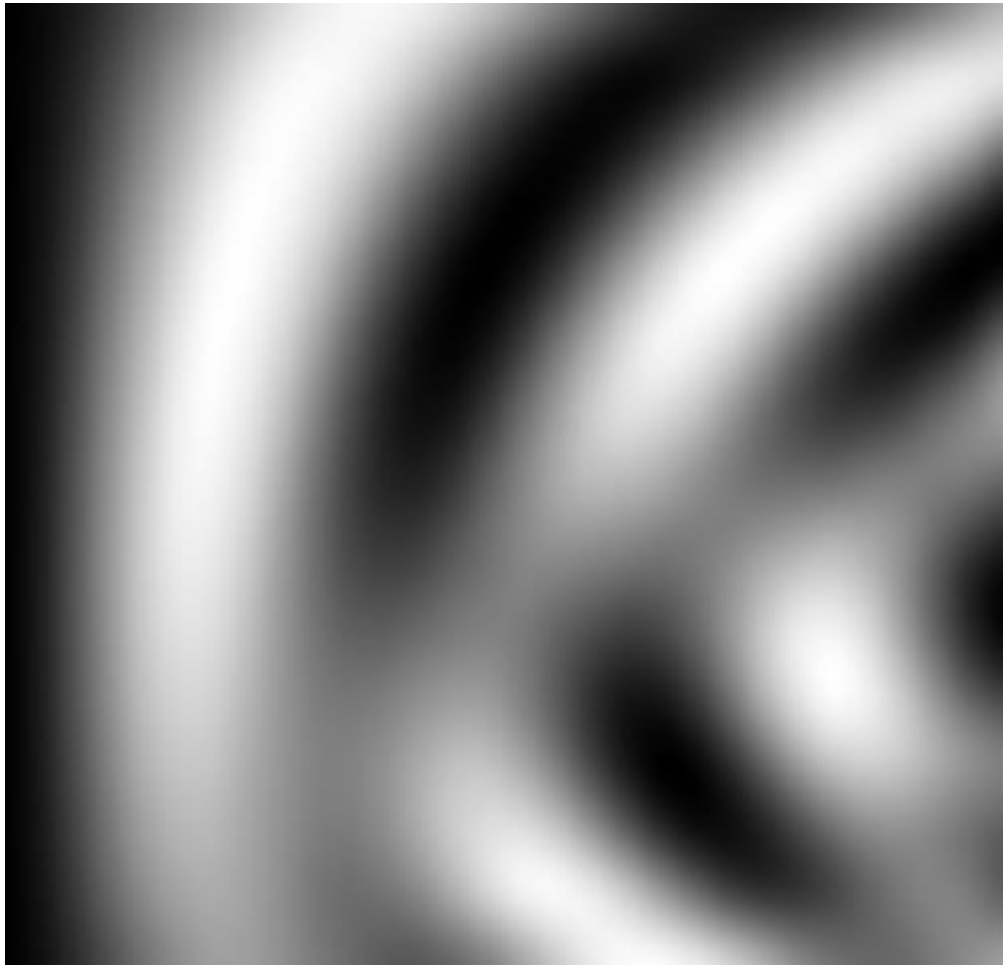
Analysis and Design of Highly Efficient Polarization Independent Transmission Gratings

Abstract

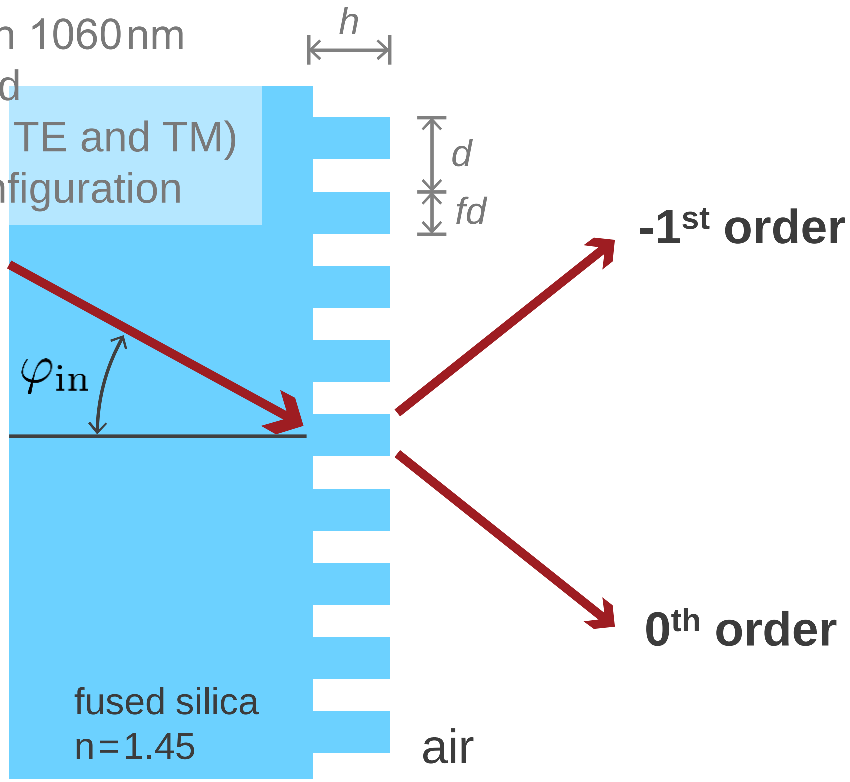


Gratings, especially those with feature size comparable to the wavelength, are known to possess polarization-dependent optical properties. That makes it difficult to design gratings with high diffraction efficiencies for arbitrary polarizations. Following the concept reported in literature [T. Clausnitzer, *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

plane wave

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



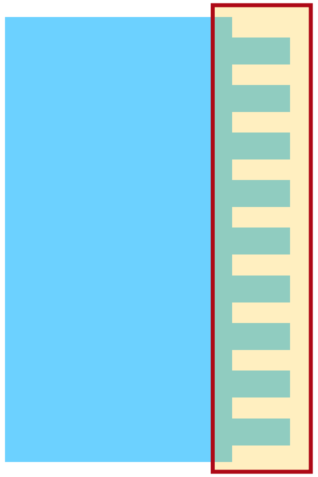
How to optimized the grating structure parameters so to maximize the diffraction efficiency of -1st transmission order, for unpolarized input light?

?

