

1-4 February 2020, Training Online

VirtualLab Fusion Applications, Technology & Workflows
Grating Modeling and Design

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Jena, Germany

Course Agenda

Part I	Part III
<ul style="list-style-type: none">• Grating construction and modeling<ul style="list-style-type: none">- Grating structure specifications- Thin element approximation (TEA)- Fourier modal method (FMM, a.k.a. RCWA)- Specific grating analysis tools	<ul style="list-style-type: none">• Grating design/optimization<ul style="list-style-type: none">- Optimization of slanted grating for waveguide coupling- Parametric optimization tool
<ul style="list-style-type: none">• Rigorous modeling examples<ul style="list-style-type: none">- Blazed grating for spectral separation- Ultra-sparse dielectric nano-wire grid polarizers- Parameter sweeping tool	<ul style="list-style-type: none">• Grating design/optimization<ul style="list-style-type: none">- Design of polarization-independent high-efficiency gratings- Design of anti-reflection moth-eye structures
Part II	Part IV
<ul style="list-style-type: none">• Rigorous modeling examples<ul style="list-style-type: none">- Slanted gratings simulation with varying parameters- Volume holographic gratings and their sensitivity- Diffraction property of a passive parity-time (PT) grating- Analysis of CMOS sensors with microlens array	<ul style="list-style-type: none">• Metagratings<ul style="list-style-type: none">- Rigorous analysis of nanopillars as metasurface building blocks- Design of a blazed metagrating
<ul style="list-style-type: none">• Grating within optical system<ul style="list-style-type: none">- Angular-filter volume grating for higher diffraction order suppression- Resonant waveguide grating and its angular/spectral property- Using gratings as test objects in imaging system	<ul style="list-style-type: none">• Metagratings<ul style="list-style-type: none">- Beam-splitting metagrating design- IFTA for phase profile generation• General Q&A

Teams



LightTrans (since 1999)

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

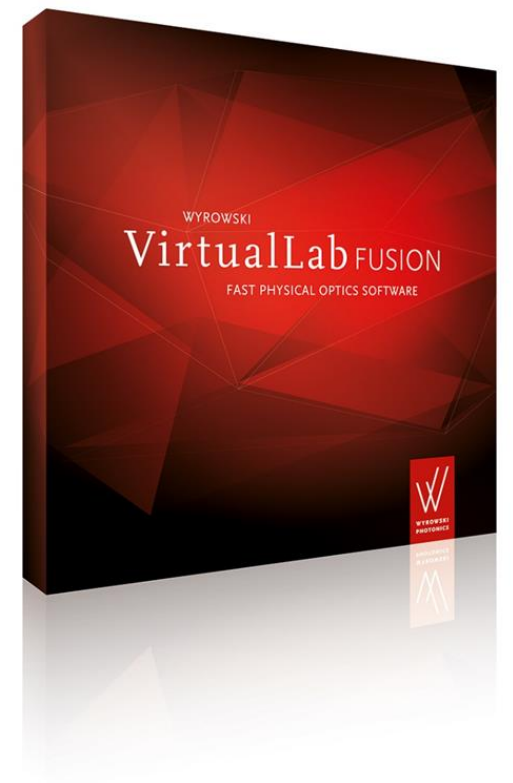


(since 2014)



photo from wikitravel

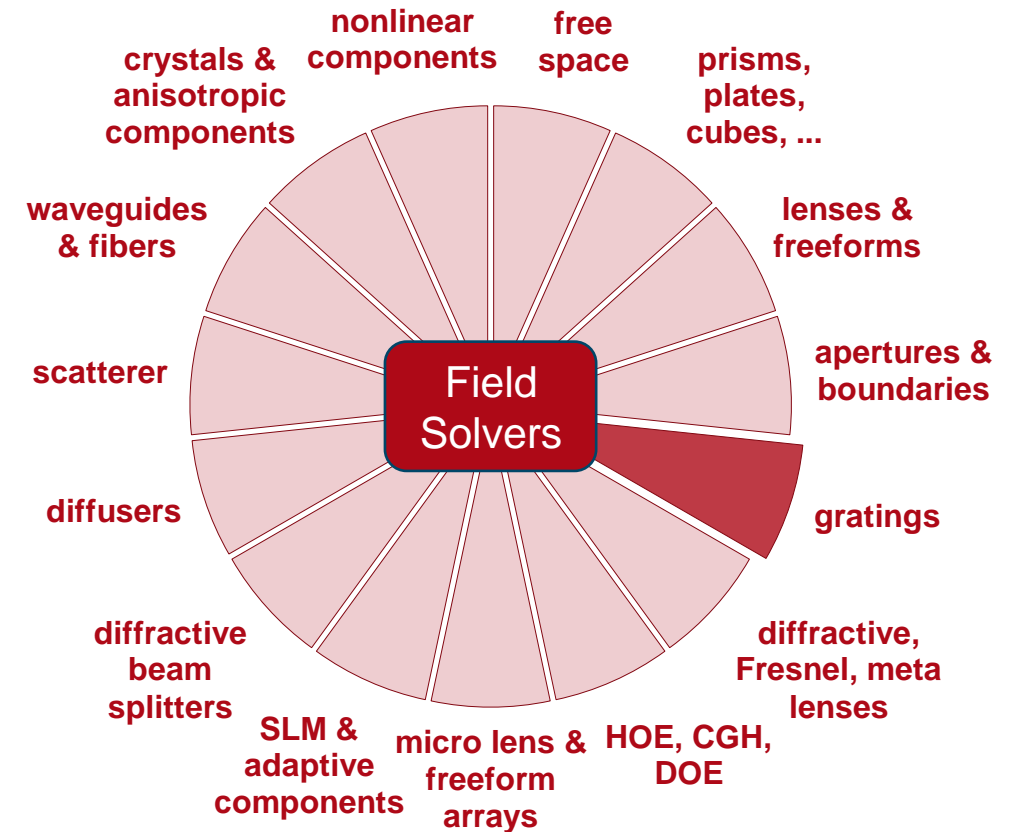
Optical Design Software and Services



Field Tracing Technologies – Gratings

Field Tracing comprises:

- Application of different electromagnetic field solvers in different regions of one system.
- Interconnection of any type of general and specialized field solver.

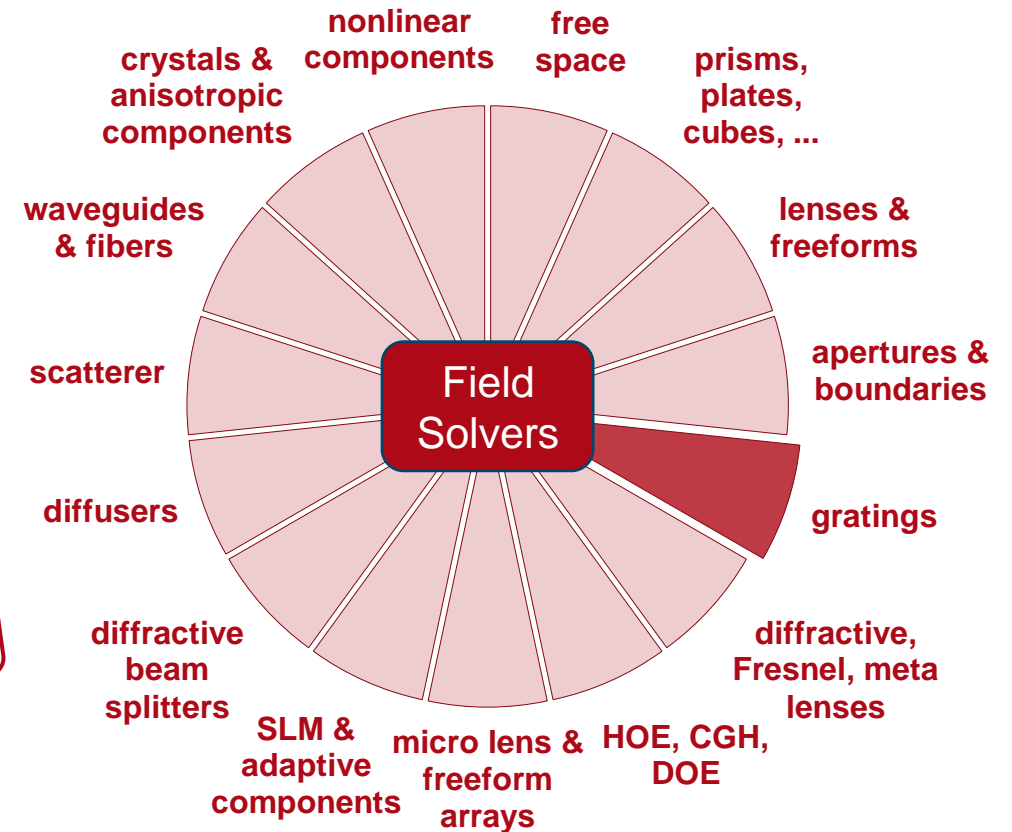


Field Tracing Technologies – Gratings

Aim of this training:

- to be able to construct customized grating structure;
- to know grating modeling technologies;
- to use helpful tools for grating problem study and analysis;
- and, by applying the above to solve practical problems.

learning by examples!



Part I

- Grating structure specifications
- Thin element approximation (TEA)
- Fourier modal method (FMM, a.k.a. RCWA)
- Specific grating analysis tools
- Blazed grating for spectral separation
- Ultra-sparse dielectric nano-wire grid polarizers
- Parameter sweeping tool

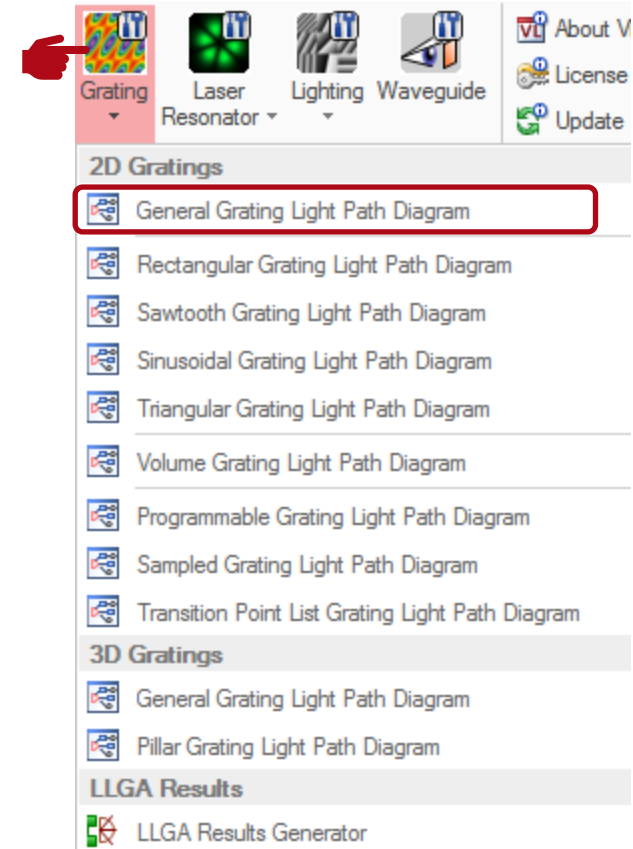
Configuration of Grating Structures by Using Interfaces

This Use Case Shows ...

- How to configure grating structures in Grating Toolbox by using interfaces, e.g.:
 - rectangular grating interface
 - transition point list interface
 - sawtooth grating interface
 - sinusoidal grating interface
- How to change advanced options & inspect defined structure before calculation.

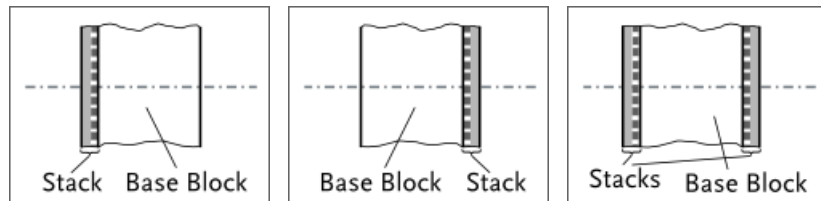
Grating Toolbox Initialization

- Initialization
 - Start →
Grating →
General Grating Light Path Diagram
- note: For usage of special type of grating, e.g. with rectangular shape, the specific light path diagram can be chosen directly.

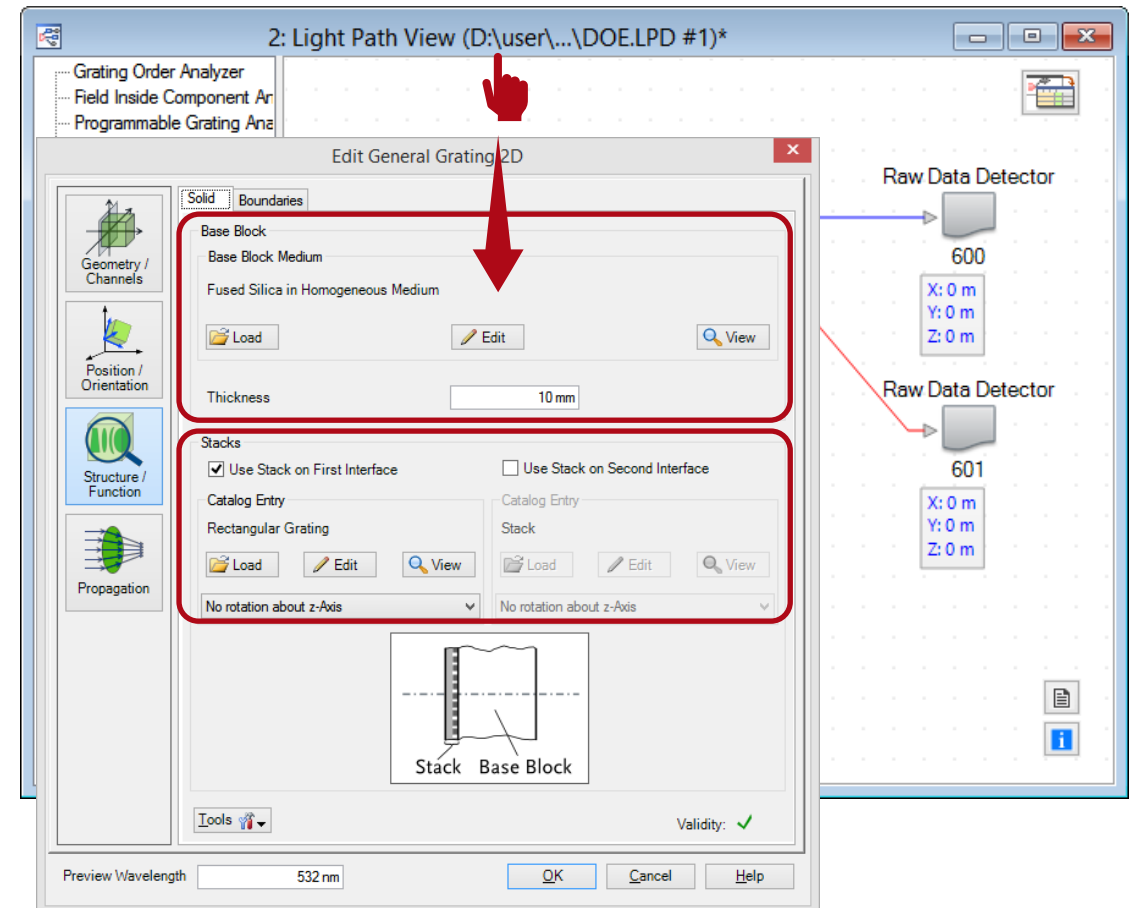


Grating Structure Settings

- First, the thickness and the material of the substrate (*Base Block*) have to be defined.
- In VirtualLab grating structures are defined in a so called stack.
- Stacks can be attached to either one or both sides of the substrate.

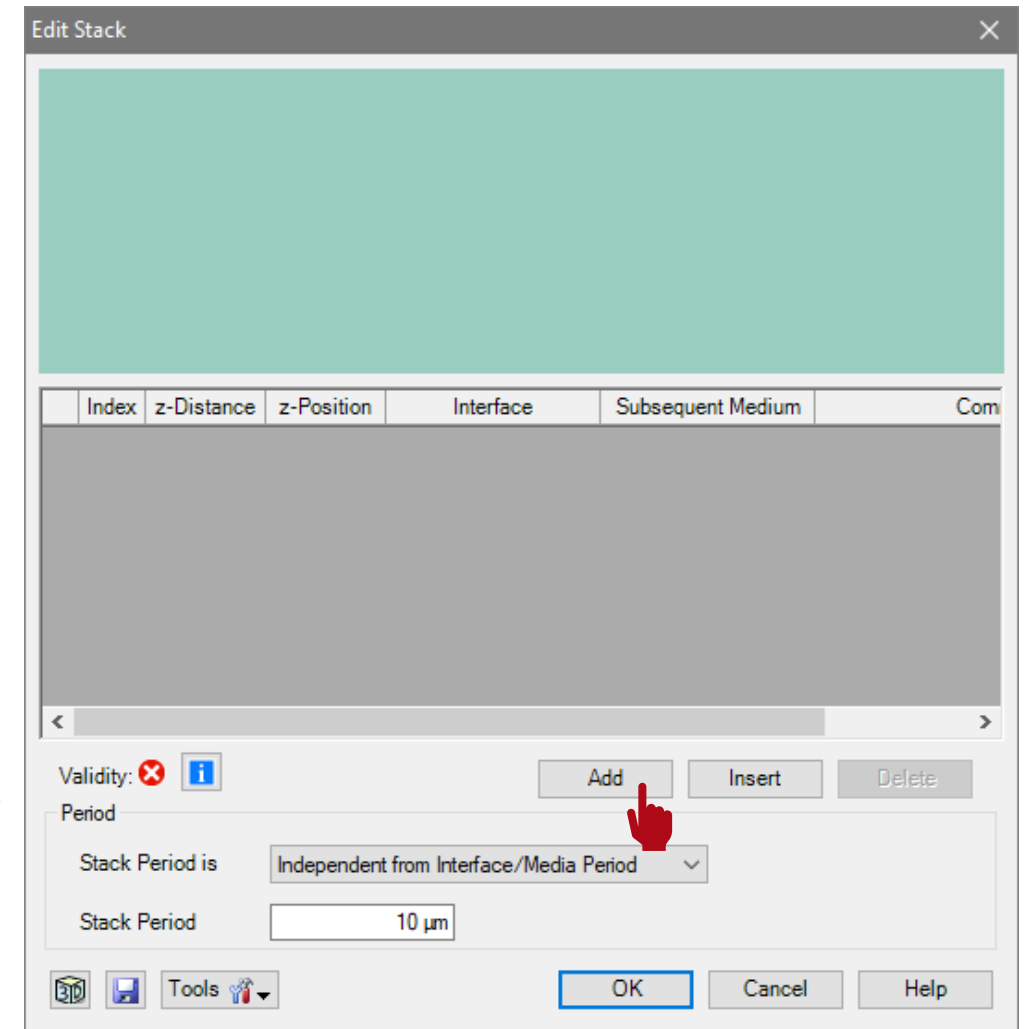
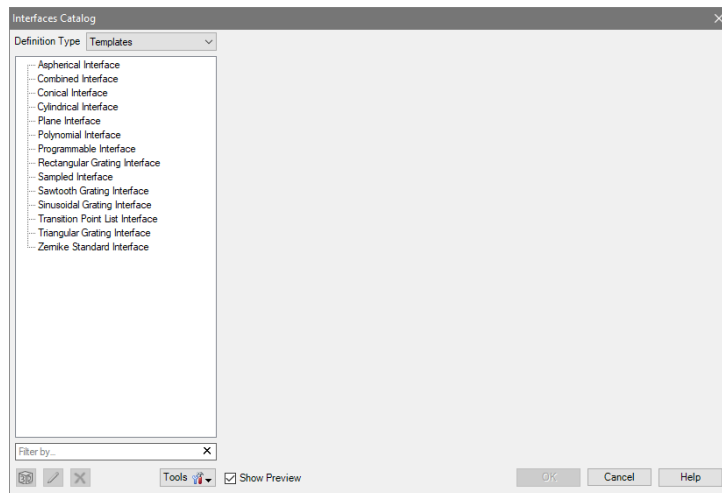


- For example, a stack on the first interface is chosen.



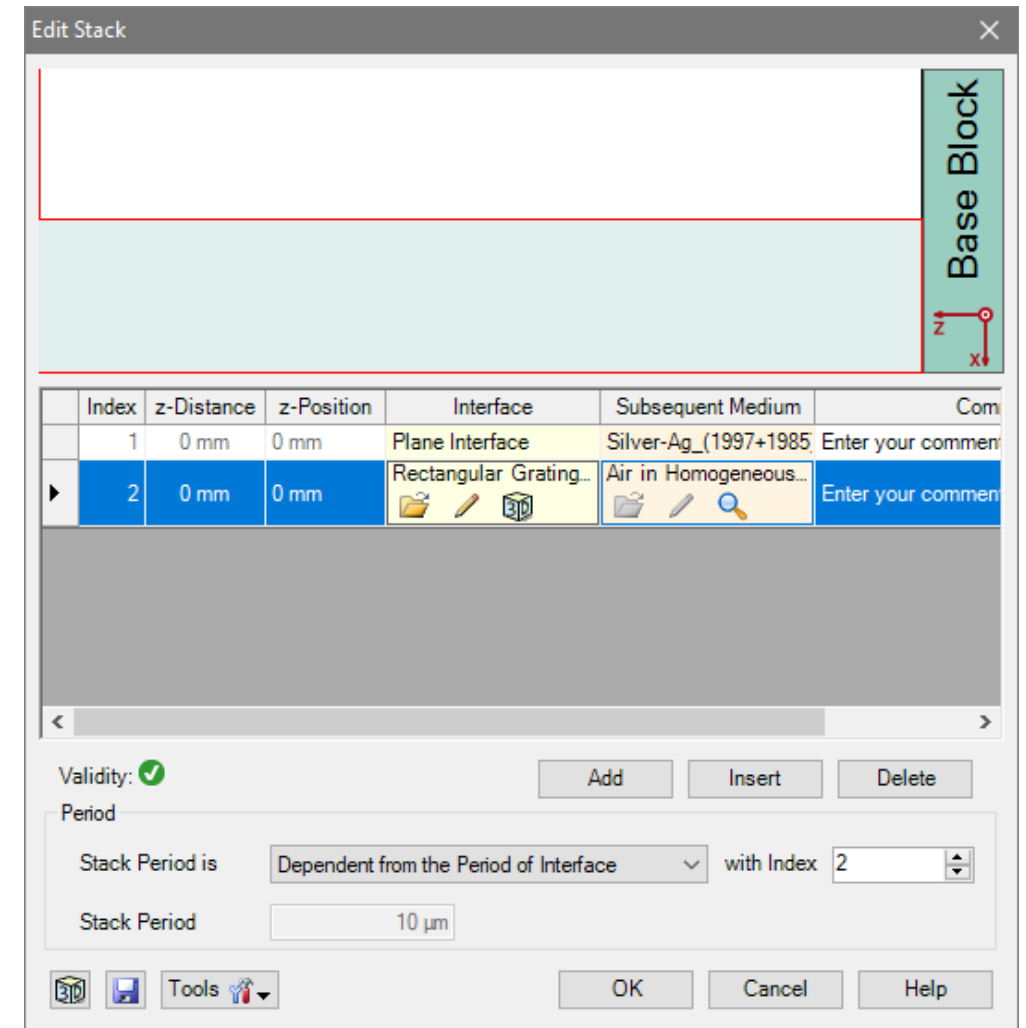
Stack Editor

- In the *Stack Editor* interfaces can be added or inserted from catalog.
- The catalog of VirtualLab provides several types of interfaces. All of them can be used to define a grating.



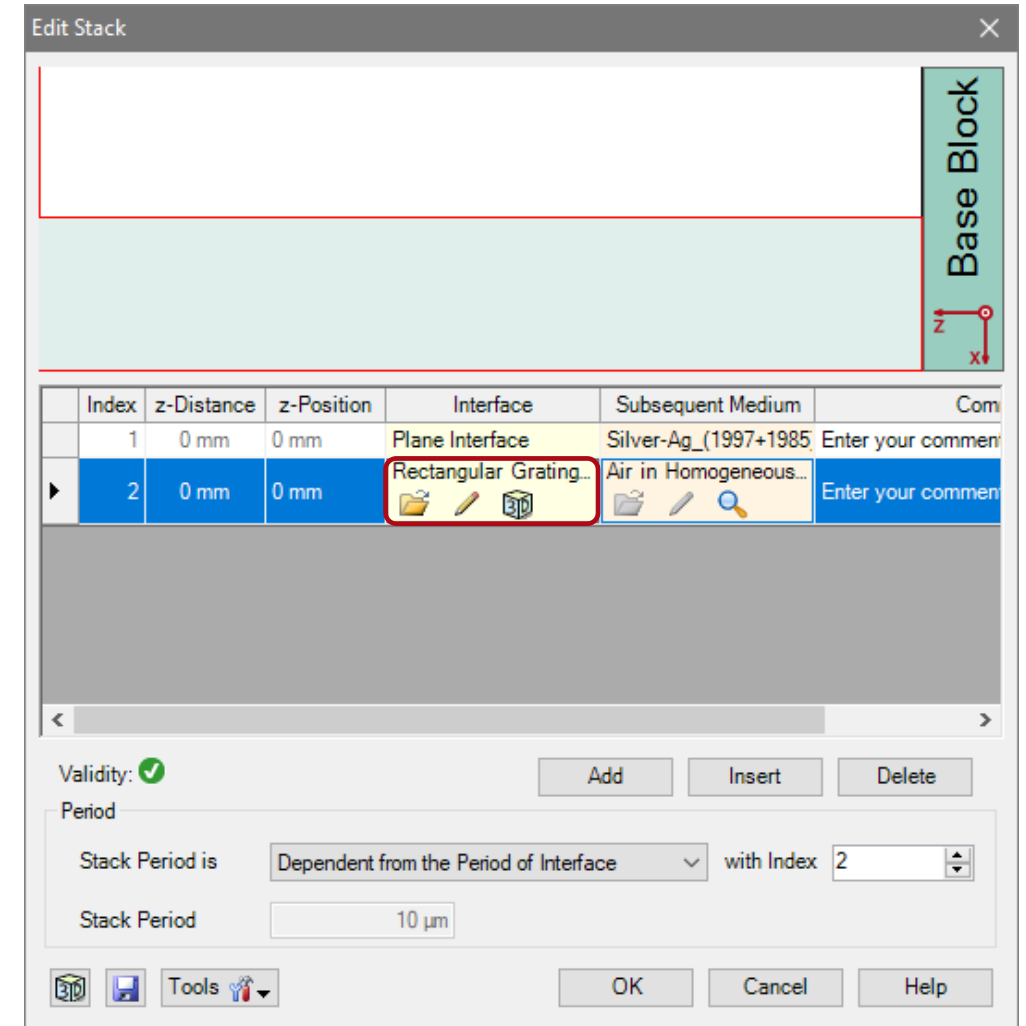
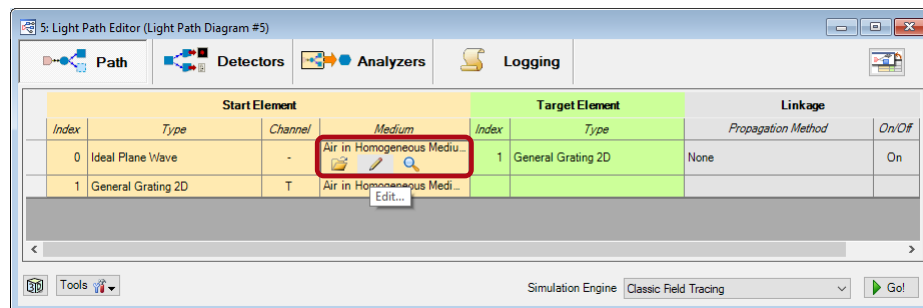
Rectangular Grating Interface

- One possible interface is the rectangular grating interface.
- This type of interface is appropriate for the configuration of simple binary structures.
- In this example, a grating made of silver is on a glass substrate.
- For this purpose, an additional plane interface was added in order to separate the grating structure from base block.
- In the view of the stack editor, different materials are indicated by other colors based on their index of refraction (dark means higher).



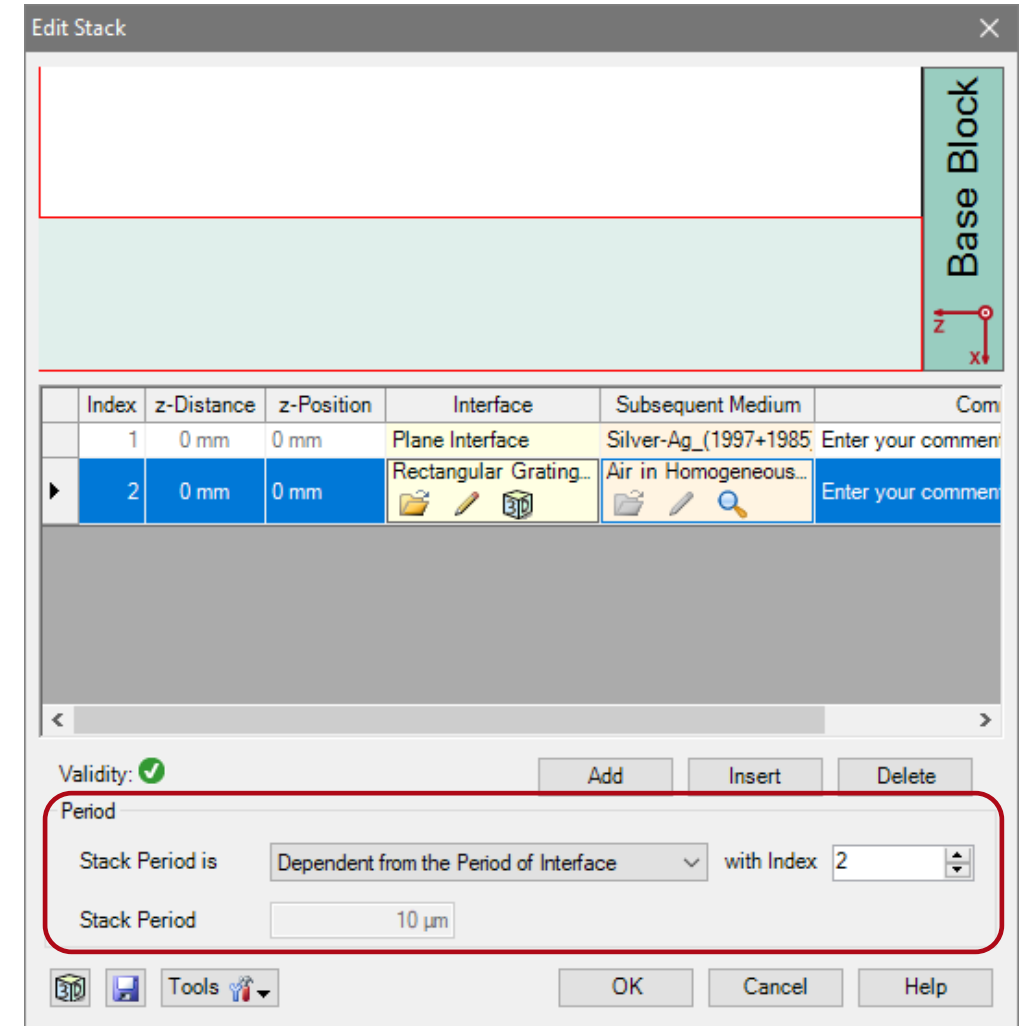
Rectangular Grating Interface

- Please note: the order of the interfaces is always counted from the surface of the substrate.
- The selected interface is highlighted red in the view.
- Further, the medium in front of the grating (means behind last interface) can not be defined here. It is automatically taken from the material in front of the grating component.
- This material can be changed in the *Light Path Editor*.



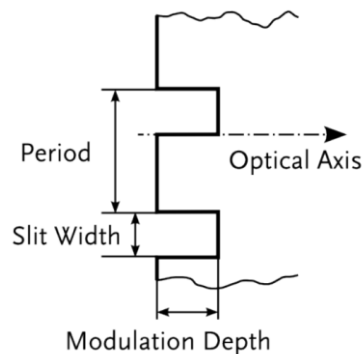
Rectangular Grating Interface

- The *Stack Period* allows to control the period of the whole configuration.
- This period is also taken for the periodic boundary conditions of the FMM algorithm.
- In case of simple grating structures, it is recommended to choose the option *Dependent from Period of Interface* and select the proper index of the periodic interface.



Rectangular Grating Interface Parameters

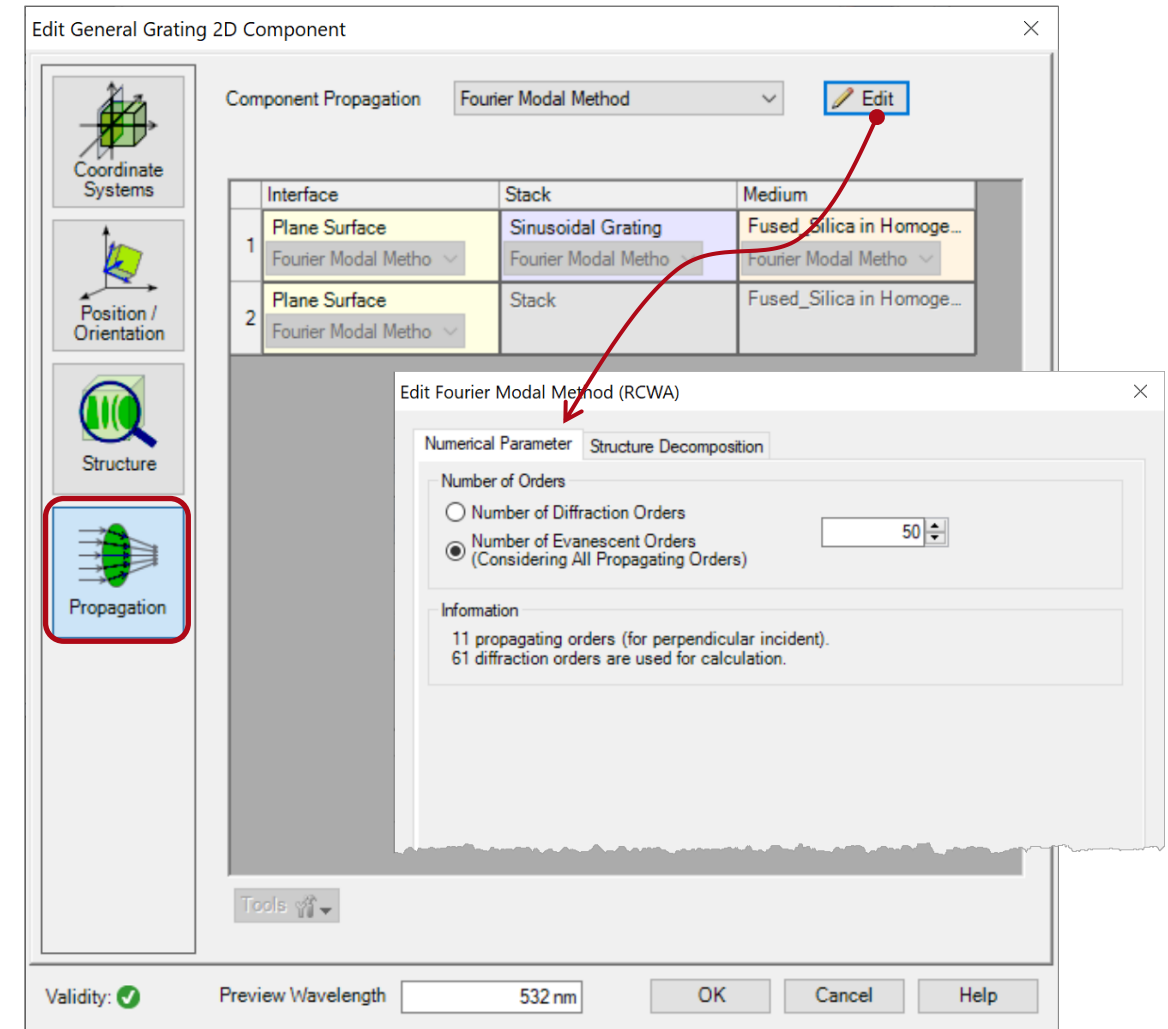
- The rectangular grating interface is defined by the following parameters
 - slit width (absolute or relative)
 - grating period
 - modulation depth
- A lateral shift and rotation can be set optionally.



The screenshot shows the 'Edit Rectangular Grating Interface' dialog box with four tabs: 'Structure', 'Height Discontinuities', 'Scaling of Elementary Interface', and 'Periodization'. The 'Structure' tab is active. It contains three sections: 'Special Rectangular Grating Values' with a 'Slit Width' dropdown set to '5 μm'; 'Common Grating Values' with 'Extension' set to '10 μm' and 'Modulation Depth' set to '1 μm'; and 'Position' with 'Lateral Shift' set to '0 mm' and 'Rotation Angle' set to '0°'. The 'Validity' indicator shows a green checkmark. At the bottom are 'OK', 'Cancel', and 'Help' buttons.

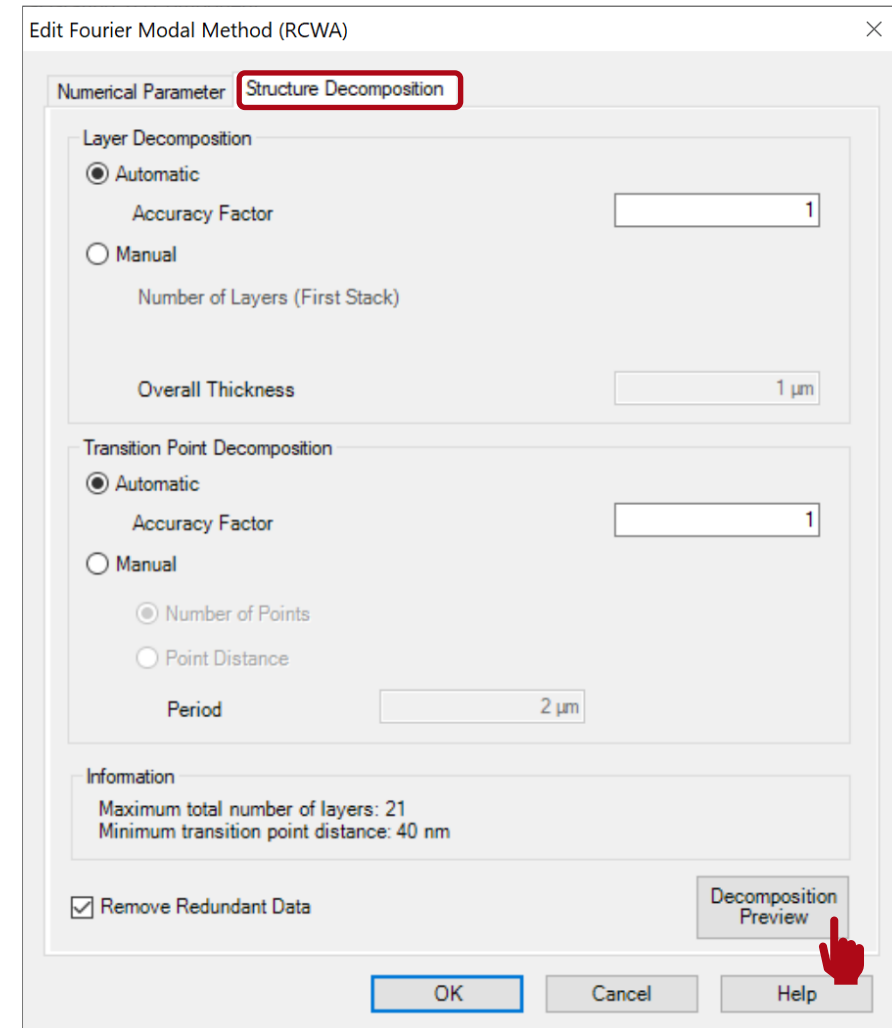
Advanced Options & Information

- In the propagation menu several advanced options are available.
- The propagation method tab allows to edit the accuracy settings of the FMM algorithm.
- Either the numbers of considered total orders or evanescent orders can be set.
- This might be useful, if metallic gratings are considered.
- In contrast, in case of dielectric gratings, the default setting will be sufficient.



Advanced Options & Information

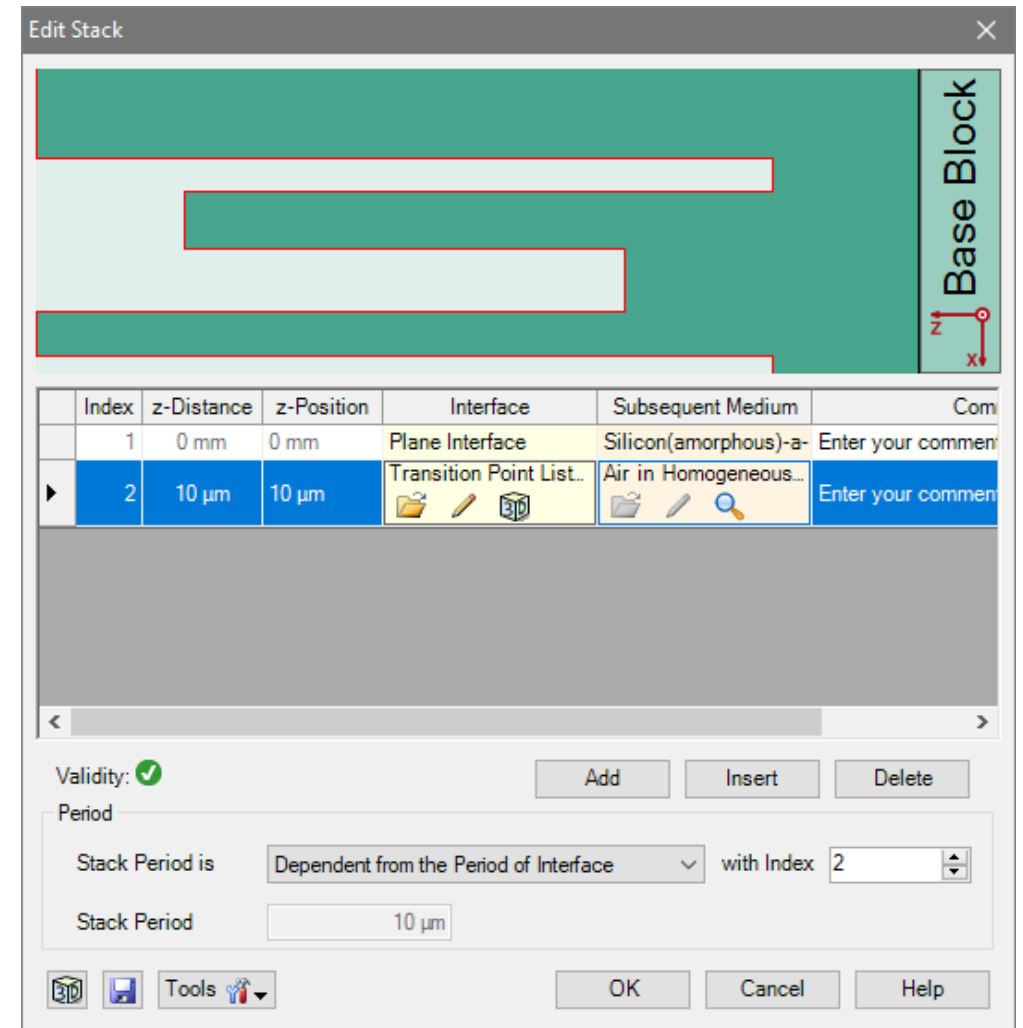
- The *Advanced Settings* tab provides information about the decomposition of the structure.
- The *Layer Decomposition* and *Transition Point Decomposition* settings can be used to adjust the discretization of the structure. The default settings are appropriate for nearly all grating structures.
- Further, information about the number of layers and transition points are provided.
- The *Decomposition Preview* button provides a depiction of the structure data which are used for the FMM calculation. The refractive index is illustrated by a color scale.



Transition Point List Interface

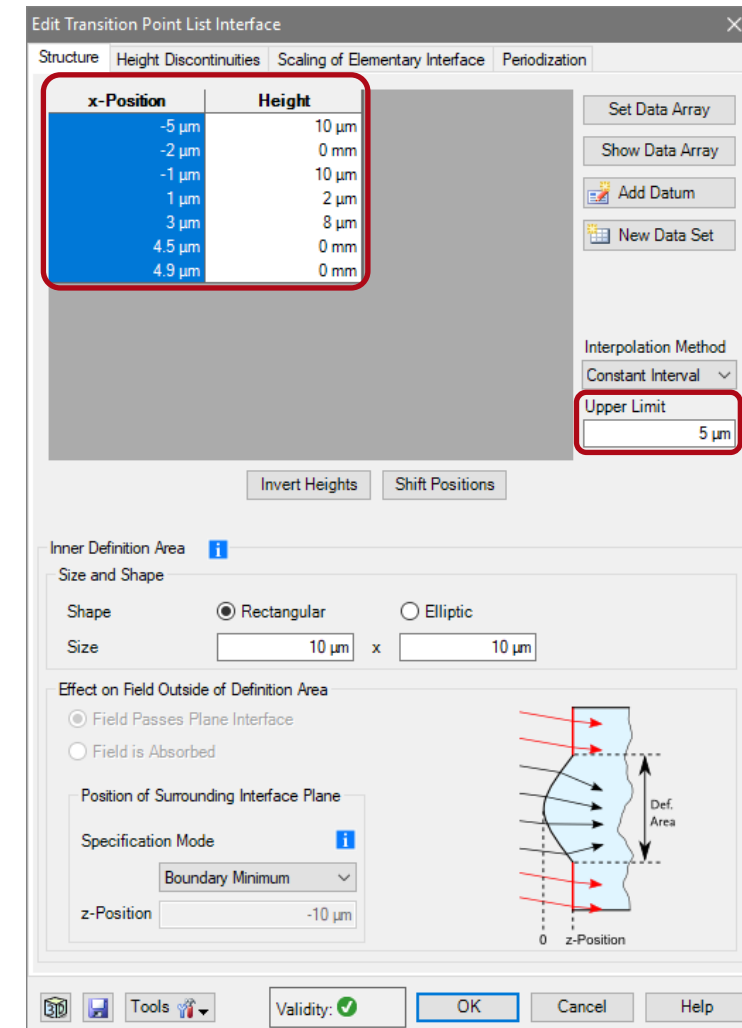
Transition Point List Interface

- Another type of interface which can be used for the configuration of gratings is the transition point list interface.
- This interface allows to configure a structure based on height values for different positions inside the period.
- Again, a plane interface is used to separate the grating material or medium from the one of the substrate.



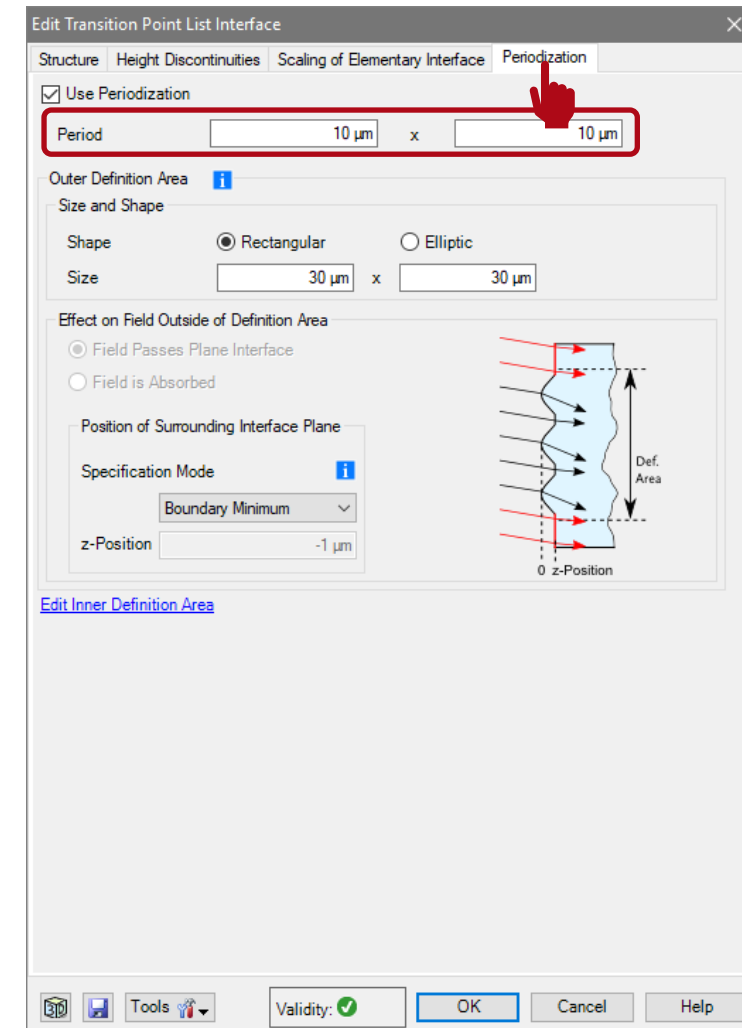
Transition Point List Parameters

- The transition point list interface is defined by a list which contains the data of x-positions and heights.
- The *Upper Limit* has to be set to a value larger than half of the desired grating period, but is set automatically in case of periodic structures.



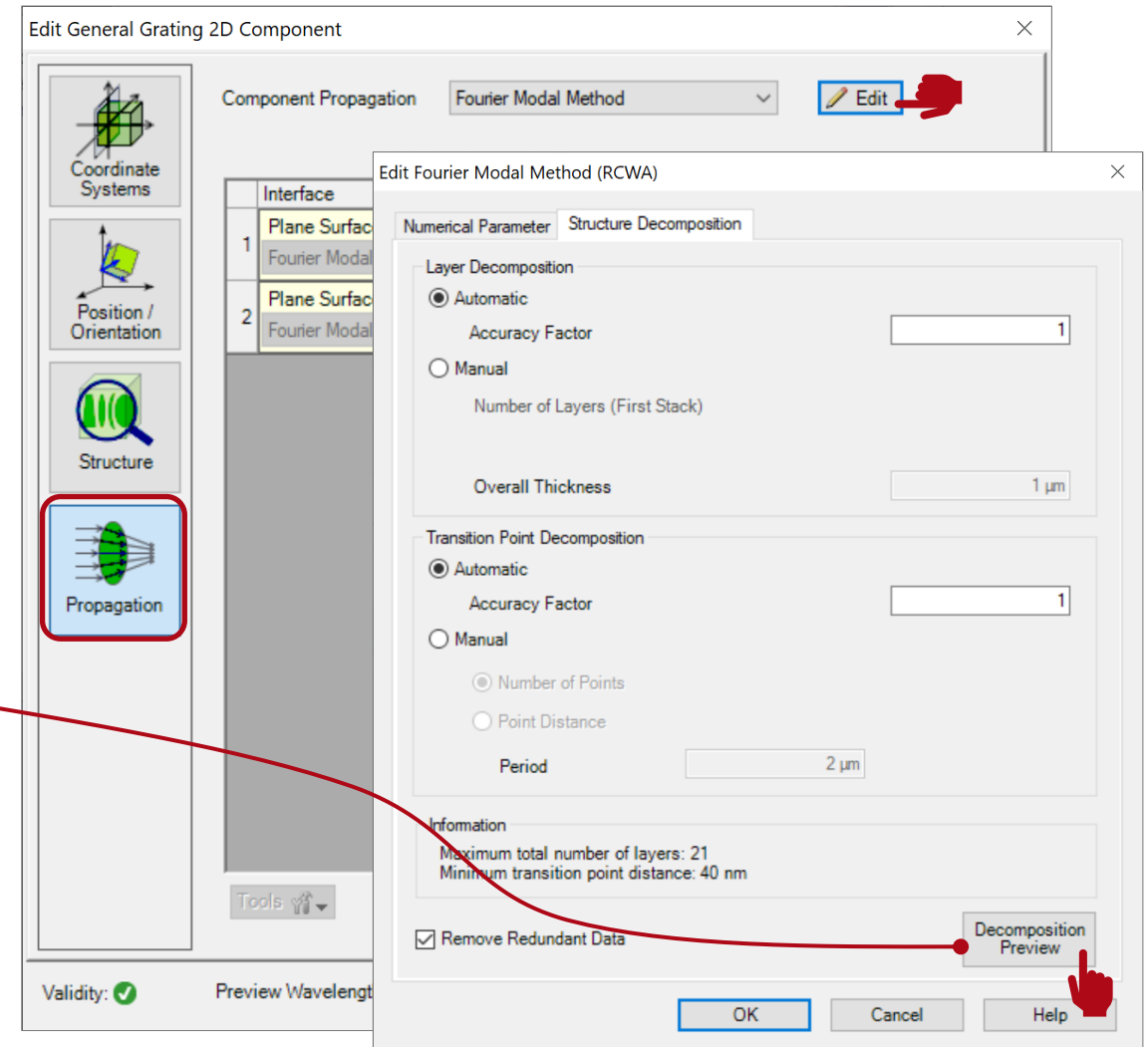
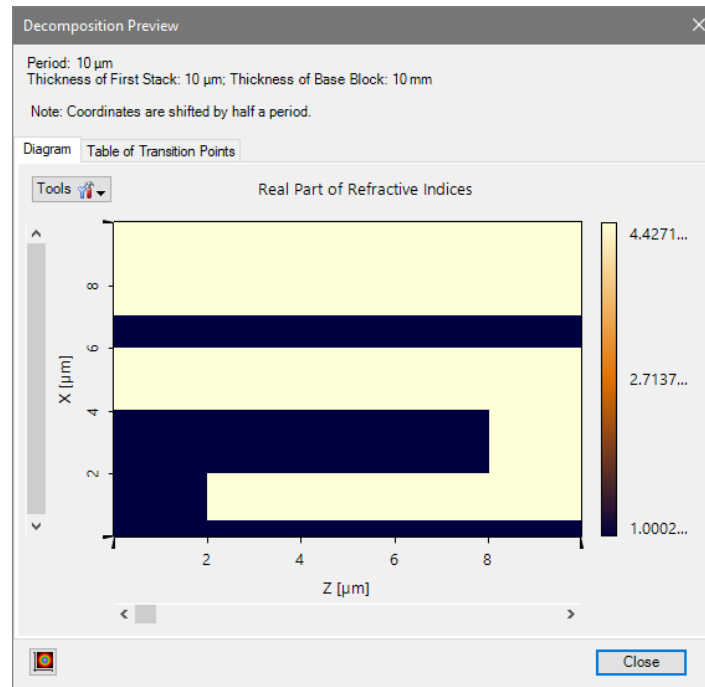
Transition Point List Parameters

- The period of this interface has to be set in the *Periodization* tab.
- Here, the periods in x- and y-direction can be defined.
- The settings of the inner and outer definition area can be neglected in this case, because the extension of the interface is already truncated by the periodic boundary conditions.



Advanced Options & Information

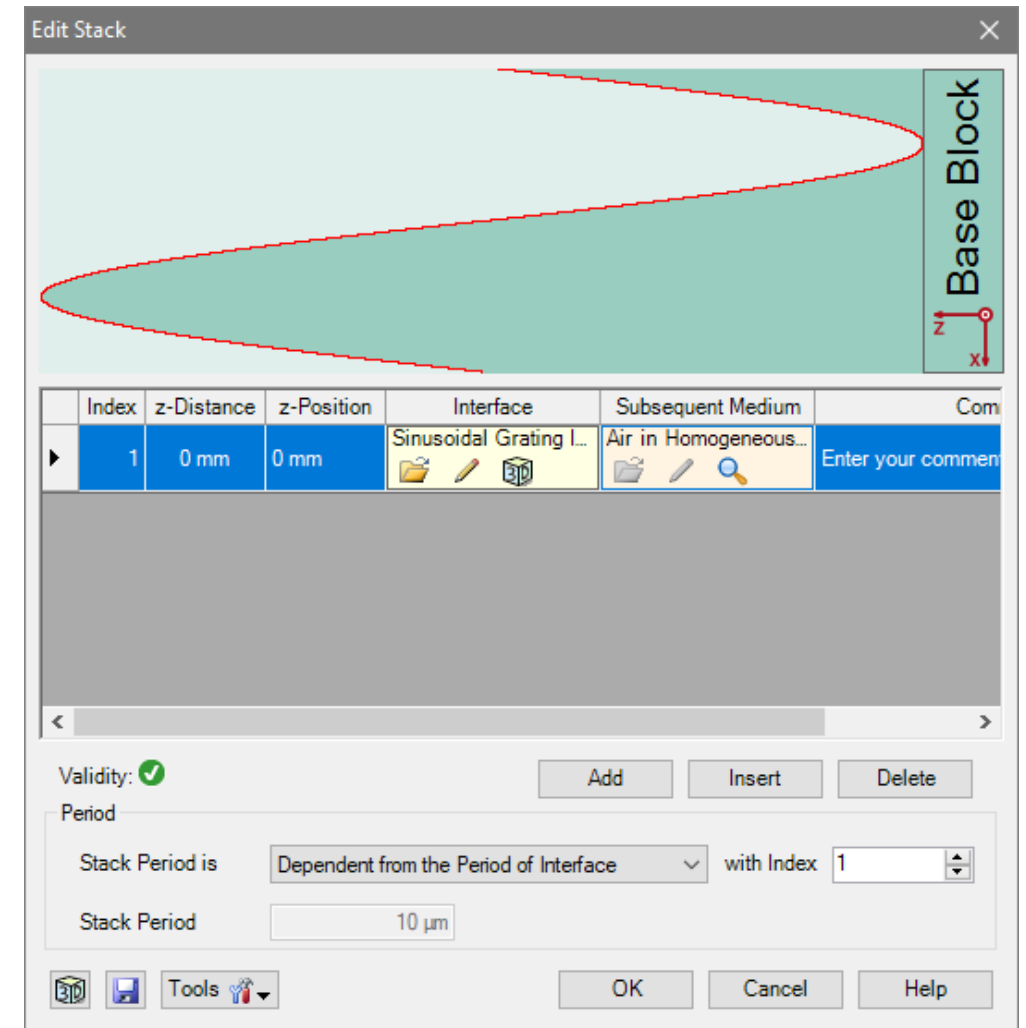
- Again, the data of the decomposed structure can be adjusted and investigated on the advanced settings tab page.



Sinusoidal Grating Interface

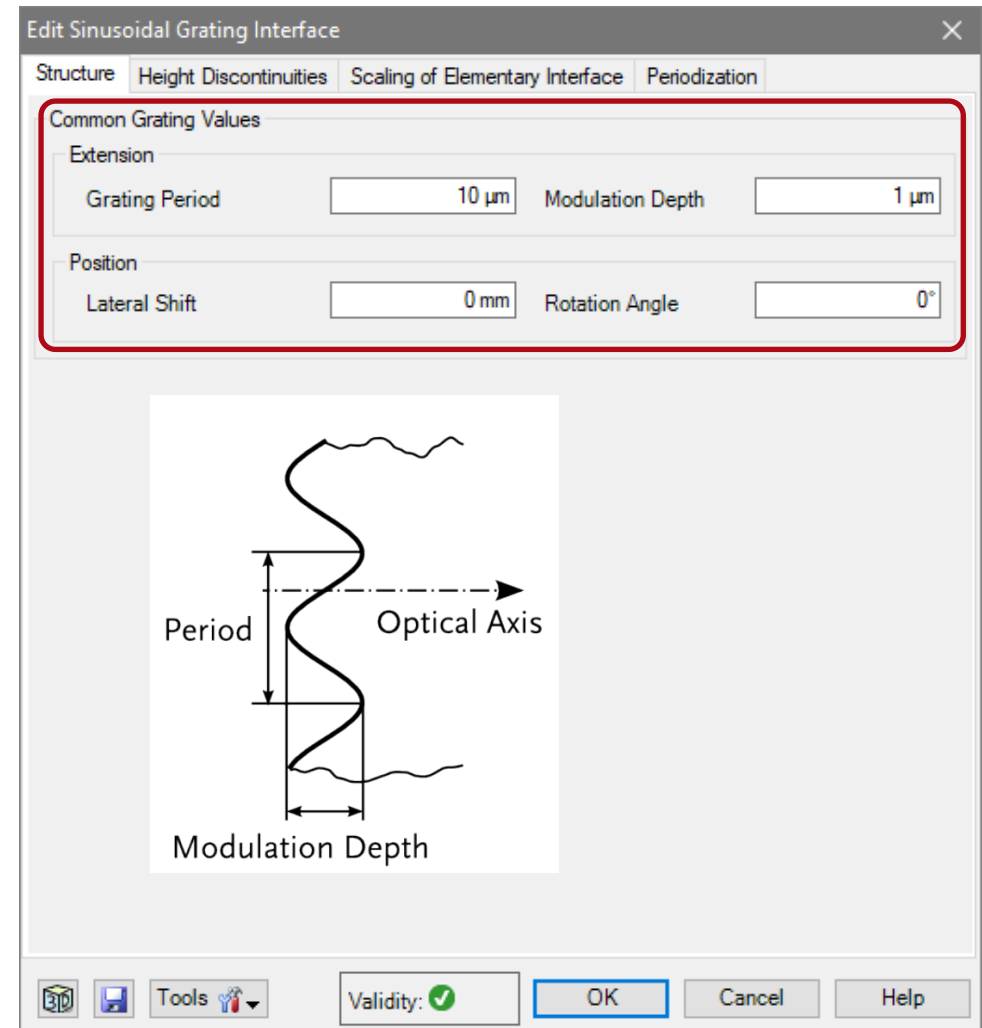
Sinusoidal Grating Interface

- Another type of interface which can be used for the configuration of gratings is the sinusoidal grating interface.
- This interface allows to configure gratings with a smooth shape of a sinusoidal function.
- If a single interface is used to describe the grating structure, the materials are chosen automatically:
 - material of ridges: material of substrate
 - material of grooves: material in front of grating



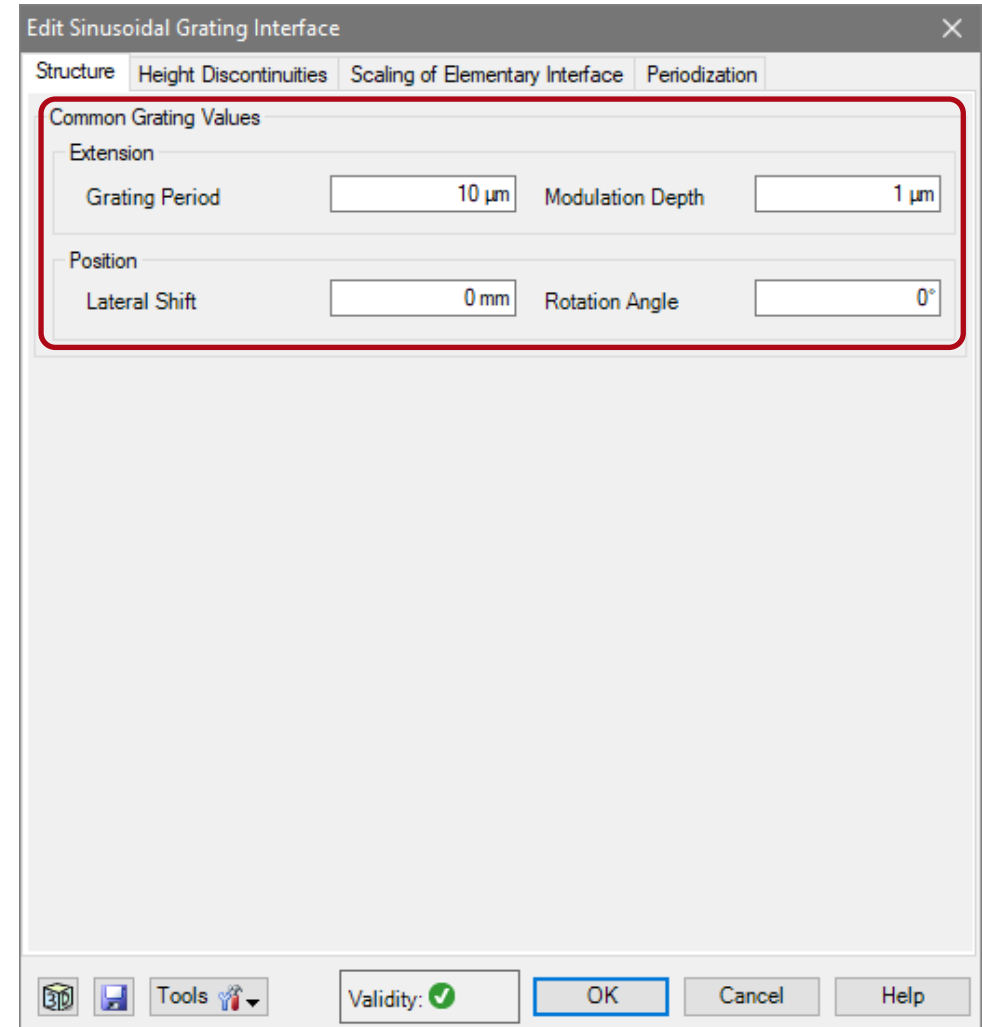
Sinusoidal Grating Interface Parameters

- The sinusoidal grating interface is also defined by the following parameters:
 - grating period
 - modulation depth
- A lateral shift and rotation can be set optionally.
- As this is a grating interface (likewise to the rectangular and sawtooth one) no periodization has to be chosen.



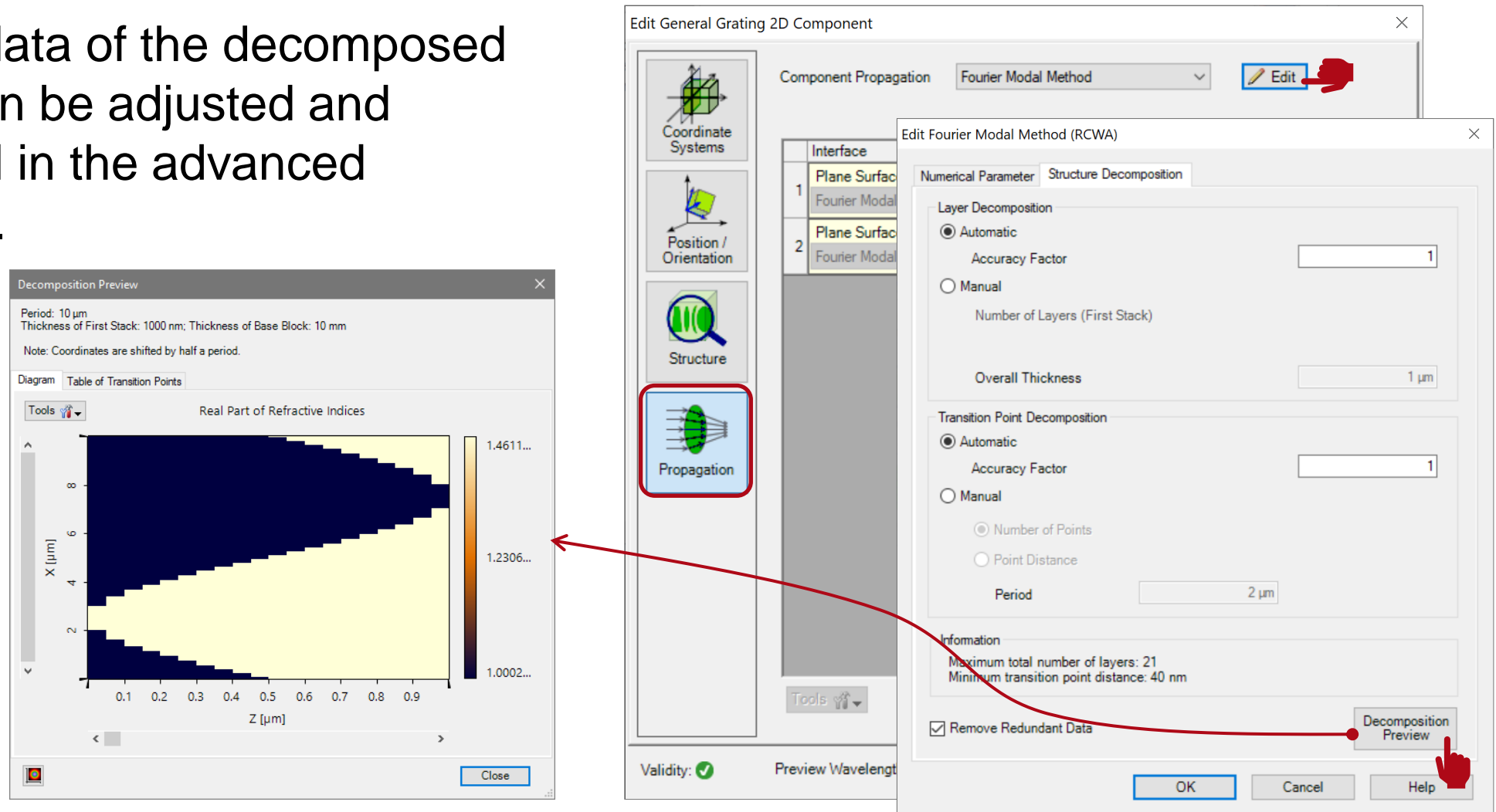
Sinusoidal Grating Interface Parameters

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 - grating period
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- As this is a grating interface (likewise to the rectangular and sawtooth one) no periodization has to be chosen.



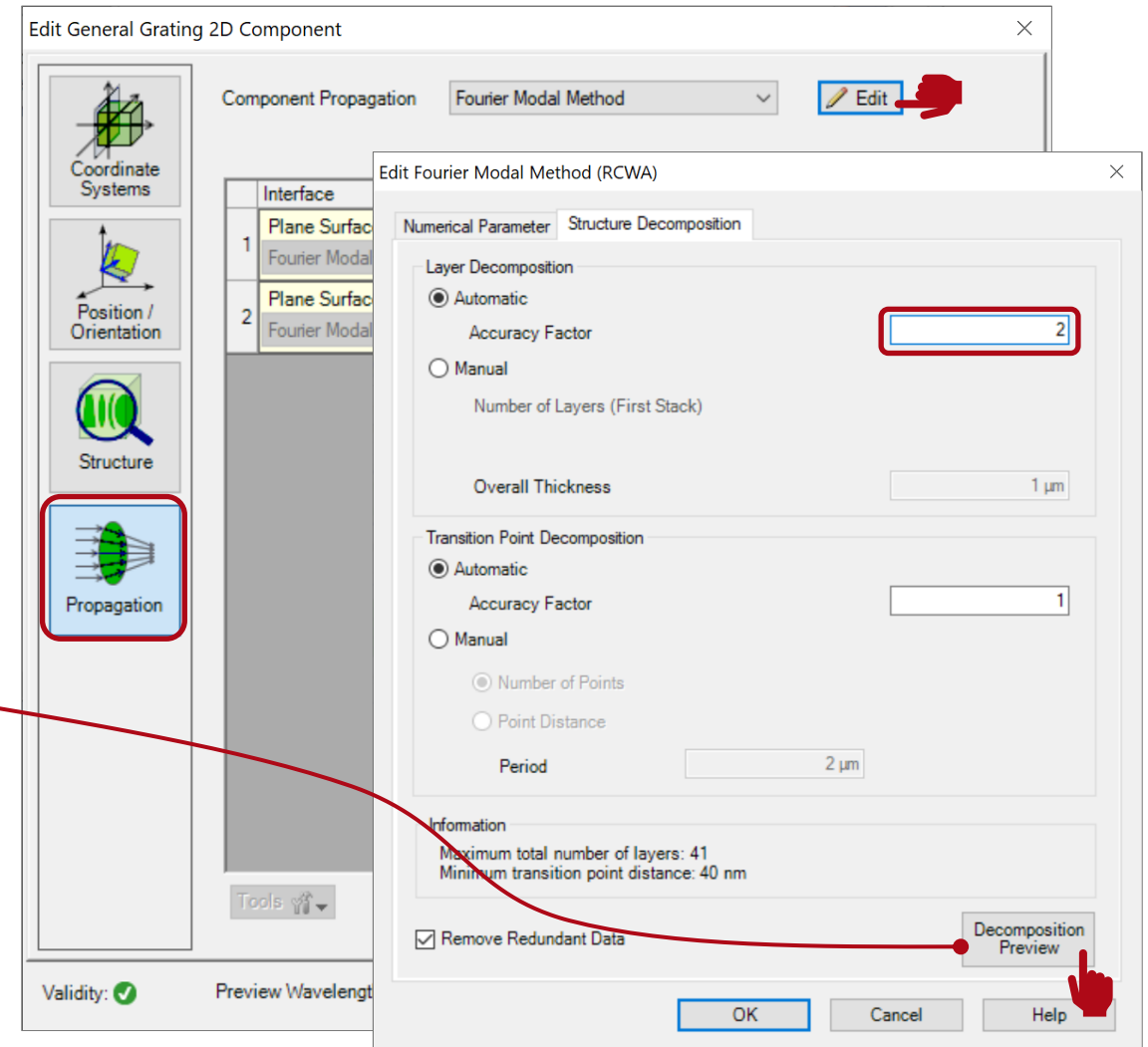
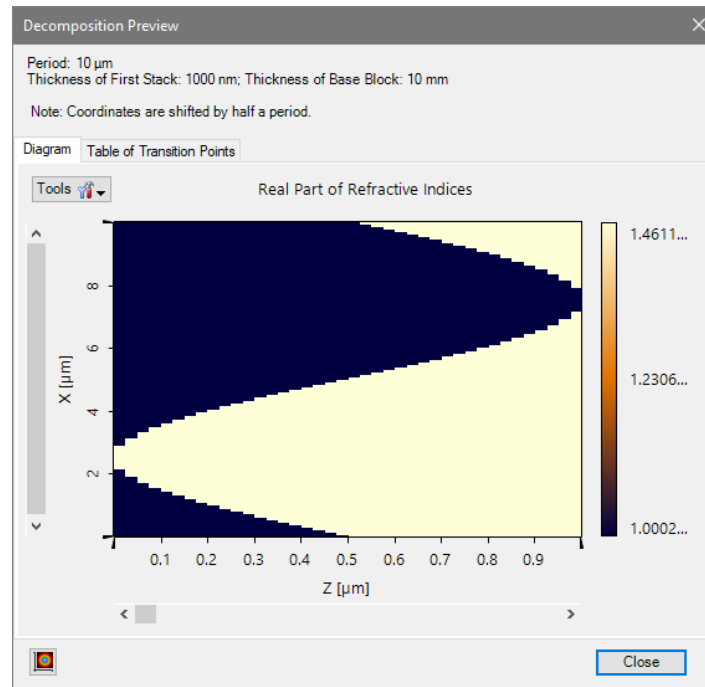
Advanced Options & Information

- Again, the data of the decomposed structure can be adjusted and investigated in the advanced settings tab.



Advanced Options & Information

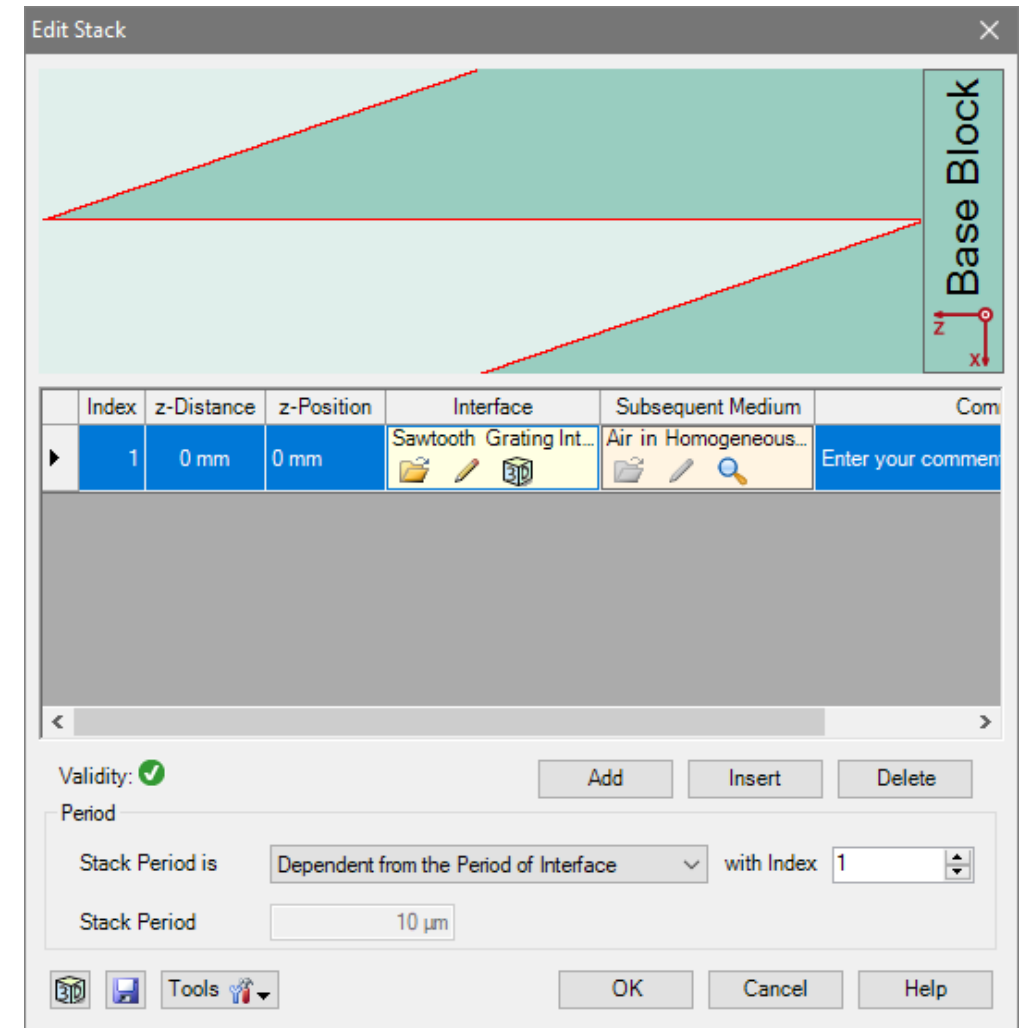
- If the number of layers is increased (e.g. by a factor of 2), the discretization becomes less rough.



