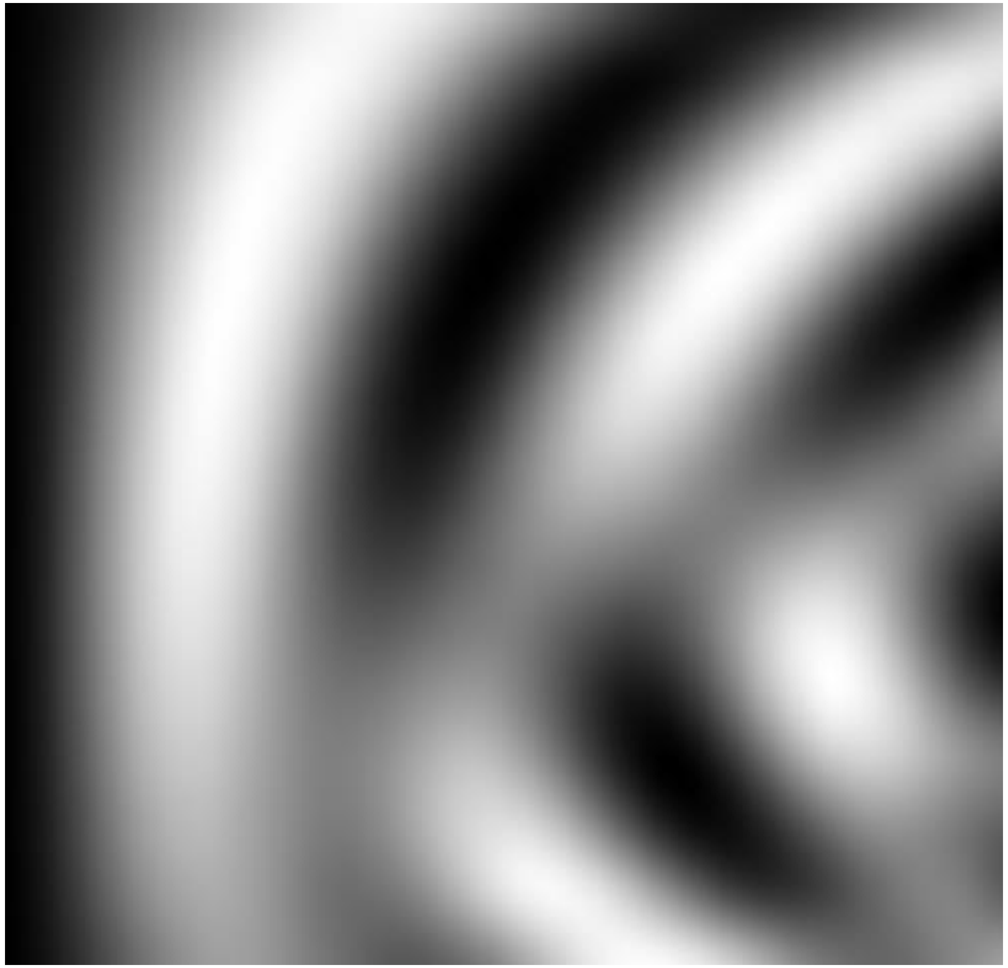
Analysis and Design of Highly Efficient Polarization Independent Transmission Gratings

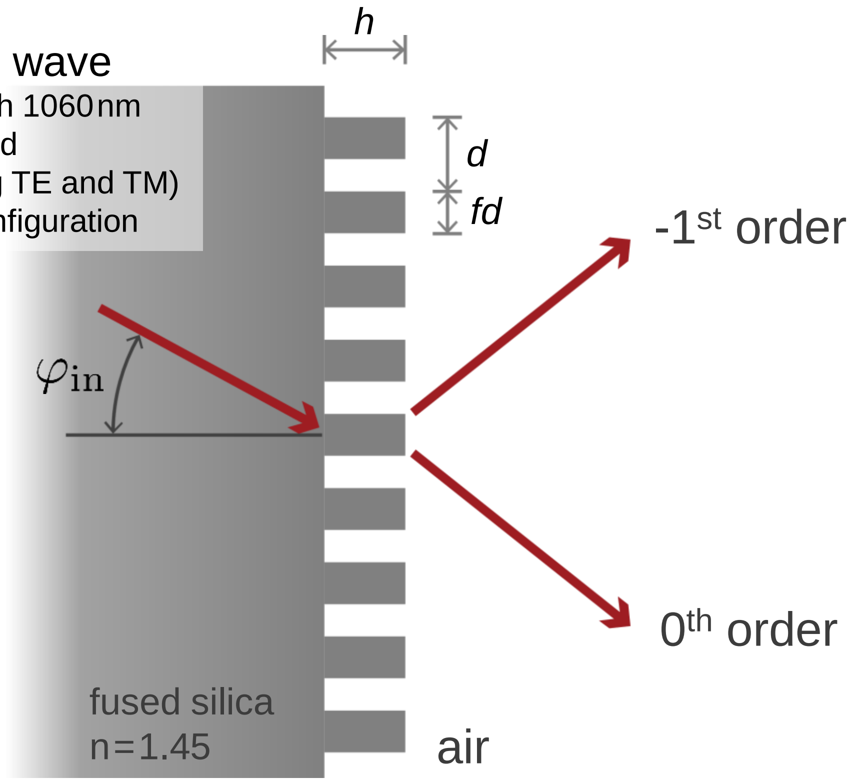
Abstract



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

input plane wave
- wavelength 1060 nm
- unpolarized (averaging TE and TM)
- Littrow configuration



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

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

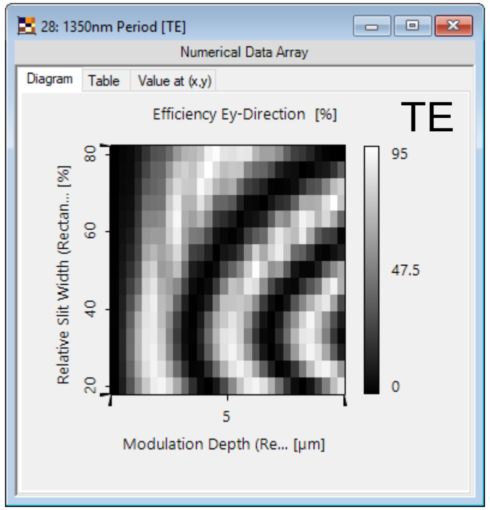
?

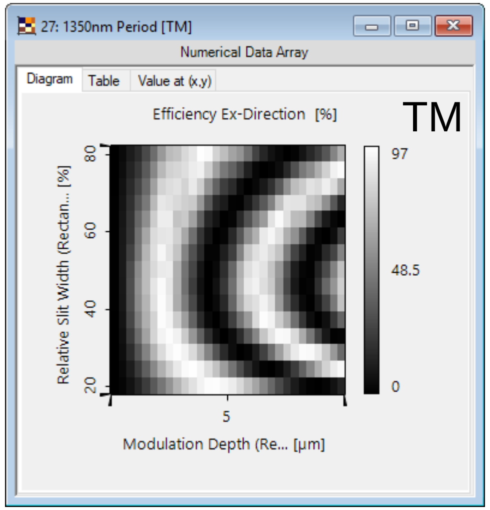
Parameter	Value Range
grating depth *h*	0.1-10 µm
grating period *d*	550-1350 nm
fill factor *f*	20-80%

Rigorous Analysis of Grating Property vs. Parameters

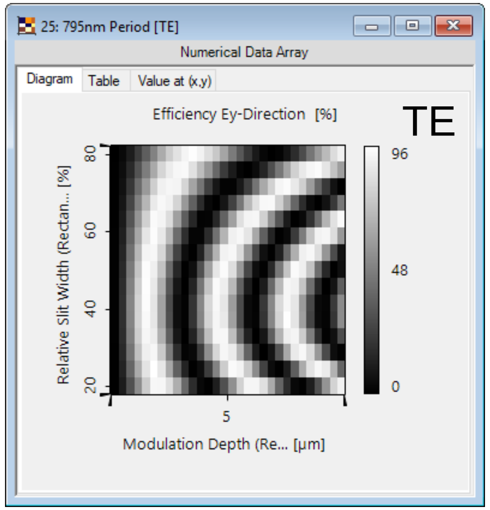
Diffraction Efficiency @ Different Grating Periods