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

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

Connected Modeling Techniques: Grating Structure

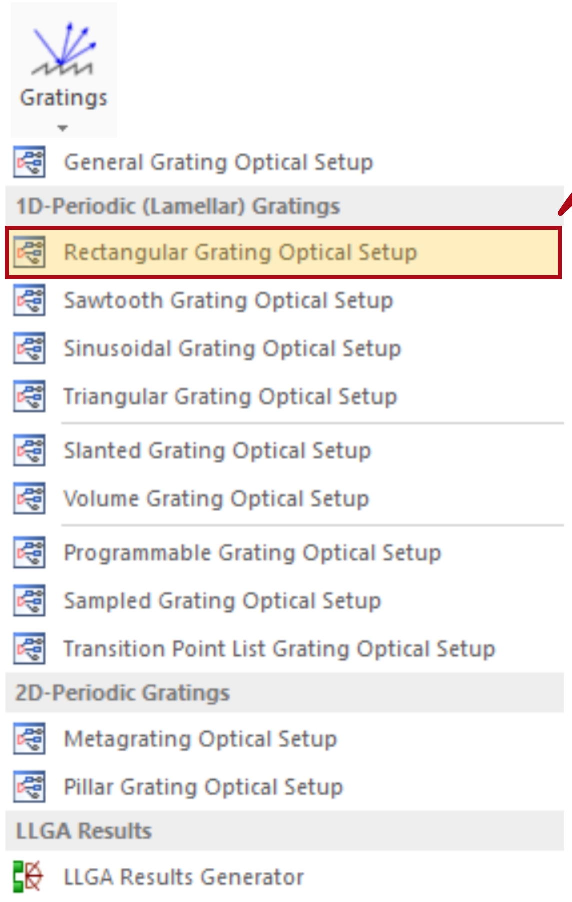


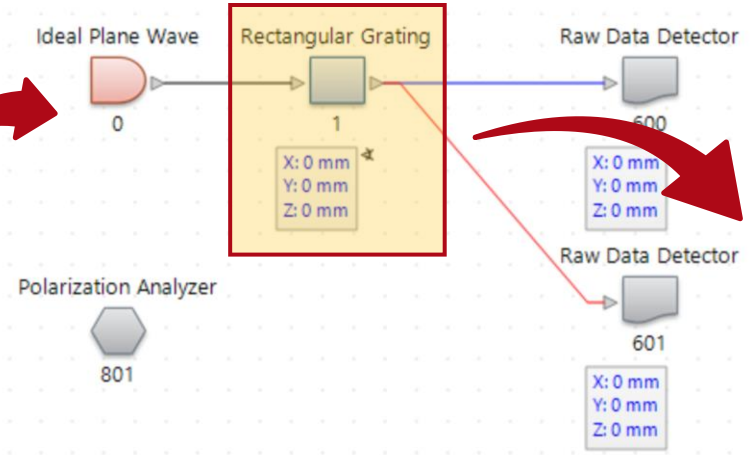
Available modeling techniques for microstructures:

Methods	Preconditions	Accuracy	Speed	Comments
Functional Approach	-	low	very high	diffraction angles acc. to grating equation; manual efficiencies
Thin Element Approximation (TEA)	smallest features > ~10λ	high	very high	inaccurate for larger NA and thick elements; x-domain
	smallest features < ~2λ	low	very high	
Fourier Modal Method (FMM)	period < ~ (5λ × 5λ)	very high	high	rigorous solution; fast for structures and periods similar to the wavelength; more demanding for larger periods; k-domain
	period > ~ (15λ × 15λ)	very high	slow	

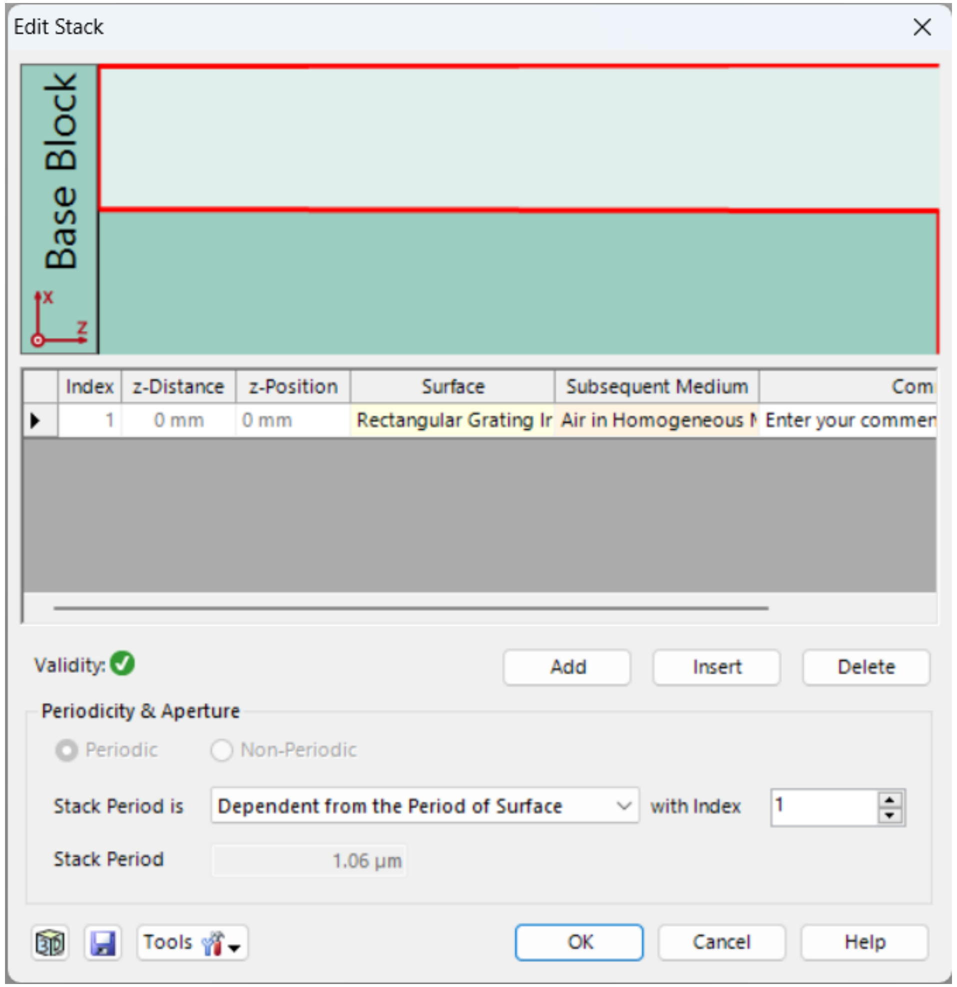
Due to the small feature sizes (in the order of magnitude of the wavelength), the **Fourier Modal Method (FMM)** provides a very accurate and fast solution and hence is used for the analysis.

