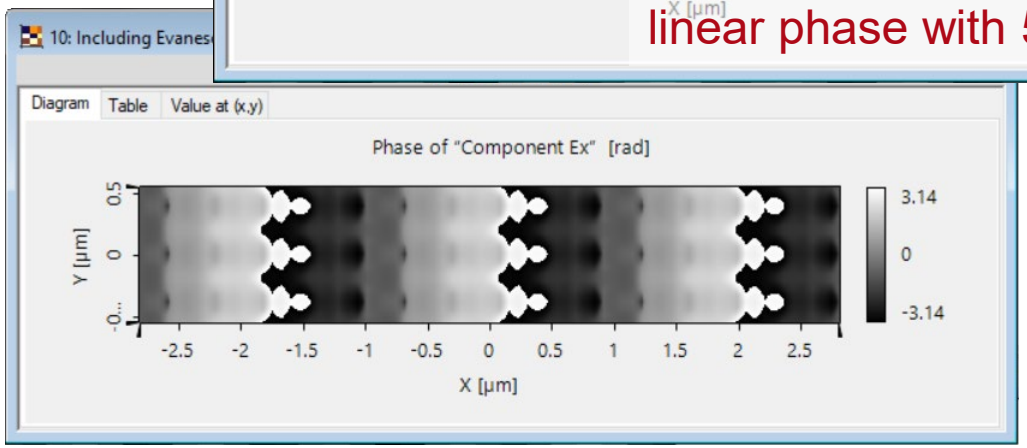
Performance Evaluation: Transmitted Phase Distribution



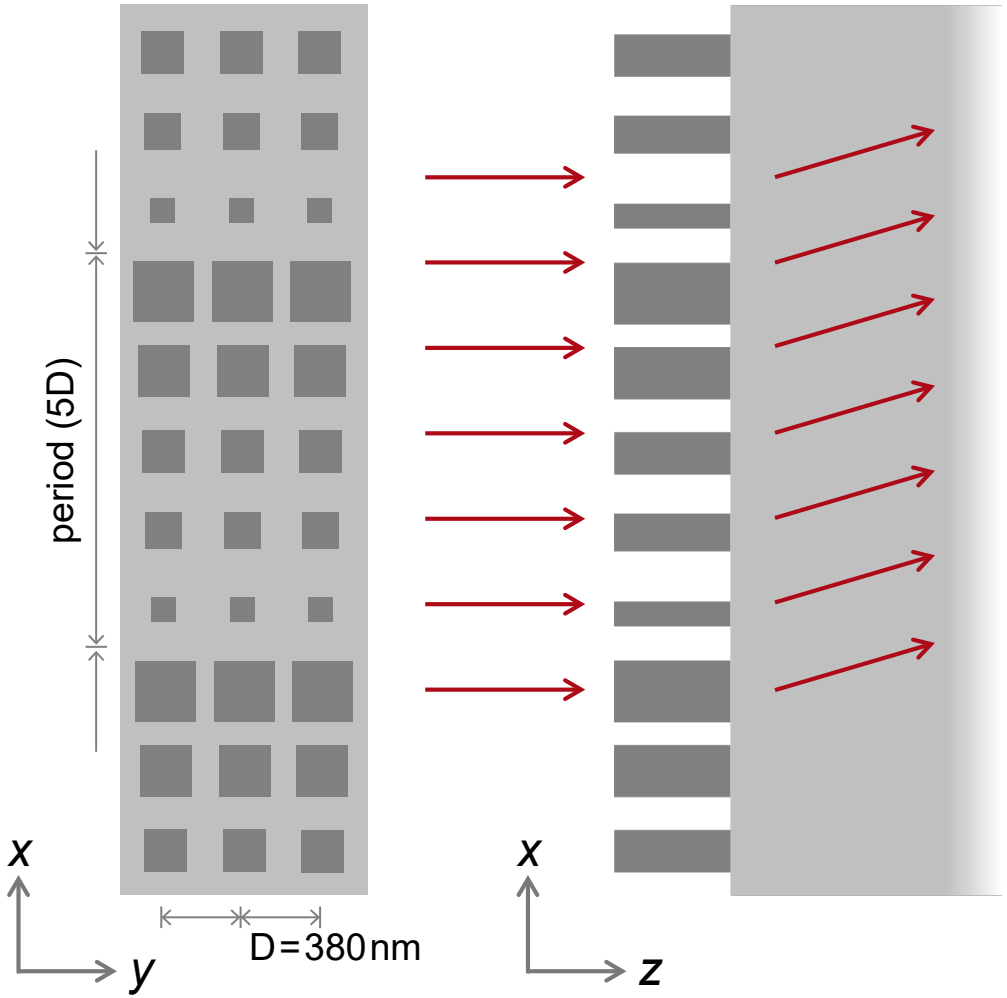
5μm behind the grating (evanescent waves damped)

