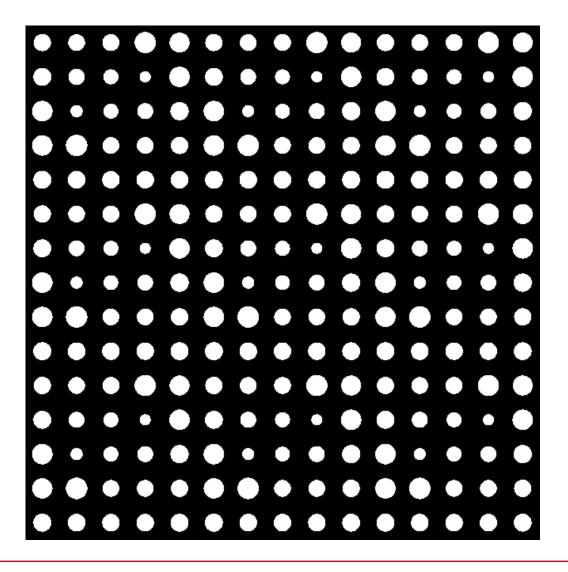


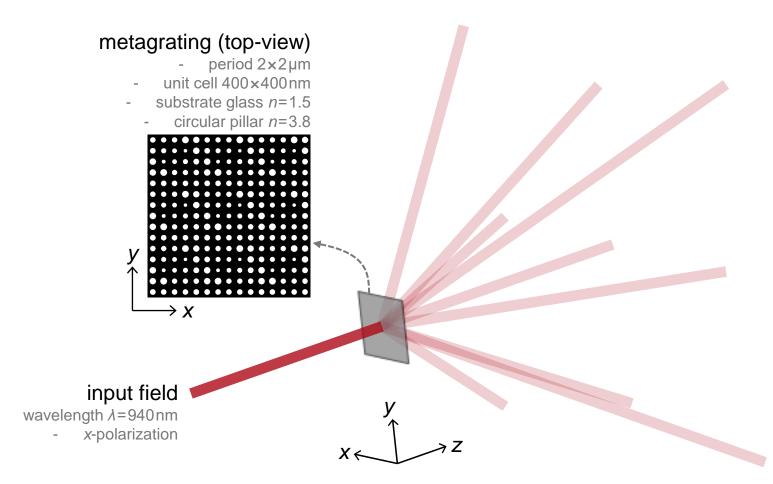
# Design of 2D Non-Paraxial Beam-Splitting Metagrating

### Abstract



Metagratings are shown to have advantages when compared with traditional gratings, especially in nonparaxial cases. In this example, we design a two-dimensional (2D) metagrating that splits the input into 3x3 beams. The metagrating is constructed with circular nano pillars, and in VirtualLab Fusion, we use FMM/RCWA to evaluate the diffraction efficiency of the metagrating. And, we show how to use the parametric optimization tool to improve the uniformity of the diffraction efficiencies.

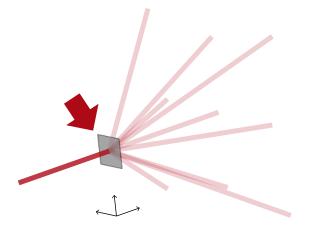
### **Design Task**



How to design a metagrating that splits the input into  $3 \times 3$  beams, with

- uniform power distribution into the 3×3 beams, and
- high overall transmission power of the 3×3 beams?