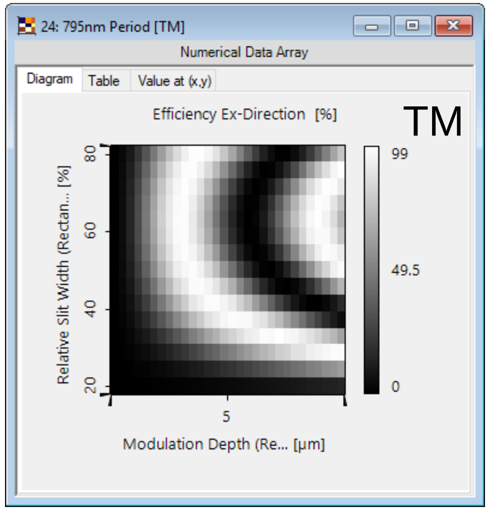
period=1350nm



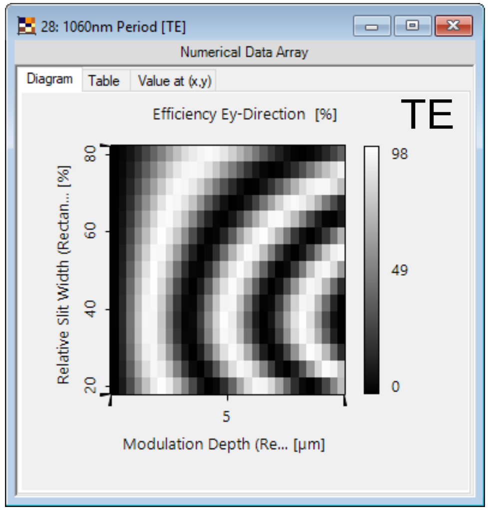


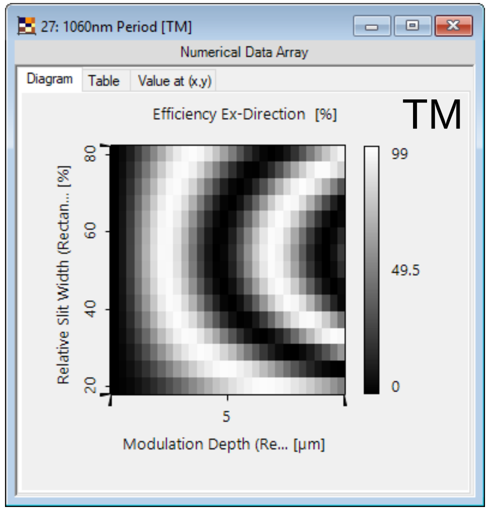
period=795nm



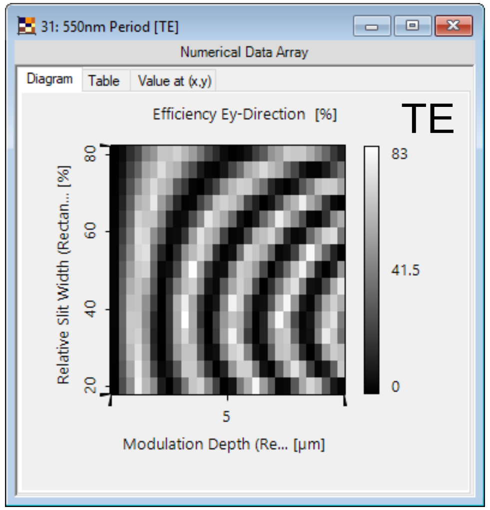


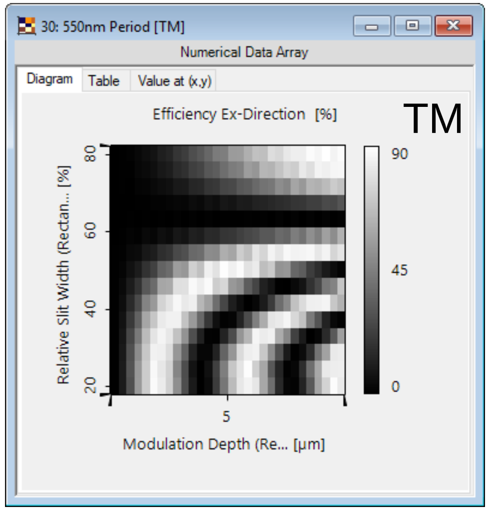
period=1060nm





period=550nm





Considerations on Grating Period Choice

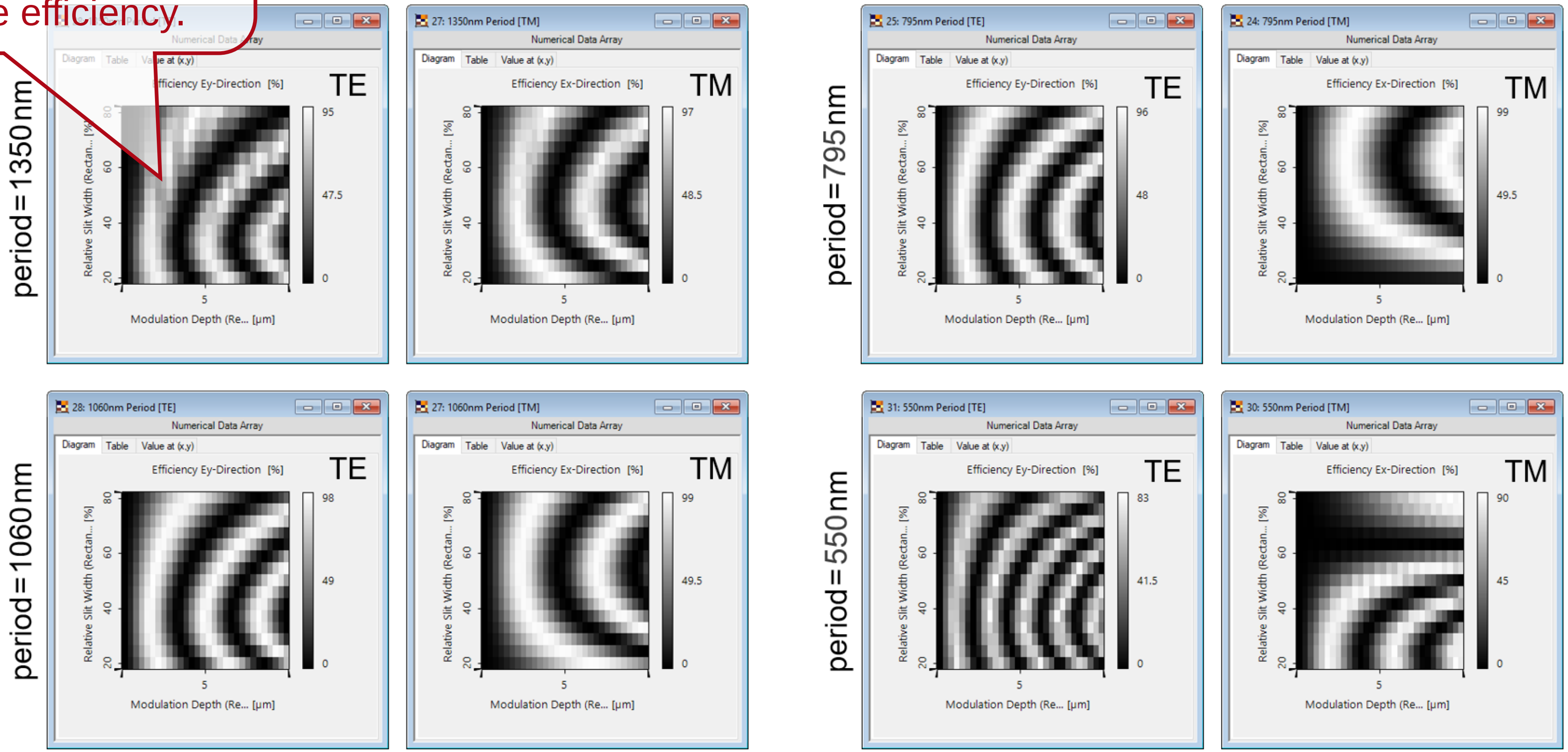
Large period leads to higher diffraction orders in the substrate, and causes additional modulation in the efficiency.