directly b





Performance Evaluation: Diffraction Efficiency

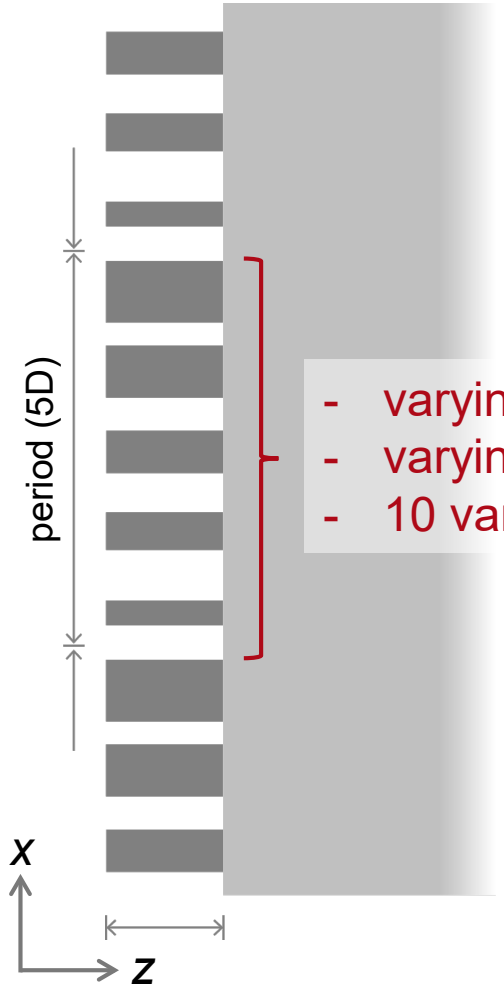


grating performance evaluation

	Efficiency
TE-polarization	80.2%
TM-polarization	74.2%
Average	**77.2%**

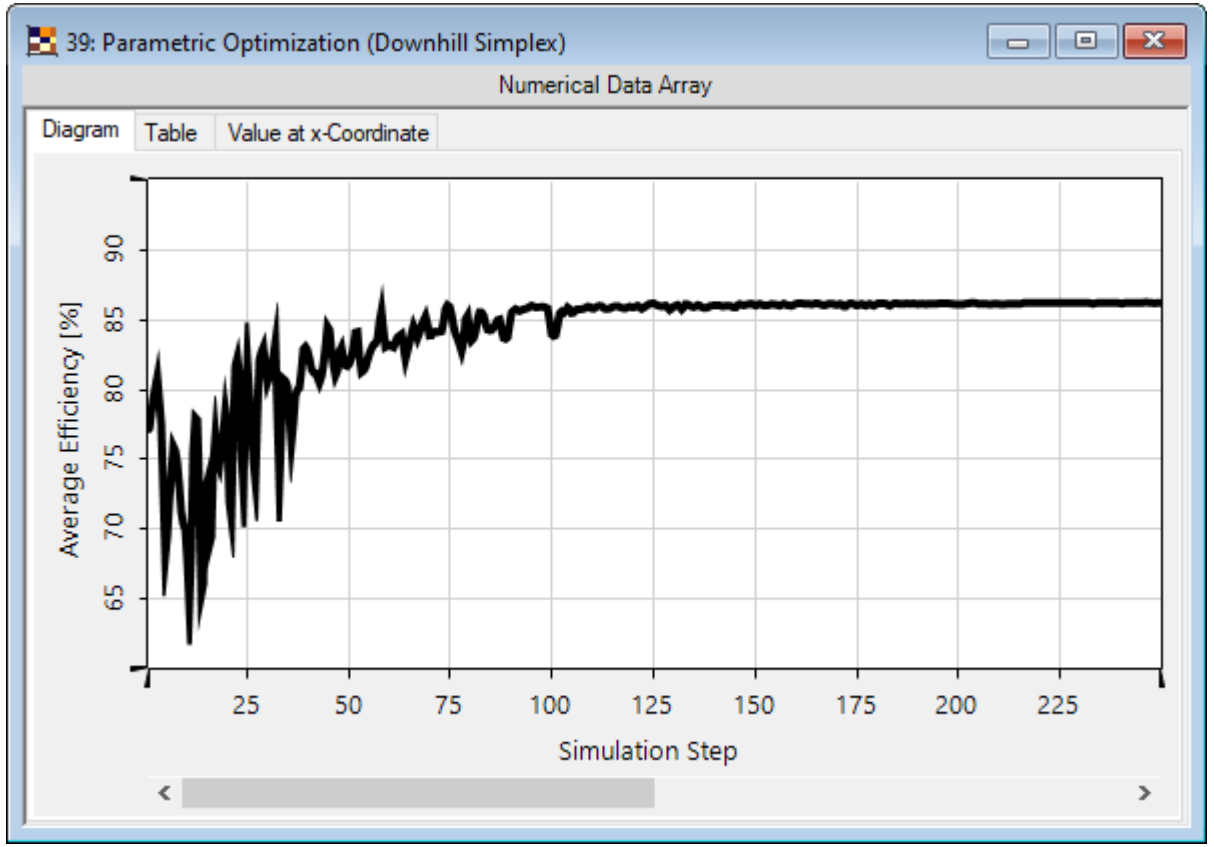
Same average efficiency value reported in
P. Lalanne, *et al.*, Opt. Lett. 23, 1081-1083 (1998)