### **Connected Modeling Techniques: Metagrating**

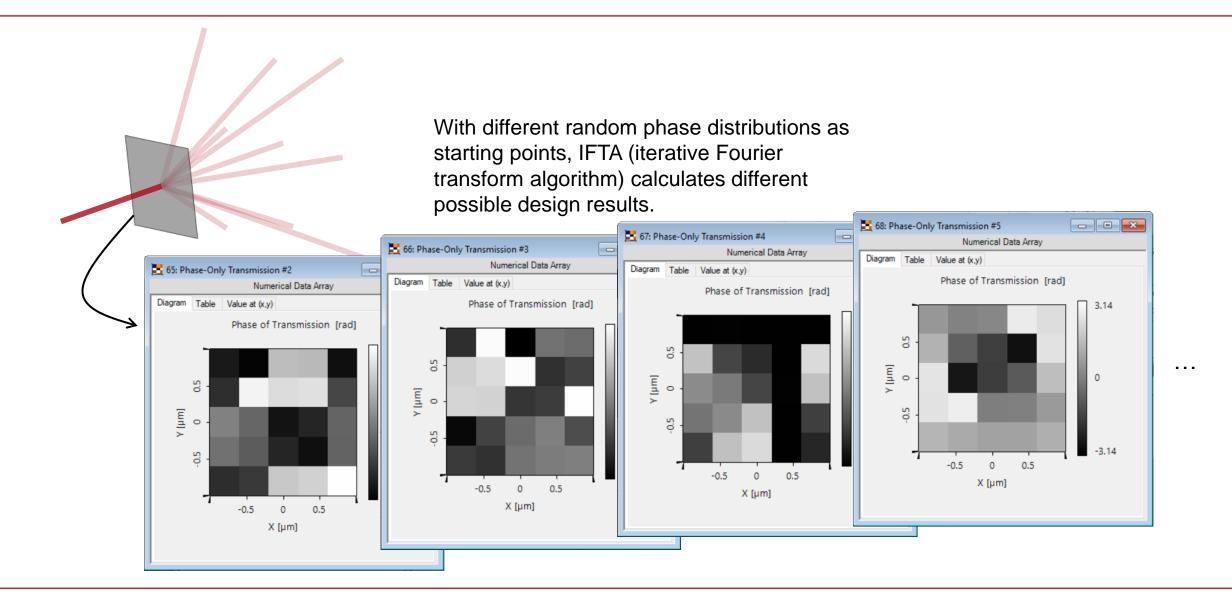


Available modeling techniques for periodic micro and nano structures:

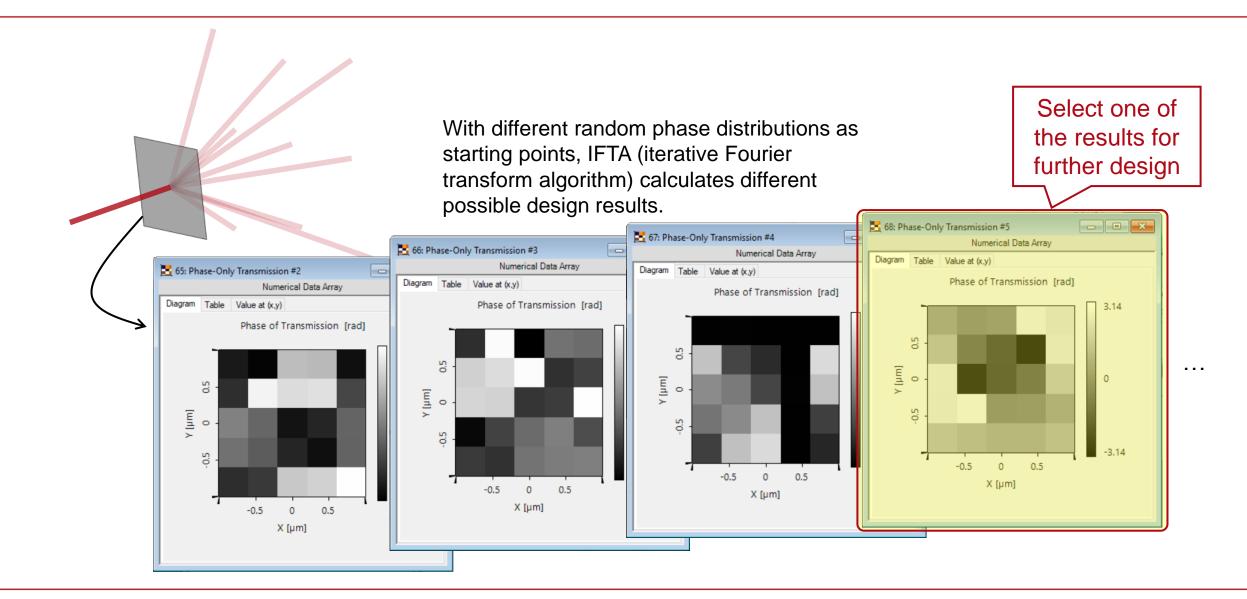
Methods	Preconditions	Accuracy Speed		Comments		
Fourier Modal Method (FMM)	None	High	High	Small periods		
Thin Element	Teatures, tim		High High Thickness about wavelength & features larger than about			
Approximation	Otherwise	Low	High	wavelengths		
FMM in KogelnikThick volume gratings; Bragg condition		High	Very high	Method is electromagnetic formulation of Kogelnik's approach		
	No Bragg condition	Low	Very high			