Sawtooth Grating Interface

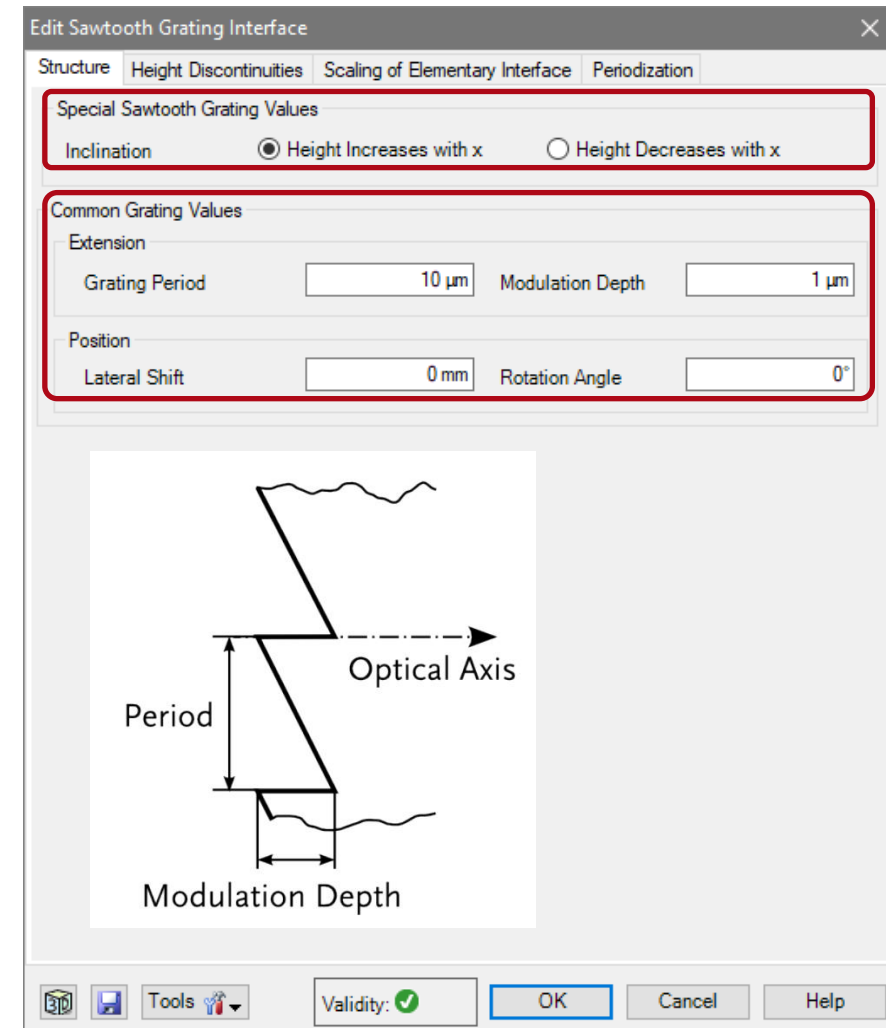
Sawtooth Grating Interface

- Another type of interface which can be used for the configuration of gratings is the sawtooth grating interface.
- This interface allows to configure gratings with blazed structure.
- If a single interface is used to describe the grating structure, the materials are chosen automatically:
 - material of ridges: material of substrate
 - material of grooves: material in front of grating



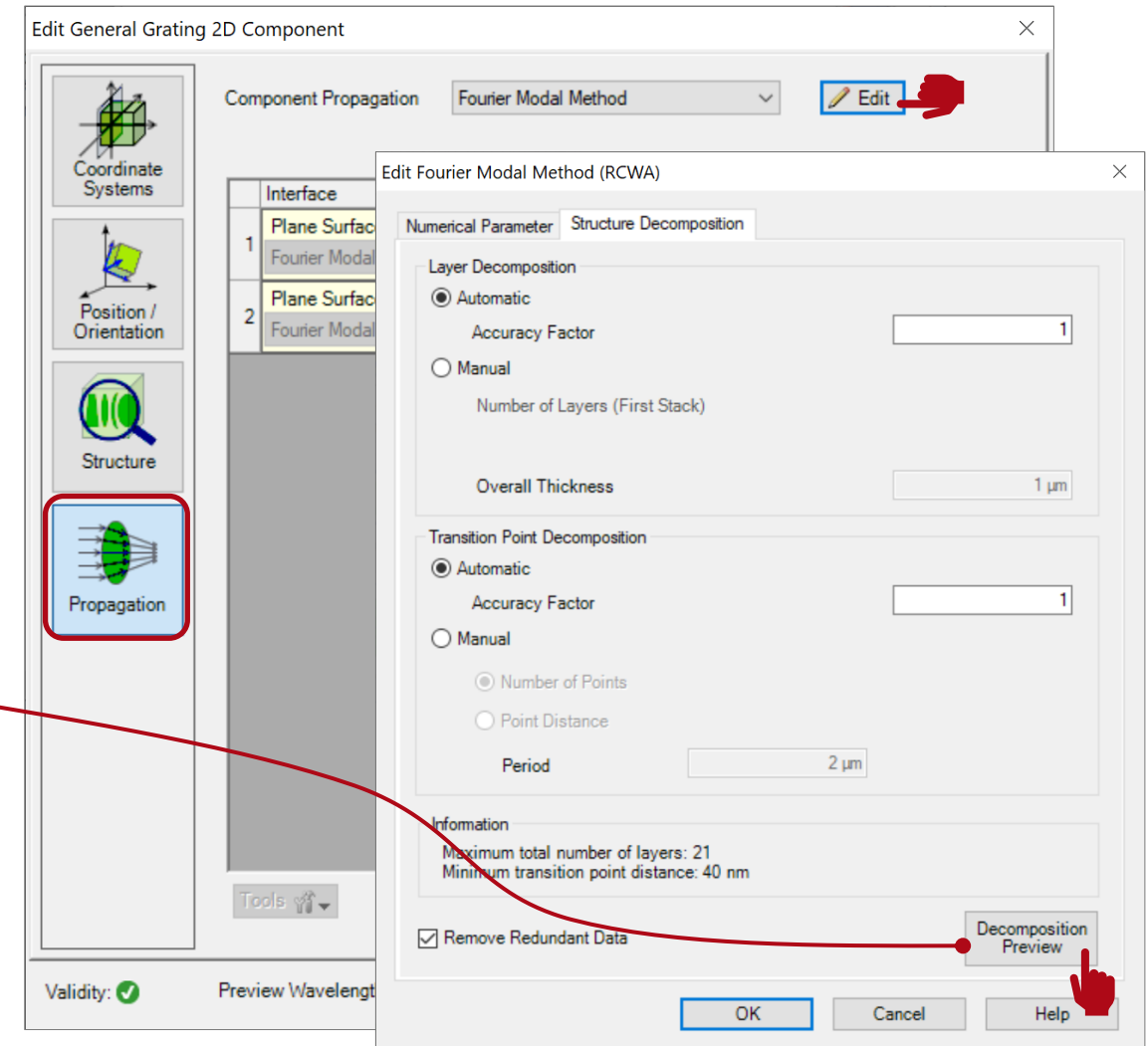
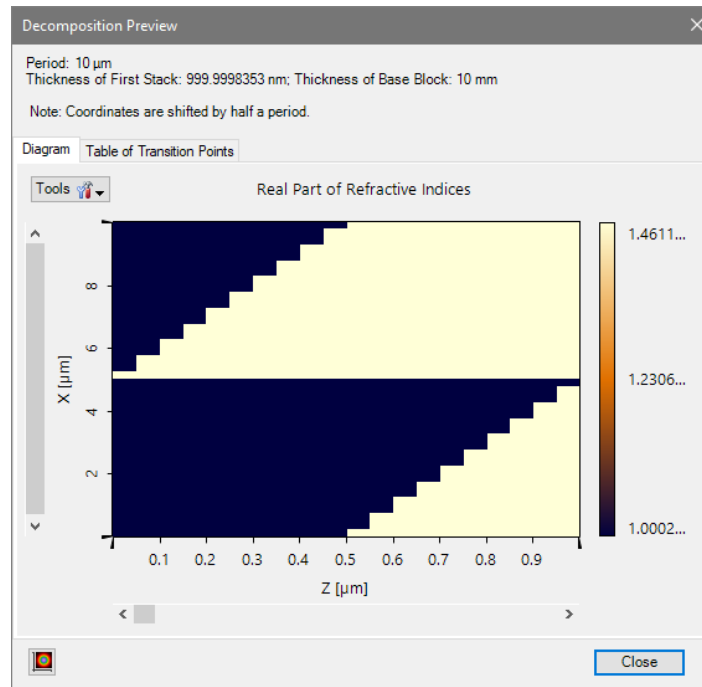
Sawtooth Grating Interface Parameters

- The sawtooth grating interface is also defined by the following parameters:
 - grating period
 - modulation depth
- Further, the direction of the blaze can be adjusted by setting the inclination.
- A lateral shift and rotation can be set optionally.
- As this is a grating interface (likewise to the rectangular and sinusoidal one) no periodization has to be chosen.



Advanced Options & Information

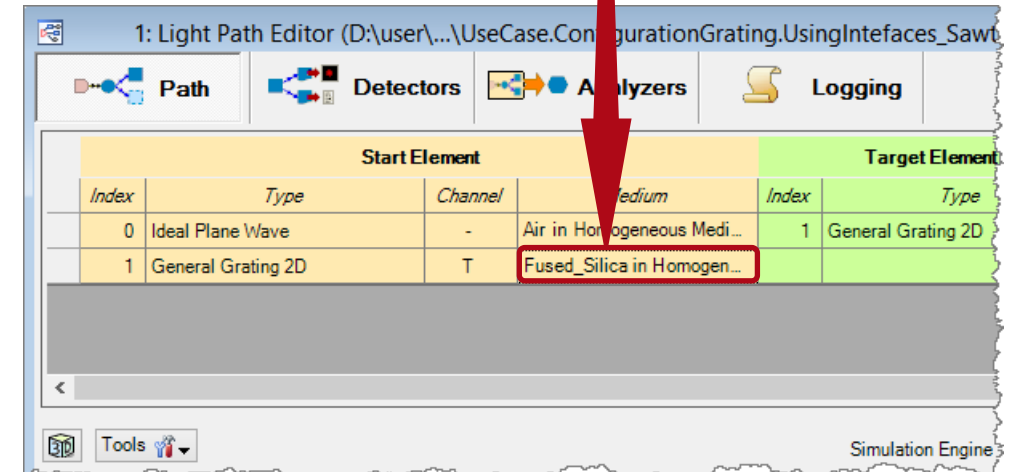
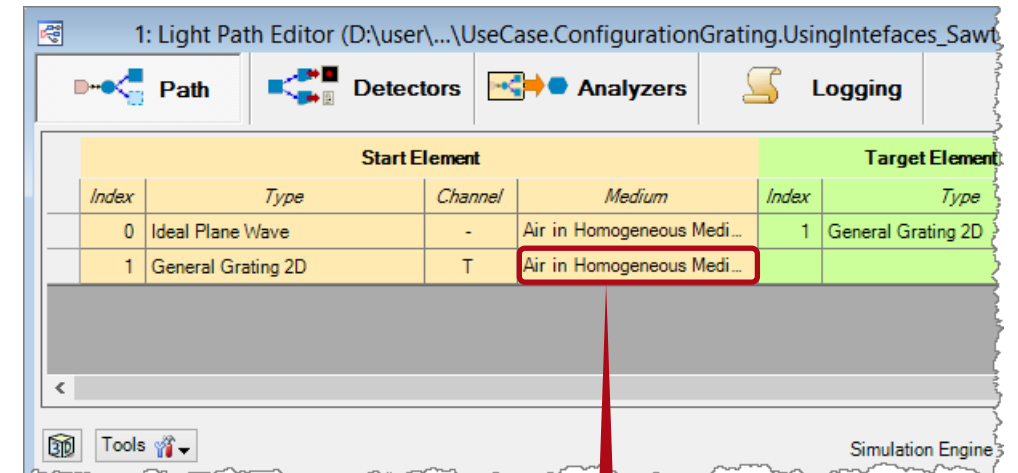
- Again, the data of the decomposed structure can be adjusted and investigated in the advanced settings.



Remark on the Position of the Detector

Remark on the Detector Position

- In VirtualLab the detector is located subsequent to the substrate in air by default.
- This is necessary if the grating is included in a complex optical setup.
- However, the perfect plane and parallel substrate may cause some interference effects, which not occur in reality.
- Thus, for calculation of just grating efficiencies it is appropriate to set the detector inside the substrate material (likewise to most of grating evaluation software).
- This avoids the undesired influence of those interference effects.



Document Information

title	Configuration of Grating Structures by Using Interfaces
document code	GRT.0004
version	1.2
edition	VirtualLab Fusion Advanced
software version	2020.2 (Build 1.116)
category	Feature Use Case
further reading	<ul style="list-style-type: none">- <u>Configuration of Grating Structures by Using Special Media</u>- <u>Blazed Grating Analysis by Fourier Modal Method</u>- <u>Ultrasparse Dielectric Nanowire Grid Polarizers</u>

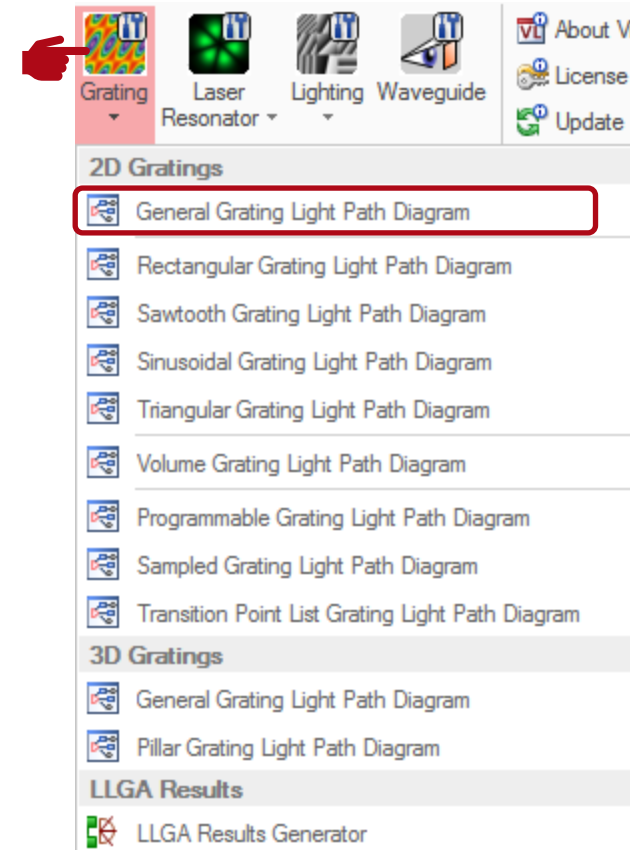
Configuration of Grating Structures by Using Special Media

This Use Case Shows ...

- How to configure grating structures in Grating Toolbox by using special media, e.g.:
 - slanted grating medium
 - volume grating medium
- How to change advanced options & inspect defined structure before calculation.

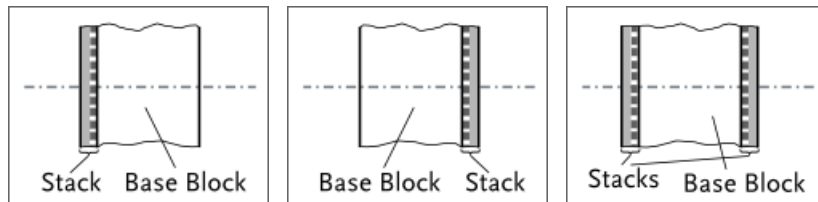
Grating Toolbox Initialization

- Initialization
 - Start →
Grating →
General Grating Light Path Diagram
- note: For usage of special type of grating, e.g. slanted grating or volume grating, the specific light path diagram can be chosen directly.

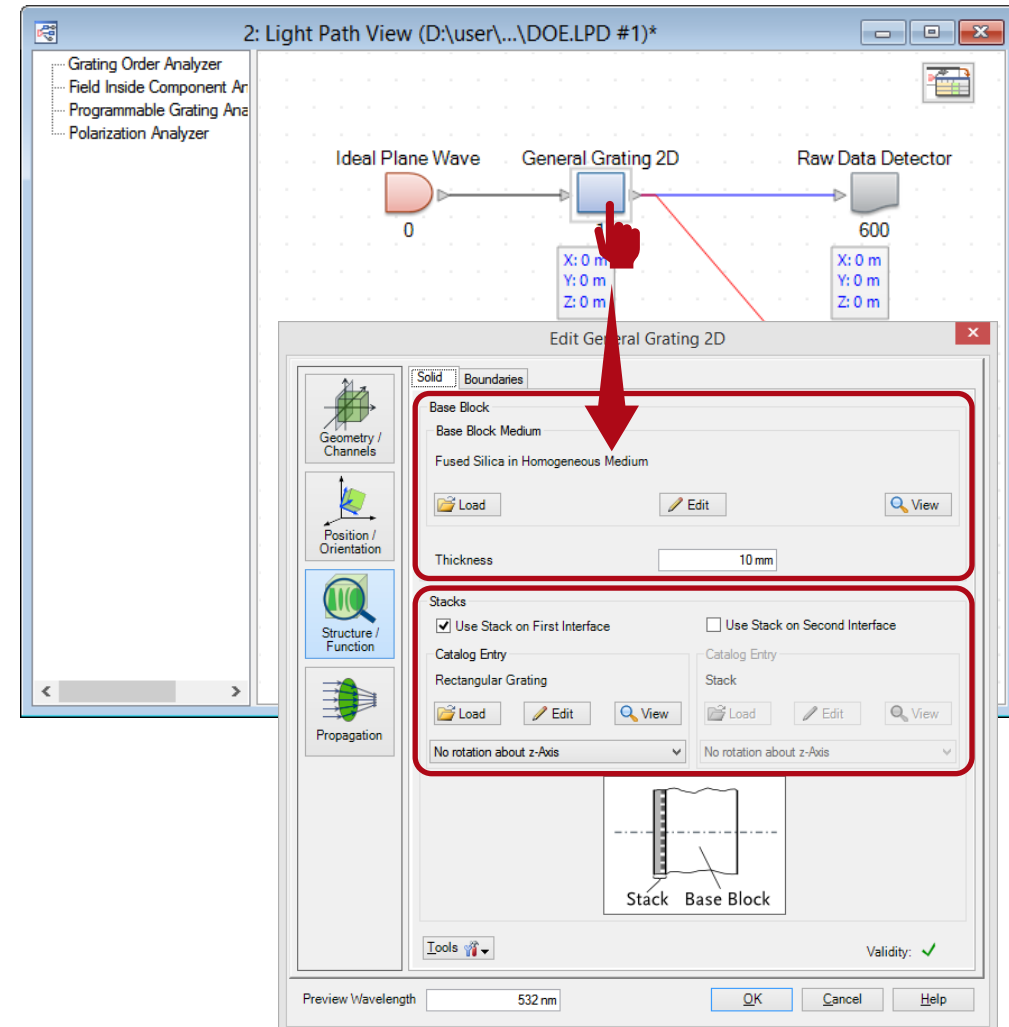


Grating Structure Settings

- First, the thickness and the material of the substrate (Base Block) have to be defined.
- In VirtualLab grating structures are defined in a so called stack.
- Stacks can be attached to either one or both sides of the substrate.

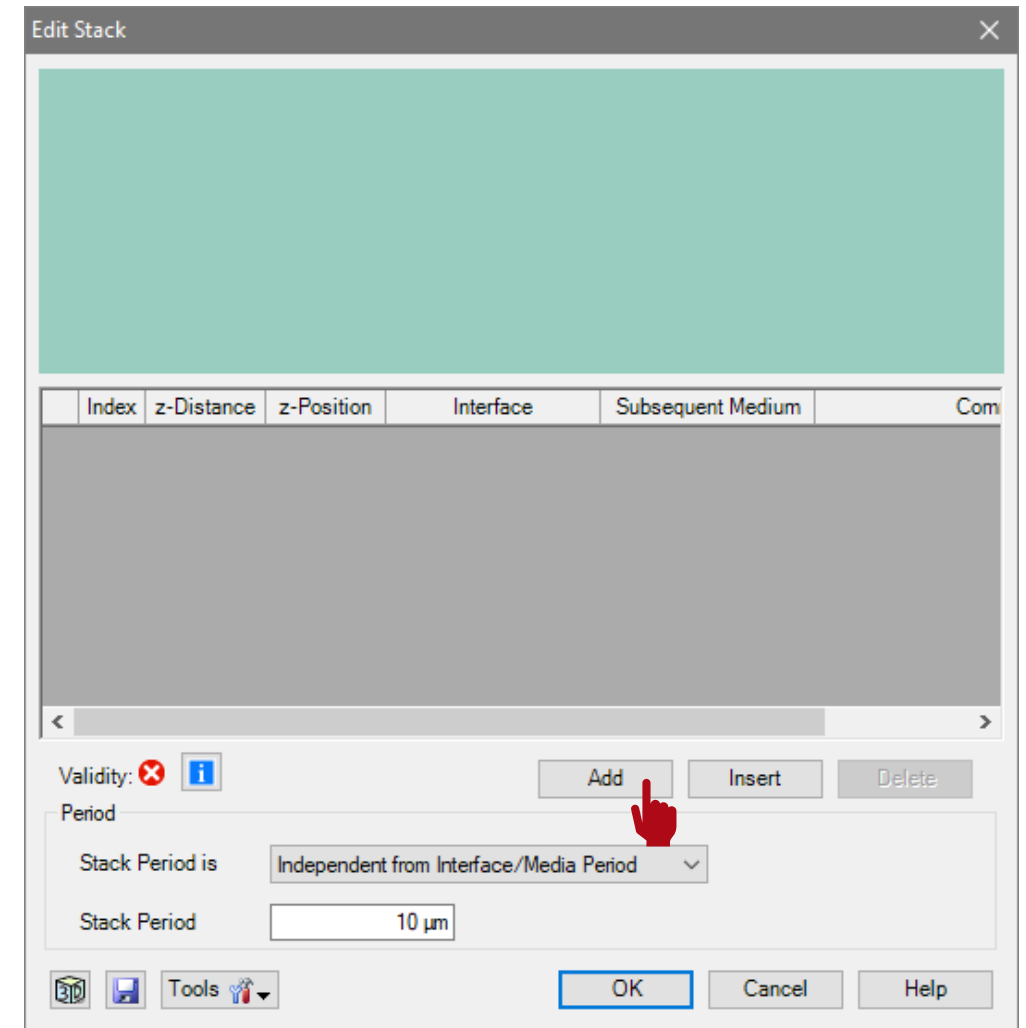
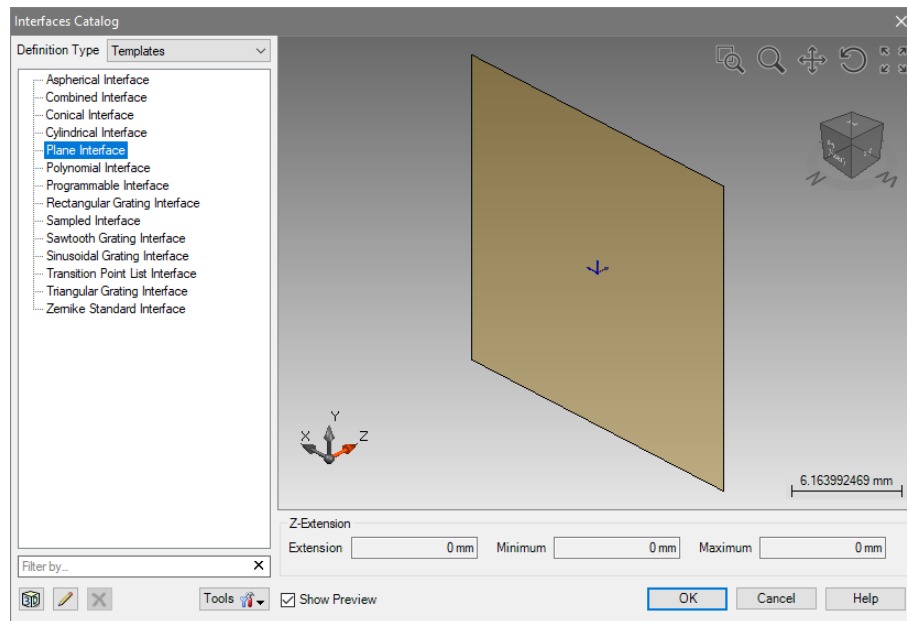


- For example, a stack on the first interface is chosen.



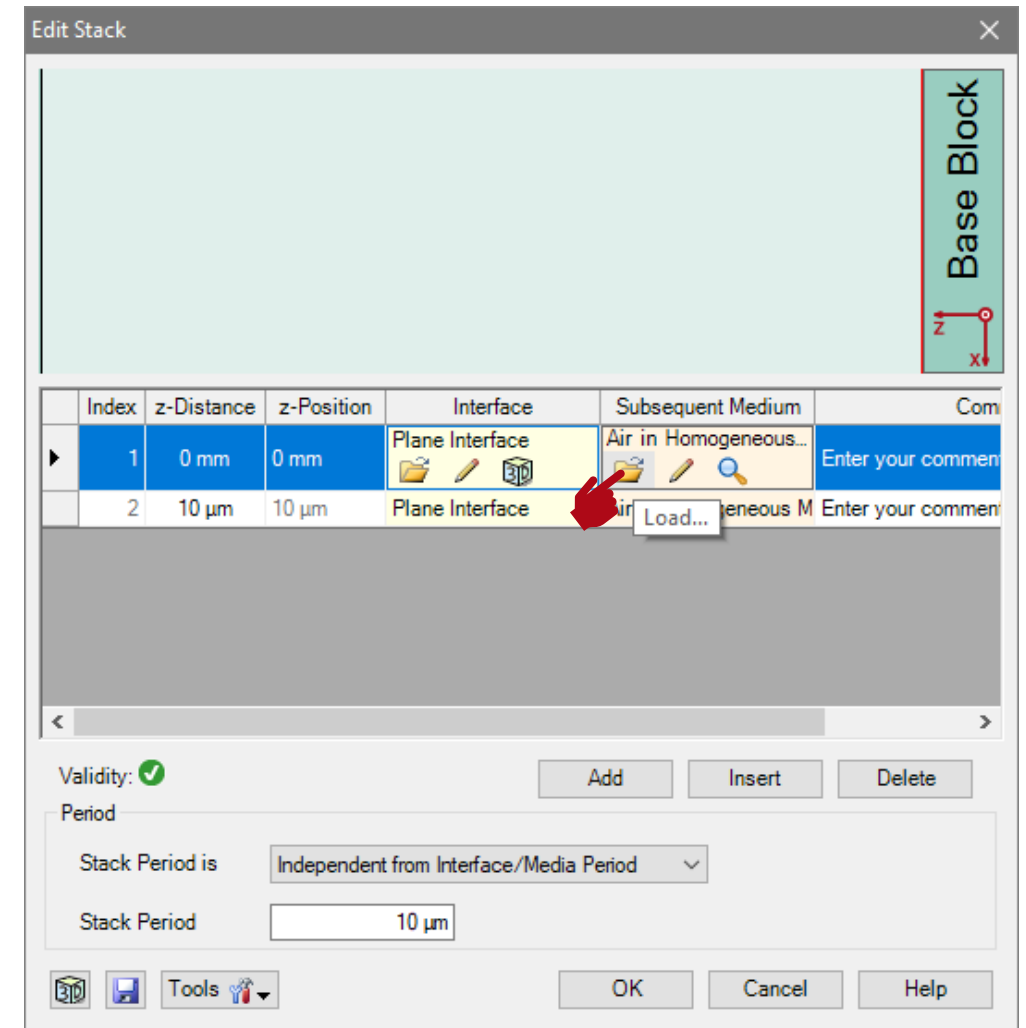
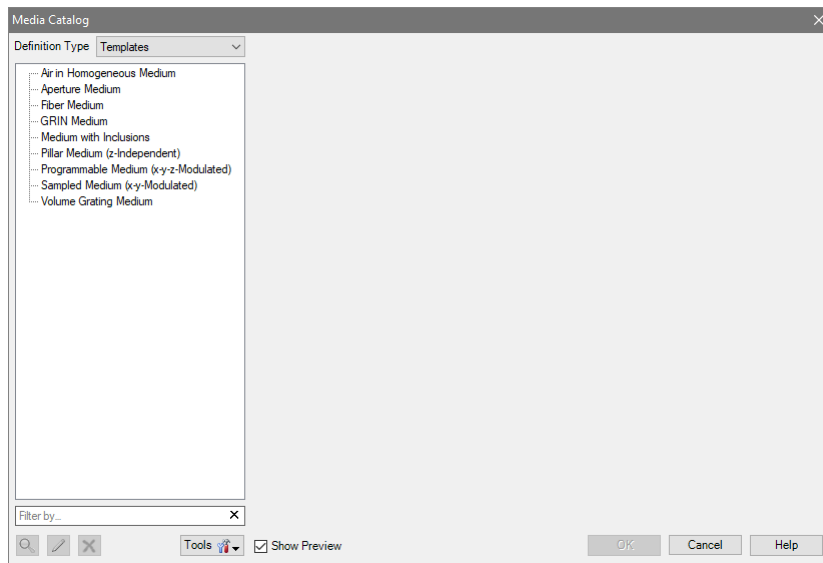
Stack Editor

- In the Stack Editor interfaces and media can be added or inserted from catalog.
- In order to define a grating by a special medium, two plane interfaces have to be added, which act as boundaries.



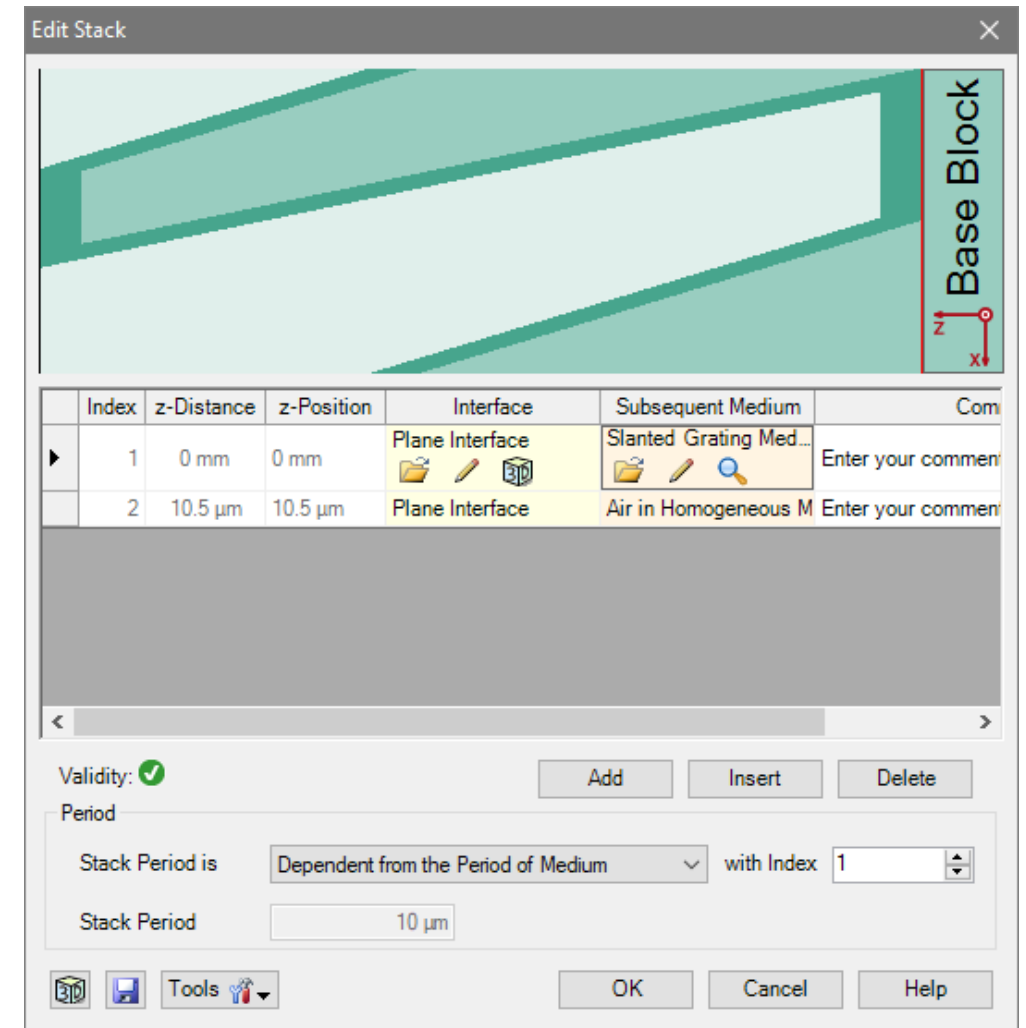
Stack Editor

- The medium between the two plane interfaces can be either homogenous or modulated.
- By using a latter one complex grating structures, like slanted gratings, can be described very efficiently.



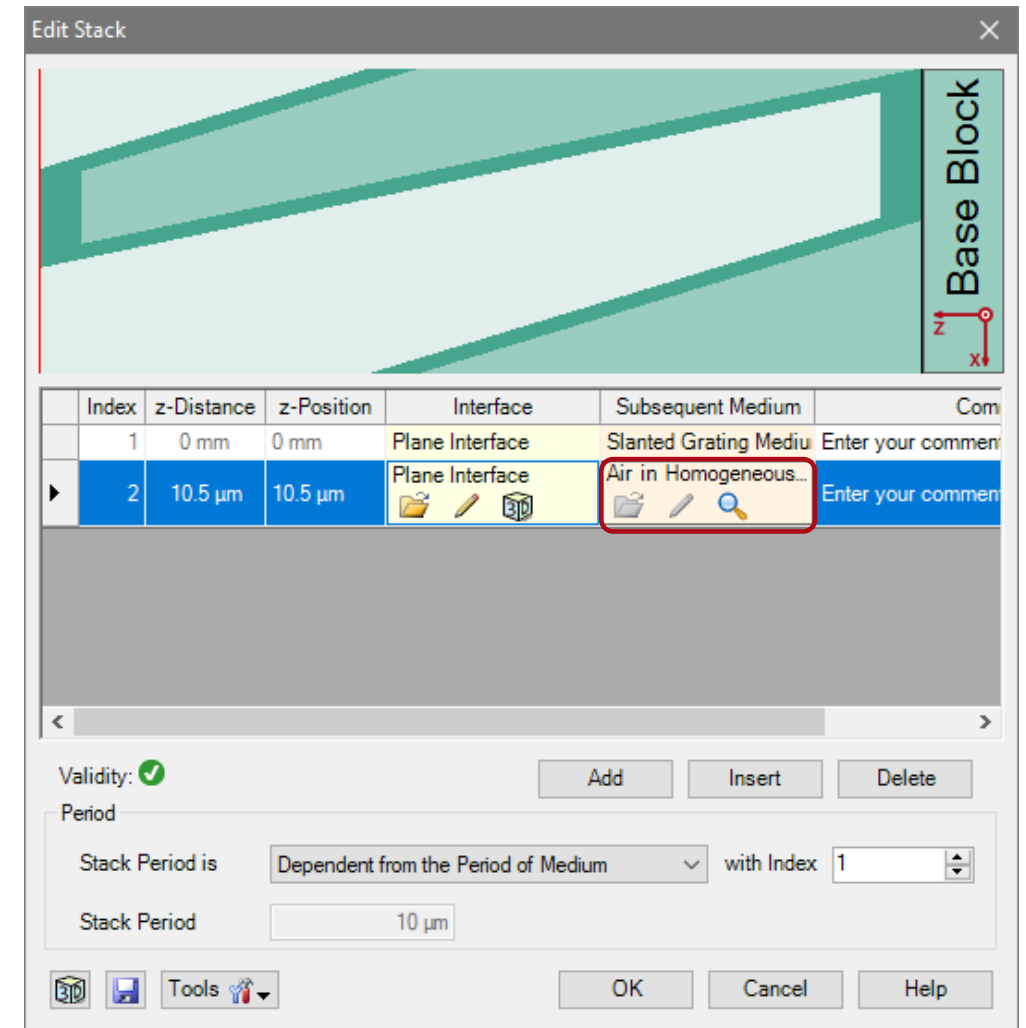
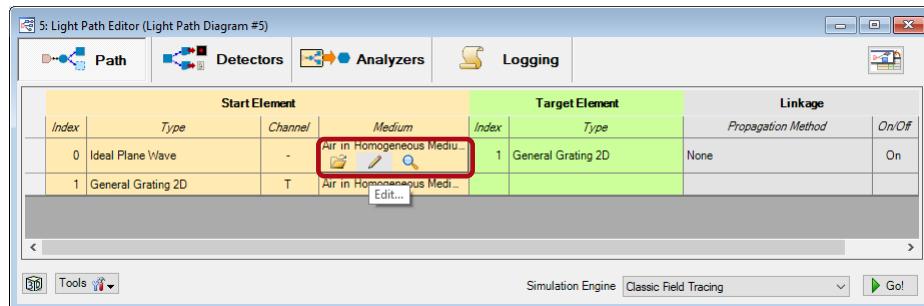
Coated Slanted Grating Medium

- In the catalog category “Templates” the Slanted Grating Medium can be found.
- This type of medium enables the use of slanted grating structures either with or without an additional coating.
- In this example, a grating made of fused silica with a coating consisting of chromium is located on a glass substrate.
- In the view of the stack editor, different materials are indicated by other colors based on their index of refraction (dark means higher).



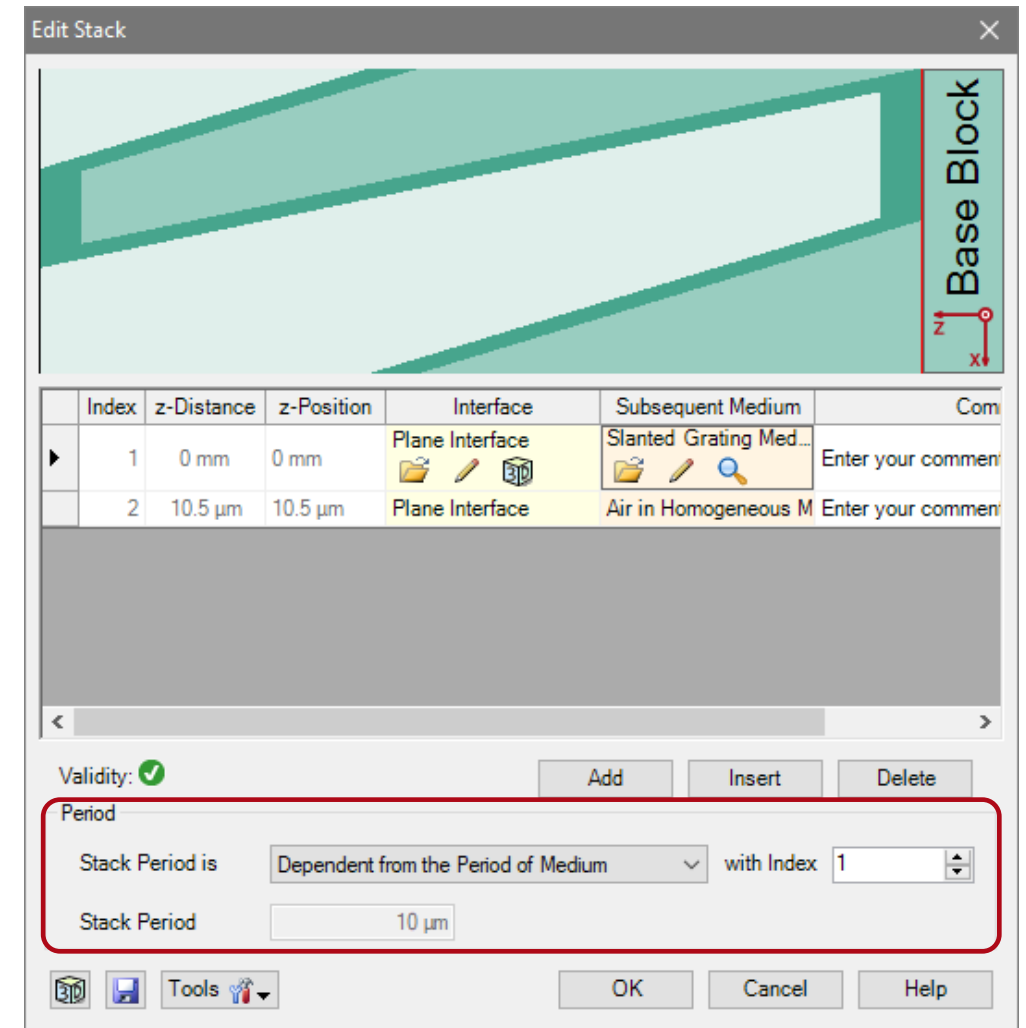
Coated Slanted Grating Medium

- Please note: the order of the interfaces is always counted from the surface of the substrate.
- The selected interface is highlighted red in the view.
- Further, the medium in front of the grating (means behind last interface) can not be defined here. It is automatically taken from the material in front of the grating component.
- This material can be changed in the Optical Setup Editor.



Coated Slanted Grating Medium

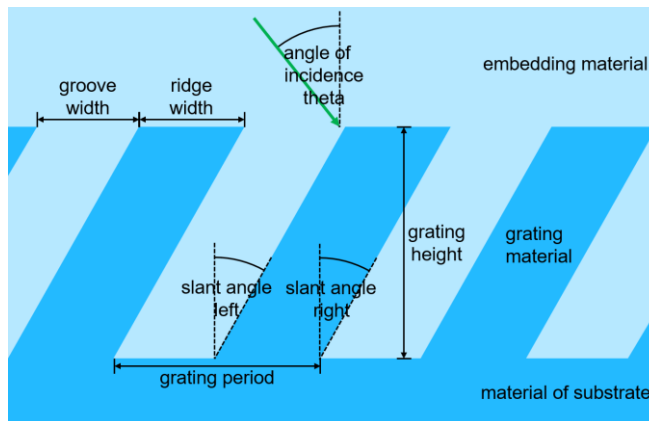
- The Stack Period allows to control the period of the whole configuration.
- This period is also taken for the periodic boundary conditions of the FMM algorithm.
- In case of simple grating structures, it is recommended to choose the option Dependent from Period of Medium and select the proper index of the periodic medium.
- Further, the distance between both interfaces is controlled by the grating height, automatically.



Coated Slanted Grating Medium Parameters

The slanted grating is defined by the following parameters:

- grating material (material of ridges)
- material of grooves
- fill factor (either referring to top or bottom)
- z-extension (grating height along z-direction)
- slant angle of side walls (left and right)
- material of coating
- thickness of coating for each side individually
- grating period

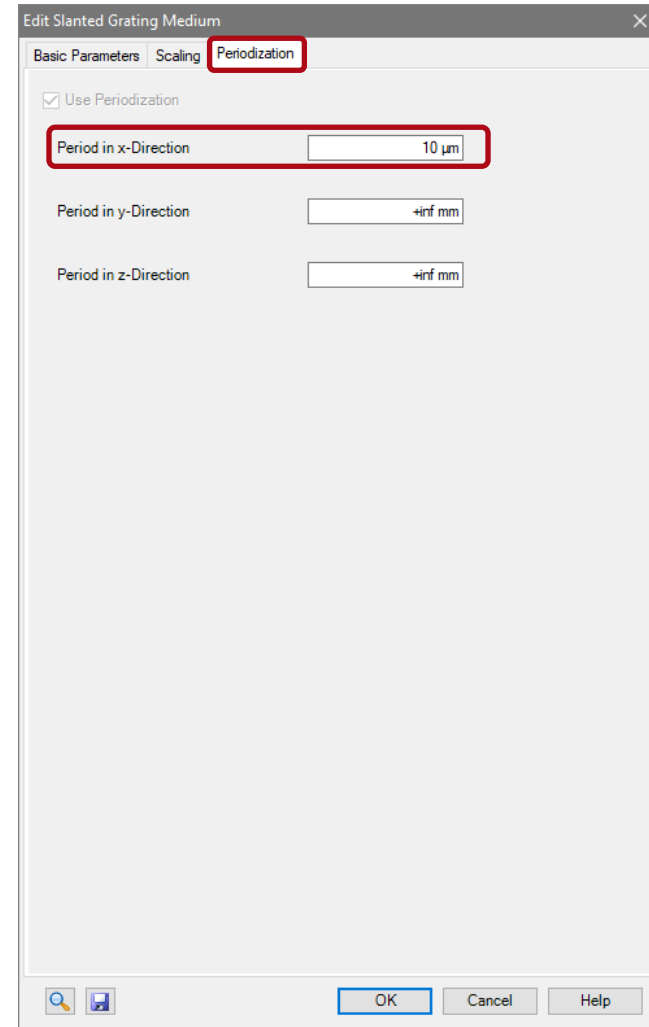


The screenshot shows the 'Edit Slanted Grating Medium' dialog box with the following parameters:

- Grating Material:**
 - Name: Fused Silica
 - Catalog Material: [dropdown]
 - State of Matter: Solid
- Groove Material:**
 - Name: Air
 - Catalog Material: [dropdown]
 - State of Matter: Gas or Vacuum
- Fill Factor:** 50 % (Refers to ... Bottom ☒ Top ☐)
- z-Extension:** 10 μm
- Slant Angle Left:** 40° **Slant Angle Right:** 30°
- Apply Coating:** ☒
- Coating Material:**
 - Name: Chromium
 - Catalog Material: [dropdown]
 - State of Matter: Solid
- Coating Thickness:** 500 nm (for all four sides of the grating ridges)

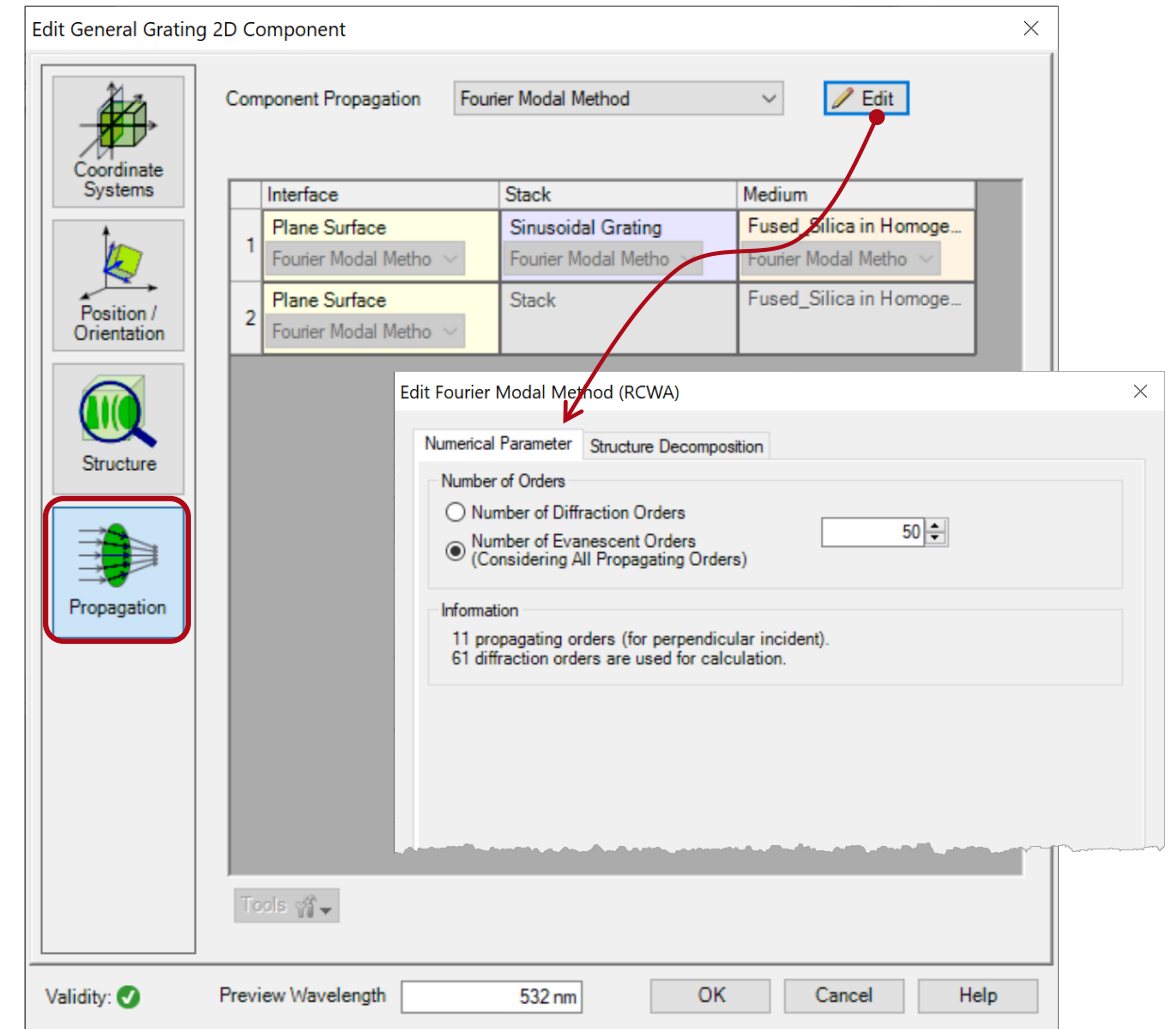
Coated Slanted Grating Medium Parameters

- As this grating is based on a medium definition type, the grating period has to be set in the periodization tab.



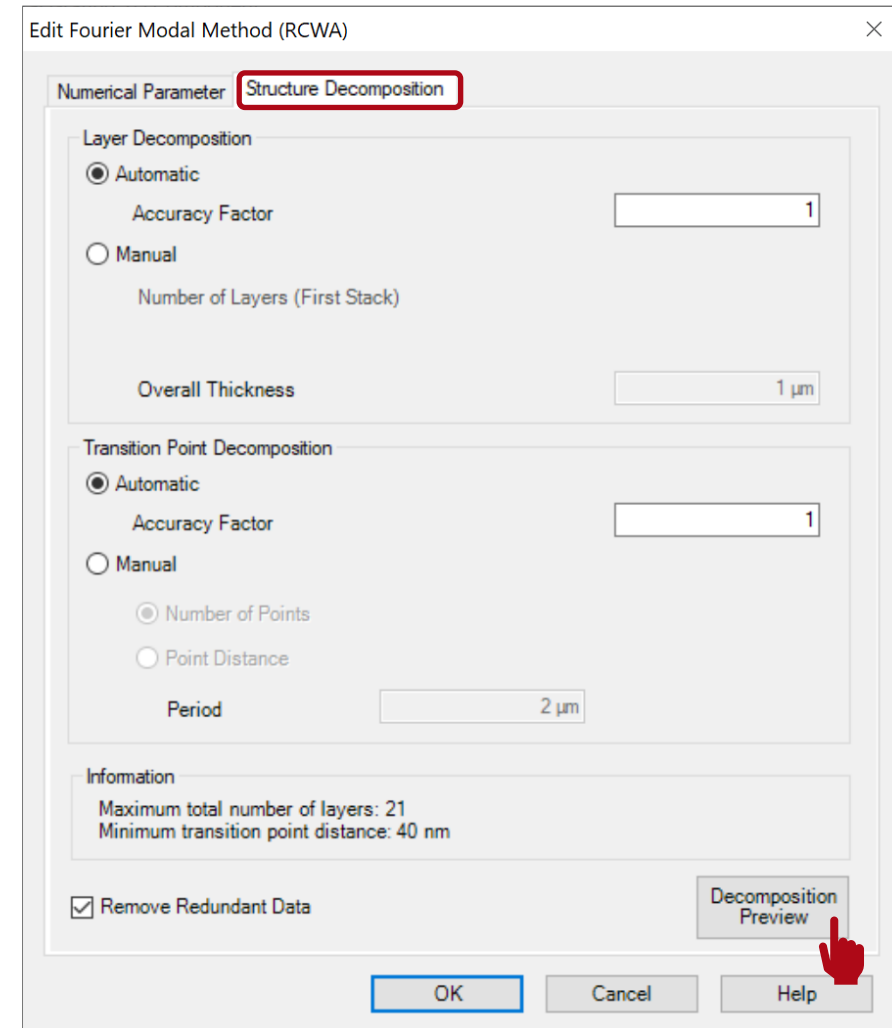
Advanced Options & Information

- In the propagation menu several advanced options are available.
- The propagation method tab allows to edit the accuracy settings of the FMM algorithm.
- Either the numbers of considered total orders or evanescent orders can be set.
- This might be useful, if metallic gratings are considered.
- In contrast, in case of dielectric gratings, the default setting will be sufficient.



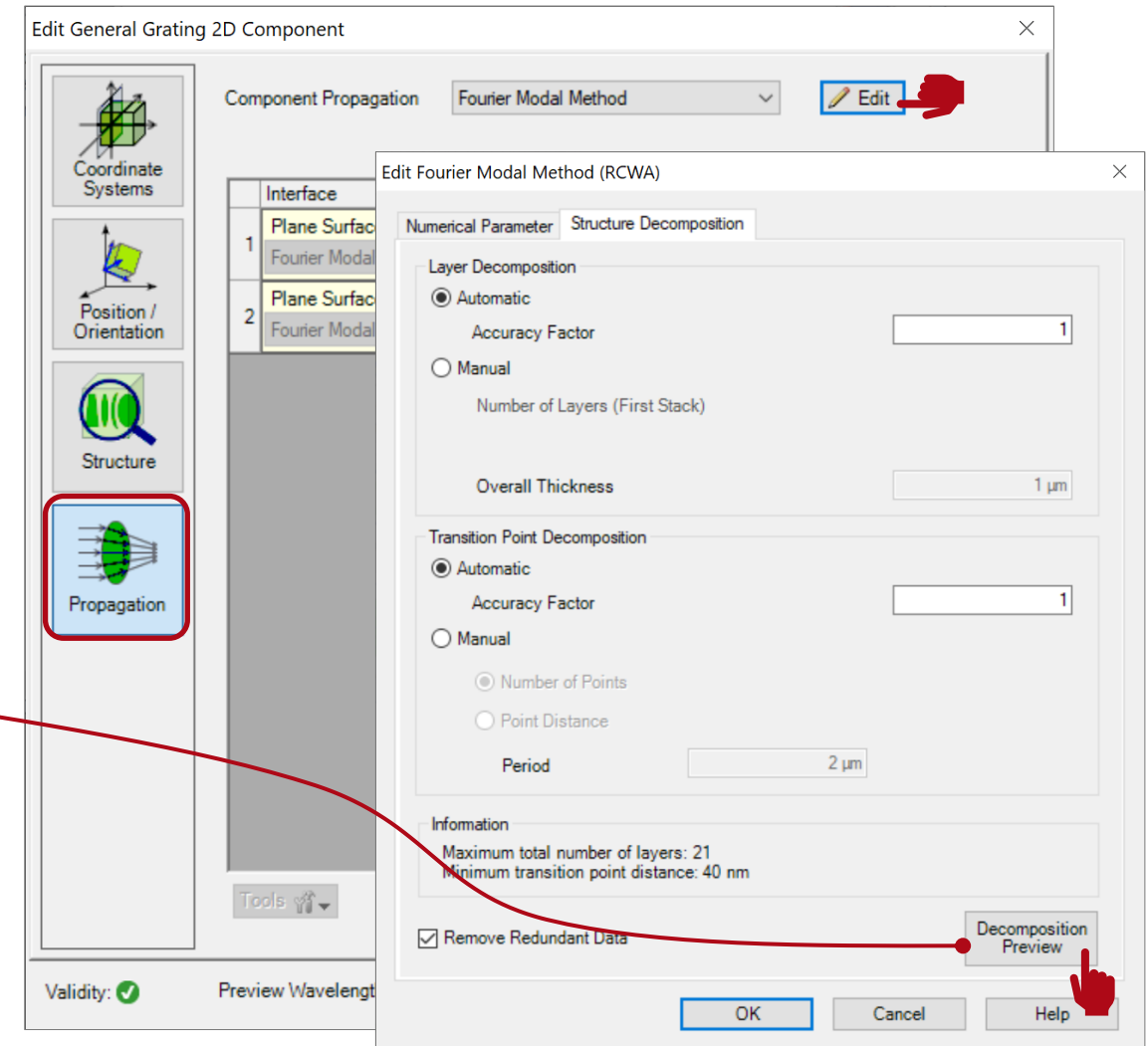
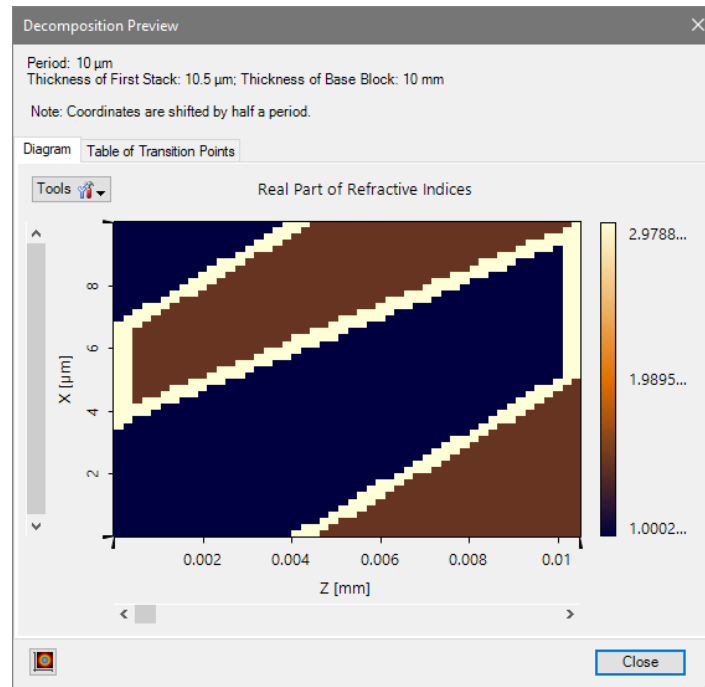
Advanced Options & Information

- The Advanced Settings tab provides information about the decomposition of the structure.
- The Layer Decomposition and Transition Point Decomposition settings can be used to adjust the discretization of the structure. The default settings are appropriate for nearly all grating structures.
- Further, information about the number of layers and transition points are provided.
- The Decomposition Preview button provides a depiction of the structure data which are used for the FMM calculation. The refractive index is illustrated by a color scale.



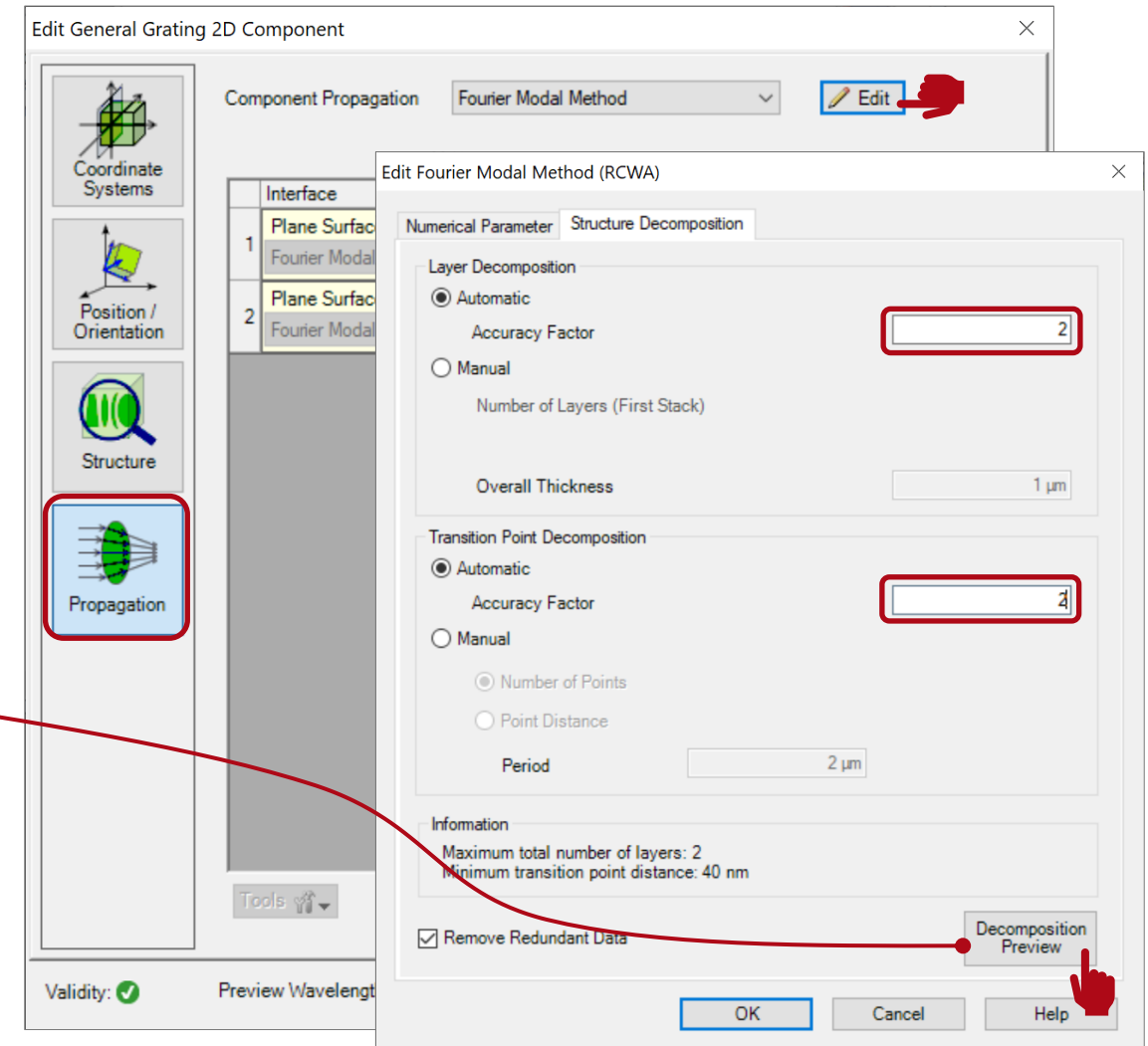
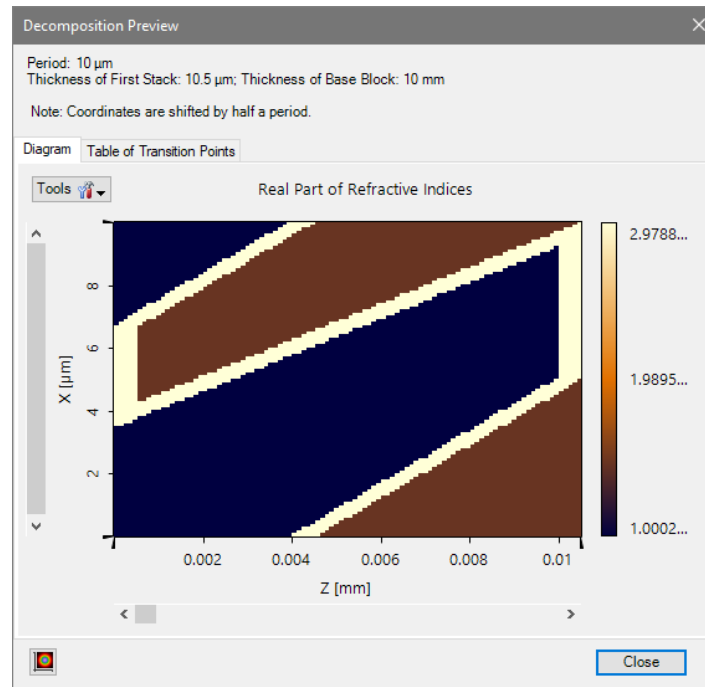
Advanced Options & Information

- The decomposition preview of the defined coated slanted grating.
- VirtualLab suggests a discretization in 51 layers (1 layer is representing the substrate)



Advanced Options & Information

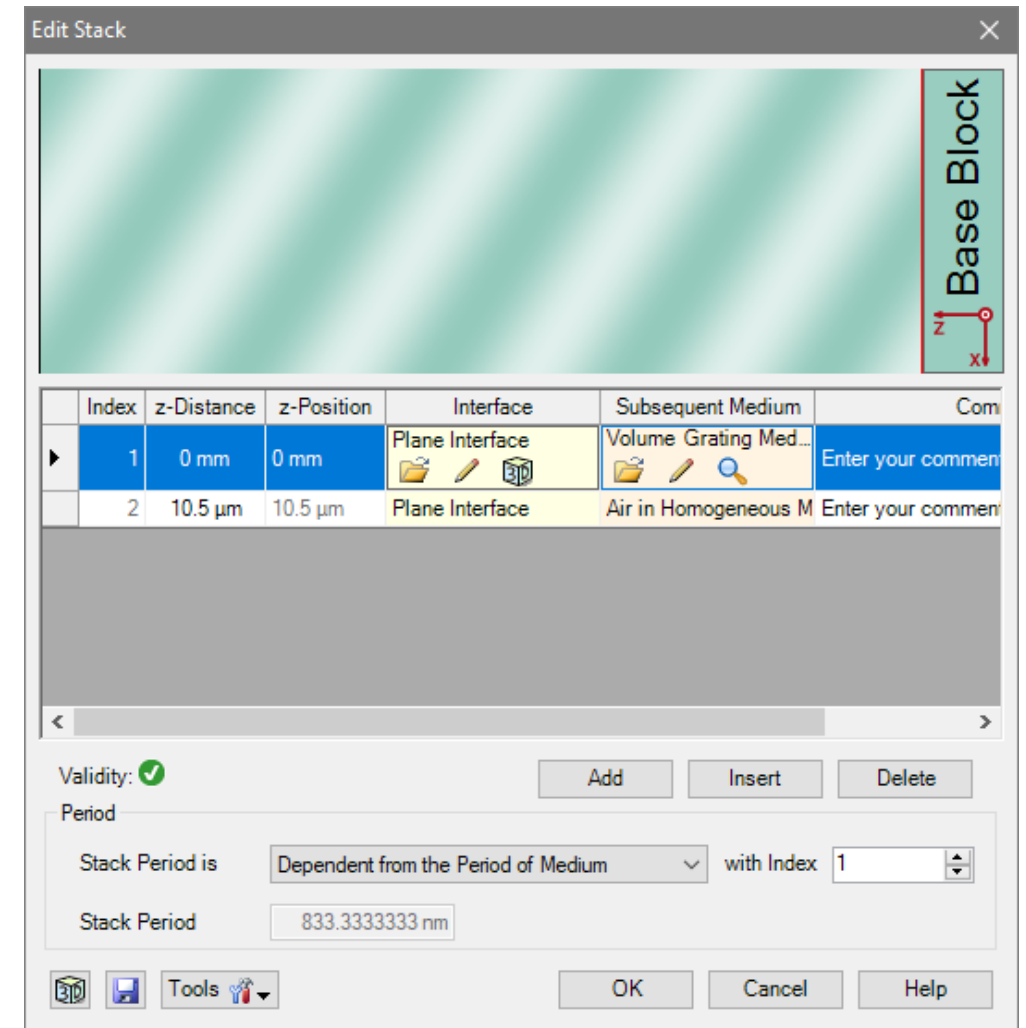
- If the numbers of layers and transition points are increased (e.g. by a factor of 2), the discretization becomes less rough. (because a medium is sampled both values have to be increased)



Volume Grating Medium

Volume Grating Medium

- Another type of medium which can be used for the configuration of gratings is the volume grating medium.
- This interface allows to configure a modulations of the refractive index, which was e.g. generated by holographic exposure.
- Again, two plane interfaces are used as boundaries of the medium.



Volume Grating Medium Parameters

- In order to describe volume grating VirtualLab simulates the interference pattern of a certain number on impinging waves.
- First, a holographic medium has to be chosen, that provides the initial index of refraction.
- Further, the period and orientation of the index modulation are controlled by the angle of incidence (alpha) and wavelength of reference and signal wave.
- Moreover, by introducing a quantized k-space respectively incidence angle, the numerical effort can be reduced significantly.

Edit Volume Grating Medium

Basic Parameters | Scaling | Periodization

Holographic Material

Name: Acrylic

Catalog Material: [dropdown]

State of Matter: Solid

Interferogram | Index Modulation

Directions are defined in: ☒ Vacuum ☐ Holographic Material

Representation of Direction: Cartesian Angles

No.	Power Factor	Alpha	Alpha (Quant.)	Dir.	Wavelength (Vacuum)	Wavelength (Medium)
1	1	40°	39.67261473°	→	532 nm	355.8411042 nm
2	1	0°	0°	→	532 nm	355.8411042 nm

Append Edit Delete

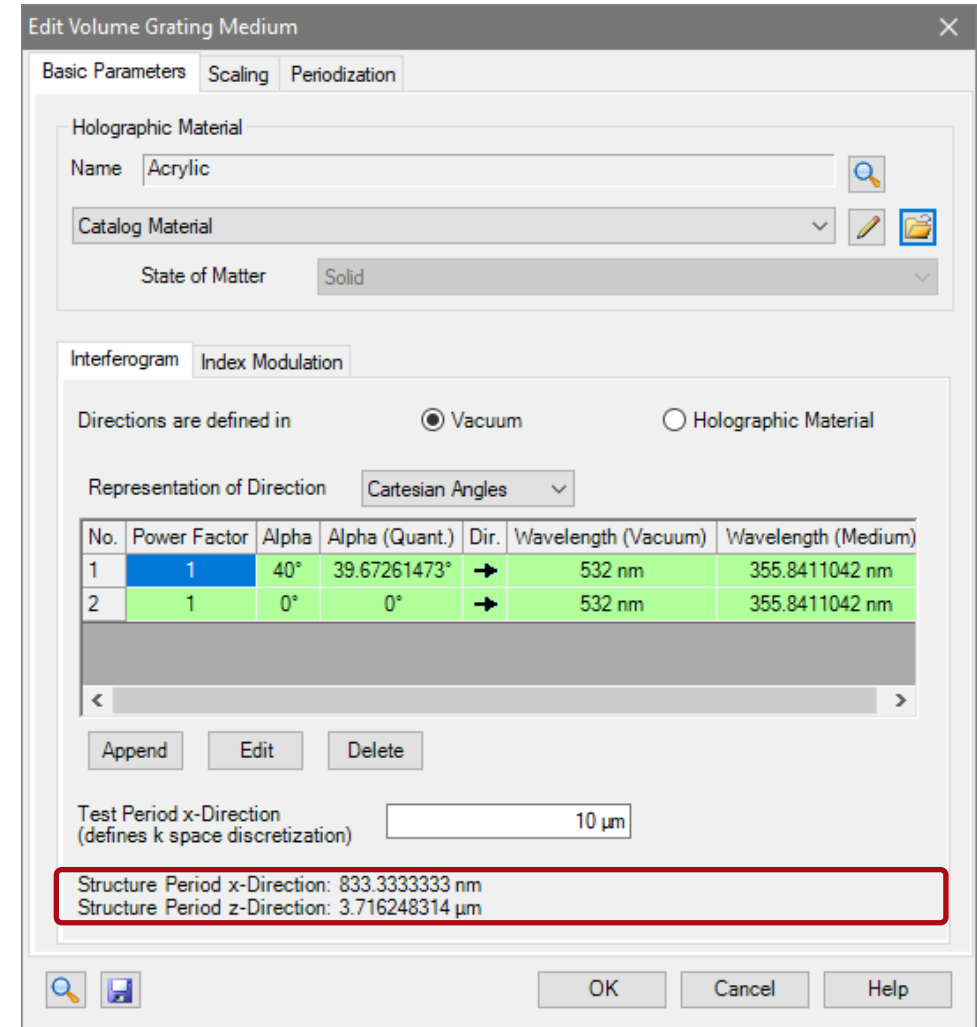
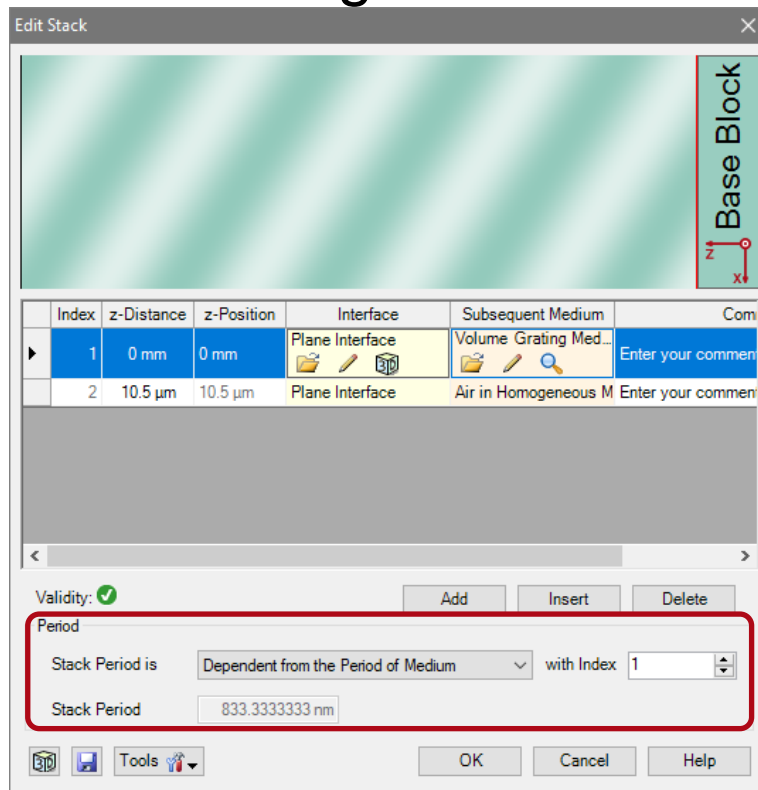
Test Period x-Direction (defines k space discretization): 10 μm

Structure Period x-Direction: 833.3333333 nm
Structure Period z-Direction: 3.716248314 μm

OK Cancel Help

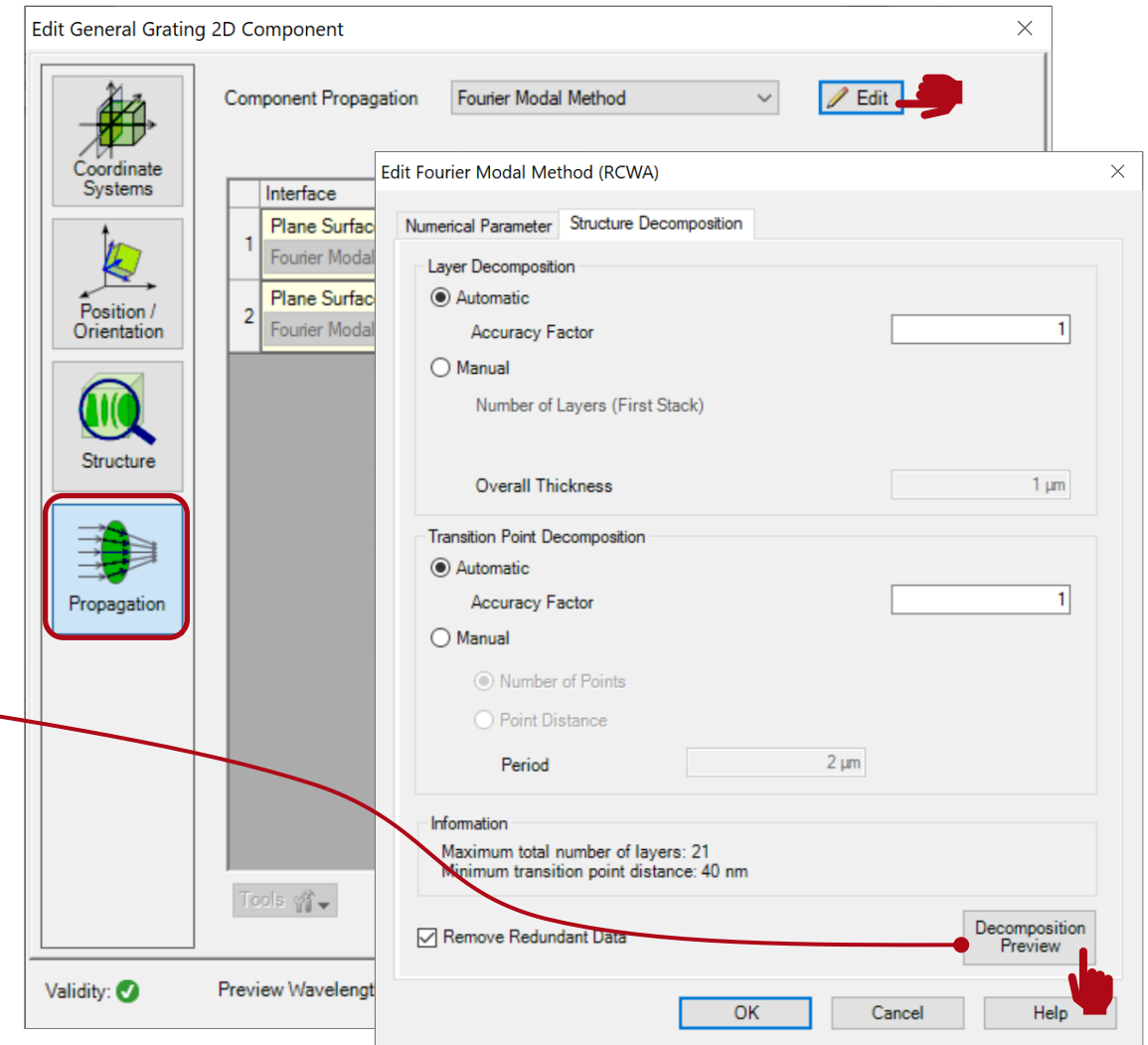
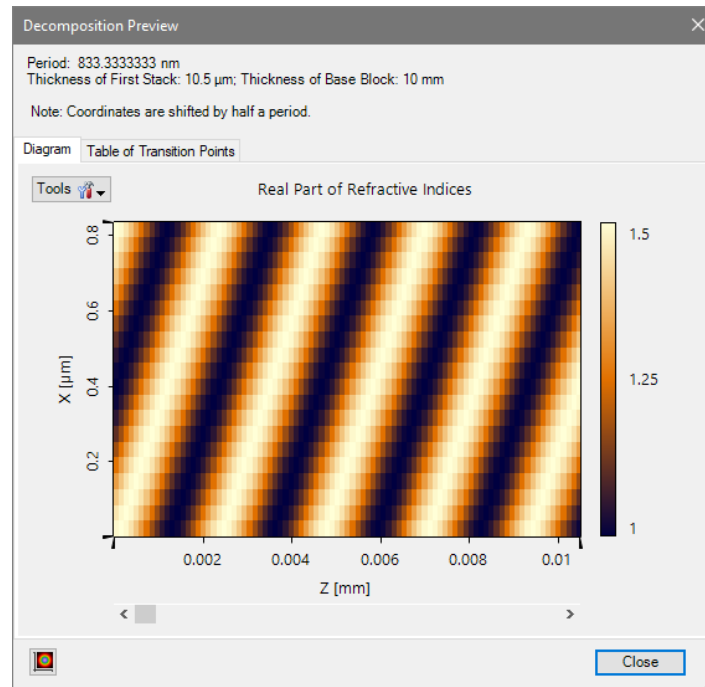
Volume Grating Medium Parameters

- The resulting period of the volume grating can be found either in the setting or stack dialog.