Post-Optimization of Metagrating

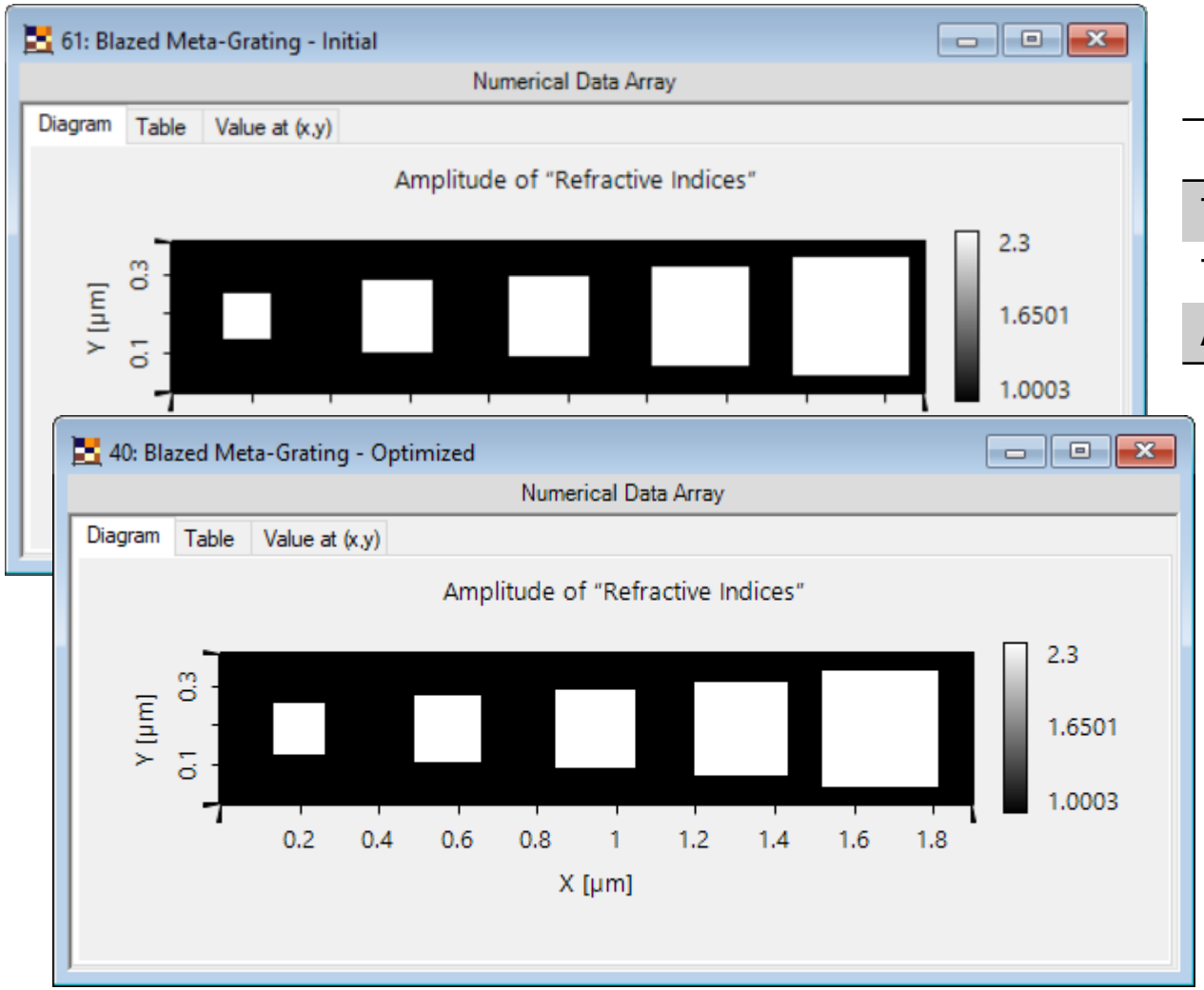


- varying pillar positions
- varying pillar diameters
- 10 variables in total

downhill simplex optimization with FMM/RCWA for grating analysis



Post-Optimization: Initial vs. Optimized Structure



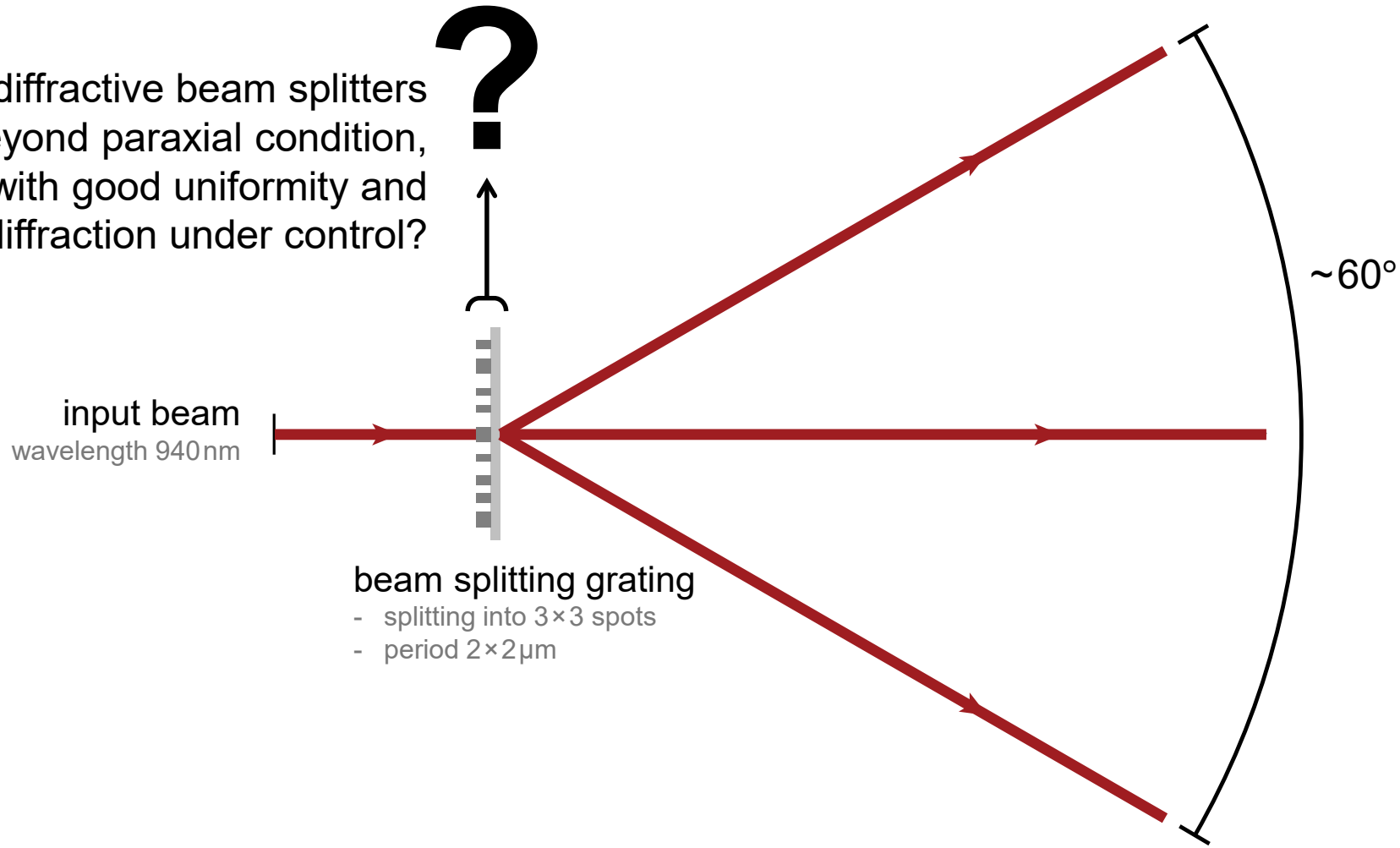
	Efficiency
TE-polarization	80.2%
TM-polarization	74.2%
Average	**77.2%**

	Efficiency
TE-polarization	85.5%
TM-polarization	87.0%
Average	**86.3%**

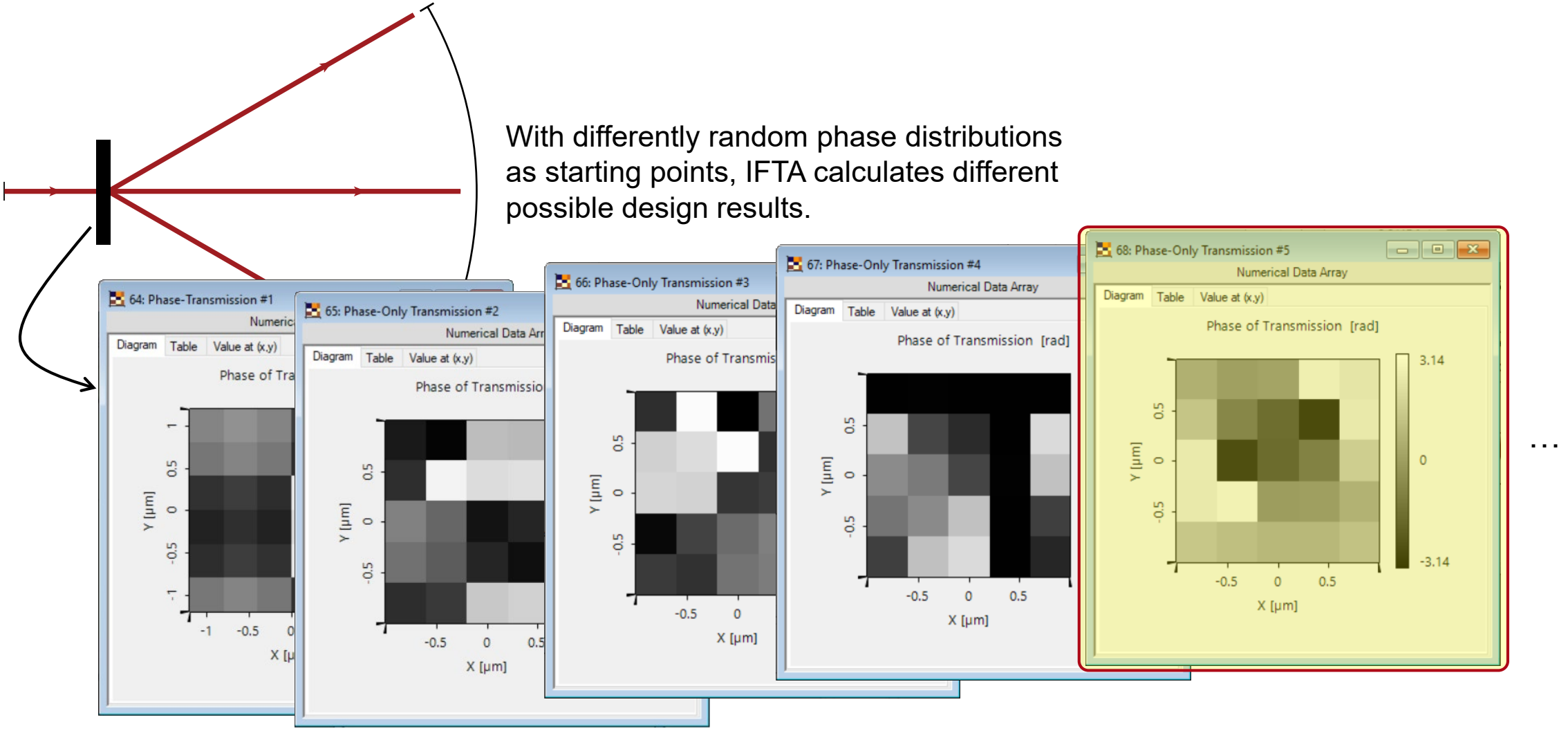
Design of Meta-Grating as Large-Angle Spot Projector

Design Task

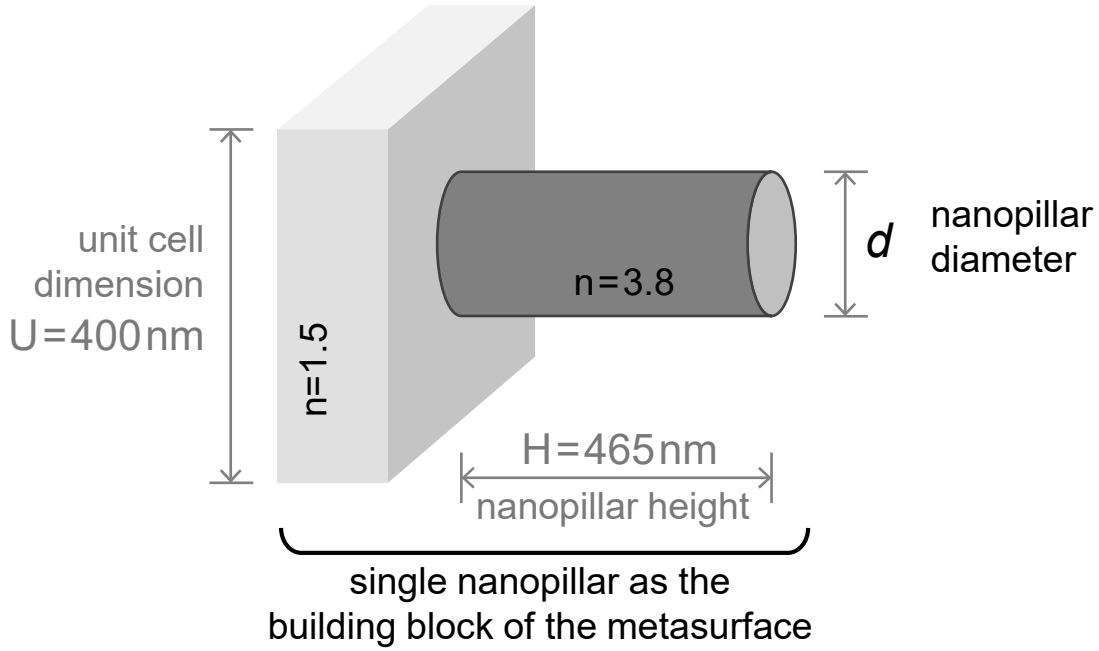
How to design diffractive beam splitters that work beyond paraxial condition, especially with good uniformity and zeroth-order diffraction under control?