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

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

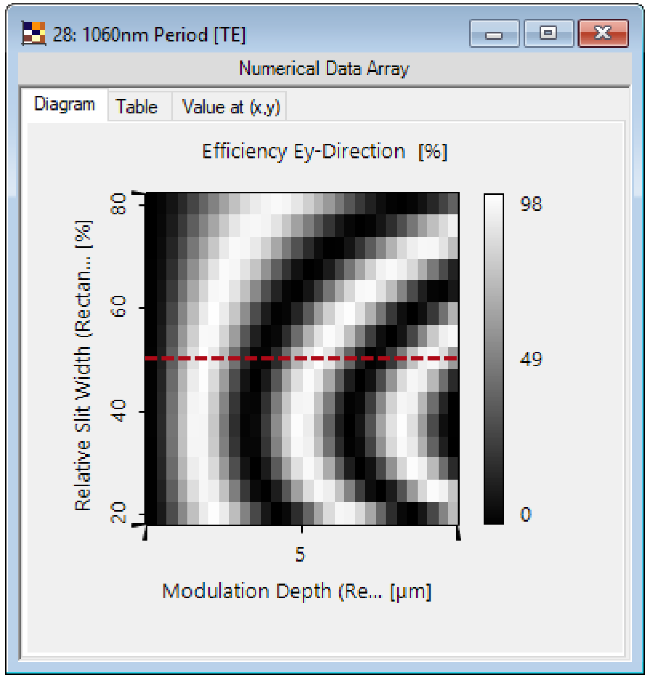
$$\lambda/2 < d < 3\lambda/2n$$

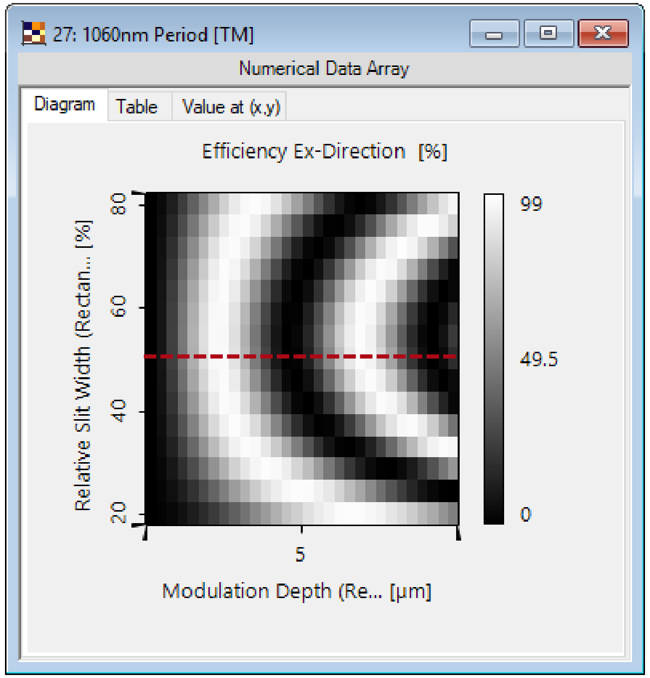
where n is the refractive index of the substrate.



Polarization-Dependent Diffraction Property

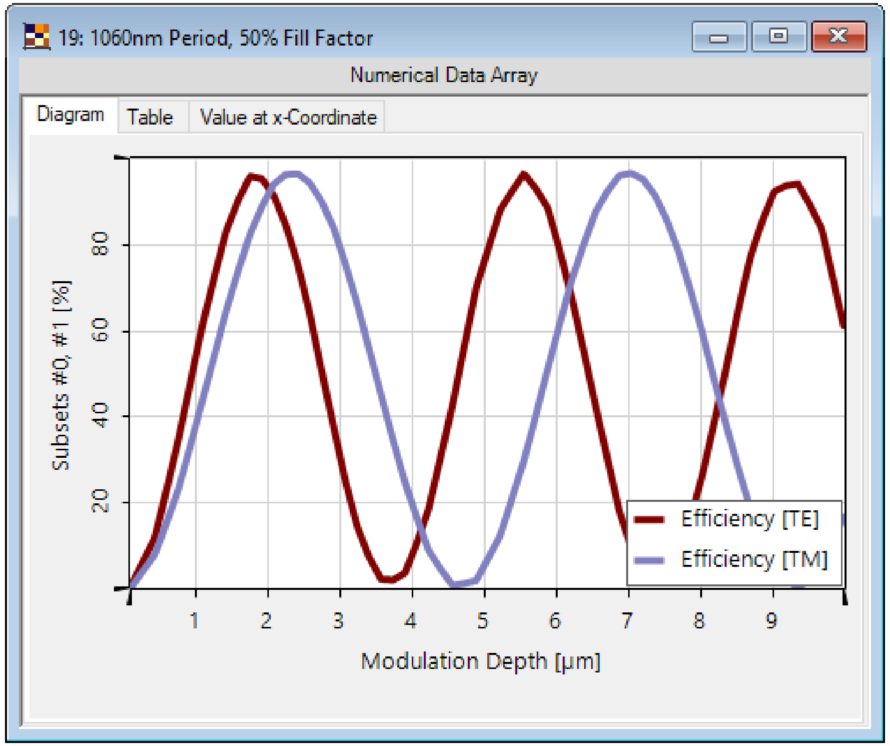
diffraction efficiency analysis for given period 1060 nm





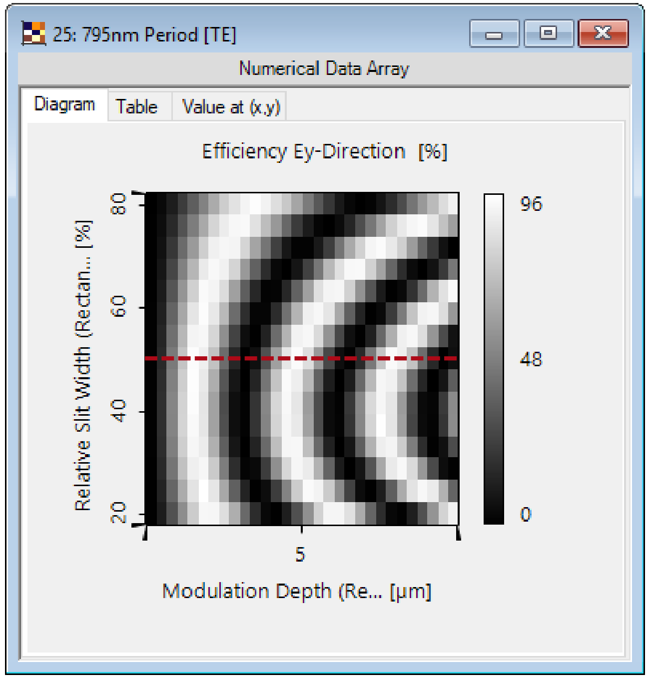
Parameter	Value
grating depth *h*	0.1-10 µm
grating period *d*	**1060 nm**
fill factor *f*	20-80%