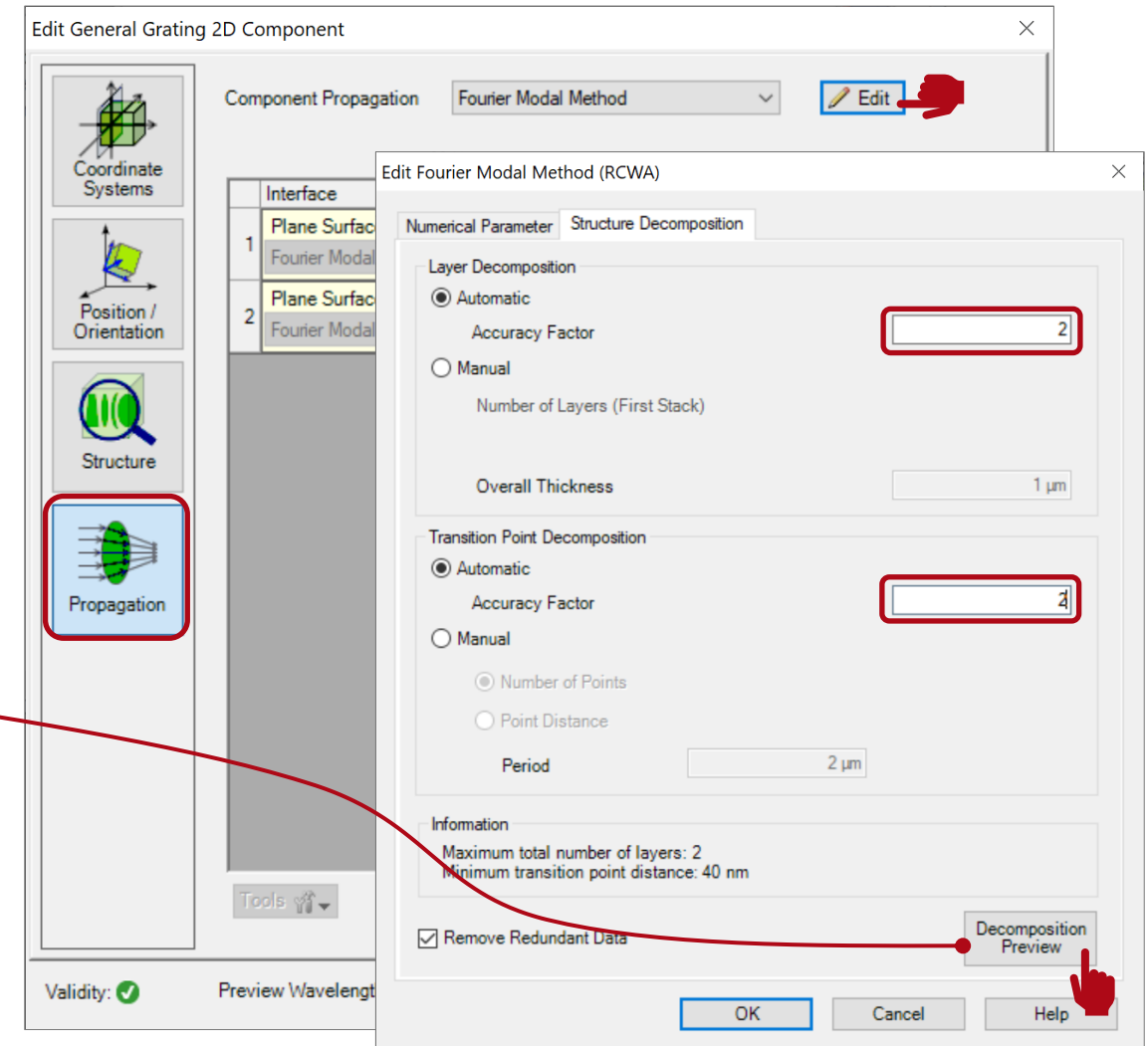
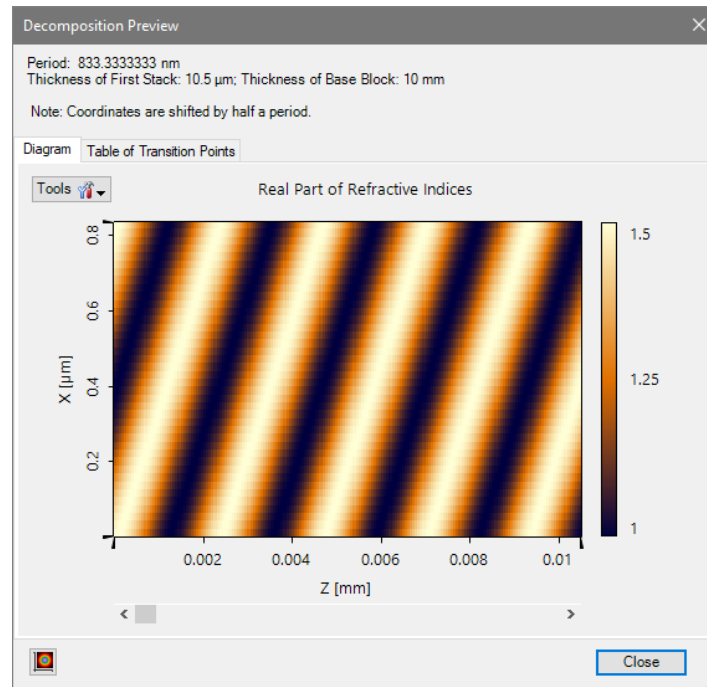
Advanced Options & Information

- Again, the data of the decomposed structure can be adjusted and investigated on the advanced settings tab page.



Advanced Options & Information

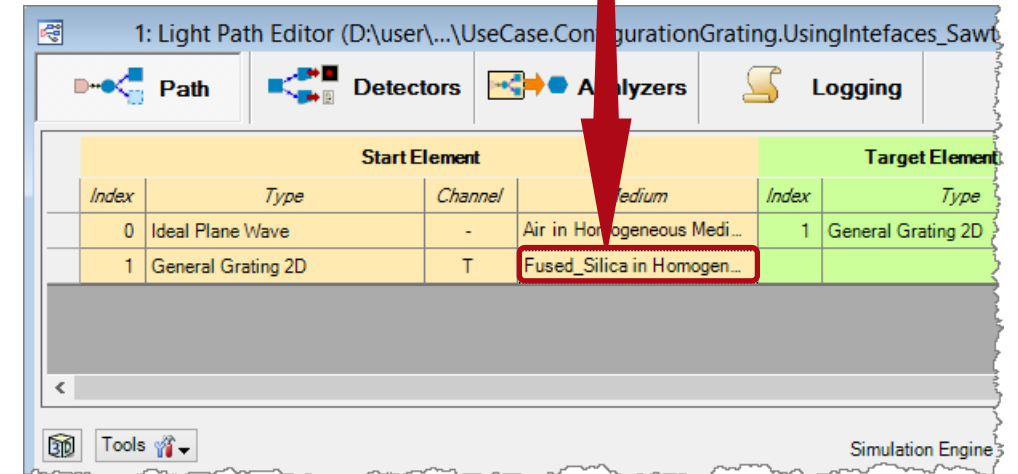
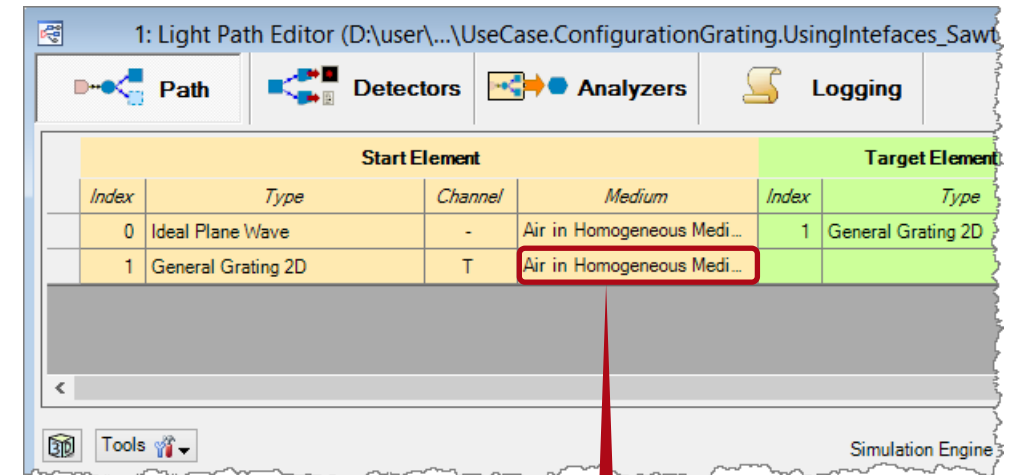
- If the numbers of layers and transition points are increased (e.g. by a factor of 2), the discretization becomes smoother, at the expense of an increased numerical effort.



Remark on the Position of the Detector

Remark on the Detector Position

- In VirtualLab the detector is located subsequent to the substrate in air by default.
- This is necessary if the grating is included in a complex optical setup.
- However, the perfect plane and parallel substrate may cause some interference effects, which not occur in reality.
- Thus, for calculation of just grating efficiencies it is appropriate to set the detector inside the substrate material (likewise to most of grating evaluation software).
- This avoids the undesired influence of those interference effects.

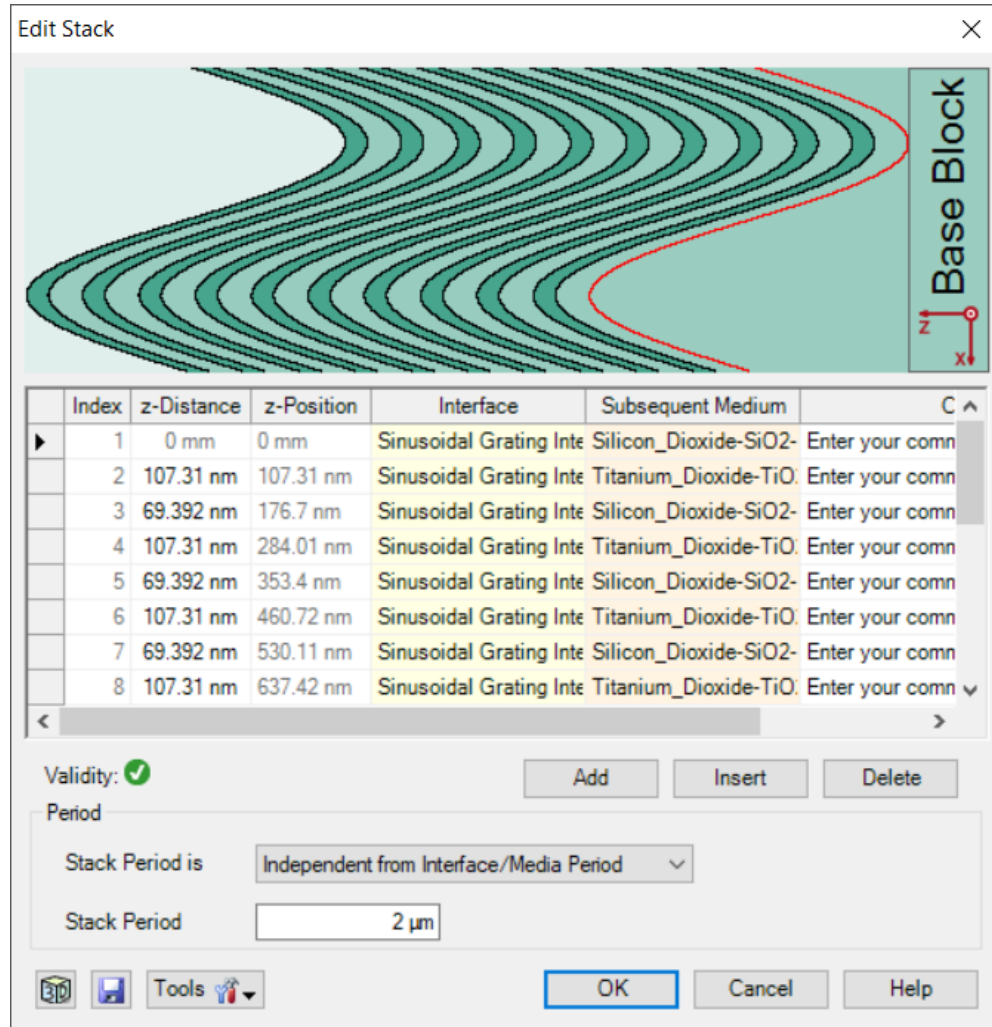


Document Information

title	Configuration of Grating Structures by Using Special Media
document code	GRT.0005
version	1.2
edition	VirtualLab Fusion Advanced
software version	2020.2 (Build 1.116)
category	Feature Use Case
further reading	<ul style="list-style-type: none">- <u>Configuration of Grating Structures by Using Interfaces</u>- <u>Rigorous Simulation of Holographic Generated Volume Grating</u>

Grating Order Analyzer

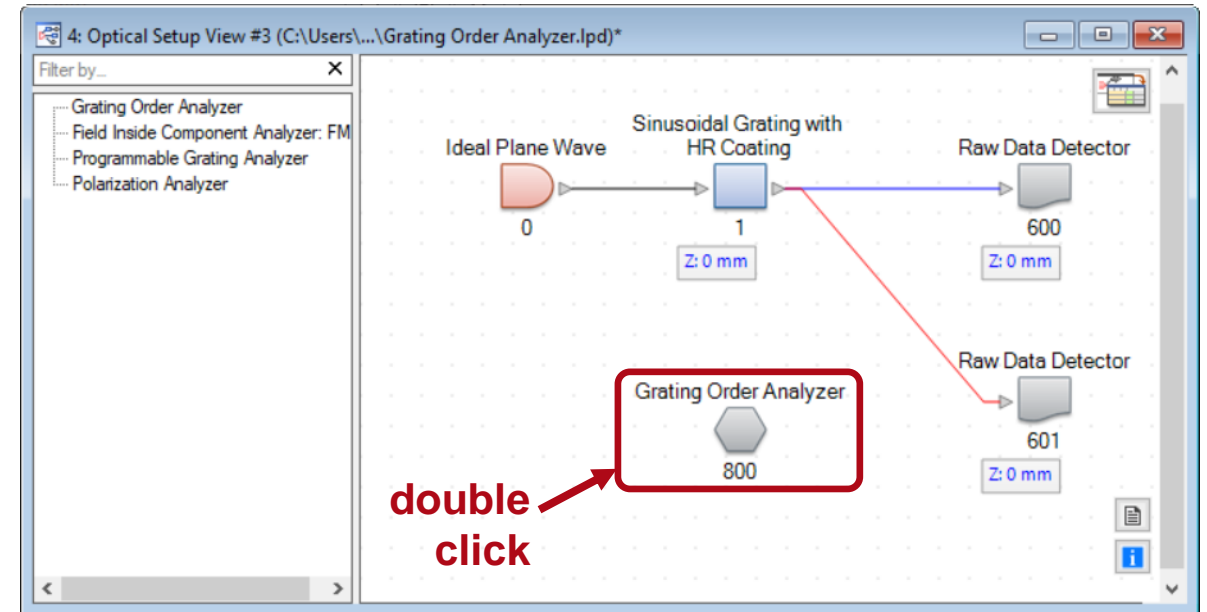
Grating Specification



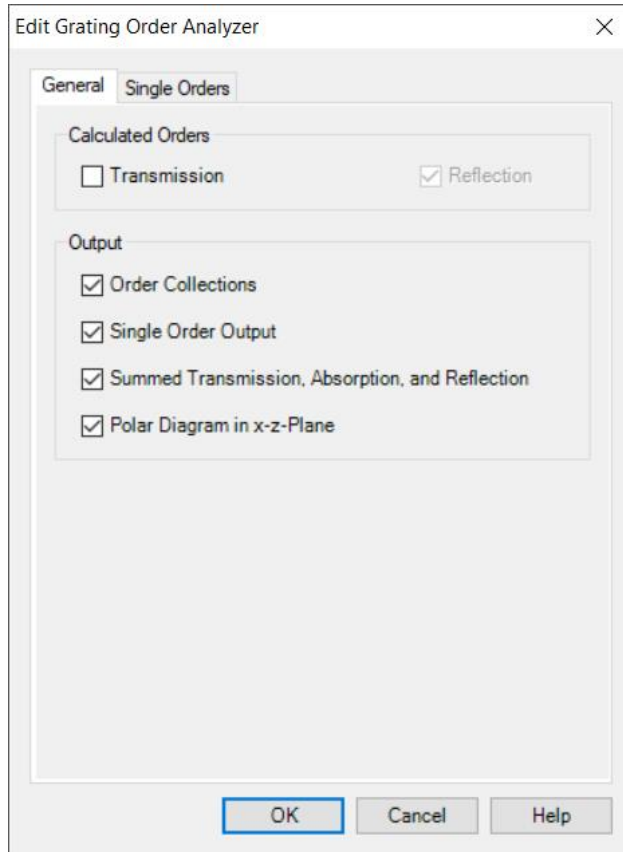
- For the demonstration of the Grating Order Analyzer for 1D gratings we use a sinusoidal grating with HR coating.
- The grating parameters can be specified within the stack that can be accessed in the edit dialog of the grating component.

Grating Order Analyzer Settings

- After the grating structure has been defined you can configure the Grating Order Analyzer.
- Various output options can be specified.
- This is done through the edit dialog of the analyzer which is opened by double clicking it element in the optical setup view.

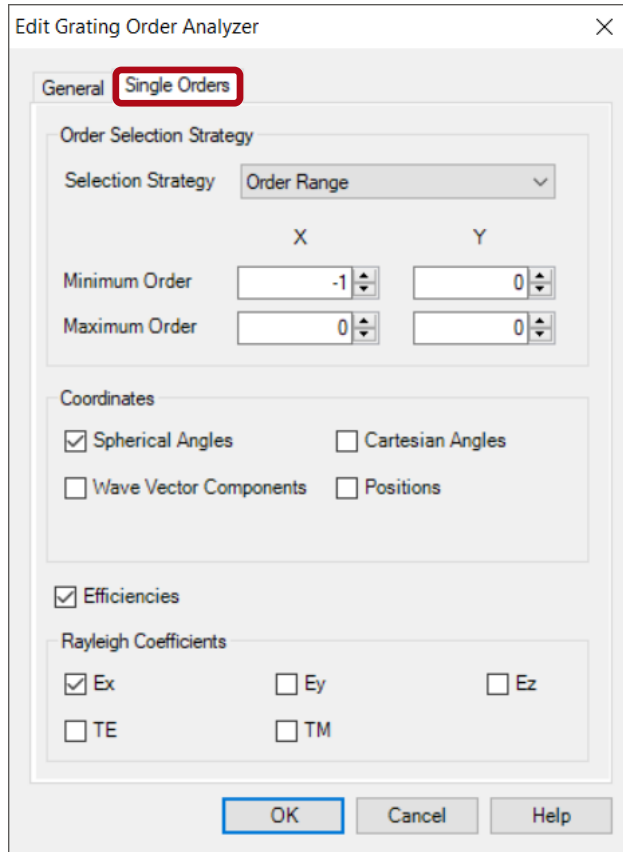


General Settings



- In the General tab, you can select whether transmission and/or reflection shall be analyzed.
- In addition you can specify whether you would like to evaluate the summed transmission, absorption and reflection values, and whether you would like to show a polar diagram.

Single Orders Settings



- In the Single Orders tab you can select whether information for single orders shall be logged.
- This option is very helpful if you would like to use the parameter run or the parametric optimization of VirtualLab Fusion to analyze and optimize the grating for specific orders.

Single Orders Settings

Edit Grating Order Analyzer

General

Single Orders

Order Selection Strategy

Selection Strategy

Order Range

X

Y

Minimum Order

-1

0

Maximum Order

0

0

Coordinates

☒ Spherical Angles

☐ Cartesian Angles

☐ Wave Vector Components

☐ Positions

☒ Efficiencies

Rayleigh Coefficients

☒ Ex

☐ Ey

☐ Ez

☐ TE

☐ TM

OK

Cancel

Help

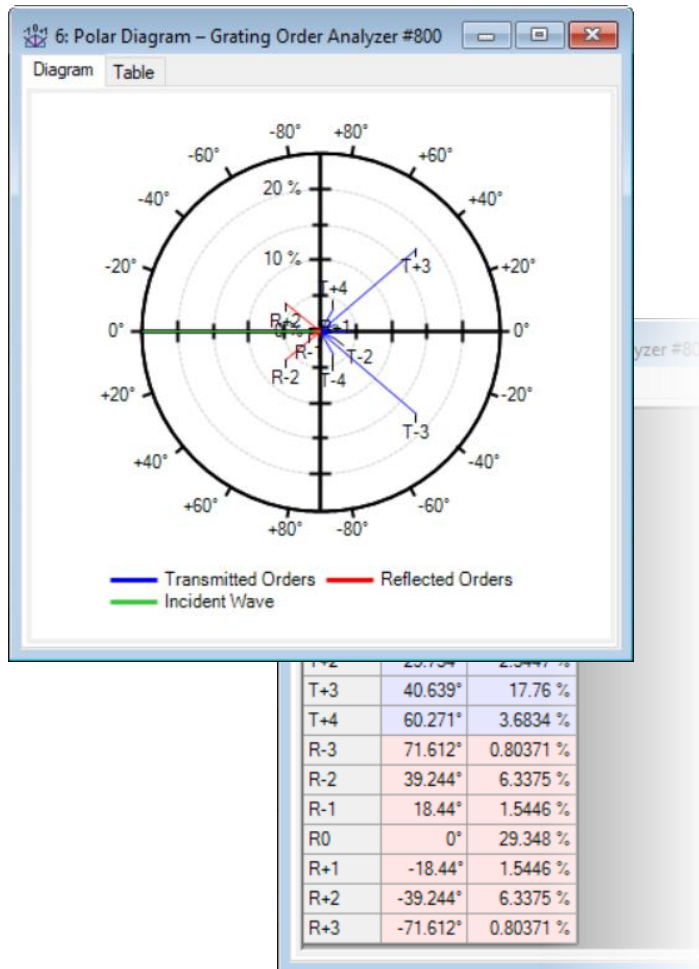
Parameter	Description
Order Selection Strategy	The user can define which order shall be evaluated. The user can define whether to analyze All orders, analyze only those orders which have an efficiency Above a Given Threshold or calculate only orders in a manually defined Order Range . Depending on the selection strategy the user has to define additional parameters.
Coordinates	Logging of the coordinates of the orders is also supported. The user can specify whether to show the coordinates in Spherical Angles , Cartesian Angles , Wave Vector Components or Positions . For the Position calculation a z-distance between the grating and the screen has to be specified.
Efficiencies	The user can select whether efficiencies shall be logged.
Rayleigh Coefficients	In addition it is possible to log the Rayleigh coefficients. The user can select to show the coefficient E_x , E_y , E_z , TE or TM .

Outputs in Detector Tab

Detector Results				
	Date/Time	Detector	Sub - Detector	Result
12	03/24/2019 09:11:50	Grating Order Analyzer #800	Overall Reflection Efficiency	46.719 %
11			Overall Transmission Efficiency	53.281 %
10			Overall Reflection and Transmission Efficiency	100 %
9			Absorption	0 %
8	03/24/2019 09:11:50	Grating Order Analyzer #800 (Results for Individual Orders)	Spherical Angle Theta R[-1; 0]	18.44°
7			Spherical Angle Phi R[-1; 0]	0°
6			Efficiency R[-1; 0]	1.5446 %
5			Rayleigh coefficient Ex R[-1; 0]	121.05 · exp(-1.695 · i) mV/m
4			Spherical Angle Theta R[0; 0]	0°
3			Spherical Angle Phi R[0; 0]	0°
2			Efficiency R[0; 0]	29.348 %
1			Rayleigh coefficient Ex R[0; 0]	541.74 · exp(-0.11644 · i) mV/m
Messages Detector Results				

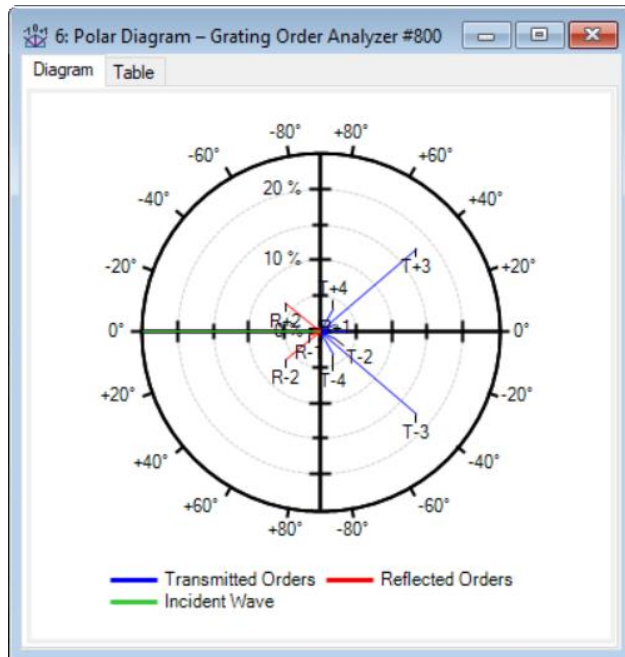
- If the Grating Order Analyzer is processed within the Optical Setup, the single order output values are logged into the detector results tab.
- These values are also available in the parameter run and the parametric optimization.

Outputs in Polar Diagram



- The polar diagram output of the Grating Order Analyzer plots the efficiencies of both the reflected and the transmitted orders versus the angles in the x-z-plane.
- It also provides a table of all angles and efficiencies of the displayed orders.

Polar Diagram Settings



- You can zoom into the polar diagram with the mouse wheel, the Property Browser and the ribbon.
- You can configure which orders are shown by right-clicking on the diagram.

Select Diffraction Orders to Show

Type of Orders to Show

☒ Incident Wave ☒ Transmitted Orders ☒ Reflected Orders

Minimum Angle Maximum Angle

☐ Use Stride

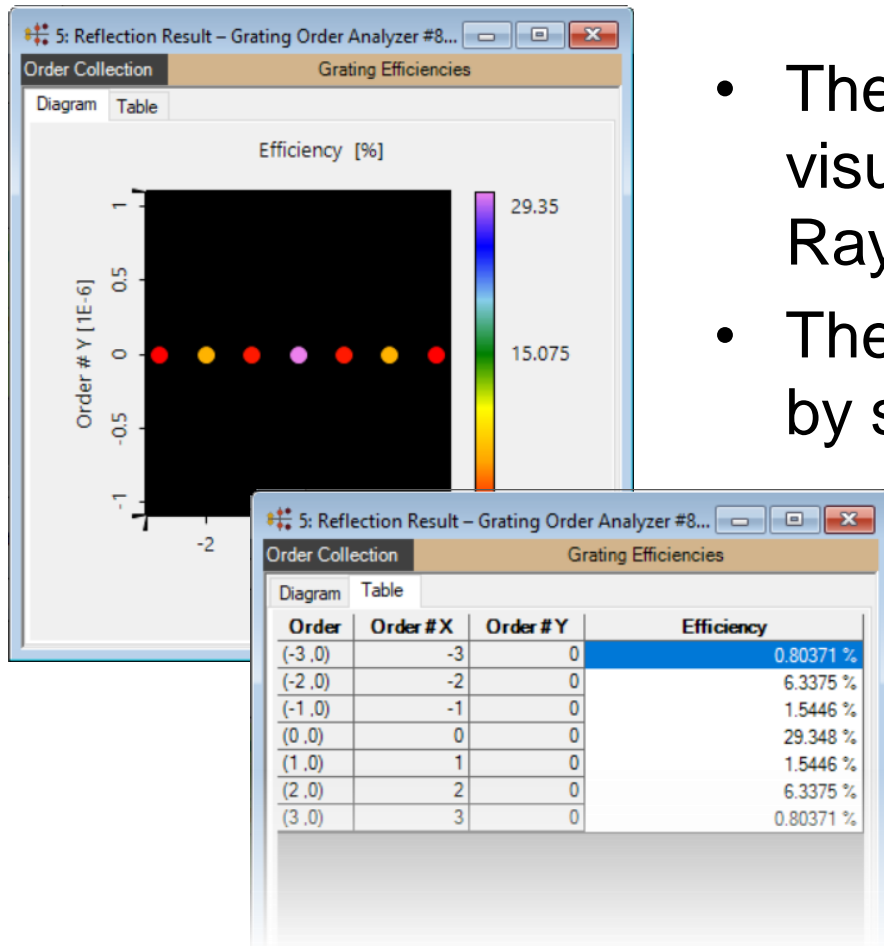
Order	Angle	Efficiency
<input checked="" type="checkbox"/> I	0°	100 %
<input checked="" type="checkbox"/> T-4	-60.27°	3.683 %
<input checked="" type="checkbox"/> T-3	-40.64°	17.76 %
<input checked="" type="checkbox"/> T-2	-25.73°	2.345 %
<input checked="" type="checkbox"/> T-1	-12.54°	0.8165 %
<input checked="" type="checkbox"/> T0	0°	4.072 %
<input checked="" type="checkbox"/> T+1	12.54°	0.8165 %
<input checked="" type="checkbox"/> T+2	25.73°	2.345 %

Select All Select None

View

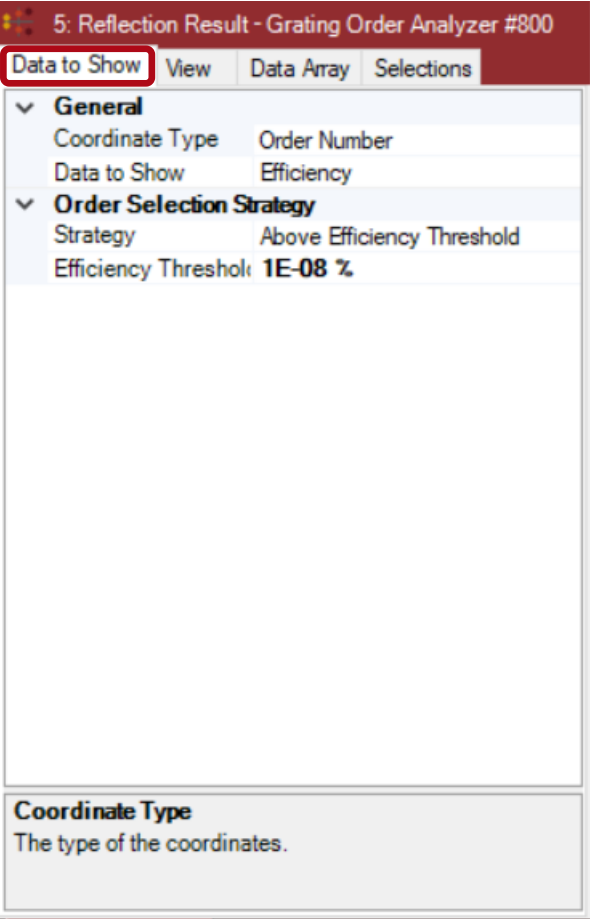
General	
Window Size	400, 420
y-Axis	
Maximum	25 %
Minimum	0 %

Outputs in Order Collection



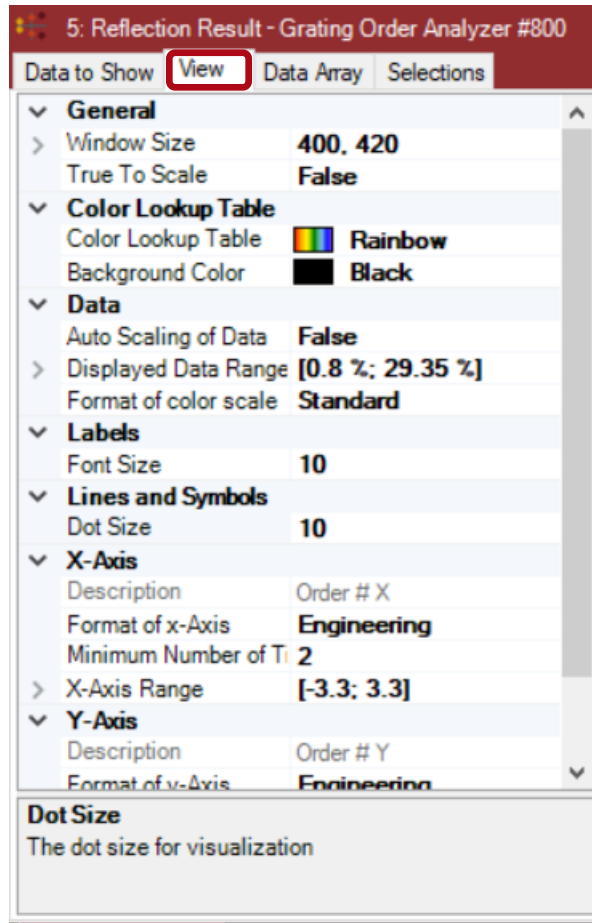
- The Grating Order Collection object is used to visualize the calculated grating efficiencies or the Rayleigh coefficients over different coordinates.
- The user can configure the data that shall be shown by setting diverse options via the property browser.

Order Collection Settings



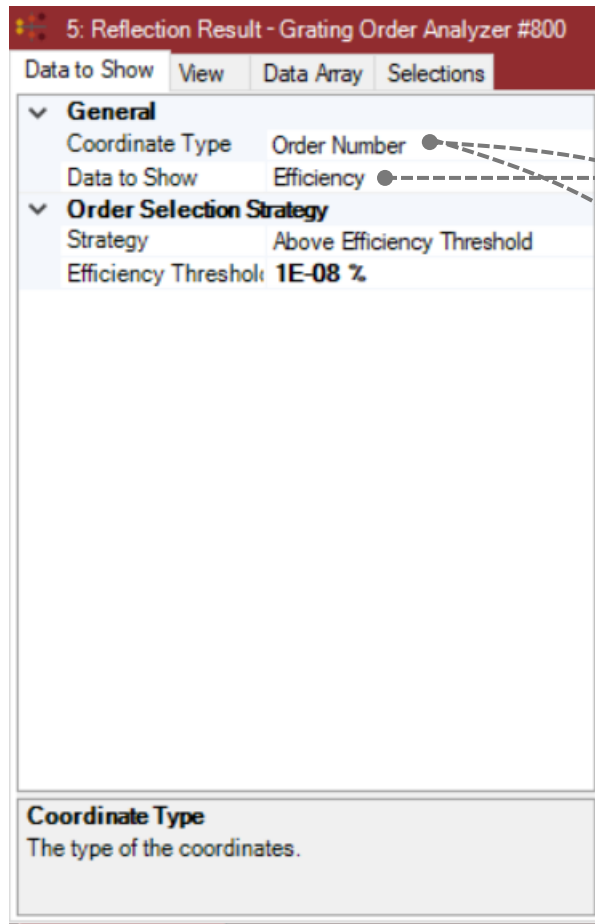
Option	Description
Coordinate Type	This property can be used to define the coordinates over which the data shall be visualized. Currently the order collection supports the visualization over Cartesian Angles , Spherical Angles , Wave Number Vectors and Positions .
Data to Show	It is possible to select the different data values that should be shown. The user can select to display the efficiency or the Rayleigh coefficient over the selected coordinate type. For Rayleigh coefficients E_x , E_y , E_z , TM and TE are supported.
Order Selection Strategy	The user can define which order shall be displayed. The user can define whether to show All , show only orders which have an efficiency Above a Given Threshold or show only orders for a manually defined Order Range . Depending on the selection strategy the user has to define additional parameters.

Order Collection Settings

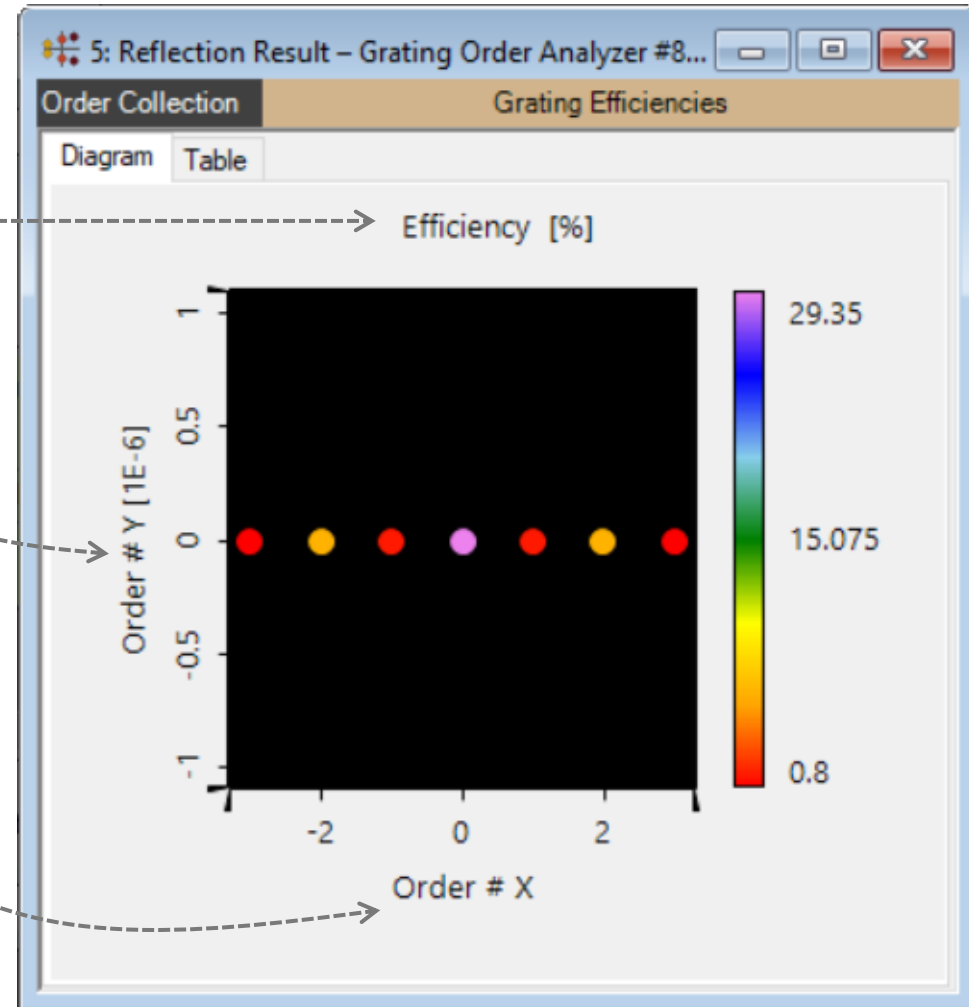


- In the View tab of the property browser, the user can set up additional view parameters.
- Most important for the customization of the view are the color settings.
- The user can select the background color for the view as well as the color lookup table that shall be used to define the colors for the displayed data values.

Example of Customized Order Collection Settings

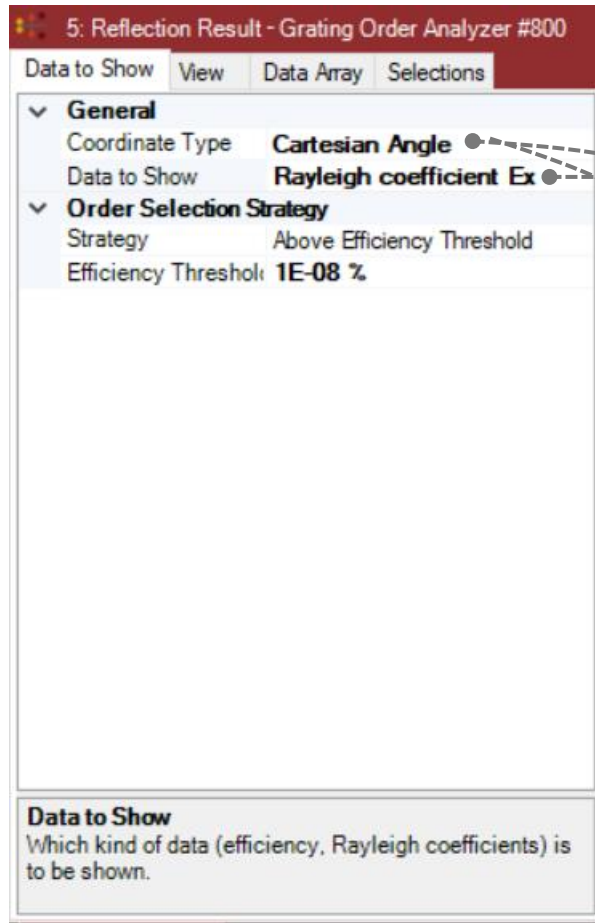


settings

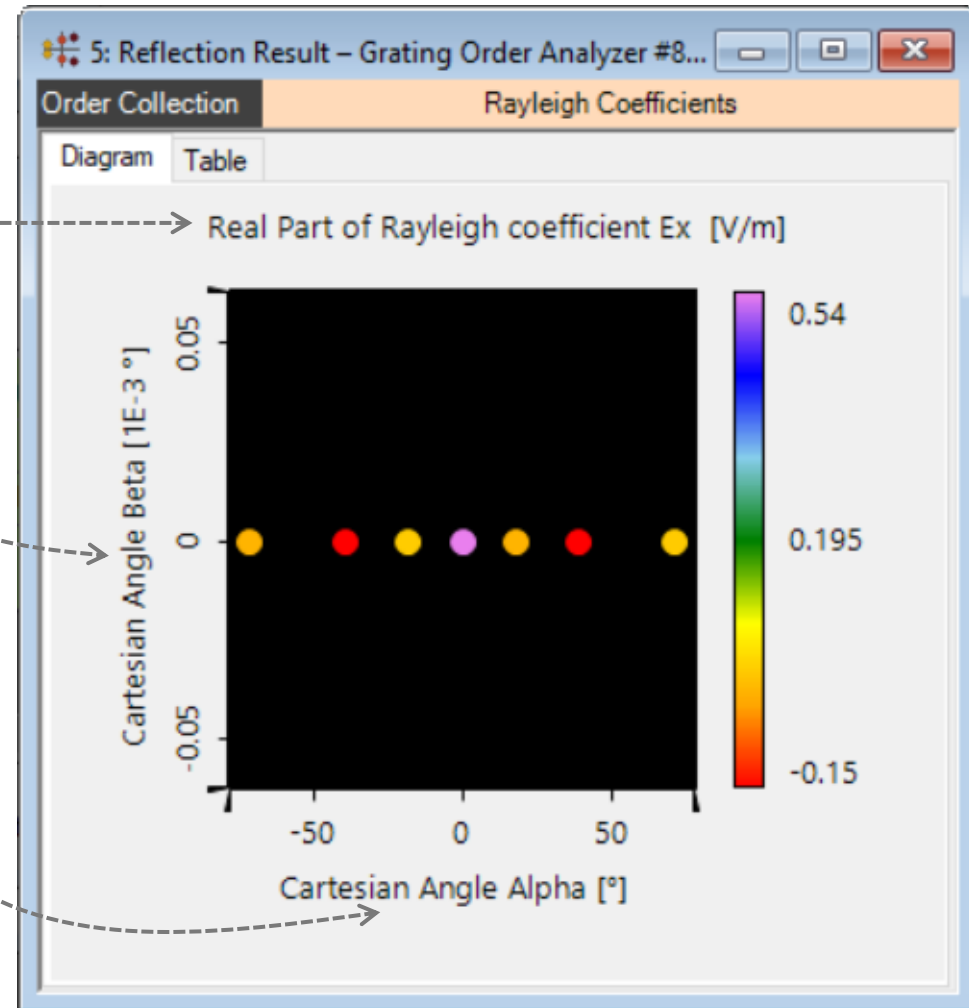


result

Example of Customized Order Collection Settings

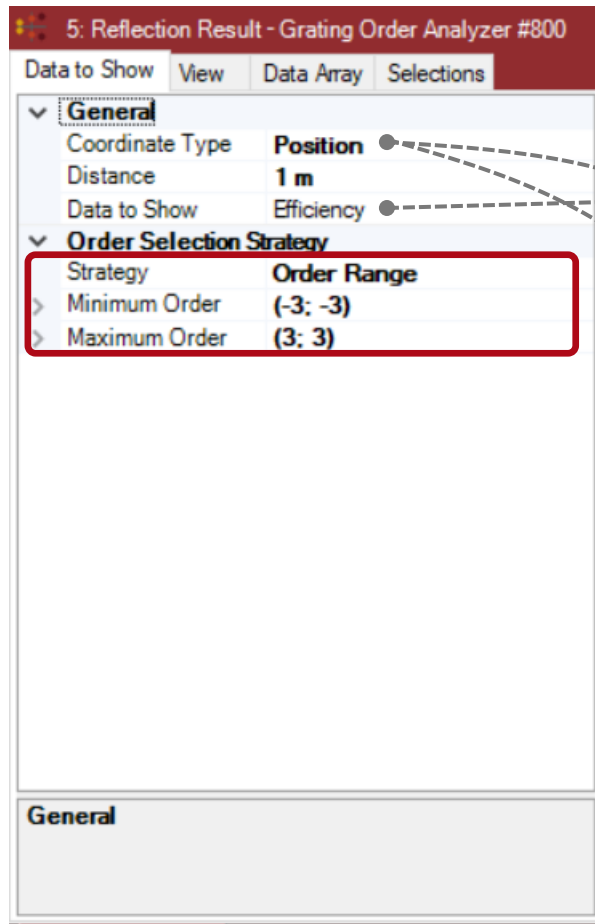


settings

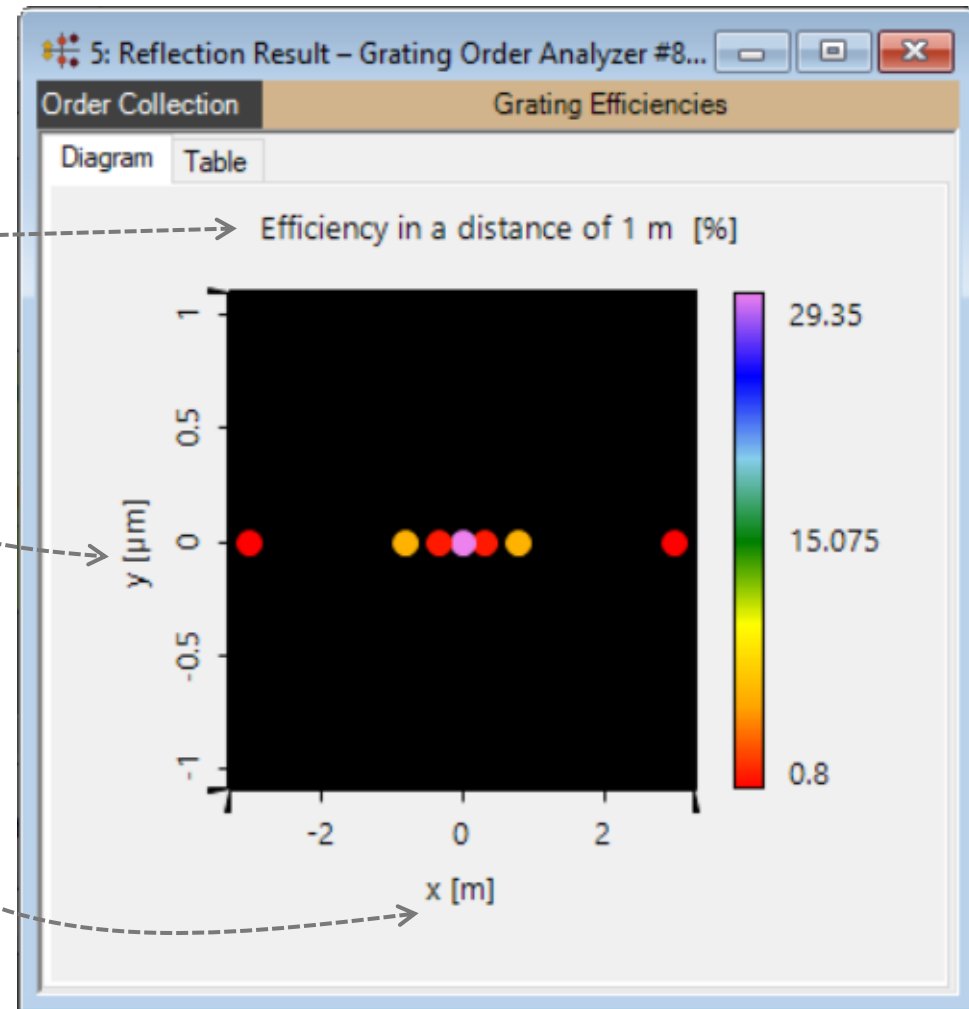


result

Example of Customized Order Collection Settings

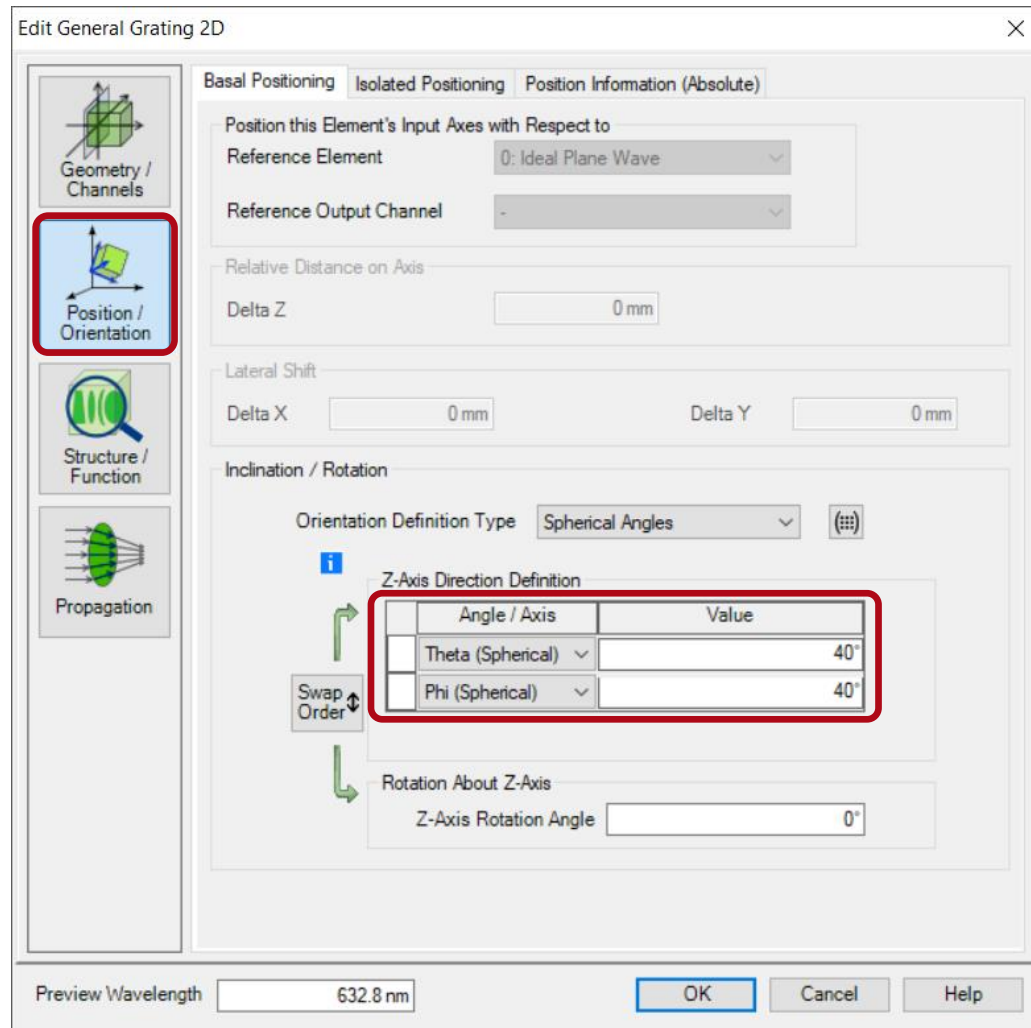


settings



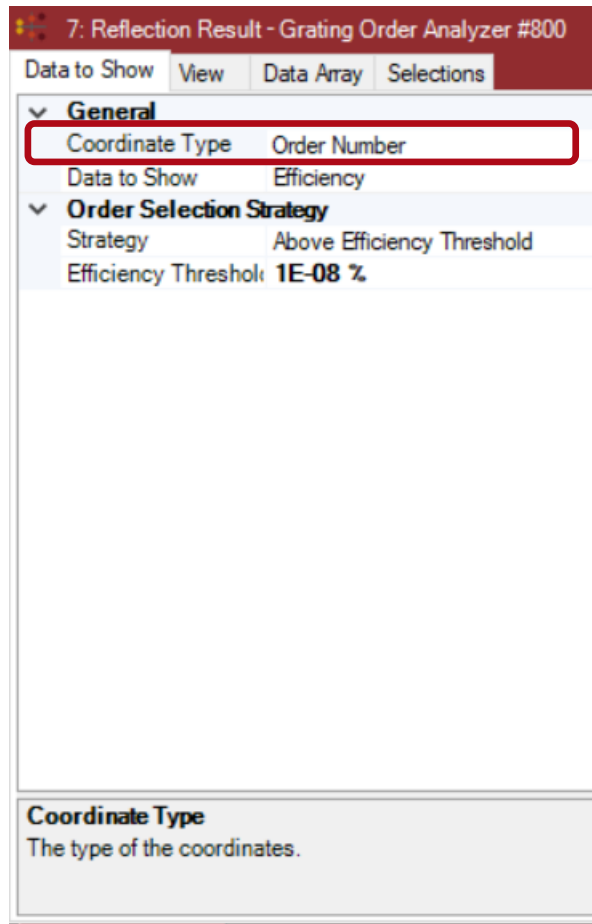
result

Visualization of Conical Diffraction

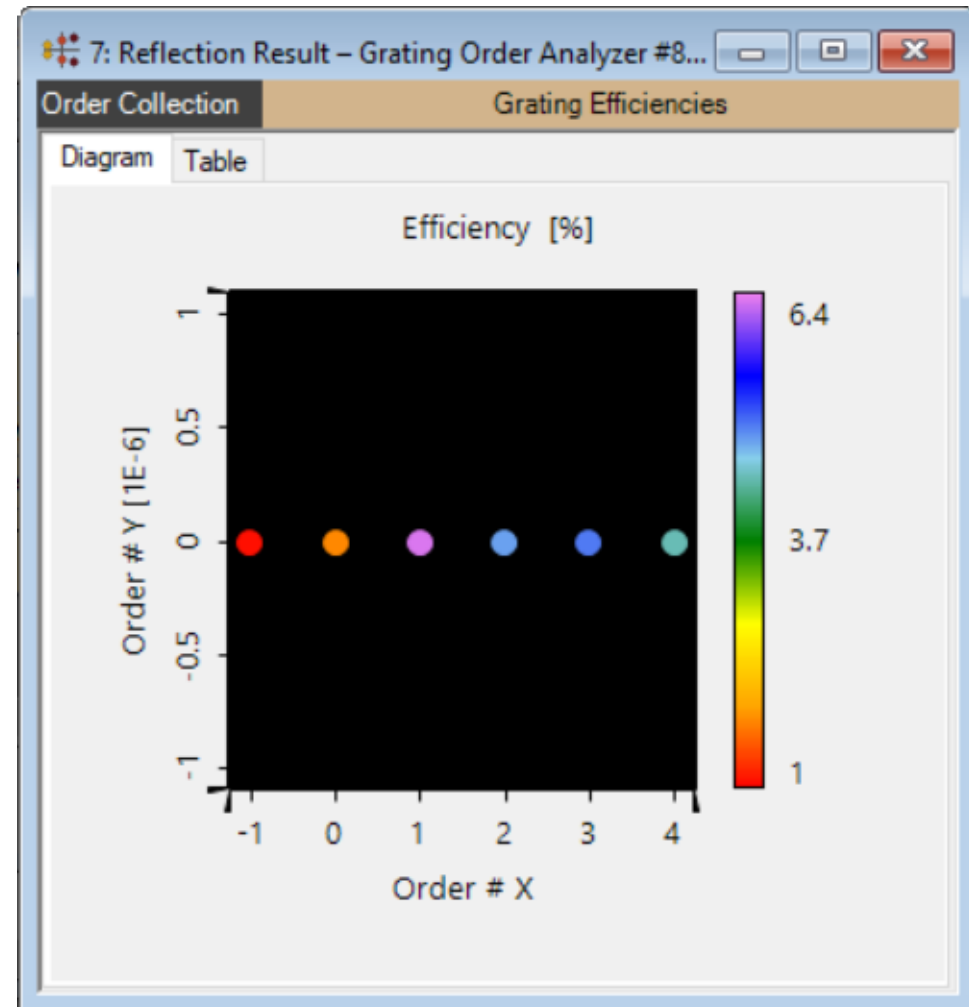


- Within the positions and orientation definition of the grating the user can define an arbitrary orientation.
- This is done in the Position / Orientation tab within the edit dialog of the grating.
- For this use case we use $\Theta = 40^\circ$ and $\Phi = 40^\circ$.

Efficiencies vs. Diffraction Order Number

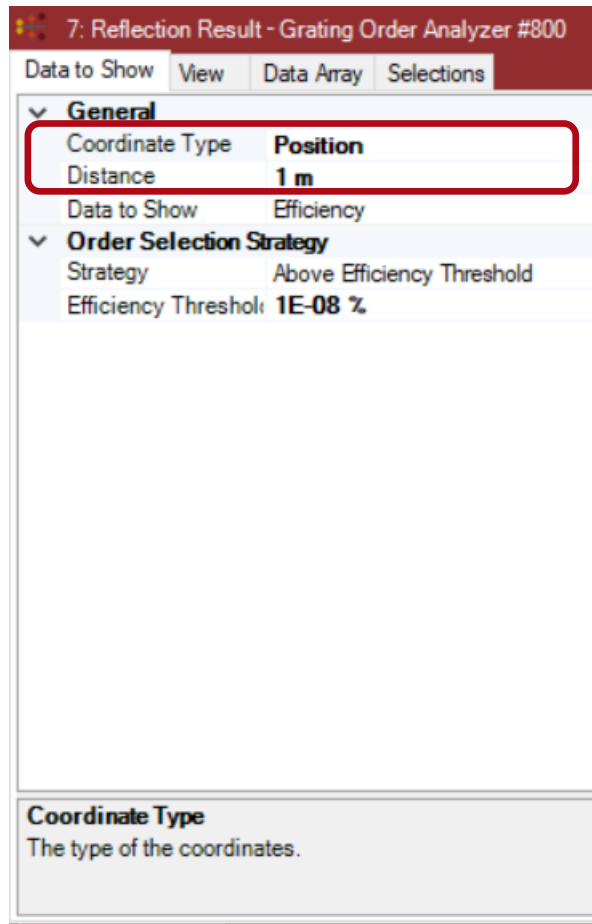


settings

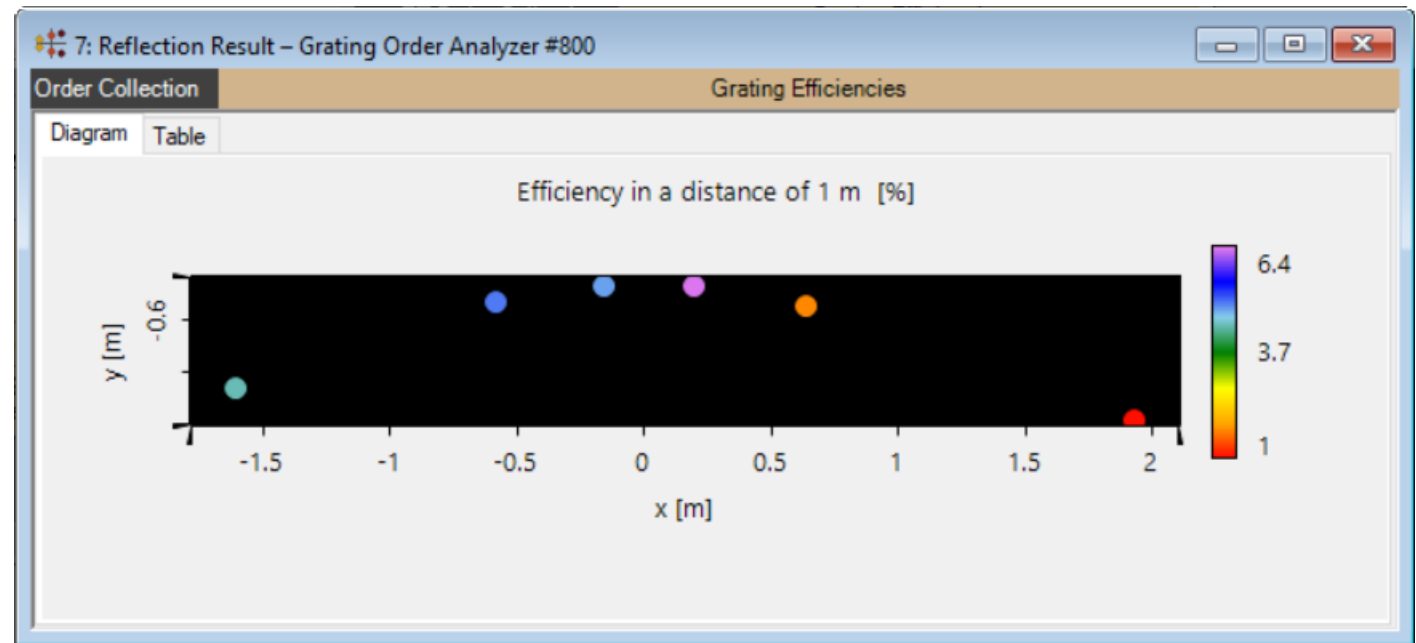


result

Efficiencies vs. Diffraction Order Position

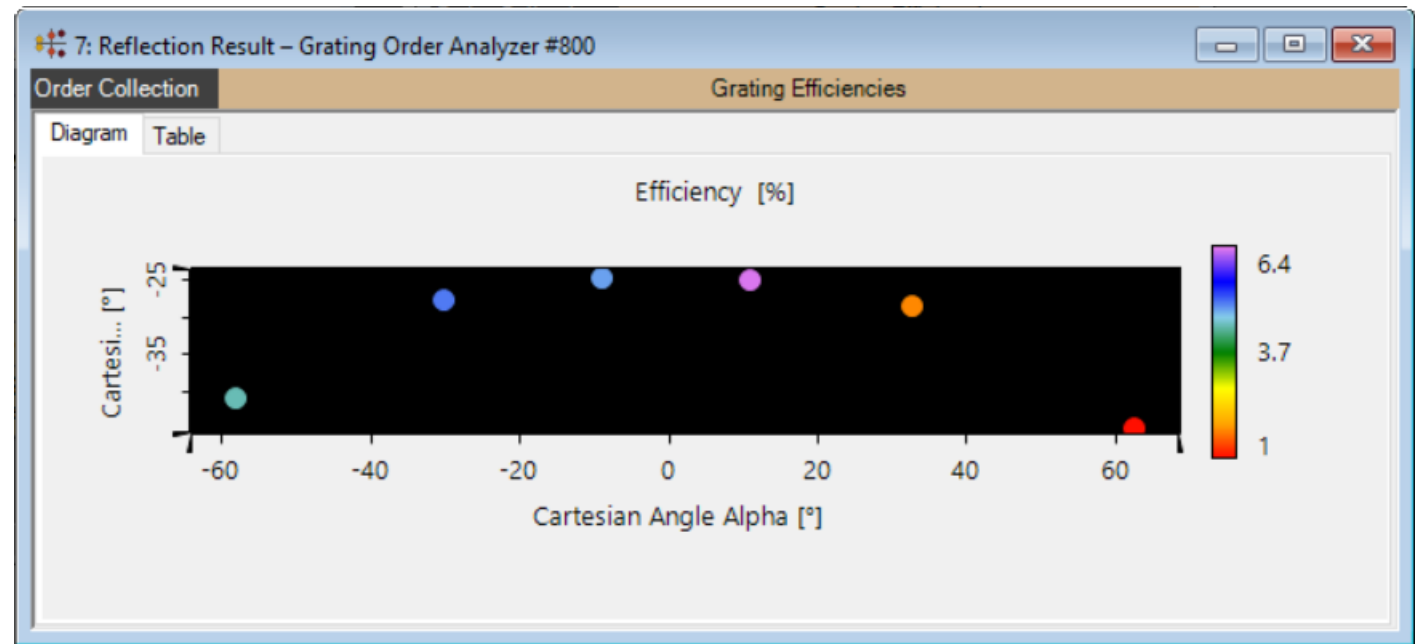
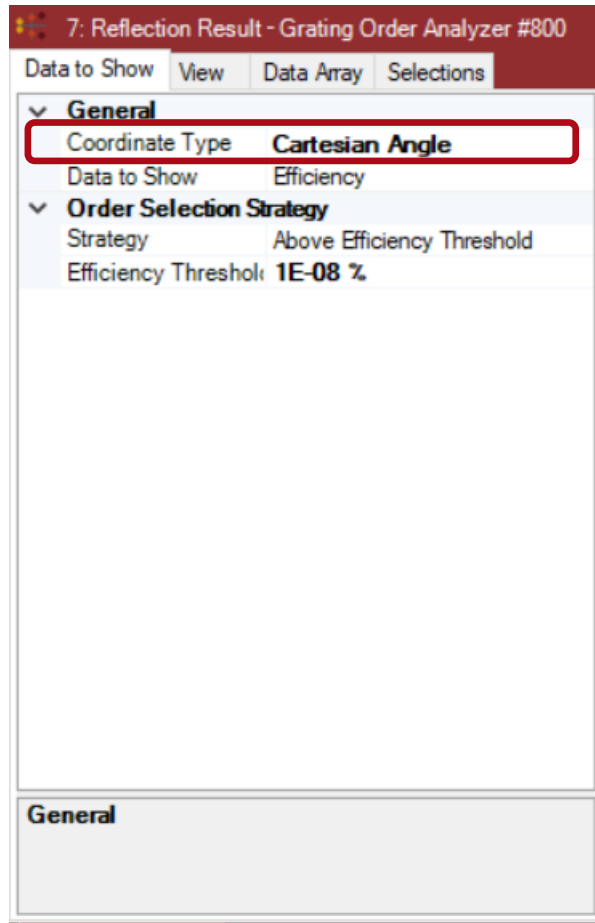


settings



result

Efficiencies vs. Diffraction Order Cartesian Angle

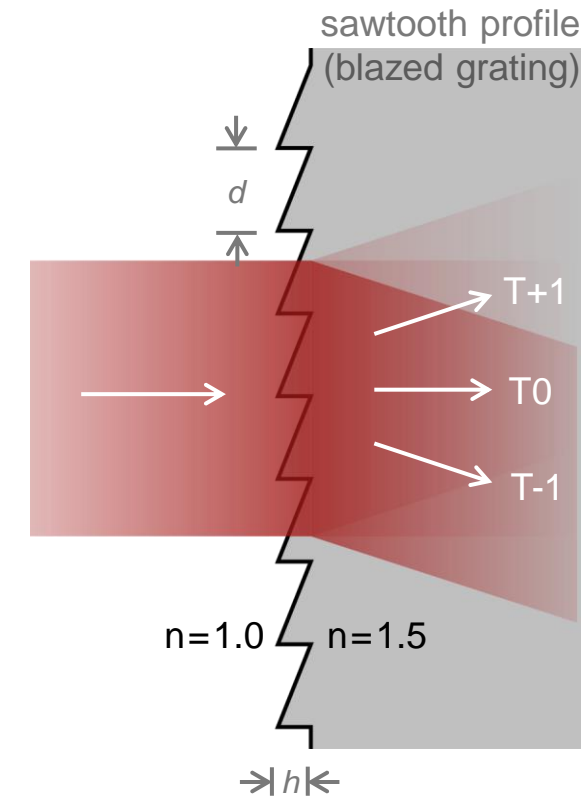
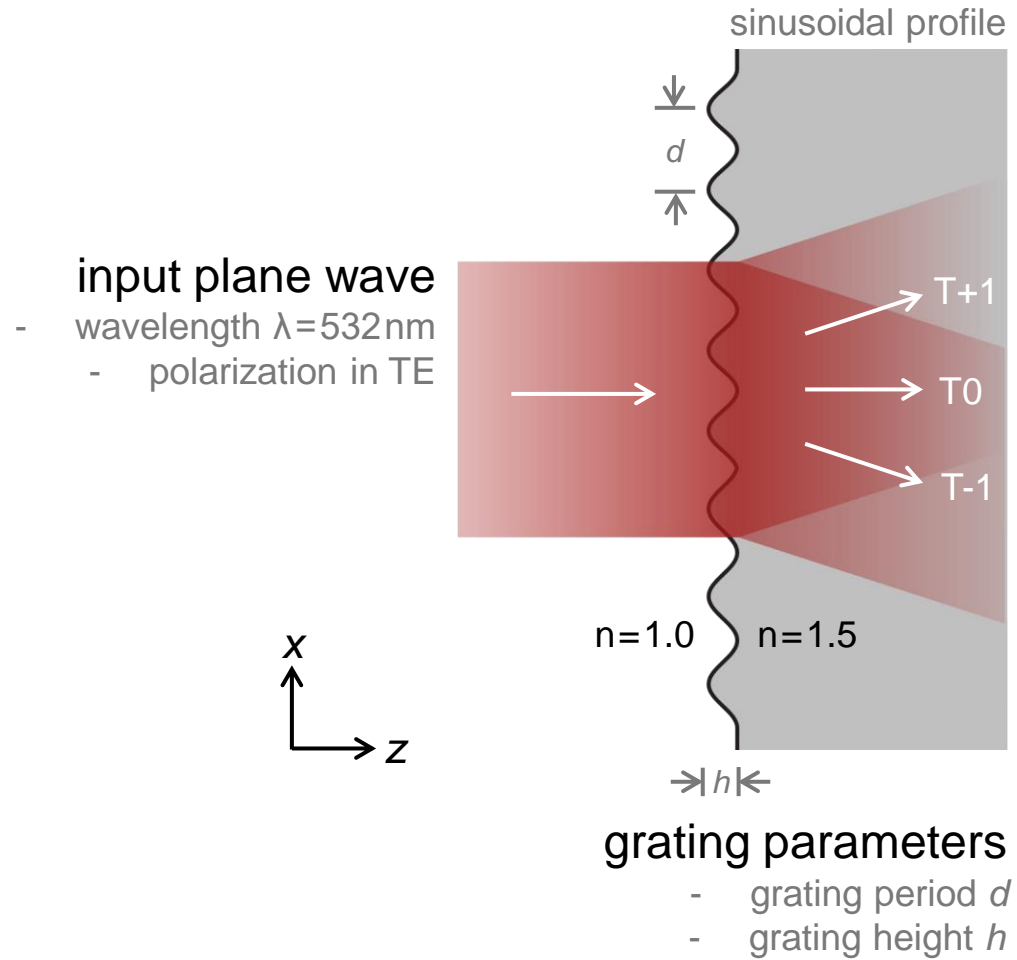


Document Information

title	Grating Order Analyzer
document code	GRT.0002
version	1.1
toolbox(es)	Grating Toolbox
VL version used for simulations	7.4.0.49
category	Feature Use Case
further reading	<ul style="list-style-type: none">- Analysis of Blazed Grating by Fourier Modal Method- Optimization of Lightguide Coupling Grating for Single Incidence Direction

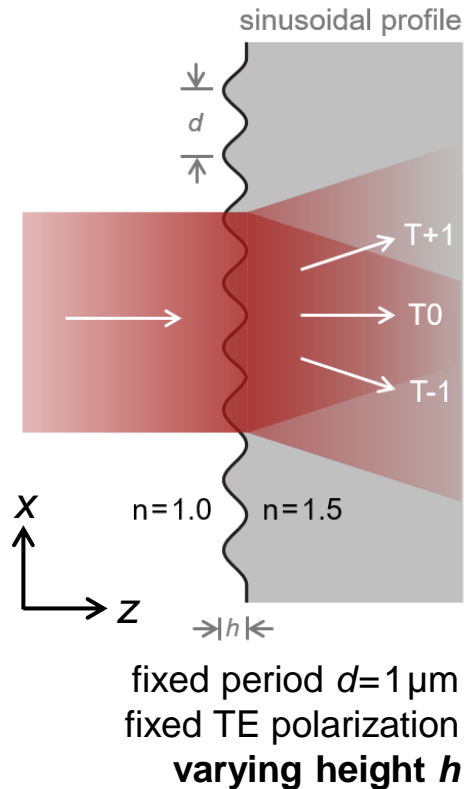
Thin-Element Approximation vs. Fourier Modal Method for Grating Modeling

Modeling Task

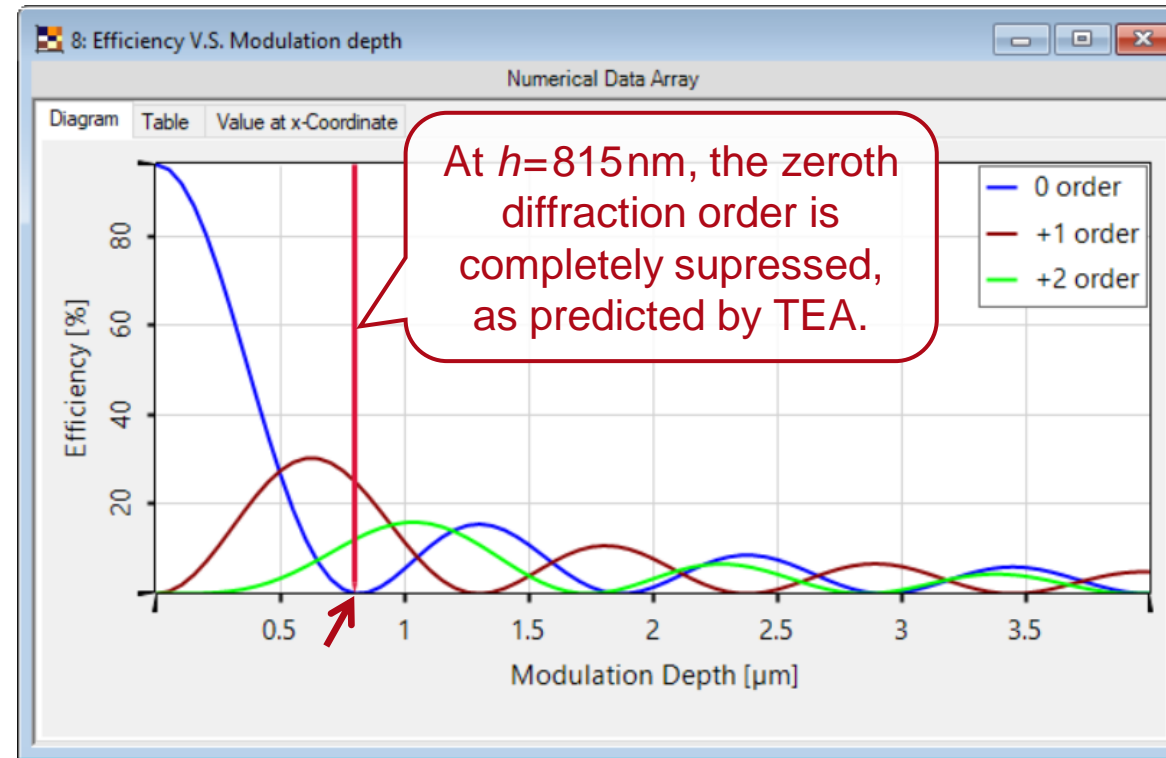


For both the sinusoidal and the blazed gratings, we analyze the gratings with TEA and FMM, and compare/analyze the results from both methods.