As a rigorous eigenmode solver, the Fourier modal method (also known as rigorous coupled wave analysis, RCWA) provides a very high accuracy. Due to the small periods and distances in this setup, the calculation speed is fast. FMM is then the best compromise of accuracy and speed for the simulation of the beam-splitting metagrating.

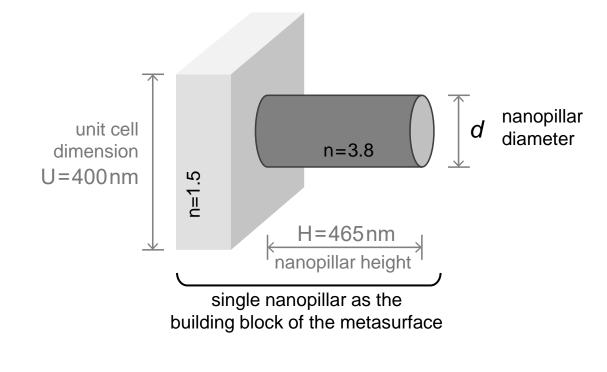
### **Phase-Only Transmission Design (IFTA)**

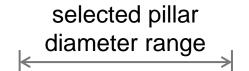


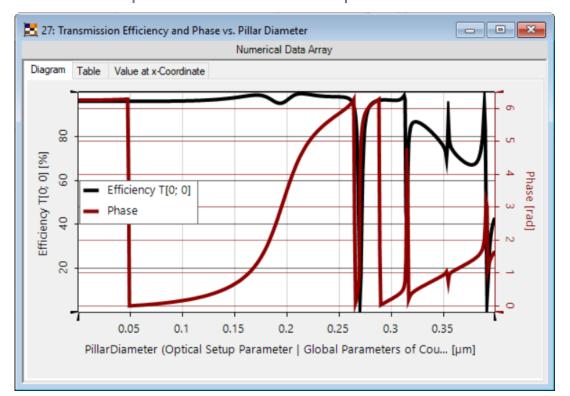
### **Phase-Only Transmission Design (IFTA)**