Grating Optical Setup

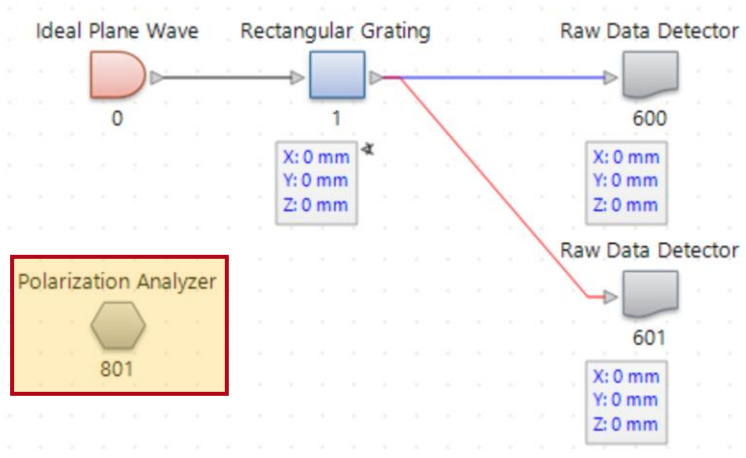


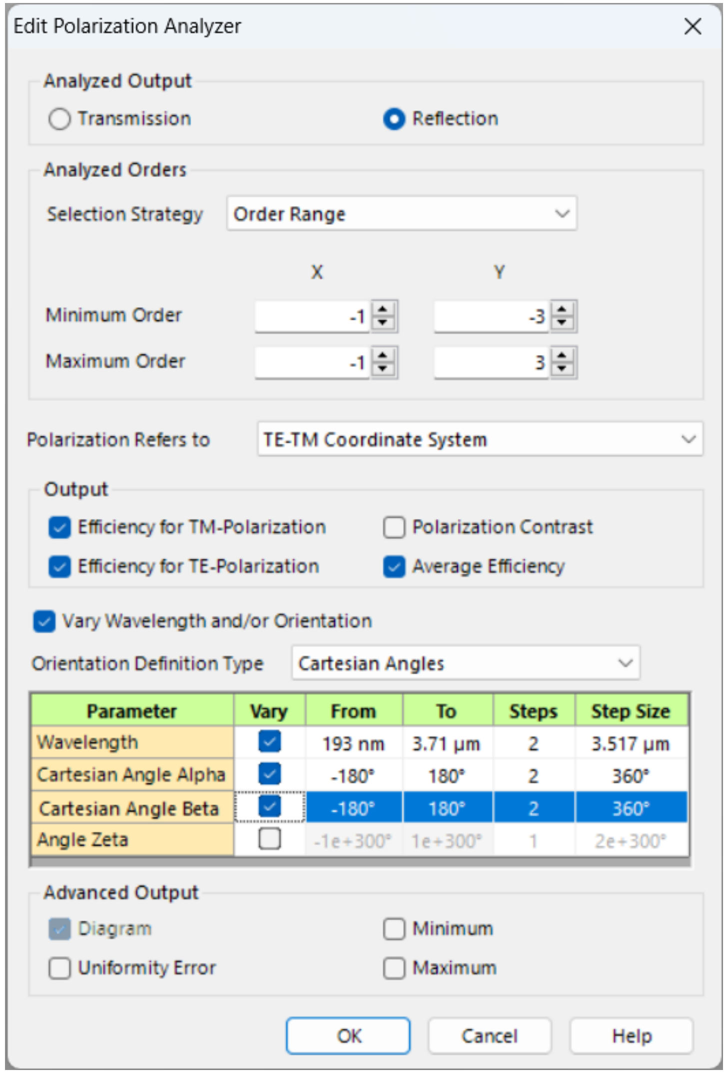


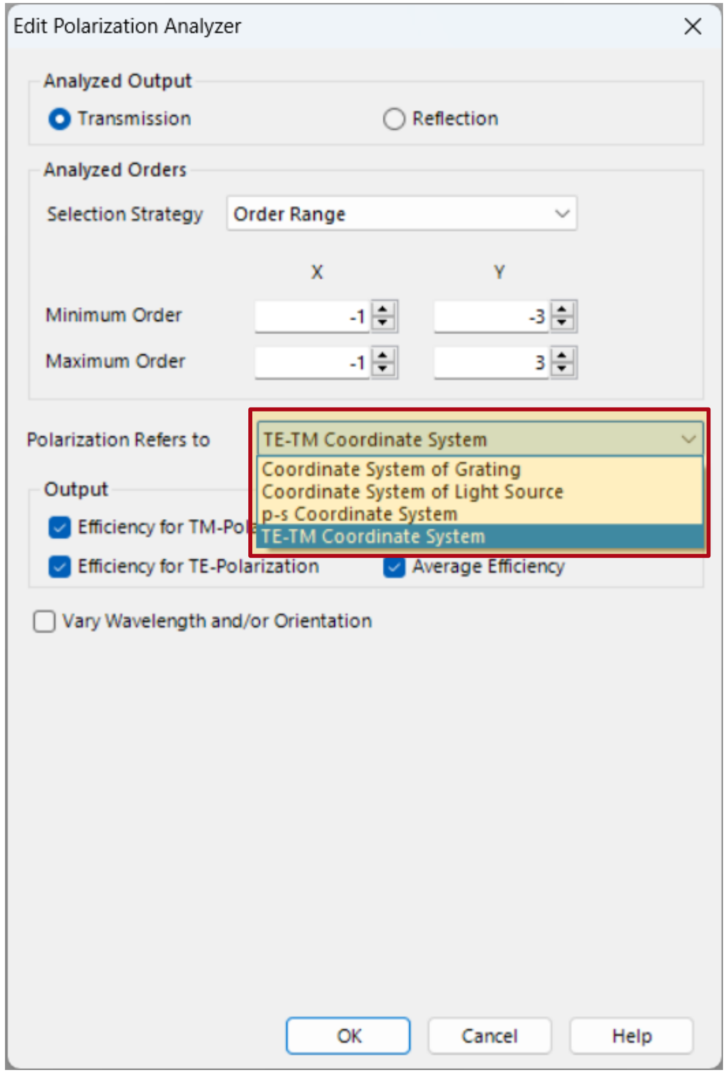
With the *Grating Package*, the user gains access to the grating specific optical setup that allows for a deeper investigation of different kind of gratings by applying the Fourier Modal method (FMM), which is also known as rigorous coupled wave analysis (RCWA).



Polarization Analyzer





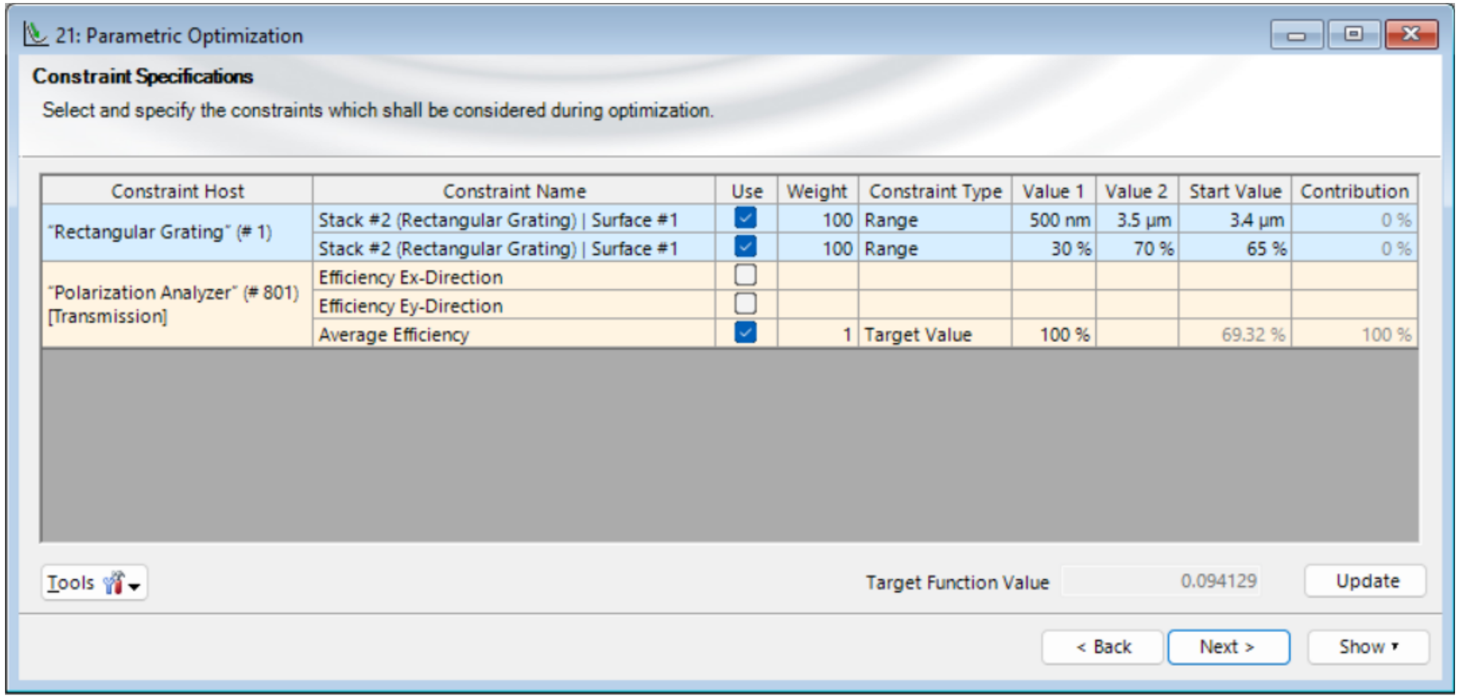


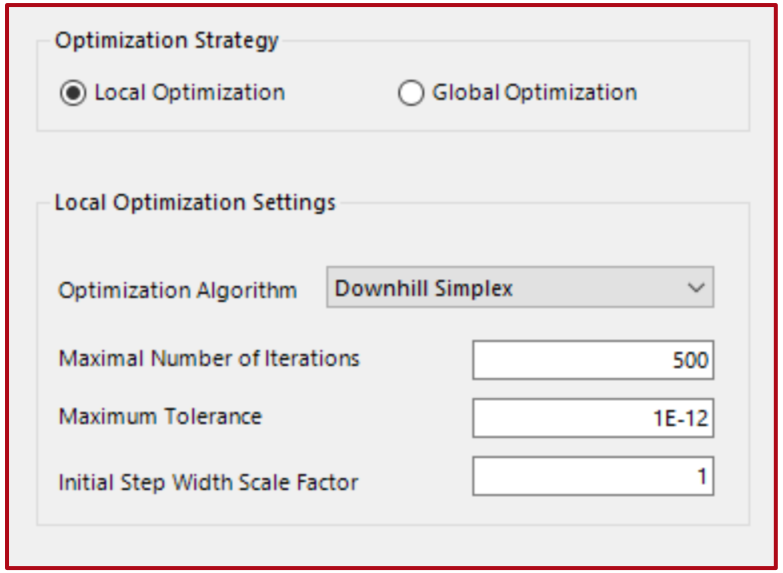
One of these tools is the *Polarization Analyzer,* which allows for the definition of different coordinate systems and has an inbuilt *Parameter Run* function.