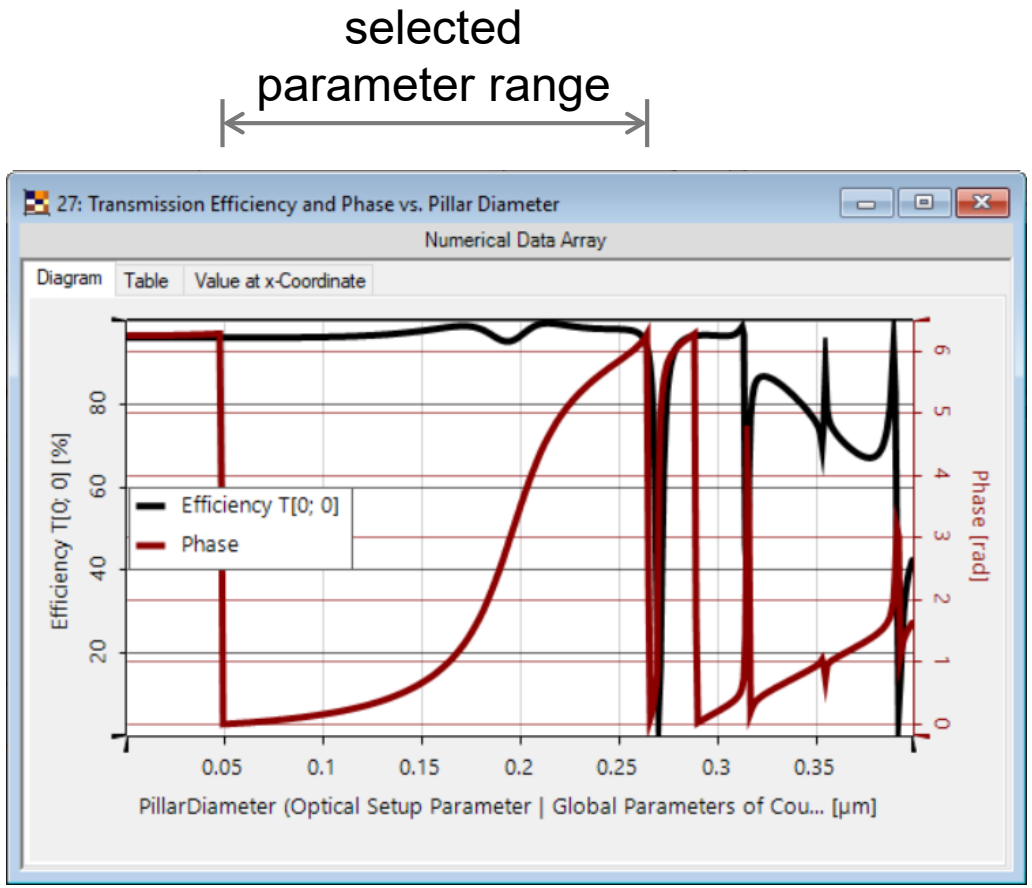


Desired Phase Profile Design (IFTA)