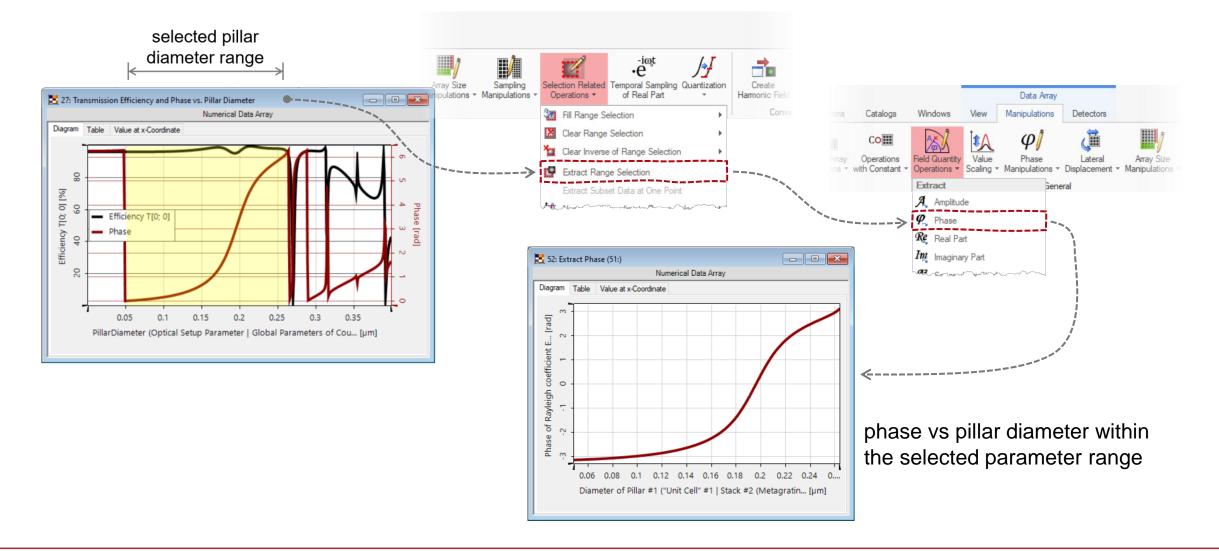
### **Metasurface Unit Cell Analysis**





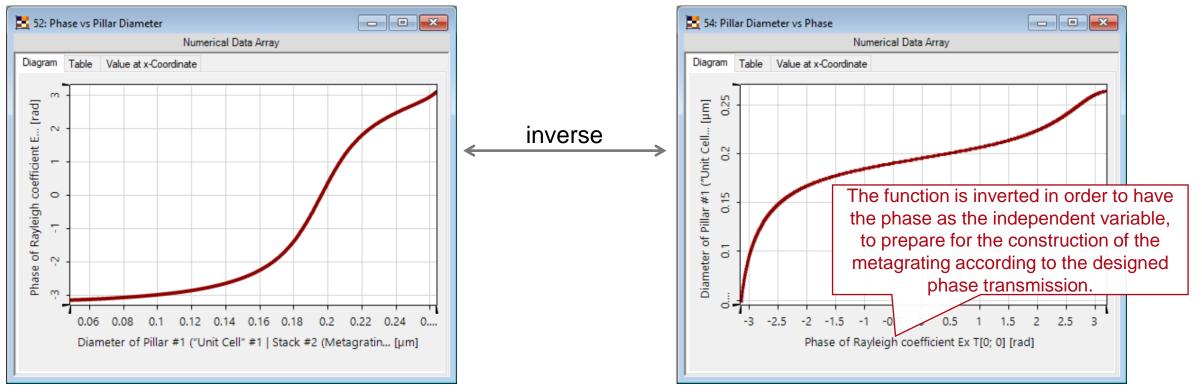


### **Unit Cell Parameter Range Selection**



### **Phase vs Pillar Diameter and Its Inverse**

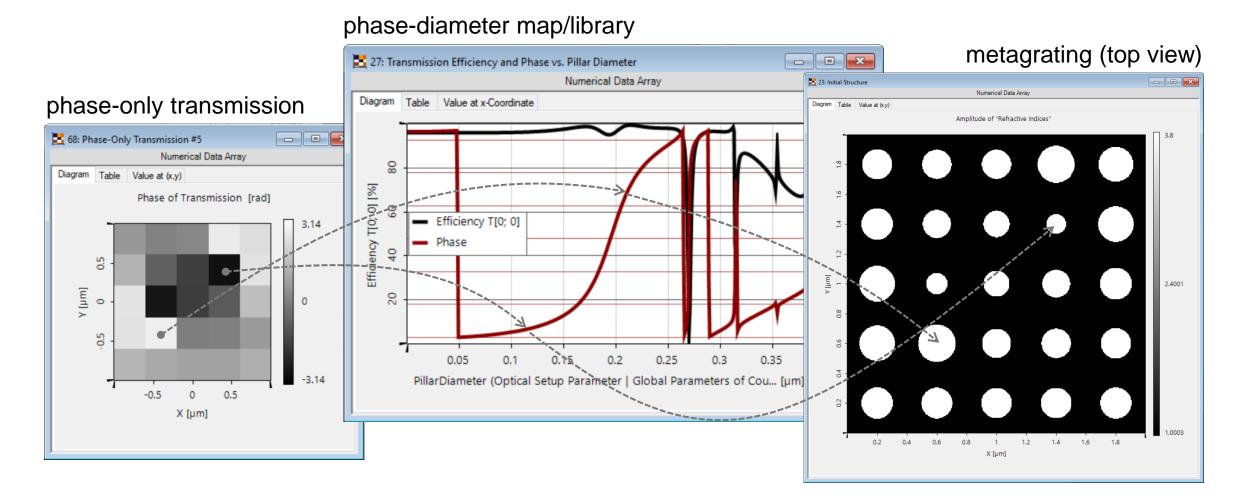
### phase value vs pillar diameter (result from last step)