More Information under:

Polarization Analyzer

Optimization

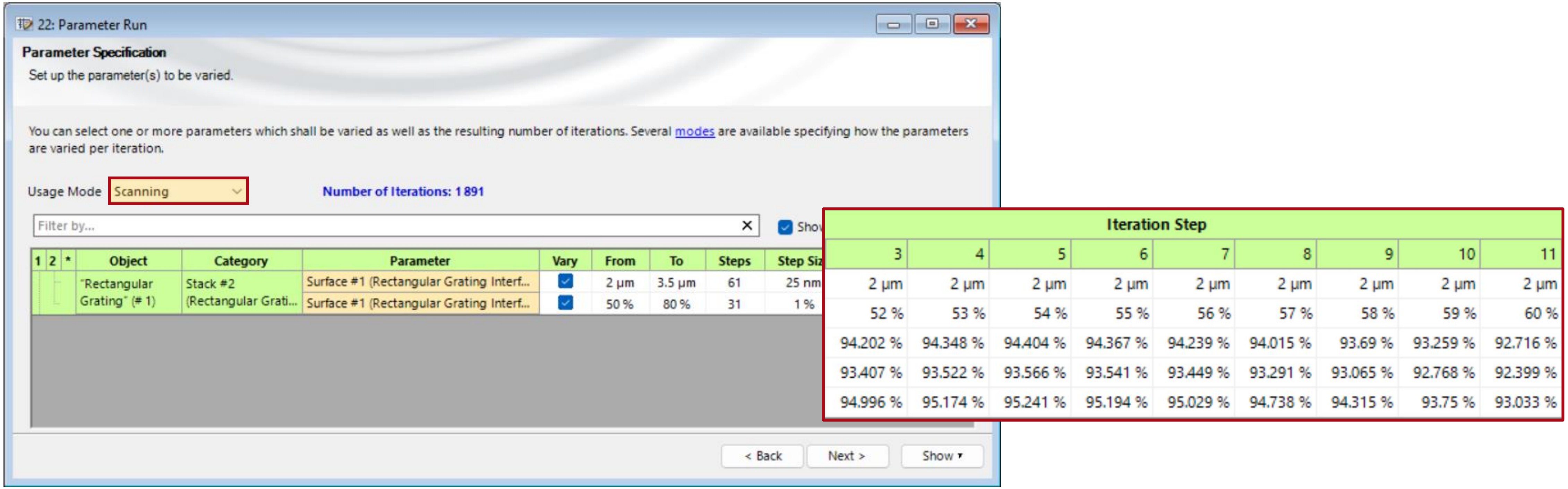




In order to find optimized grating parameters, the *Optimization* document enables the definition of parameter constraints and weights for the target values. Find more information under

Introduction to the Parametric Optimization Document

Parameter Run



The *Parameter Run* is designed to help the optical engineer investigate the effect of varying parameters and manufacturing deviations. It is possible to define which parameters shall be varied and to either investigate all possible combinations by choosing *Scanning* mode or to only randomly pick a sample by choosing *Random* mode. As in this example only a few parameters are varied, *Scanning* mode was chosen.

Considerations on Grating Period Choice

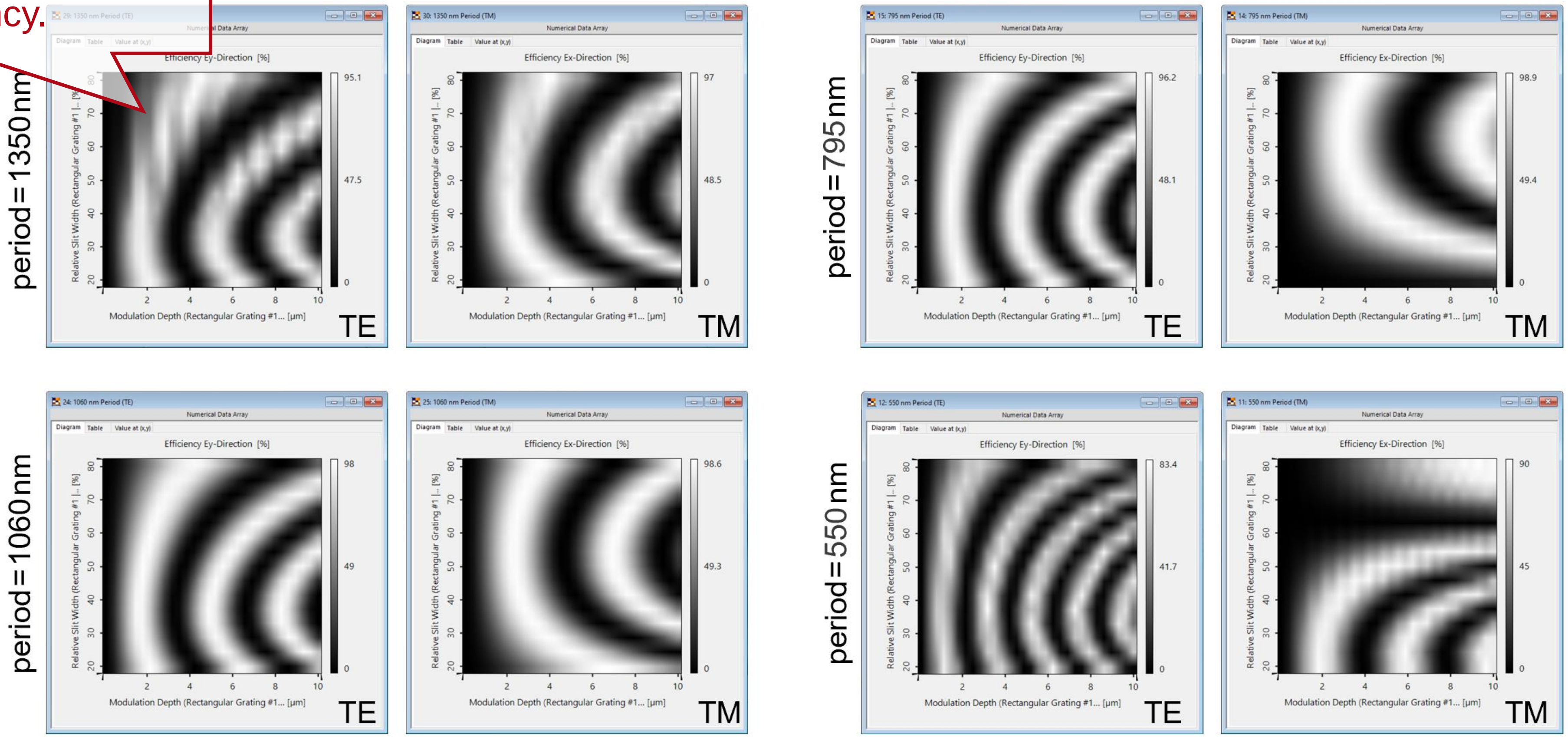
Large period leads to higher diffraction orders in the substrate, and causes additional modulation in the efficiency.