Building Block / Unit Cell Analysis



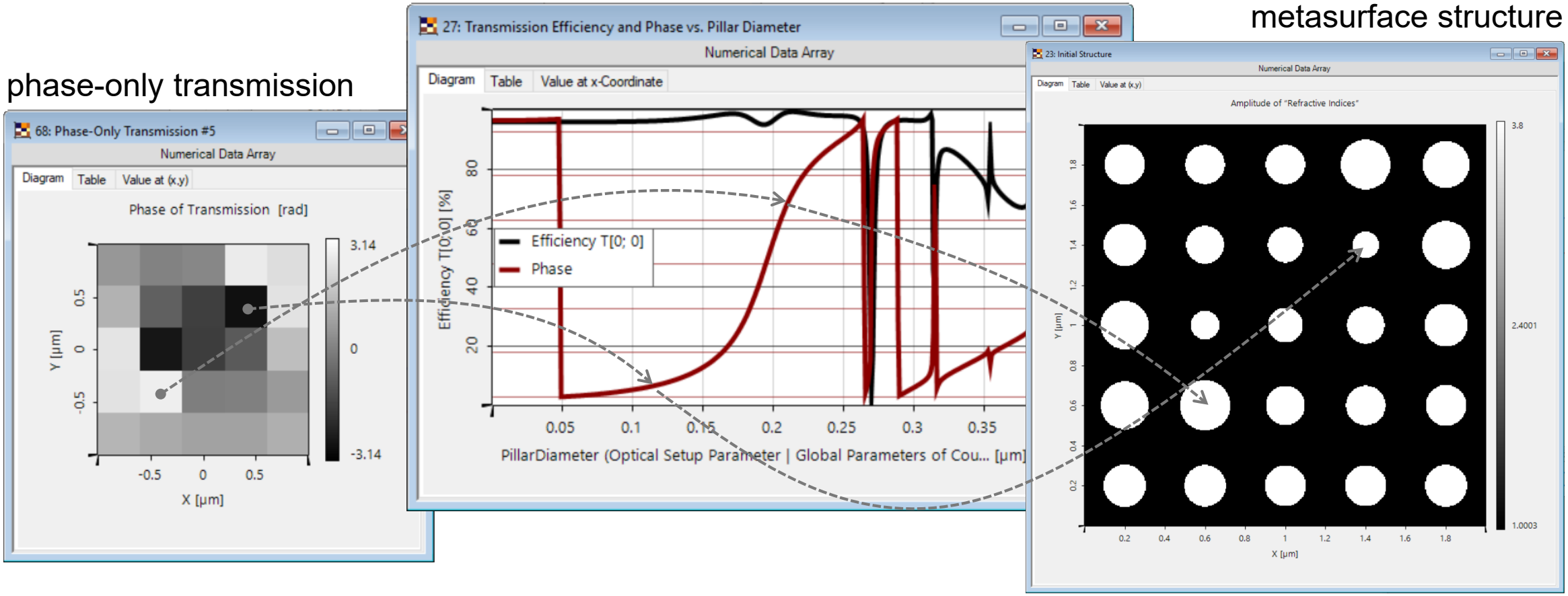


Distribution of Cells

phase-only transmission

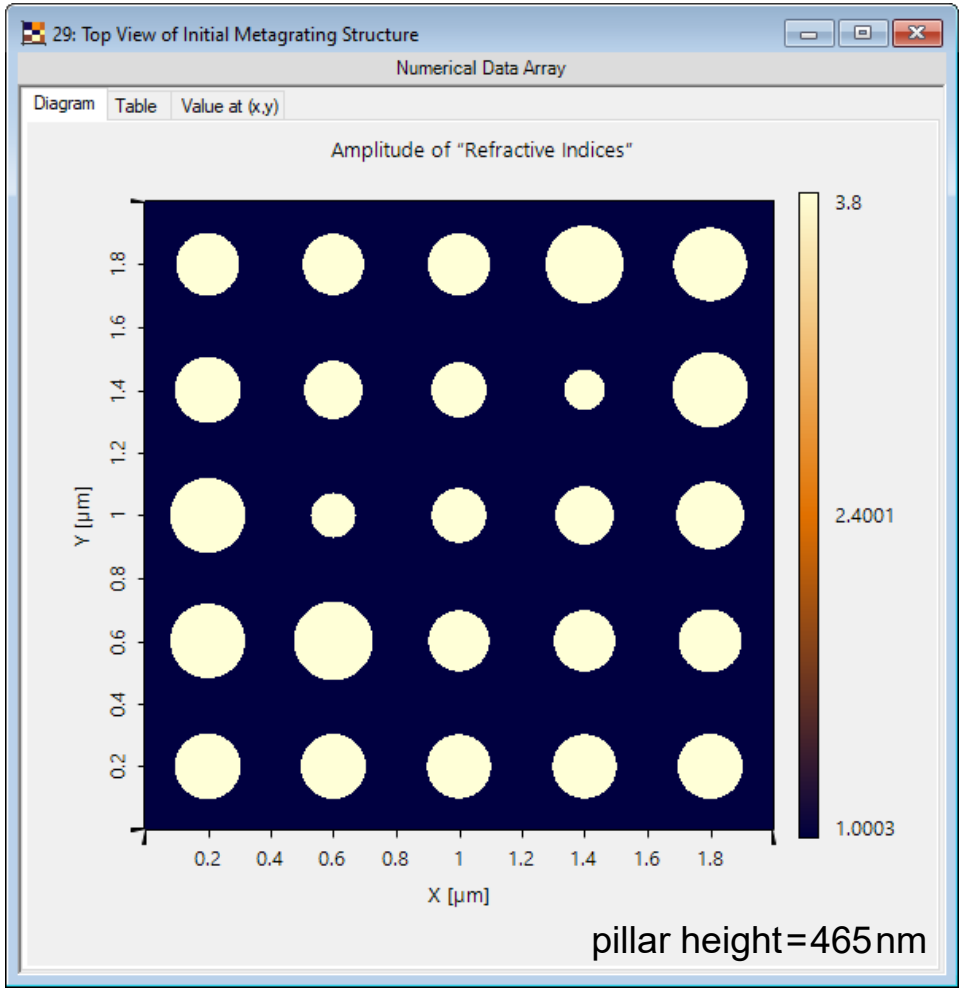
phase-diameter map / library

metasurface structure

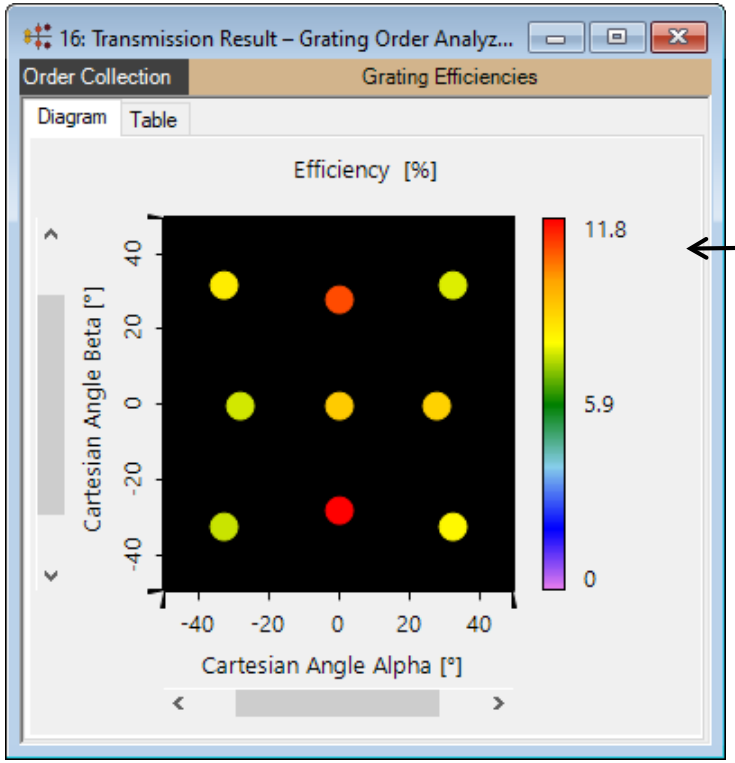


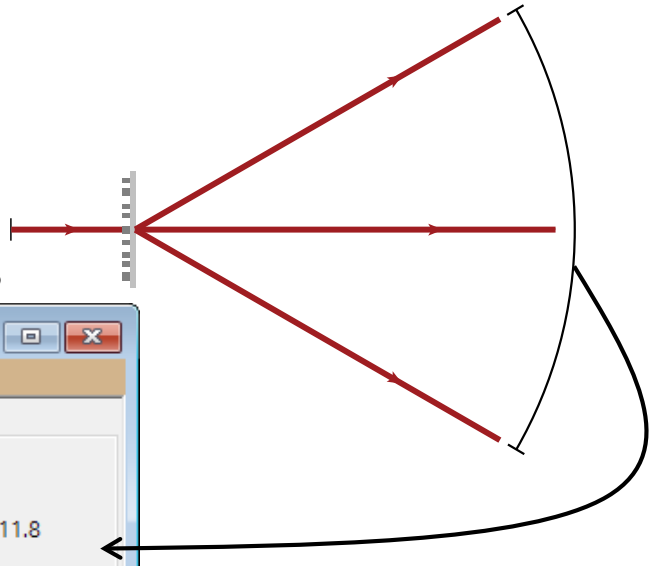
Performance Evaluation: Initial Design

top view of initial metagrating



diffraction efficiencies

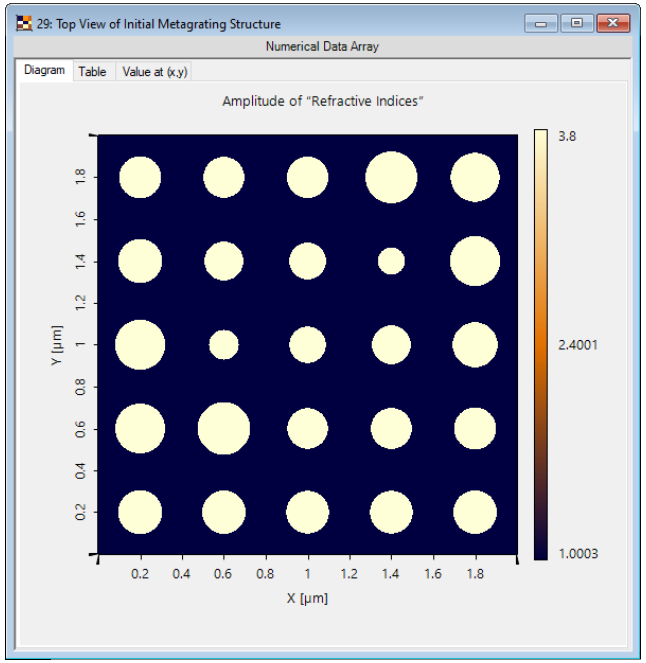




Overall efficiency	79.4%
Uniformity error (PV)	22.7%
Uniformity error (RMS)	16.7%