In this example, function inversion can be done with the VirtualLab C# Module: Appx\_01\_Calculate Inverse of 1D Function.cs

pillar diameter vs phase value

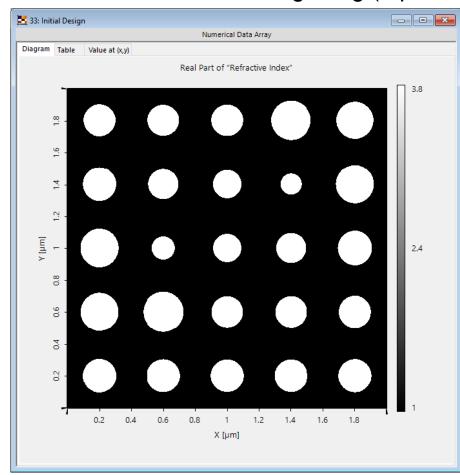
# **Metagrating Construction**



In this example, pillar distribution can be done with the VirtualLab C# Module: Appx\_02\_Calculate Pillar Diameters from Phase Profile.cs

### **Evaluation of Initial Metasurface Design**

#### initial metagrating (top-view)



### diffraction efficiencies

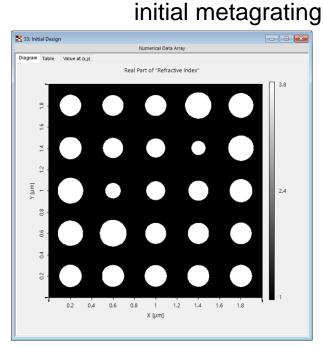
€ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓ ↓	_	•	Grating Order D	Data	
Diagram Table	Ampli	tude of "Efficie			
				9.1	
5 1 1.5	•	ullet	•		
Order # Y -0.5 0 0.5	•	•	•	4.55	overall efficiency
-15 -1-	•	•	•		uniformity error (PV)
-1	-1.5 -1 -(	0.5 0 0 Order # X	.5 1 1.5	0	uniformity error (RMS)

79.6%

25.3%

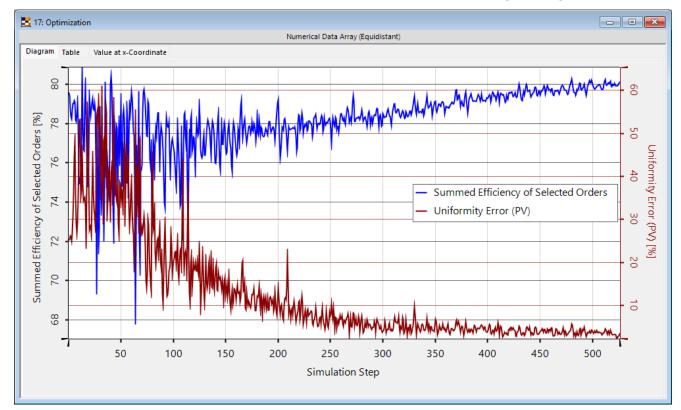
16.9%

# **Parametric Optimization**



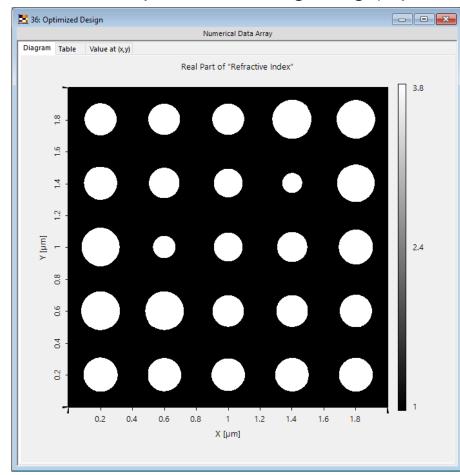
- keep pillar positions
- **vary** pillar diameters (25 variables)