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

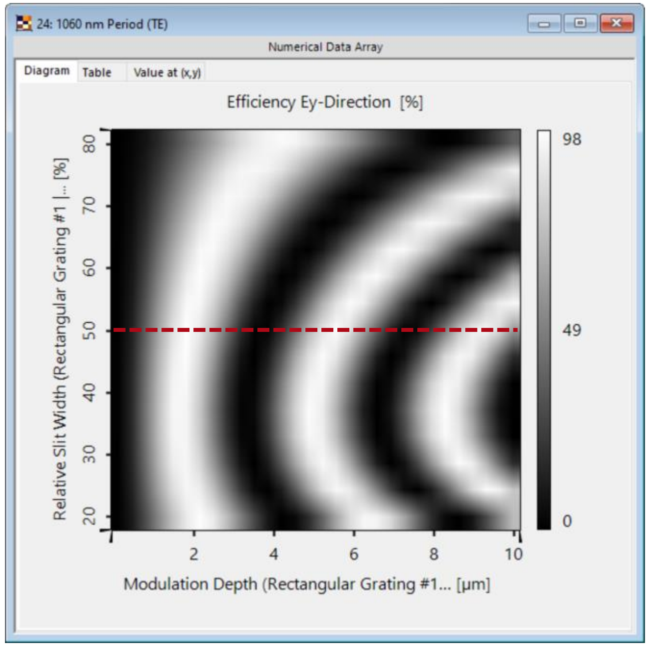
$$\lambda/2 < d < 3\lambda/2n$$

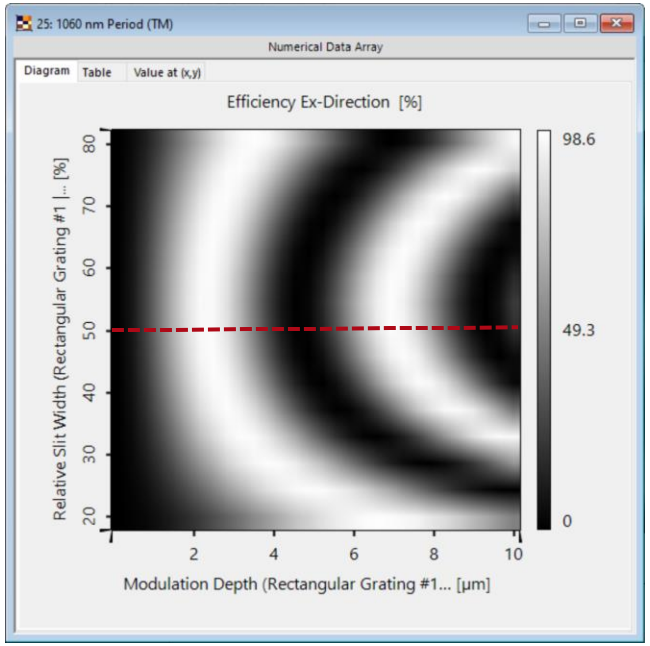
where n is the refractive index of the substrate.



Polarization-Dependent Diffraction Property

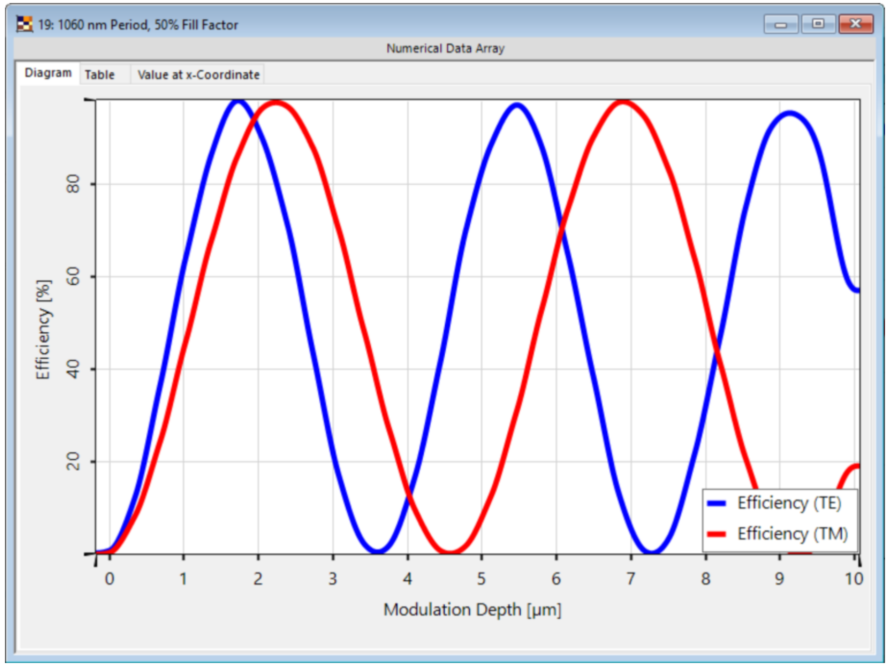
diffraction efficiency analysis for given period 1060 nm





diffraction efficiencies vs. grating depth

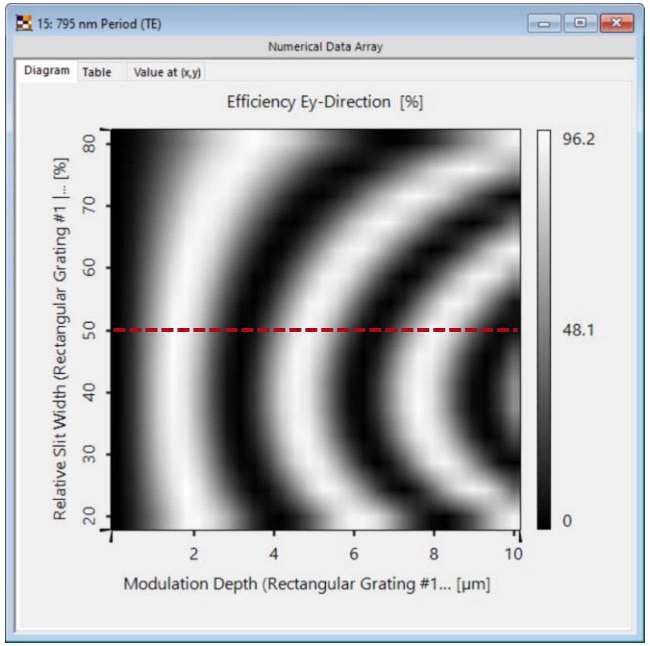
(grating period = 1060 nm, fill factor = 50%)

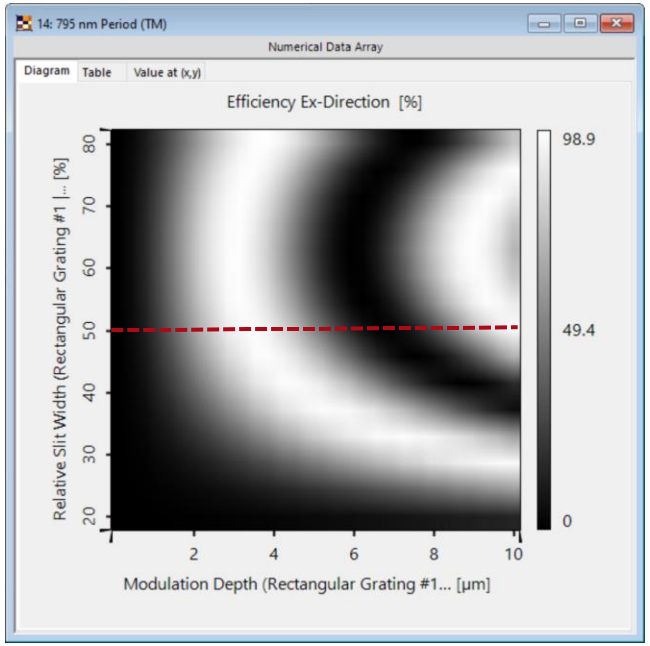


Parameter	Value
grating depth *h*	0.1 - 10 µm
grating period *d*	**1060 nm**
fill factor *f*	20 - 80%

