

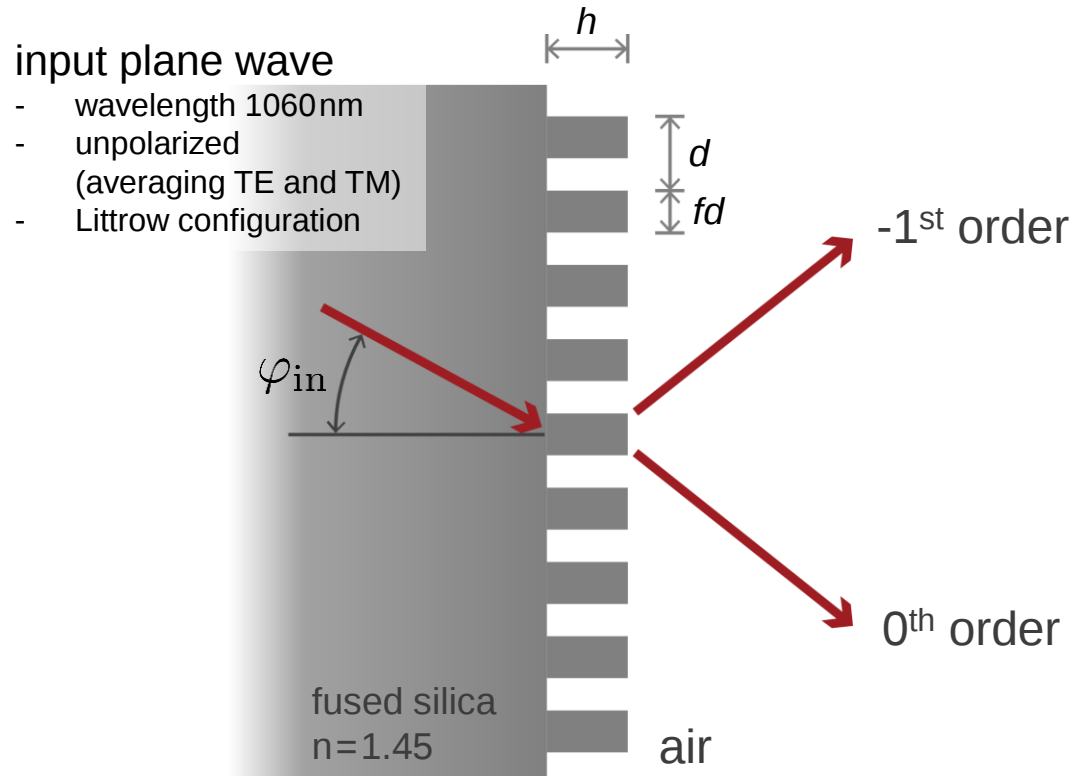
Analysis and Design of Highly Efficient Polarization Independent Transmission Gratings

Abstract



Gratings, especially those with feature size comparable to the wavelength, are known to possess polarization-dependent optical properties. That makes it difficult to design gratings with high diffraction efficiencies for arbitrary polarizations. Following the concept reported in literature [T. Clausnitzer, *et al.*, Proc. SPIE **5252**, 174-182 (2003)], we show how to analyze the polarization-dependent property of gratings rigorously, as well as how to use parametric optimization to design polarization-independent gratings with high diffraction efficiency.

Design Task



How to optimized the grating structure parameters so to maximize the diffraction efficiency of -1st transmission order, for unpolarized input light?

?

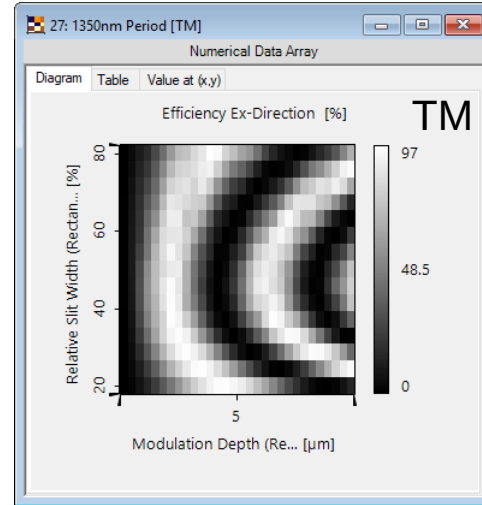
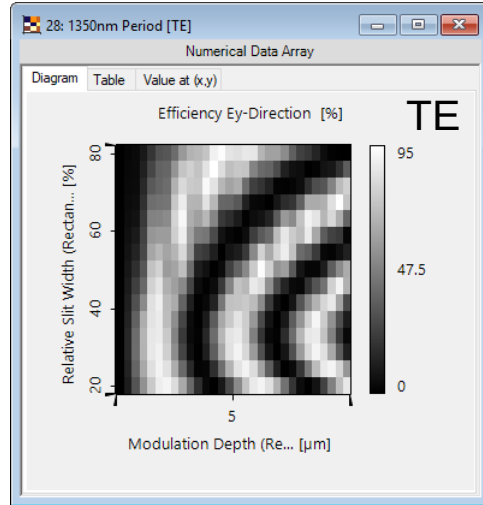
Parameter	Value Range
grating depth h	0.1 - 10 μ m
grating period d	550 - 1350nm
fill factor f	20 - 80%

reference: T. Clausnitzer, *et al.*, „Highly efficient polarization independent transmission gratings for pulse stretching and compression,“*Proc. SPIE* **5252**, 174-182 (2003)

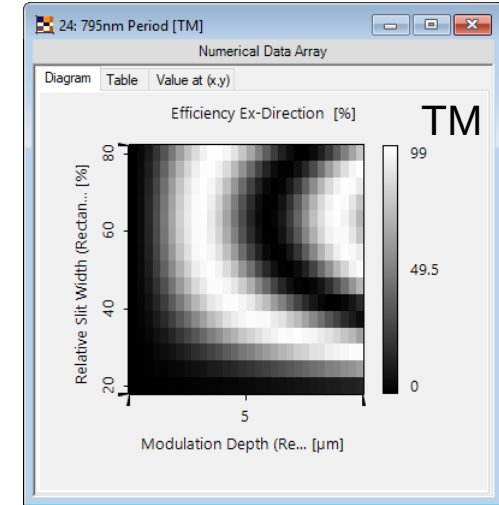
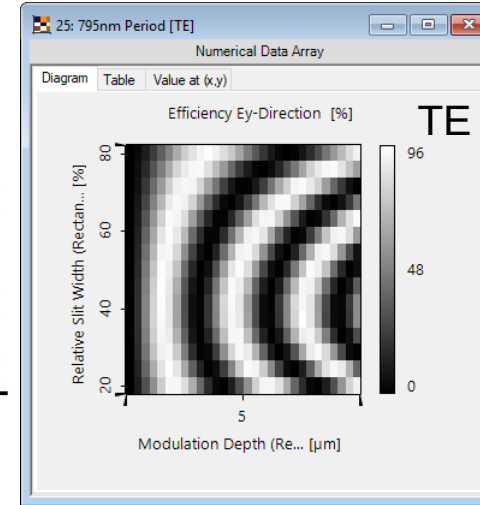
Rigorous Analysis of Grating Property vs. Parameters

Diffraction Efficiency @ Different Grating Periods

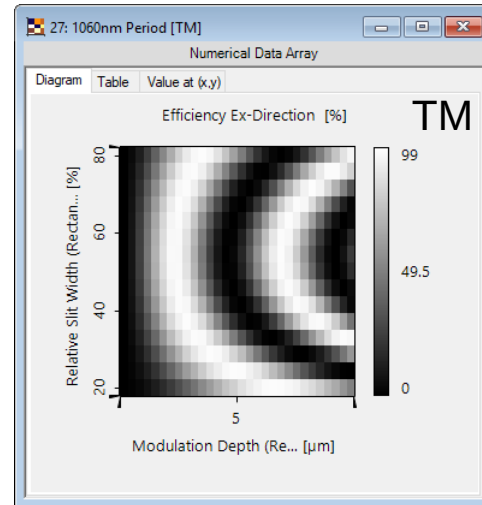
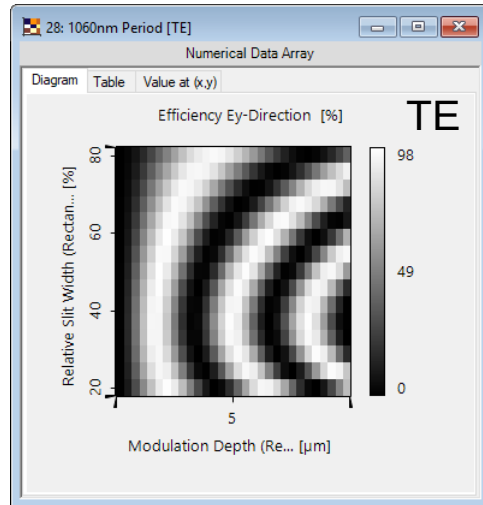
period=1350nm