Sinusoidal Grating – Efficiency vs. Height (TEA Only)

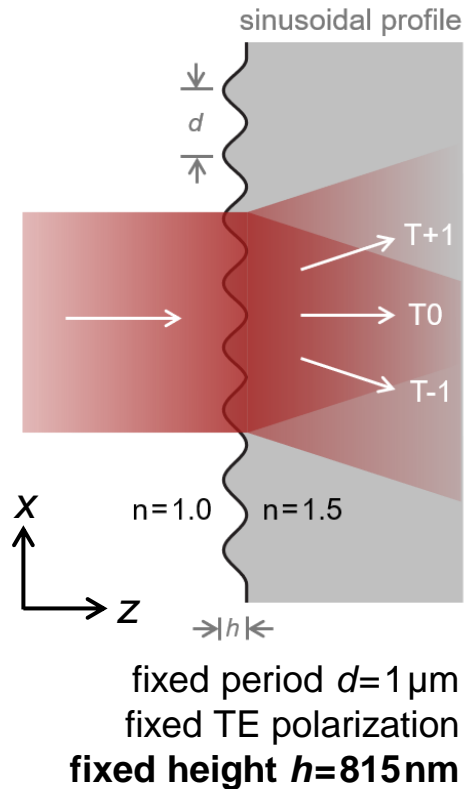


It is often efficient to use TEA as a fast design tool for searching proper grating parameters. However, the limitation of the method shall be noticed.

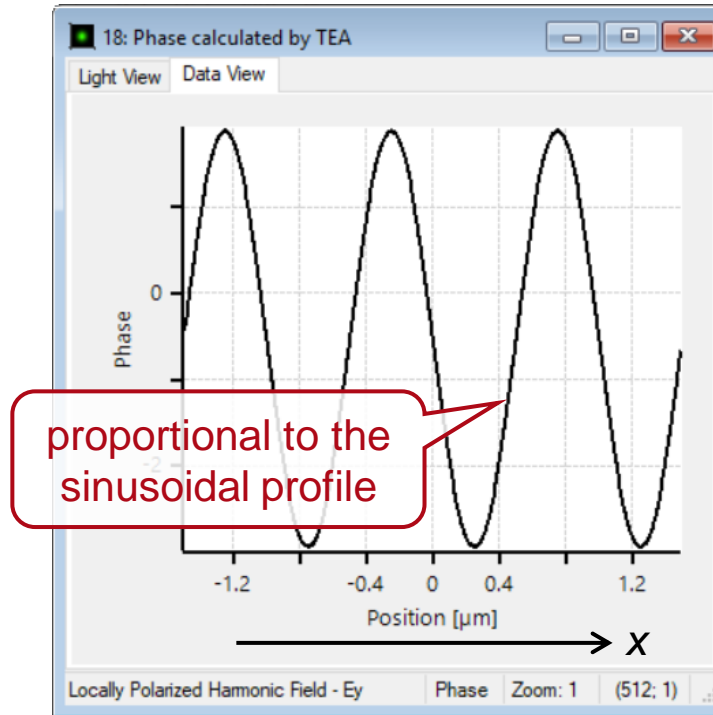


To have symmetric diffraction effect without zeroth order, we pick up $h=815\text{nm}$ as the grating height.

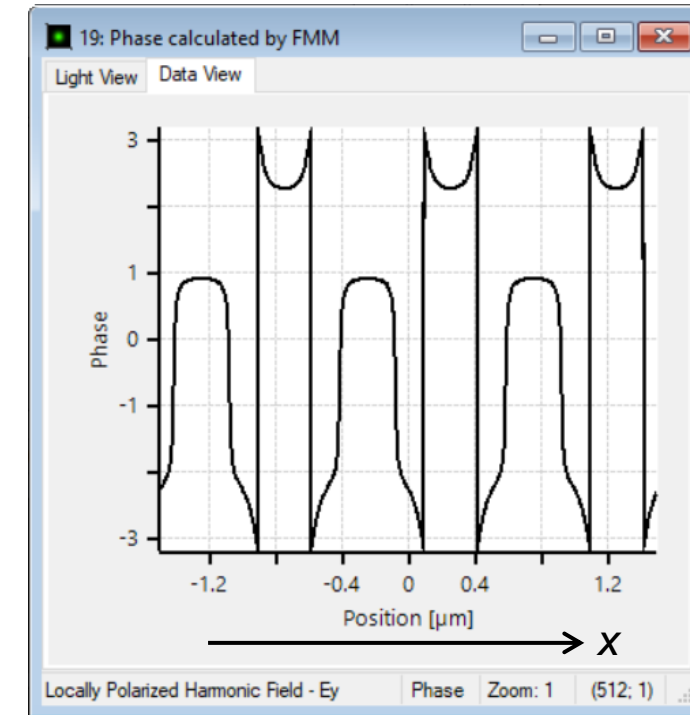
Sinusoidal Grating – Transmitted Phase Profiles



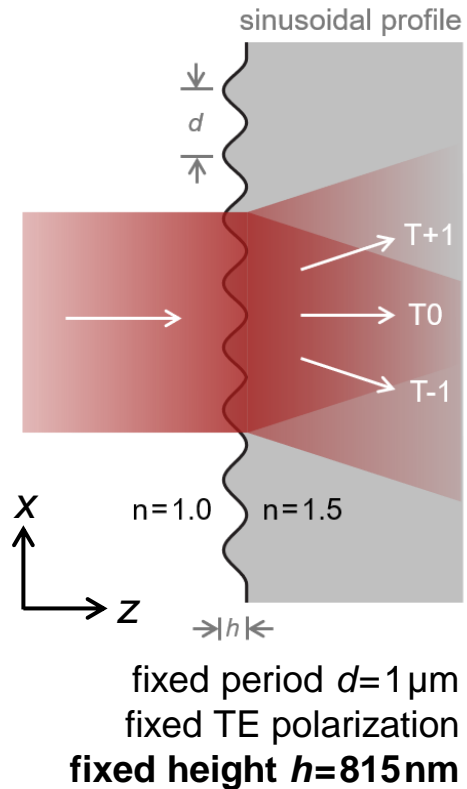
phase behind grating (TEA)



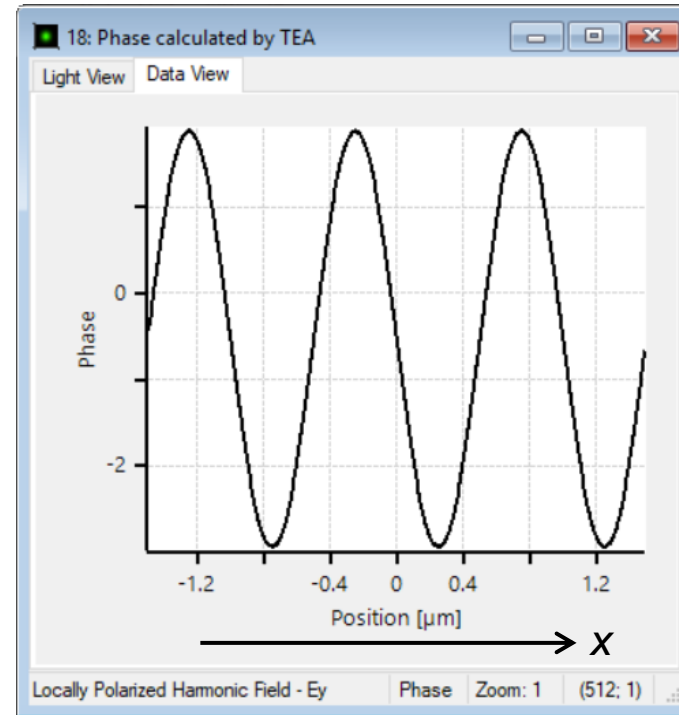
phase behind grating (FMM)



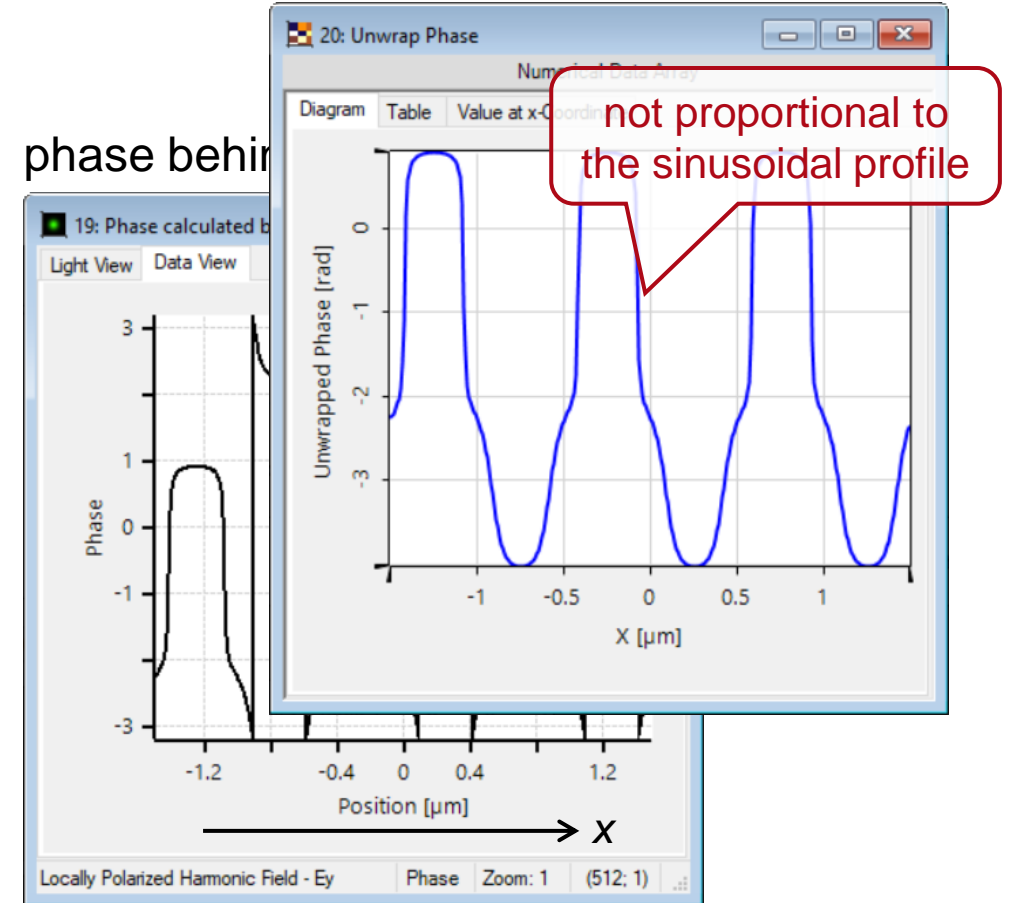
Sinusoidal Grating – Transmitted Phase Profiles



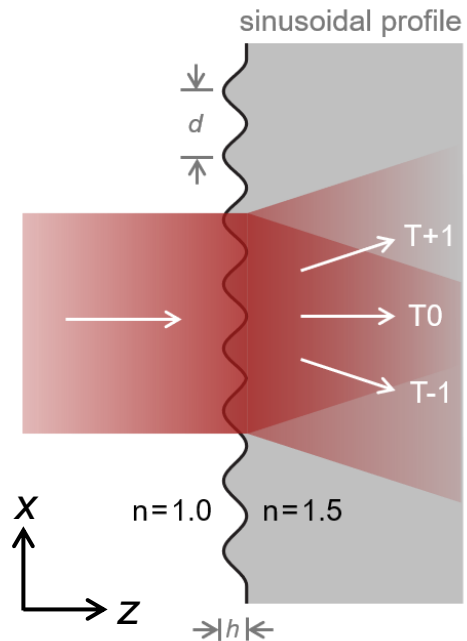
phase behind grating (TEA)



unwrapped phase (FMM)

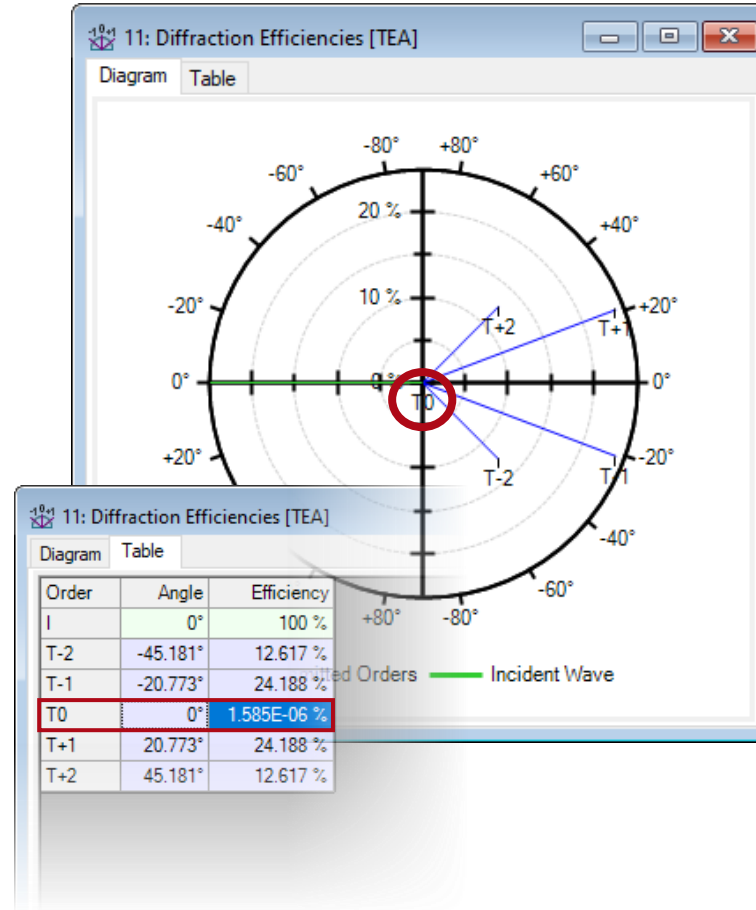


Sinusoidal Grating – Diffraction Efficiencies

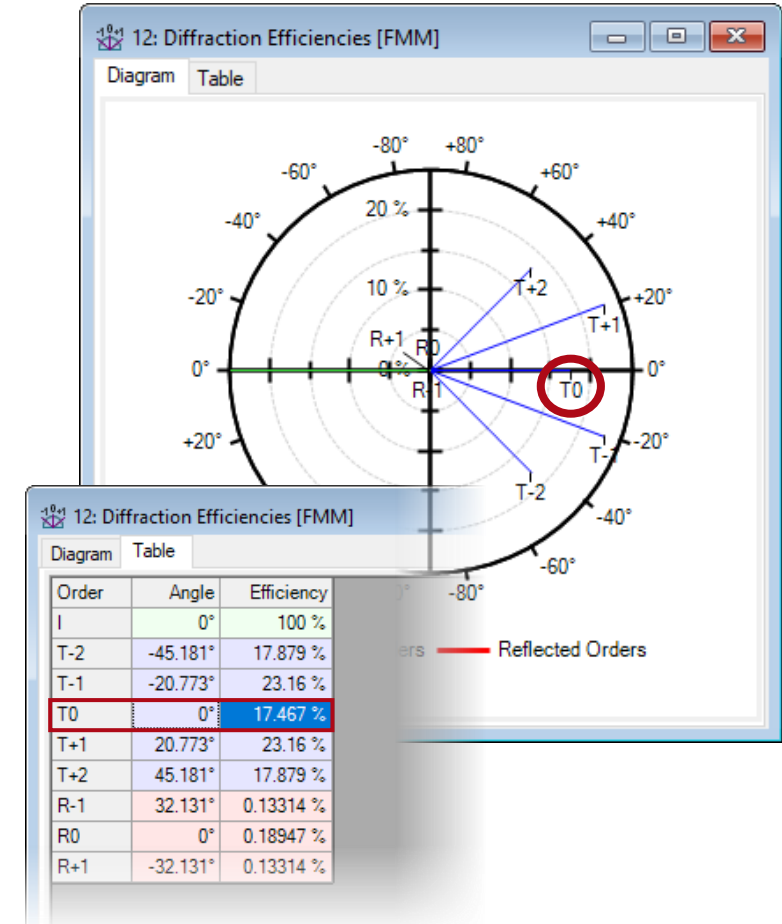


fixed period $d=1\mu\text{m}$
fixed TE polarization
fixed height $h=815\text{nm}$

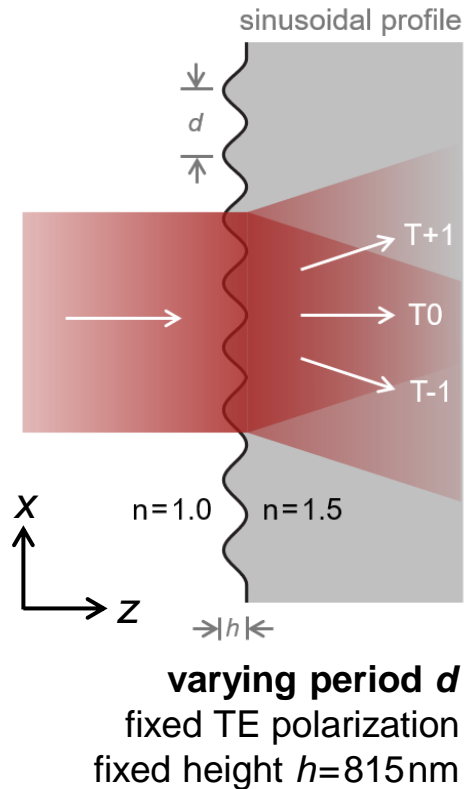
diffraction efficiencies (TEA)



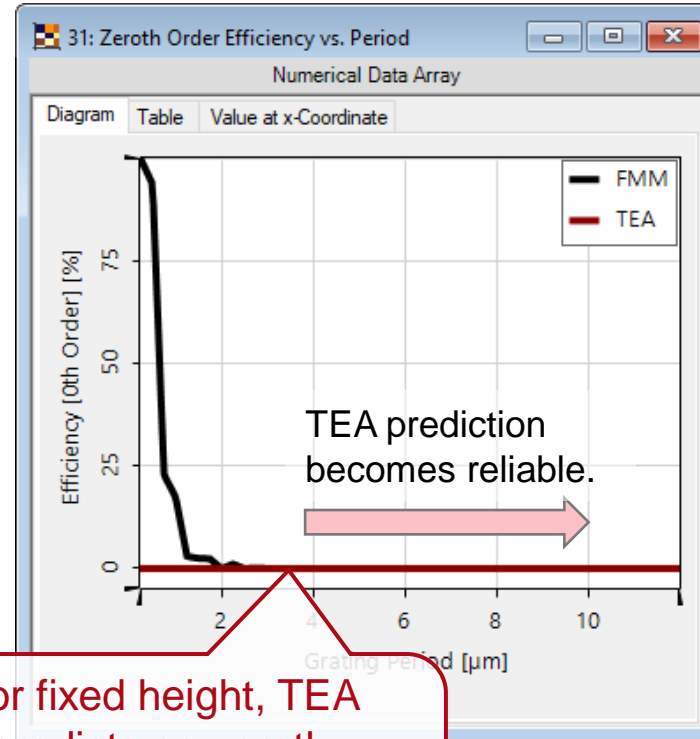
diffraction efficiencies (FMM)



Sinusoidal Grating – Efficiencies vs. Period

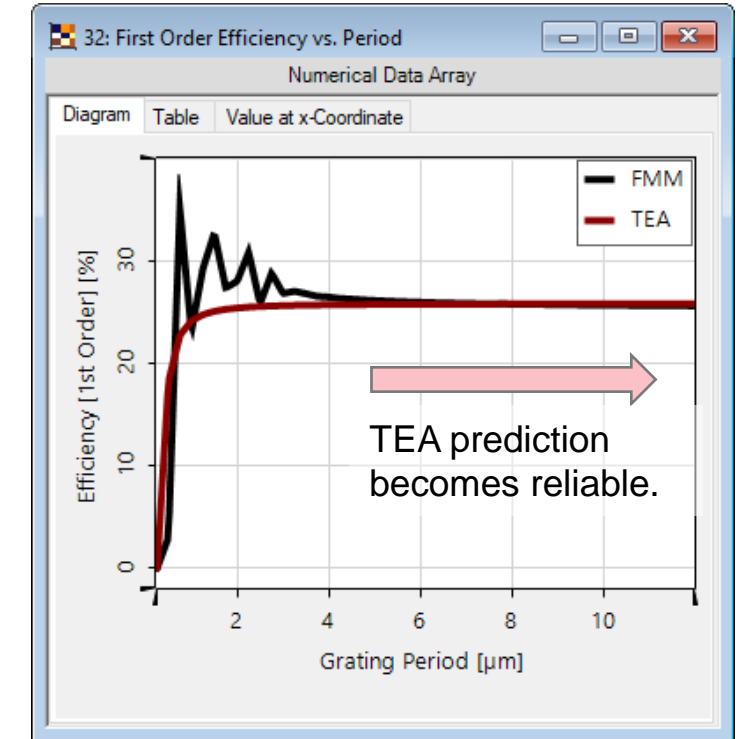


diffraction efficiencies – 0th order

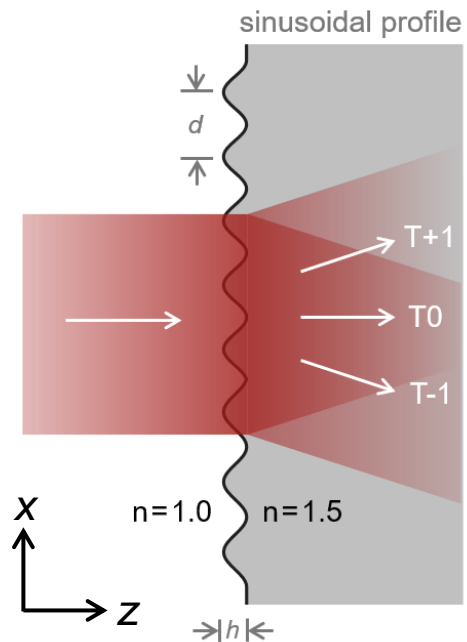


For fixed height, TEA predicts no zeroth diffraction order regardless of the grating period.

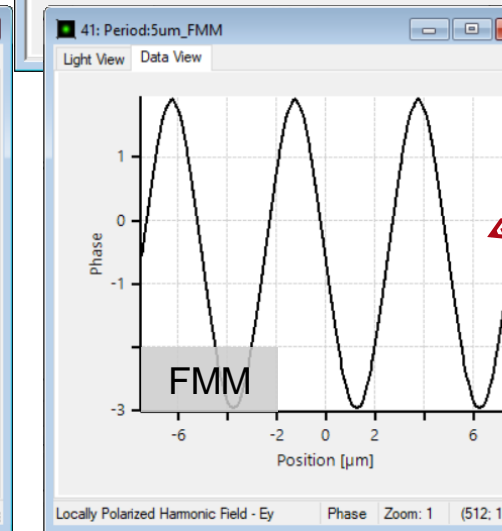
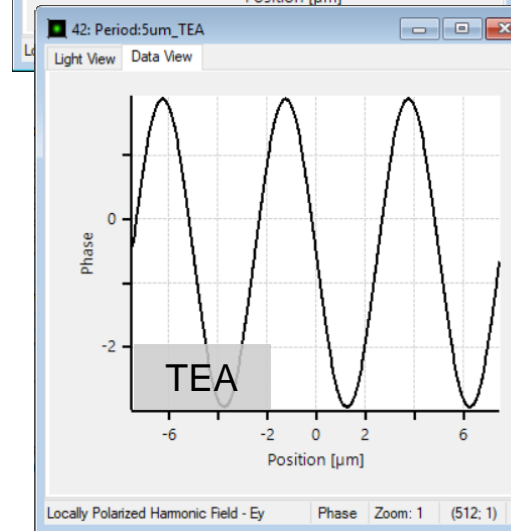
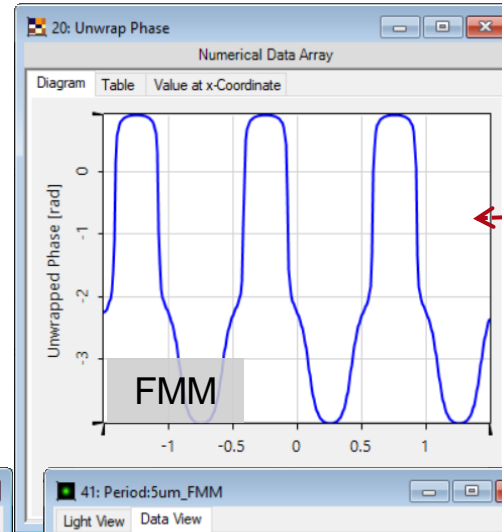
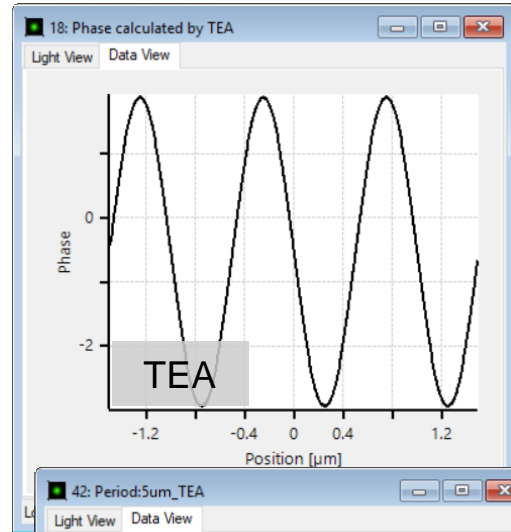
diffraction efficiencies – 1st order



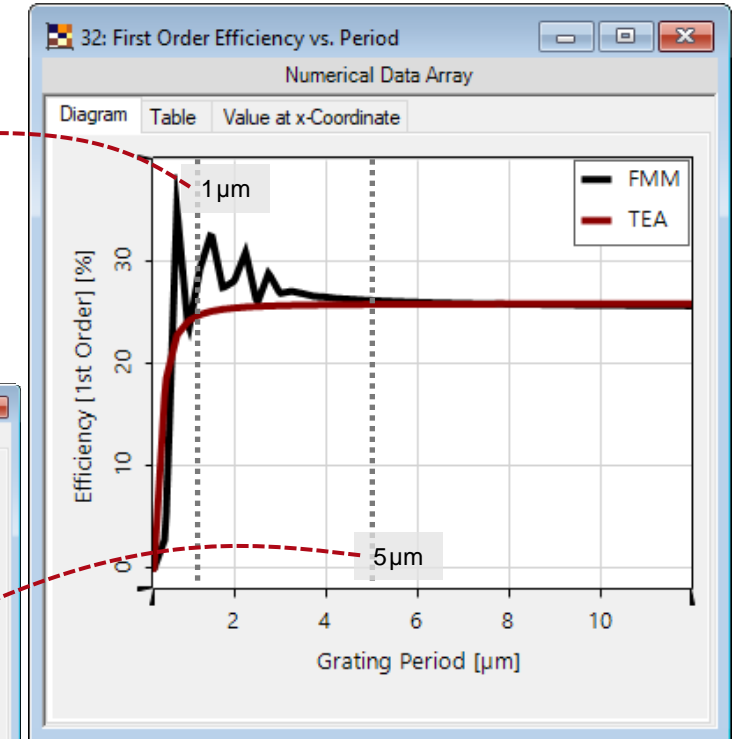
Sinusoidal Grating – Phase Profiles at Selected Periods



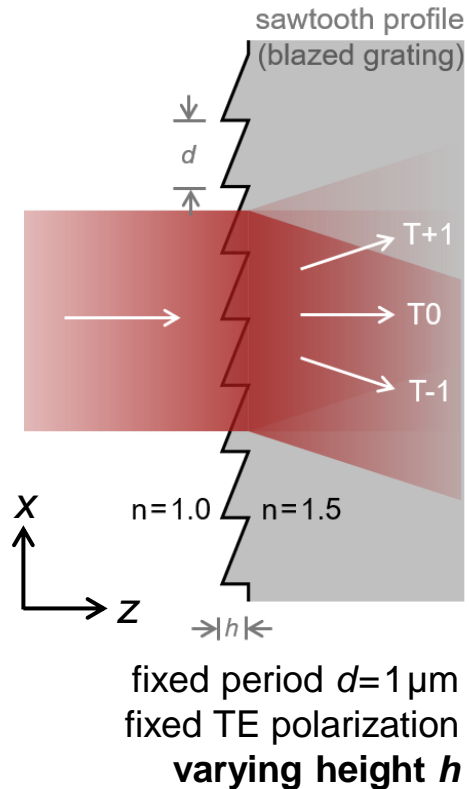
period $d=1\mu\text{m}$ or $5\mu\text{m}$
fixed TE polarization
fixed height $h=815\text{nm}$



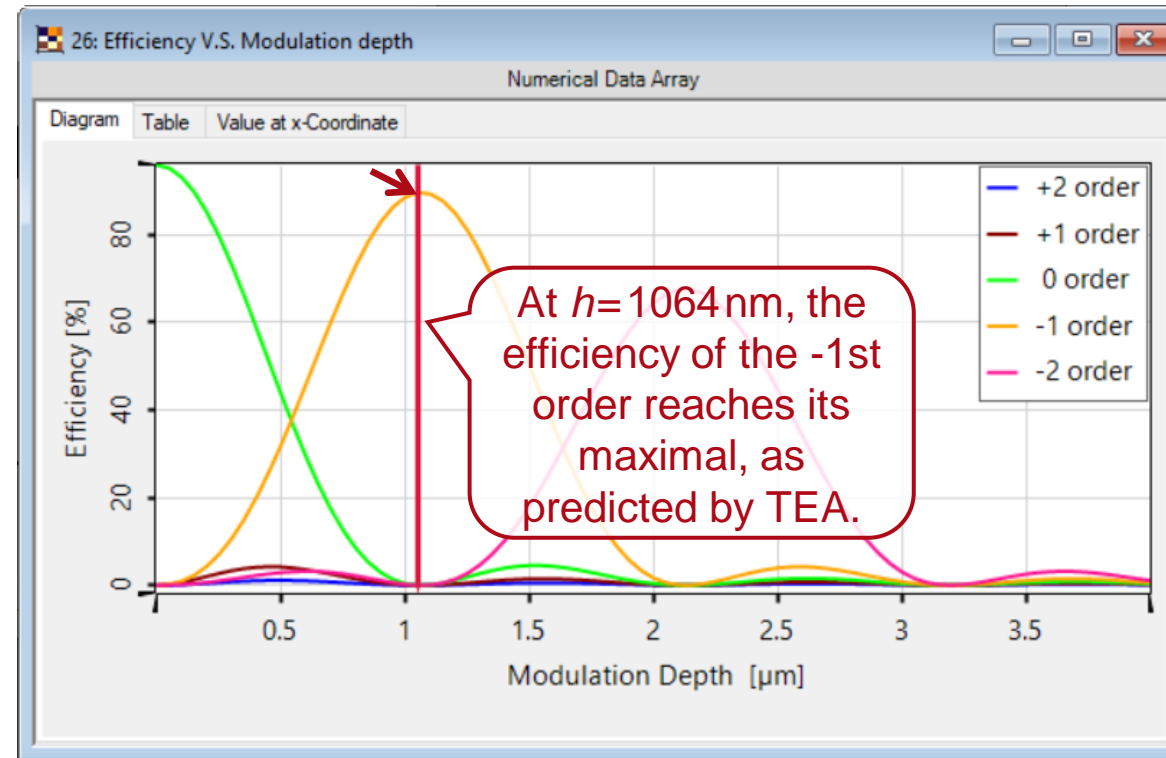
diffraction efficiencies – 1st order



Blazed Grating – Efficiency vs. Height (TEA Only)

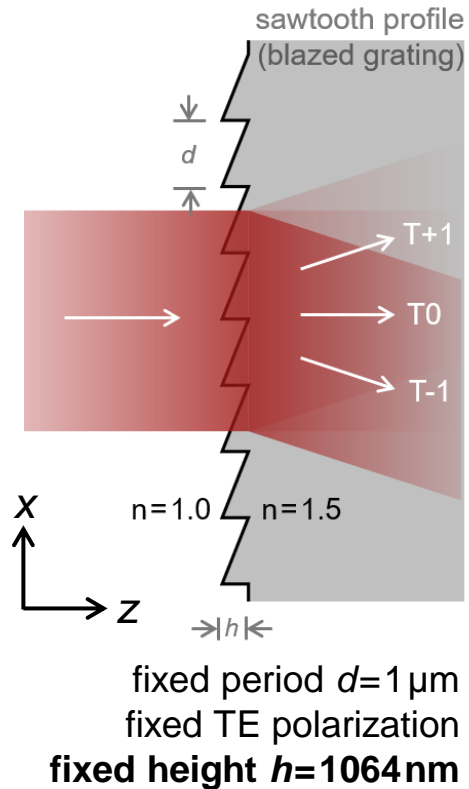


It is often efficient to use TEA as a fast design tool for searching proper grating parameters. However, the limitation of the method shall be noticed.

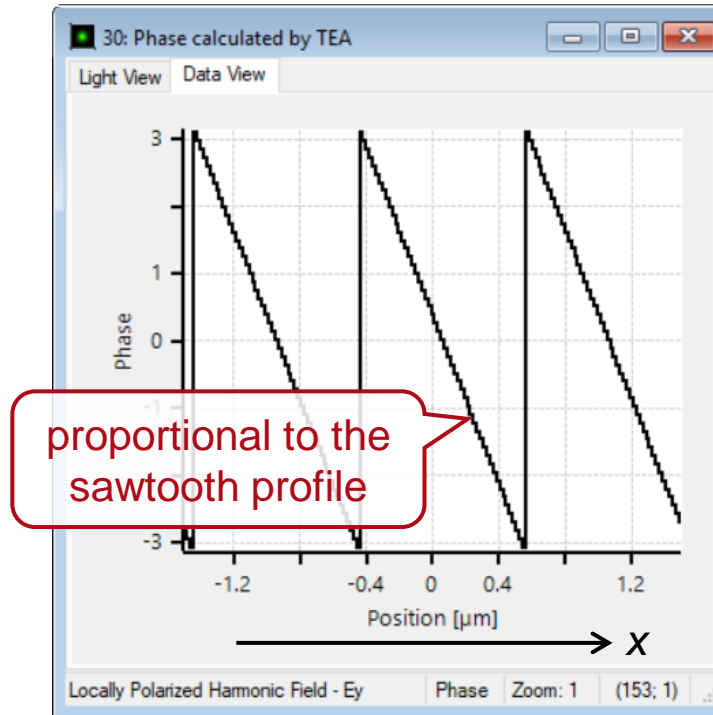


To maximize the diffraction efficiency of the -1st order, we pick up $h=1064\text{ nm}$ as the grating height.

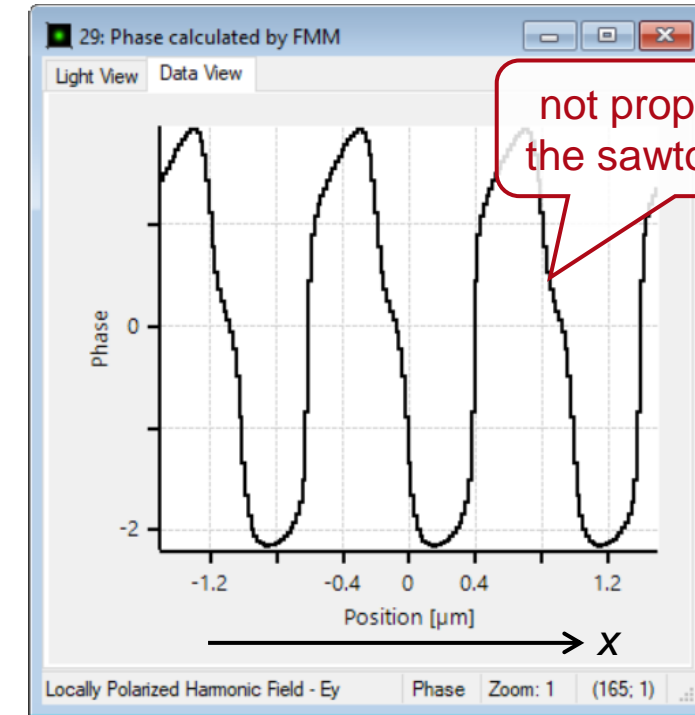
Blazed Grating – Transmitted Phase Profiles



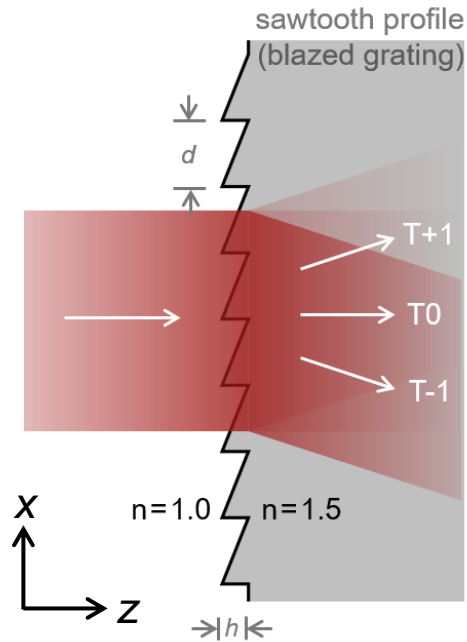
phase behind grating (TEA)



phase behind grating (FMM)

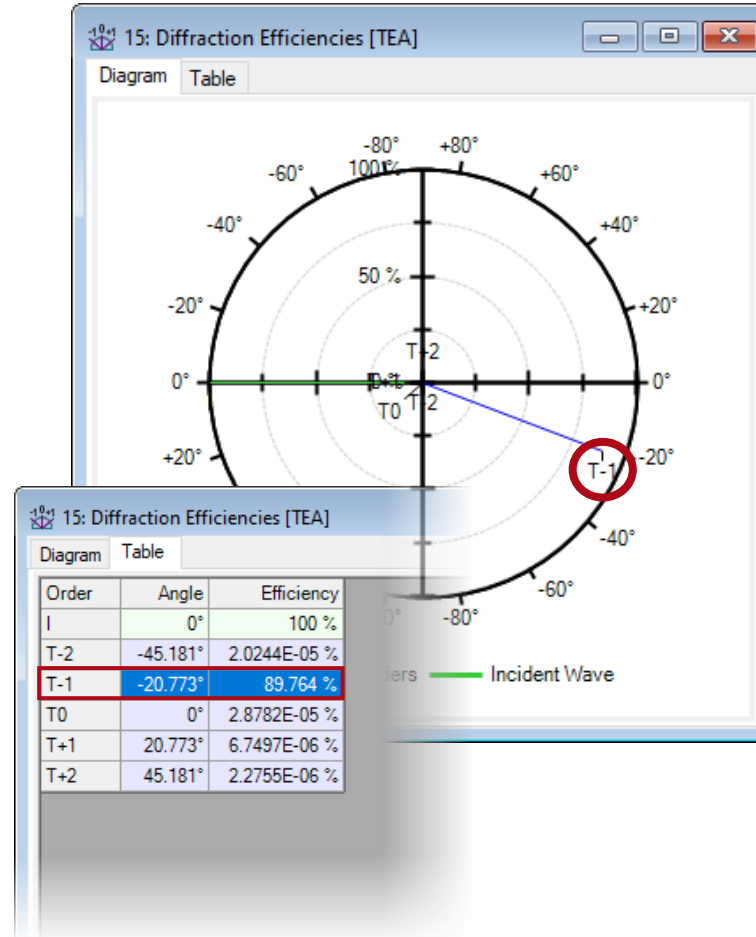


Blazed Grating – Diffraction Efficiencies

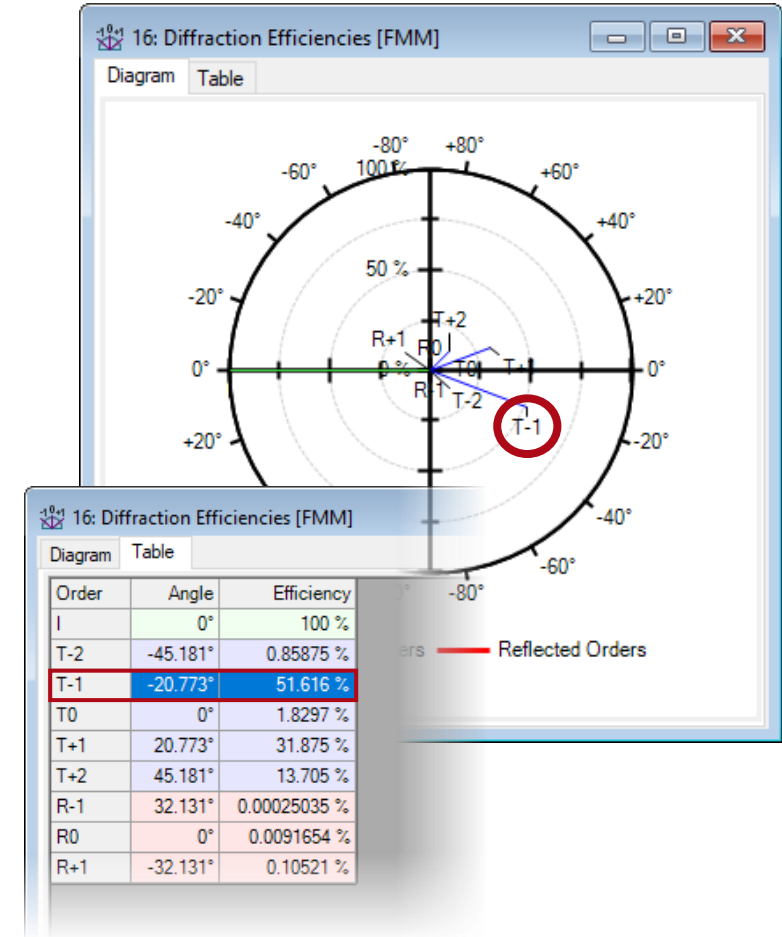


fixed period $d=1\ \mu\text{m}$
fixed TE polarization
fixed height $h=1064\text{nm}$

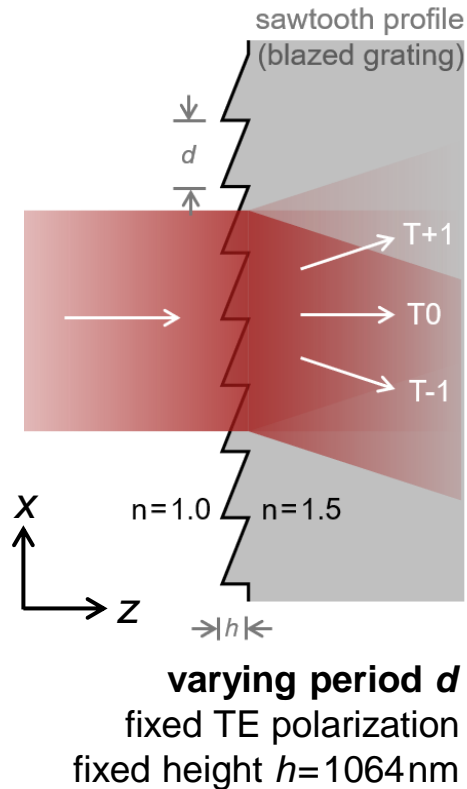
diffraction efficiencies (TEA)



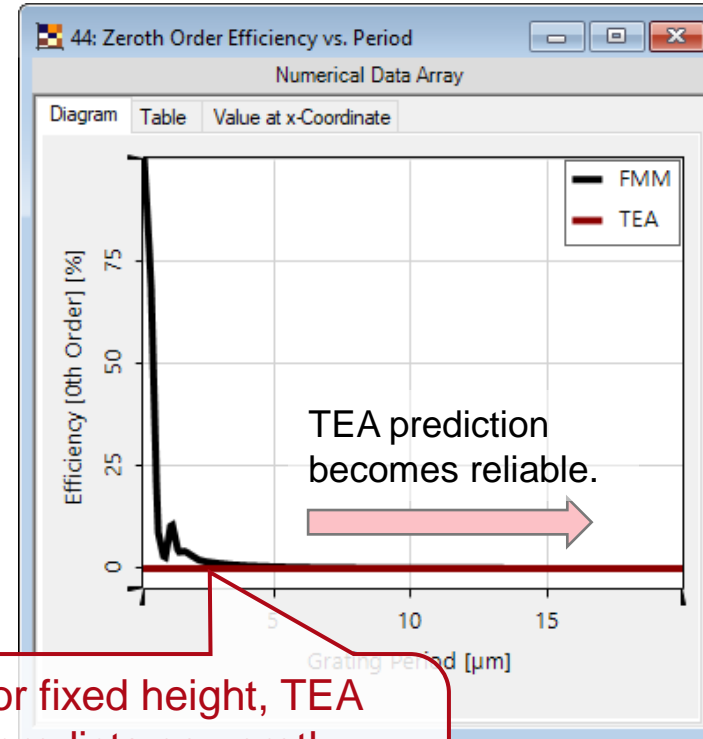
diffraction efficiencies (FMM)



Blazed Grating – Efficiencies vs. Period

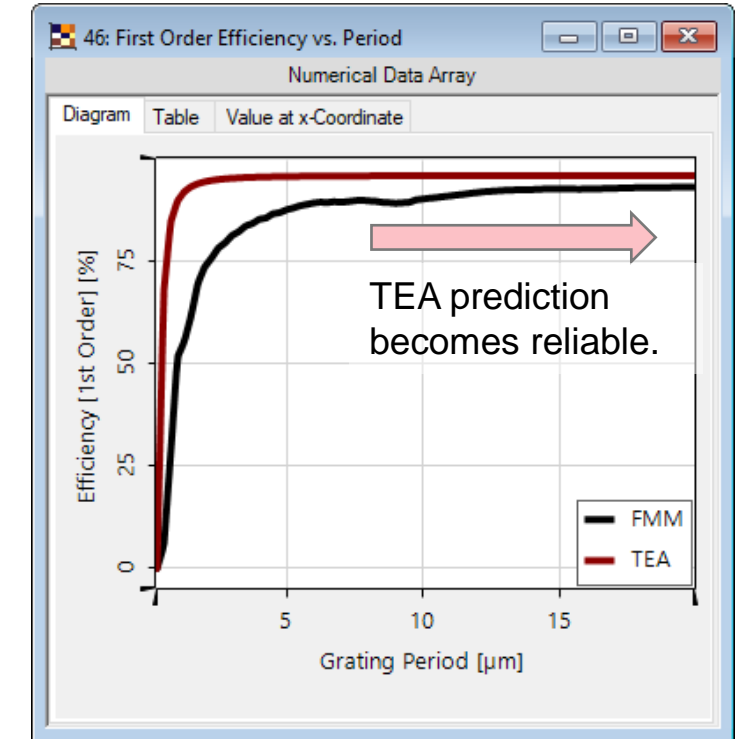


diffraction efficiencies – 0th order

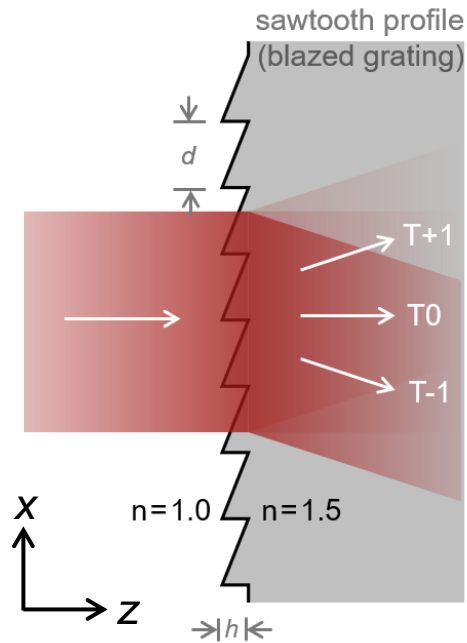


For fixed height, TEA predicts no zeroth diffraction order regardless of the grating period.

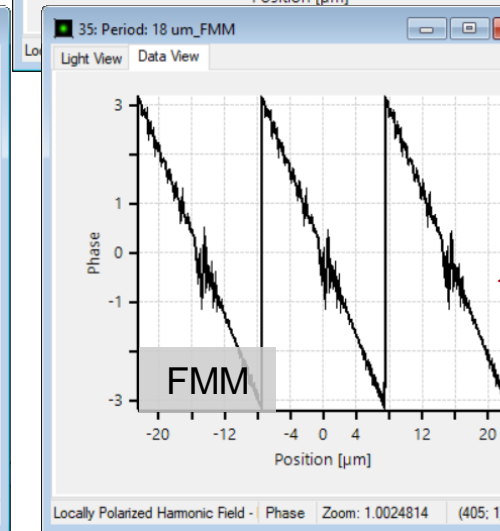
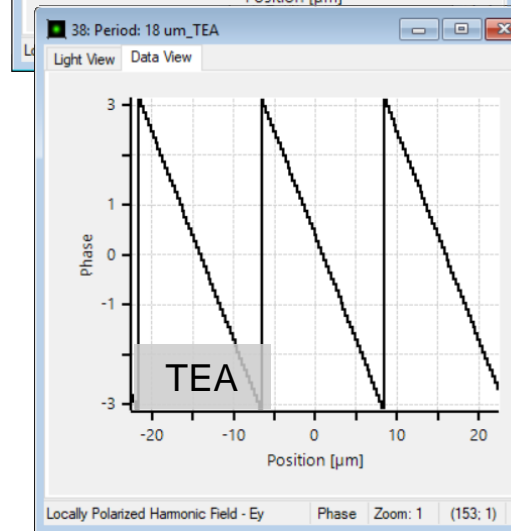
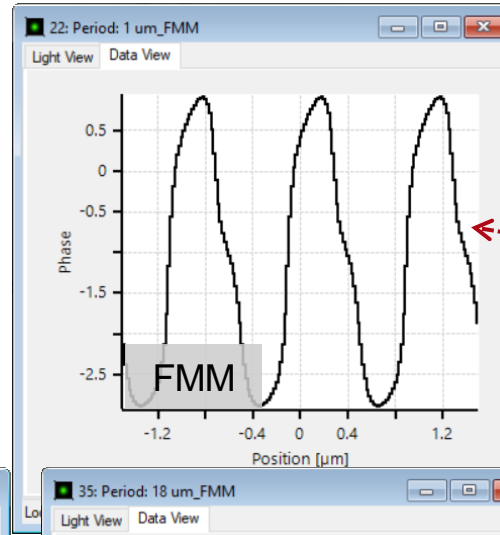
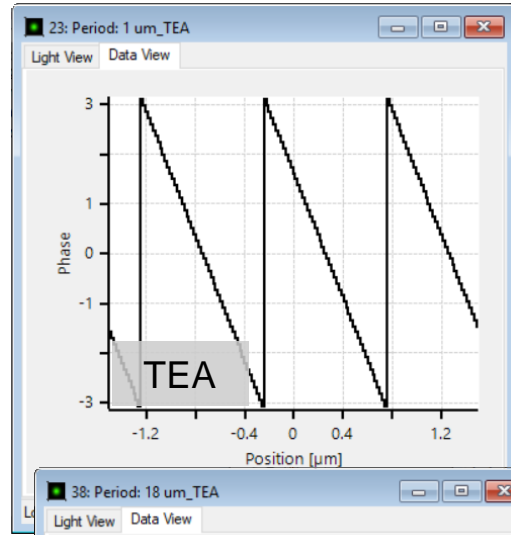
diffraction efficiencies – 1st order



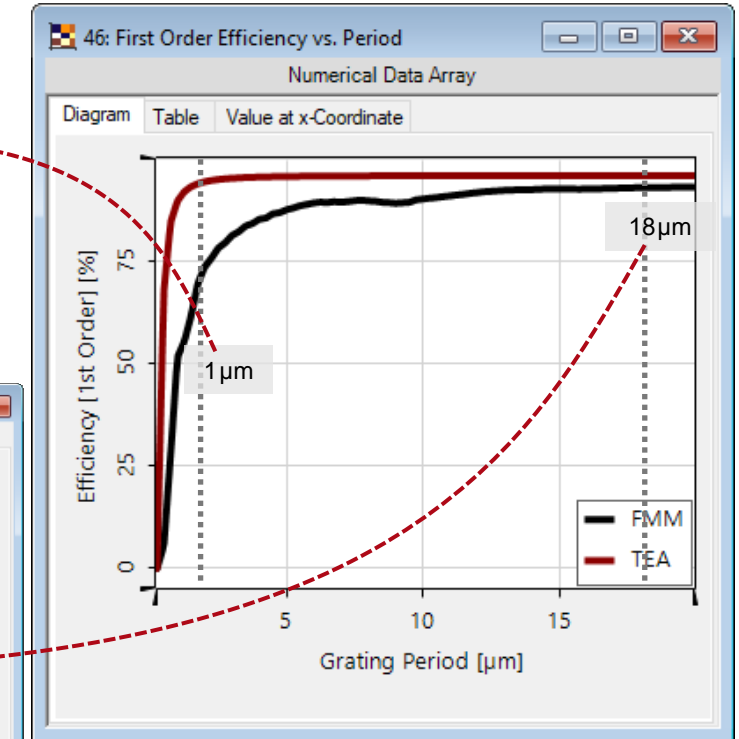
Sinusoidal Grating – Phase Profiles at Selected Periods



period $d=1\mu\text{m}$ or $18\mu\text{m}$
fixed TE polarization
fixed height $h=1064\text{nm}$

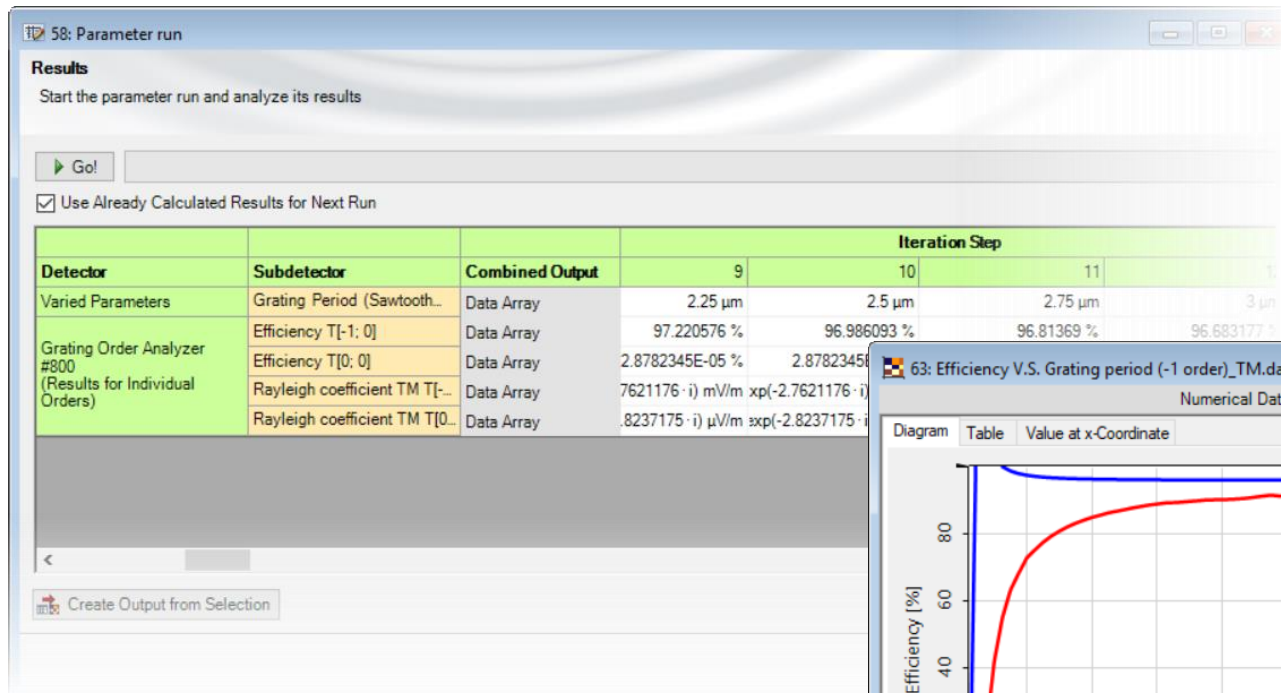


diffraction efficiencies – 1st order

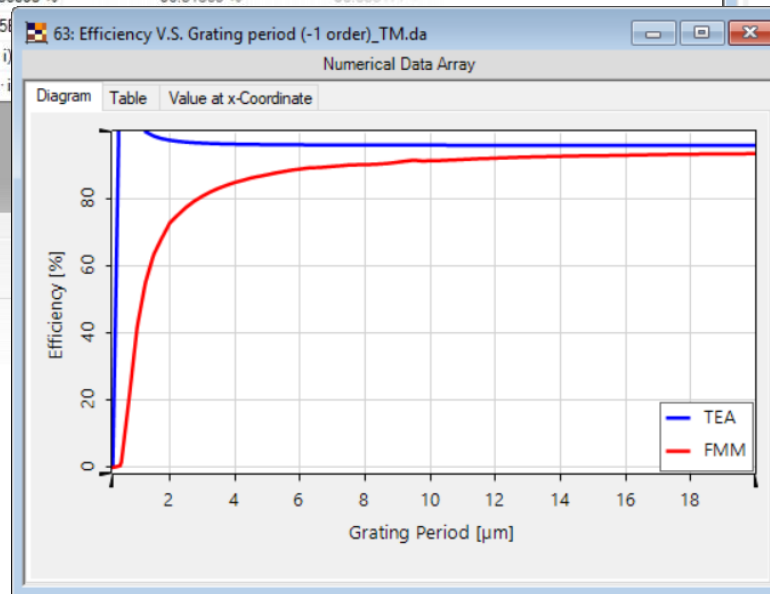


Peek into VirtualLab Fusion

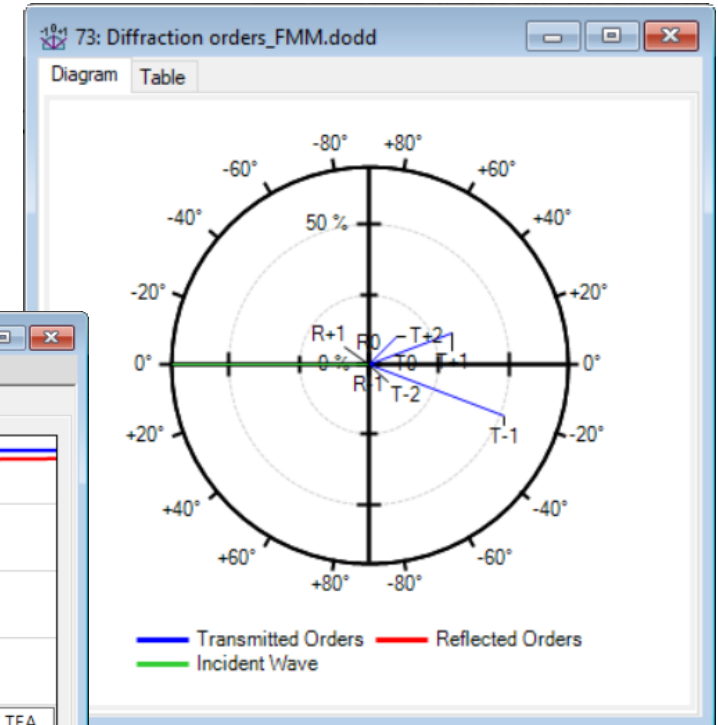
scanning of diffraction efficiency vs. specific parameter(s)



different methods to model gratings – TEA or FMM

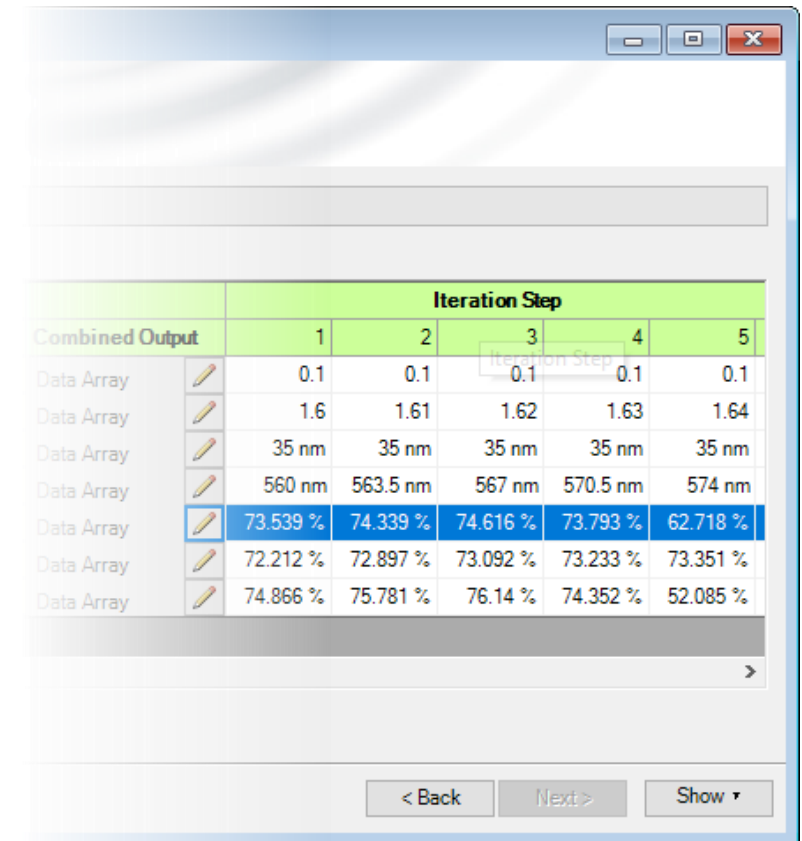


diffraction efficiency analysis and visualization in polar diagram



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]
- Check influence from different parameters with Parameter Run
 - [Usage of the Parameter Run Document](#) [Use Case]



The screenshot shows a window titled 'Iteration Step' with a table of results. The table has columns for 'Combined Output' and five iteration steps (1 to 5). The rows represent different data arrays, with the last row highlighted in blue.

		Iteration Step				
		1	2	3	4	5
Data Array		0.1	0.1	0.1	0.1	0.1
Data Array		1.6	1.61	1.62	1.63	1.64
Data Array		35 nm	35 nm	35 nm	35 nm	35 nm
Data Array		560 nm	563.5 nm	567 nm	570.5 nm	574 nm
Data Array		73.539 %	74.339 %	74.616 %	73.793 %	62.718 %
Data Array		72.212 %	72.897 %	73.092 %	73.233 %	73.351 %
Data Array		74.866 %	75.781 %	76.14 %	74.352 %	52.085 %

Navigation buttons: < Back, Next >, Show ▾

Document Information

title	Thin Element Approximation (TEA) vs. Fourier Modal Method (FMM) for Grating Modeling
document code	GRT.0019
version	2.0
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.202)
category	Application Use Case
further reading	<ul style="list-style-type: none">- Analysis of Slanted Gratings for Lightguide Coupling- Grating Order Analyzer

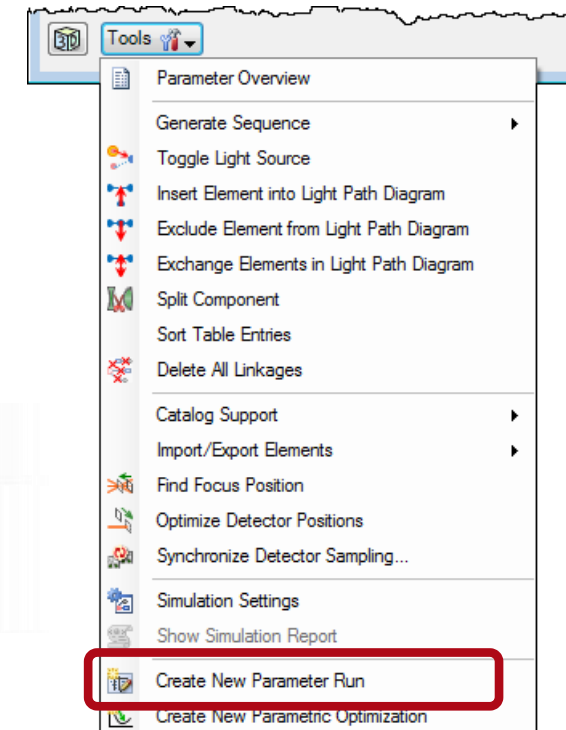
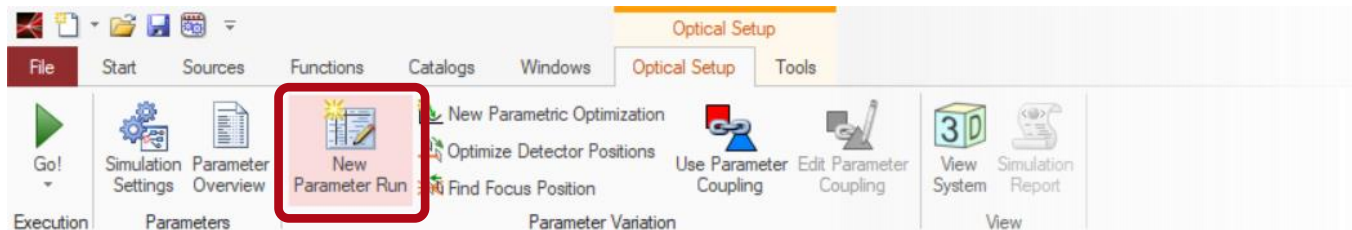
Usage of the Parameter Run Document

Parameter Run Document

- The Parameter Run document allows the variation of the numerical parameters of an Optical Setup.
- It can be used e. g.
 - to investigate the system's sensitivity for parameter tolerances
 - to optimize parameters
 - to evaluate the changing profile of a beam in the vicinity of a focus
 - ...
- One or multiple parameters can be varied.
- Detector results are recorded within the Parameter Run document.
- A copy of the original Optical Setup is stored in the Parameter Run document.

New Parameter Run

- To generate a new Parameter Run an open and activated Optical Setup window is required.
- A new Parameter Run document can be generated via
 - ribbon
 - Optical Setup Tools
 - shortcut Ctrl + P



Parameter Specification Page

Parameter Specification
Set up the parameter(s) to be varied.

You can select one or more parameters which shall be varied as well as the resulting number of iterations. Several [modes](#) are available specifying how the parameters are varied per iteration.

Usage Mode: Standard

Filter by: ☐ Show Only Varied Parameters

1 2 *	Object	Category	Parameter	Vary	From	To	Steps	Step Size	Original Value
	Ideal Plane Wave #0		Wavelength	<input checked="" type="checkbox"/>	210.0655221 nm	3.71 μ m	2	3.499934478 μ m	532 nm
			Weight	<input type="checkbox"/>	0	1E+300	1	1E+300	1
				Polarization Angle	<input type="checkbox"/>	0°	360°	1	360°
	Sawtooth Grating #1								
	Virtual Screen #600	Basal Positioning	Distance Before	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	2E+303 mm	0 mm
			Window Size Scaling X	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Window Size Scaling Y	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Resolution Scaling X	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
	Virtual Screen #601	Basal Positioning	Distance Before	<input type="checkbox"/>	-1E+303 mm	1E+303 mm	1	2E+303 mm	0 mm
			Window Size Scaling X	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Window Size Scaling Y	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Resolution Scaling X	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1
			Resolution Scaling Y	<input type="checkbox"/>	1E-300	1E+300	1	1E+300	1

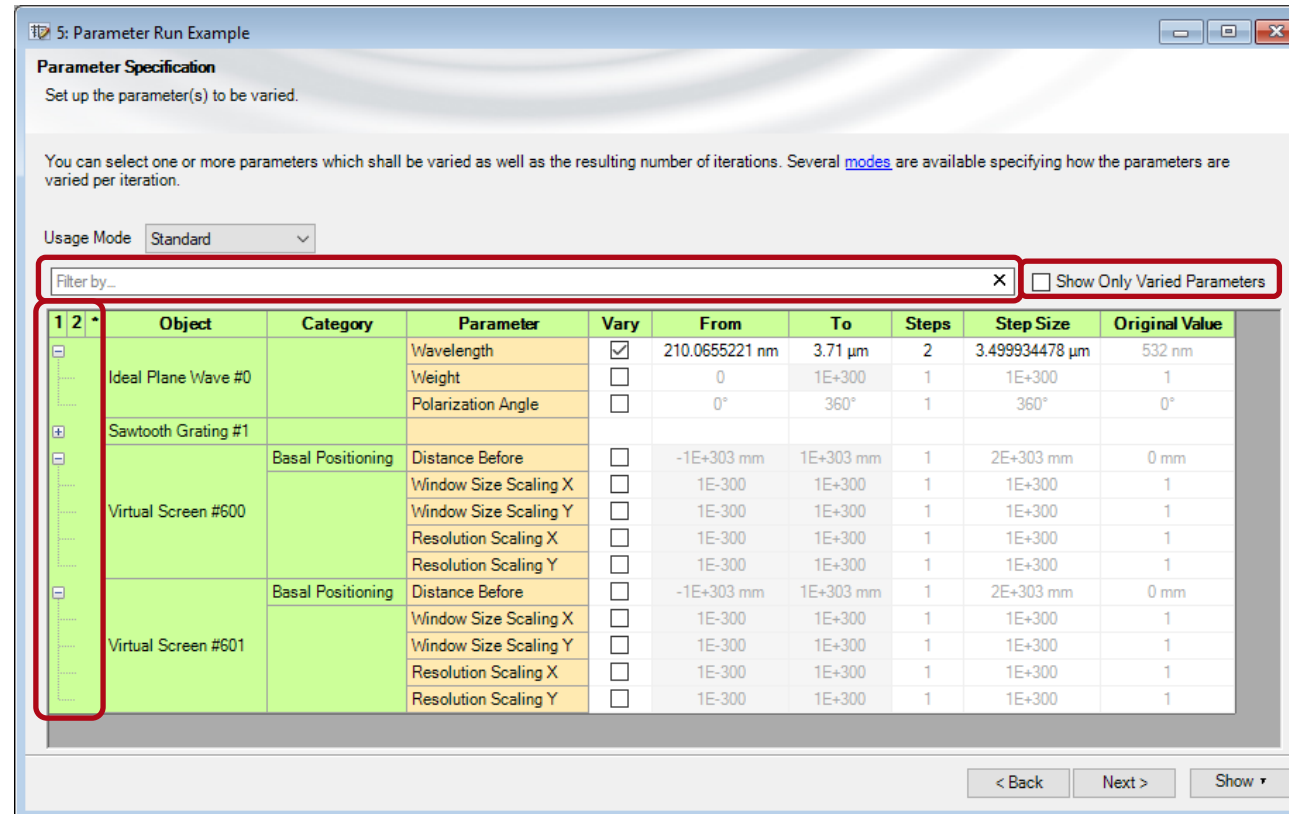
< Back Next > Show ▾

- This page allows you to select the parameters that should be varied.
- The parameter range and the number of steps can be specified.
- Four different Usage Modes (Standard, Programmable, Scanning, Random) will be Explained later.

Parameter Specification Page

You can

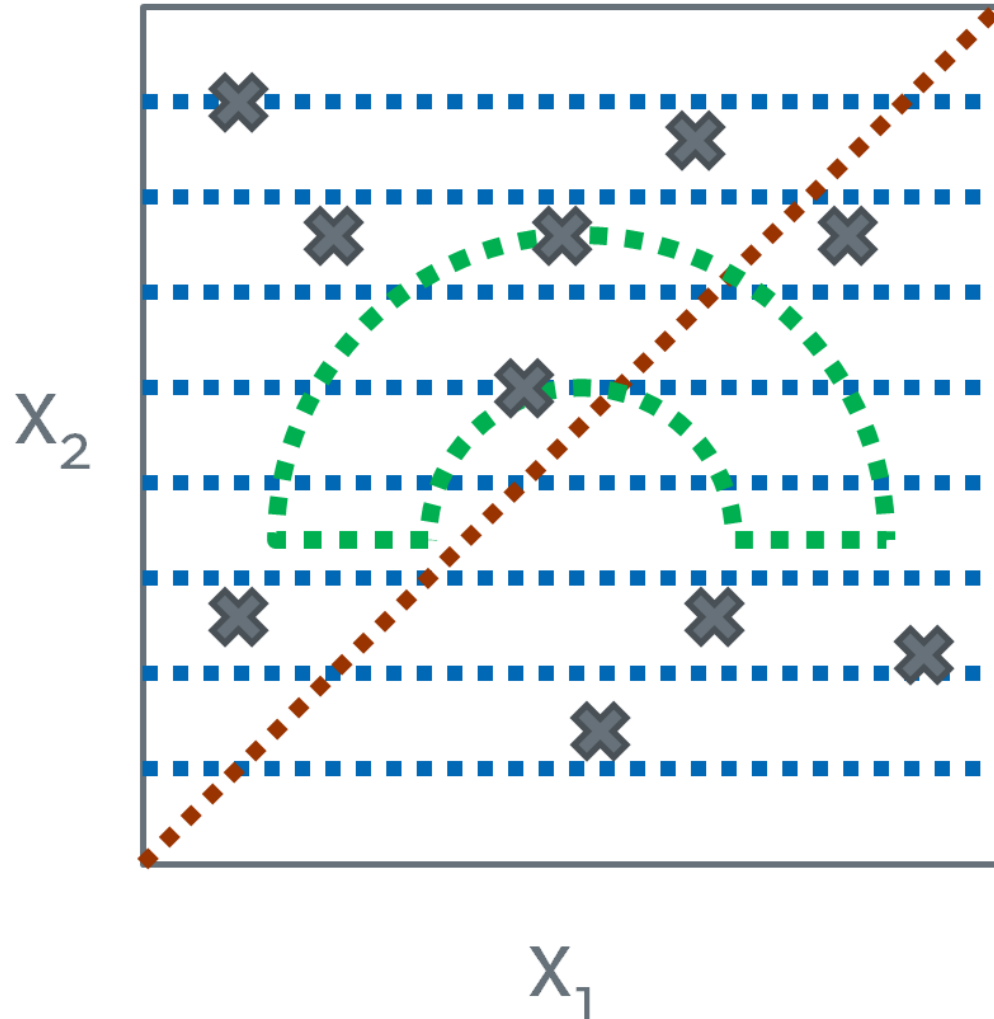
- filter for specific parameters
- show only the ones that are already set for variation
- fold/unfold the parameter list for a clearer representation by using the first three columns



Usage Modes

- **Standard Mode:**
Linear variation of all selected parameters between minimum and maximum value.
- **Programmable Mode:**
Customized parameter values per variation step. A table with the parameter values per variation step is filled by a snippet.
- **Scanning Mode:**
Scan of parameter space – all possible parameter combinations are simulated.
- **Random Mode:**
Random variation of parameters between minimum and maximum value. Sometimes also called Monte-Carlo-Simulation. A seed can be used for reproducible results.

Usage Modes



- Illustration of the different usage modes for the parameter run. A two-dimensional parameter space defined by two parameters X_1 and X_2 is shown.
- **Red:** Resulting parameter sets for the standard mode.
- **Green:** Example how the parameter sets can be generated by a snippet in the programmable mode.
- **Blue:** Resulting parameter sets for the scanning mode.
- **Grey:** Some randomly generated parameter sets.

Detecting Devices Specification Page

Detecting Devices Specification
Set up the detecting devices whose results you want to analyze

This page allows you to select one or more detecting devices (detectors, analyzers, or virtual screens). At least one detecting device must be selected. If you click on the "Open" button of one detecting device, the corresponding edit dialog is displayed.

In the upper part you can select the simulation engine(s) that shall be executed in the parameter run. Furthermore you can select the detectors that shall be evaluated by the selected simulation engine(s).

☒ Unified Field Tracing

Detecting Device		Edit Dialog
Virtual Screen #600	<input checked="" type="checkbox"/>	Open
Virtual Screen #601	<input checked="" type="checkbox"/>	Open

In the lower part you can select the analyzers that shall be executed in the parameter run. They are independent from the simulation engine(s) selected above.

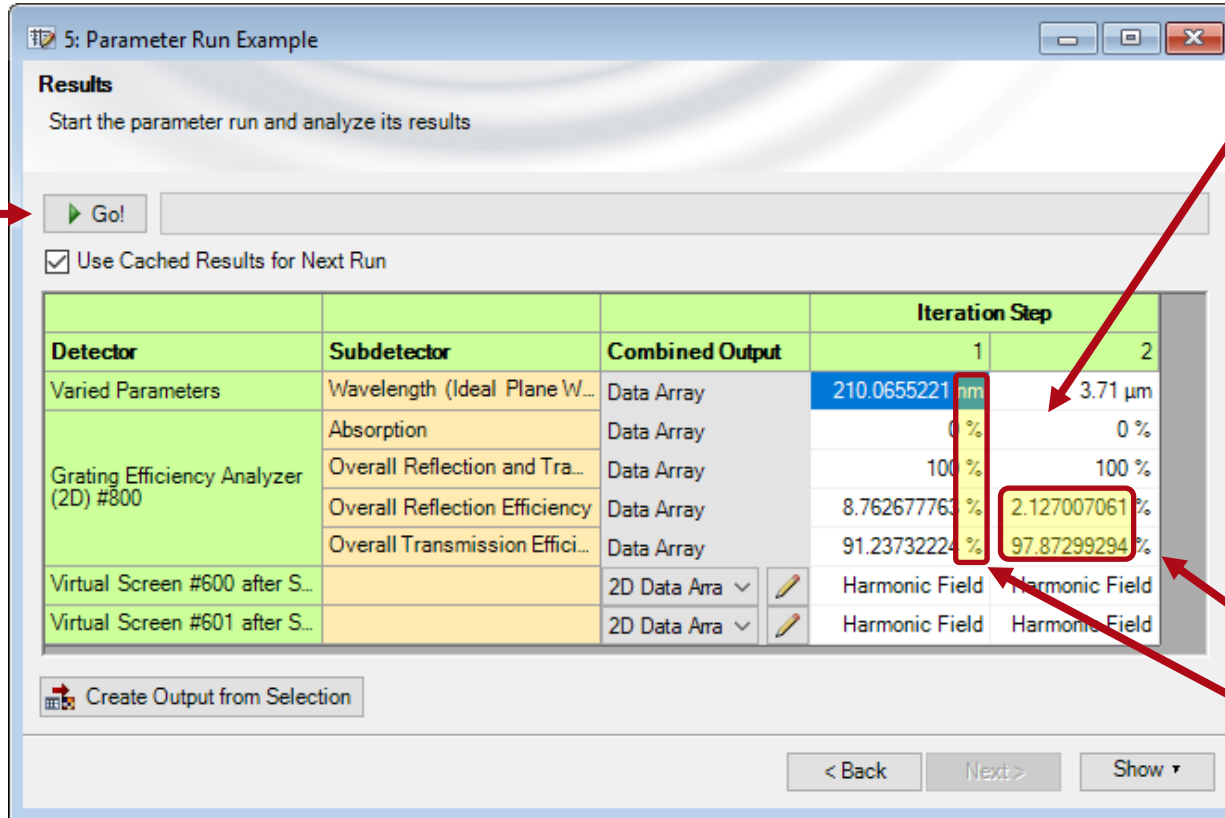
Analyzer		Edit Dialog
Grating Efficiency Analyzer (2D) #800	<input checked="" type="checkbox"/>	Open

< Back Next > Show LPD

- This page allows to select which simulation engines, detectors, screens and analyzers are evaluated.
- The detecting devices can be configured after clicking Open to get to the edit dialog.