#### downhill simplex optimization with FMM/RCWA for grating analysis



# **Evaluation of Optimized Metagrating Design**

### optimized metagrating (top-view)



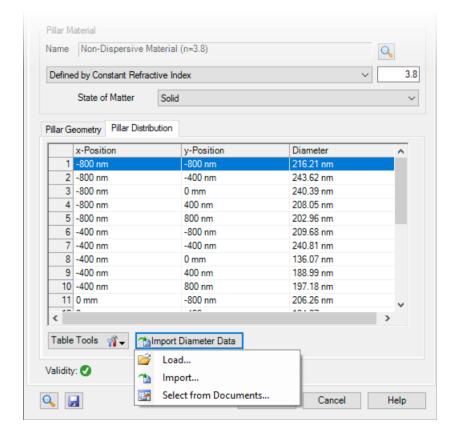
#### diffraction efficiencies 12 20: Optimized Result - • × Order Collection Grating Order Data Diagram Table Amplitude of "Efficiency" [%] 9.1 <del>1</del>.5 -0.5 Order # Y 0 4.55 79.9% overall -0.5 efficiency 5 uniformity 2.3% -1.5 1 error (PV) 1.6% uniformity -1.5 -1 -0.5 0 0.5 1 1.5 error (RMS) Order # X