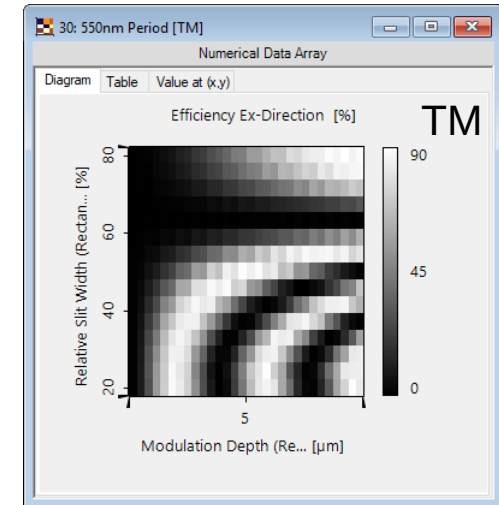
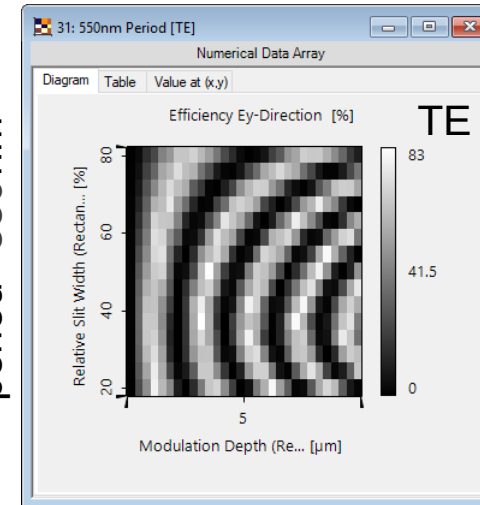
period=795nm



period=1060nm



period=550nm



Considerations on Grating Period Choice

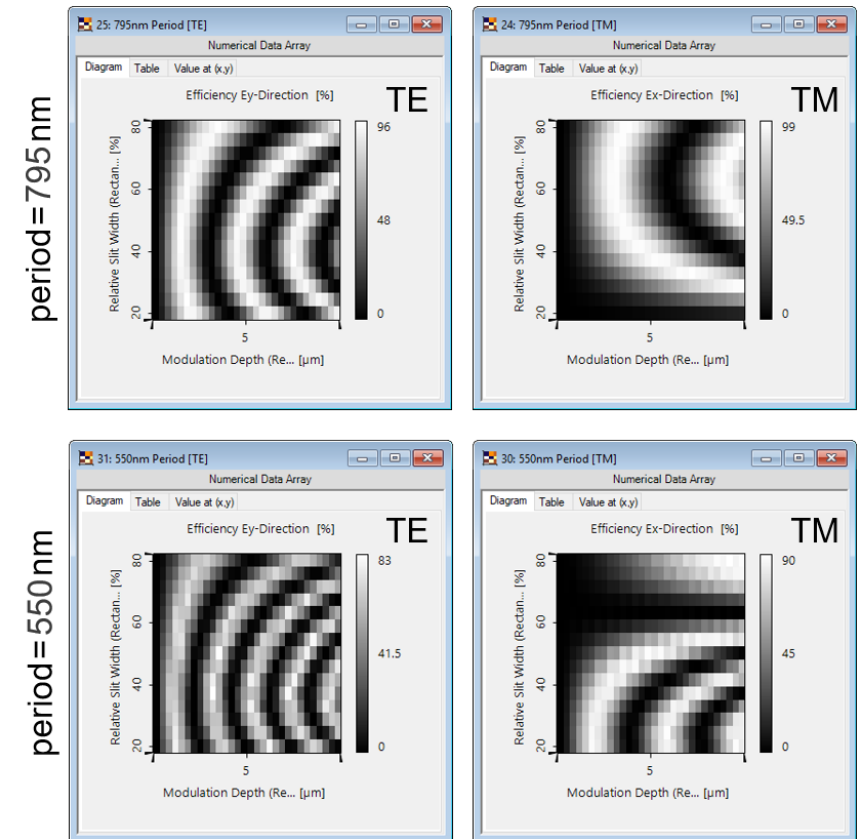
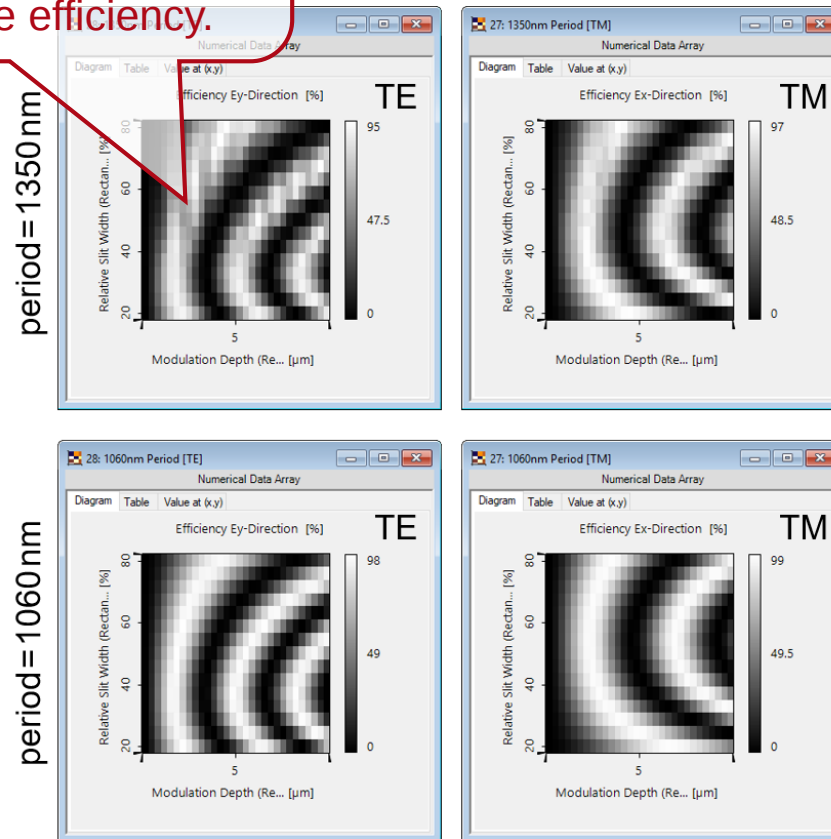
Large period leads to higher diffraction orders in the substrate, and causes additional modulation in the efficiency.