Results Page

Starts and stops the parameter variation.



Results

Start the parameter run and analyze its results

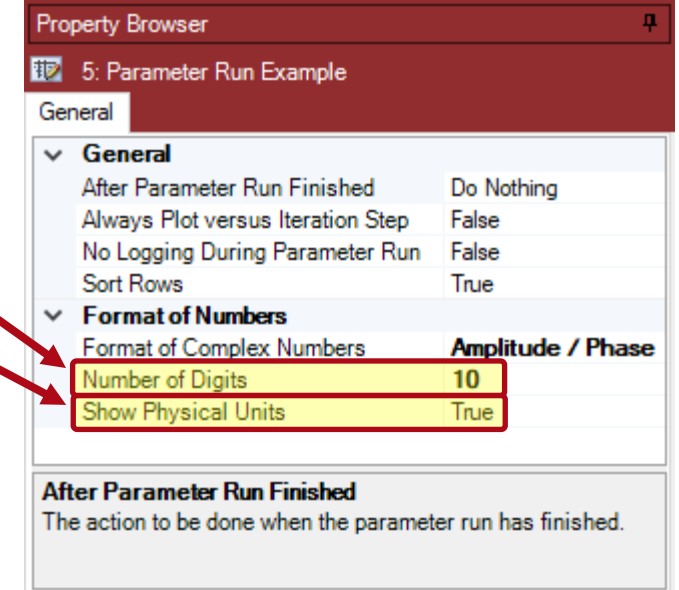
☒ Use Cached Results for Next Run

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Varied Parameters	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 μm
	Absorption	Data Array	0 %	0 %
Grating Efficiency Analyzer (2D) #800	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra ▾	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra ▾	Harmonic Field	Harmonic Field

Create Output from Selection

Simulation results:
Double click on a document to view it in a separate window.

In the Property Browser you can change the formatting of the shown physical values (number of digits and whether physical units are shown) so that you can better export them to e.g. spread sheet programs via copy & paste.



Property Browser

5: Parameter Run Example

General

General

After Parameter Run Finished	Do Nothing
Always Plot versus Iteration Step	False
No Logging During Parameter Run	False
Sort Rows	True

Format of Numbers

Format of Complex Numbers	Amplitude / Phase
Number of Digits	10
Show Physical Units	True

After Parameter Run Finished

The action to be done when the parameter run has finished.

Optical Setups within Parameter Run

The screenshot shows the 'Parameter Run' window in VirtualLab Fusion. The 'Execution' tab is active, showing a 'Go!' button and a dropdown menu for 'After Completion' set to 'Do Nothing'. Below this, there are buttons for 'Show Optical Setup', 'No Logging During Execution', 'Create Output from Selection', and 'Delete Results'. The 'Optical Setup' button is highlighted with a red box. A red arrow points from this button to the 'Results' table in the '5: Parameter Run Example' window. The 'Results' table shows the following data:

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Grating Efficiency Analyzer (2D) #800	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 μm
	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

At the bottom of the 'Results' window, there are buttons for '< Back', 'Next >', and a 'Show' button with a dropdown arrow, which is also highlighted with a red box. A red arrow points from this 'Show' button to the 'Property Browser' window on the right.

The 'Property Browser' window shows the 'General' tab for '5: Parameter Run Example'. It lists the following properties:

- After Parameter Run Finished: Do Nothing
- Always Plot versus Iteration Step: False
- No Logging During Parameter Run: False
- Sort Rows: True
- Format of Numbers: Amplitude / Phase
- Format of Complex Numbers: 10
- Number of Digits: 10
- Show Physical Units: True

At the bottom of the 'Property Browser' window, there is a section for 'After Parameter Run Finished' with the text 'The action to be done when the parameter run has finished.'

Displays the optical setup:

- initial
- from any iteration

Logging of Parameter Run Results

The screenshot shows the VirtualLab Fusion software interface. The 'Parameter Run' window is open, displaying a table of results for a 'Grating Efficiency Analyzer (2D) #800'. The table has columns for 'Detector', 'Subdetector', 'Combined Output', and 'Iteration Step'. The 'Iteration Step' column is further divided into two sub-columns, 1 and 2. The 'Property Browser' is also open, showing the 'General' tab with various settings. A red box highlights the 'No Logging During Parameter Run' option, which is set to 'False'. A red arrow points to this option. Another red arrow points to the 'No Logging During Execution' button in the 'Parameter Run' window's toolbar.

Wyrowski VirtualLab Fusion (2nd Generation Technology Update [Build 7.4.0.49])

File Start Sources Functions Catalogs Windows

Execution: Go! After Completion: Do Nothing

Optical Setup: Show Optical Setup

Result Table: No Logging During Execution, Create Output from Selection, Delete Results

5: Parameter Run Example

Results

Start the parameter run and analyze its results

Go!

☒ Use Cached Results for Next Run

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Varied Parameters	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 μm
Grating Efficiency Analyzer (2D) #800	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

Create Output from Selection

< Back Next > Show ▾

Property Browser

5: Parameter Run Example

General

- General
 - After Parameter Run Finished: Do Nothing
 - Always Plot versus Iteration Step: False
 - No Logging During Parameter Run: False
 - Sort Rows: True
- Format of Numbers
 - Format of Complex Numbers: Amplitude / Phase
 - Number of Digits: 10
 - Show Physical Units: True

After Parameter Run Finished

The action to be done when the parameter run has finished.

Property Browser VirtualLab Explorer

- For time critical simulations especially for Parameter Runs with many iterations, the simulation time can be reduced by **deactivating the logging**.
- Thus the results are only shown after all iterations are finished.
- In order to see the results of a running Parameter Run document that have been produced so far, you can duplicate the document via the Windows ribbon; then VirtualLab creates a Parameter Run document of the current status with all already calculated results.

Display of Parameter Run Results

The screenshot shows the WYROWSKI VirtualLab Fusion software interface. The main window is titled '5: Parameter Run Example'. It features a 'Results' section with a 'Go!' button and a checkbox for 'Use Cached Results for Next Run'. Below this is a table displaying simulation results. The table has columns for 'Detector', 'Subdetector', 'Combined Output', and 'Iteration Step' (1 and 2). The data includes 'Varied Parameters', 'Grating Efficiency Analyzer (2D) #800', and 'Virtual Screen' results. A red box highlights the 'Delete Results' button in the top right corner of the main window, with a red arrow pointing to it labeled '1.'. The 'Property Browser' on the right side shows settings for the 'Parameter Run Example', including 'General' and 'Format of Numbers' sections. Red boxes highlight the 'Always Plot versus Iteration Step', 'No Logging During Parameter Run', 'Sort Rows', 'Format of Complex Numbers', and 'Amplitude' options, with red arrows pointing to them labeled '2.' and '3.'.

Detector	Subdetector	Combined Output	Iteration Step 1	Iteration Step 2
Varied Parameters	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 μm
Grating Efficiency Analyzer (2D) #800	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

1. It is possible to delete the results in order to save a smaller Parameter Run document (e.g. for email sending).
(Sometimes the saving or opening of a Parameter Run document with many and/or huge results takes longer than the simulation of all iterations.)
2. The user can select different orders for the display of the results.
3. There are different options to display complex numbers.

Saving (& Shutdown) after Parameter Run Completion?

Allows you to save the results after the simulation has finished and then shut down your computer.

The screenshot shows the 'Parameter Run' window in the Wyrowski VirtualLab Fusion software. The 'Execution' tab is active, showing a 'Go!' button and a dropdown menu set to 'Do Nothing'. The 'Optical Setup' tab shows a 'Show Optical Setup' button. The 'Result Table' tab shows a table with columns for 'Detector', 'Subdetector', 'Combined Output', and 'Iteration Step'.

The 'Results' section of the 'Parameter Run' window contains the following table:

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Grating Efficiency Analyzer (2D) #800	Varied Parameters	Data Array	210.0655221 nm	3.71 μm
	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
Virtual Screen #600 after S...	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field
		2D Data Arra	Harmonic Field	Harmonic Field

The 'Property Browser' window is also visible, showing the 'General' tab with a dropdown menu set to 'Do Nothing'.

Results Page – Combined Outputs

The results for each (sub-)detector can be combined into a Data Array, Animation, Harmonic Fields Set or Ray Distribution. Which combined outputs are available depends on the type and dimensionality of the original documents.

Create the combined output – or stop the creation if it takes too long. Clicking/Double clicking on a cell in the Detector or Subdetector column is a shortcut to selecting the whole row and start the output creation with the current combined output.

Results
Start the parameter run and analyze its results

☒ Use Cached Results for Next Run

Detector	Subdetector	Combined Output	Iteration Step	
			1	2
Varied Parameters	Wavelength (Ideal Plane W...	Data Array	210.0655221 nm	3.71 μ m
Grating Efficiency Analyzer (2D) #800	Absorption	Data Array	0 %	0 %
	Overall Reflection and Tra...	Data Array	100 %	100 %
	Overall Reflection Efficiency	Data Array	8.762677763 %	2.127007061 %
	Overall Transmission Effici...	Data Array	91.23732224 %	97.87299294 %
Virtual Screen #600 after S...		2D Data Arra	Harmonic Field	Harmonic Field
Virtual Screen #601 after S...		2D Data Arra	Harmonic Field	Harmonic Field

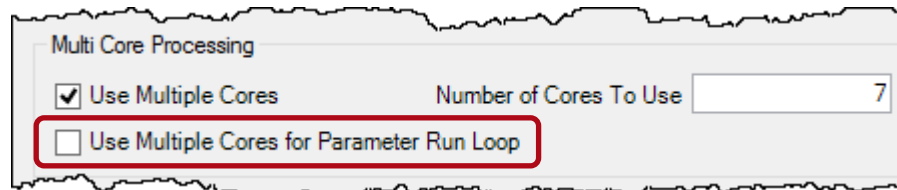
< Back Next > Show ▾

- Select the results to combine.
- Clicking on a cell in the Detector or Subdetector column selects the whole row.

- Choose the desired combined output.
- Several combined outputs can be configured by clicking on the pencil icon.

Parallelization & Amount of Data

- The execution of the different iterations of a Parameter Run simulation is very well parallelized. Thus it represents a very efficient method to simulate many different settings very fast.
- But in case already one simulation is extremely memory consuming, parallel executions are out of the question. They would not be possible or slow down the whole process if VirtualLab may swap such large data on hard disc instead of keeping it in the RAM.
- Then the parallelization should be switched off for Parameter Run Loop.
- VirtualLab will still do parallel computations, as parallelization is also used within single system simulations.



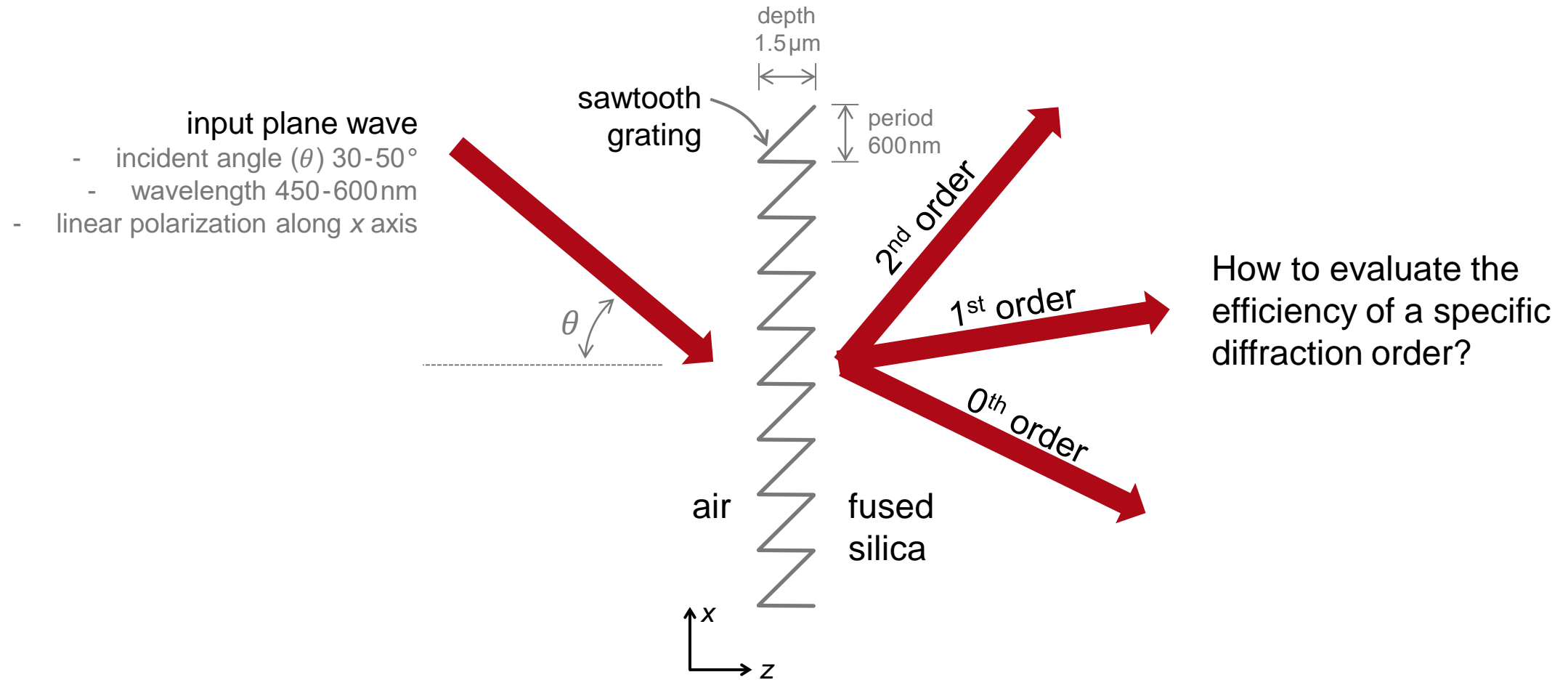
Document Information

title	Usage of the Parameter Run Document
document code	MISC.0071
version	2.0
toolbox(es)	Starter Toolbox
VL version used for simulations	7.4.0.49
category	Feature Use Case
further reading	<ul style="list-style-type: none">- Programming a Scanning Parameter Run- Application of the Programmable Mode of a Parameter Run- Tolerance Analysis of a Fiber-Coupling Setup

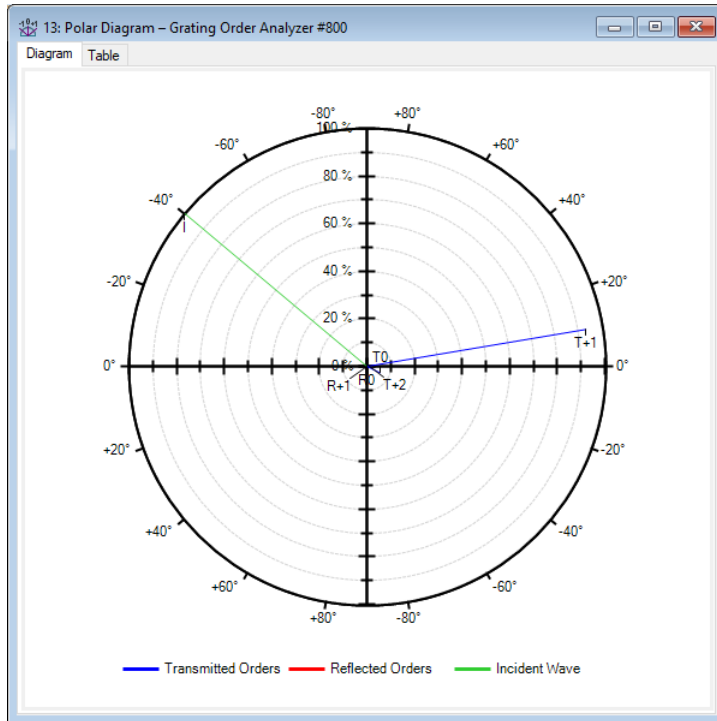
GRT.0001

Analysis of Blazed Grating by Fourier Modal Method

Modeling Task



Results from Single FMM Simulation



polar diagram

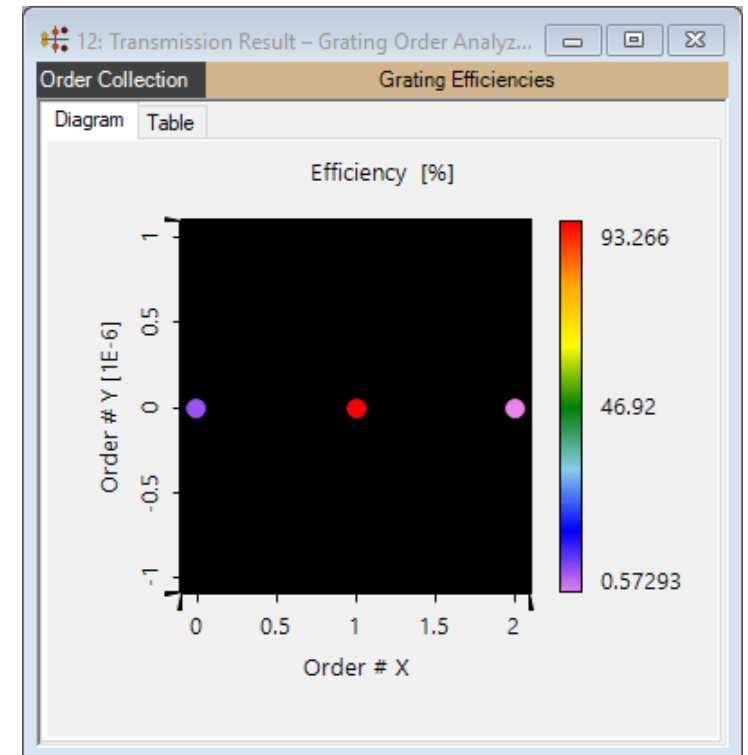
used for projected visualization of grating efficiencies for transmission and reflection

result table (transmission)

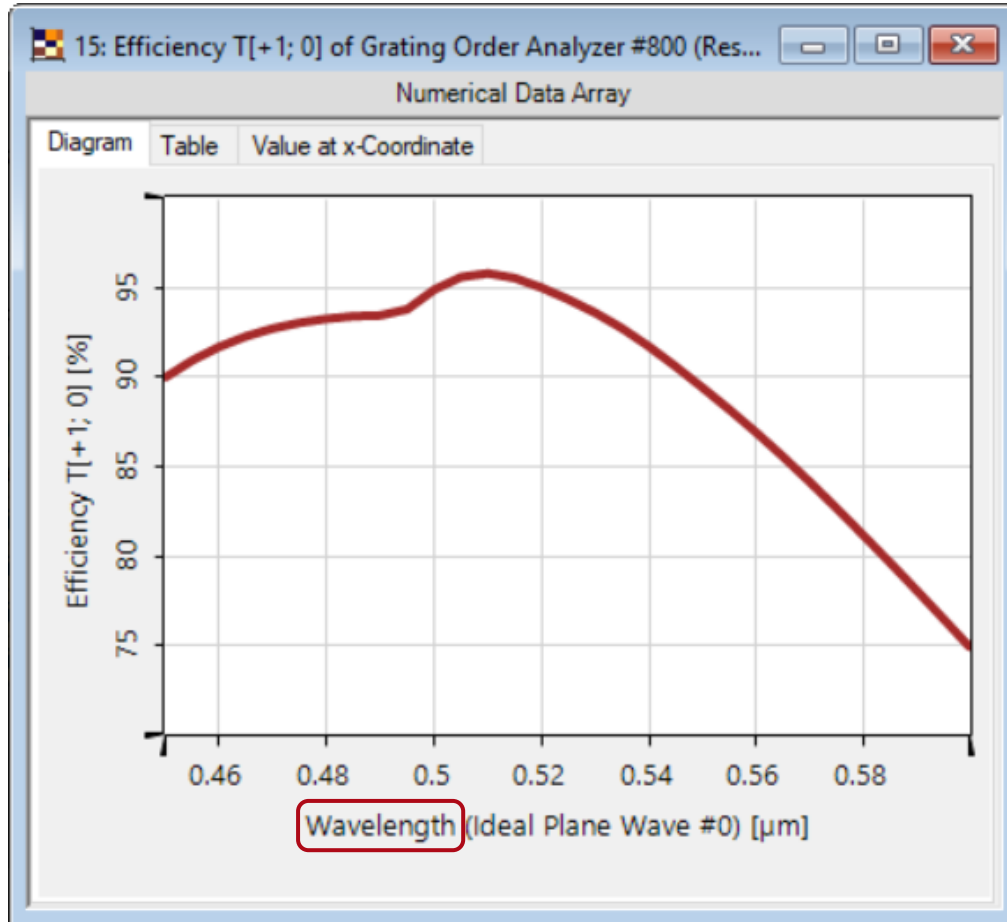
	angle	efficiency
0 th order	-26.107°	6.1579%
1 st order	9.6014°	93.266%
2 nd order	50.682°	0.57293%

order collection

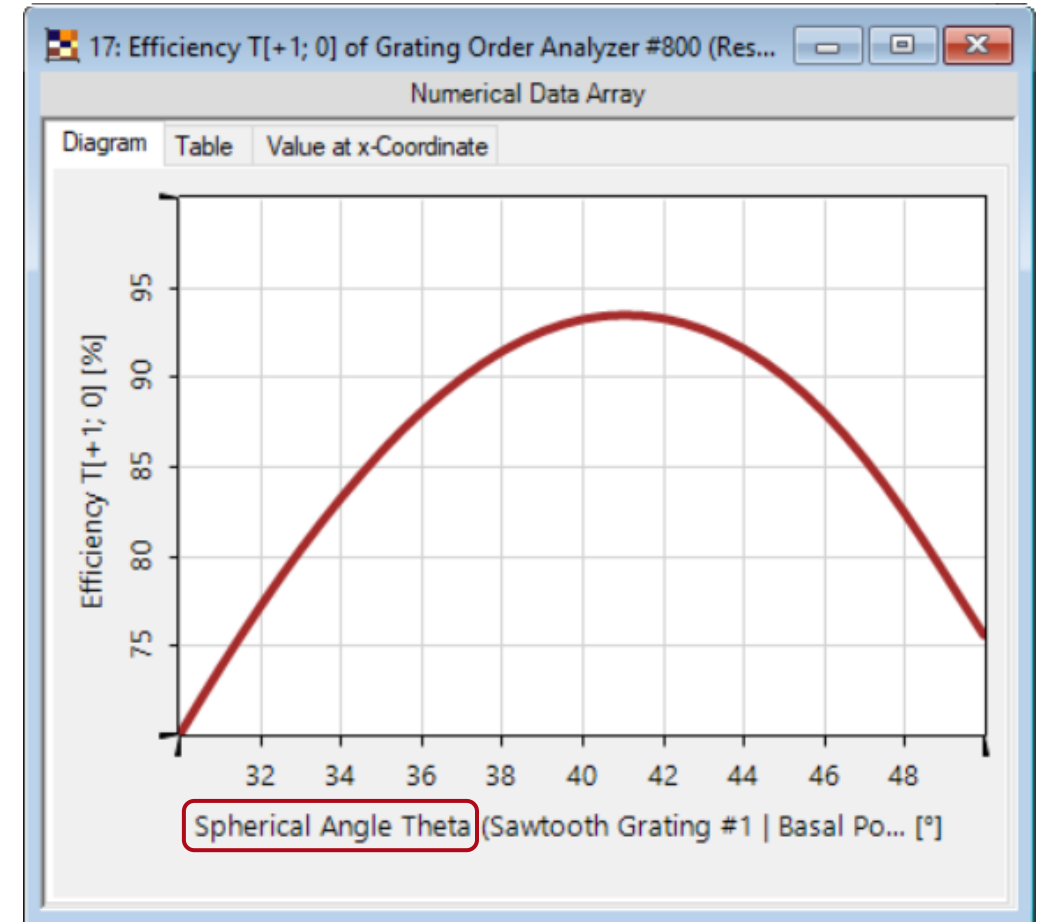
display of efficiency or other quantity with respect to e.g. diffraction order, angle, etc.



Parameter Scanning (1D)

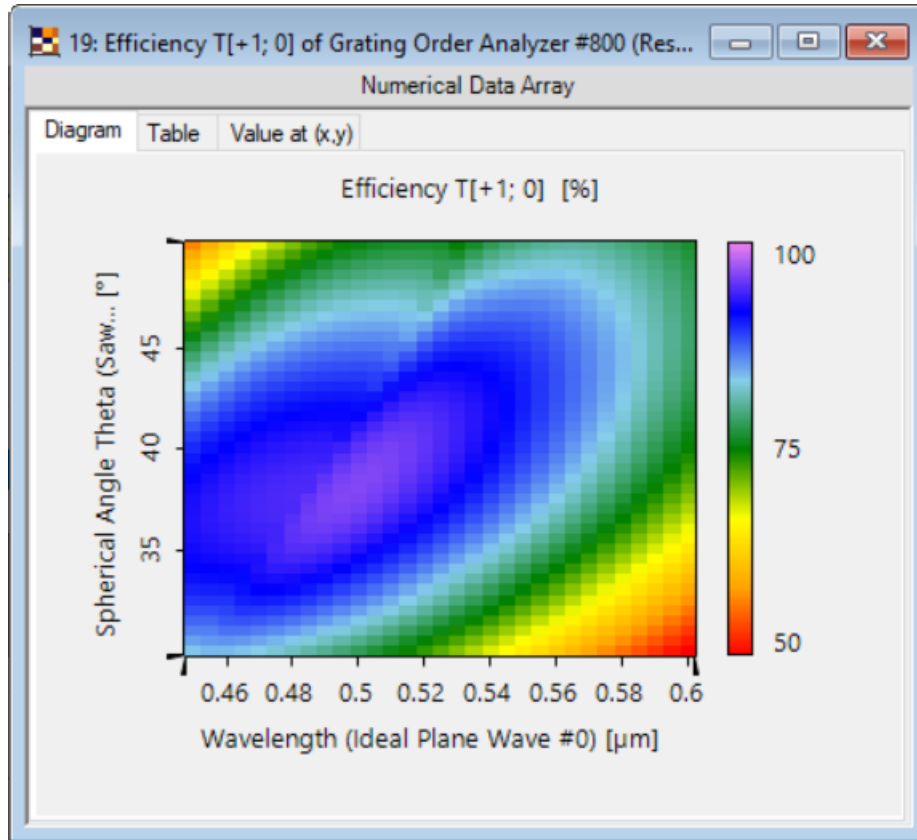


parameter variation (@ $\theta = 40^\circ$)
- wavelength from 450nm to 600nm



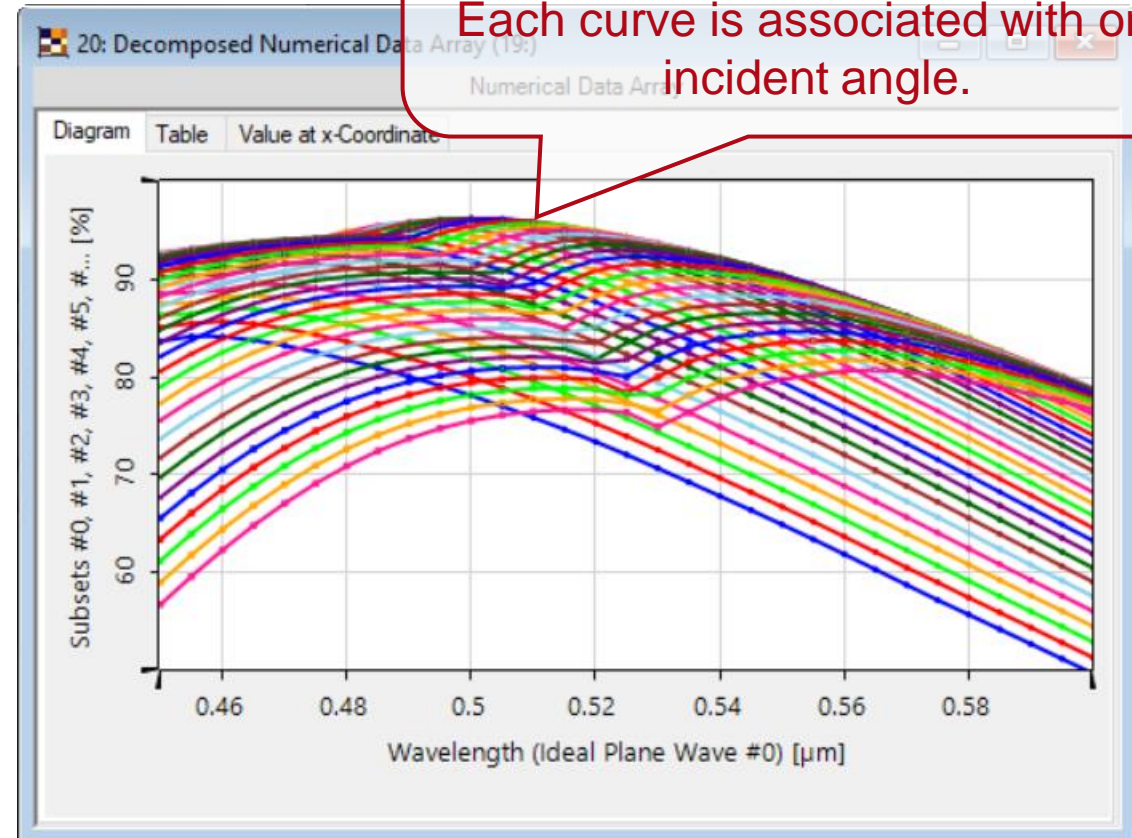
parameter variation (@ $\lambda = 532\text{nm}$)
- incidence angle theta from 30° to 50°

Parameter Scanning (2D)



parameter variation

- wavelength from 450nm to 600nm
- incidence angle theta from 30° to 50°

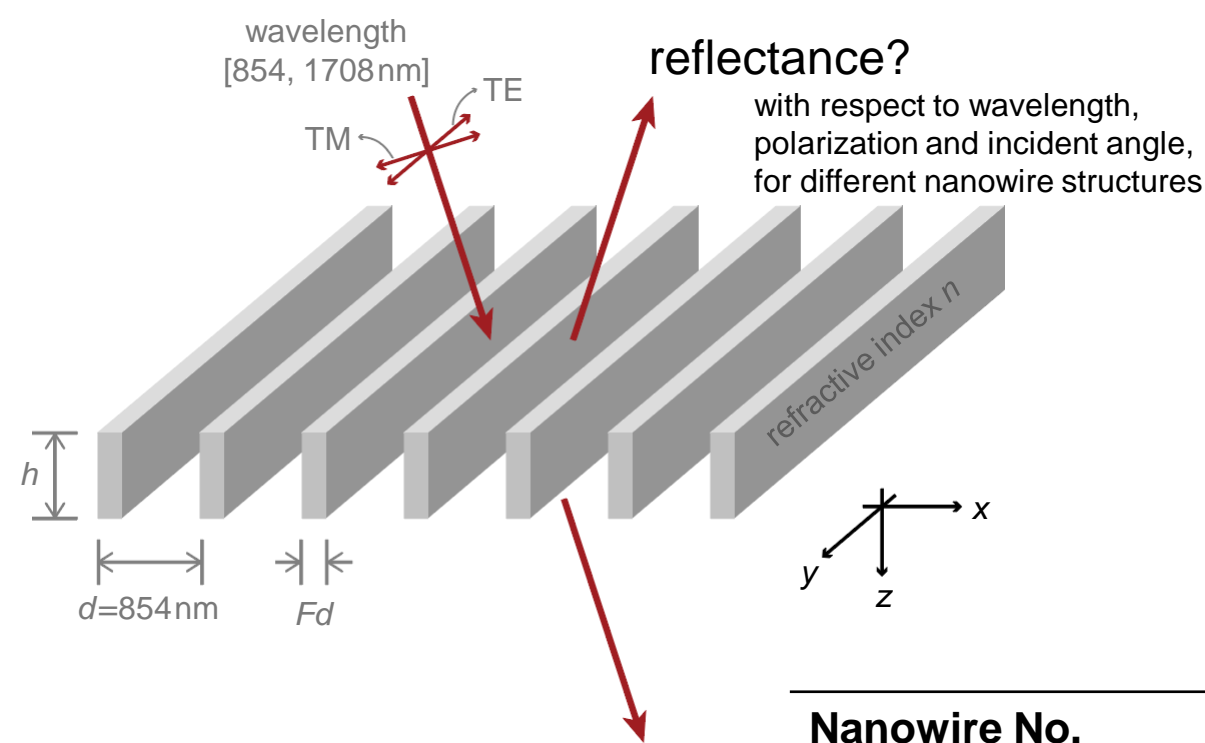


Document Information

title	Analysis of Blazed Grating by Fourier Modal Method
document code	GRT.0001
version	1.1
toolbox(es)	Grating Toolbox
VL version used for simulations	7.4.0.49
category	Feature Use Case
further reading	<ul style="list-style-type: none">- Grating Order Analyzer- Optimization of Lightguide Coupling Grating for Single Incidence Direction

Ultra-Sparse Dielectric Nano-Wire Grid Polarizers

Modeling Task

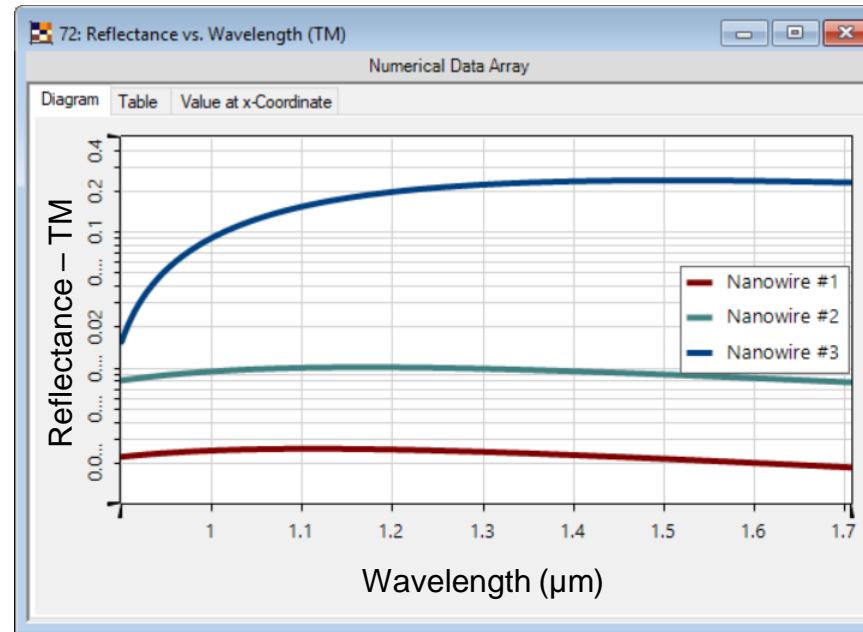
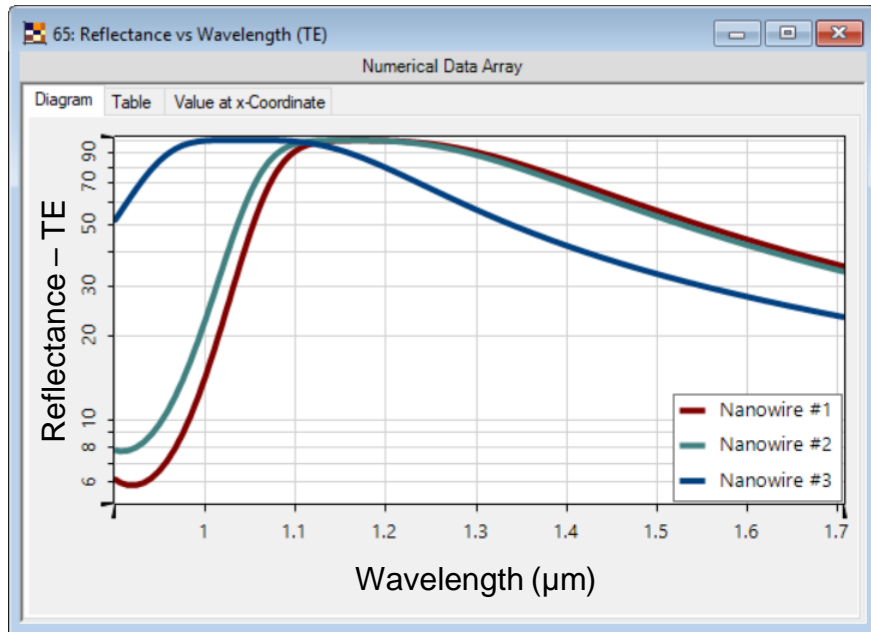


Nanowire No.	#1	#2	#3
refractive index n	10	7.07	3.16
height h	269nm	270nm	292nm
filling factor F	0.01	0.02	0.1

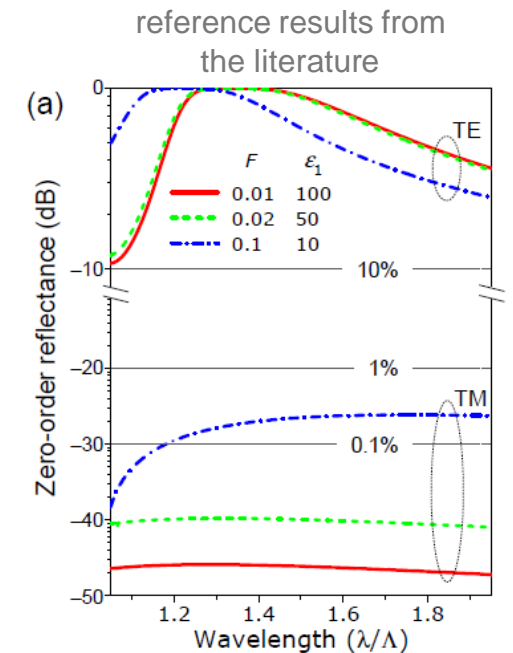
Parameters are taken from reference paper: J. W. Yoon *et al.*, Opt. Express **23**, 28849-28856 (2015).

Parameter Scanning (1D)

Fourier modal method (FMM) simulation in VirtualLab Fusion

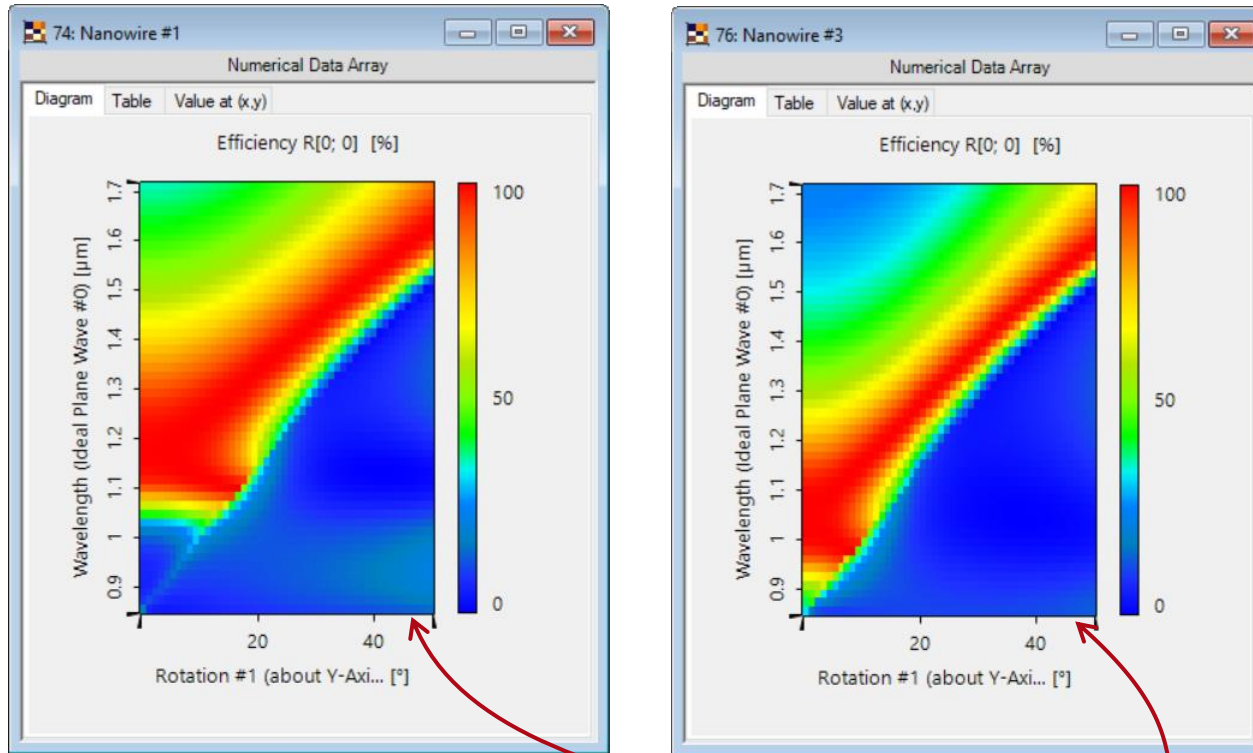


Nanowire No.	#1 —	#2 —	#3 —
refractive index n	10	7.07	3.16
height h	269nm	270nm	292nm
filling factor F	0.01	0.02	0.1

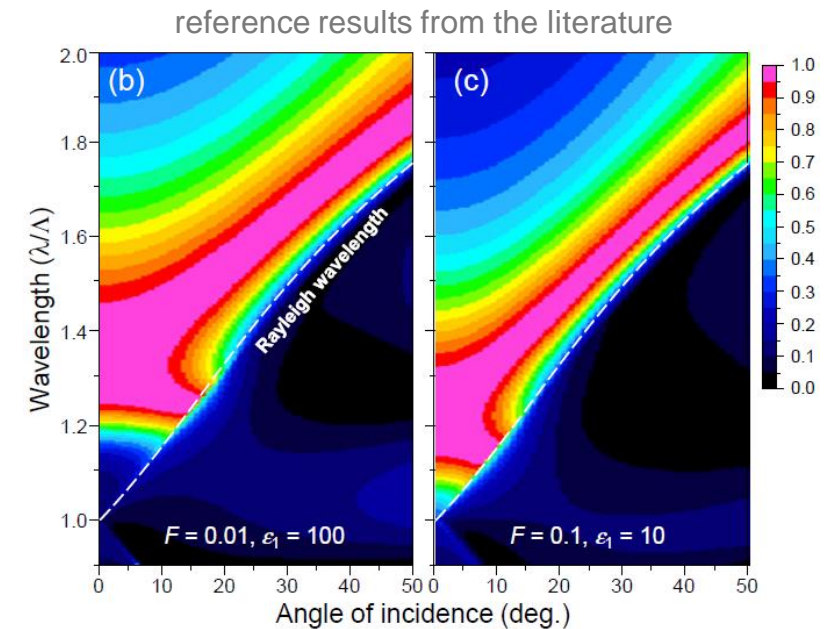


Parameter Scanning (2D)

Fourier modal method (FMM) simulation in VirtualLab Fusion, for TE polarization

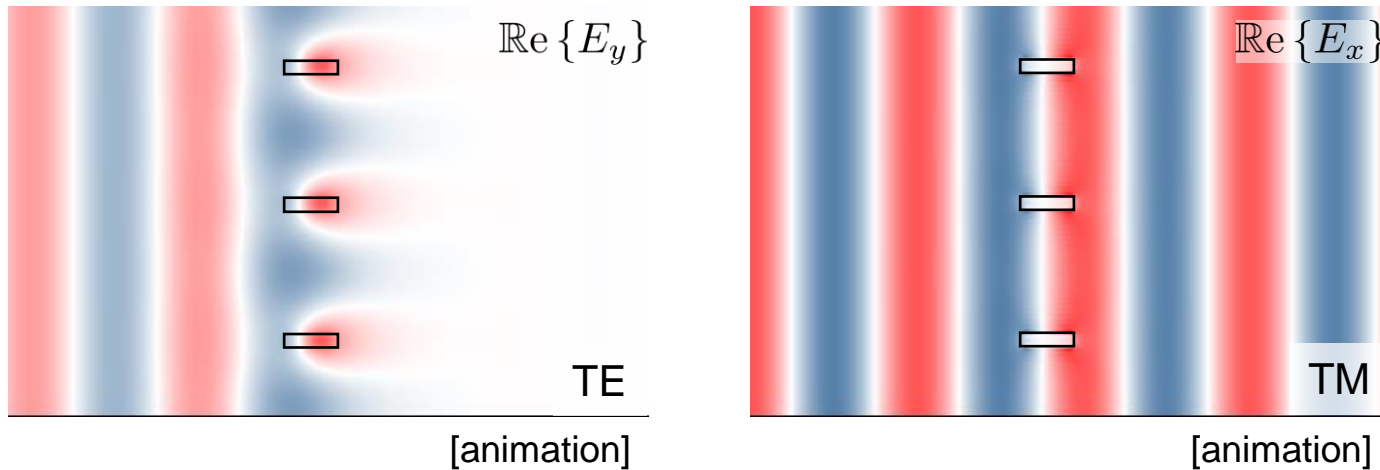


Nanowire No.	#1	#2	#3
refractive index n	10	7.07	3.16
height h	269nm	270nm	292nm
filling factor F	0.01	0.02	0.1

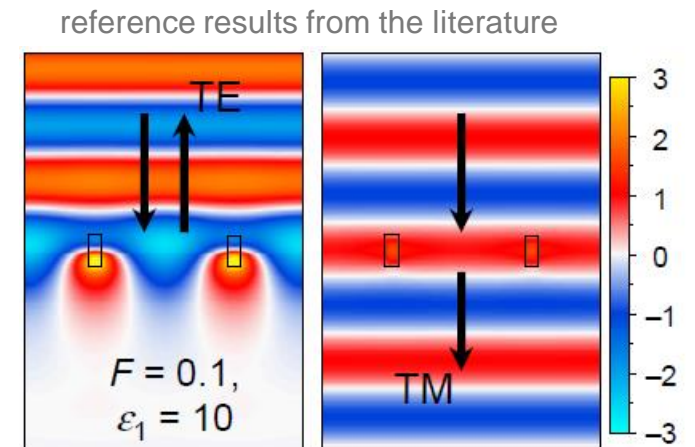


Visualization of Field Inside Grating

Fourier modal method (FMM) simulation in VirtualLab Fusion @1045nm

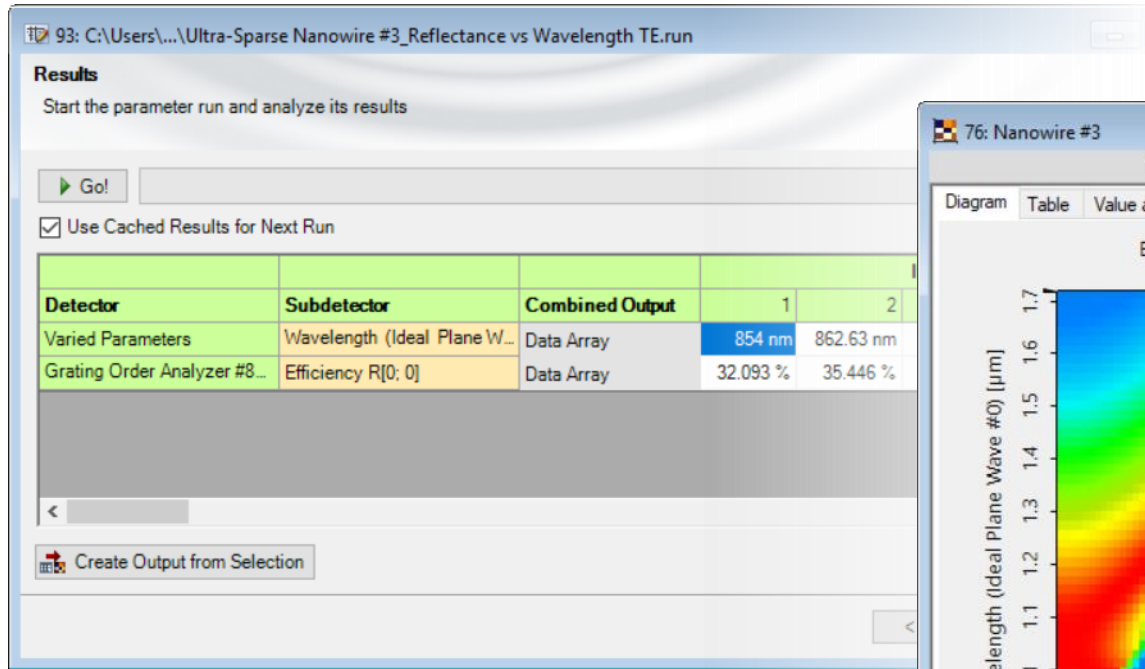


Nanowire No.	#1	#2	#3
refractive index n	10	7.07	3.16
height h	269nm	270nm	292nm
filling factor F	0.01	0.02	0.1

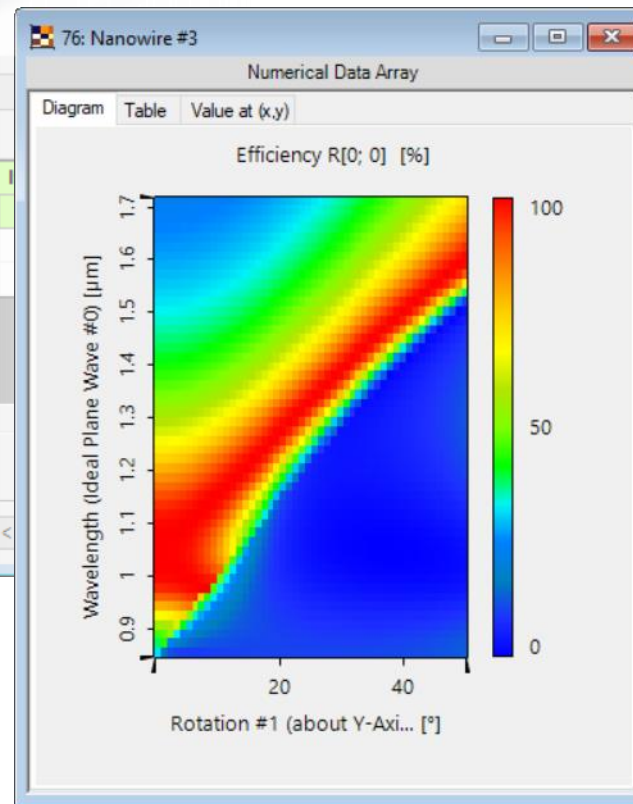


Peek into VirtualLab Fusion

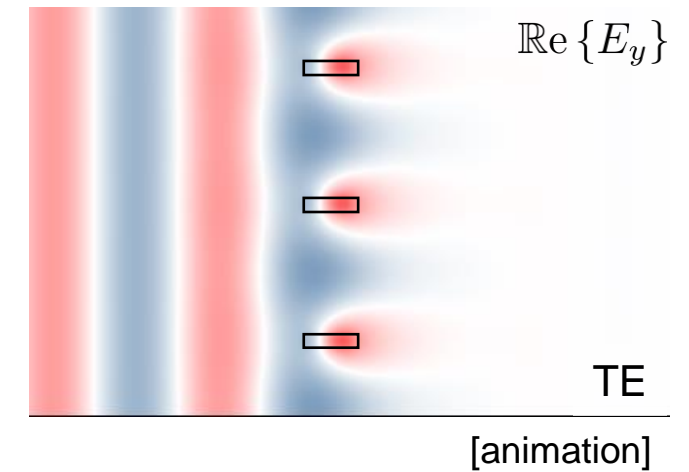
analysis of diffraction efficiency vs. specific parameter(s)



two-dimensional diffraction
efficiency analysis

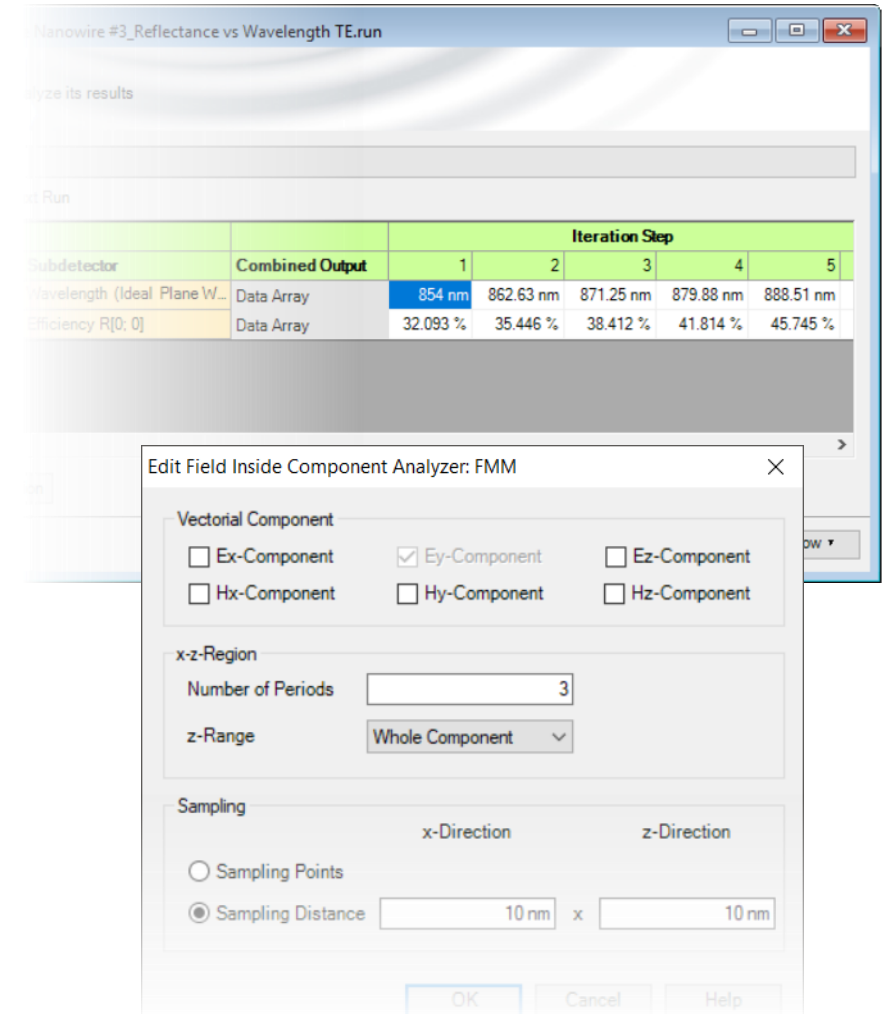


visualization of field inside grating



Workflow in VirtualLab Fusion

- Construct grating structure
 - [Configuration of Grating Structures by Using Interfaces](#) [Use Case]
 - [Configuration of Grating Structures by Using Special Media](#) [Use Case]
- Analyze grating diffraction efficiency
 - [Grating Order Analyzer](#) [Use Case]
- Check influence from different parameters with Parameter Run
 - [Usage of the Parameter Run Document](#) [Use Case]
- Calculate field inside grating structure



Document Information

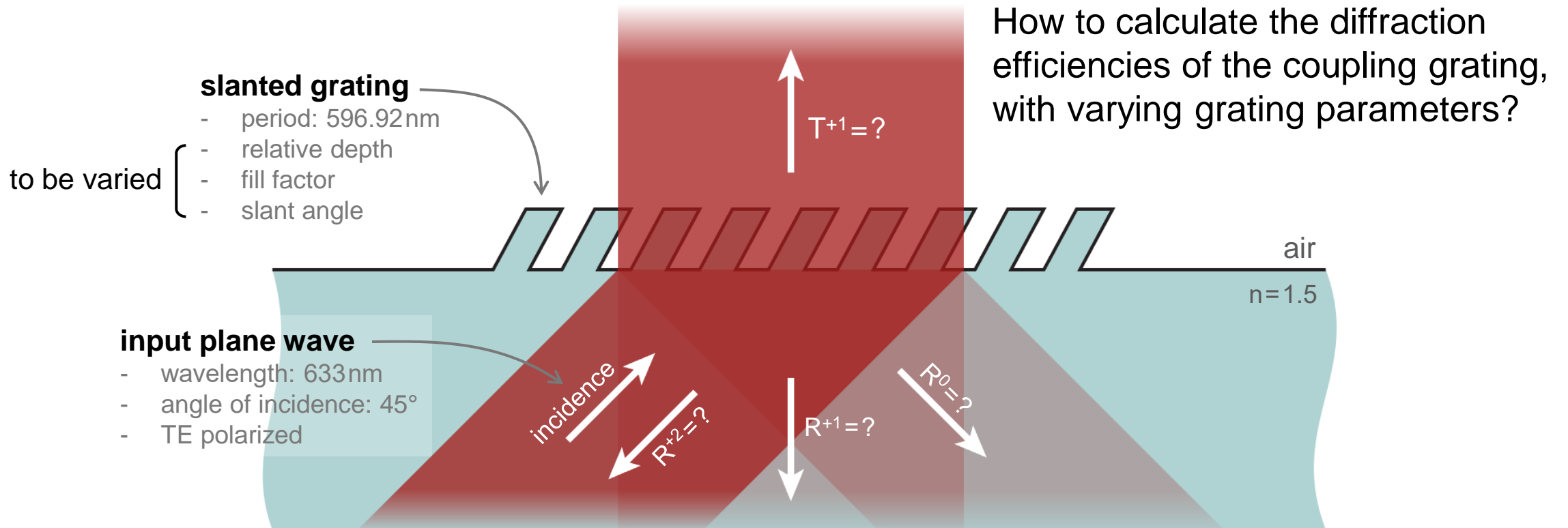
title	Ultra-Sparse Dielectric Nano-Wire Grid Polarizers
document code	GRT.0006
version	2.0
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.202)
category	Application Use Case
further reading	<ul style="list-style-type: none">- Grating order analyzer- Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures- Rigorous Analysis of Nanopillar Metasurface Building Block

Part II

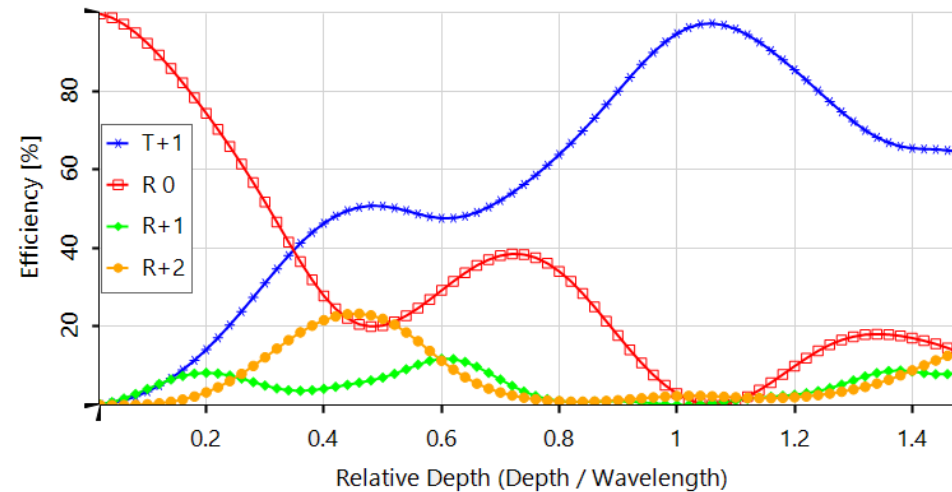
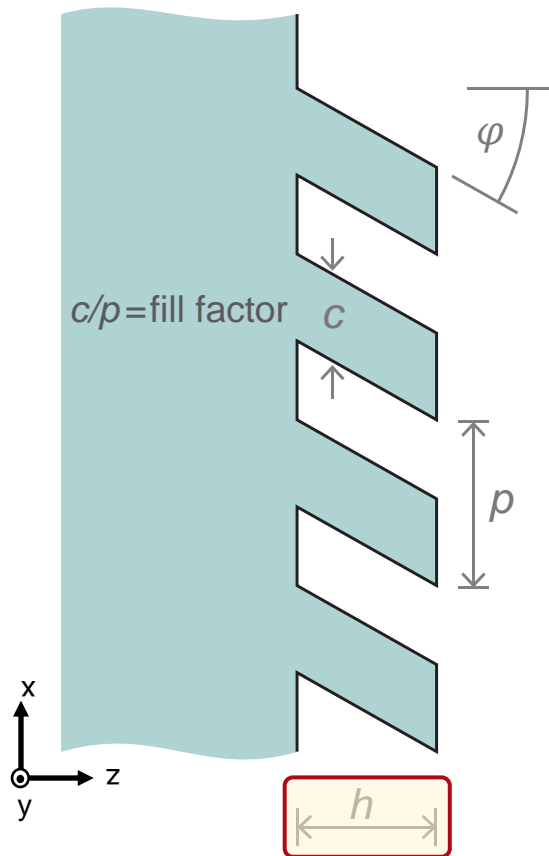
- Slanted gratings simulation with varying parameters
- Volume holographic gratings and their sensitivity
- Diffraction property of a passive parity-time (PT) grating
- Analysis of CMOS sensors with microlens array
- Angular-filter volume grating for higher diffraction order suppression
- Resonant waveguide grating and its angular/spectral property
- Using gratings as test objects in imaging system

Analysis of Slanted Gratings for Lightguide Coupling

Modeling Task



Diffraction Efficiency vs. Relative Depth



Grating Parameter	Value & Unit
relative depth	to be varied
slant angle ϕ	-30°
fill factor c/p	50%

simulation by Fourier modal method (FMM), also known as RCWA, in VirtualLab Fusion

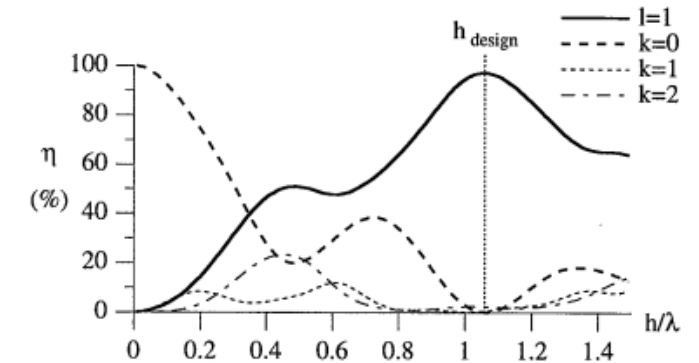
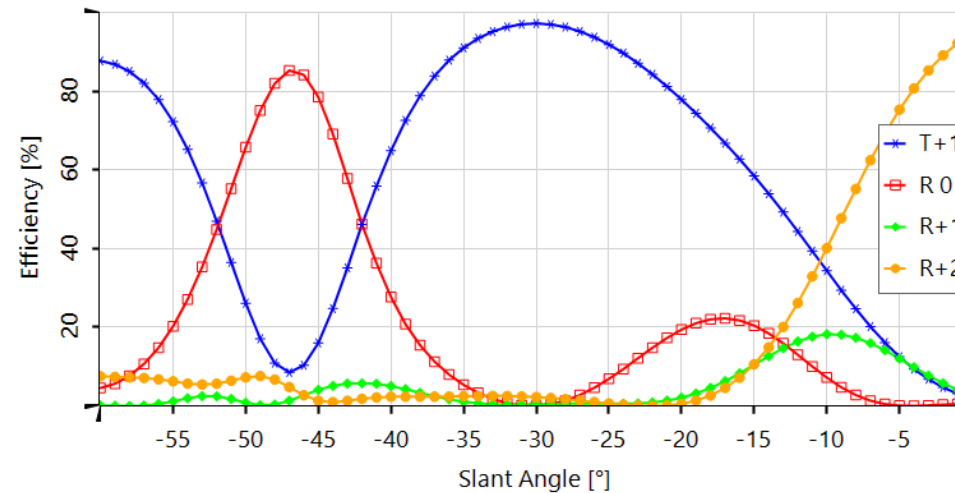
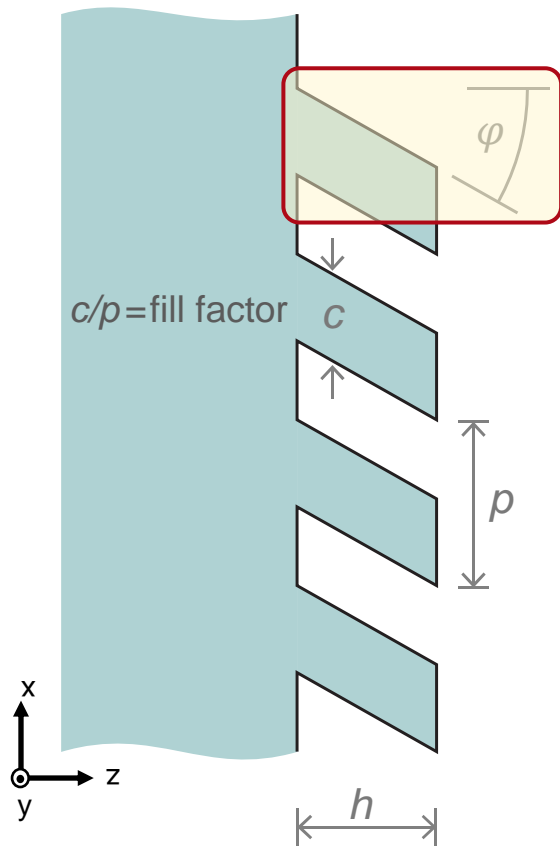


Figure from J. Michael Miller, *et al.*, Appl. Opt. 36, 5717-5727 (1997)

Diffraction Efficiency vs. Slant Angle



Grating Parameter	Value & Unit
relative depth	1.058λ
slant angle ϕ	to be varied
fill factor c/p	50%

simulation by Fourier modal method (FMM), also known as RCWA, in VirtualLab Fusion

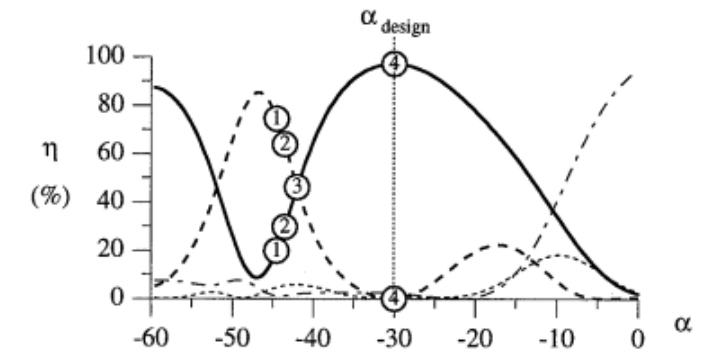
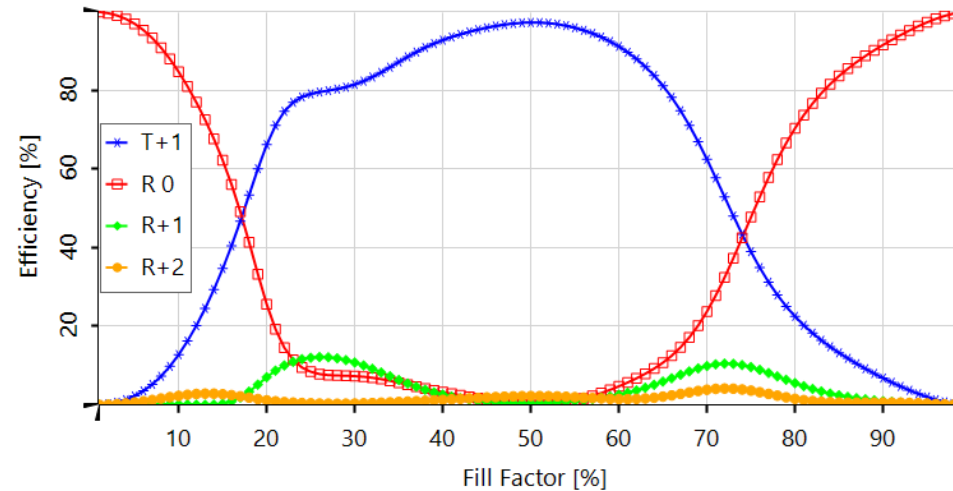
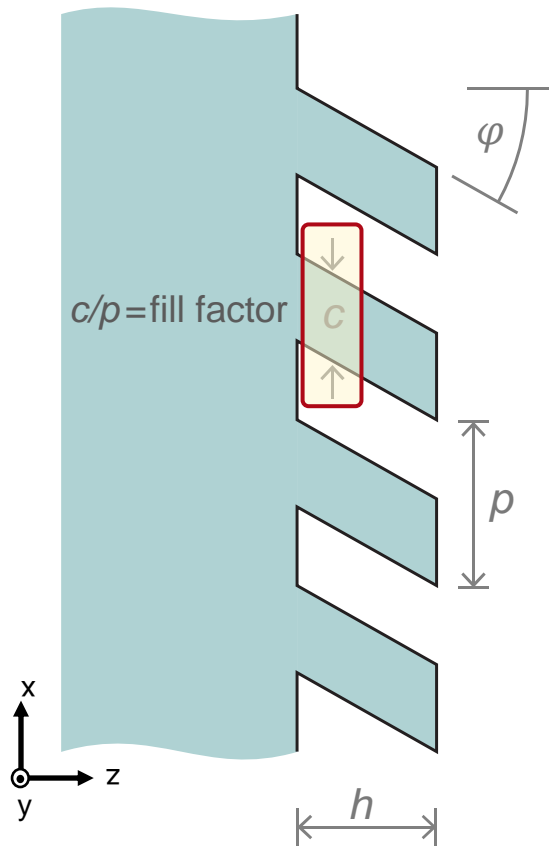


Figure from J. Michael Miller, *et al.*, Appl. Opt. 36, 5717-5727 (1997)

Diffraction Efficiency vs. Fill Factor



simulation by Fourier modal method (FMM), also known as RCWA, in VirtualLab Fusion

Grating Parameter	Value & Unit
relative depth	1.058λ
slant angle φ	-30°
fill factor c/p	to be varied

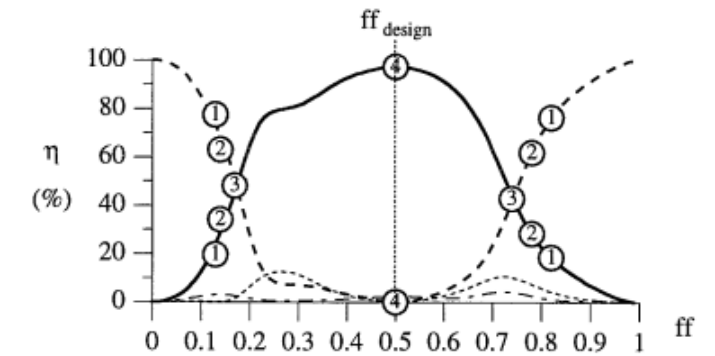
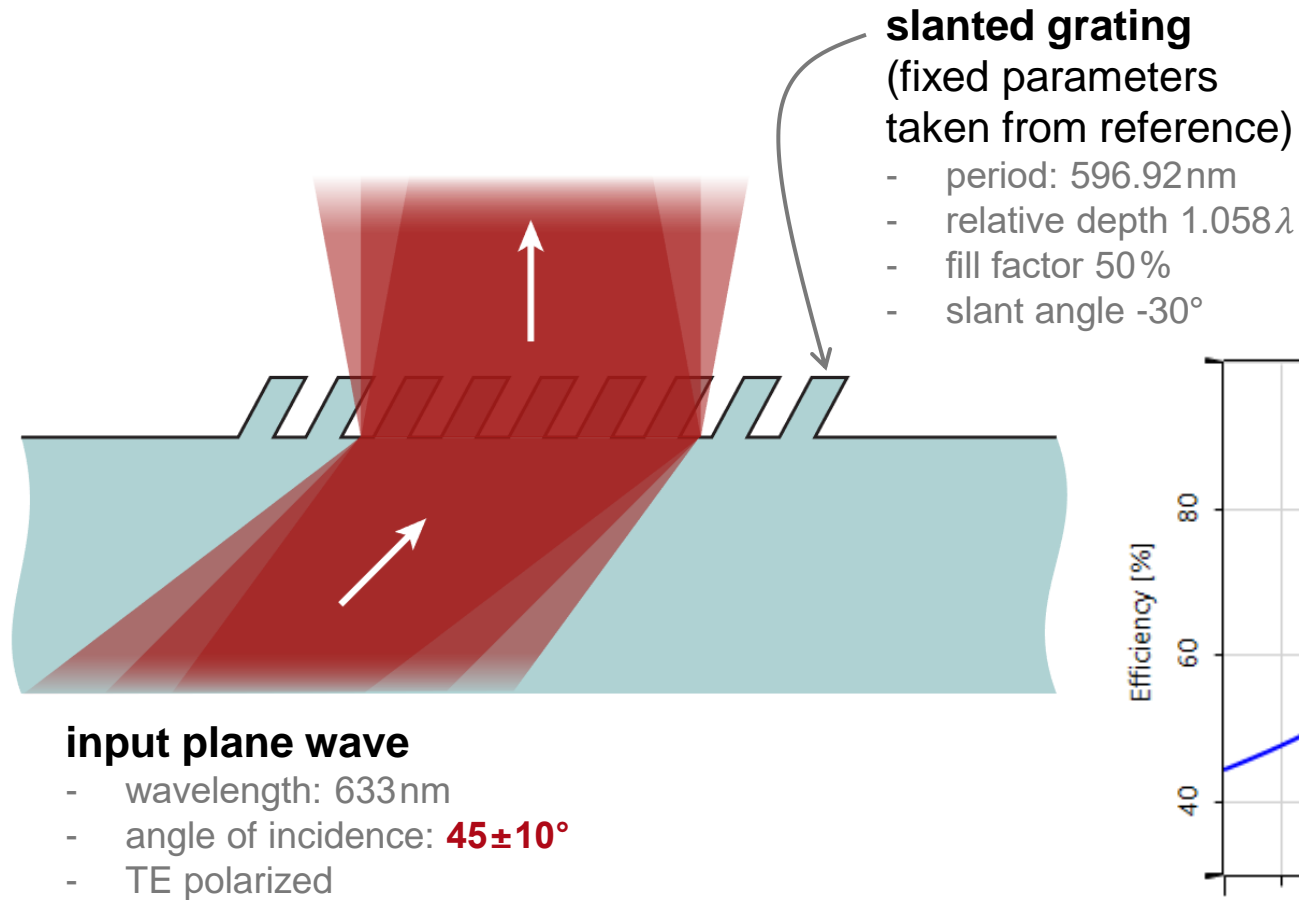
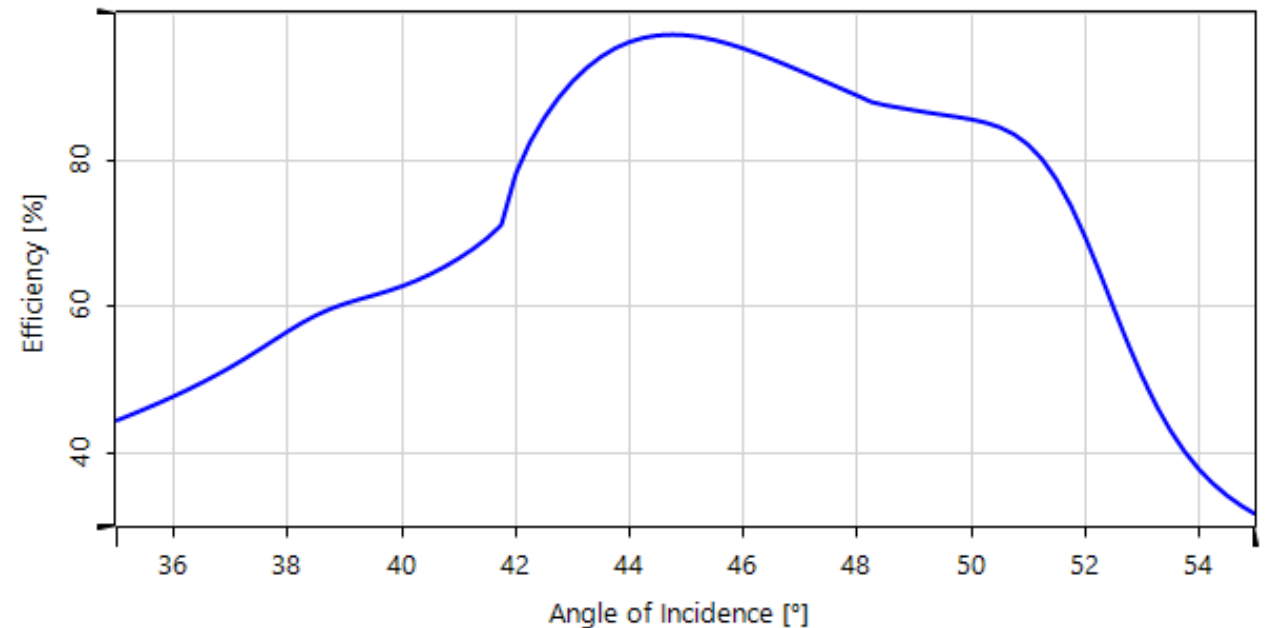


Figure from J. Michael Miller, *et al.*, Appl. Opt. 36, 5717-5727 (1997)

Diffraction Efficiency vs. Angle of Incidence

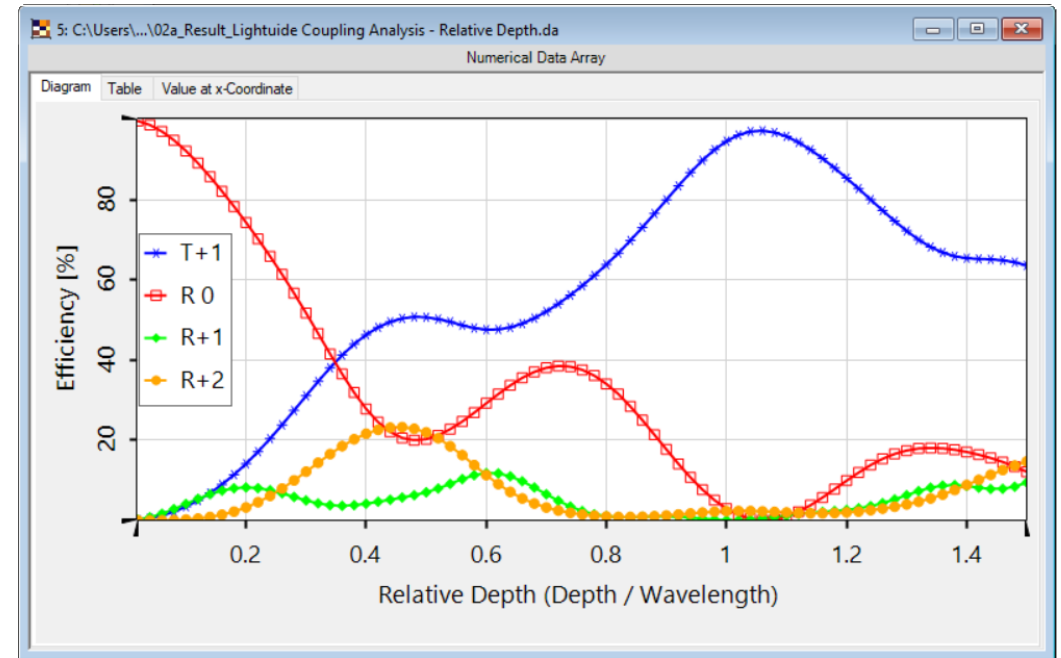
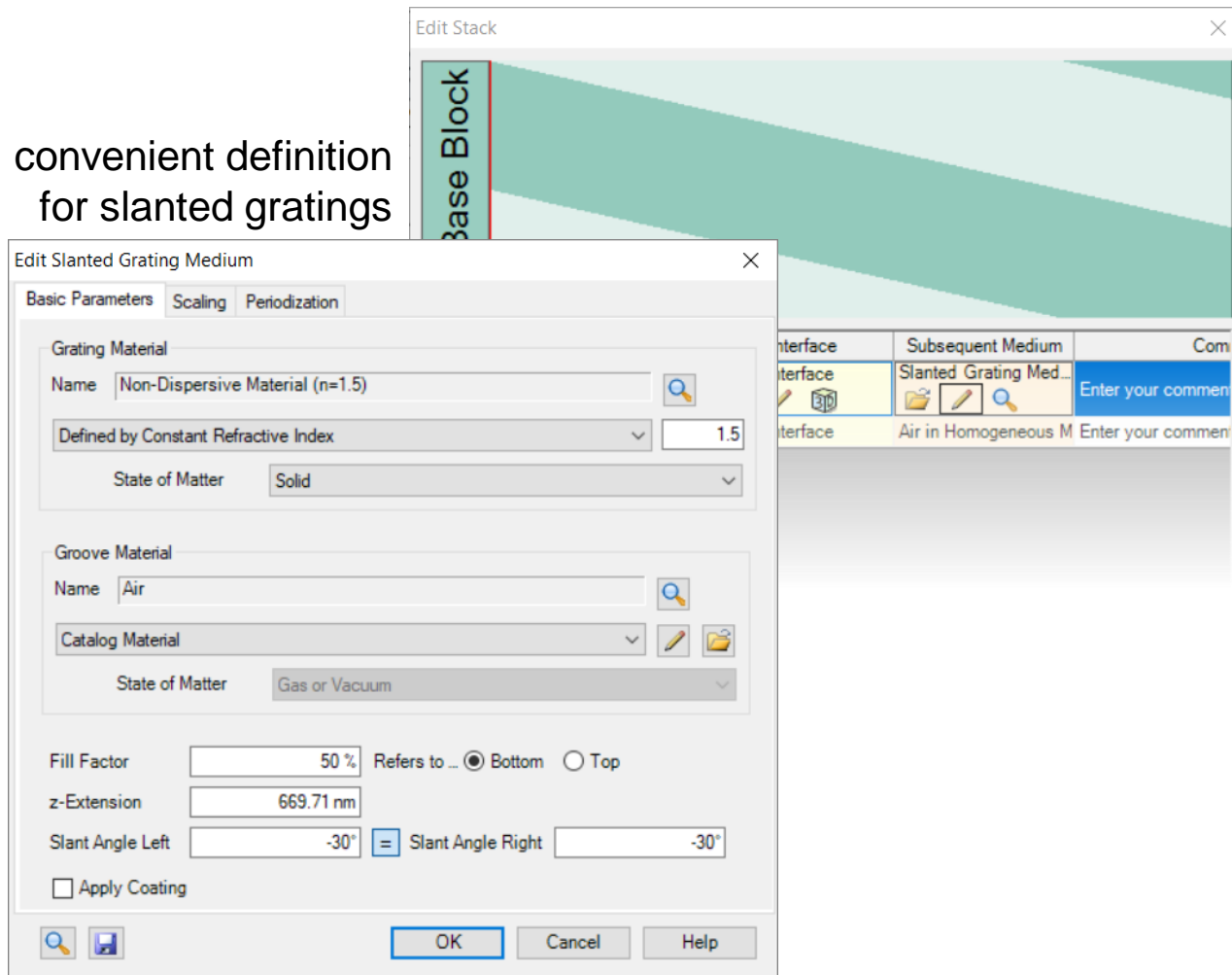


Grating diffraction efficiency is usually sensitive to the angle of incidence.