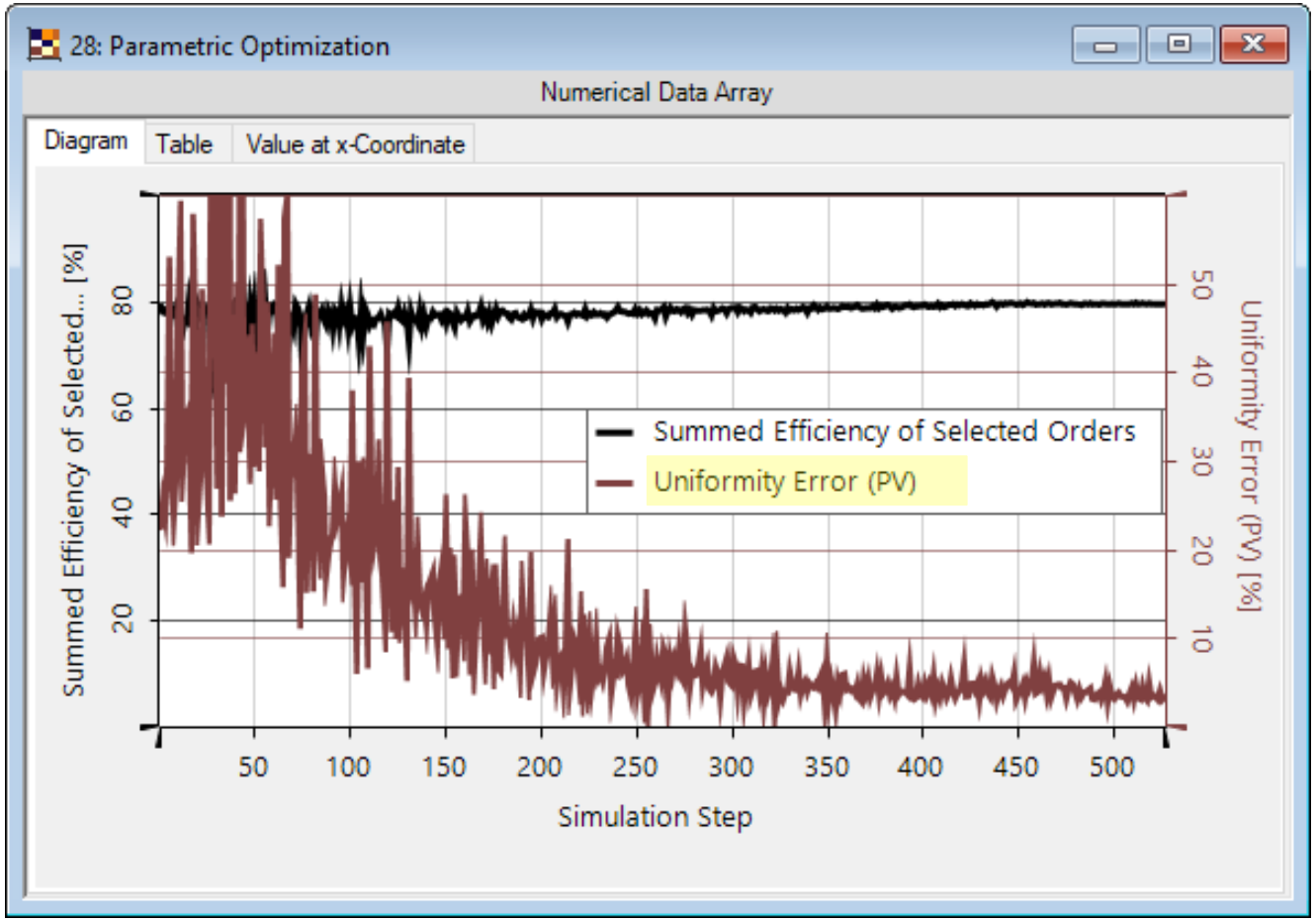
Post-Optimization of Metagrating (PV Uniformity Error)

initial structure



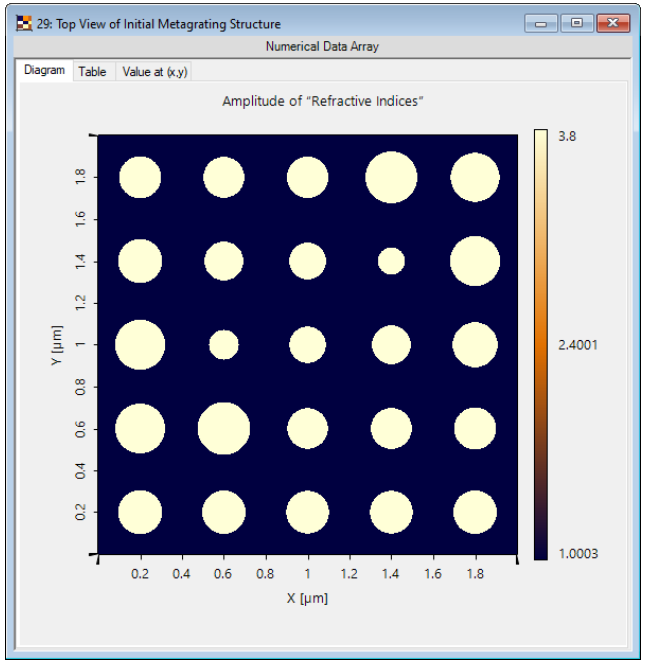
- keep pillar positions
- varying pillar diameters
- 25 variables in total

downhill simplex optimization with FMM/RCWA for grating analysis



Post-Optimization of Metagrating (RMS Uniformity Error)