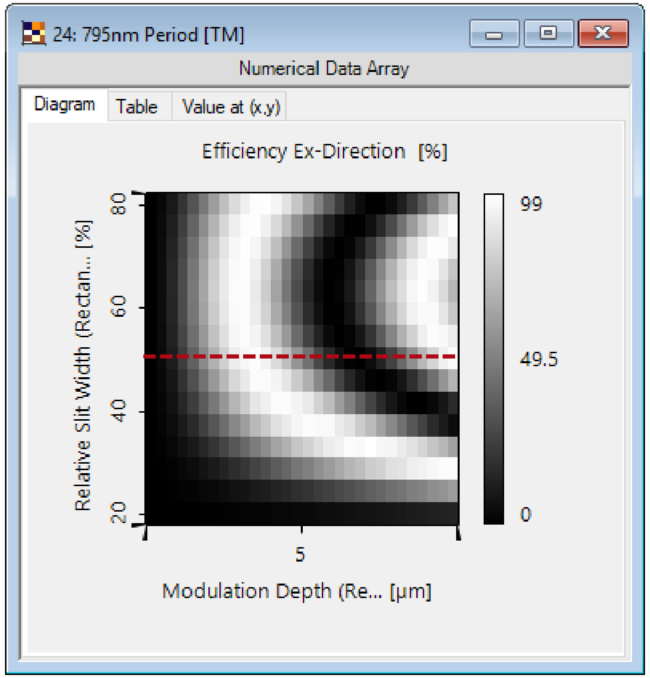
diffraction efficiencies vs. grating depth
(grating period = 1060 nm, fill factor = 50%)



Polarization-Dependent Diffraction Property

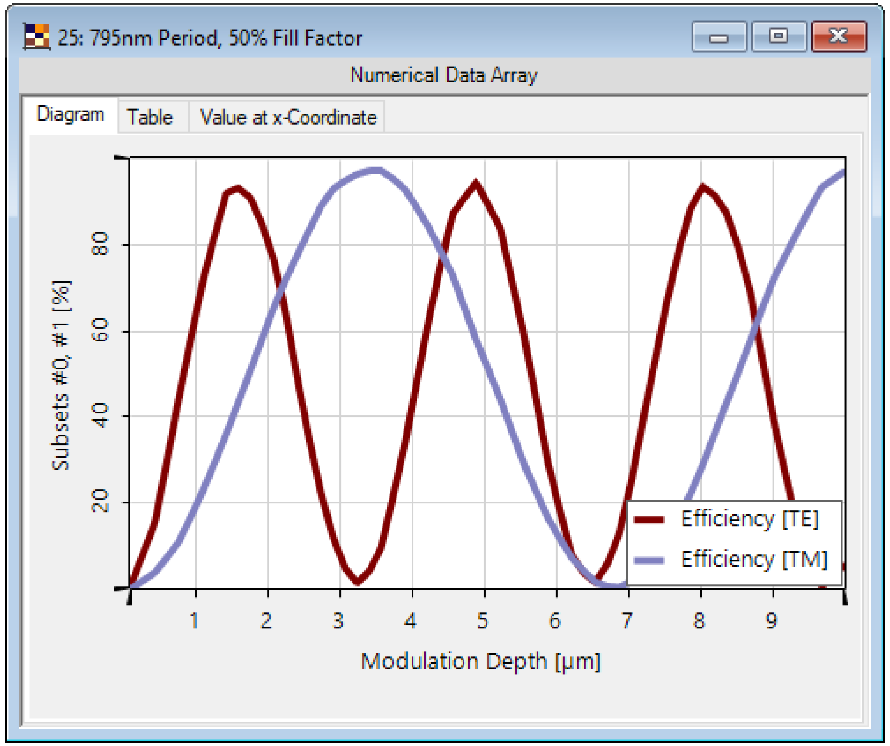
diffraction efficiency analysis for given period 795 nm





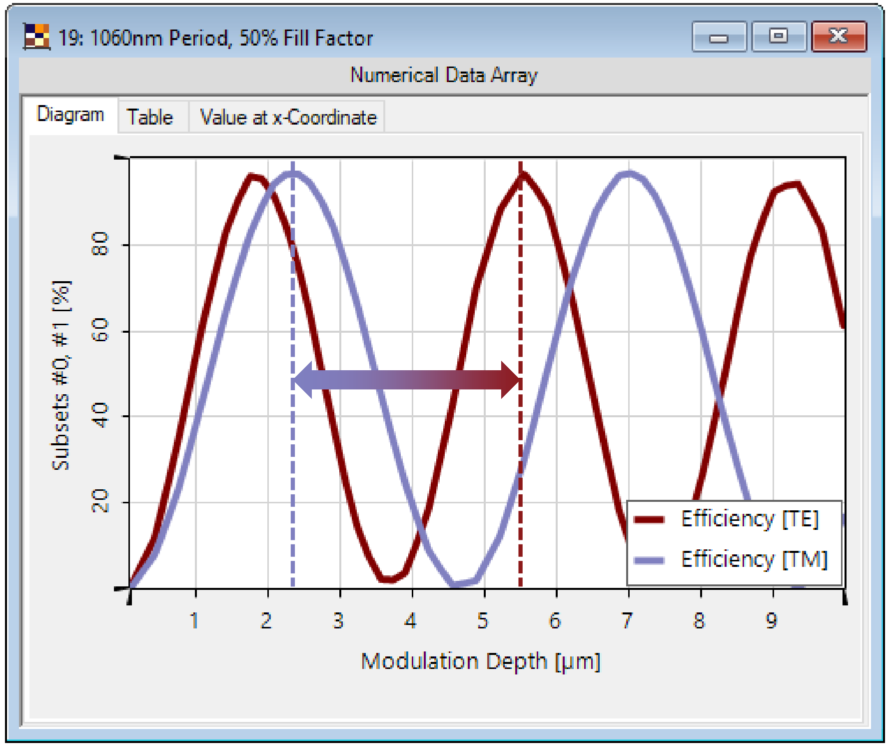
Parameter	**Value**
grating depth *h*	0.1 - 10 µm
grating period *d*	**795 nm**
fill factor *f*	20 - 80%

analysis of diffraction efficiency with fixed fill factor 50%

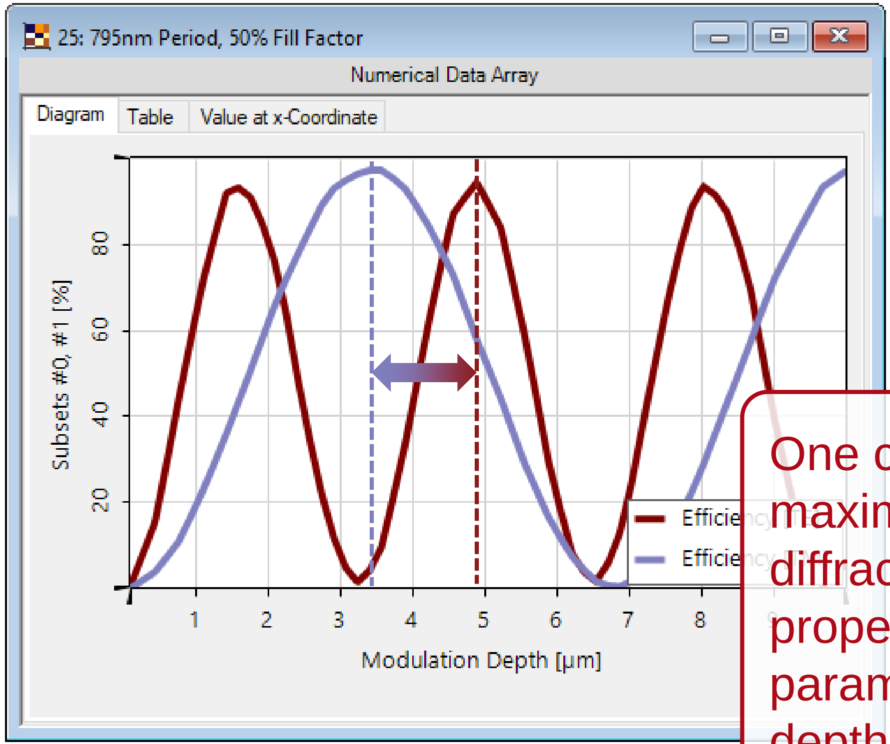


Polarization-Dependent Diffraction Property

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.