Peek into VirtualLab Fusion

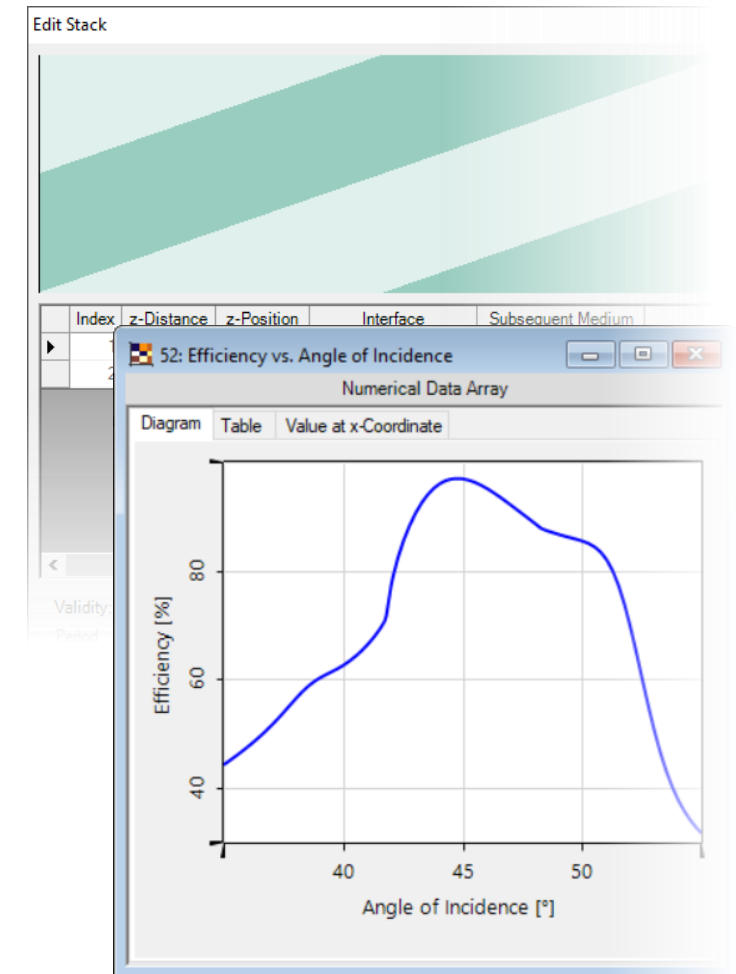
convenient definition
for slanted gratings



rigorous diffraction efficiency calculation and visualization

Workflow in VirtualLab Fusion

- Configuration of lightguide coupling grating structure
 - [Advanced Configuration of Slanted Grating](#) [Use Case]
 - [Configuration of Grating Structures by Using Special Media](#) [Use Case]
 - [Configuration of Grating Structures by Using Interfaces](#) [Use Case]
- Analyze coupling grating diffraction efficiency
 - [Customized Detector for Lightguide Coupling Grating Evaluation](#) [Use Case]
- Check efficiency by scanning over specific parameter
 - [Usage of Parameter Run](#) [Use Case]

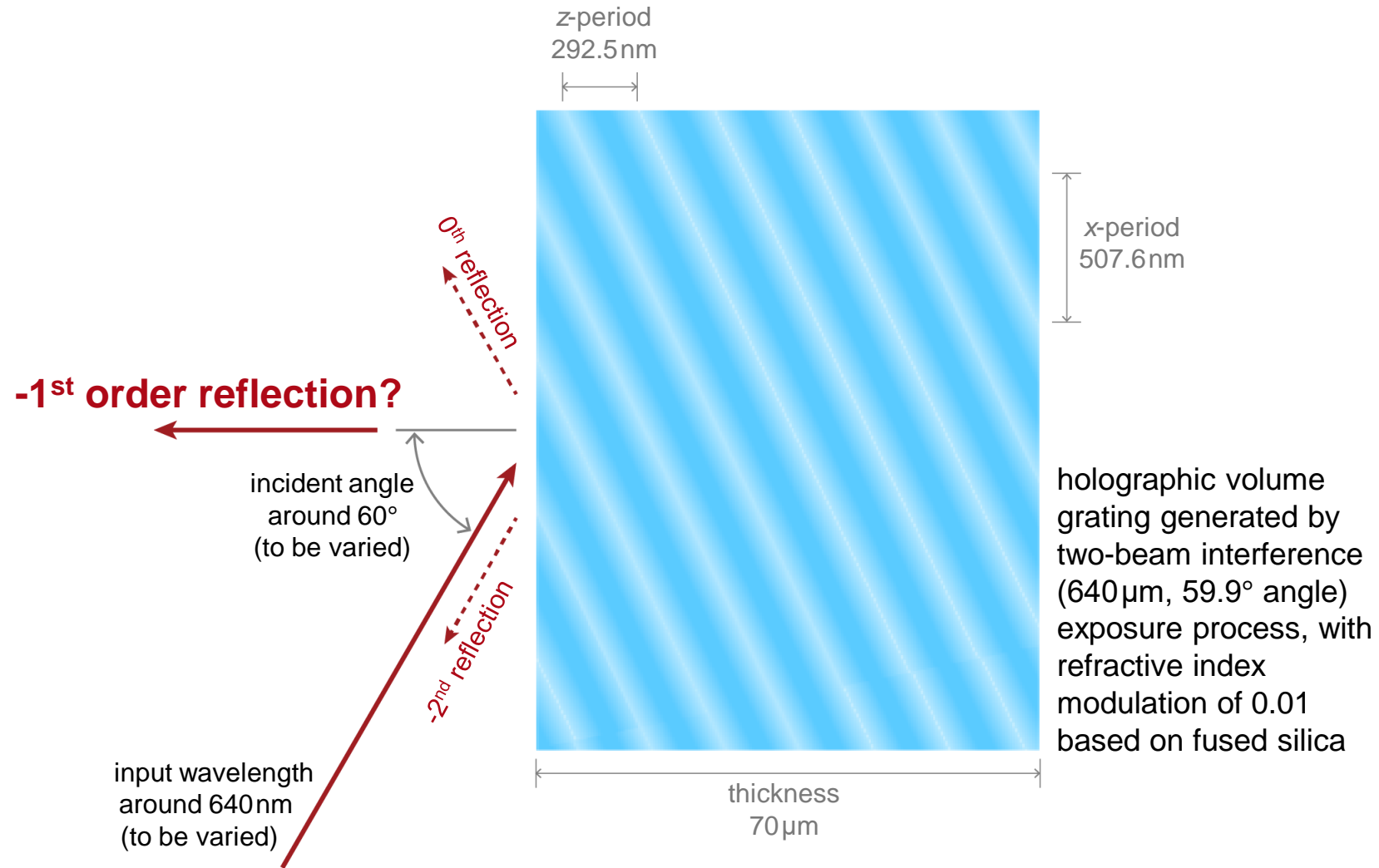


Document Information

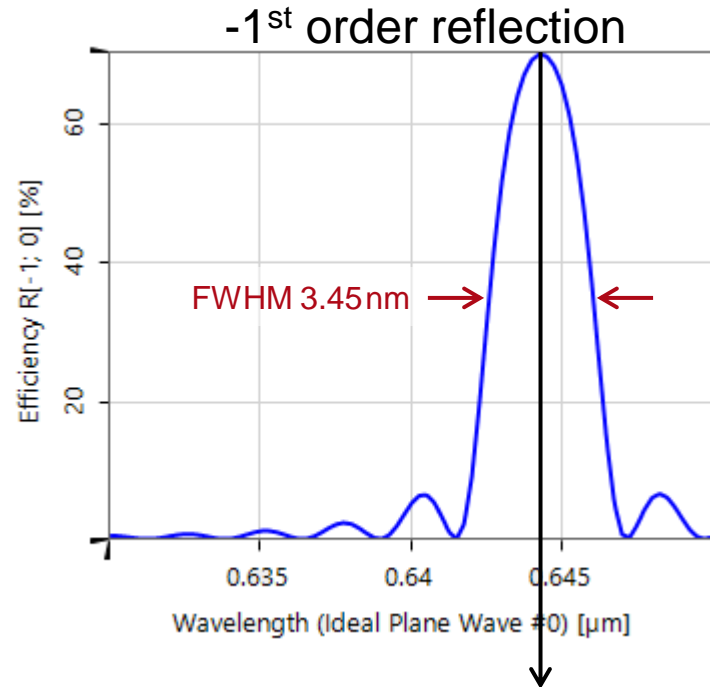
title	Analysis of Slanted Gratings for Lightguide Coupling
document code	GRT.0009
version	2.0
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.202)
category	Application Use Case
further reading	<ul style="list-style-type: none">- <u>Parametric Optimization and Tolerance Analysis of Slanted Gratings</u>- <u>Configuration of Grating Structures by Using Special Media</u>

Rigorous Simulation of Holographic Generated Volume Grating

Modeling Task

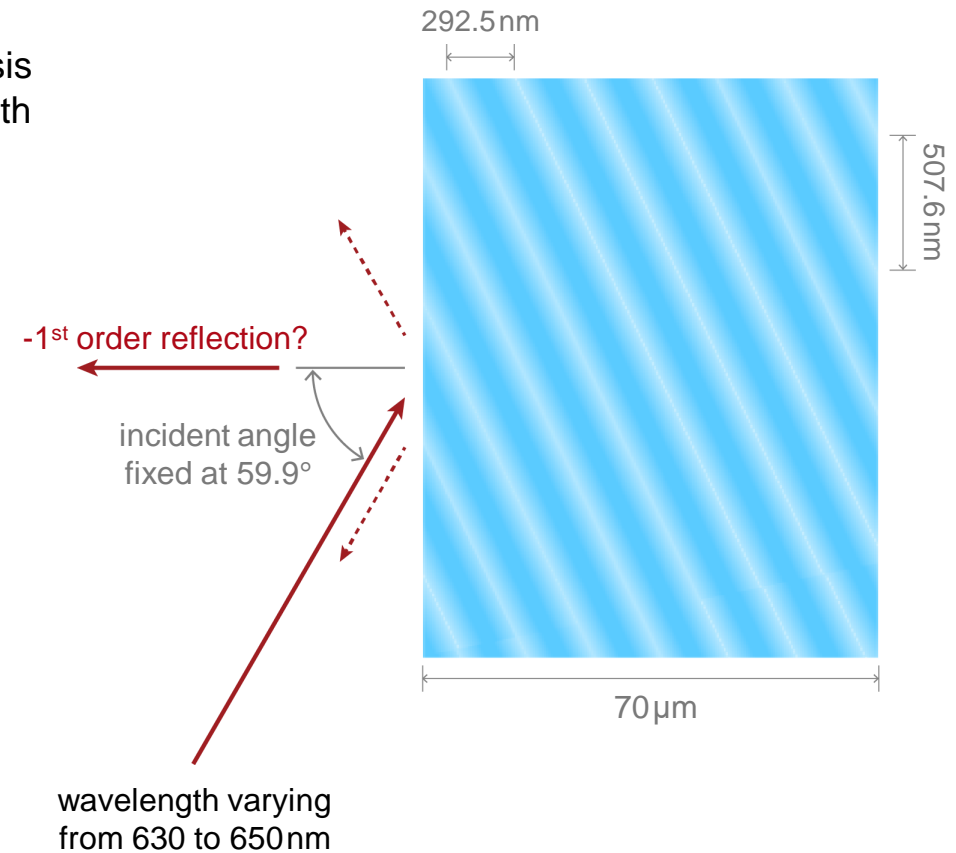


Diffraction Efficiency vs. Wavelength

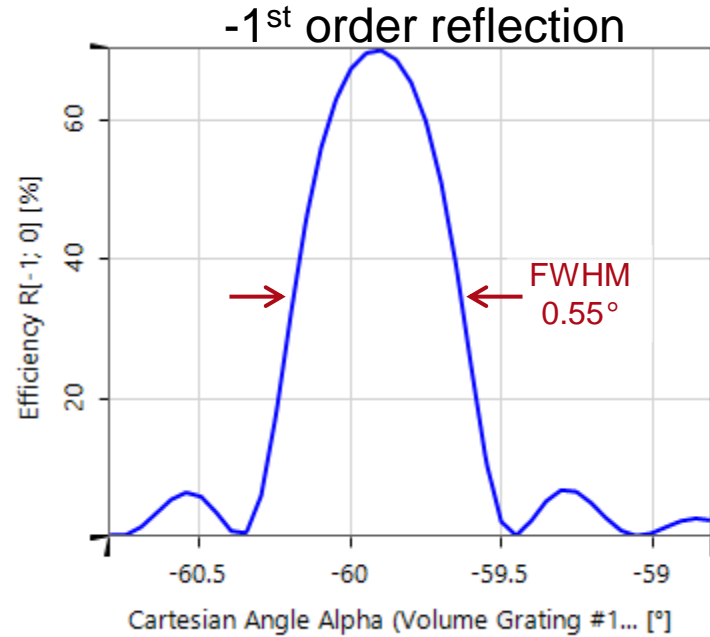


shift of wavelength dependent reflection due to locally increased effective refraction index

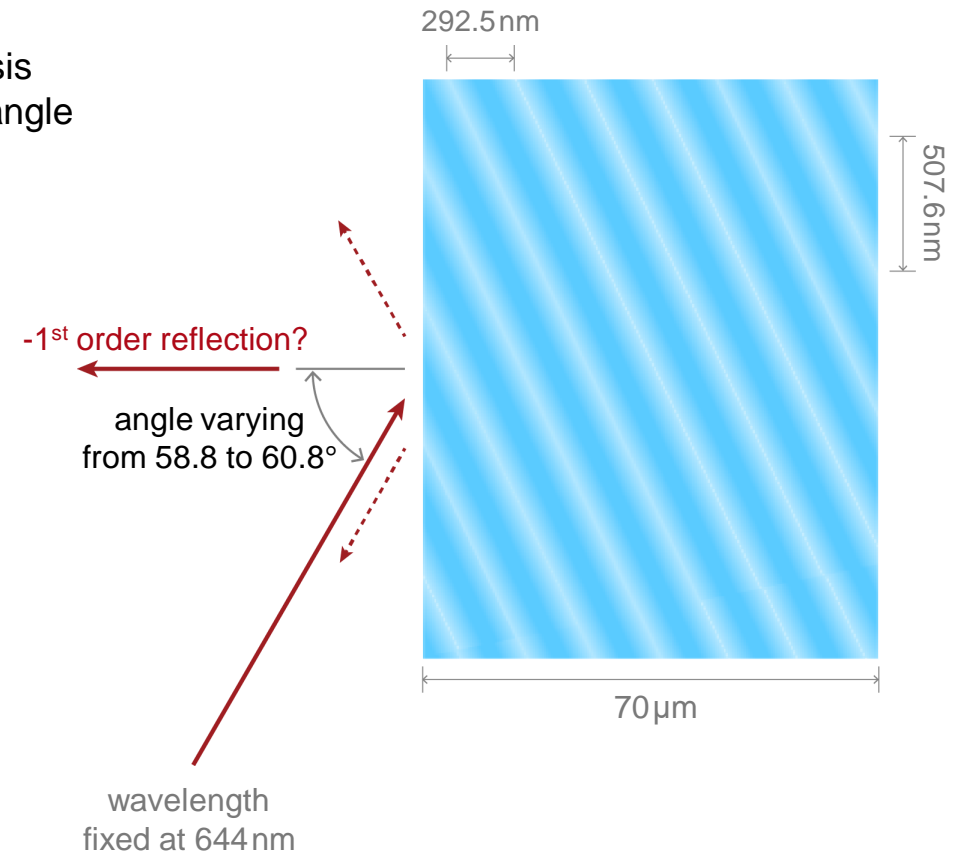
rigorous FMM analysis for varying wavelength



Diffraction Efficiency vs. Angle of Incidence



rigorous FMM analysis
for varying incident angle



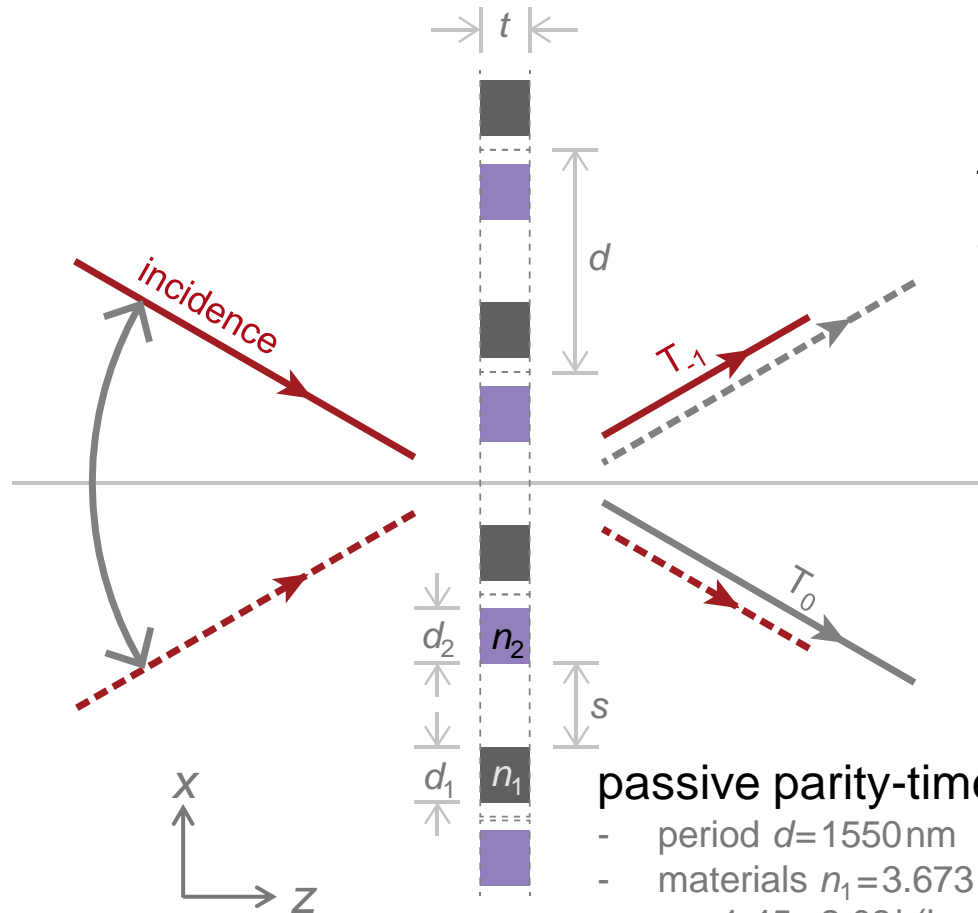
Document Information

title	Rigorous Simulation of Holographic Generated Volume Grating
document code	GRT.0003
version	1.1
toolbox(es)	Grating Toolbox
VL version used for simulations	7.5.0.158
category	Application Use Case
further reading	- <u>Configuration of Grating Structures by Using Special Media</u>

Diffraction Property of a Passive Parity-Time Grating

Modeling Task

- input plane wave
- wavelength 1550nm
 - polarization TM or TE
 - incidence angle varying from -89° to 89°

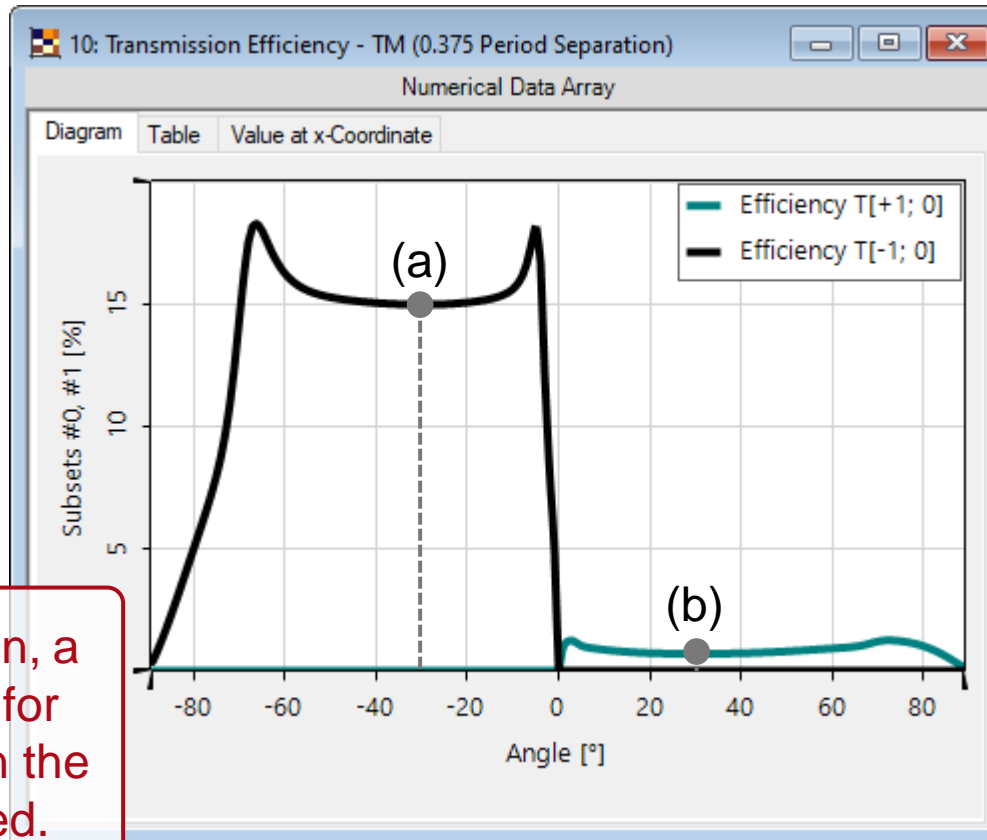
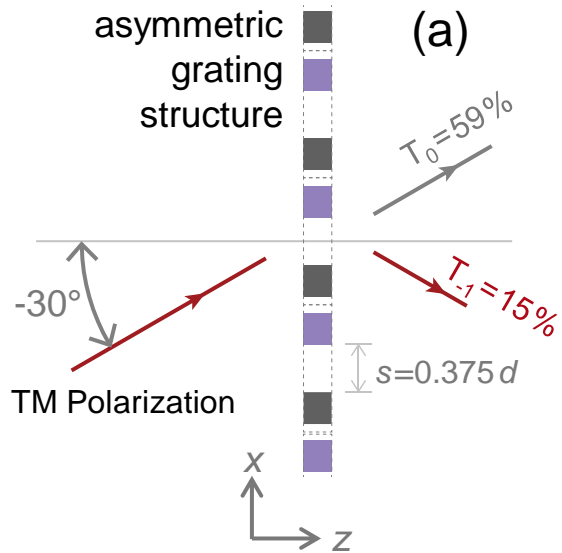


How does the diffraction property of the grating depends on the incidence angle, and the separation (s) between the grating stripes?

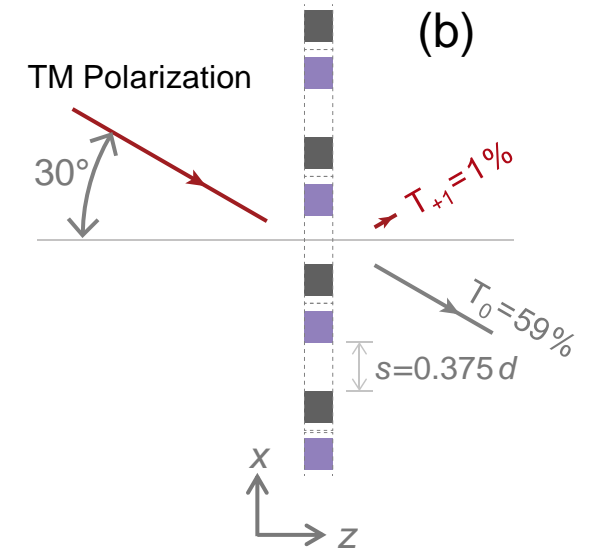
passive parity-time grating

- period $d=1550\text{nm}$
- materials $n_1=3.673$ (lossless), $n_2=1.45+2.03i$ (lossy)
- widths of stripes $d_1=d_2=0.25d$
- varying separation (s) between stripes

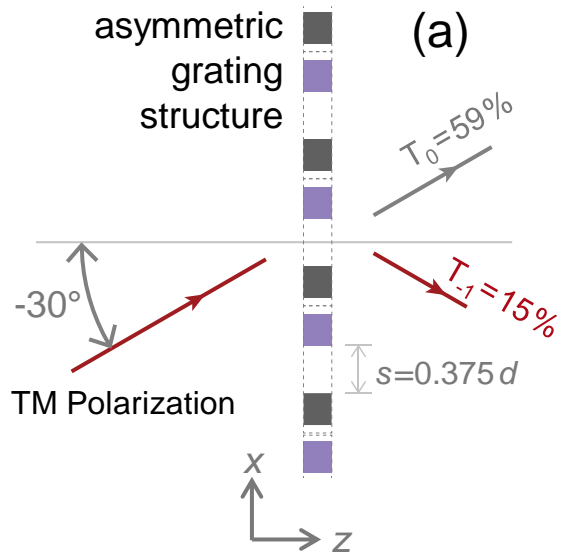
Stripe Separation ($s=0.375d$) – TM Polarization



With proper stripe separation, a clear contrast can be seen for the diffraction behavior when the incidence direction is flipped.



Stripe Separation ($s=0.375d$) – TM Polarization



With proper stripe separation, a clear contrast can be seen for the diffraction behavior when the incidence direction is flipped.

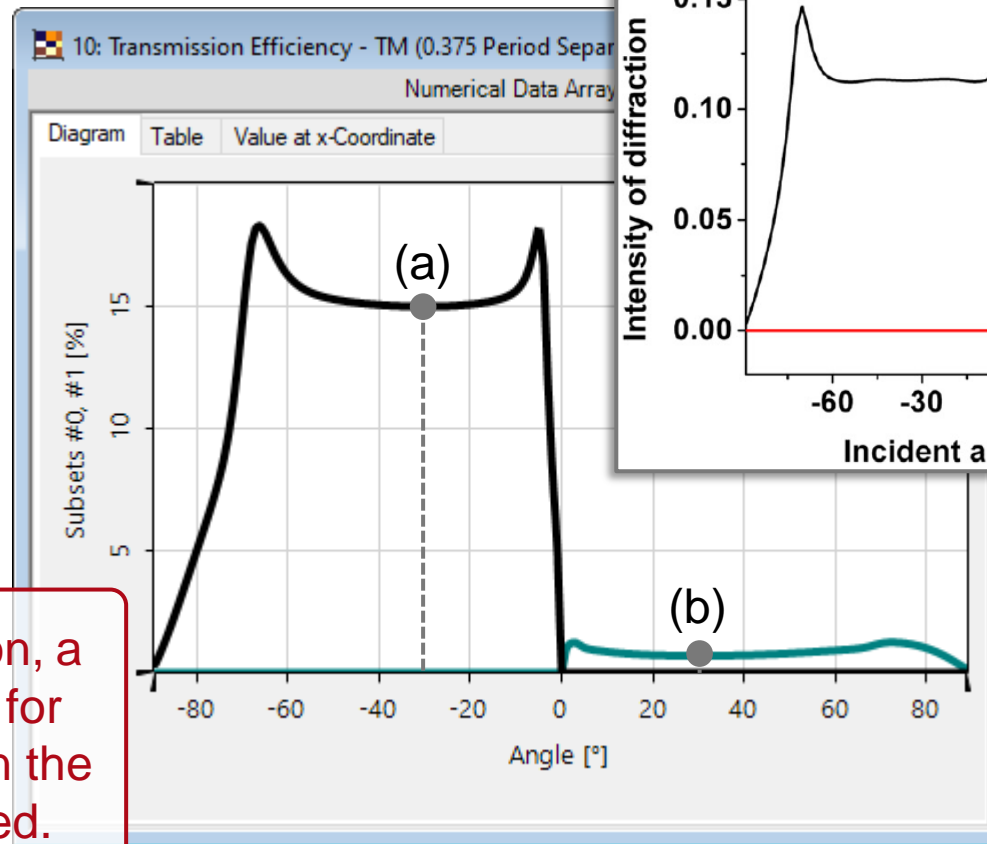
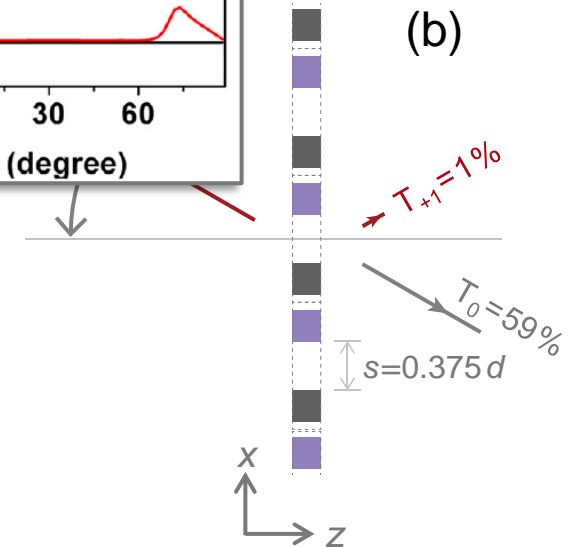
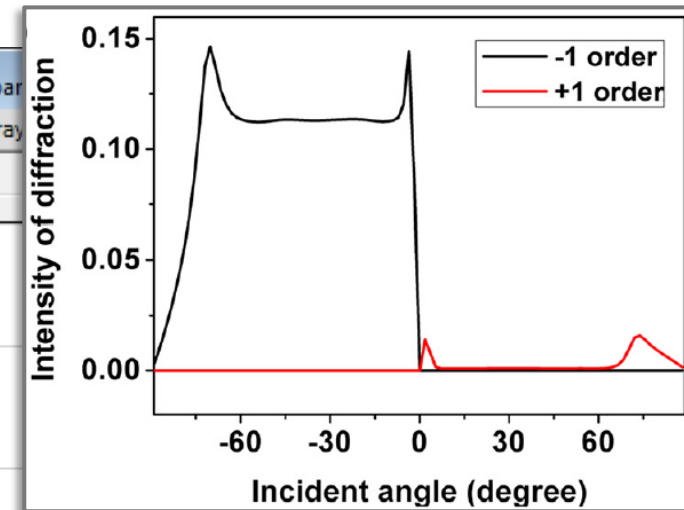
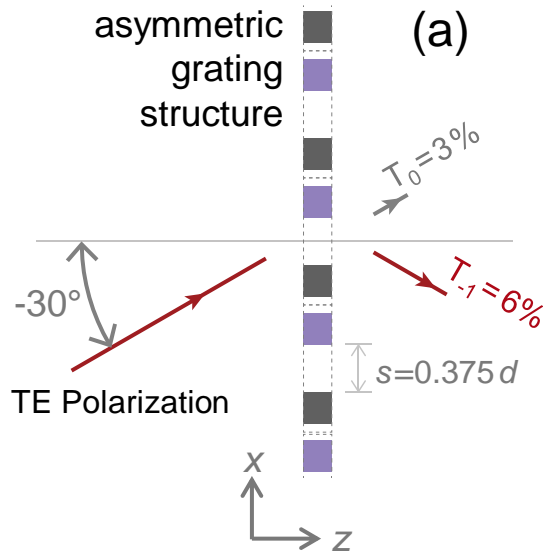


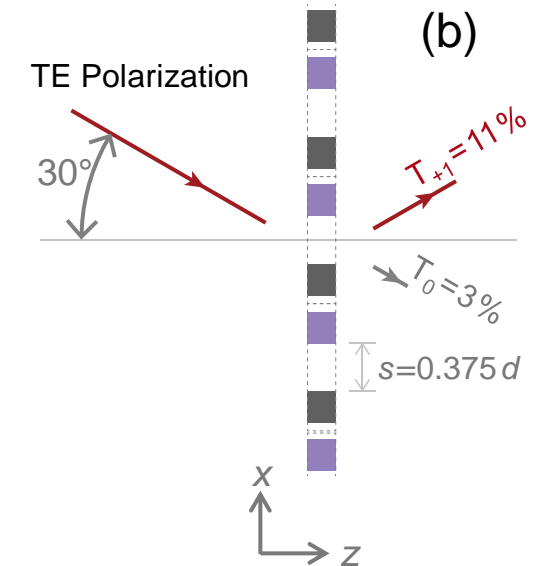
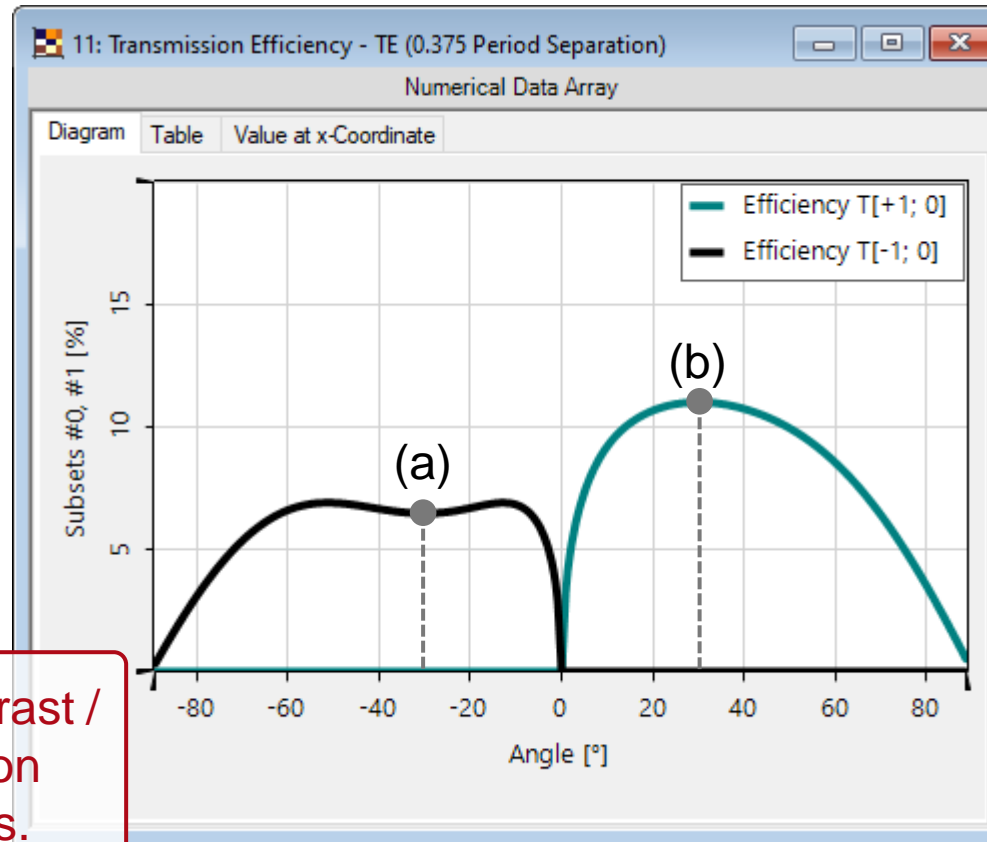
Fig.5(b) from X. Zhu, *et al.*,
Appl. Phys. Lett. 109, 111101 (2016)



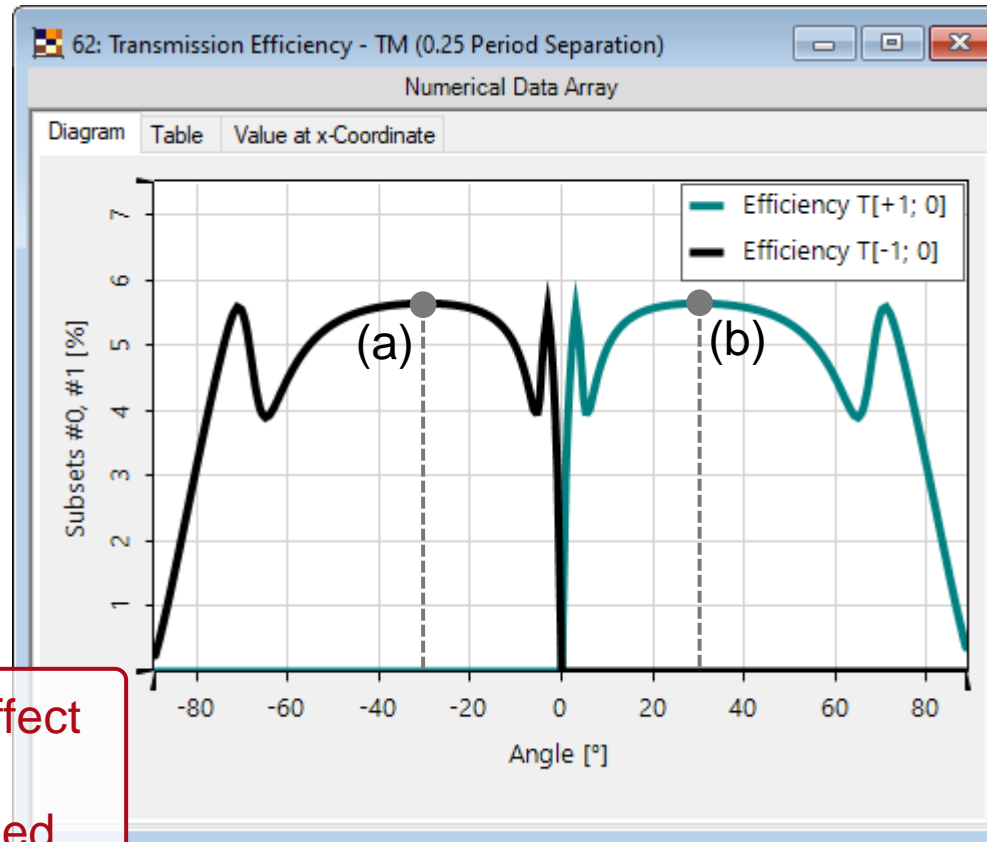
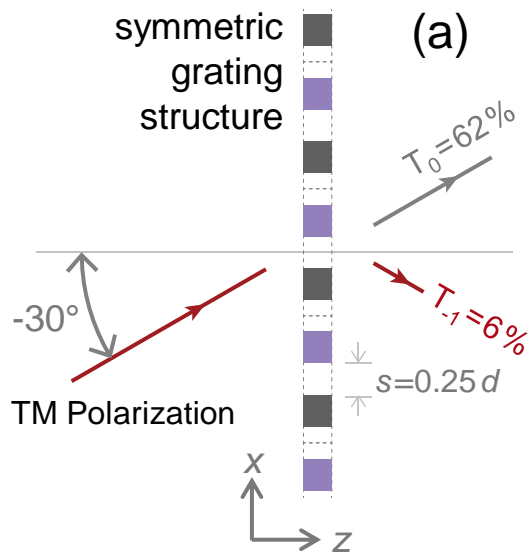
Stripe Separation ($s=0.375 d$) – TE Polarization



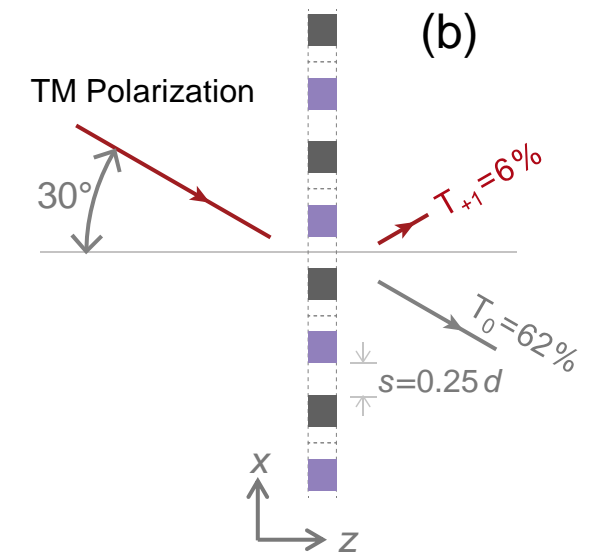
For TE polarization, the contrast / asymmetry of the diffraction effect is no longer obvious.



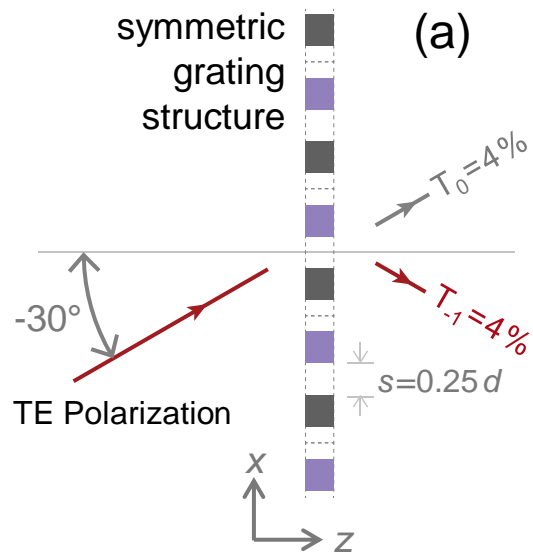
Stripe Separation ($s=0.25 d$) – TM Polarization



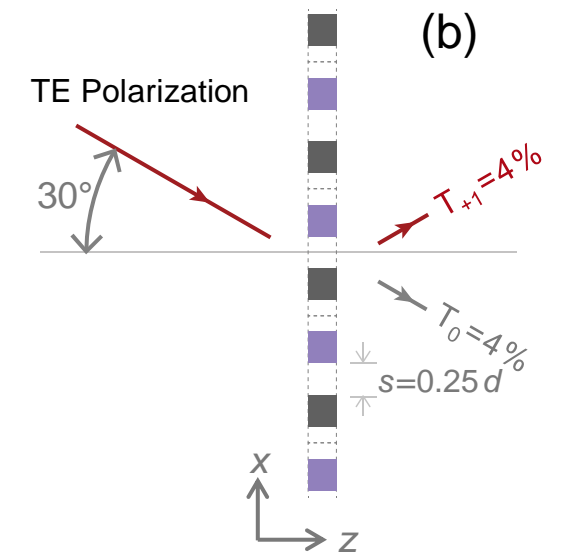
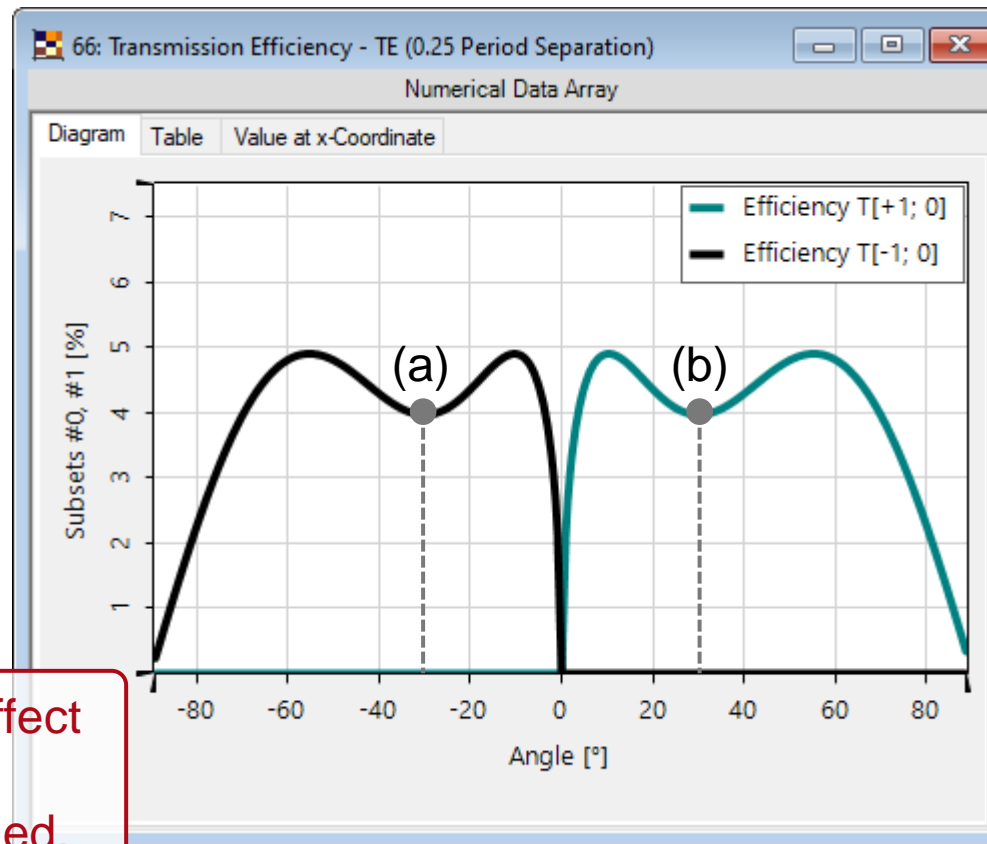
No asymmetric diffraction effect is seen when the stripe separation is evenly designed.



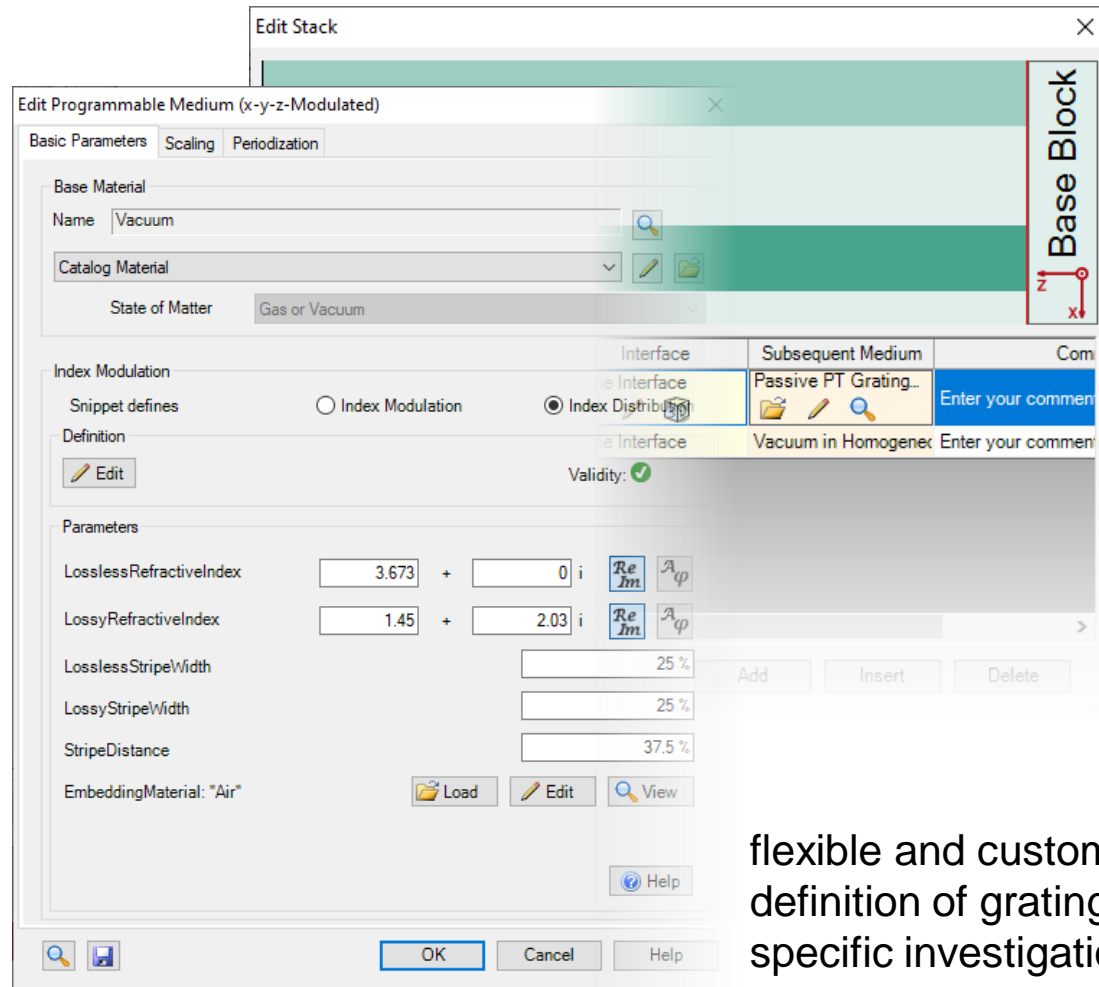
Stripe Separation ($s=0.25 d$) – TE Polarization



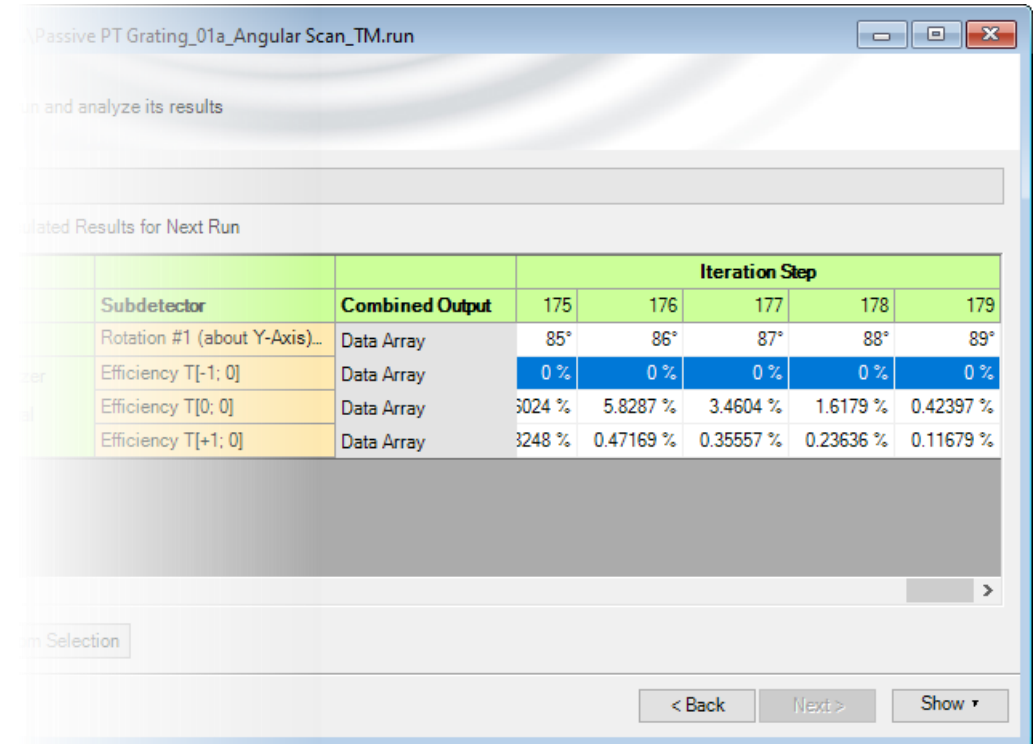
No asymmetric diffraction effect is seen when the stripe separation is evenly designed, regardless of polarization.



Peek into VirtualLab Fusion

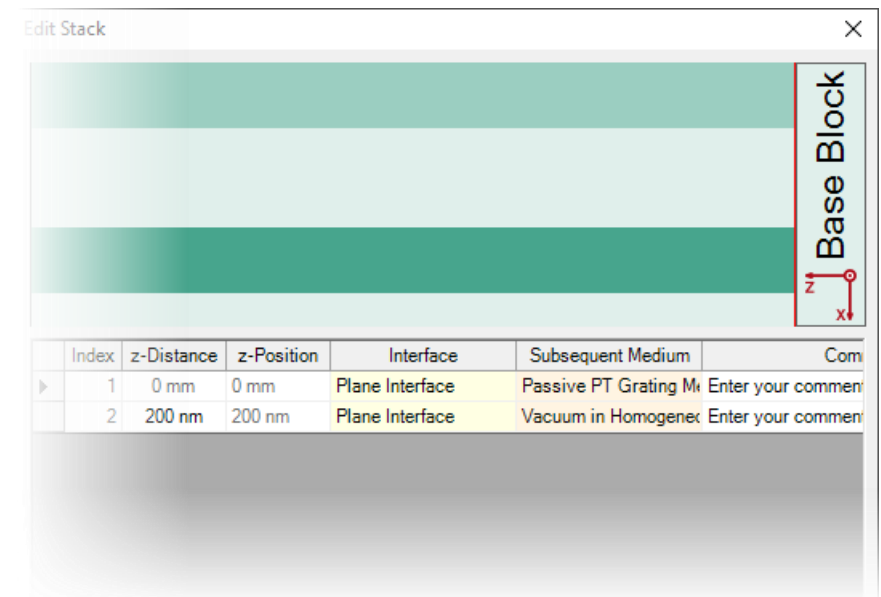


flexible and customizable definition of gratings for specific investigation



Workflow in VirtualLab Fusion

- Construct grating structure
 - [Configuration of Grating Structures by Using Special Media](#) [Use Case]
- Analyze grating diffraction efficiency
 - [Grating Order Analyzer](#) [Use Case]
- Check influence from different parameters with Parameter Run
 - [Usage of the Parameter Run Document](#) [Use Case]

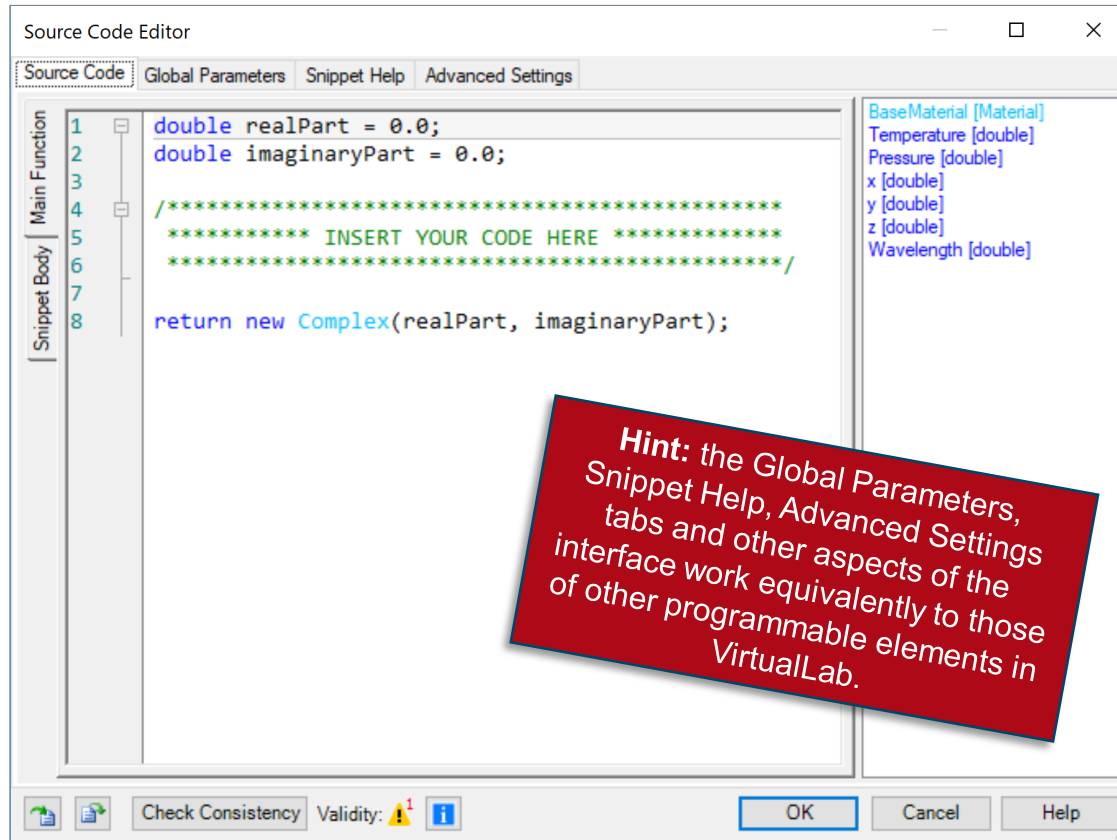


Document Information

title	Diffraction Property of a Passive Parity-Time Grating
document code	GRT.0018
version	1.2
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.202)
category	Application Use Case
further reading	<ul style="list-style-type: none">- Ultra-Sparse Dielectric Nano-Wire Grid Polarizers- Rigorous Analysis of Nanopillar Metasurface Building Block

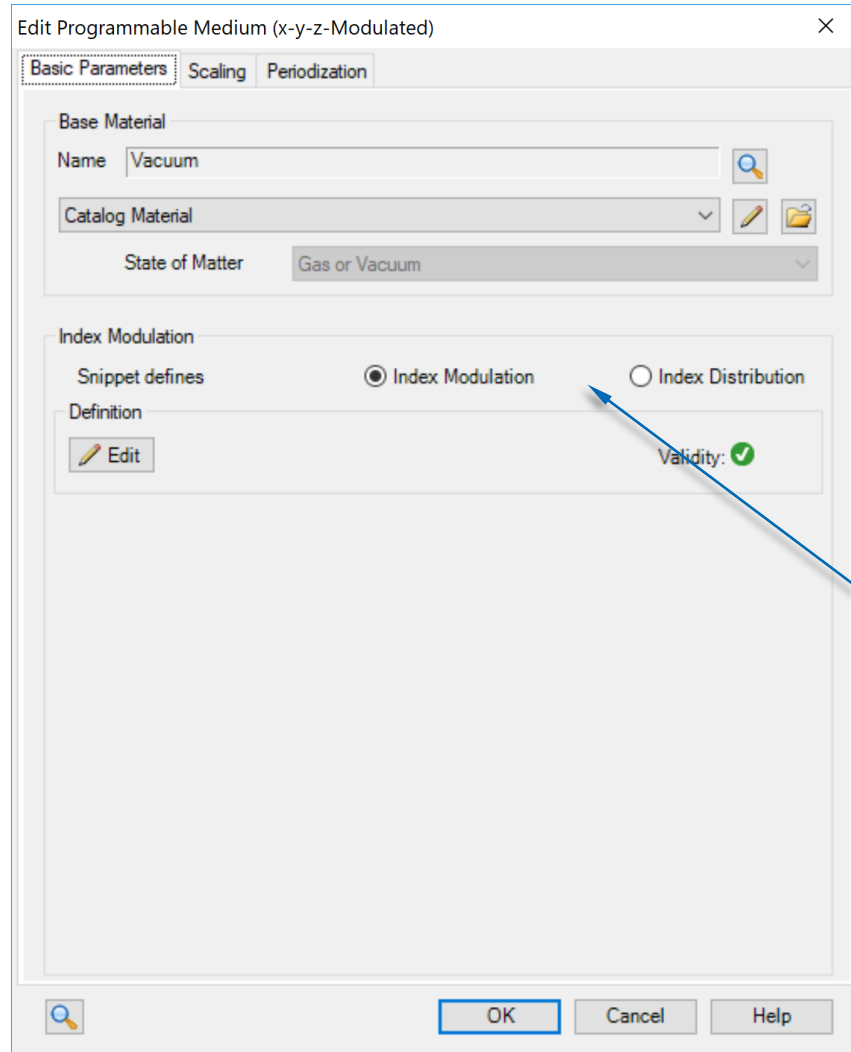
How to Work with the Programmable Medium

Writing the Code



- The panel on the right shows a list of available independent parameters.
- **BaseMaterial** refers to the material which is used to define the dispersion (wavelength-dependence) of the refractive index of the medium.
- **Temperature** and **Pressure** are parameters whose value is fixed in the configuration of the optical system.
- **x**, **y** and **z** span the volume of the medium. Any inhomogeneity in the medium will be simulated by programming a function which depends on at least one of these three parameters.
- The parameter **Wavelength** permits the user to access the value of the wavelength.

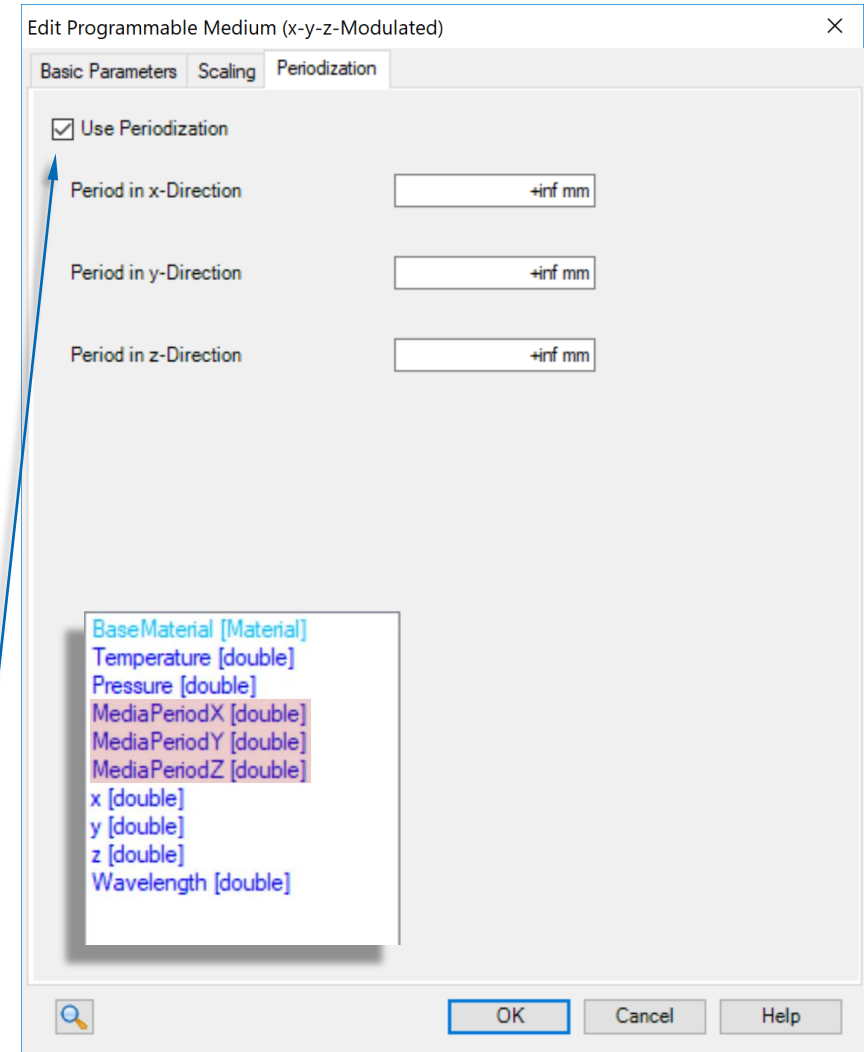
Base Material, Scaling & Periodization



Change the Base Material (subsequently accessible in the code of the Programmable Medium) here. Use a Material from the Catalog, a constant value of n , or a custom material!

The option Index Modulation adds the value of the refractive index of the Base Material to the value computed by the current snippet. Index Distribution directly defines the value of the refractive index.

Ticking the option Use Periodization activates additional global parameters in the snippet!

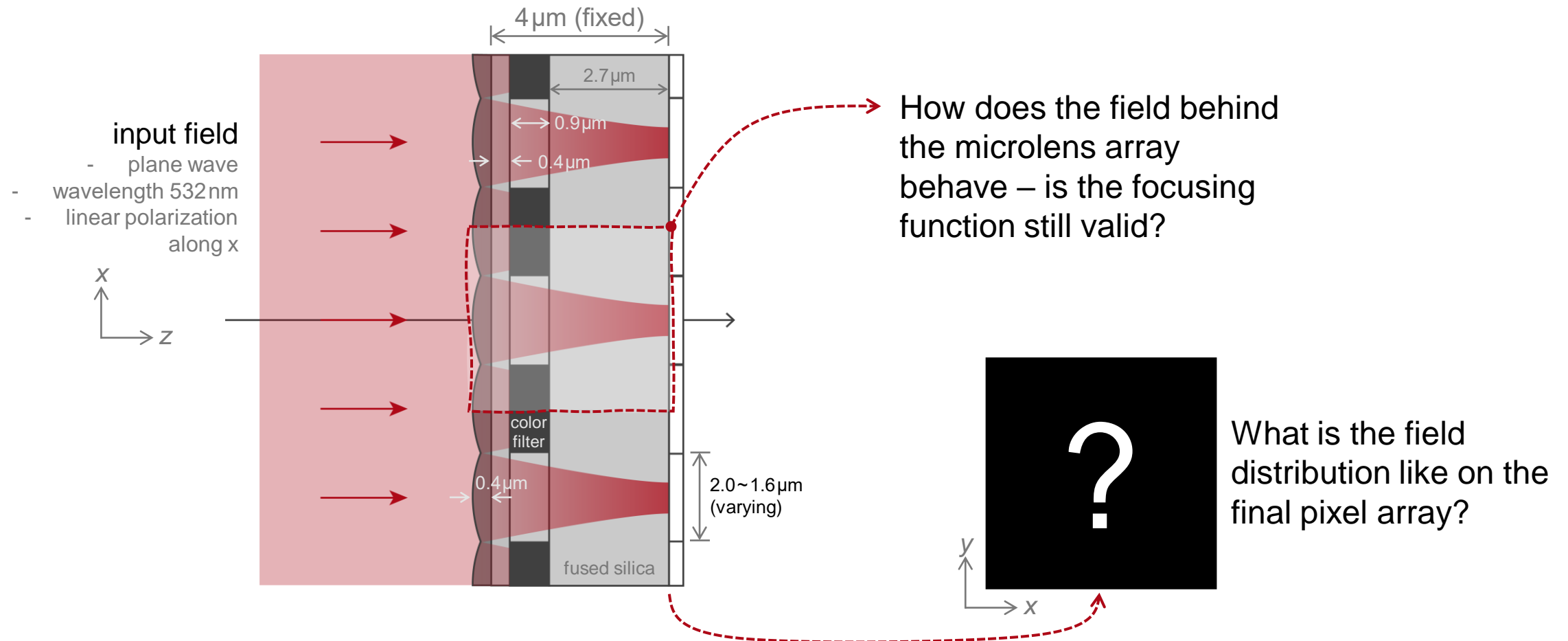


Document Information

title	How to Work with the Programmable Medium and Example (Thermal Lens)
document code	CZT.0104
version	1.0
toolbox(es)	Starter Toolbox
VL version used for simulations	7.4.0.49
category	Feature Use Case
further reading	<ul style="list-style-type: none">- How to Work with the Programmable Material and Example (Linear Dependence)- Gaussian Beam Focused by a Thermal Lens

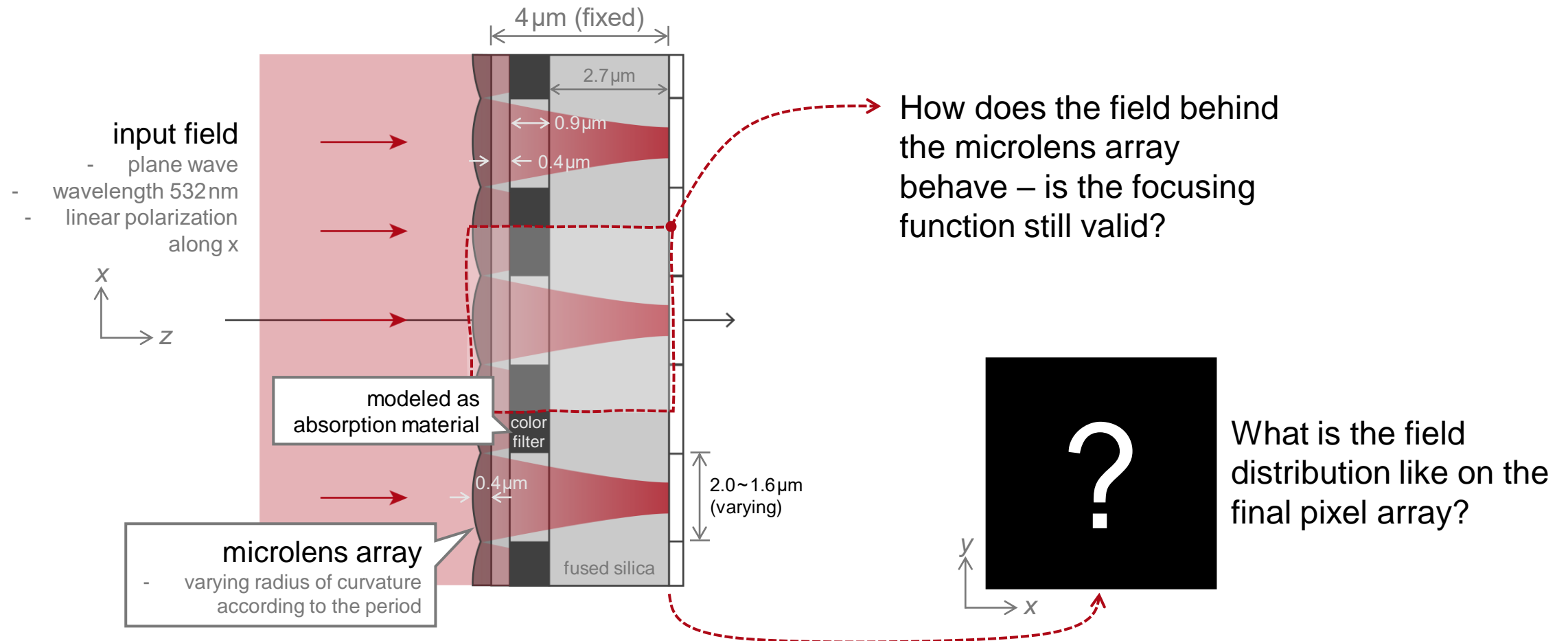
Analysis of CMOS Sensors with Microlens Array

Modeling Task



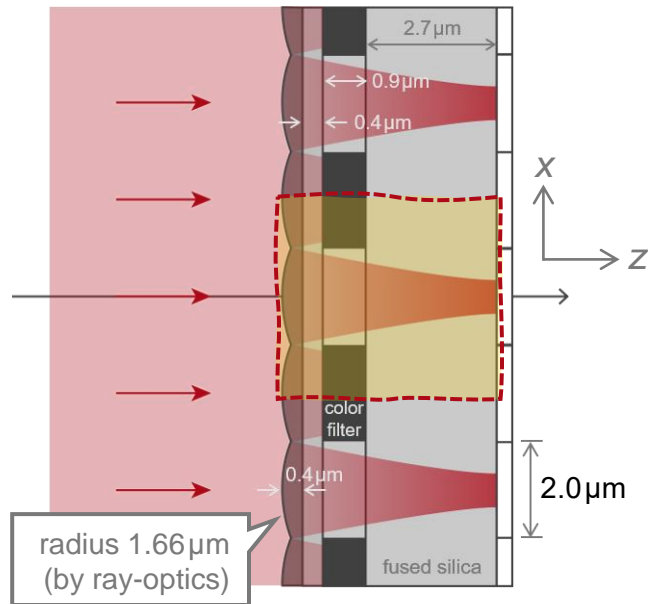
geometry parameters adapted from Y. Huo, *et al.*, Opt. Express 18, 5861-5872 (2010)

Modeling Task

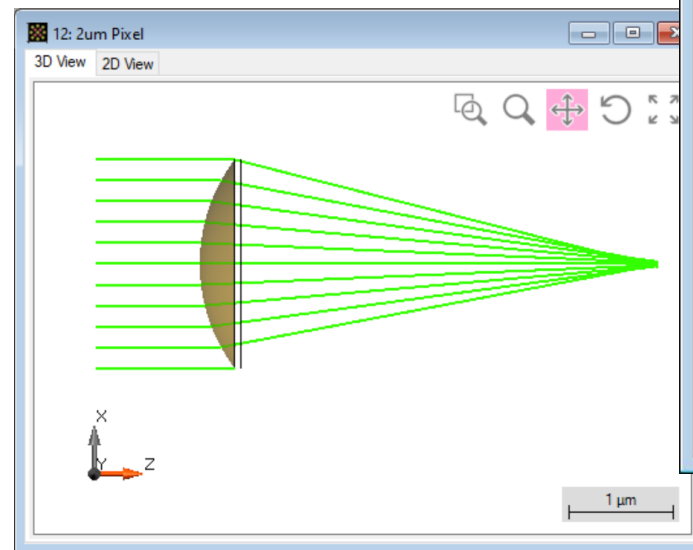


geometry parameters adapted from Y. Huo, *et al.*, Opt. Express 18, 5861-5872 (2010)

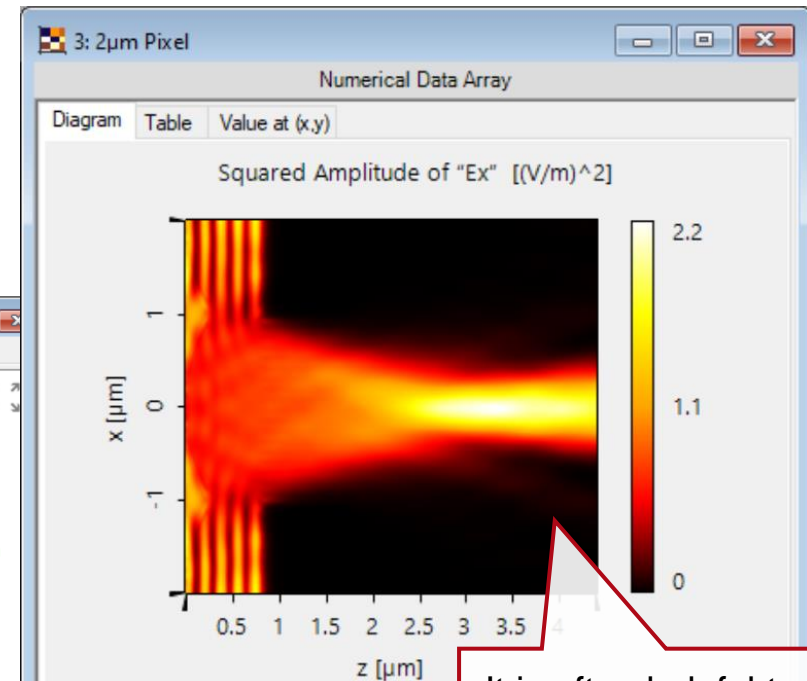
Microlens for 2 μm Pixel (x-z Simulation)



ray-optics design

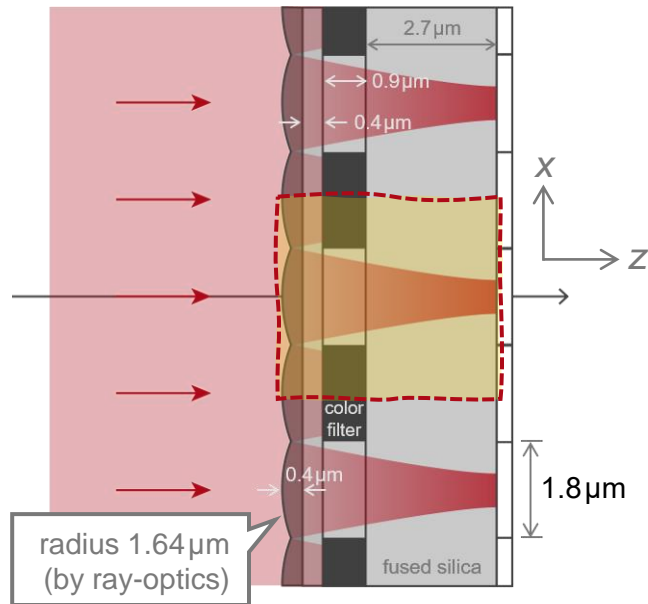


FMM / RCWA simulation (x-z)

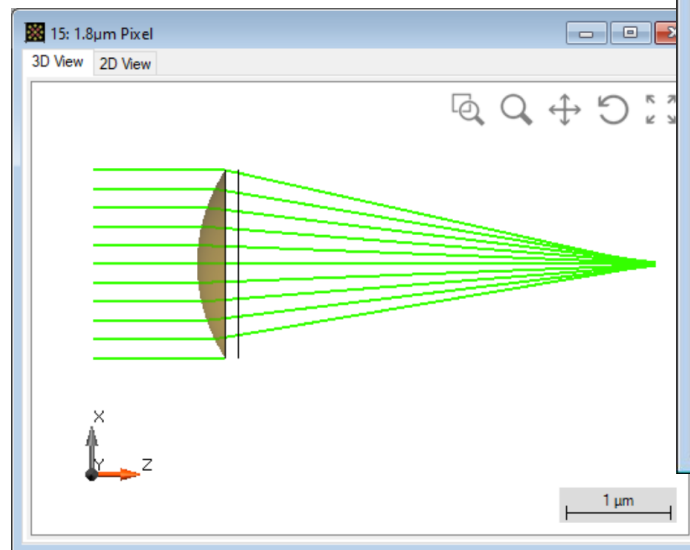


It is often helpful to make a 2D (x-z) simulation first so to get a fast understanding of the situation.