To ensure -1st transmission order exist (in air) and to avoid higher diffraction orders (in substrate), the grating period follows

$$\lambda/2 < d < 3\lambda/2n$$

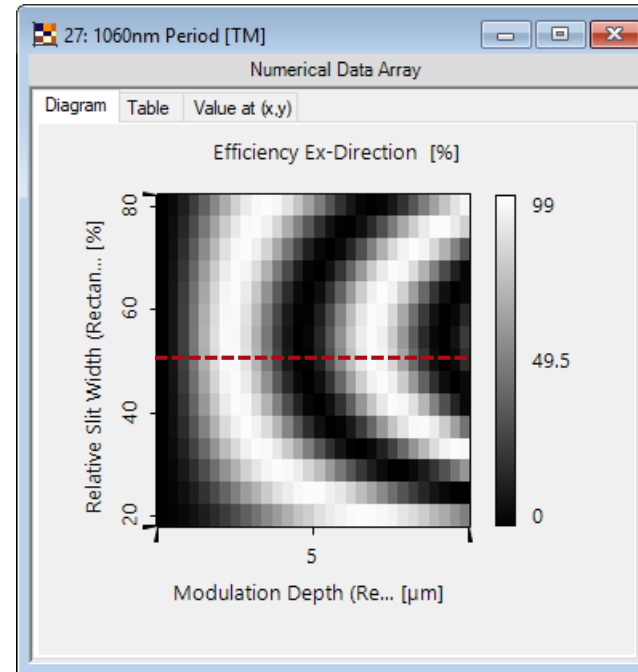
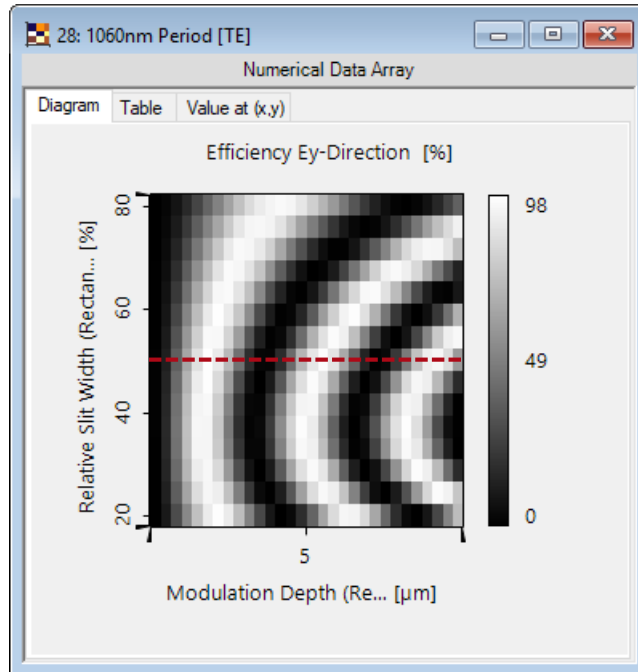
where n is the refractive index of the substrate.

Similar analysis can be found in T. Clausnitzer, *et al.*, Proc. SPIE **5252**, 174-182 (2003).



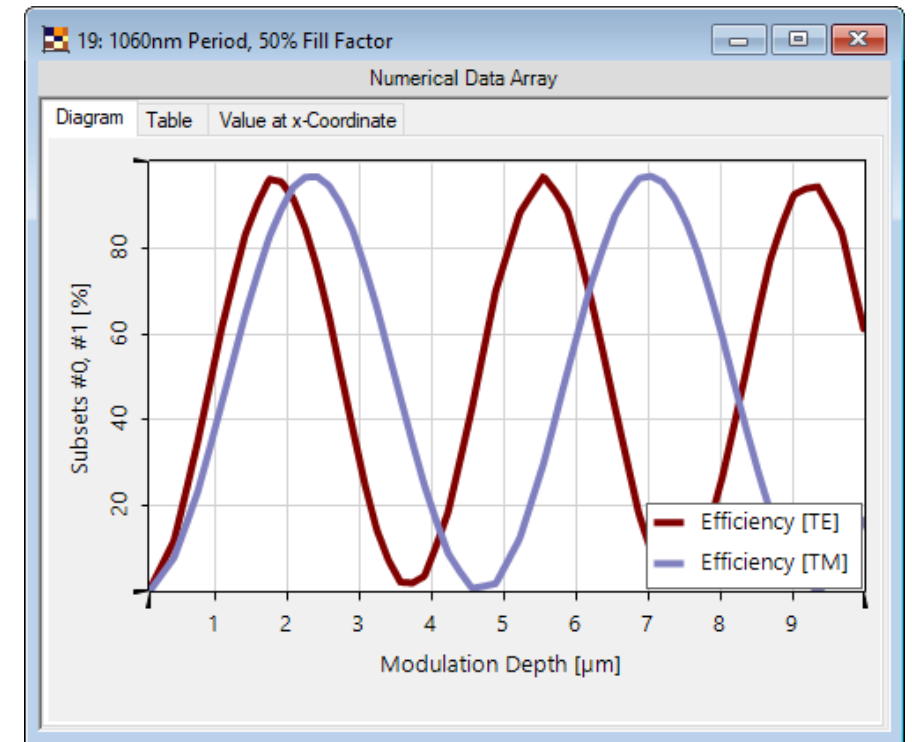
Polarization-Dependent Diffraction Property

diffraction efficiency analysis for given period 1060nm



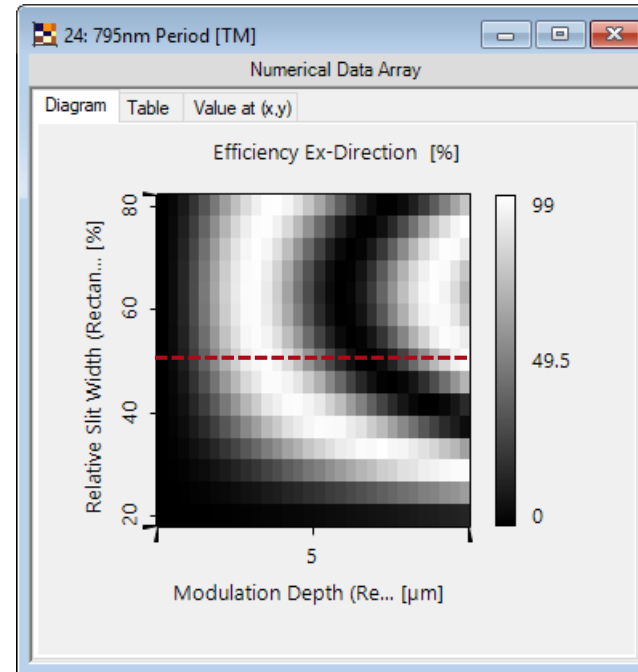
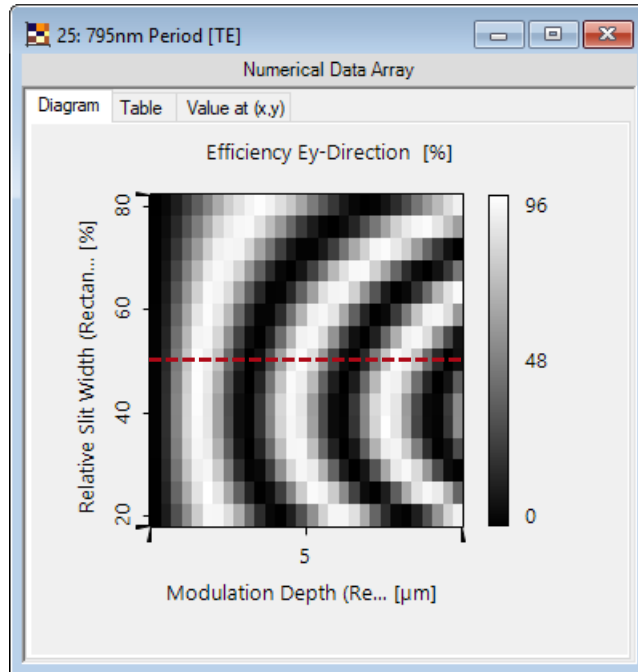
Parameter	Value
grating depth h	0.1-10μm
grating period d	1060 nm
fill factor f	20-80%

diffraction efficiencies vs. grating depth
(grating period=1060nm, fill factor=50%)