initial structure



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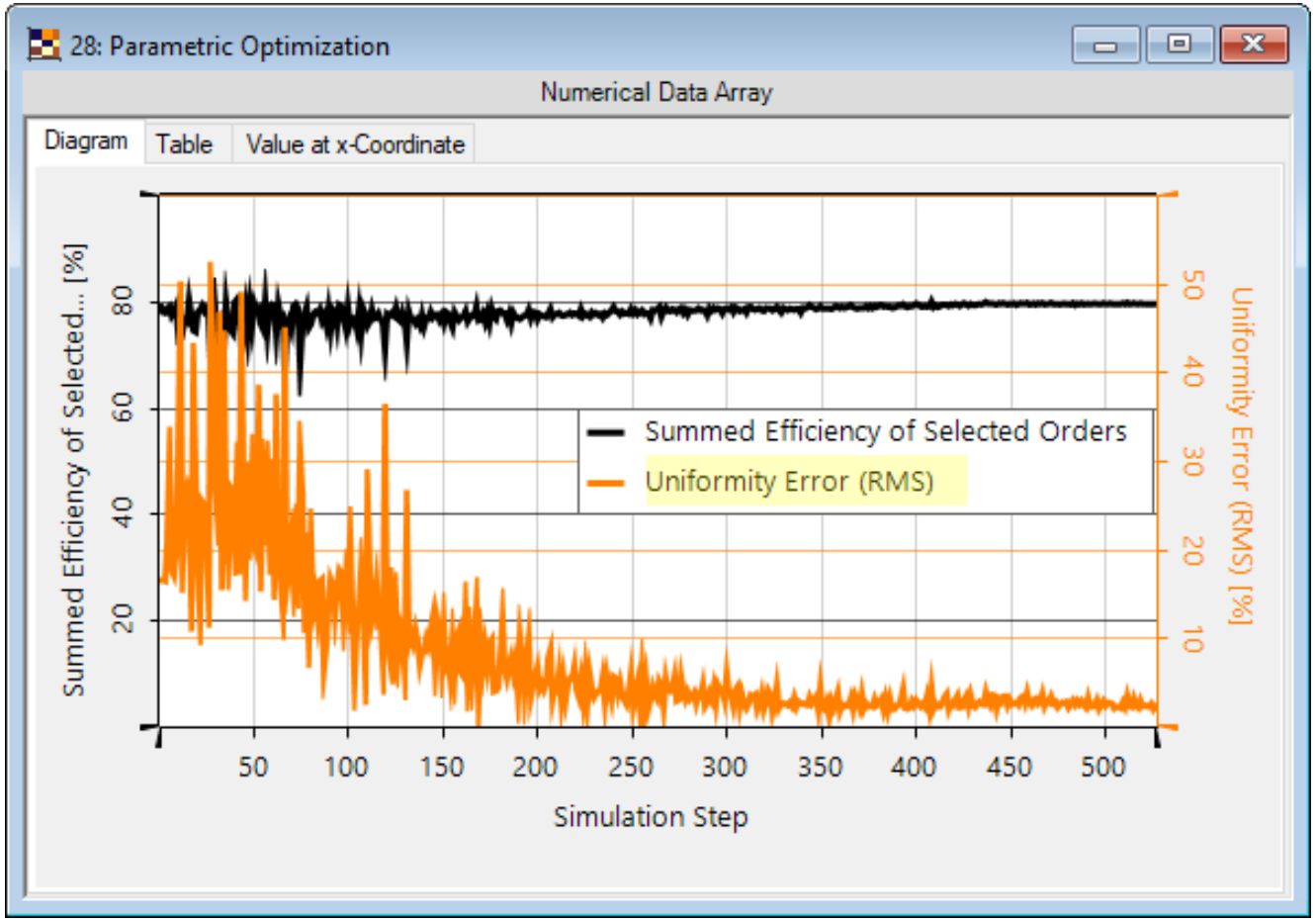
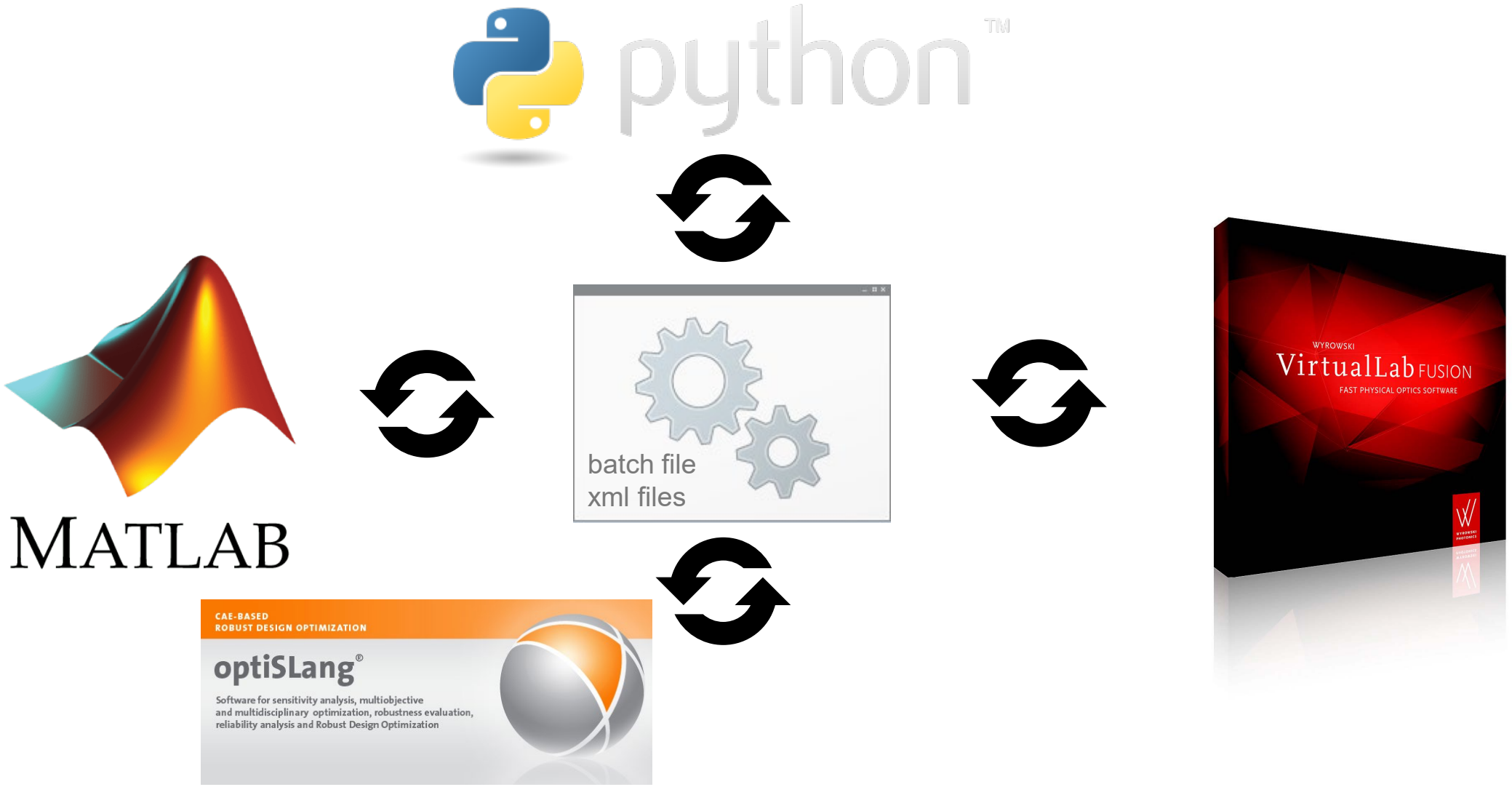
- 25 variables in total