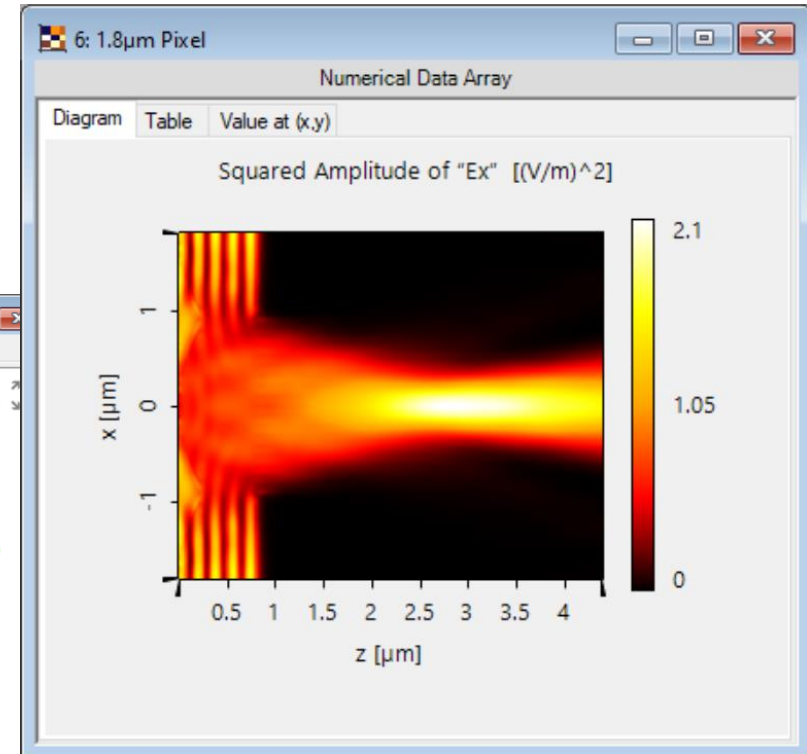
Microlens for 1.8 μm Pixel (x-z Simulation)



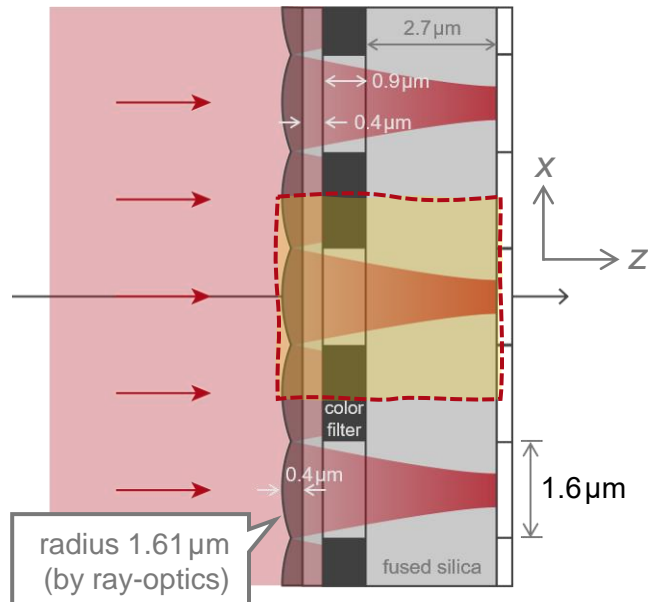
ray-optics design



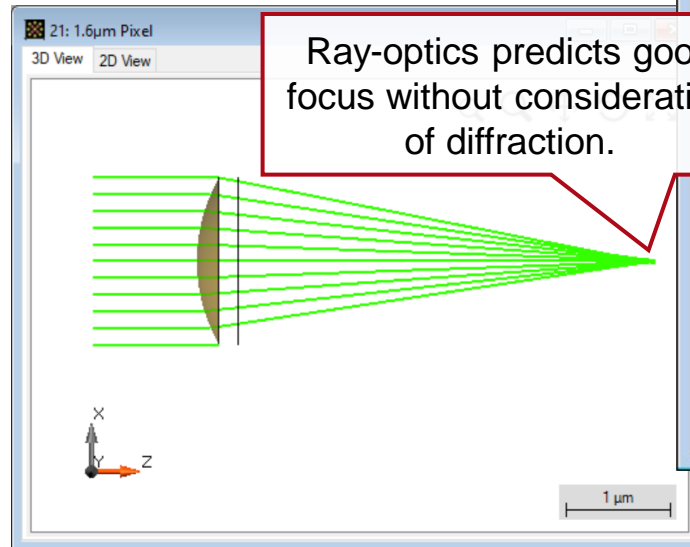
FMM / RCWA simulation (x-z)



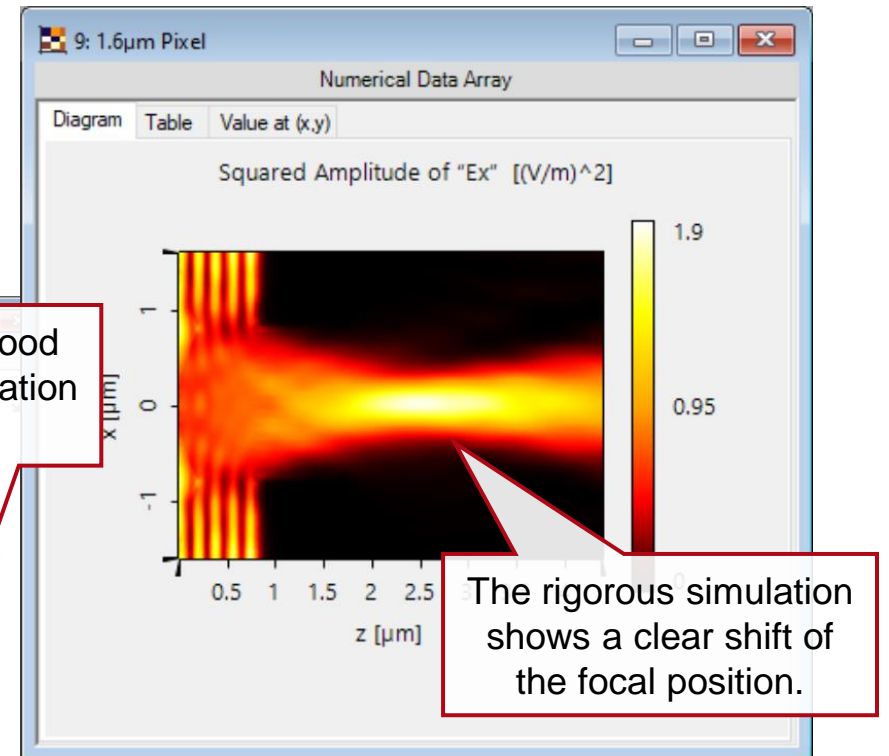
Microlens for 1.6 μm Pixel (x-z Simulation)



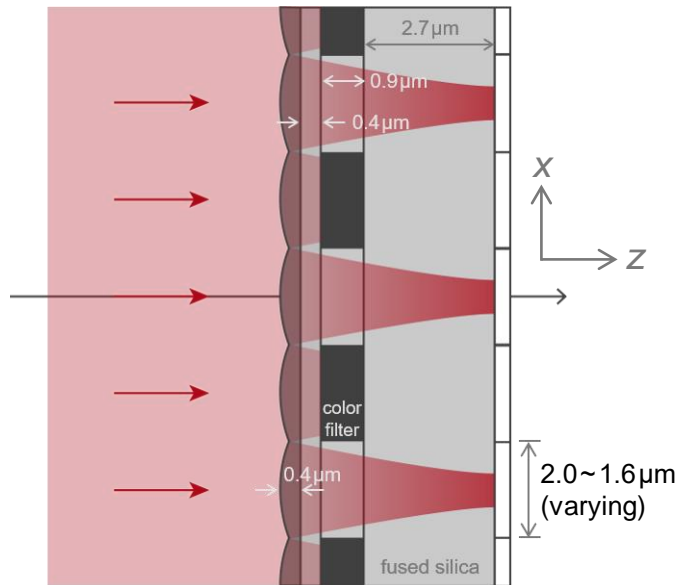
ray-optics design



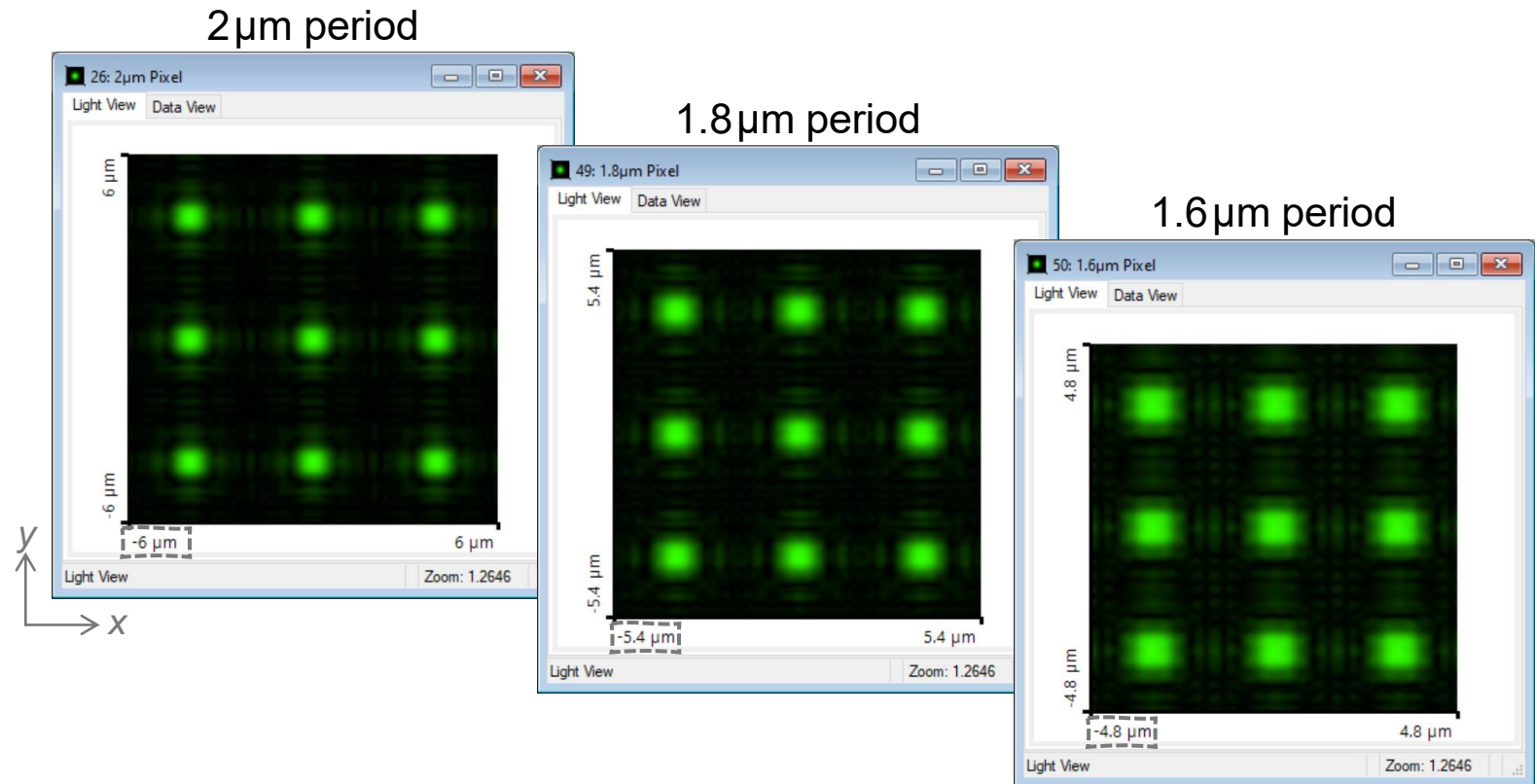
FMM / RCWA simulation (x-z)



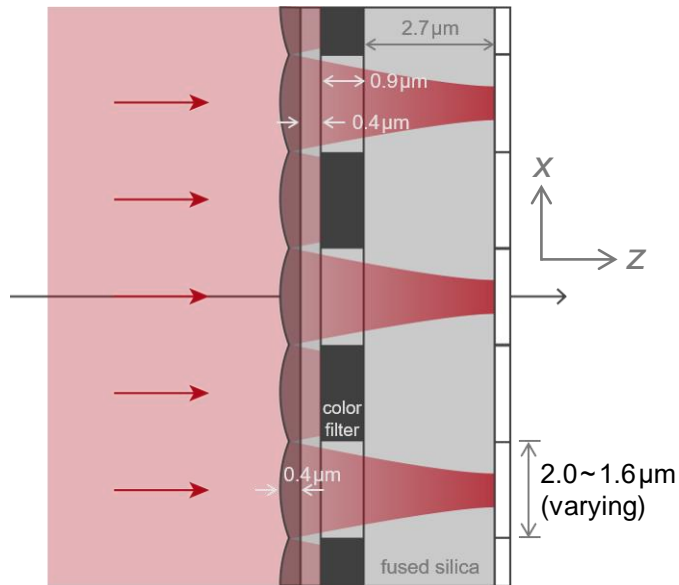
3D Simulation and Results Comparison



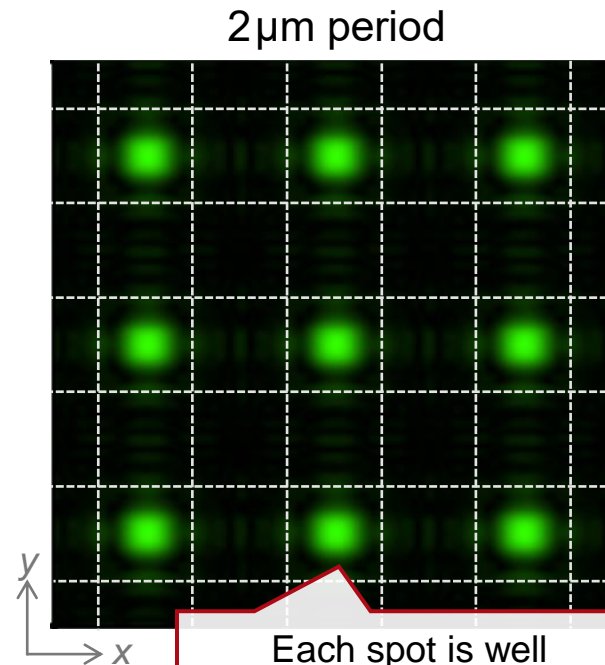
check the results
on this plane



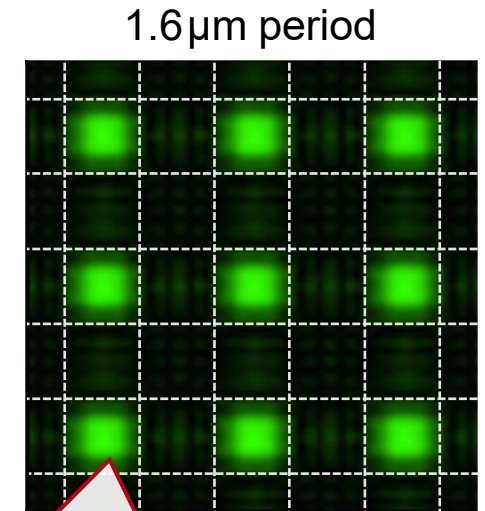
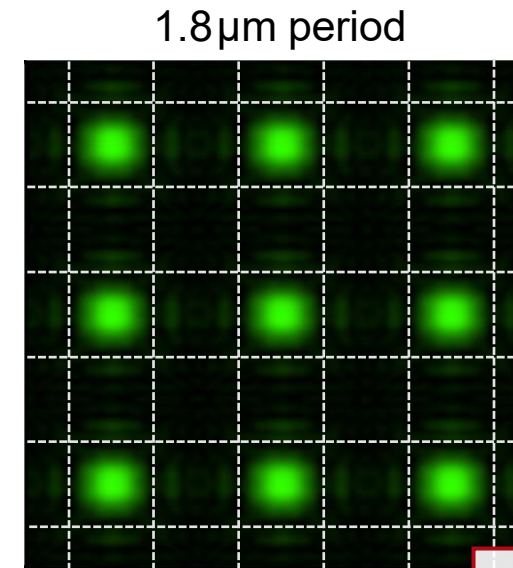
3D Simulation and Results Comparison



check the results
on this plane



Each spot is well
confined within the
corresponding pixel area.

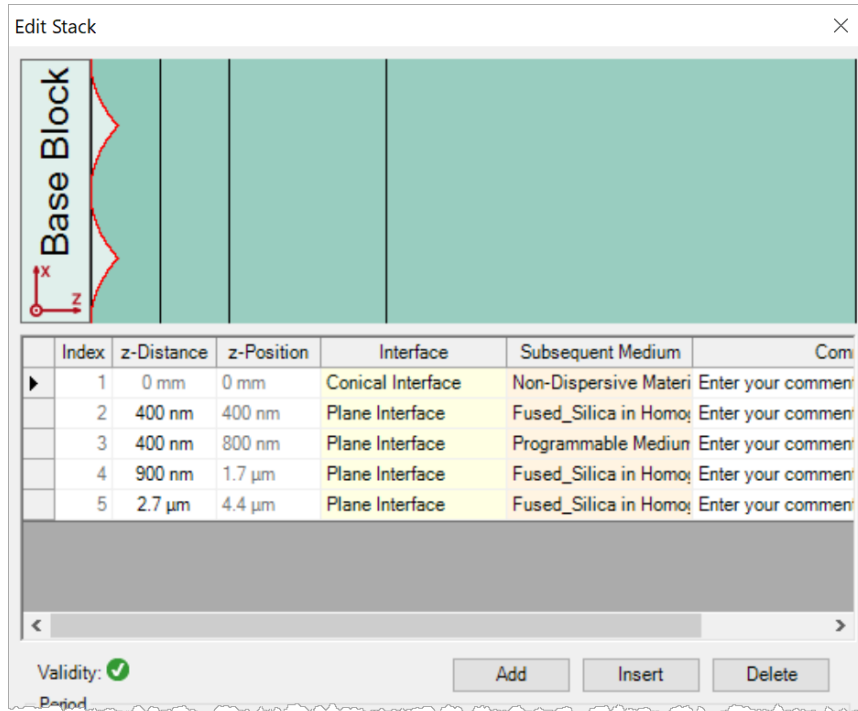


Light spots are barely
confined, and crosstalk may
happen for smaller pixels.

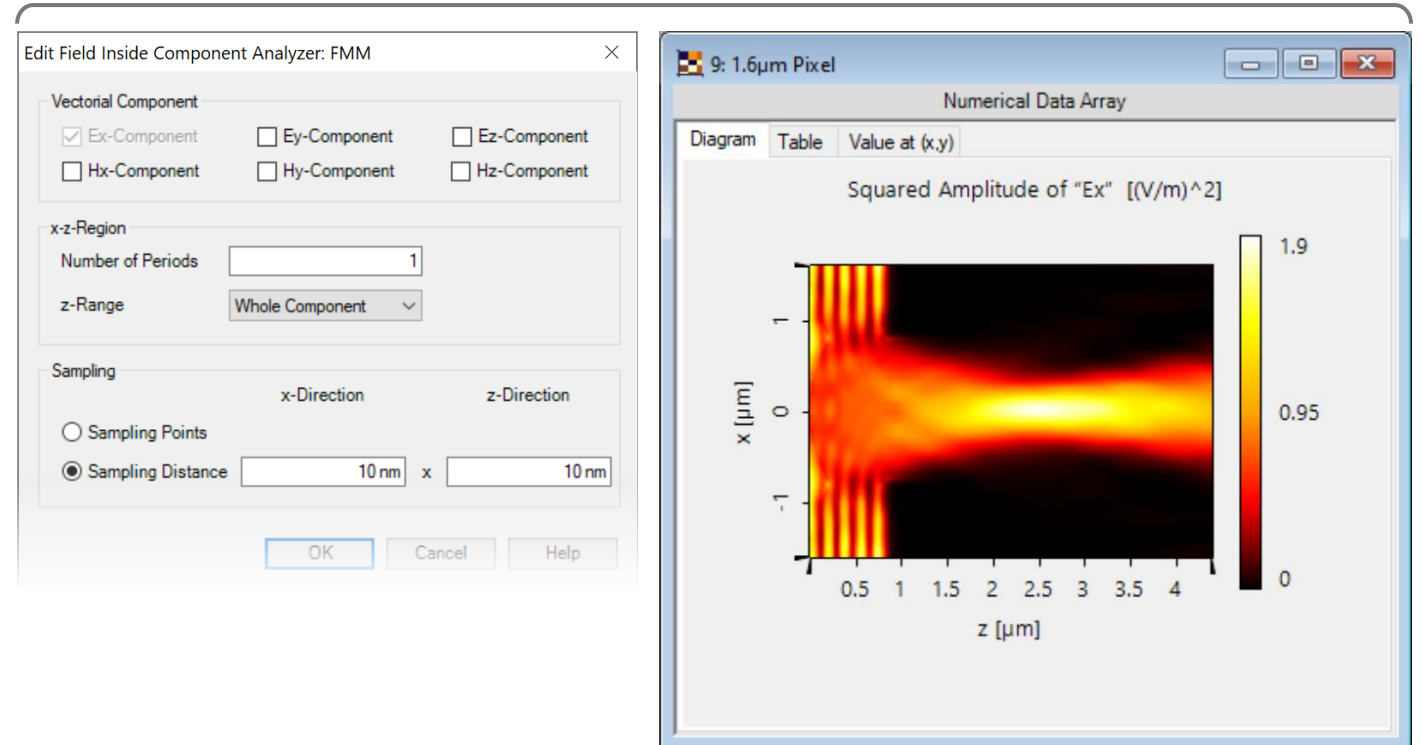
same scaling for all the result pictures

Peek into VirtualLab Fusion

flexible definition of micro-/nanostructures

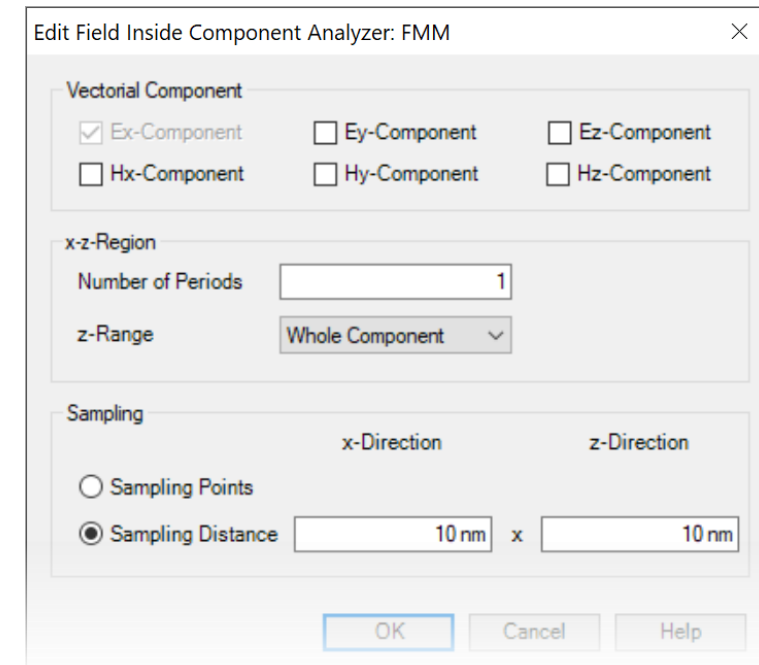


convenient setting and visualization of field inside structure



Workflow in VirtualLab Fusion

- Construct grating structure
 - [Configuration of Grating Structures by Using Interfaces](#) [Use Case]
 - [Configuration of Grating Structures by Using Special Media](#) [Use Case]
- Calculate field inside grating structure

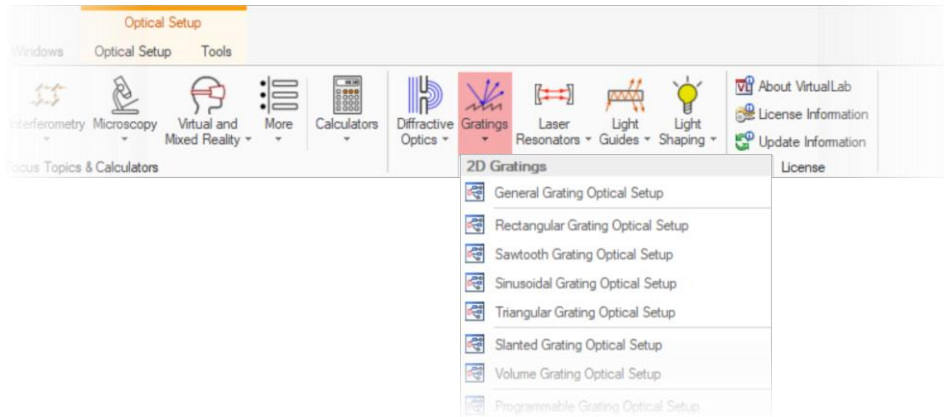


Document Information

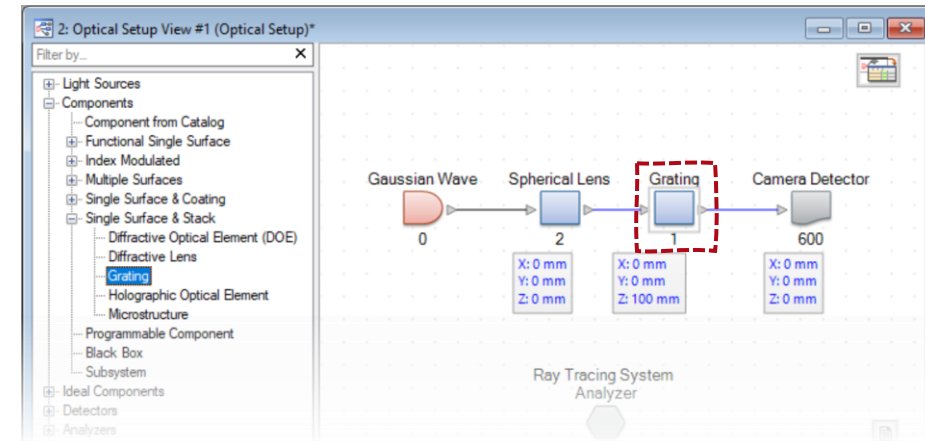
title	Analysis of CMOS Sensors with Microlens Array
document code	GRT.0026
version	1.0
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 3.4)
category	Application Use Case
further reading	<ul style="list-style-type: none">- Ultra-Sparse Dielectric Nano-Wire Grid Polarizers- Configuration of Grating Structures by Using Interfaces- Configuration of Grating Structures by Using Special Media

Modeling of Gratings within Optical System – Discussion at Examples

Grating Modeling in VirtualLab Fusion – An Overview

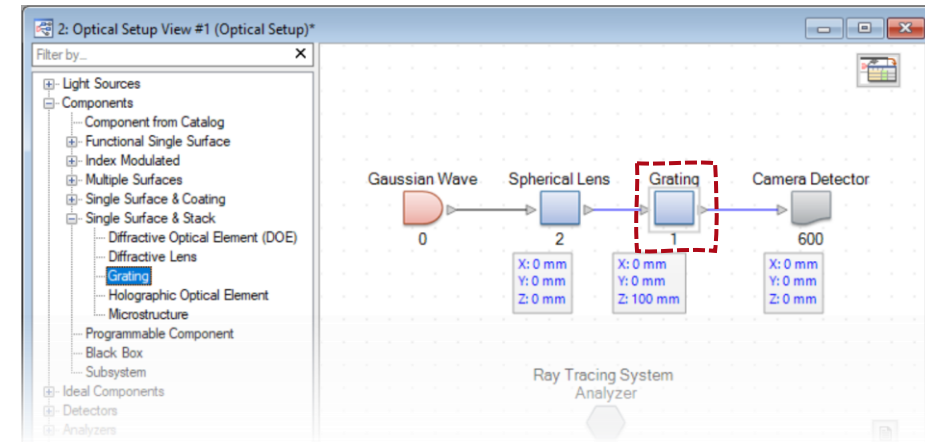
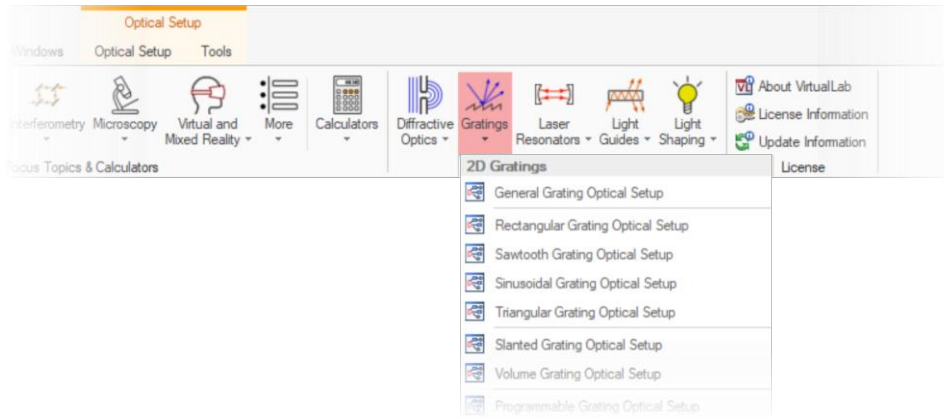


- Single grating analysis
 - Via the main window “Gratings” menu, one can enter a special evaluation environment for gratings only.
 - It helps analyze and visualize grating diffraction properties, like the diffraction angles and efficiencies.



- Grating modeling within system
 - In a general optical setup, a grating component can be inserted in any position of the system.
 - This enables the modeling of gratings within a system and so to evaluate the system performance, with the possible effects of the grating considered.

Grating Modeling in VirtualLab Fusion – An Overview



- Single grating analysis

- Via the main window “Gratings” menu, one can enter a special evaluation environment for gratings.
- It helps analyze and visualize the diffraction properties, like diffraction angles and efficiencies.

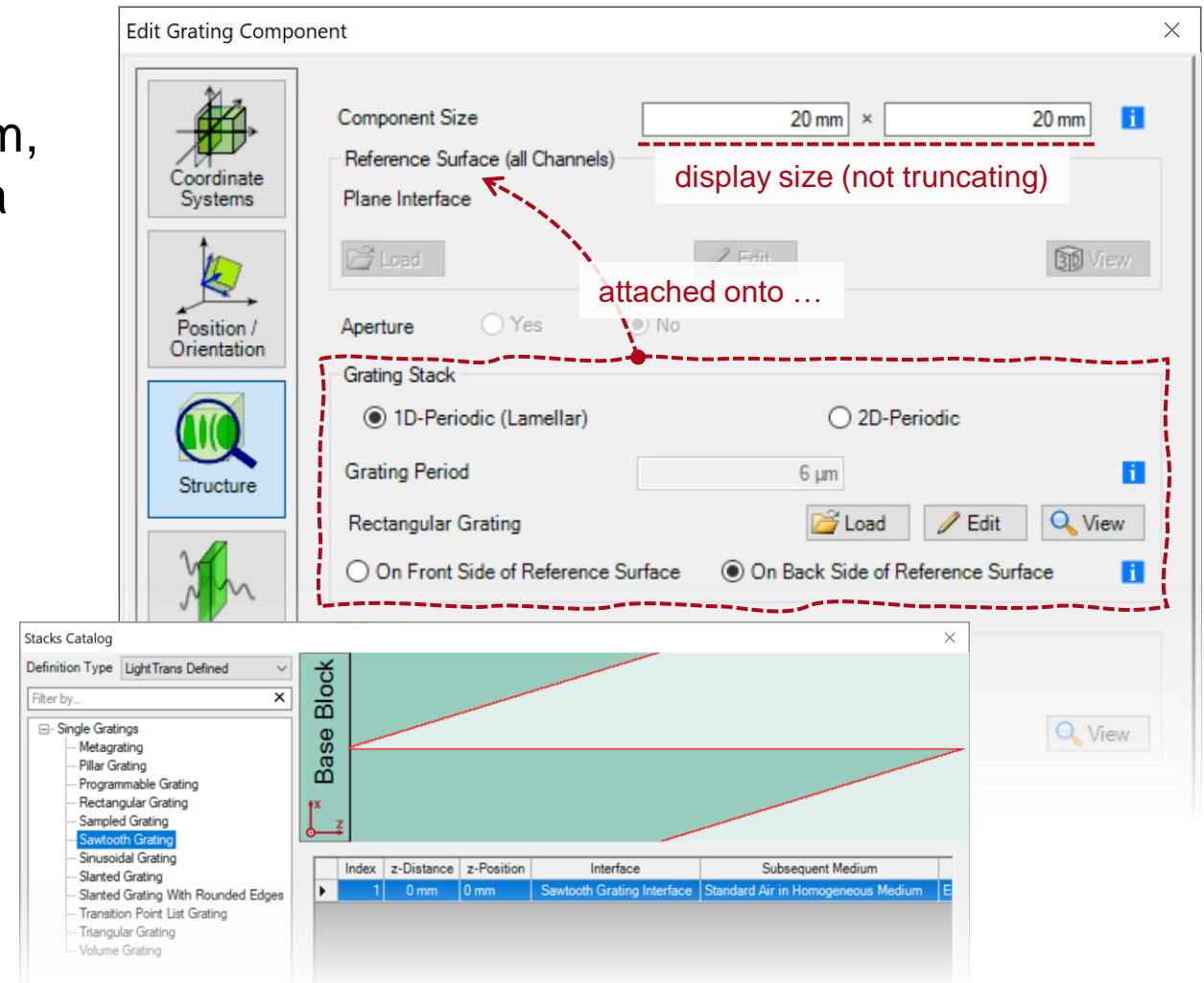
Both ways of modeling can often be used together, for example, optimize the grating structure itself first and then insert it into a system.

- Grating modeling within system

- In a general optical setup, a grating component can be inserted in any position of the system.
- This enables the modeling of gratings within a system and so to evaluate the system performance, with the possible effects of the grating considered.

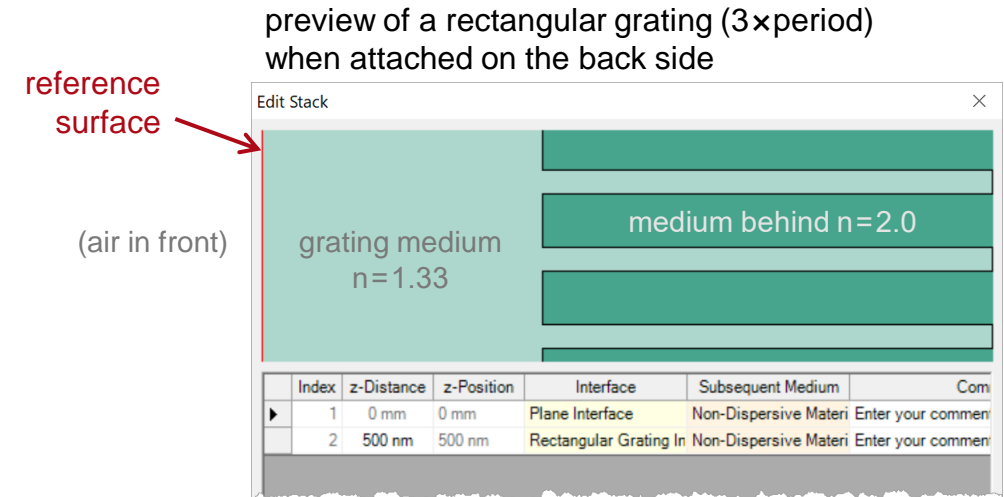
Grating Alignment in System

- Attaching grating stack
 - To describe the grating within a system, a grating stack is always attached to a reference virtual surface (planar only).
 - The reference surface can be visualized in the 3D system view and help align the grating.
- Stack orientation
 - A grating stack can be attached onto either the front or back side of the reference surface.

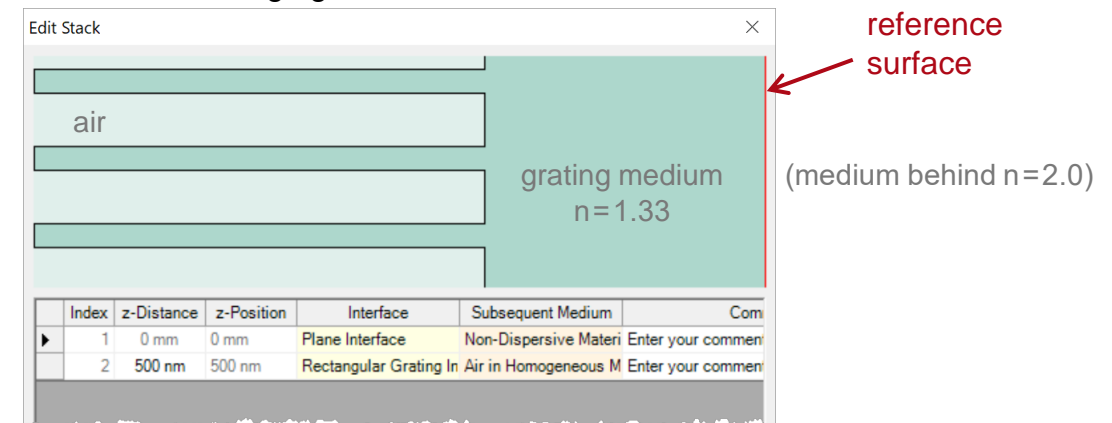


Grating Alignment in System

- Attaching grating stack
 - To describe the grating within a system, a grating stack is always attached to a reference virtual surface (planar only).
 - The reference surface can be visualized in the 3D system view and help align the grating.
- Stack orientation
 - A grating stack can be attached onto either the front or back side of the reference surface.
 - One must pay attention to the embedding medium setting when changing this option.

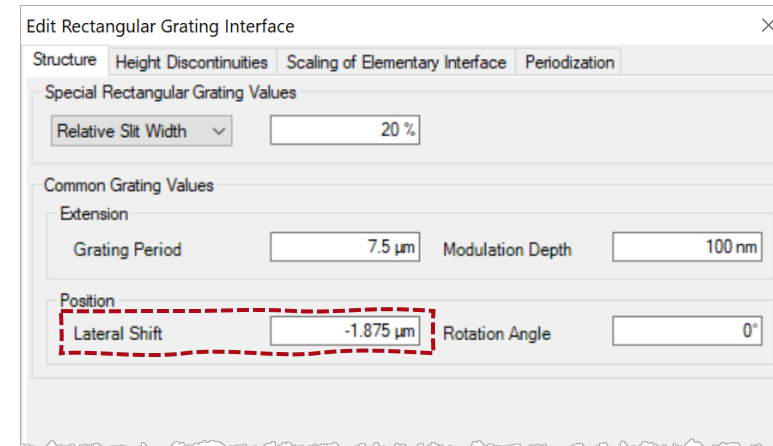


... and after changing it to the front side



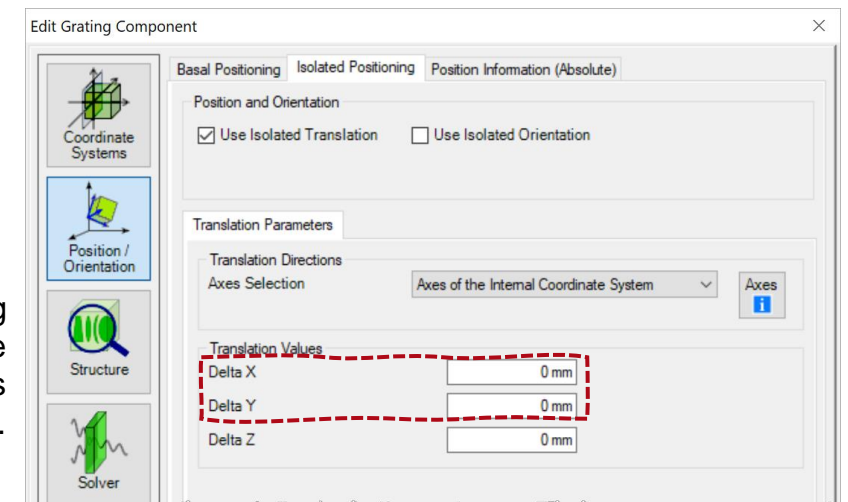
Grating Alignment in System

- Lateral positioning
 - When modeling the interaction of a general field with gratings in a system, the lateral position of the grating must be considered.
 - For example, the effect may be very different whether a laser beam is (tightly) focused on the stripe or the air gap of a linear grating.
 - The lateral position of gratings can be adjusted either
 - in the stack settings (options may differ for different gratings), or
 - via the component positioning options.



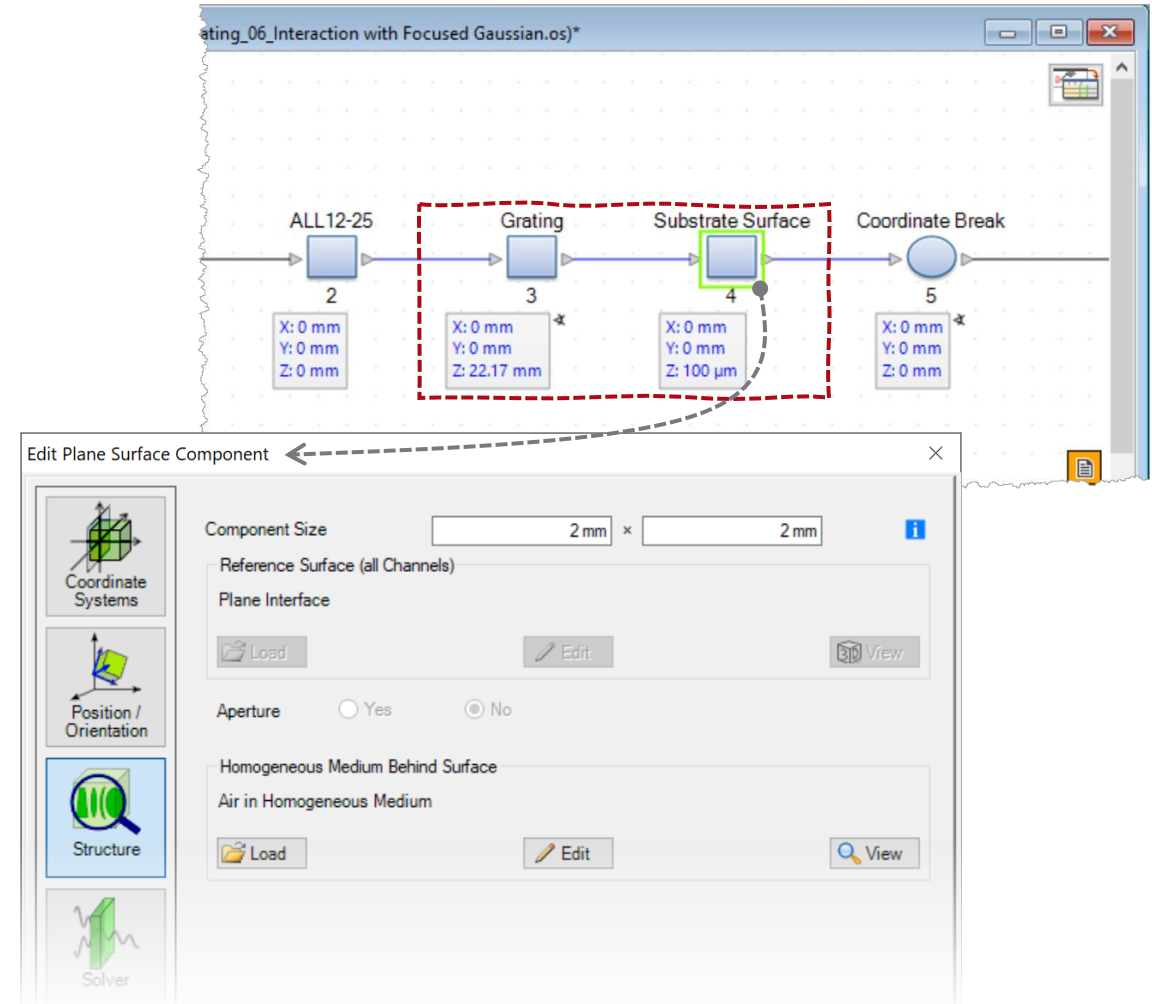
Options for lateral shift are available for e.g. the rectangular grating interface

The whole grating component can be laterally shifted, as a general option.



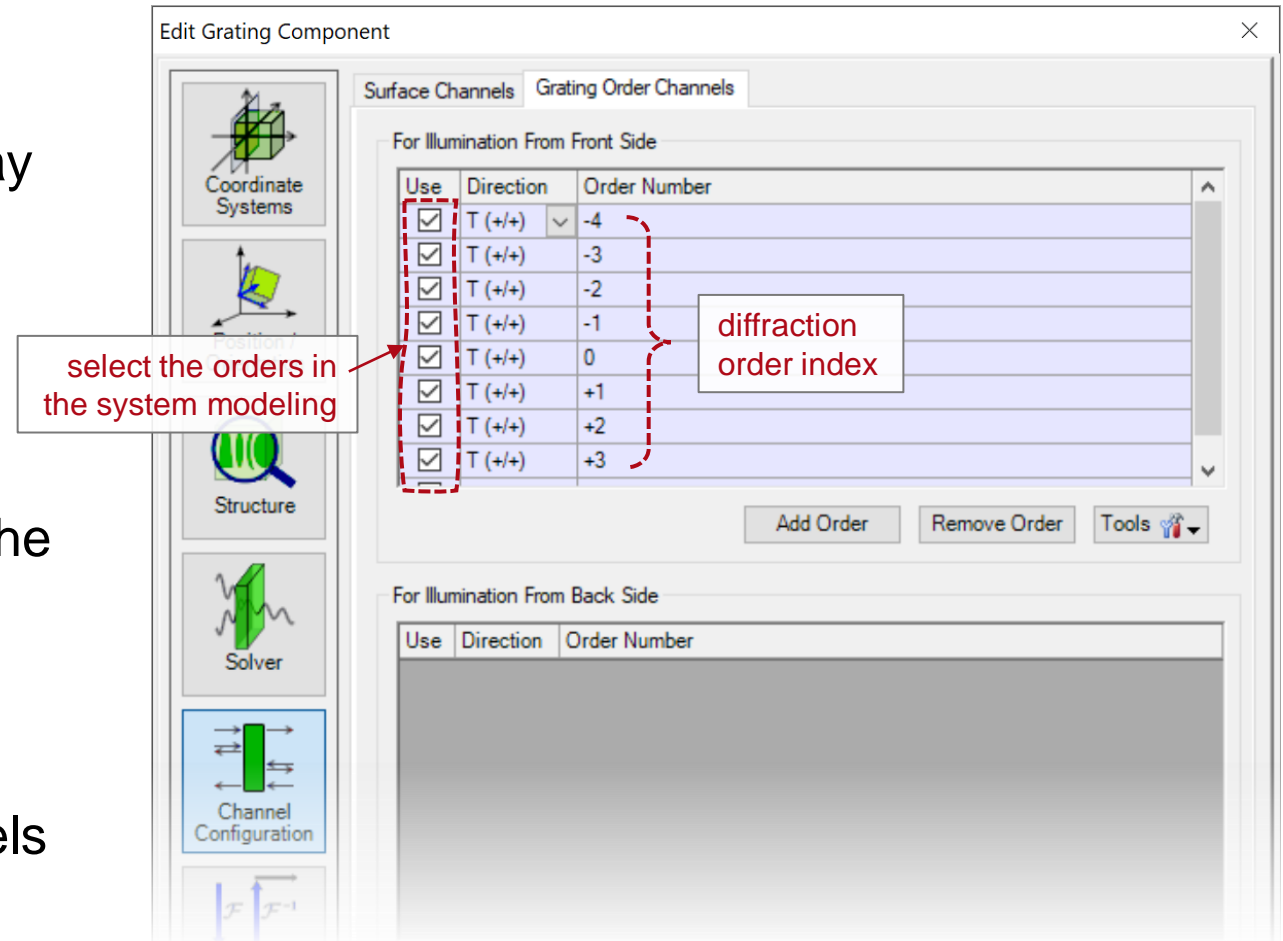
Handling of Substrate, Fresnel Loss, and Diffraction Angle

- Single grating analysis
 - As a convention, the effect of substrate is often omitted for e.g. the diffraction efficiency calculation.
- Grating modeling within system
 - But, any realistic grating structure rests on a substrate and we use a plane surface component together with a free-space in between to model it.
 - The plane surface modeling includes the Fresnel loss, but is not coupled with the FMM calculation of grating stacks.
 - It also help handle the diffraction angles in different media.



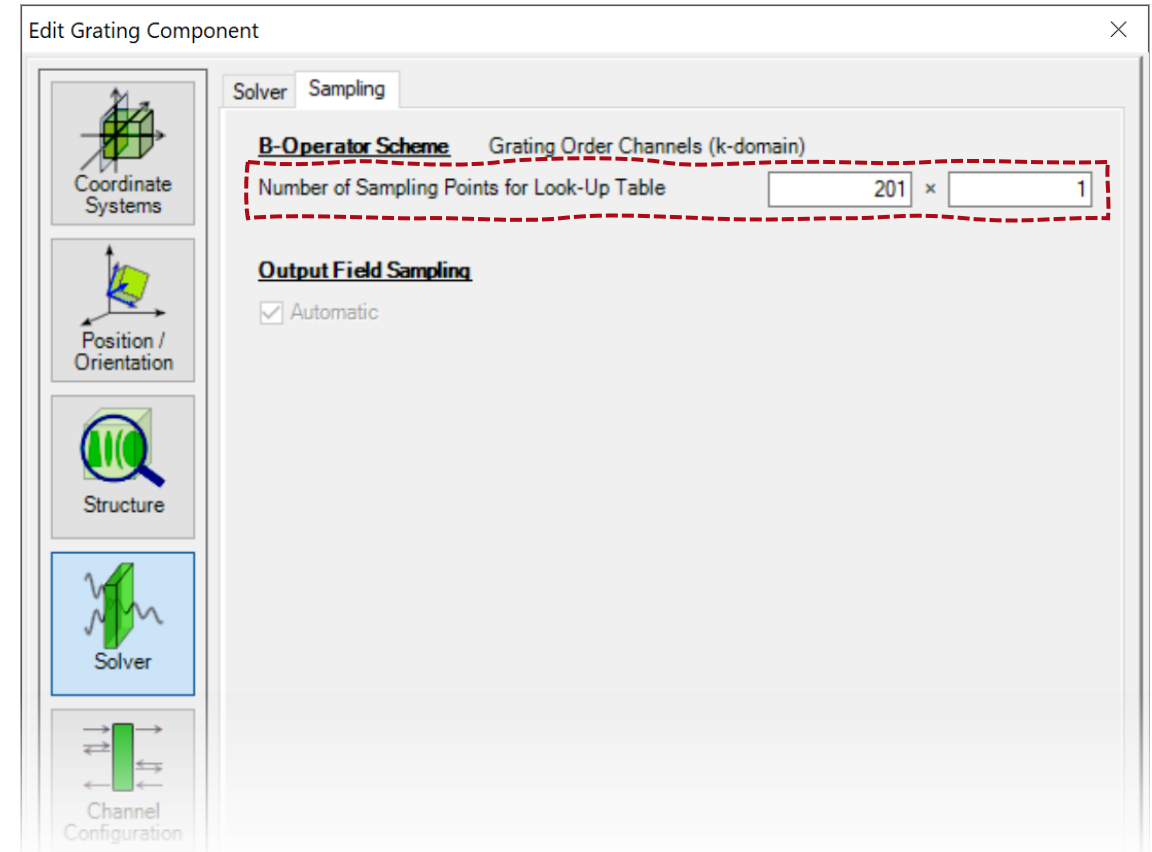
Grating Order Channel Selection

- Directions
 - Input field may illuminate the grating from either front or back side and may get reflected or transmitted.
- Diffraction order selection
 - For a direction combination, there might be multiple diffraction orders.
 - It is not always needed consider all the diffraction orders and we suggest to use only those of interests.
- Remark
 - Selection of the grating order channels does not affect the number of diffraction orders in FMM calculation.



Angular Response of Grating

- Diffraction property dependency
 - For a given grating, its diffraction property is related to the input field.
 - With different wavelength / polarization, the diffraction efficiency differs, and the same for different input angles.
 - To resolve the angle-dependent diffraction behavior, one may need to specify the sampling points k-domain (equivalent to angular space).
 - For a given input field, VirtualLab Fusion automatically determines the angular range.



Example #1: Imaging Formation of a Grating Object

Substrate Handling

For the consideration of substrate, we

- use a plane surface component to model the front surface of the substrate layer,
- set the medium behind to fused silica, and
- set the distance to the next component to 500 μm , equal to the thickness of the substrate.

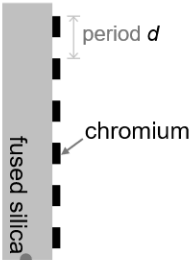


[see the full Application Use Case](#)

Grating Configuration and Alignment

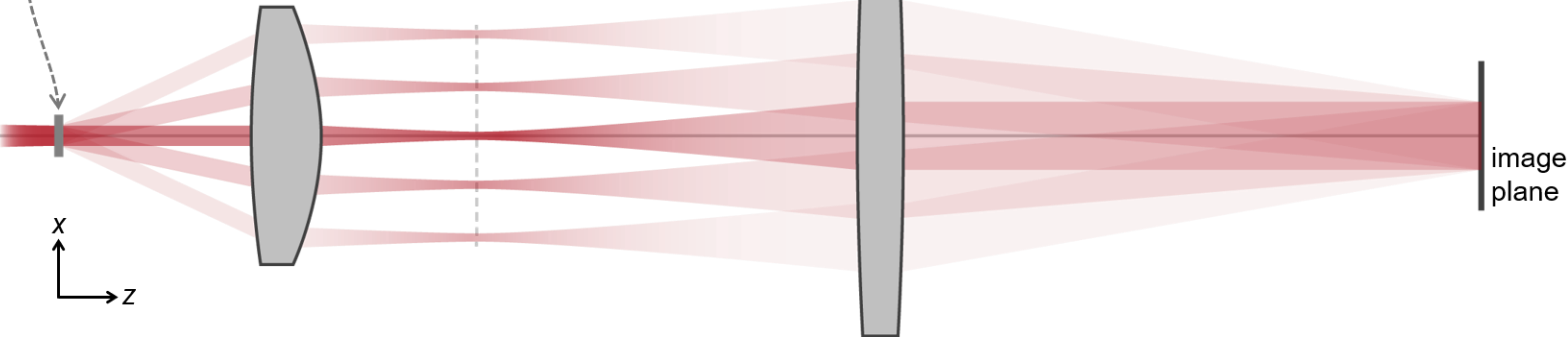
grating object

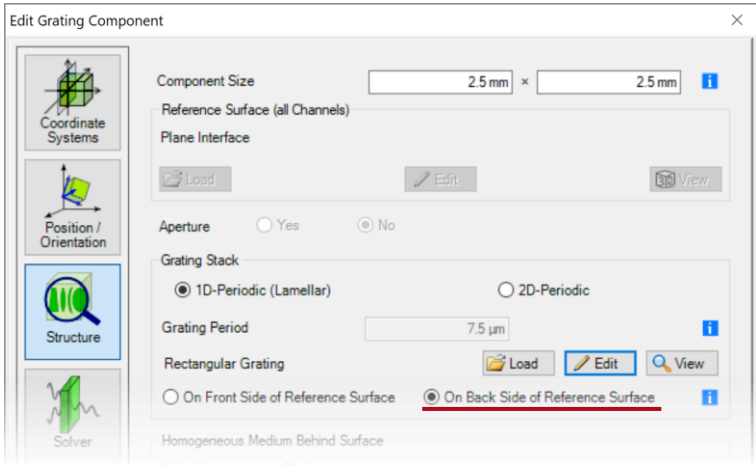
- thin chromium on substrate
- duty cycle 50%
- period $d=7.5\mu\text{m}$



input field

- Gaussian profile
- wavelength 632.8nm
- polarized along x
- waist radius 50μm (on grating front surface)





Component Size: 2.5 mm x 2.5 mm

Reference Surface (all Channels): Plane Interface

Aperture: ☐ Yes ☒ No

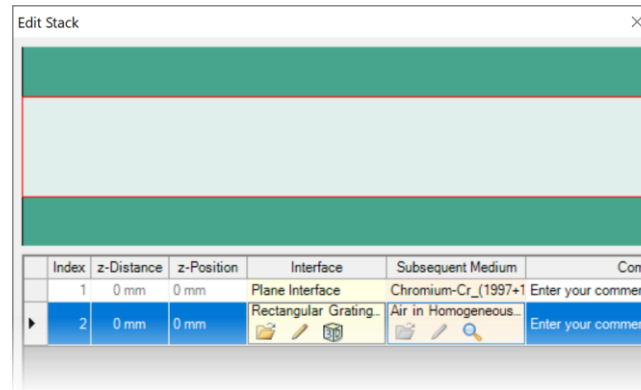
Grating Stack: ☒ 1D-Periodic (Lamellar) ☐ 2D-Periodic

Grating Period: 7.5 μm

Rectangular Grating: ☐ On Front Side of Reference Surface ☒ On Back Side of Reference Surface

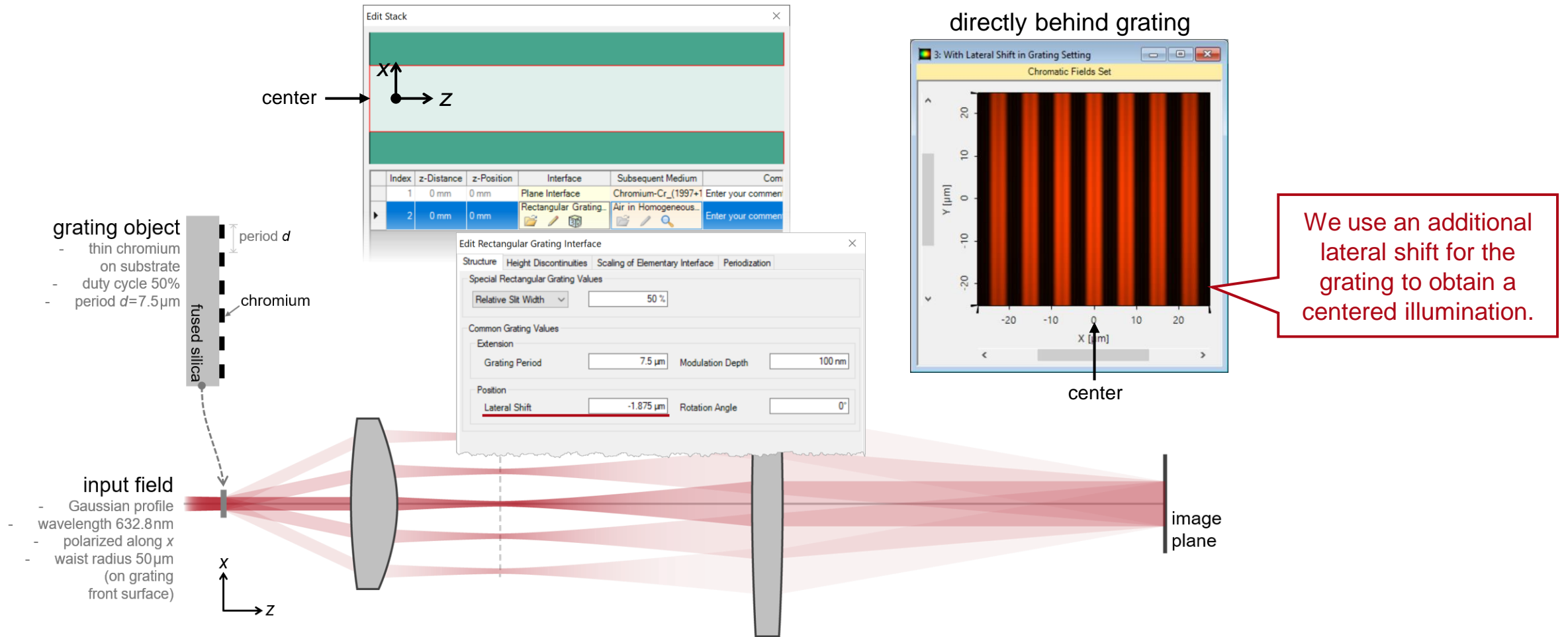
Following the sketch of the setup, we

- set the grating on the back side of the reference surface, and
- use a rectangular grating stack to represent the chromium stripes.

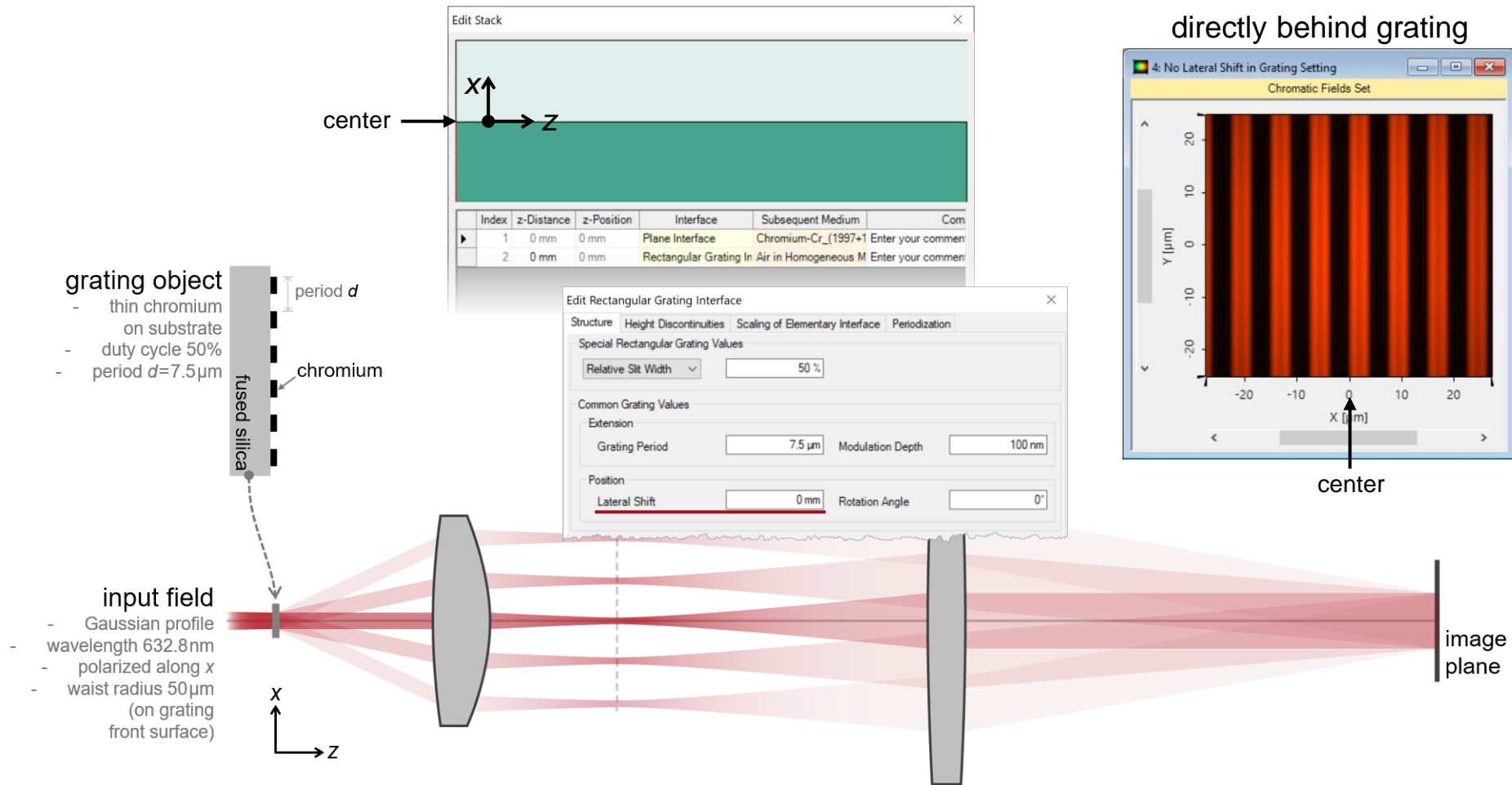


Index	z-Distance	z-Position	Interface	Subsequent Medium	Comments
1	0 mm	0 mm	Plane Interface	Chromium-Cr_(1997+1)	Enter your comment
2	0 mm	0 mm	Rectangular Grating	Air in Homogeneous	Enter your comment

Grating Configuration and Alignment



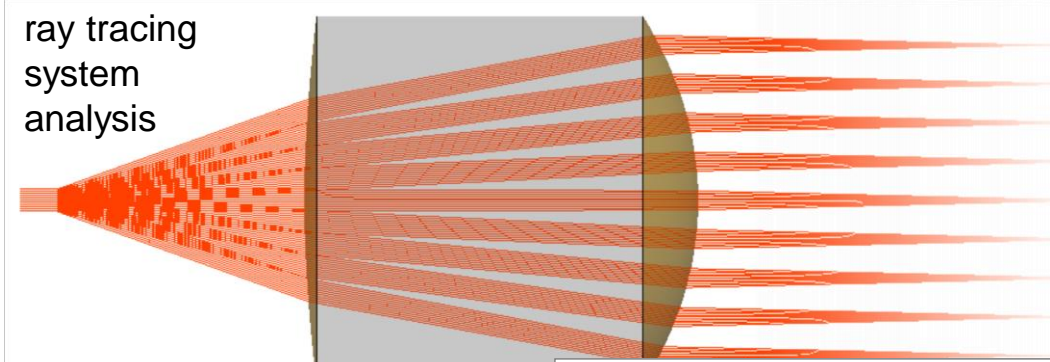
Grating Configuration and Alignment



Attention shall be paid to the lateral position of the grating: it has an influence when illuminated by general fields with limited sizes.

Grating Order Channel Selection

ray tracing system analysis



grating object

- thin chromium on substrate
- duty cycle 50%
- period $d=7.5\mu\text{m}$

period d

chromium

fused silica

input field

- Gaussian profile
- wavelength 632.8nm
- polarized along x
- waist radius $50\mu\text{m}$ (on grating front surface)

x

z

Edit Grating Component

Surface Channels Grating Order Channels

For Illumination From Front Side

Use	Direction	Order Number
<input checked="" type="checkbox"/>	T (+/+)	-4
<input checked="" type="checkbox"/>	T (+/+)	-3
<input checked="" type="checkbox"/>	T (+/+)	-2
<input checked="" type="checkbox"/>	T (+/+)	-1
<input checked="" type="checkbox"/>	T (+/+)	0
<input checked="" type="checkbox"/>	T (+/+)	+1
<input checked="" type="checkbox"/>	T (+/+)	+2
<input checked="" type="checkbox"/>	T (+/+)	+3

Add Order Remove Order Tools

For Illumination From Back Side

Use	Direction	Order Number
-----	-----------	--------------

Coordinate Systems

Position / Orientation

Structure

Solver

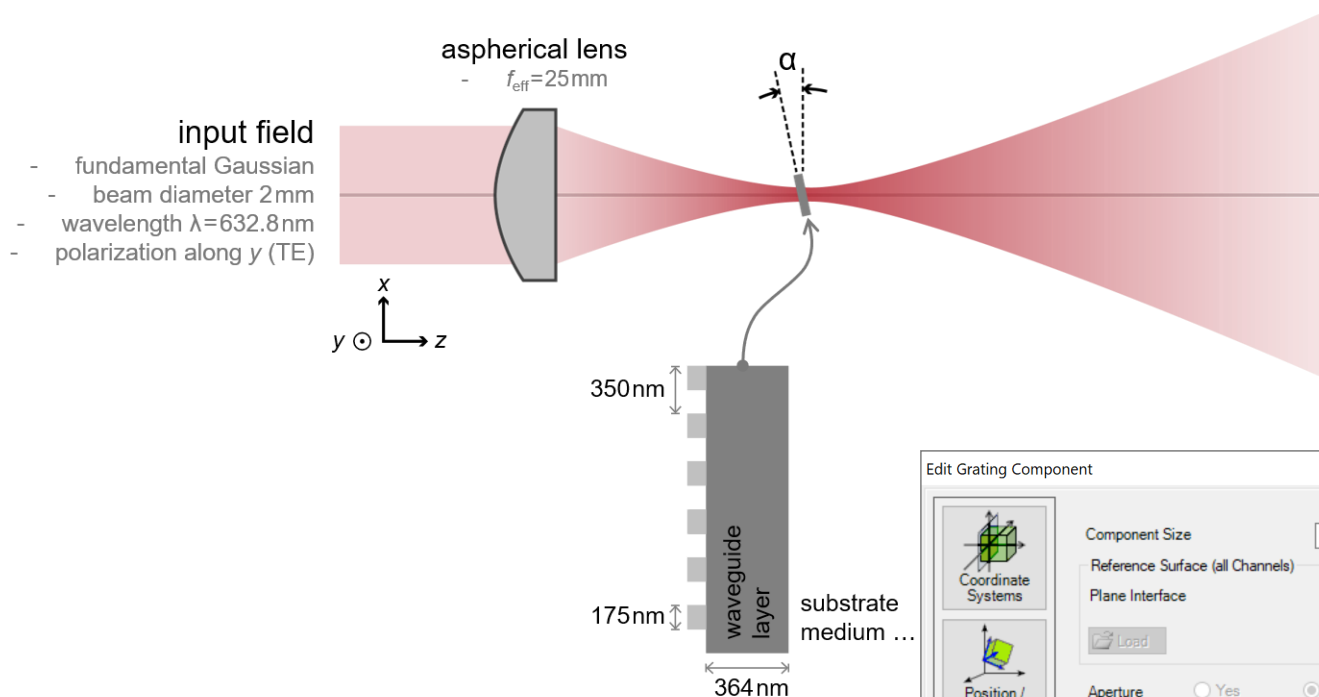
Channel Configuration

It is not always needed to consider all the diffraction orders in a system, we

- use ray tracing system analyzer to help visualize and determine the acceptance of the imaging system, and
- choose only those diffraction orders that can enter the imaging system.