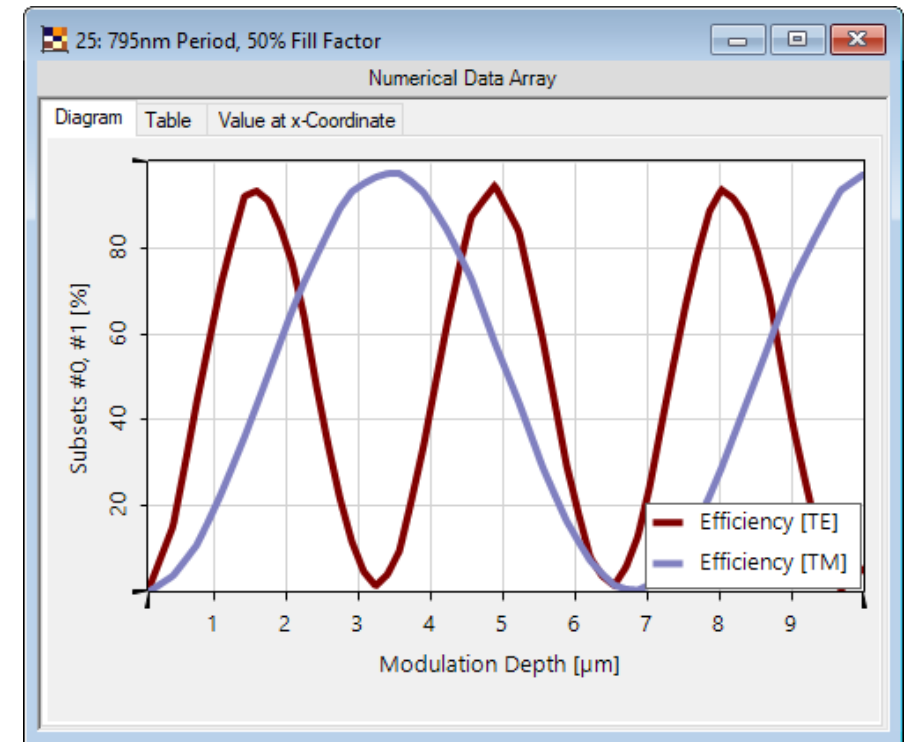
Polarization-Dependent Diffraction Property

diffraction efficiency analysis for given period 795nm



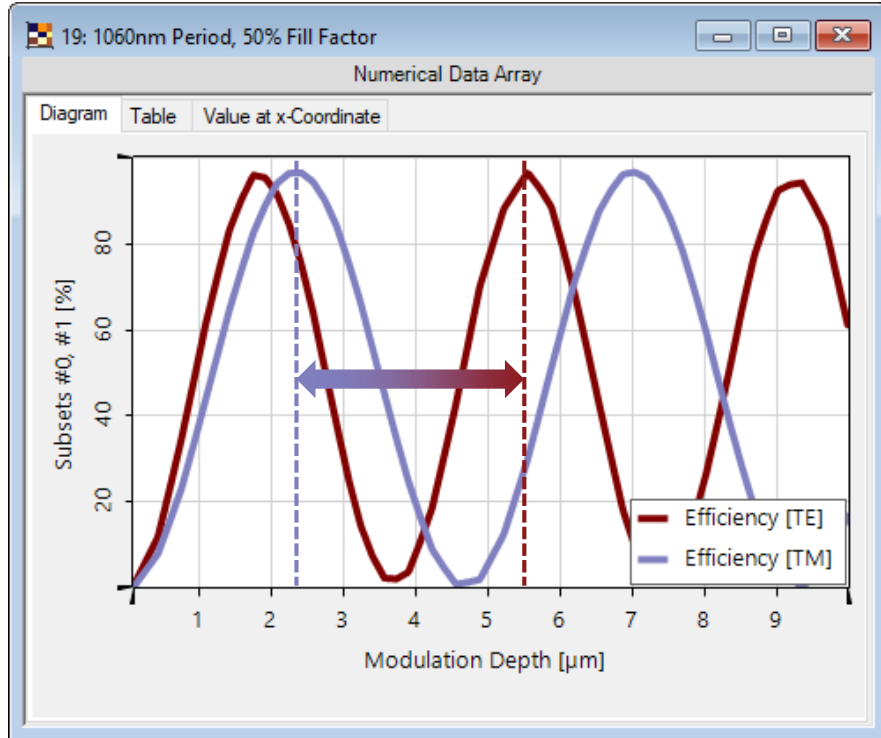
Parameter	Value
grating depth h	0.1-10μm
grating period d	795nm
fill factor f	20-80%

analysis of diffraction efficiency
with fixed fill factor 50%

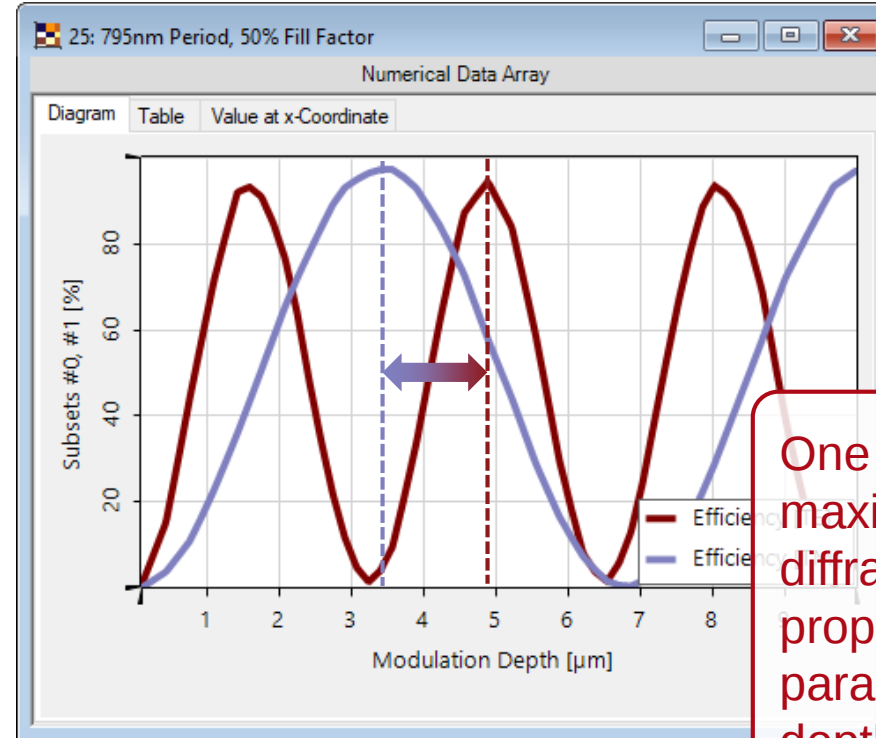


Polarization-Dependent Diffraction Property

diffraction efficiencies vs. grating depth
(grating period=**1060nm**, fill factor=50%)



diffraction efficiencies vs. grating depth
(grating period=**795nm**, fill factor=50%)



One could simultaneously maximize the TE and TM diffraction efficiencies by proper choice of grating parameters, e.g., period, depth, and fill factor.

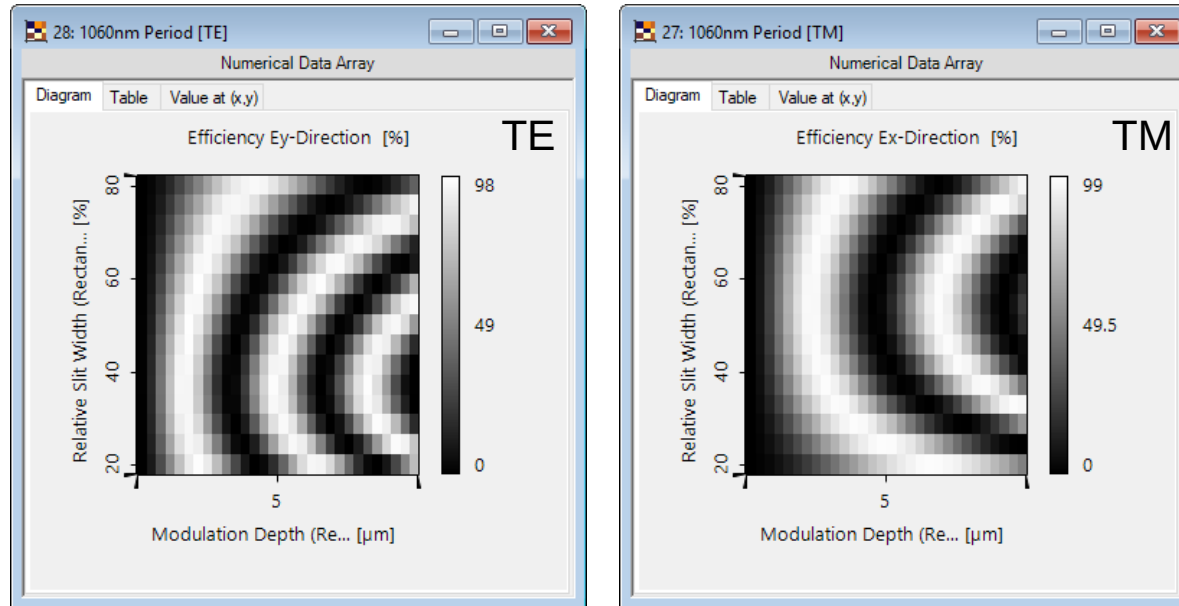
When grating period changes from 1060nm to 795nm

- the TE peak efficiency position shifts toward right i.e. larger grating depth;
- the TM peak efficiency position shifts toward left i.e. smaller grating depth.