downhill simplex optimization with FMM/RCWA for grating analysis

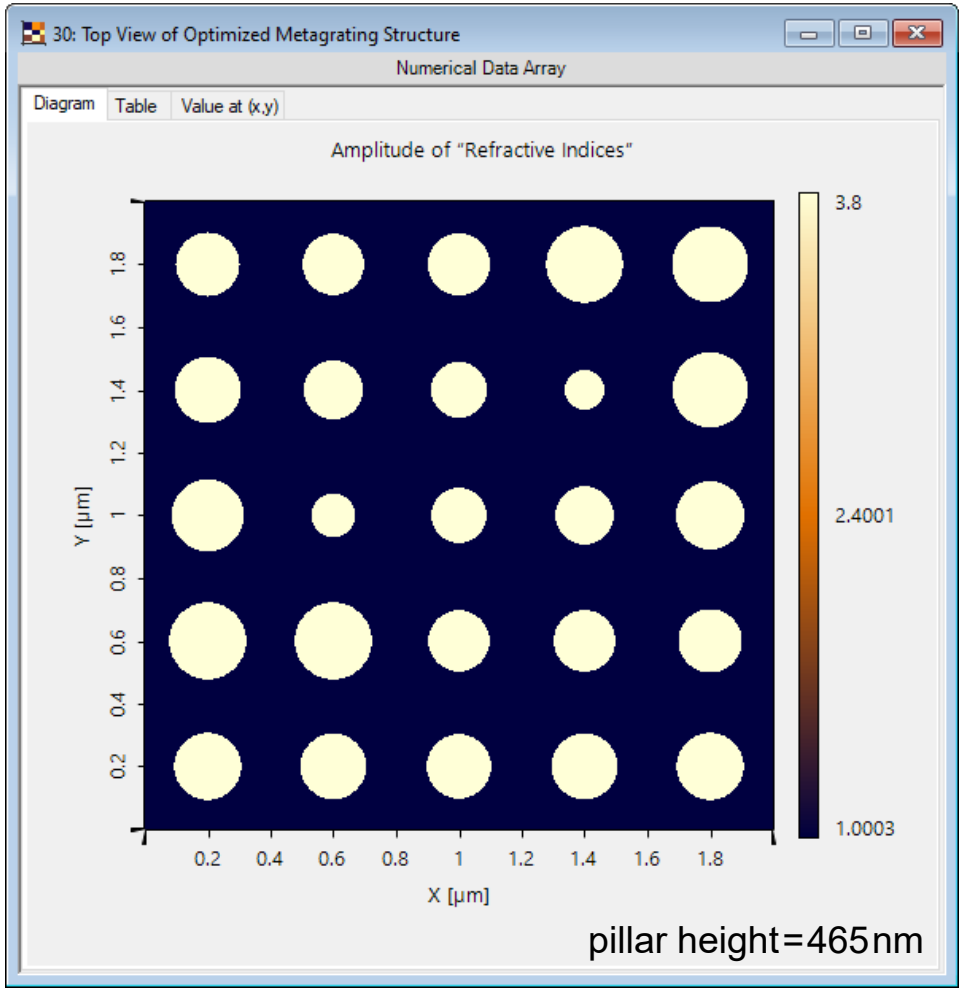


Cross-Platform Simulation and Optimization

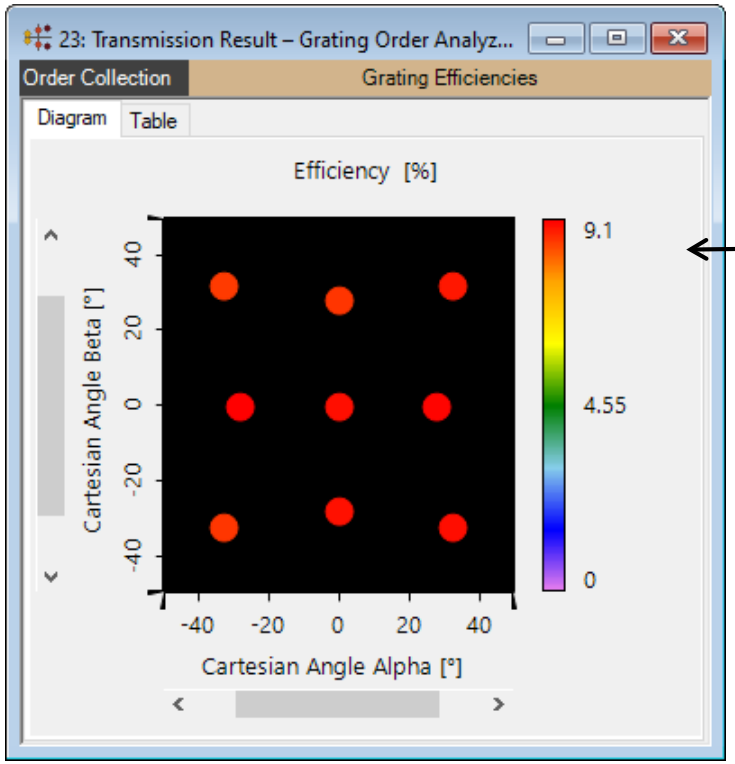


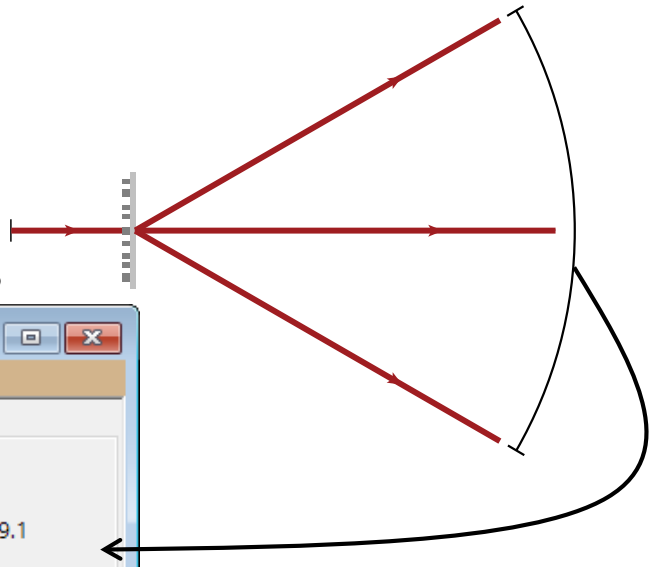
Evaluation of Optimized Metasurface Design

top view of optimized metagrating



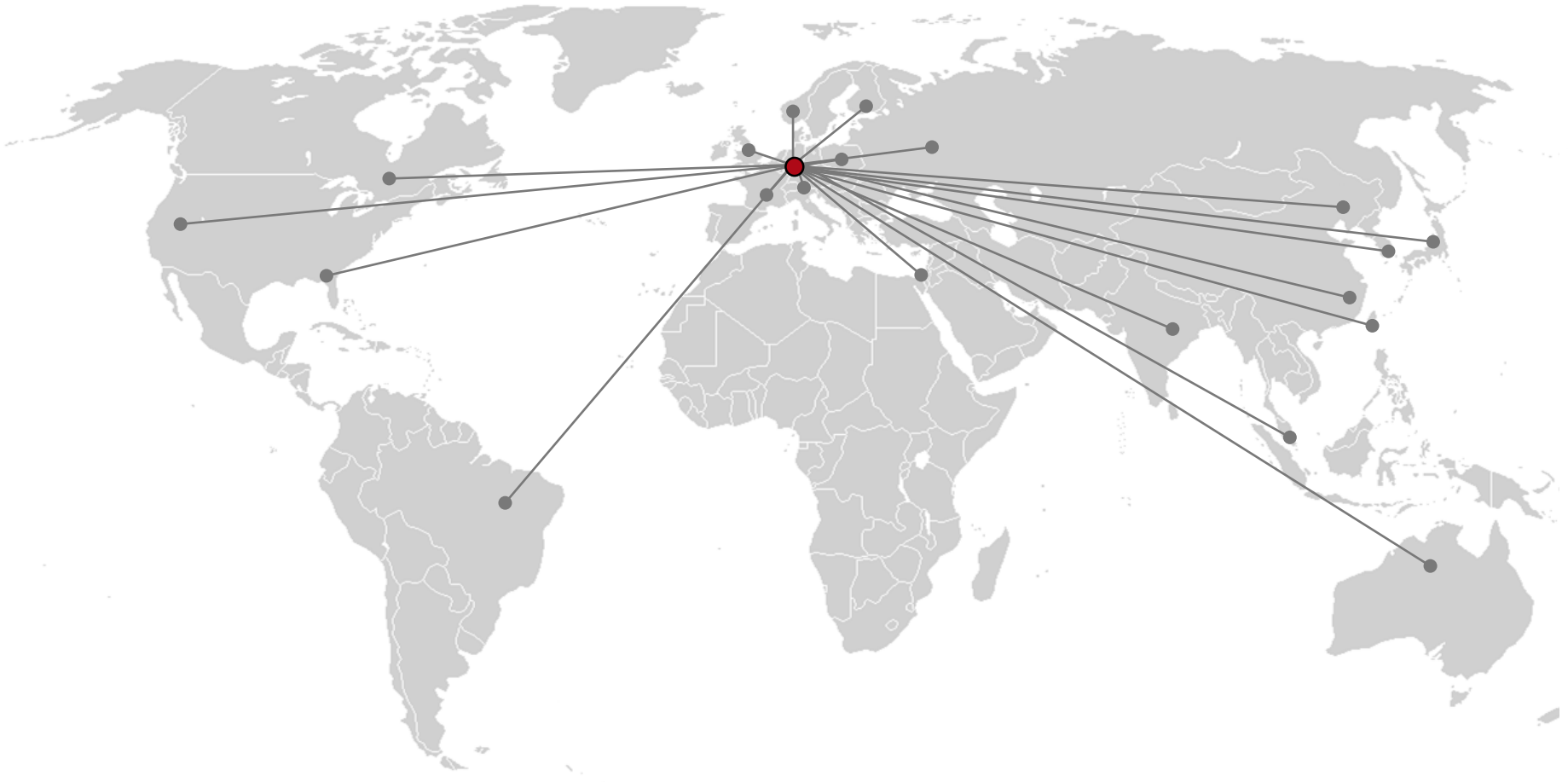
diffraction efficiencies





Overall efficiency	79.7%
Uniformity error (PV)	**3.1%**
Uniformity error (RMS)	**2.3%**

Optical Design Software and Services



Booth #4545 (German pavilion)