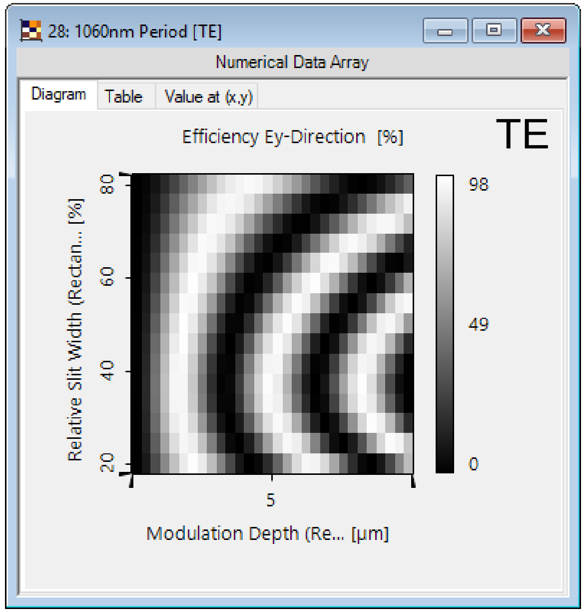
When grating period changes from 1060nm to 795nm

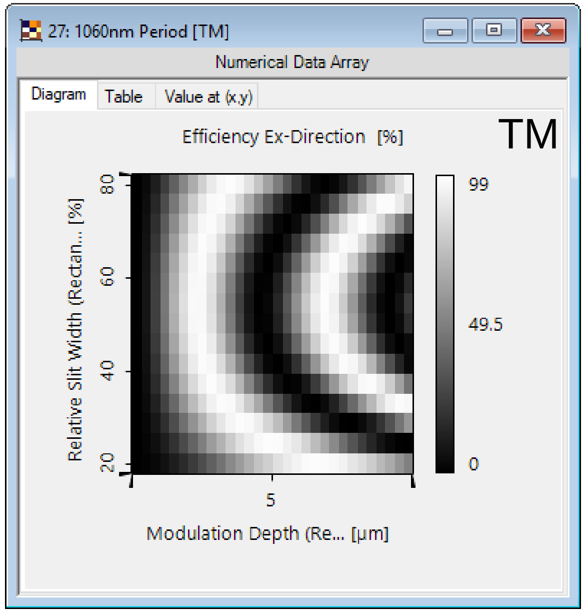
- the TE peak efficiency position shifts toward right i.e. larger grating depth;
- the TM peak efficiency position shifts toward left i.e. smaller grating depth.

Grating Design by Parametric Optimization

2D Parametric Optimization with Fixed Period

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





The average diffraction efficiency can be defined as

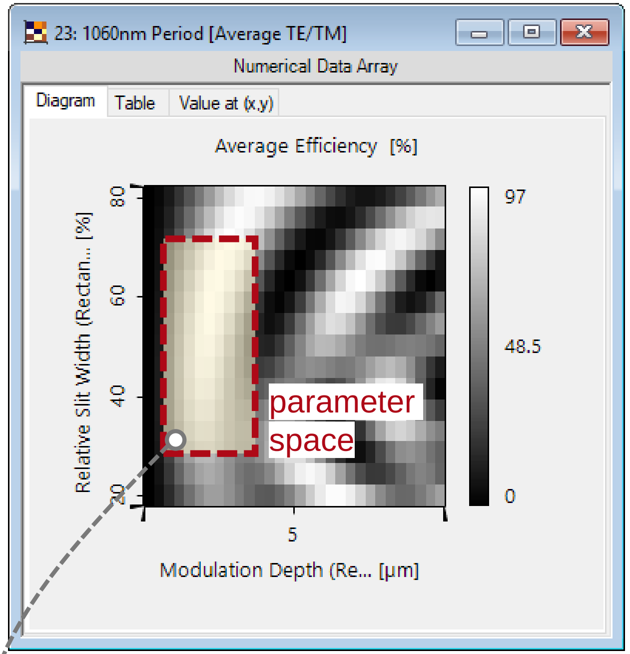
$$\eta^{\text{avg}} = \frac{1}{2}\left(\eta^{\text{TE}} + \eta^{\text{TM}}\right) ,$$

and it is to be maximized within the following parameter range

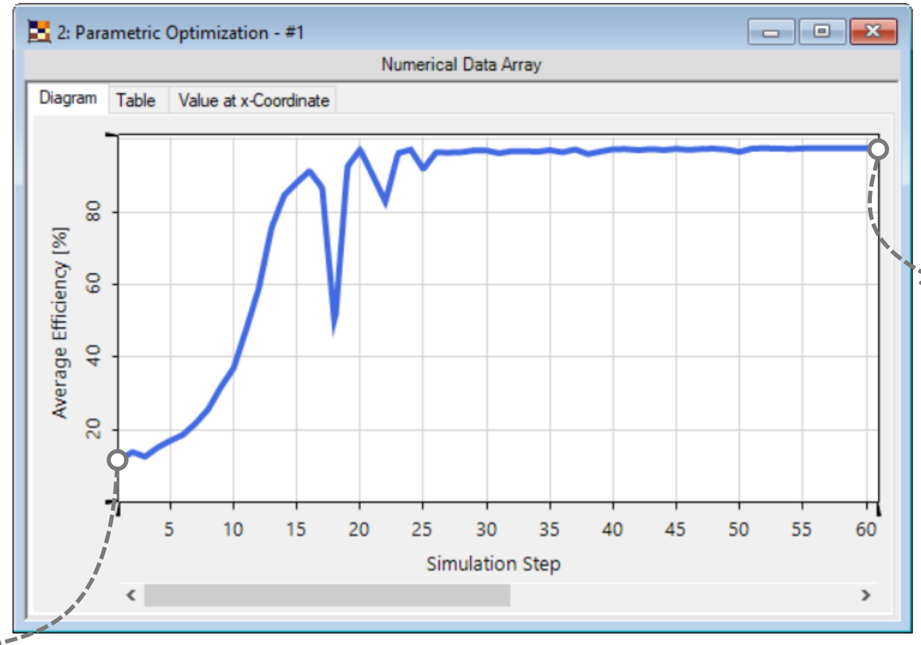
Parameter	Value Range
grating depth h	0.5-3.5 µm
fill factor f	30-70%
grating period d	**1060 nm (fixed)**