Grating Design by Parametric Optimization

2D Parametric Optimization with Fixed Period

We use fixed period of 1060nm, with grating depth and fill factor as variables, and try to optimize the averaged diffraction efficiency.



The average diffraction efficiency can be defined as

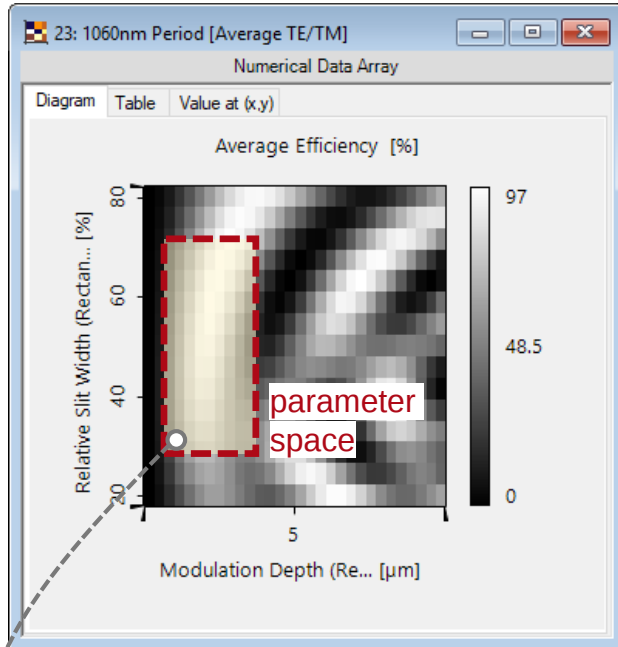
$$\eta^{\text{avg}} = \frac{1}{2} (\eta^{\text{TE}} + \eta^{\text{TM}}) ,$$

and it is to be maximized within the following parameter range

Parameter	Value Range
grating depth h	0.5-3.5μm
fill factor f	30-70%
grating period d	1060nm (fixed)

To keep a relatively low aspect ratio, we defined a reduced variation range of the grating depth and fill factor for design.

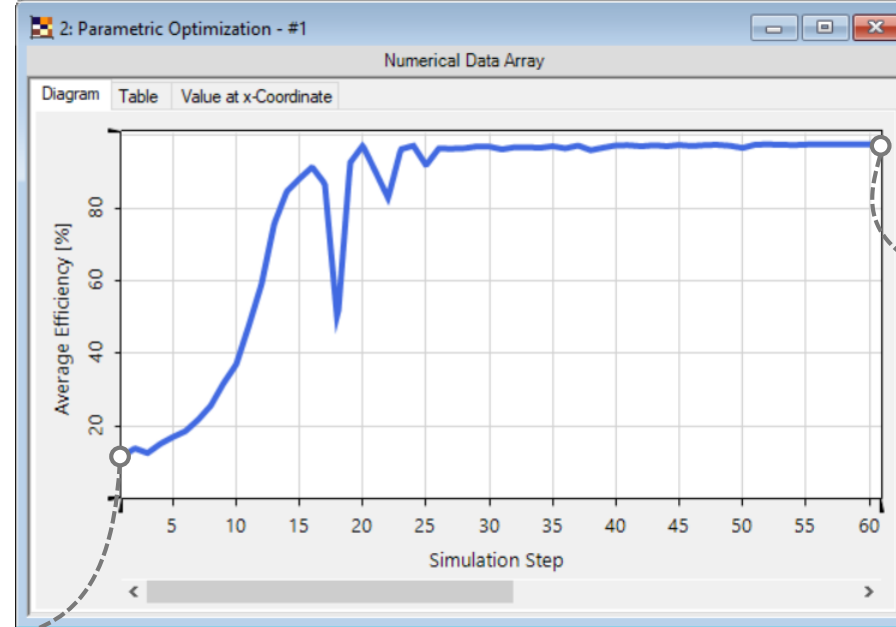
2D Parametric Optimization – Design #1



initial parameters

Parameter	Value
grating depth h	0.5 μm
fill factor f	30%
grating period d	1060 nm (fixed)

parametric optimization – downhill simplex

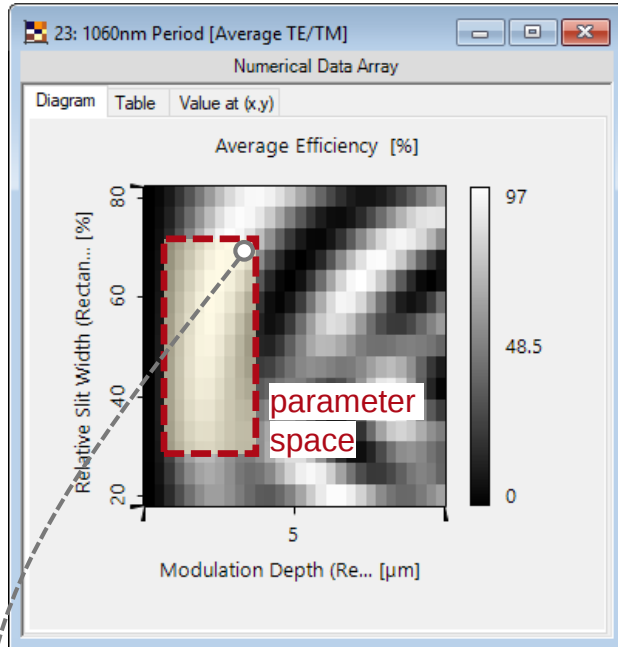


Diffraction efficiency in each optimization step is calculated using Fourier modal method (FMM, also known as RCWA).

optimized parameters

Parameter	Value
grating depth h	2.22 μm
fill factor f	59%
grating period d	1060 nm (fixed)

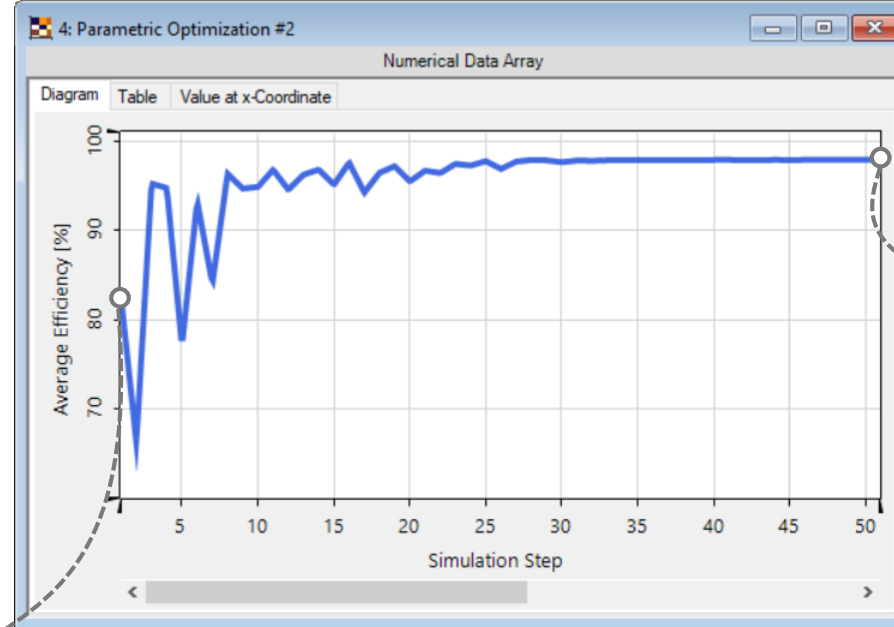
2D Parametric Optimization – Design #2



initial parameters

Parameter	Value
grating depth h	3.5 μm
fill factor f	70%
grating period d	1060 nm (fixed)

parametric optimization – downhill simplex



Diffraction efficiency in each optimization step is calculated using Fourier modal method (FMM, also known as RCWA).