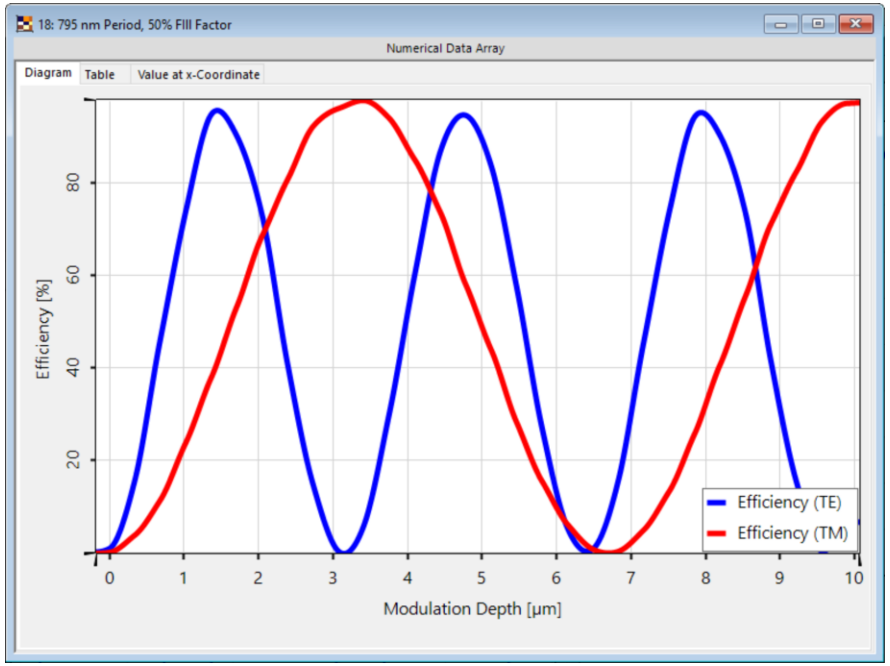
Polarization-Dependent Diffraction Property

diffraction efficiency analysis for given period 795 nm





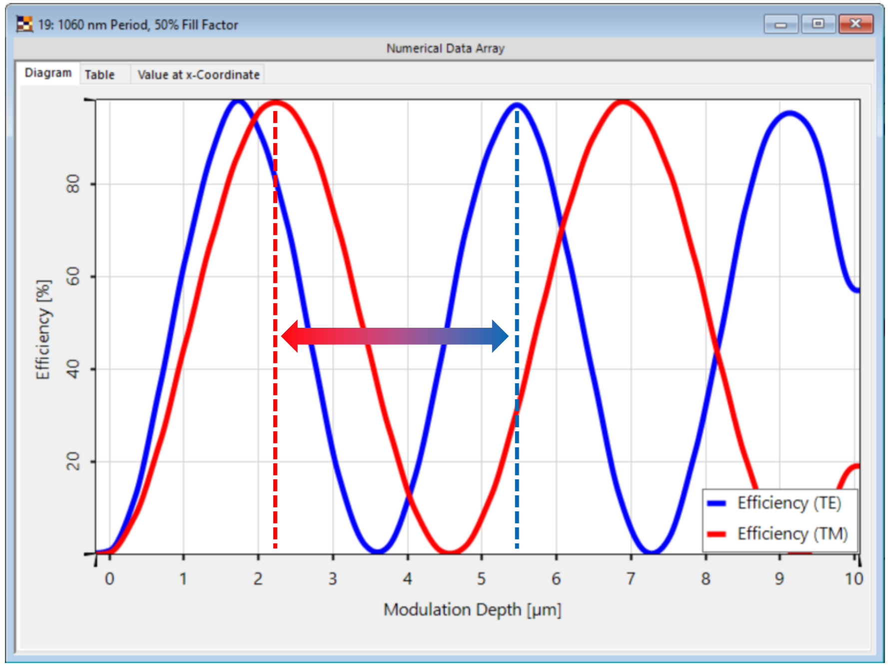
diffraction efficiencies vs. grating depth
(grating period = 795 nm, fill factor = 50%)



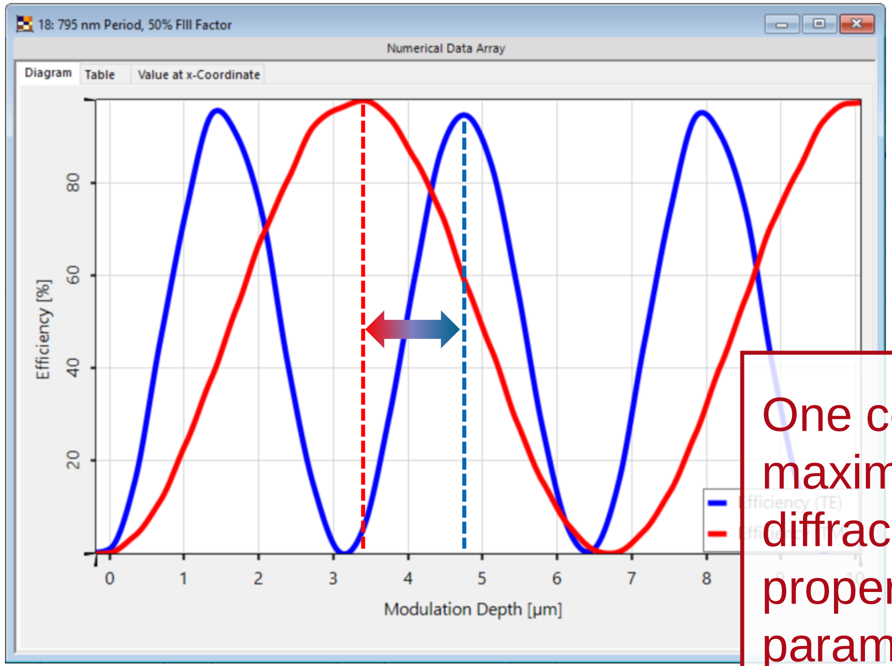
Parameter	Value
grating depth *h*	0.1 - 10 µm
grating period *d*	**795 nm**
fill factor *f*	20 - 80%

Polarization-Dependent Diffraction Property

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



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



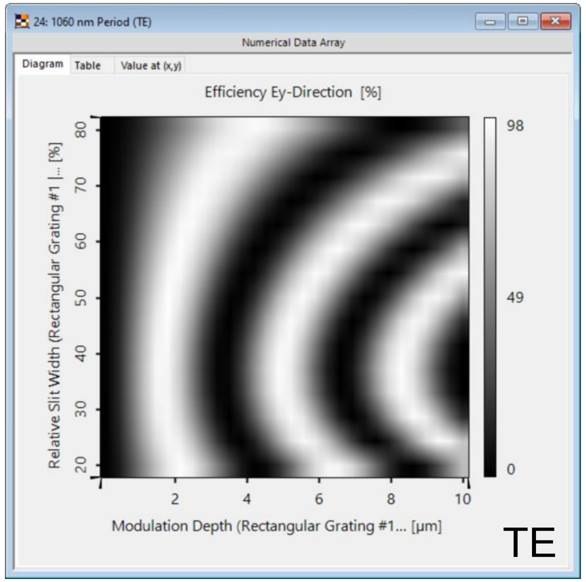
One could simultaneously maximize the TE and TM diffraction efficiencies by proper choice of grating parameters, e.g., period, depth, and fill factor.

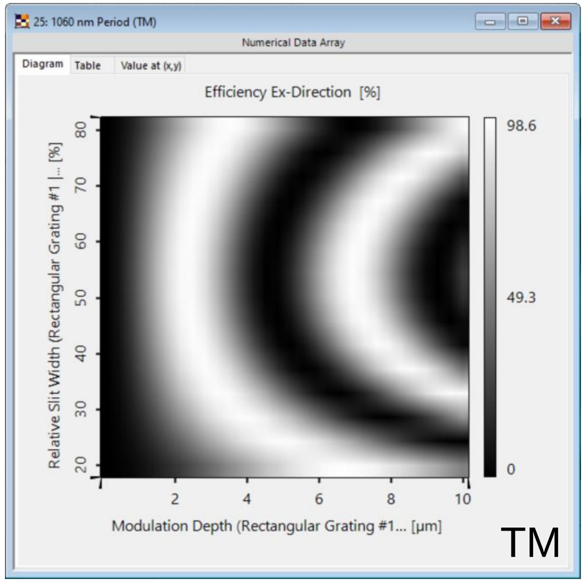
When grating period changes from 1060nm to 795nm

- 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.