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



parametric optimization – downhill simplex



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

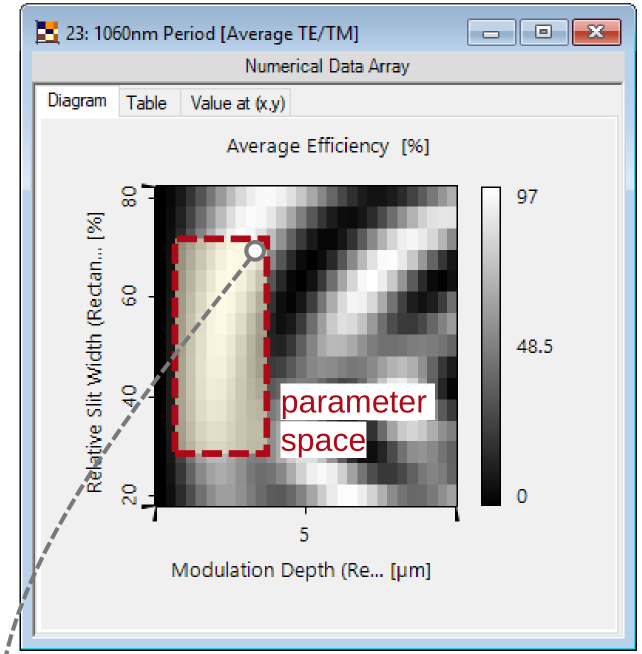
optimized parameters

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

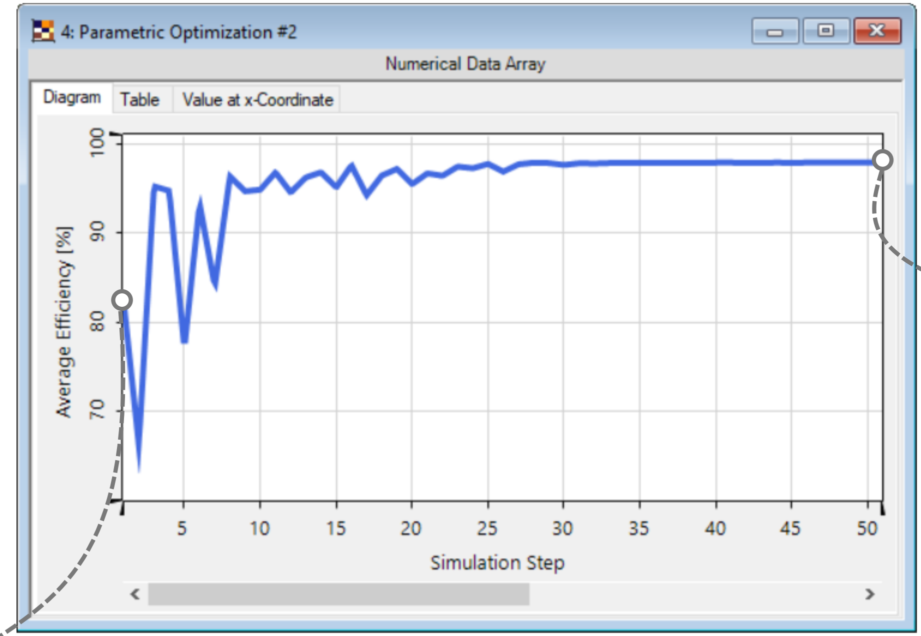
initial parameters

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

2D Parametric Optimization – Design #2



parametric optimization – downhill simplex



initial parameters

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

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

optimized parameters

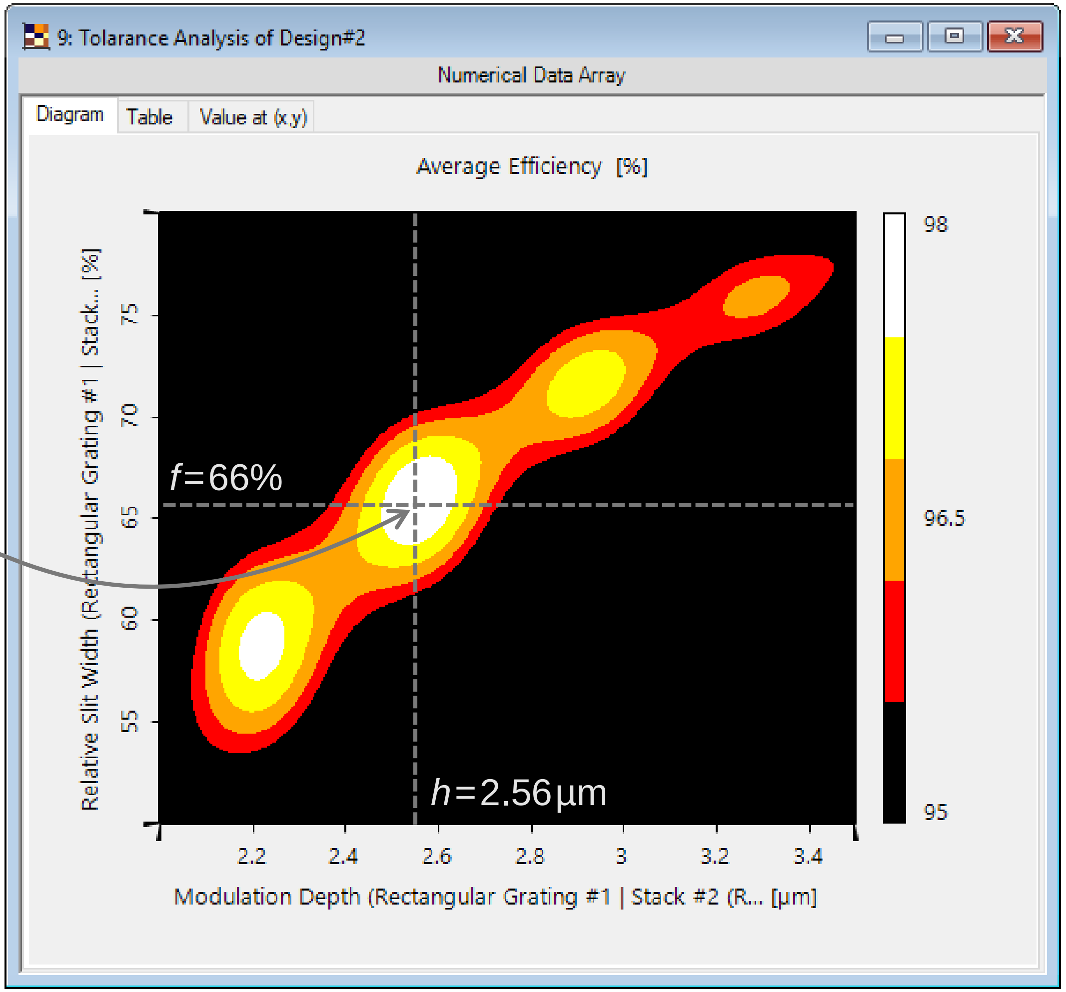
Parameter	Value
grating depth *h*	2.56µm
fill factor *f*	66%
grating period *d*	**1060nm (fixed)**

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

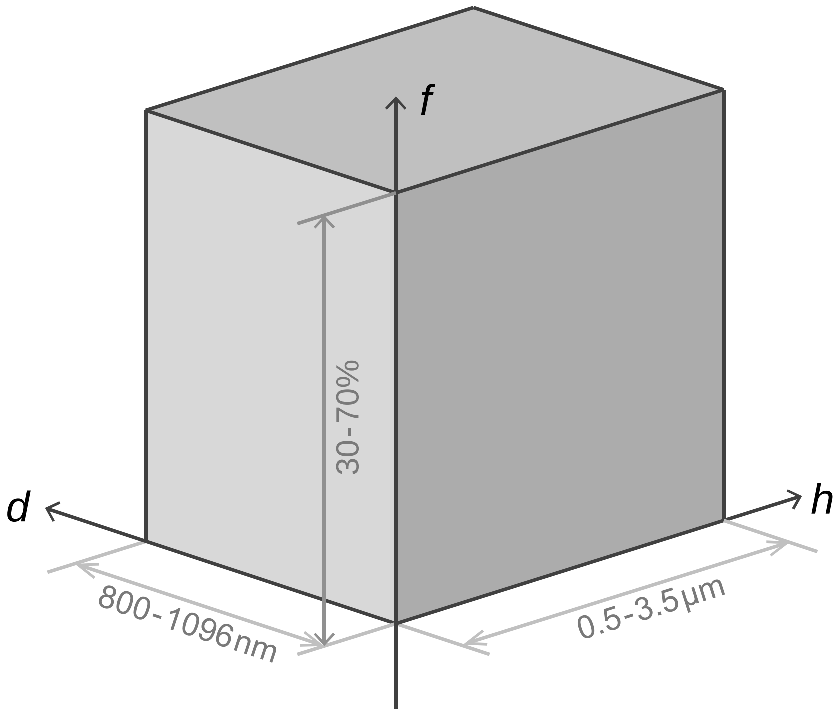
Parameter	Value
grating depth *h*	2.56 µm
fill factor *f*	66 %
grating period *d*	**1060 nm (fixed)**