optimized parameters

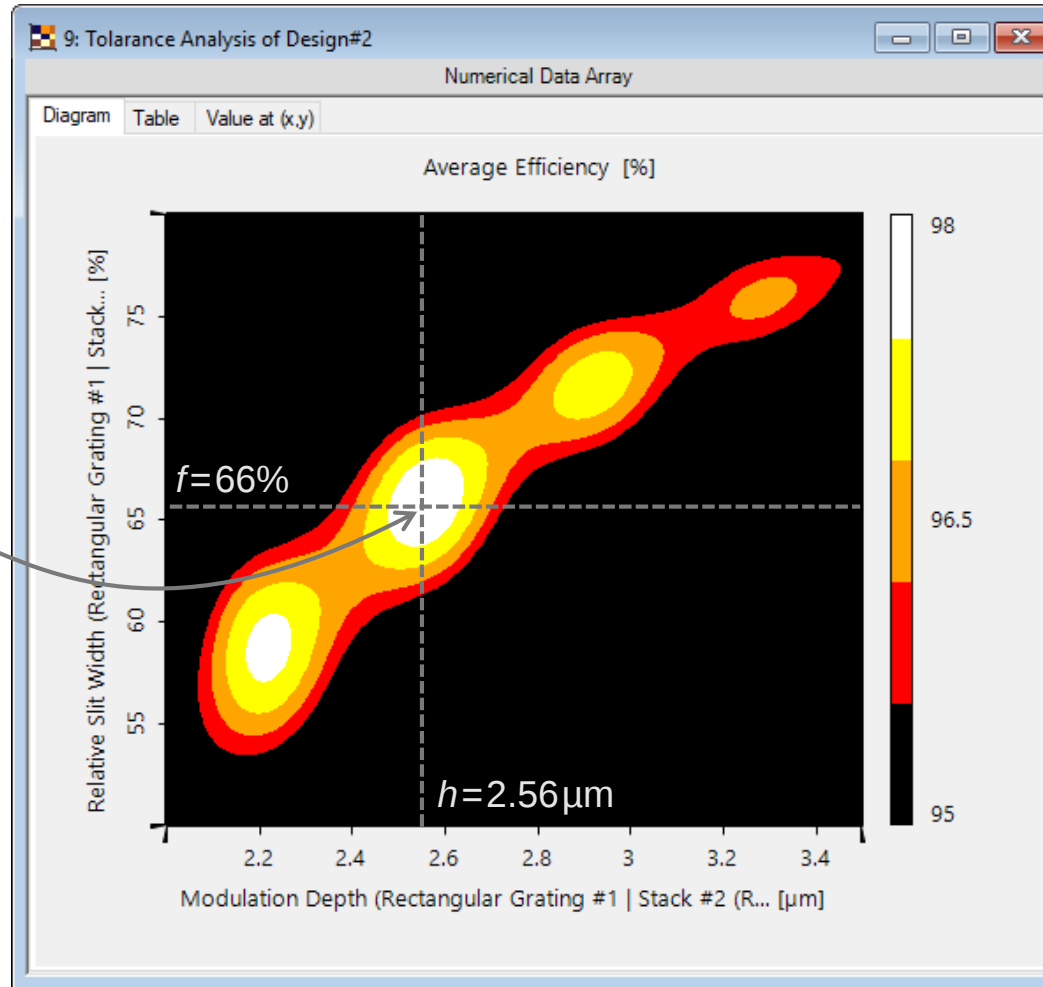
Parameter	Value
grating depth h	2.56 μm
fill factor f	66%
grating period d	1060 nm (fixed)

The same resulting parameters can be found in T. Clausnitzer, et al., Proc. SPIE **5252**, 174-182 (2003).

Fabrication Tolerance Analysis – Design #2

optimized parameters

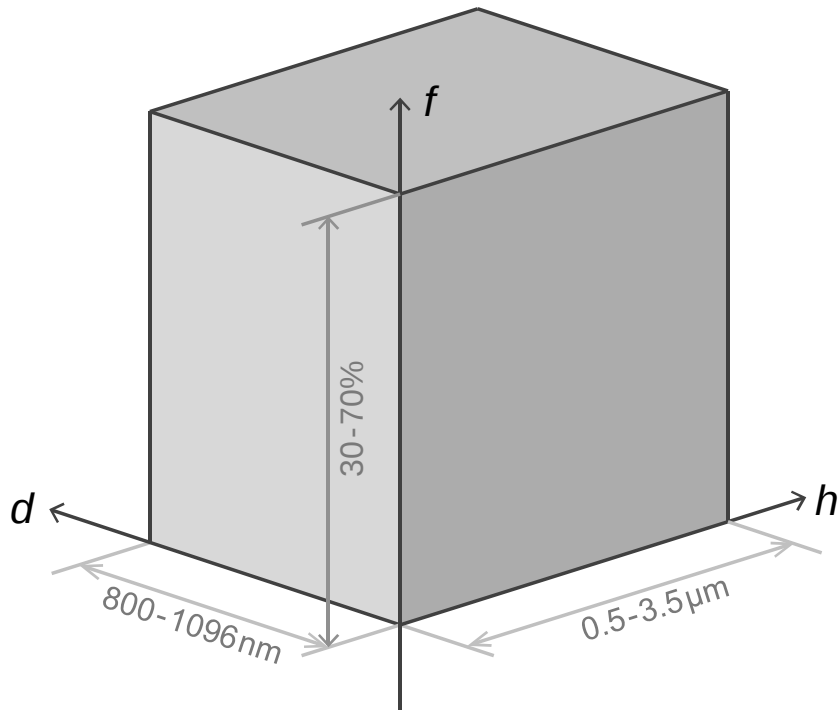
Parameter	Value
grating depth h	$2.56\mu\text{m}$
fill factor f	66%
grating period d	1060nm (fixed)



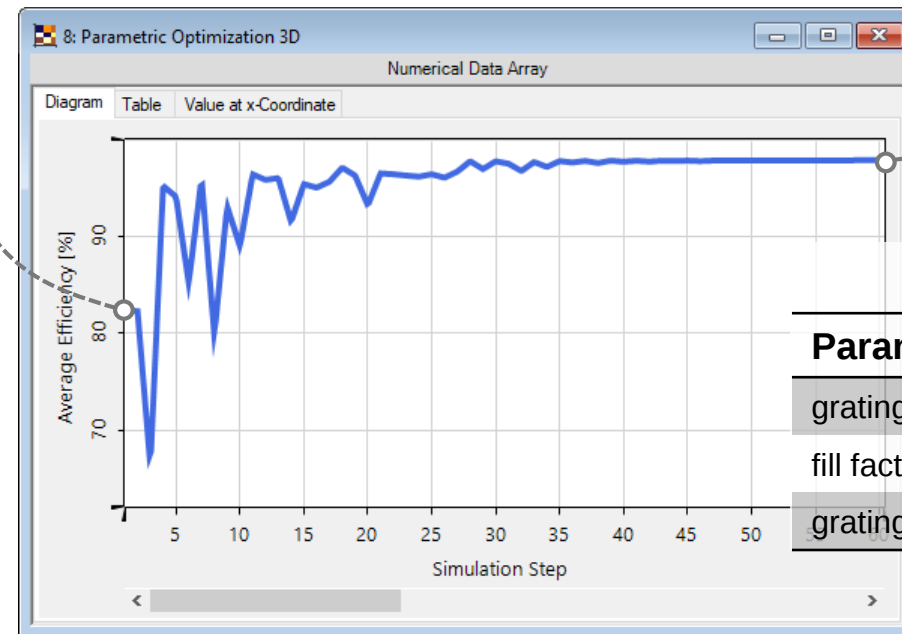
Diffraction efficiency within the region around the design parameters (efficiency value clipped above 95% only)