2D Parametric Optimization with Fixed Period

We use a 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

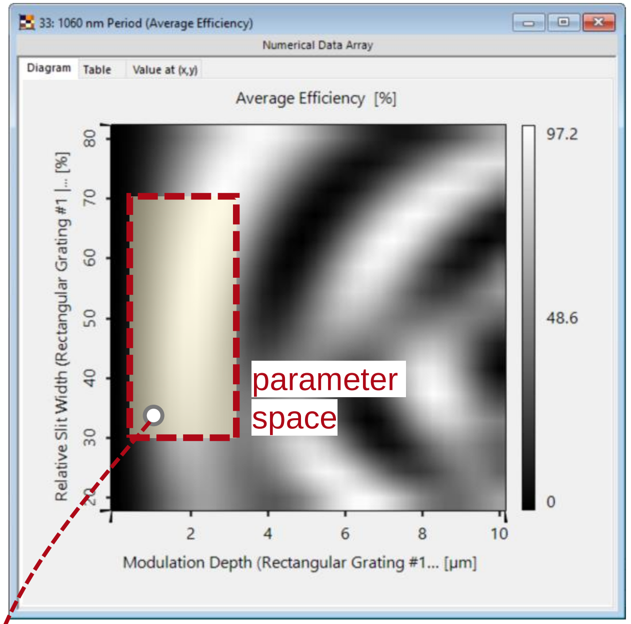
$$\eta^{\mathrm{avg}} = \frac{1}{2}\left(\eta^{\mathrm{TE}} + \eta^{\mathrm{TM}}\right) ,$$

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.

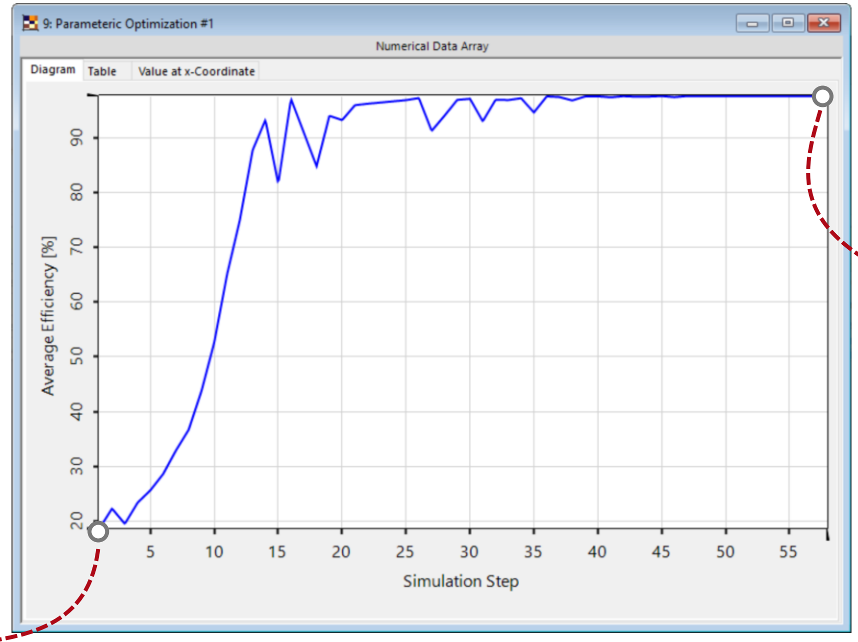
2D Parametric Optimization – Design #1



initial parameters

Parameter	Value
grating depth *h*	0.6 µm
fill factor *f*	35 %
grating period *d*	**1060 nm (fixed)**

parametric optimization – downhill simplex



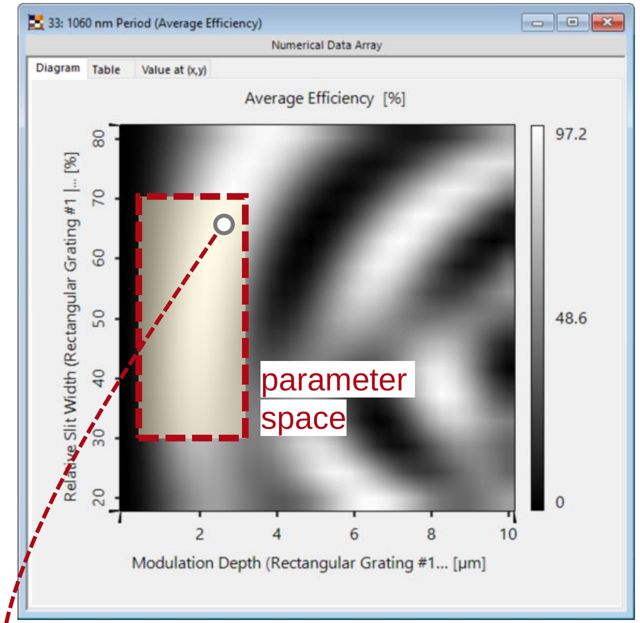
Diffraction efficiency in each optimization step is calculated using Fourier modal method (FMM, also known as RCWA).

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

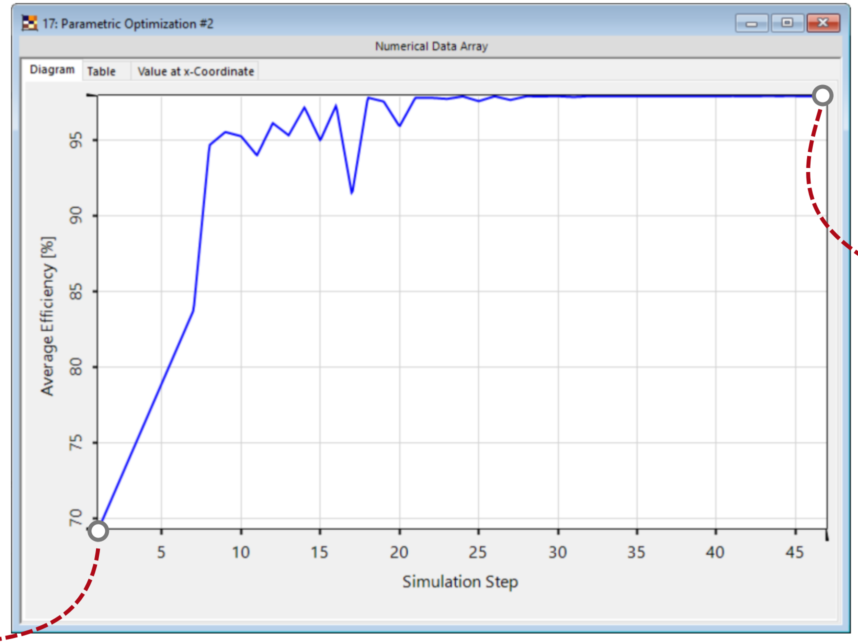
Note: To ensure that the chosen initial parameters do not lead to a local maximum we performed a second optimization with initial parameters from the other side of the parameter space.



initial parameters

Parameter	Value
grating depth *h*	3.4 µm
fill factor *f*	65%
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).