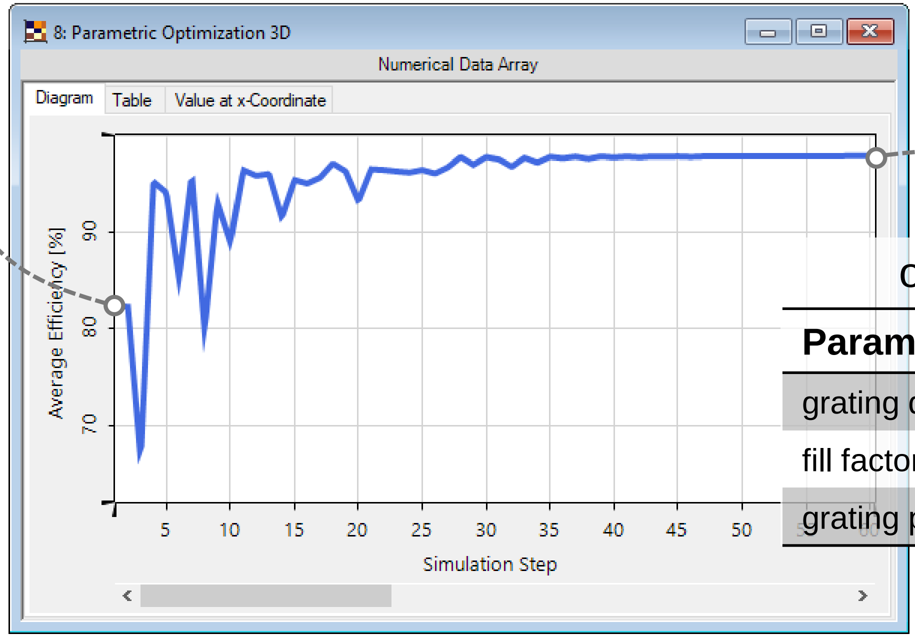
Diffraction efficiency within the region around the design parameters (efficiency value clipped above 95% only)

3D Parametric Optimization with Varying Grating Period

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



parametric optimization – downhill simplex



optimized parameters

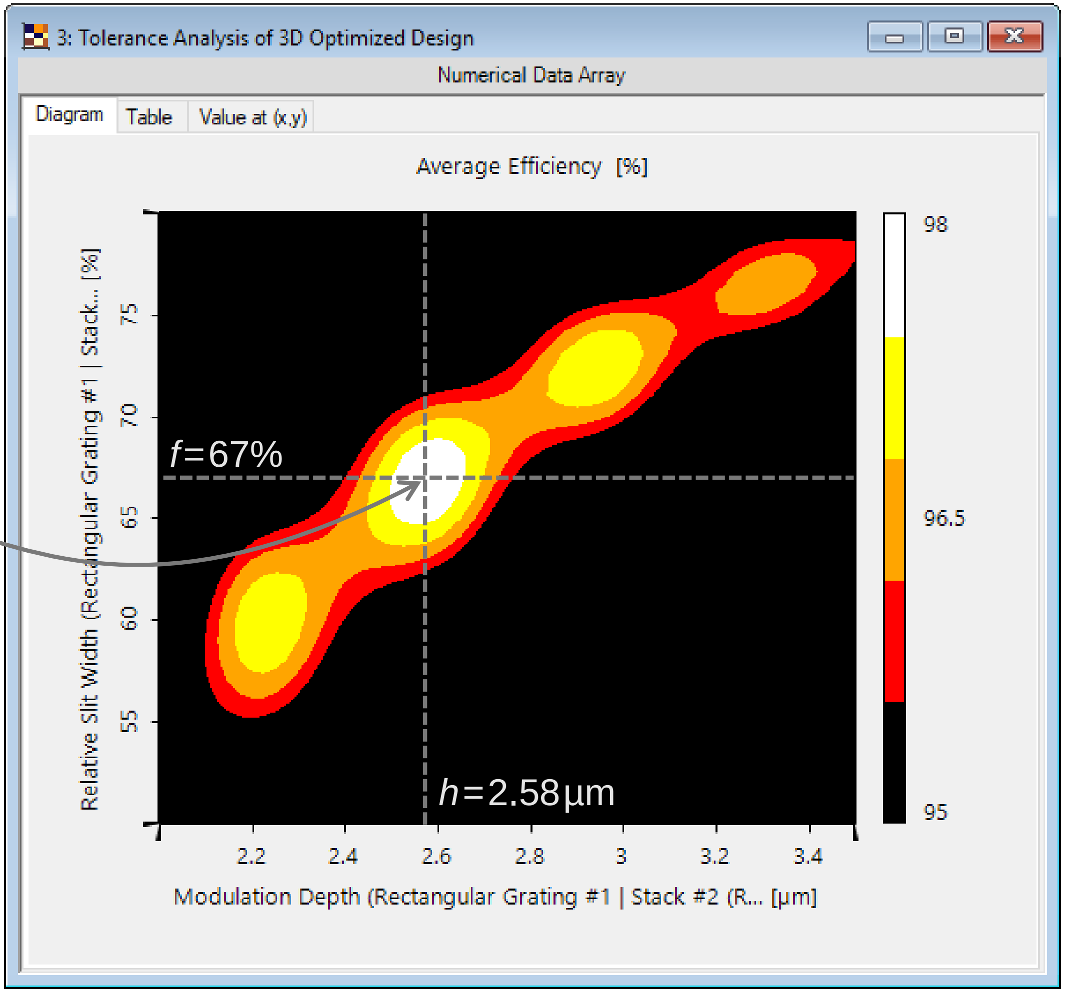
Parameter	Value
grating depth *h*	2.58µm
fill factor *f*	67%
grating period *d*	1024nm

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	2.58µm
fill factor f	67%
grating period d	1024nm (fixed)

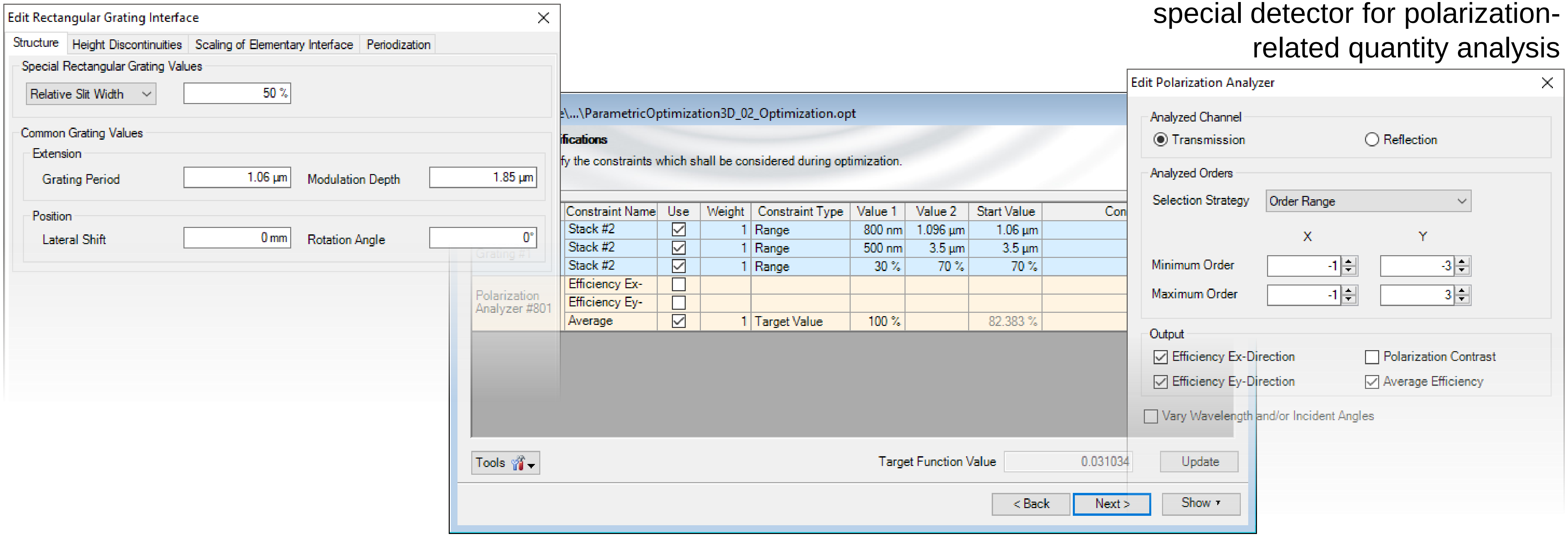


Diffraction efficiency within the region around the design parameters (efficiency value clipped above 95% only)