3D Parametric Optimization with Varying Grating Period

Parameter	Value Range	Initial Value
grating depth h	0.5-3.5 μm	3.5 μm
fill factor f	30-70%	70%
grating period d	800-1096 nm	1060 nm



parametric optimization – downhill simplex



optimized parameters

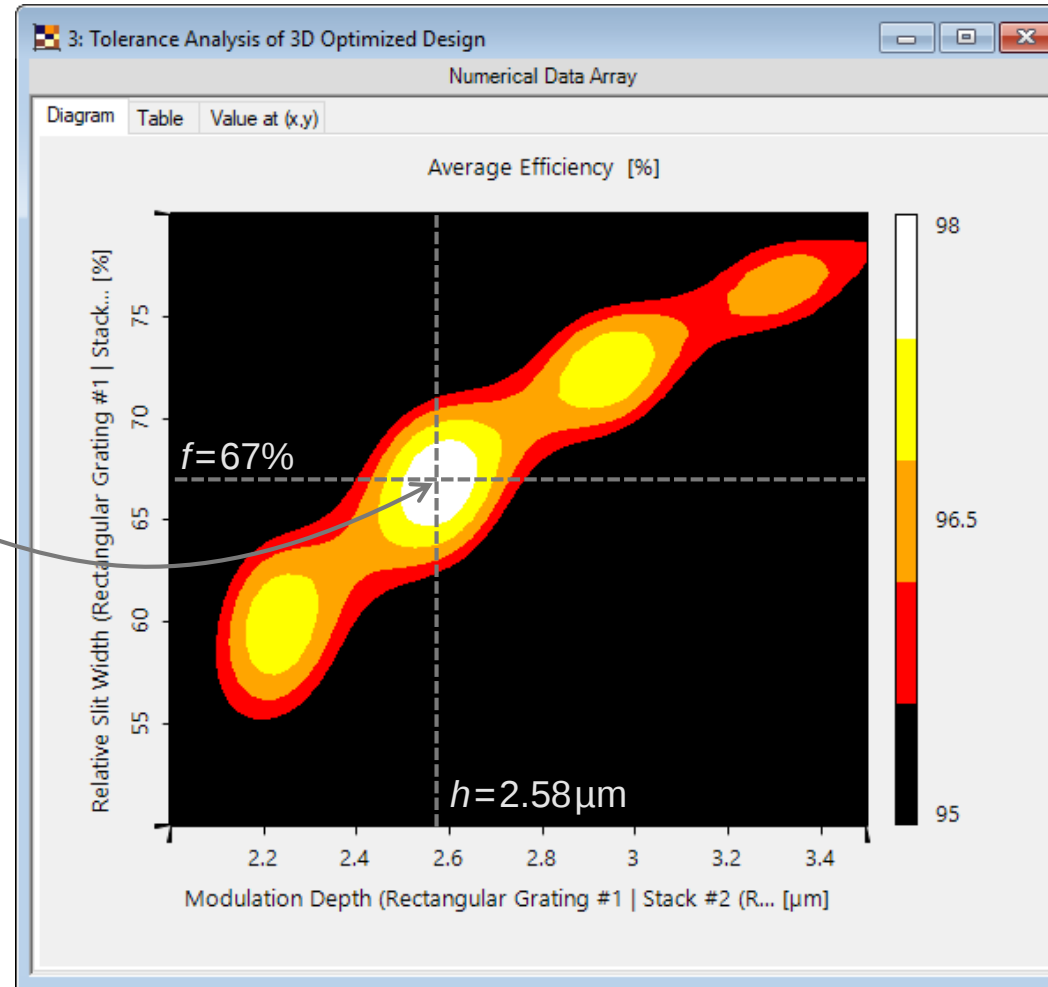
Parameter	Value
grating depth h	2.58 μm
fill factor f	67%
grating period d	1024 nm

Diffraction efficiency in each optimization step is calculated using Fourier modal method (FMM, also known as RCWA).

Fabrication Tolerance Analysis

optimized parameters

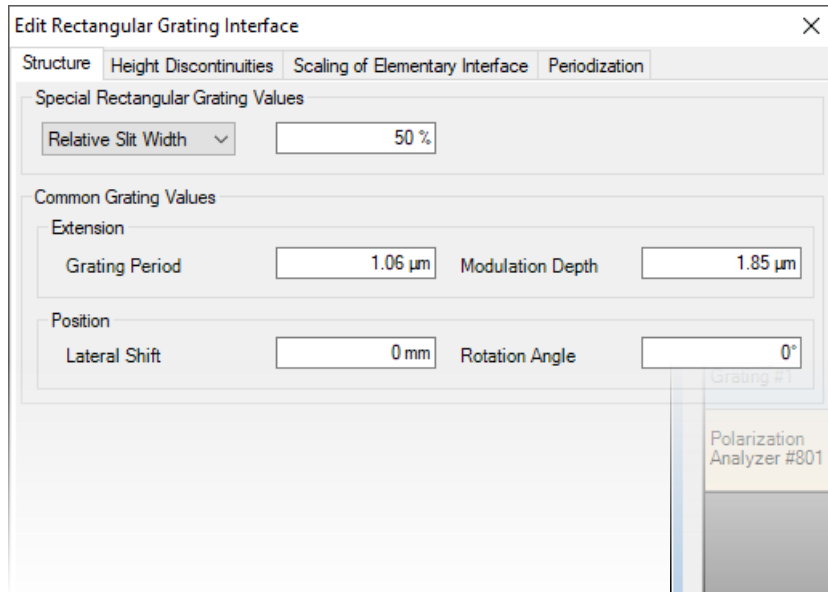
Parameter	Value
grating depth h	$2.58\mu\text{m}$
fill factor f	67%
grating period d	1024nm (fixed)



Diffraction efficiency within the region around the design parameters (efficiency value clipped above 95% only)

Peek into VirtualLab Fusion

intuitive grating parameters specification



Structure | Height Discontinuities | Scaling of Elementary Interface | Periodization