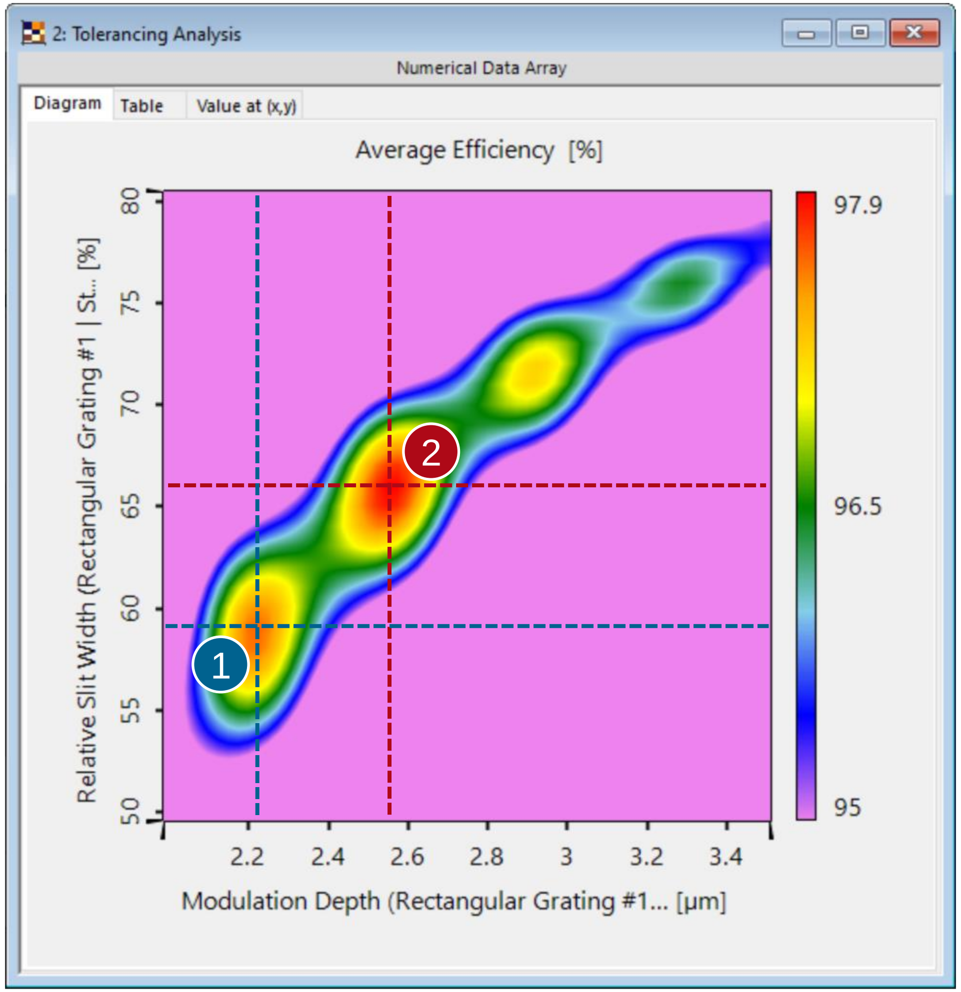
Fabrication Tolerance Analysis

optimized parameters #2 ❷

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

optimized parameters #1 ❶

Parameter	Value
grating depth *h*	2.23 µm
fill factor *f*	59 %
grating period *d*	**1060 nm (fixed)**

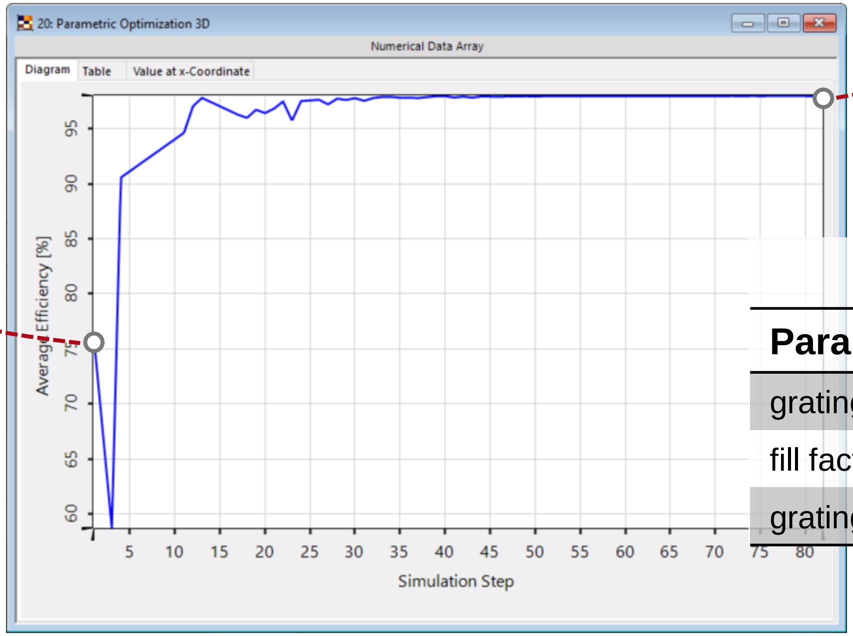


Diffraction efficiency within the region around the design parameters (efficiency value clipped above 95% only)

3D Parametric Optimization with Varying Grating Period

Parameter	Value Range	Initial Value
grating depth *h*	0.5-3.5µm	3.0µm
fill factor *f*	30-70%	60%
grating period *d*	800-1096nm	1060nm

parametric optimization – downhill simplex



optimized parameters

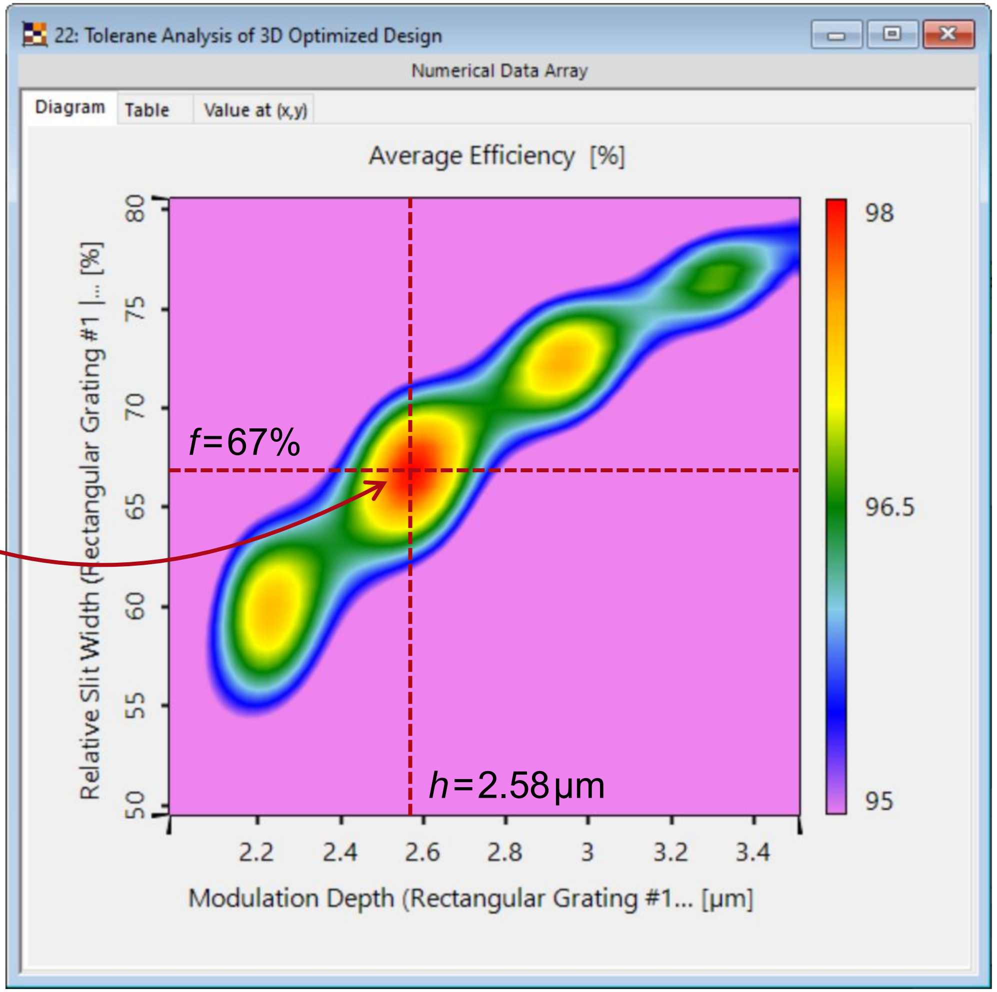
Parameter	Value
grating depth *h*	2.58µm
fill factor *f*	67%
grating period *d*	1024nm

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)

Document Information

title	Analysis and Design of Highly Efficient Polarization Independent Transmission Gratings
document code	GRT.0015
document version	1.3
required packages	Grating Package
software version	2023.2 (Build 1.242)
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 • Polarization Analyzer • Configuration of Grating Structures by Using Interfaces