### **Peek into VirtualLab Fusion**

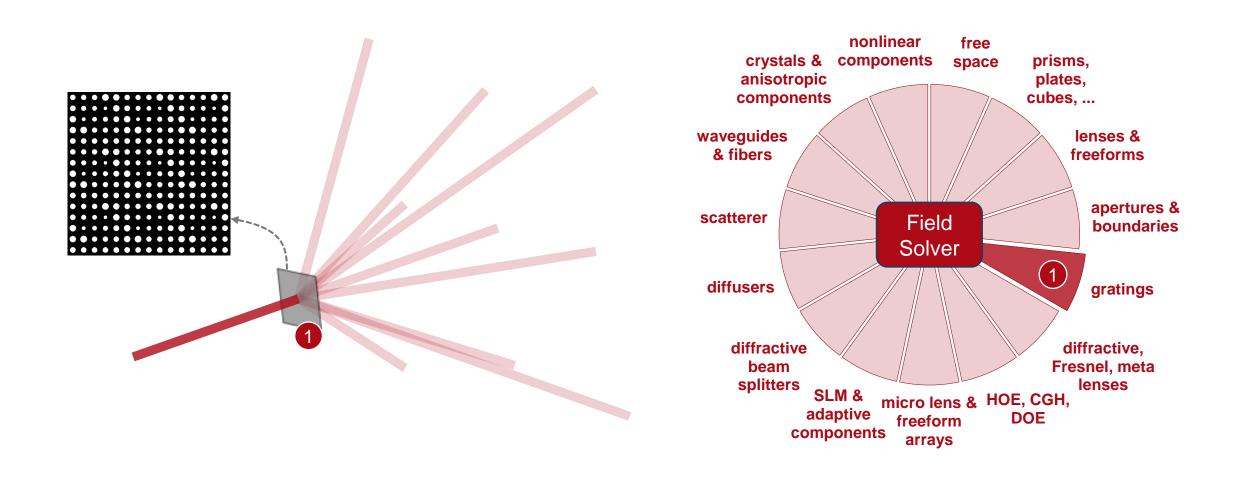
		Pillar Material Name Non-Dispers	sive Material (n=3.8)		ptimization Results		y Metagrating_04b_0ptimizing Pillar Diamete tine. The results are shown in the table.	s.opt						
		Defend by Constant	Defeestive lader	~										_
	flexible definition of 2	Defined by Constant	Refractive Index	~	3.0					Simu	lation Step			
		State of Matte	er Solid		~		Subdetector	1	2	3	4	5	6	
	metagrating surfac						Target Function Value	0.18377	0.20019	0.18909	0.23442	0.35584	0.51472	
	metagrating sunat		Drud at				Diameter of Pillar #1 (Metagrating #1   Diameter of Pillar #2 (Metagrating #1	211 nm 238 nm	232.1 nm	211 nm	211 nm	211 nm	211 nm 238 nm	
35: Initial Design		Pillar Geometry Pillar	Distribution				Diameter of Pillar #3 (Metagrating #1 I	230 nm	230 nm	201.0 mm	250 mm	230 nm	230 nm	240 1
55. mitai Design	Numerical Data Array	x-Position	v-Position	Diameter	^		Diameter of Pillar #4 (Metagrating #1 I	210 nm	210 nm	210 nm	210 nm	231 nm	210 nm	
iagram Table Value at (x.y)	Numerical Data Array	1 -800 nm	-800 nm	216.21 nm			Diameter of Pillar #5 (Metagrating #1	202 nm	202 nm	202 nm	202 nm	202 nm	222.2 nm	202 r
Amplitude of "Refractive Indices"		2 -800 nm	-400 nm	243.62 nm	_		Diameter of Pillar #6 (Metagrating #1	207 nm	207 nm	207 nm	207 nm	207 nm	207 nm	227.7 r
	3 -800 nm	0 mm	240.39 nm			Diameter of Pillar #7 (Metagrating #1 I	251 nm	251 nm	251 nm	251 nm	251 nm	251 nm	251 r	
		400 nm	208.05 nm			Diameter of Pillar #8 (Metagrating #1	143 nm	143 nm	143 nm	143 nm	143 nm	143 nm	143 r	
	5 -800 nm	400 nm	202.96 nm			Diameter of Pillar #9 (Metagrating #1	187 nm	187 nm	187 nm	187 nm	187 nm	187 nm		
		6 -400 nm	-800 nm	202.96 nm			Diameter of Pillar #10 (Metagrating #1	196 nm	196 nm	196 nm	196 nm	196 nm	196 nm	196 r
							Diameter of Pillar #11 (Metagrating #1_ Diameter of Pillar #12 (Metagrating #1_	205 nm 195 nm	205 nm	205 nm	205 nm	205 nm	205 nm	205 r
-		7 -400 nm	-400 nm	240.81 nm			Diameter of Pillar #13 (Metagrating #1	175 nm	175 nm	175 nm	175 nm	175 nm	175 nm	175 1
4		8 -400 nm	0 mm	136.07 nm			Diameter of Pillar #14 (Metagrating #1	176 nm	176 nm	176 nm	176 nm	176 nm	176 nm	176 1
		9 -400 nm	400 nm	188.99 nm			Diameter of Pillar #15 (Metagrating #1	198 nm	198 nm	198 nm	198 nm	198 nm	198 nm	198 1
1:2		10 -400 nm	800 nm	197.18 nm			Diameter of Pillar #16 (Metagrating #1	205 nm	205 nm	205 nm	205 nm	205 nm	205 nm	205 r
Ē		4001 11 0 mm	-800 nm	206.26 nm	~		Diameter of Pillar #17 (Metagrating #1_	196 nm	196 nm	196 nm	196 nm	196 nm	196 nm	196 r
(In In I		4001	100	404.07	>		D' - FD'H 440.081 44	***	***	***	***	***	***	``>
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0.2 0.	4 0.6 0.8 1 1.2 1.4 1.6 1.8											3		
	X [µm]													

### **Workflow in VirtualLab Fusion**

- Analyze metasurface unit cell
  - <u>Rigorous Analysis of Nanopillar Metasurface</u> <u>Building Block</u> [Use Case]
- Construct metagratings
  - <u>Metagrating Construction Discussion at Examples</u> [Use Case]
- Analyze grating diffraction efficiency
  - Grating Order Analyzer [Use Case]
- Parametric optimization of grating structure
  - Parametric Optimization [Tutorial Video]



### **VirtualLab Fusion Technologies**



title	Design of 2D Non-Paraxial Beam-Splitting Metagrating			
document code	GRT.0021			
version	1.4			
edition	VirtualLab Fusion Advanced			
software version	2024.1 (Build 1.132)			
category	Application Use Case			
further reading	<ul> <li>Rigorous Analysis of Nanopillar Metasurface Building Block</li> <li>Modeling and Design of Blazed Metagratings</li> </ul>			