Special Rectangular Grating Values

Relative Slit Width: 50 %

Common Grating Values

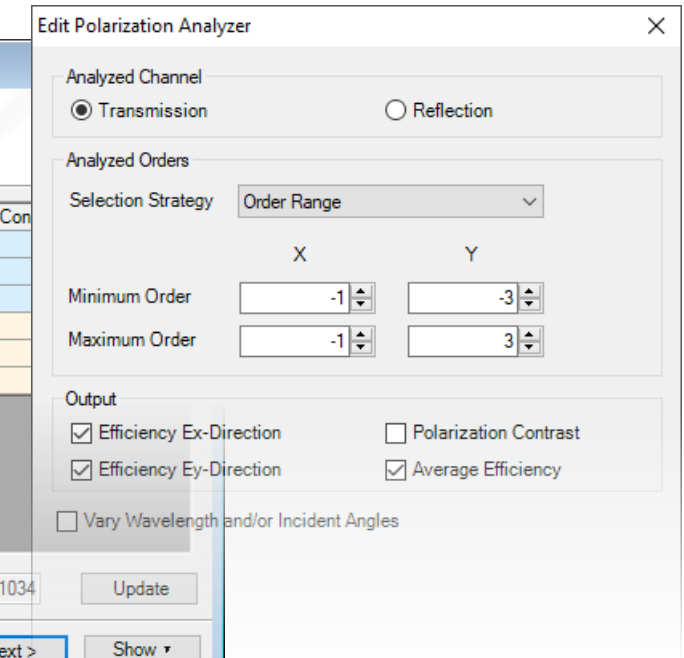
Extension

Grating Period: 1.06 μm Modulation Depth: 1.85 μm

Position

Lateral Shift: 0 mm Rotation Angle: 0°

special detector for polarization-related quantity analysis



Analyzed Channel

☒ Transmission ☐ Reflection

Analyzed Orders

Selection Strategy: Order Range

Minimum Order: X: -1 Y: -3

Maximum Order: X: -1 Y: 3

Output

☒ Efficiency Ex-Direction ☐ Polarization Contrast

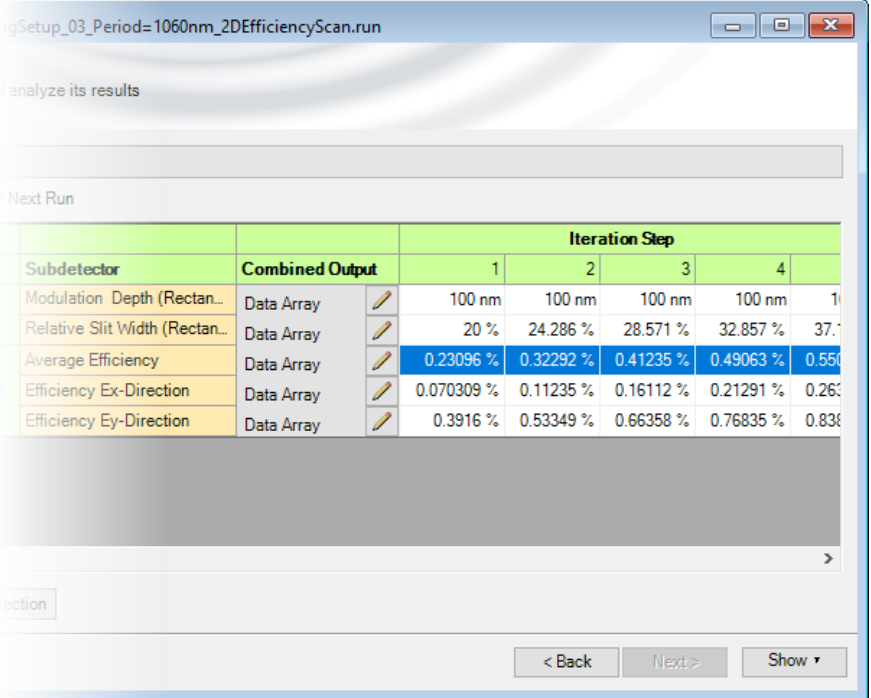
☒ Efficiency Ey-Direction ☒ Average Efficiency

☐ Vary Wavelength and/or Incident Angles

parametric optimization tools with friendly user interface

Workflow in VirtualLab Fusion

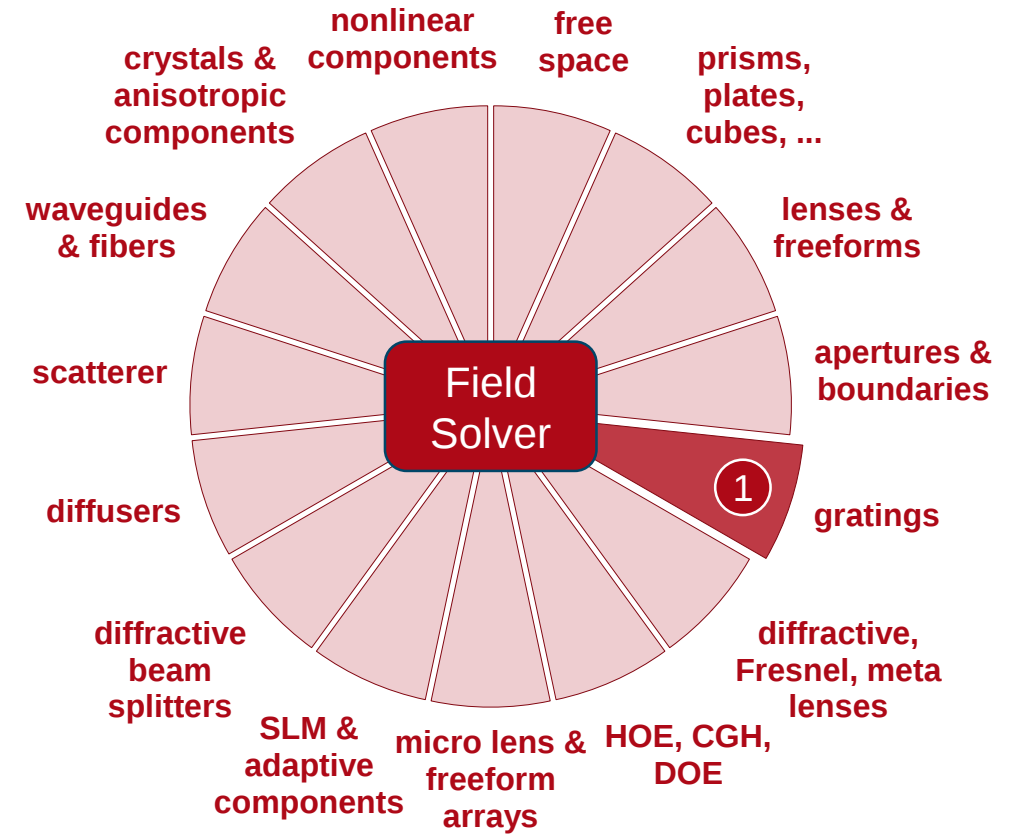
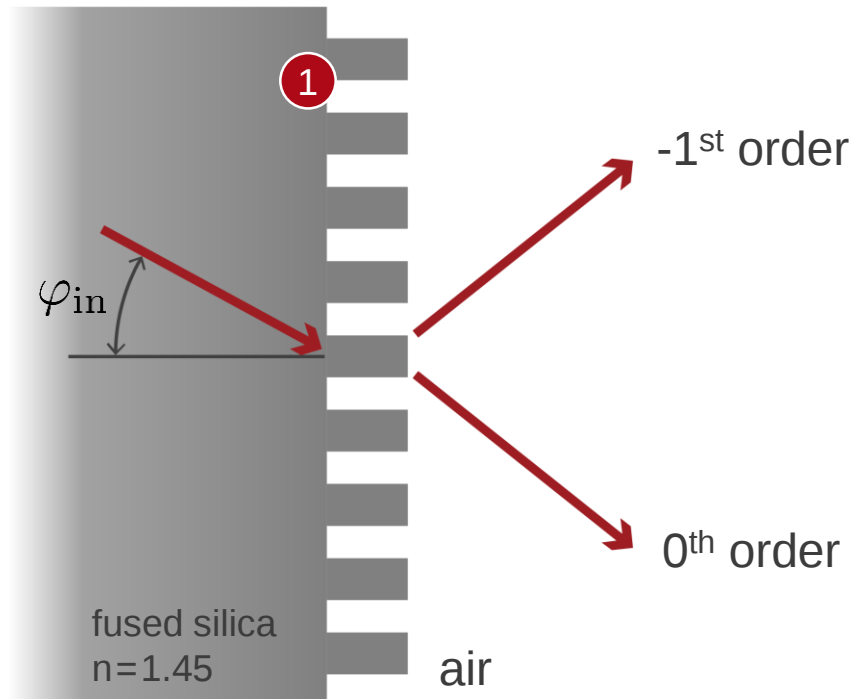
- Construct grating structure
 - [Configuration of Grating Structures by Using Interfaces](#) [Use Case]
- Analyze grating diffraction efficiency
 - [Grating Order Analyzer](#) [Use Case]
- Search for initial solutions with Parameter Run
 - [Usage of the Parameter Run Document](#) [Use Case]
- Find final design with Parametric Optimization



The screenshot shows a window titled "gSetup_03_Period=1060nm_2DEfficiencyScan.run". Below the title bar, there is a text area with the instruction "Analyze its results". Below this, there is a section labeled "Next Run" which contains a table of results. The table has columns for "Subdetector", "Combined Output", and "Iteration Step" (1, 2, 3, 4, 5). The rows represent different parameters: "Modulation Depth (Rectan...", "Relative Slit Width (Rectan...", "Average Efficiency", "Efficiency Ex-Direction", and "Efficiency Ey-Direction". Each row shows the values for the five iteration steps. The "Average Efficiency" row is highlighted in blue.

Subdetector	Combined Output	Iteration Step				
		1	2	3	4	5
Modulation Depth (Rectan...	Data Array	100 nm	100 nm	100 nm	100 nm	100 nm
Relative Slit Width (Rectan...	Data Array	20 %	24.286 %	28.571 %	32.857 %	37.143 %
Average Efficiency	Data Array	0.23096 %	0.32292 %	0.41235 %	0.49063 %	0.55882 %
Efficiency Ex-Direction	Data Array	0.070309 %	0.11235 %	0.16112 %	0.21291 %	0.26316 %
Efficiency Ey-Direction	Data Array	0.3916 %	0.53349 %	0.66358 %	0.76835 %	0.83824 %

VirtualLab Fusion Technologies



Document Information

title	Analysis and Design of Highly Efficient Polarization Independent Transmission Gratings
document code	GRT.0015
version	1.0
toolbox(es)	Grating Toolbox
VL version used for simulations	7.5.0.158
category	Application Use Case
further reading	- Ultra-Sparse Dielectric Nano-Wire Grid Polarizers - Rigorous Analysis of Nanopillar Metasurface Building Block - Parametric Optimization and Tolerance Analysis of Slanted Gratings