Peek into VirtualLab Fusion

intuitive grating parameters specification

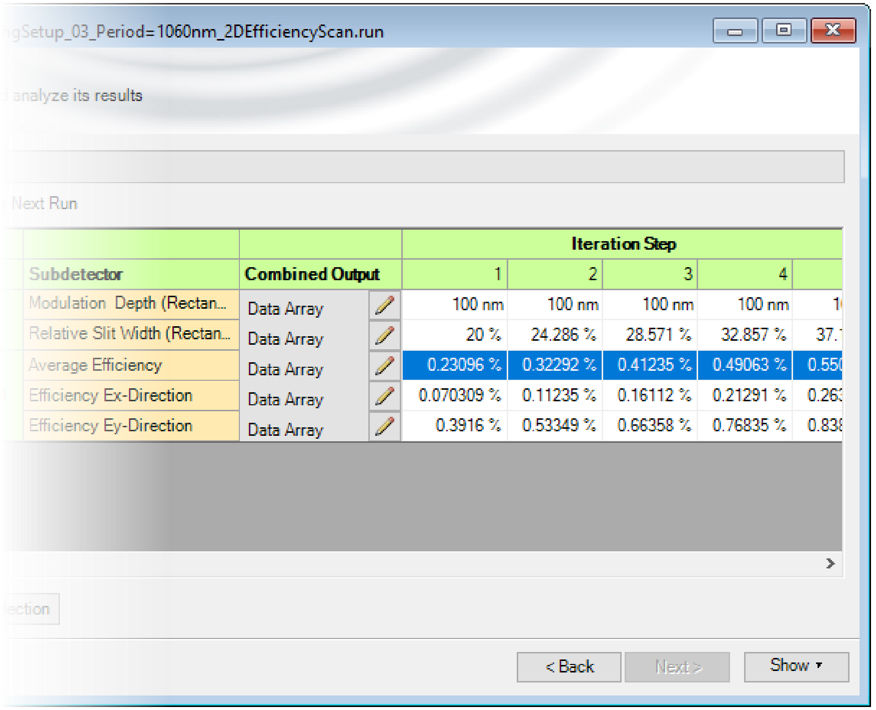
special detector for polarization-related quantity analysis



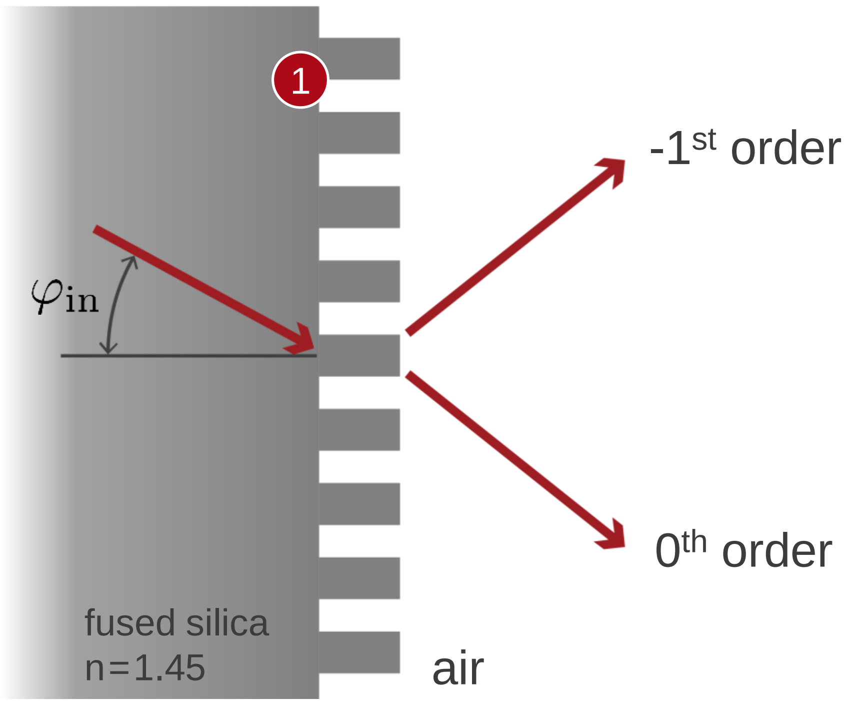
parametric optimization tools with friendly user interface

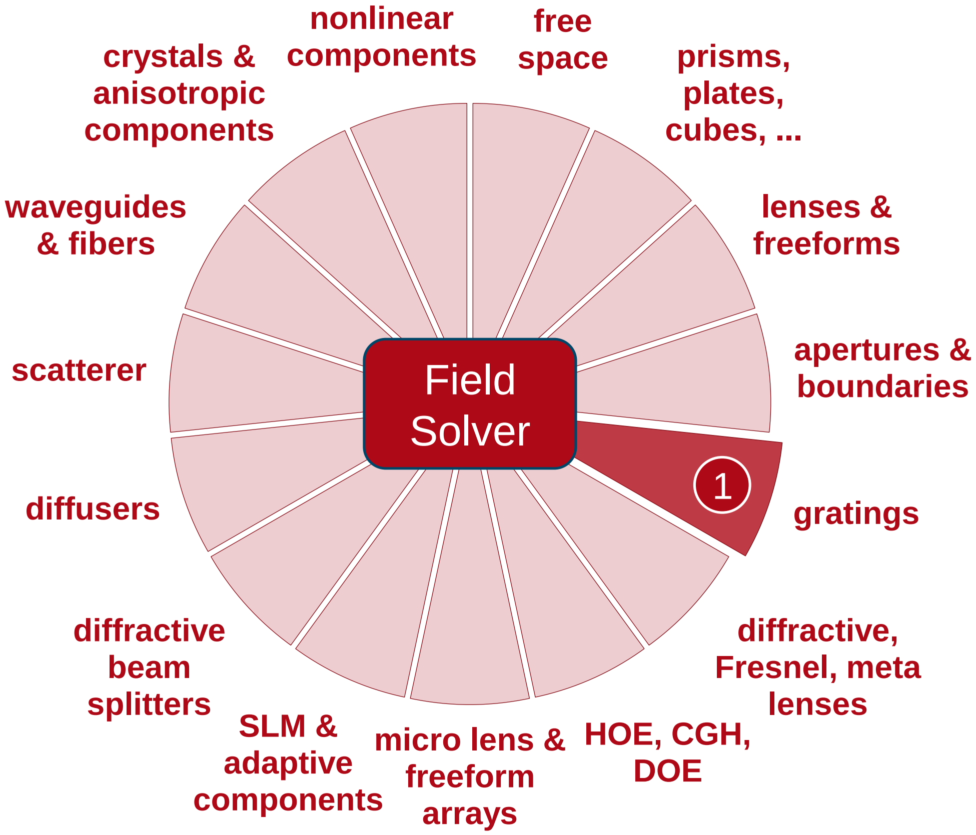
Workflow in VirtualLab Fusion

- 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



VirtualLab Fusion Technologies





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VL version used for simulations	7.5.0.158
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