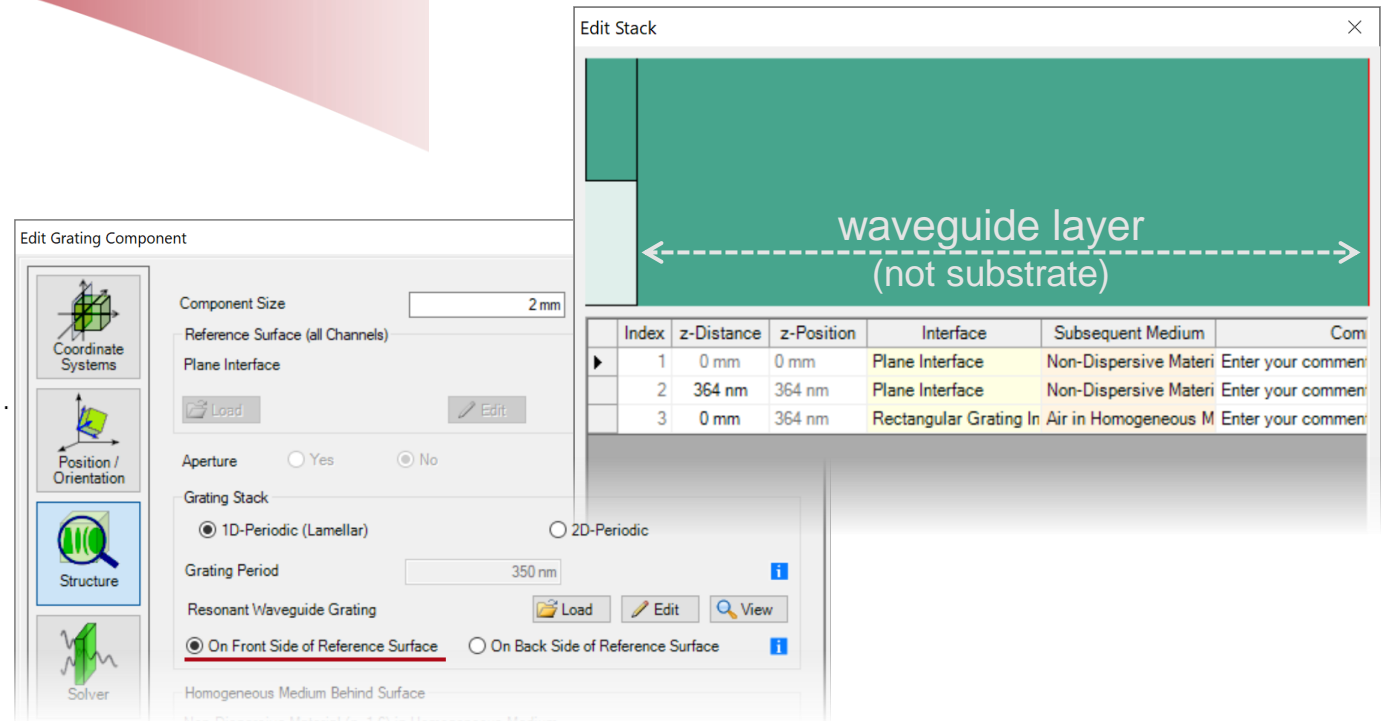
Example #2: Angular Sensitivity Testing for a Waveguide Resonant Grating

Grating Configuration and Alignment



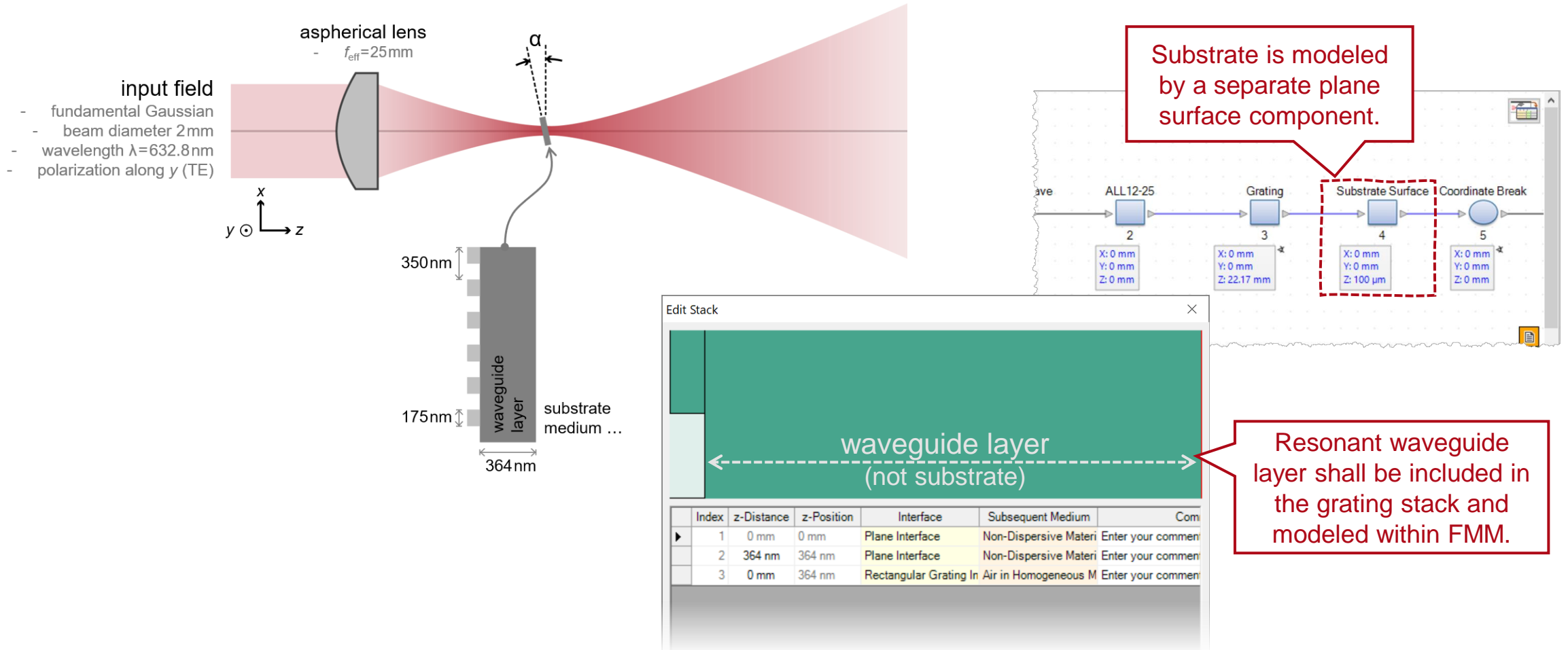
Following the sketch of the setup, we

- set the grating on the front side of the reference surface, and
- use a rectangular grating interface, with two plane interfaces, to construct the resonant waveguide grating.

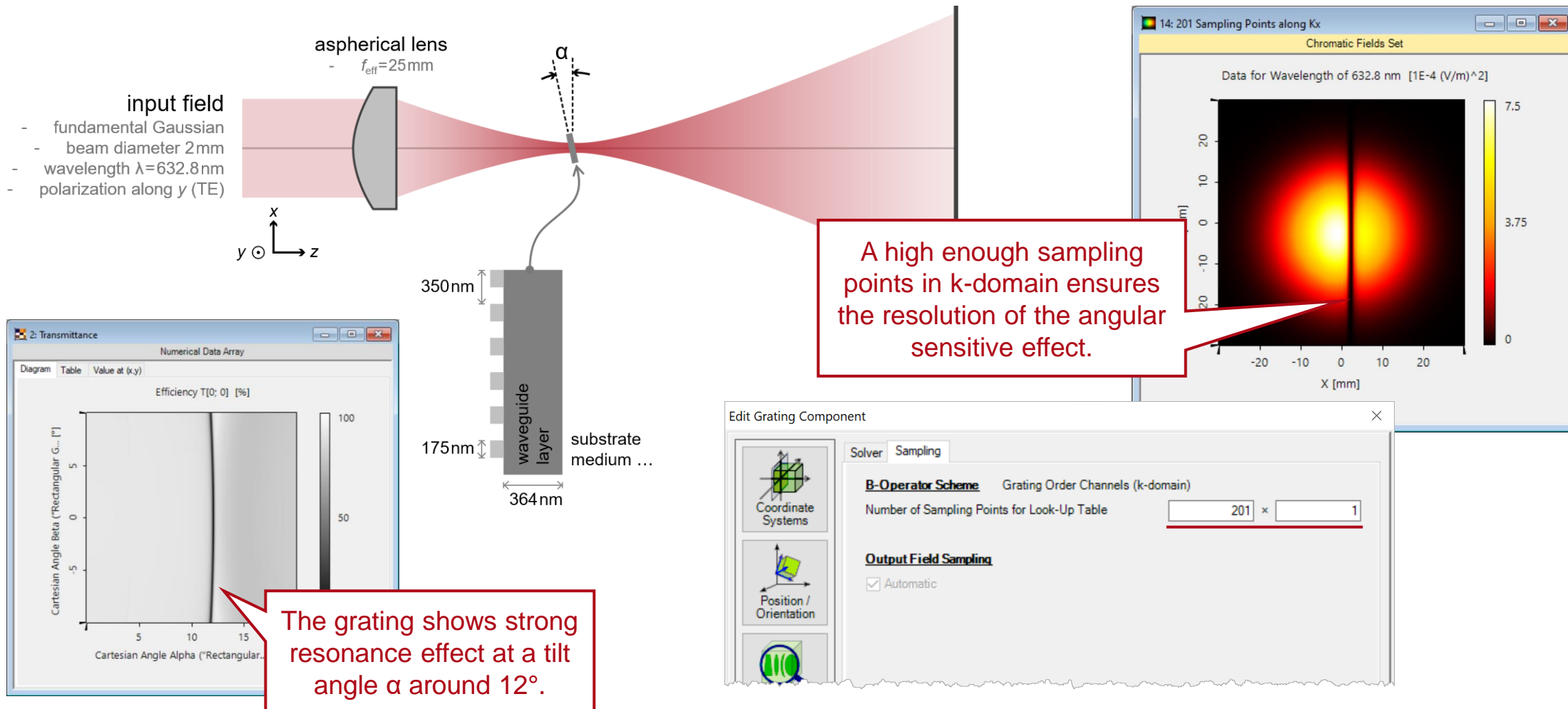


[see the full Application Use Case](#)

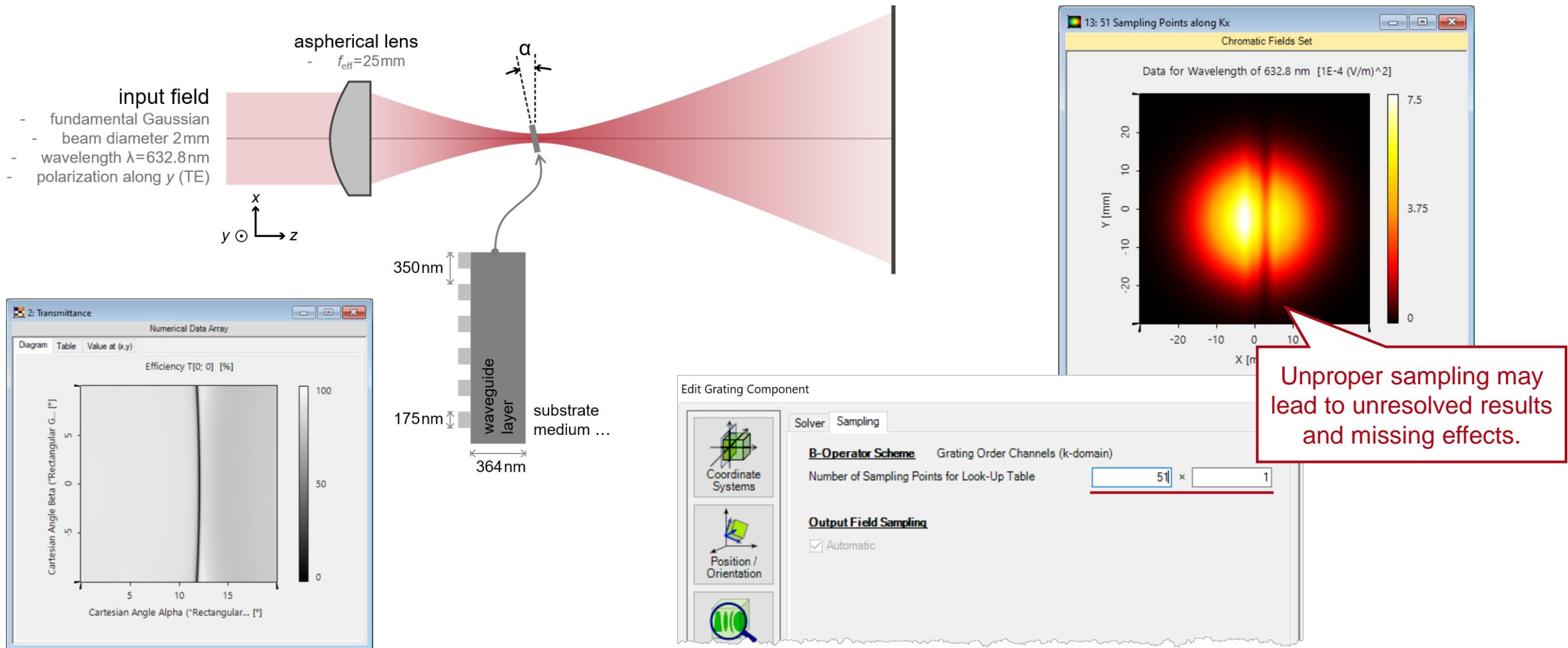
Substrate Handling



Angular Response of Resonant Waveguide Grating

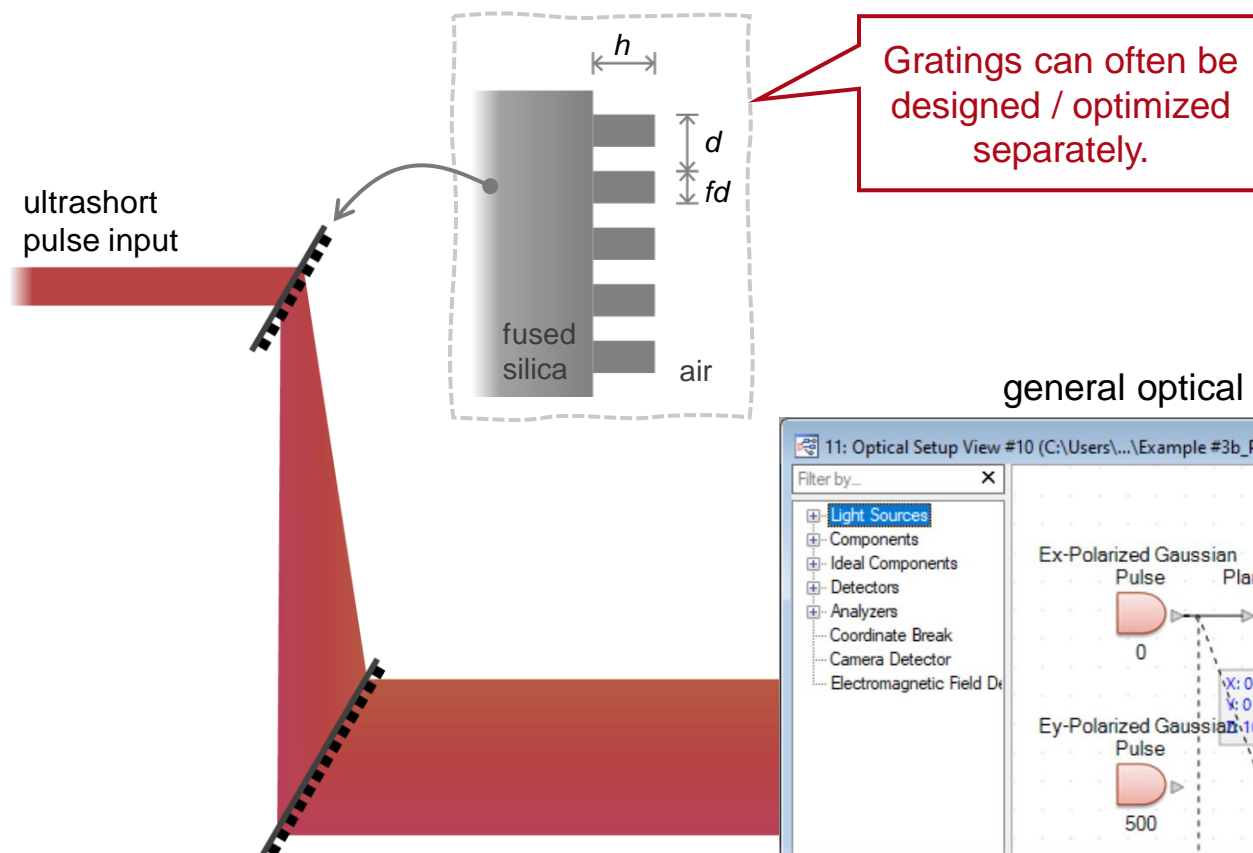


Angular Response of Resonant Waveguide Grating

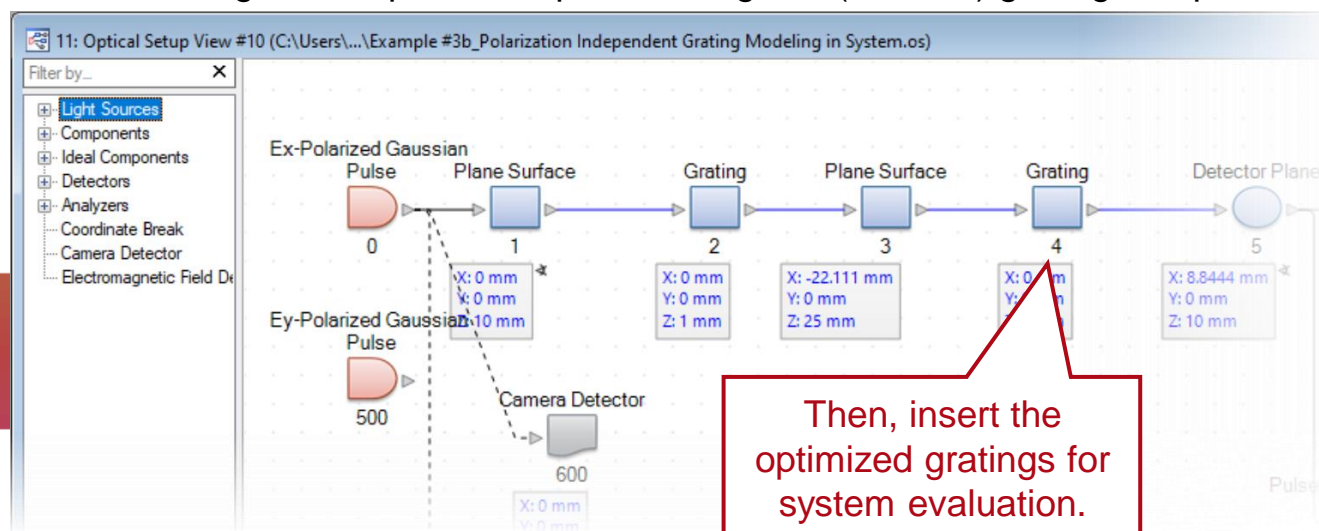


Example #3: Design Polarization-Independent Gratings and Usage in Ultrashort Pulse System

Gratings for Ultrashort Pulse Application



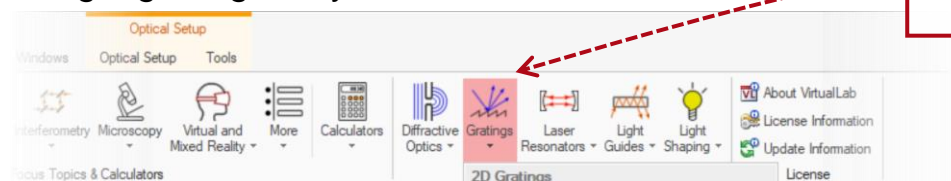
general optical setup containing two (or more) grating components



[see the full Application Use Case](#)

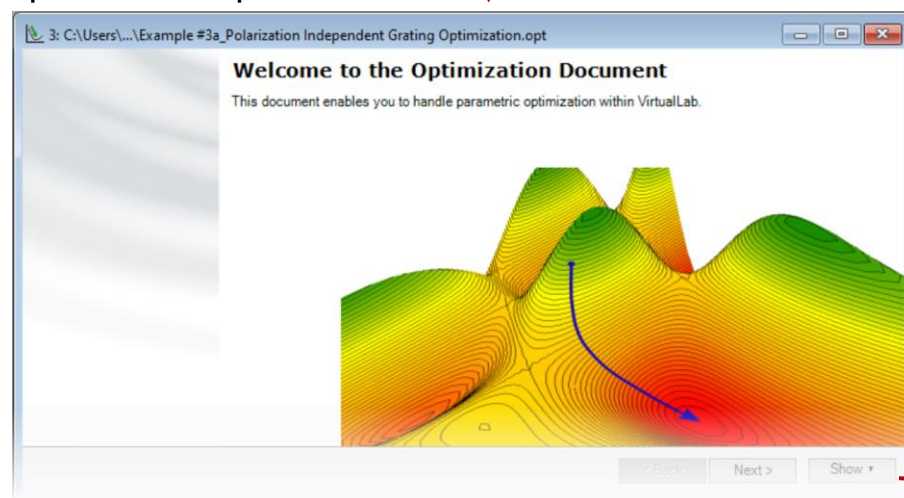
Design and Modeling Workflow

single grating analysis

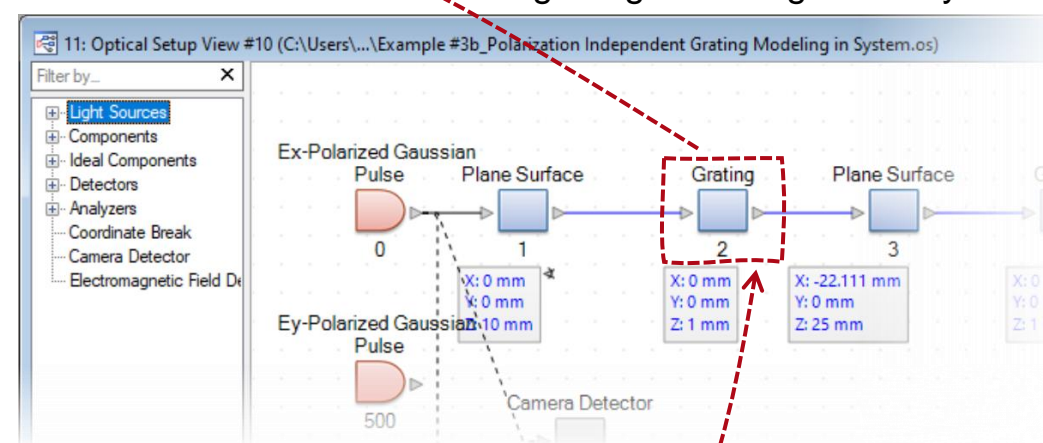


Isolate the grating for careful design / optimization.

parametric optimization



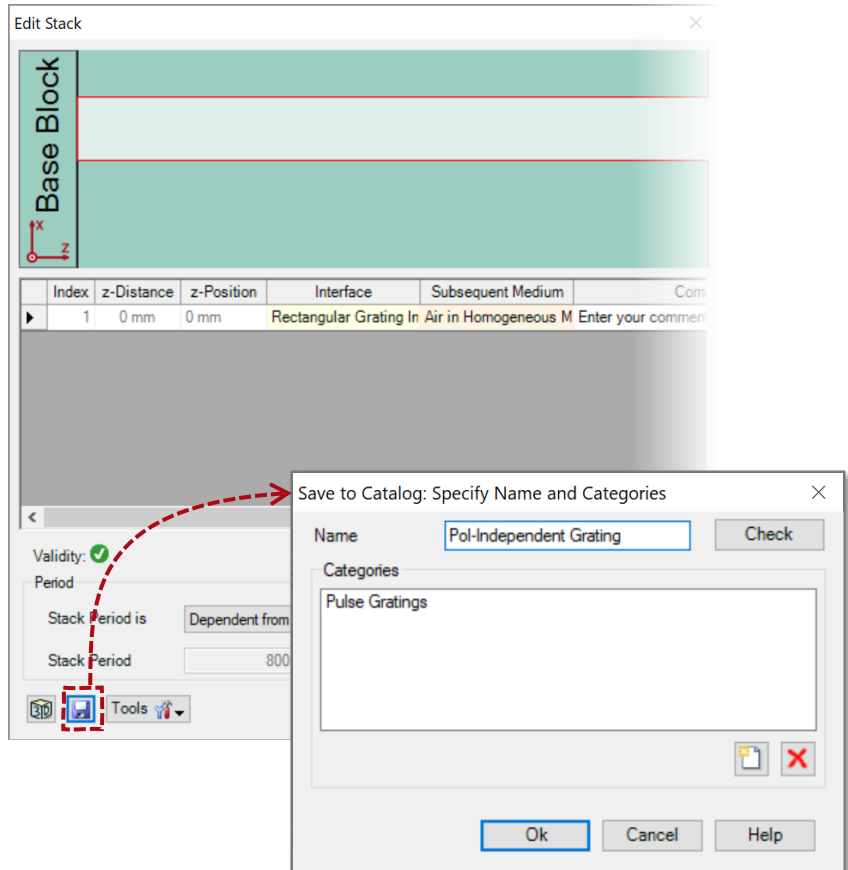
grating modeling within system



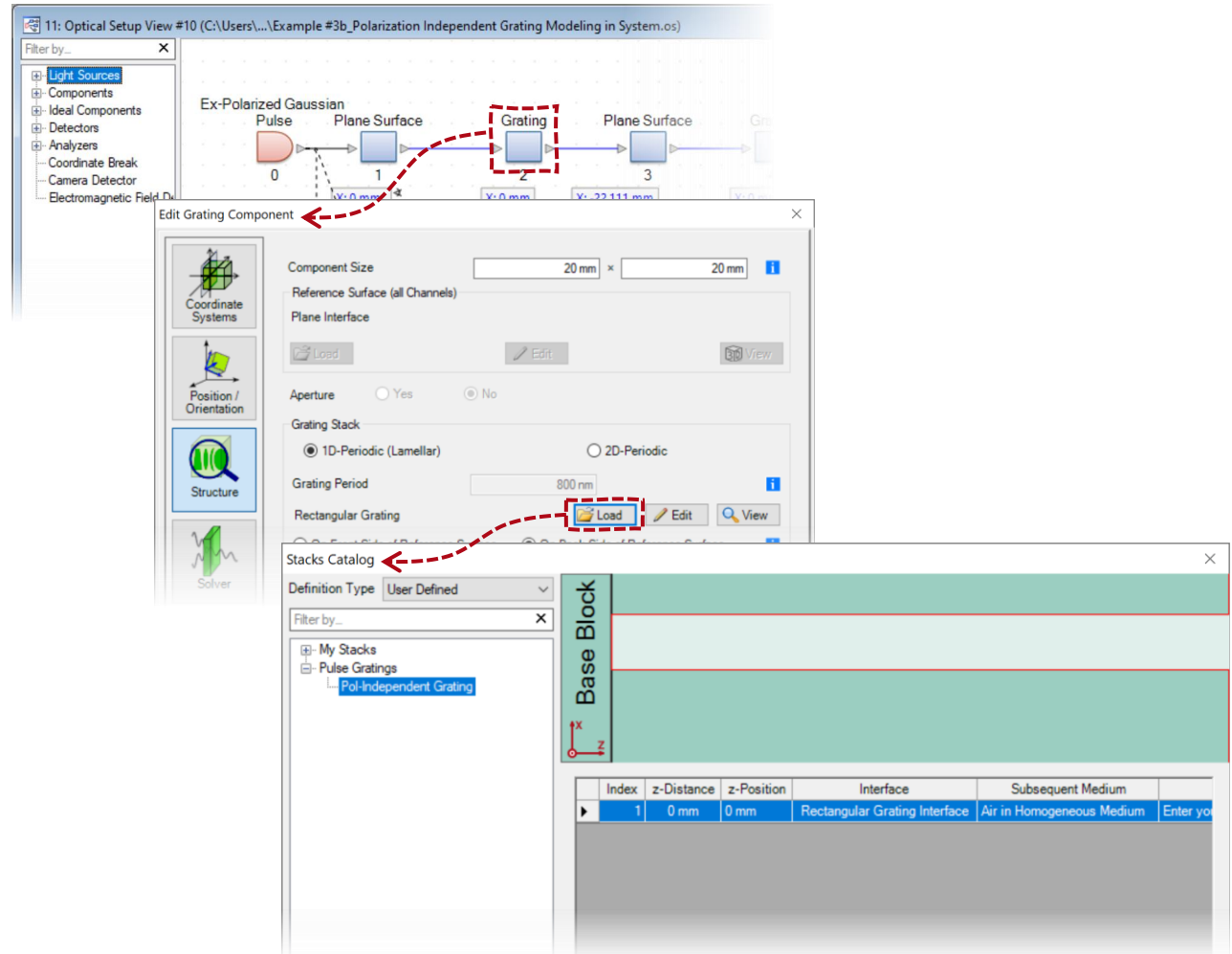
Insert the optimized grating back into system evaluation.

Exchange Gratings between Different Setups

example: optimized grating structure



general optical setup containing gratings

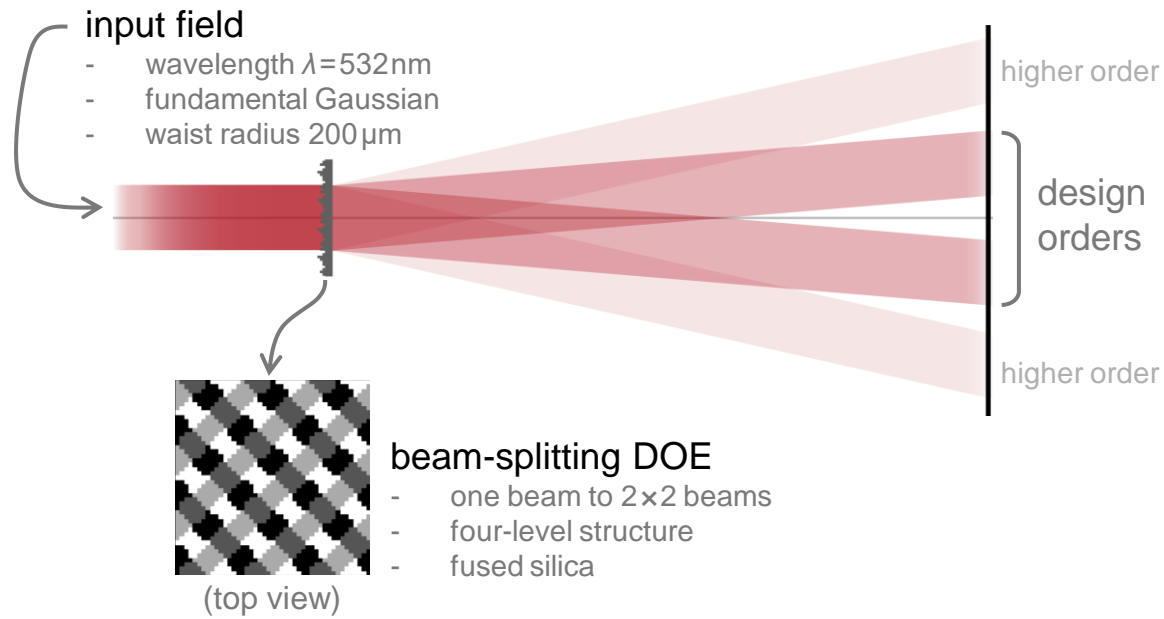


Document Information

title	Modeling of Gratings within Optical System – Discussion at Examples
document code	MISC.0005
version	1.0
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 2.8)
category	Feature Use Case
further reading	<ul style="list-style-type: none">- <u>Configuration of Grating Structures by Using Interfaces</u>- <u>Configuration of Grating Structures by Using Special Media</u>- <u>VirtualLab Fusion Technology – FMM / RCWA [S-Matrix]</u>

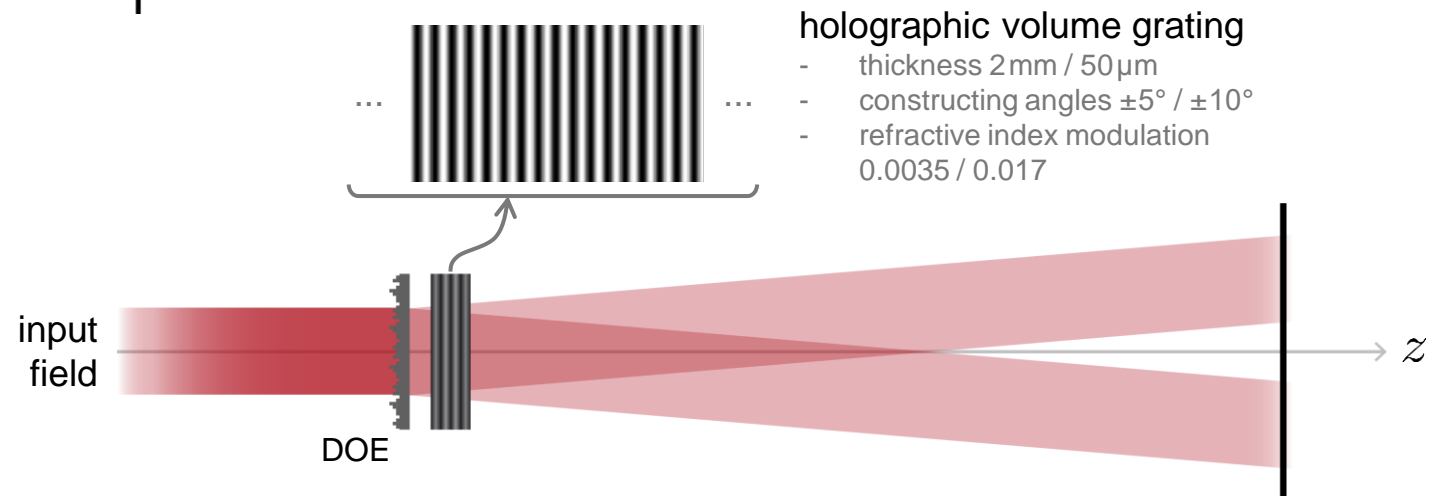
Angular-Filtering Volume Gratings for Suppressing Higher Diffraction Orders

Modeling Task



On the holographic volume grating, we show

- how to analysis its angular sensitivity, and
- how to use it as an angular filter in e.g. a DOE beam-splitting system to get rid of the undesired higher diffraction orders.

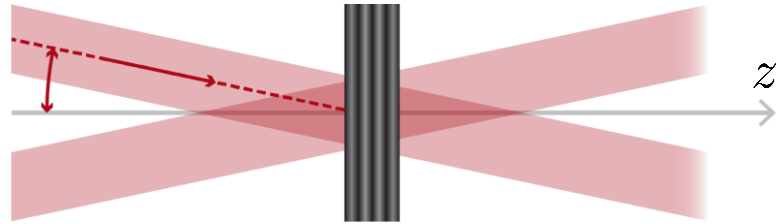


volume grating parameters from K. Bang, *et al.*, Opt. Lett. 44, 2133-2136 (2019)

Grating Angular Transmittance Analysis (5° Design)

input field

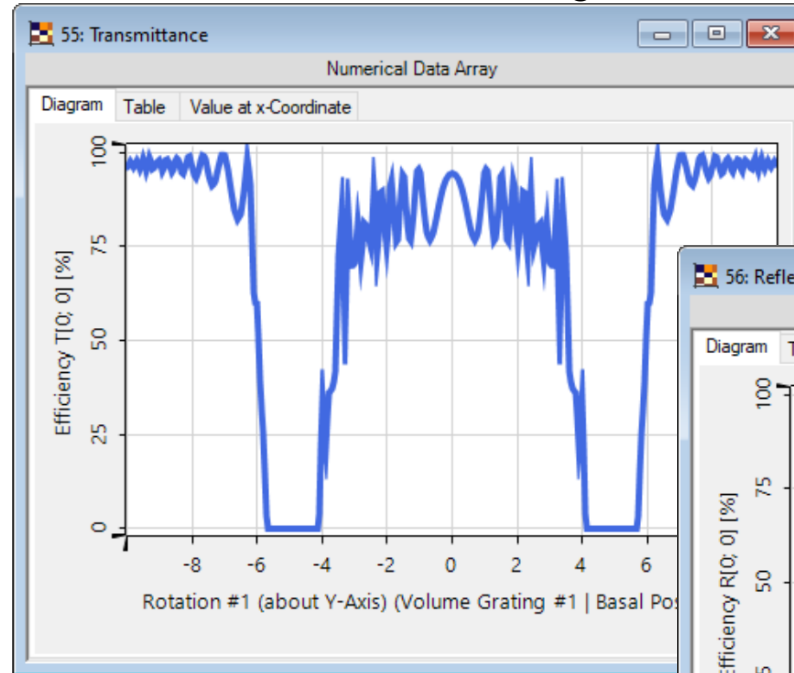
- wavelength $\lambda=532\text{nm}$
- plane wave
- incidence angle from -10 to $+10^\circ$



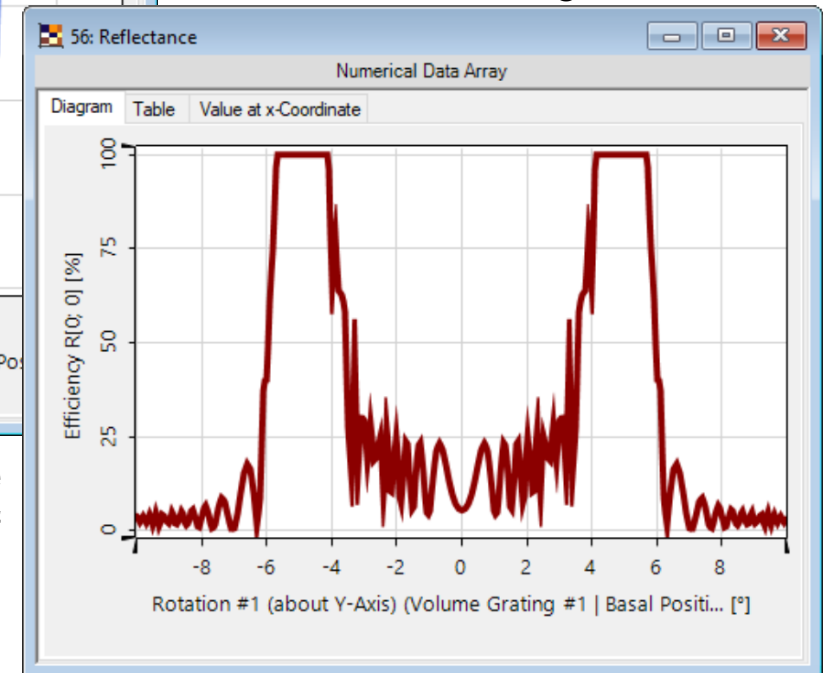
volume grating

- thickness 2 mm
- constructing angle $\pm 5^\circ$
- refractive index modulation 0.0035

transmittance vs angle



reflectance vs angle

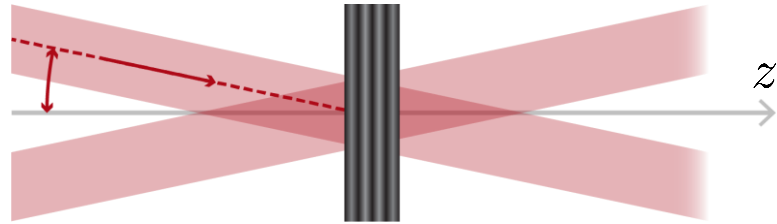


The FMM / RCWA is used to calculate the transmittance and reflectance of the holographic volume grating.

Grating Angular Transmittance Analysis (10° Design)

input field

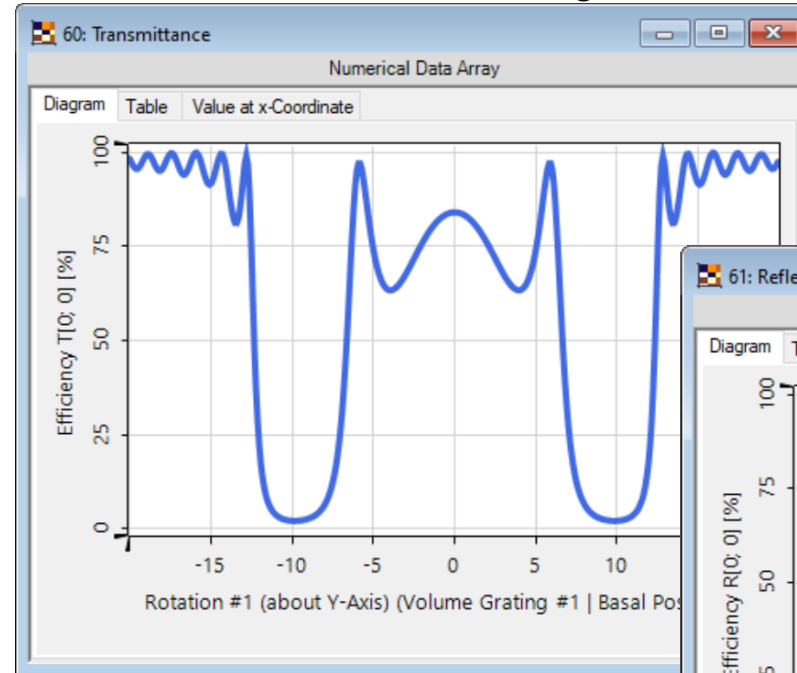
- wavelength $\lambda=532\text{nm}$
- plane wave
- incidence angle from -20 to $+20^\circ$



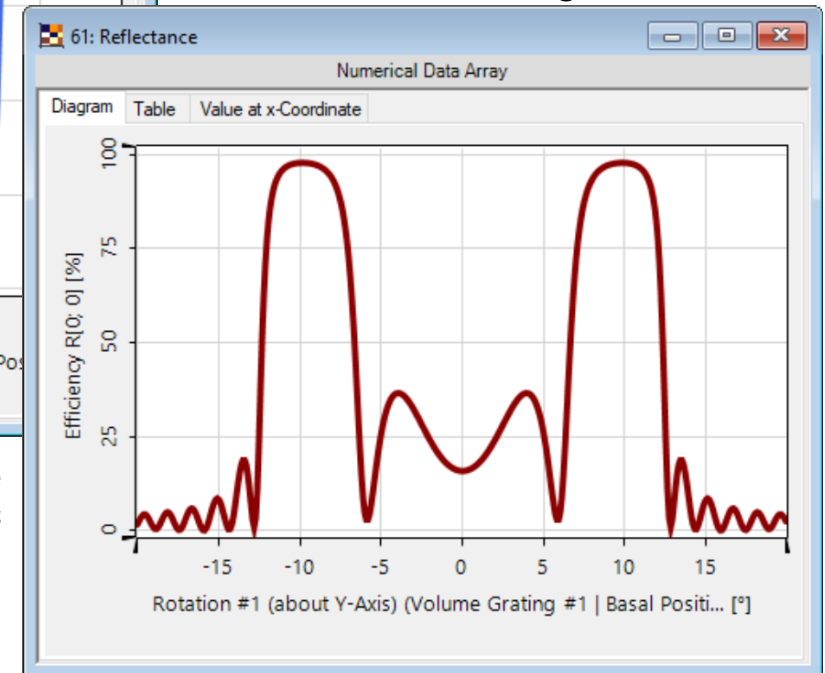
volume grating

- thickness $50\mu\text{m}$
- constructing angle $\pm 10^\circ$
- refractive index modulation 0.017

transmittance vs angle

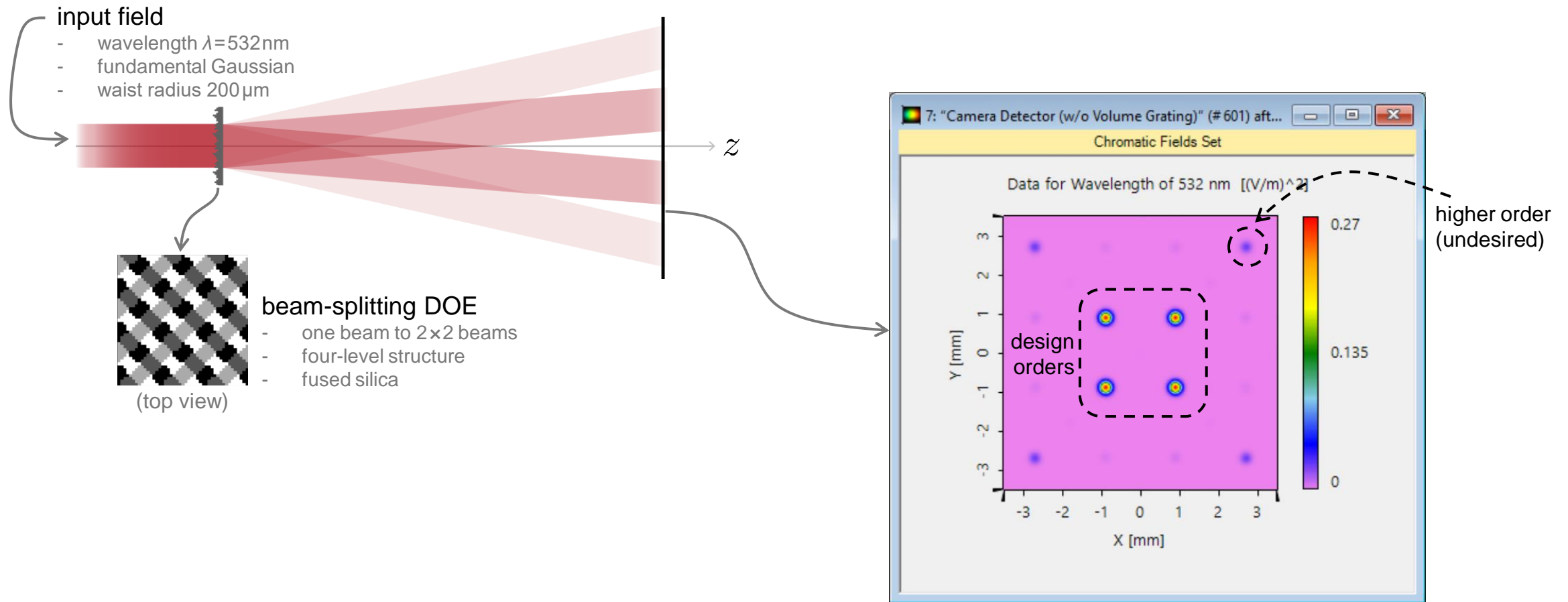


reflectance vs angle

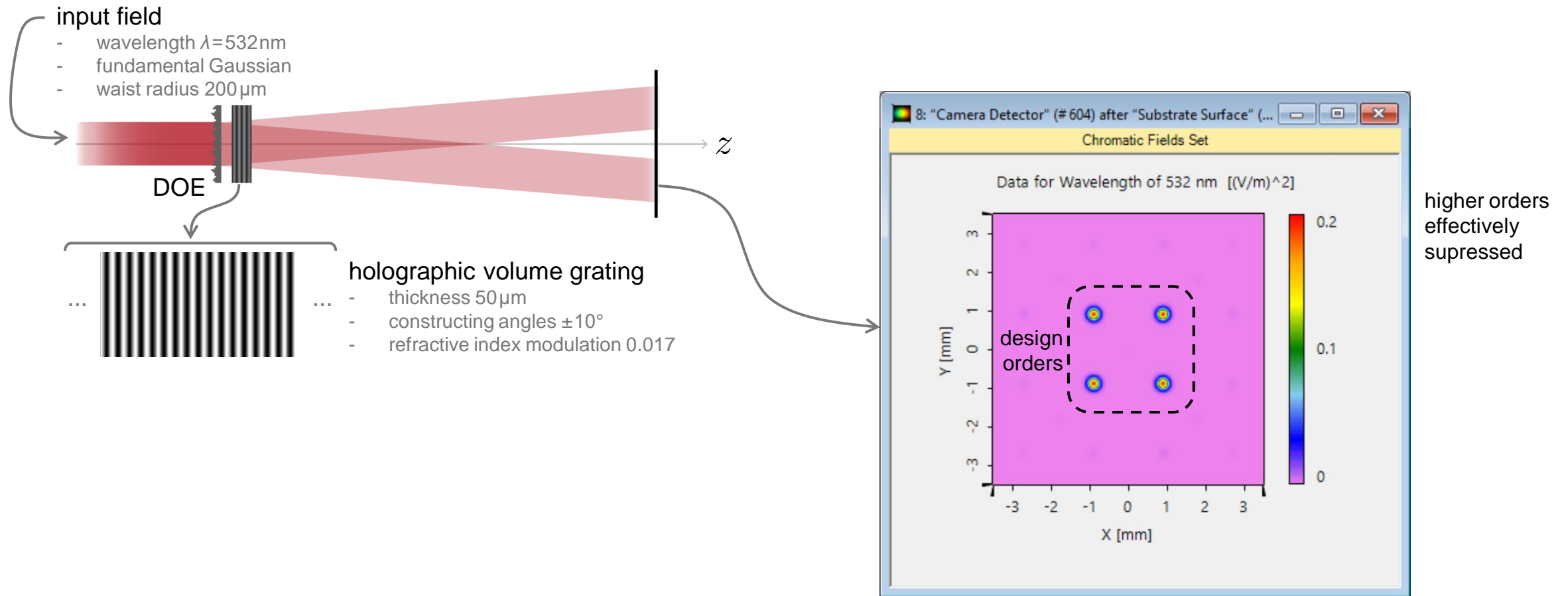


The FMM / RCWA is used to calculate the transmittance and reflectance of the holographic volume grating.

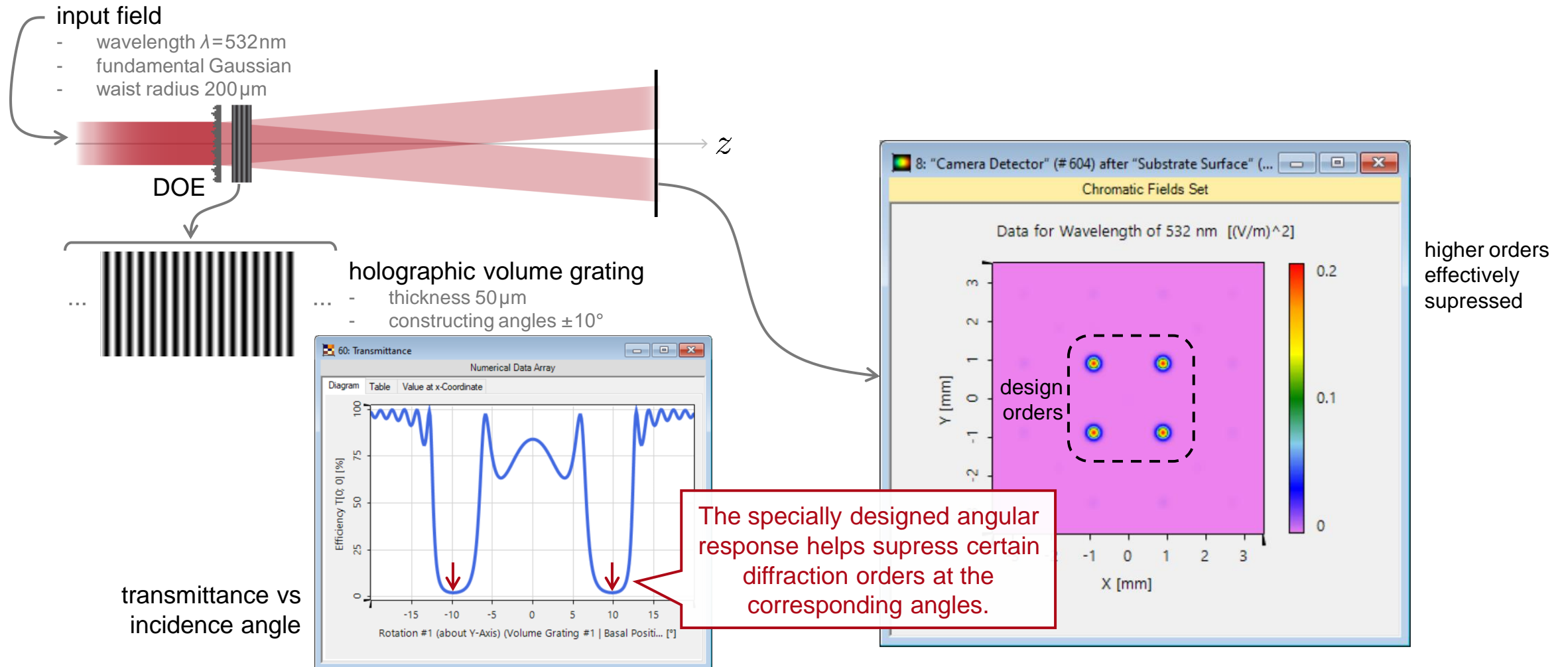
Original Beam-Splitting DOE System



Angular Filtering Effect of Volume Grating

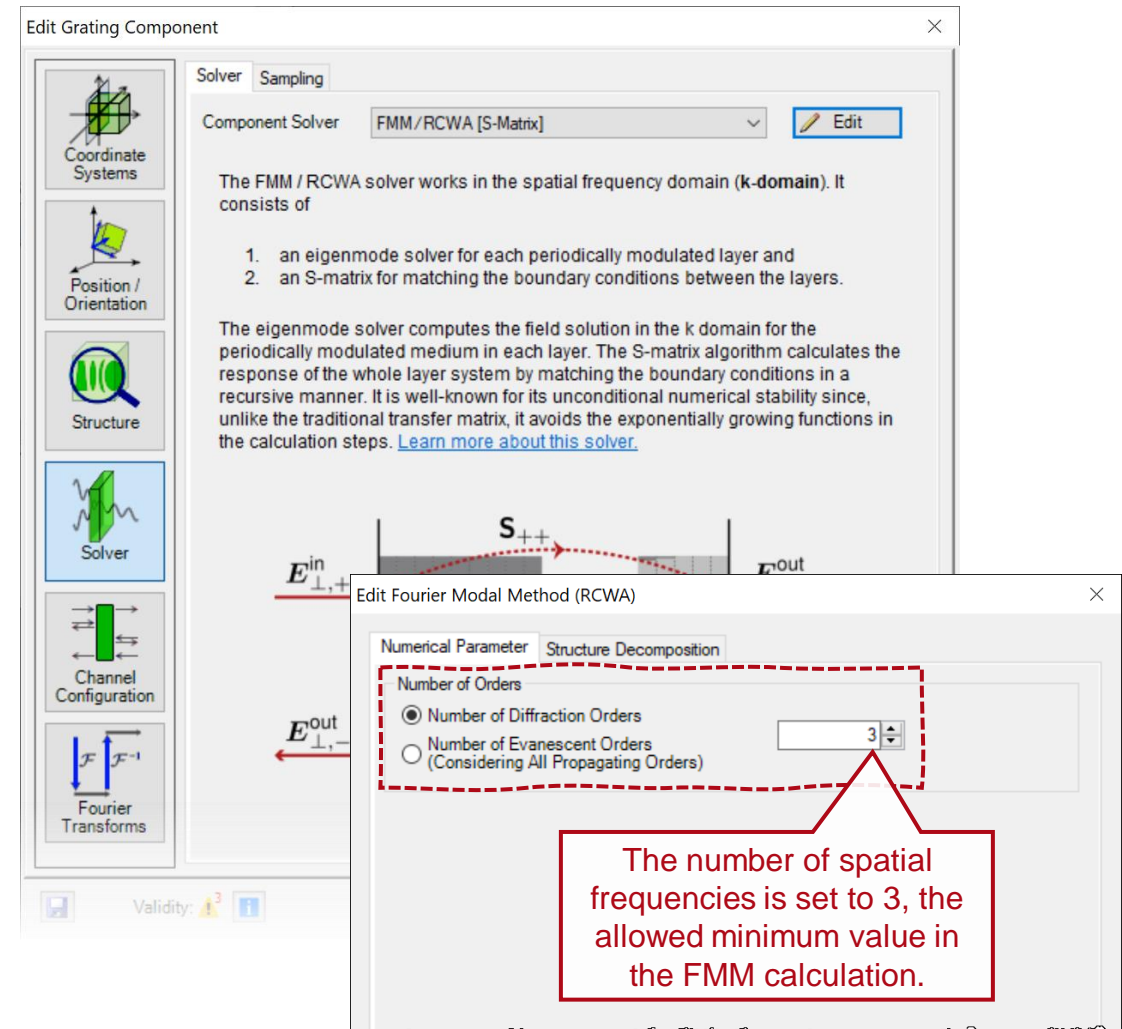
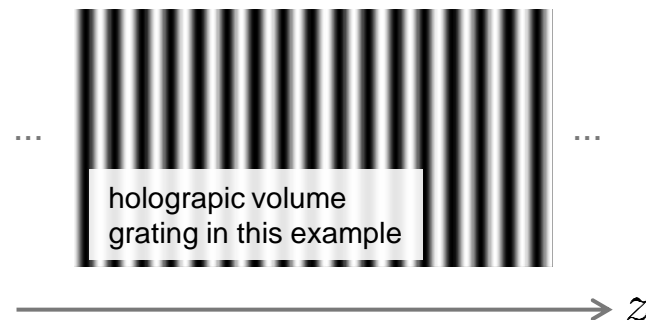


Angular Filtering Effect of Volume Grating



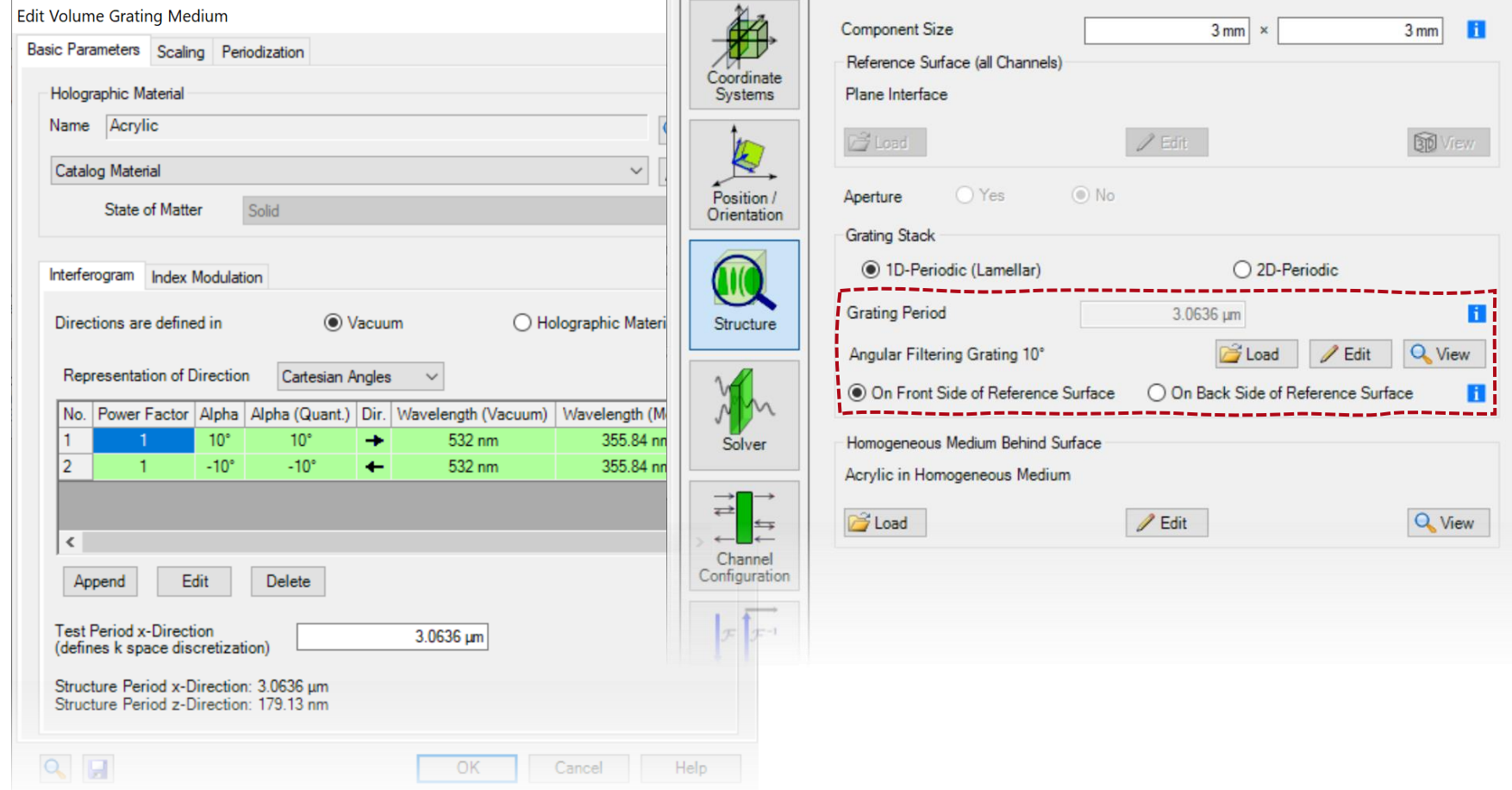
Note on Simulation Settings

- FMM / RCWA simulation setting
 - The refractive index of the holographic volume grating, in this example, varies only along the z-axis, but there is no transverse variation.
 - For such cases, there is no need to expand the electromagnetic field into multiple spatial frequency components in the FMM / RCWA calculation.



Peek into VirtualLab Fusion

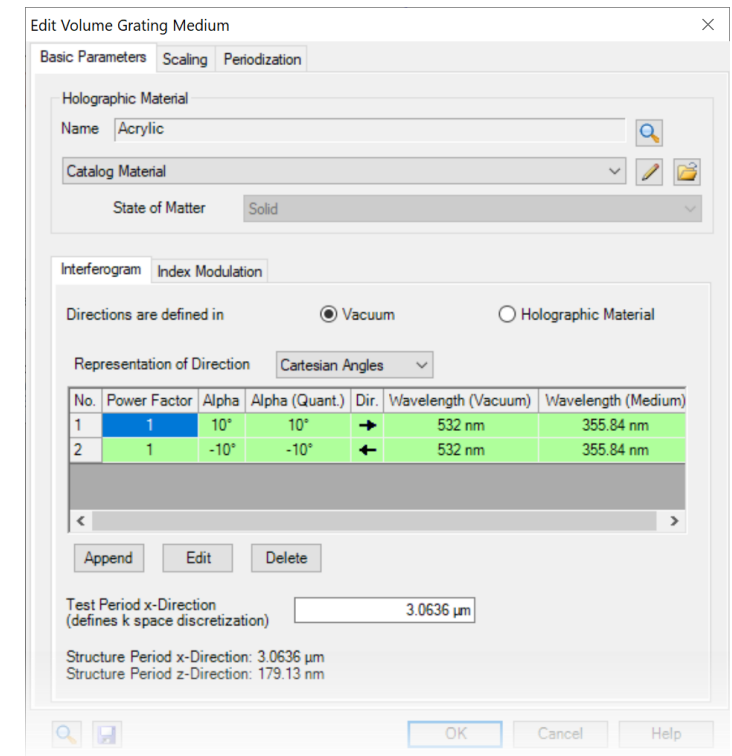
configuration of volume gratings



convenient inclusion of e.g. the volume grating into general system for further investigation

Workflow in VirtualLab Fusion

- Construct grating structures using special media
 - [Configuration of Grating Structures by Using Special Media](#) [Use Case]
- Rigorous analysis of holographic volume gratings
 - [Rigorous Simulation of Holographic Generated Volume Grating](#) [Use Case]
- Grating modeling within complex system
 - [Modeling of Gratings within Optical System - Discussion at Examples](#) [Use Case]



Document Information

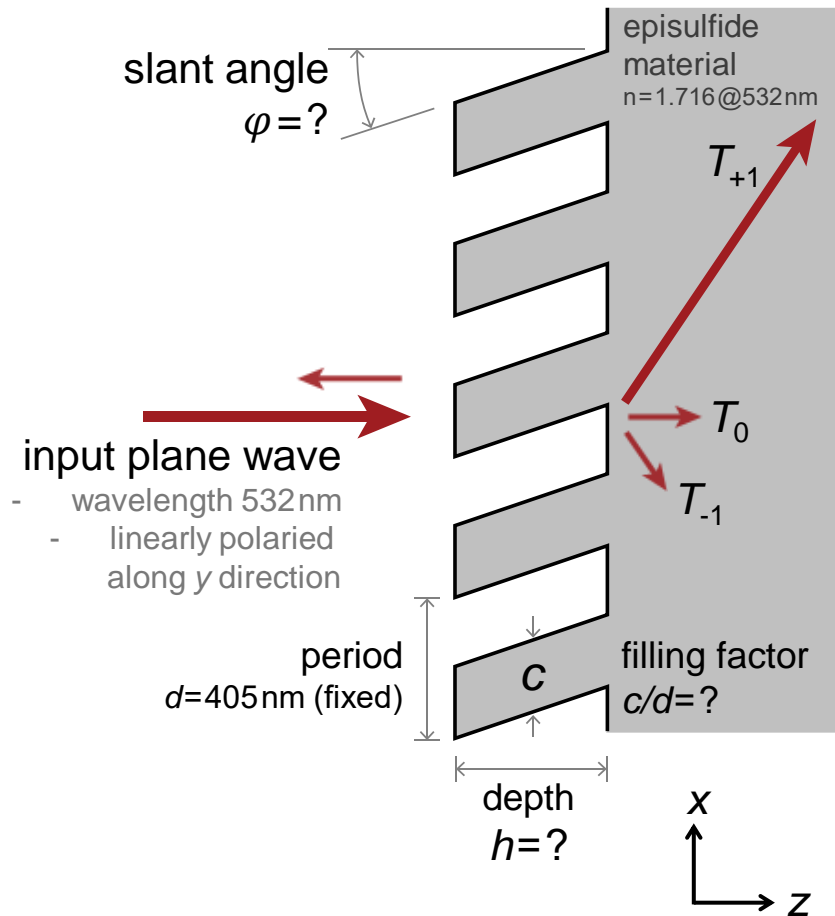
title	Angular-Filtering Volume Gratings for Suppressing Higher Diffraction Orders
document code	GRT.0025
version	1.1
edition	VirtualLab Fusion Advanced
software version	2020.2 (Build 1.116)
category	Application Use Case
further reading	<ul style="list-style-type: none">- Rigorous Simulation of Holographic Generated Volume Grating- Modeling of Gratings within Optical System - Discussion at Examples

Part III

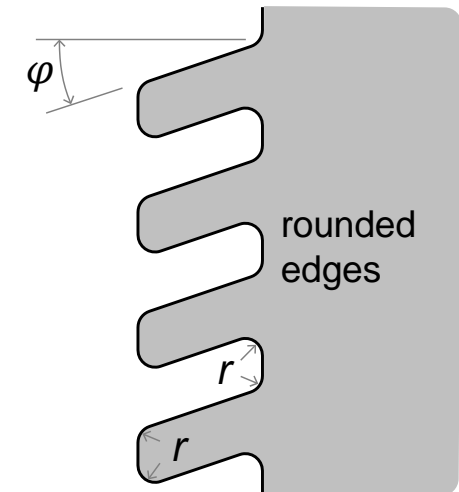
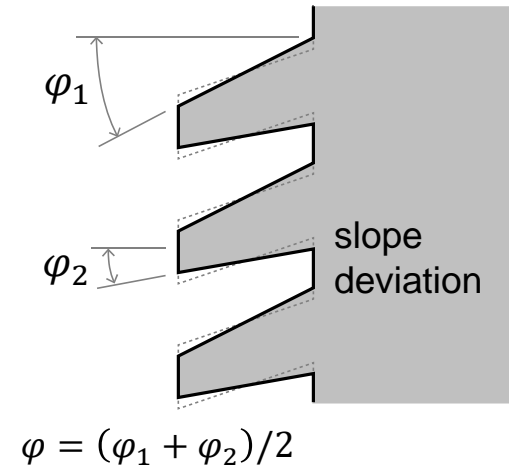
- Optimization of slanted grating for waveguide coupling
- Parametric optimization tool
- Design of polarization-independent high-efficiency gratings
- Design of anti-reflection moth-eye structures

Parametric Optimization and Tolerance Analysis of Slanted Gratings

Modeling Task



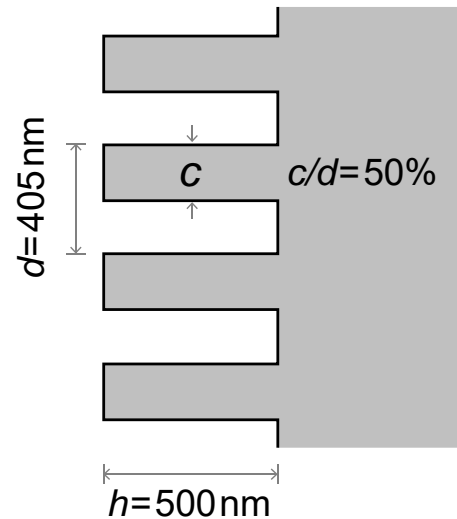
How to optimize the T_{+1} order diffraction efficiency, by adjusting the slant angle φ , grating depth h , and filling factor c/d ?



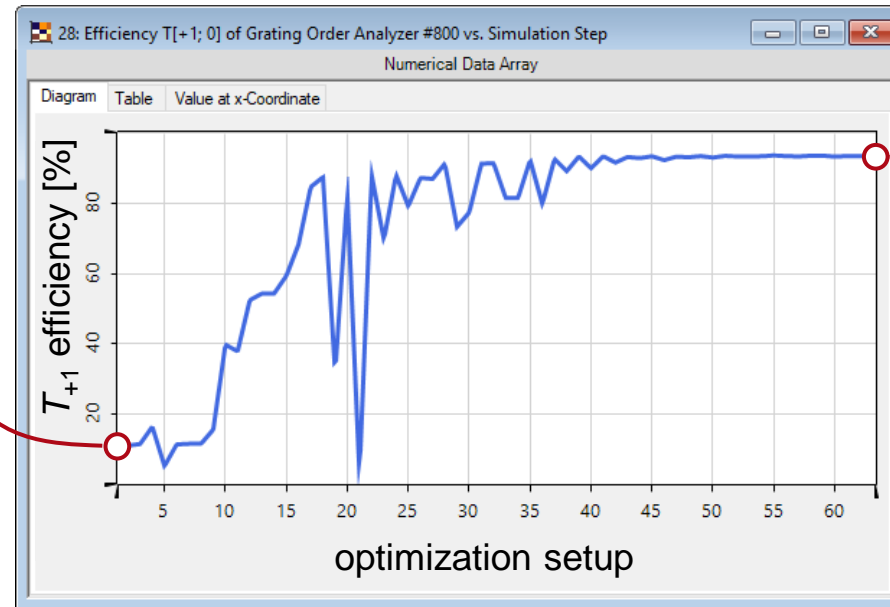
In addition, how to evaluate the grating performance with the slope deviation and the rounded edges due to the fabrication technique taken into account?

Parametric Optimization for 1st Order

initial structure

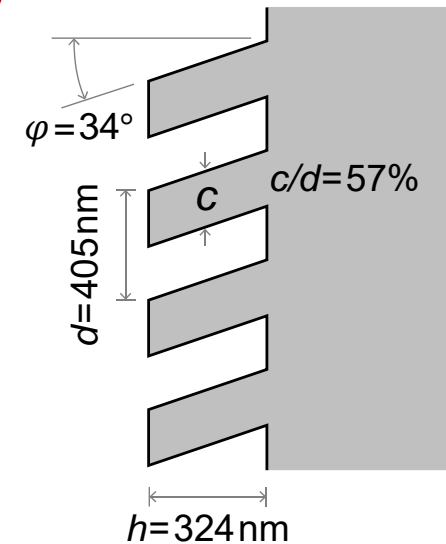


Order	Efficiency
-1	11.551%
0	72.795%
+1	11.551%



parametric optimization – downhill simplex method – with rigorous Fourier modal method (FMM) used for grating efficiency calculation

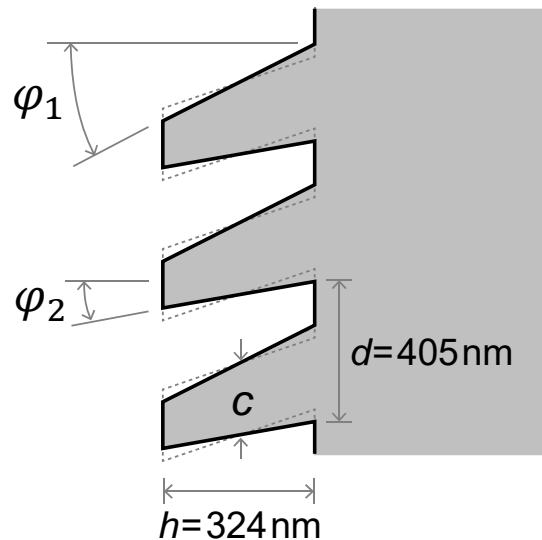
optimized structure



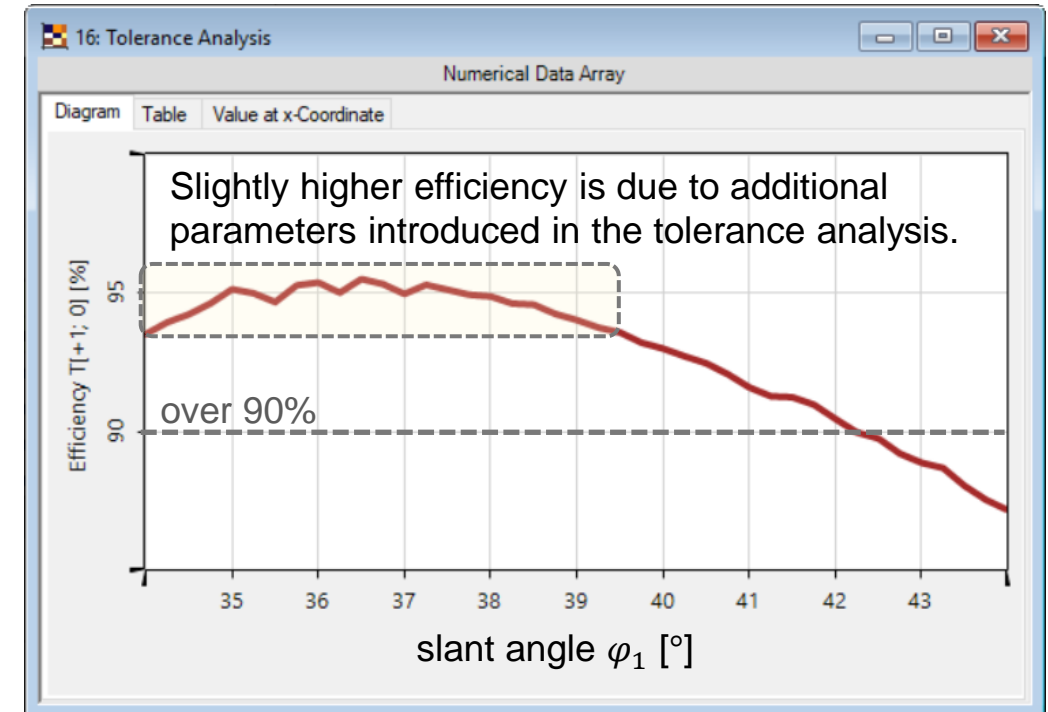
Order	Efficiency
-1	3.257%
0	0.365%
+1	93.659%

Results – Tolerance Analysis

The fabricated slanted gratings often shows a deviation from the perfect parallel grating lines. Such slope deviations should be taken into account for the tolerance analysis.



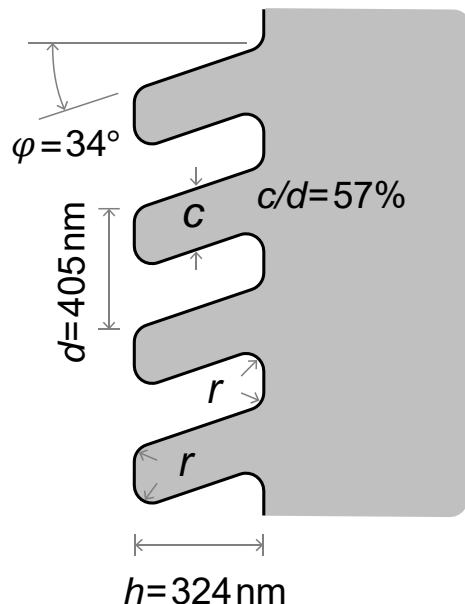
- fixed average slant angle $\varphi = (\varphi_1 + \varphi_2)/2 = 34^\circ$
- fixed filling factor (average) $c/d=57\%$
- varying φ_1 from 34 to 44°



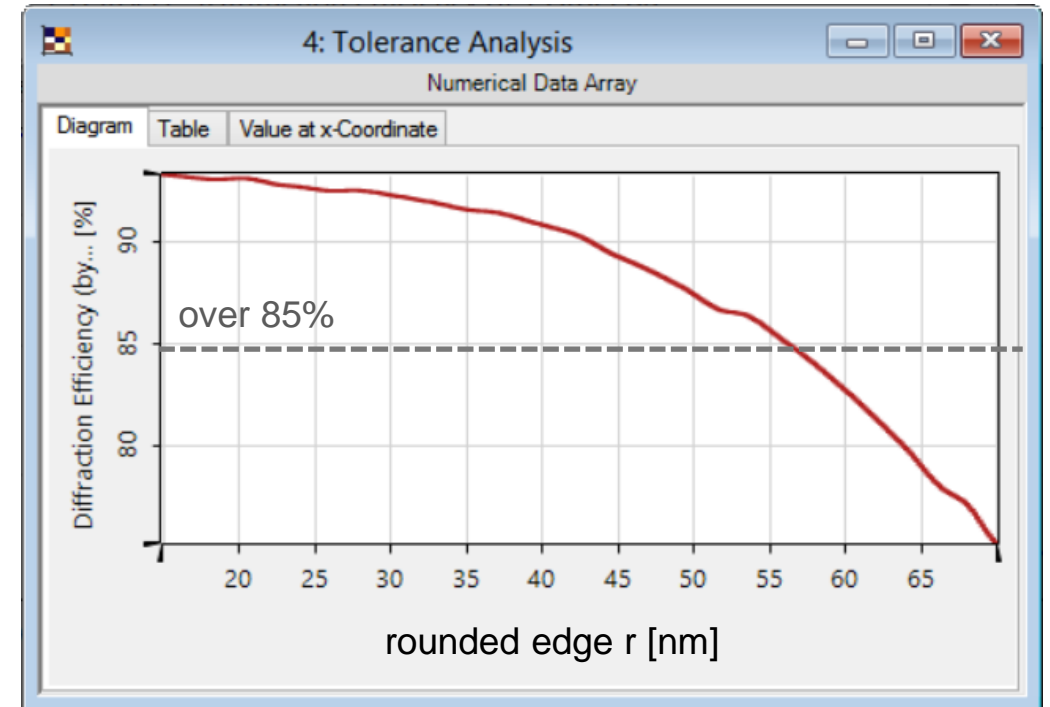
Rigorous simulation with Fourier modal method (FMM), for tolerance analysis over 50 steps, takes 30 seconds.

Results – Tolerance Analysis

The fabricated slanted gratings often shows a deviation from the perfect parallel grating lines. The rounded edges should be taken into account for the tolerance analysis.



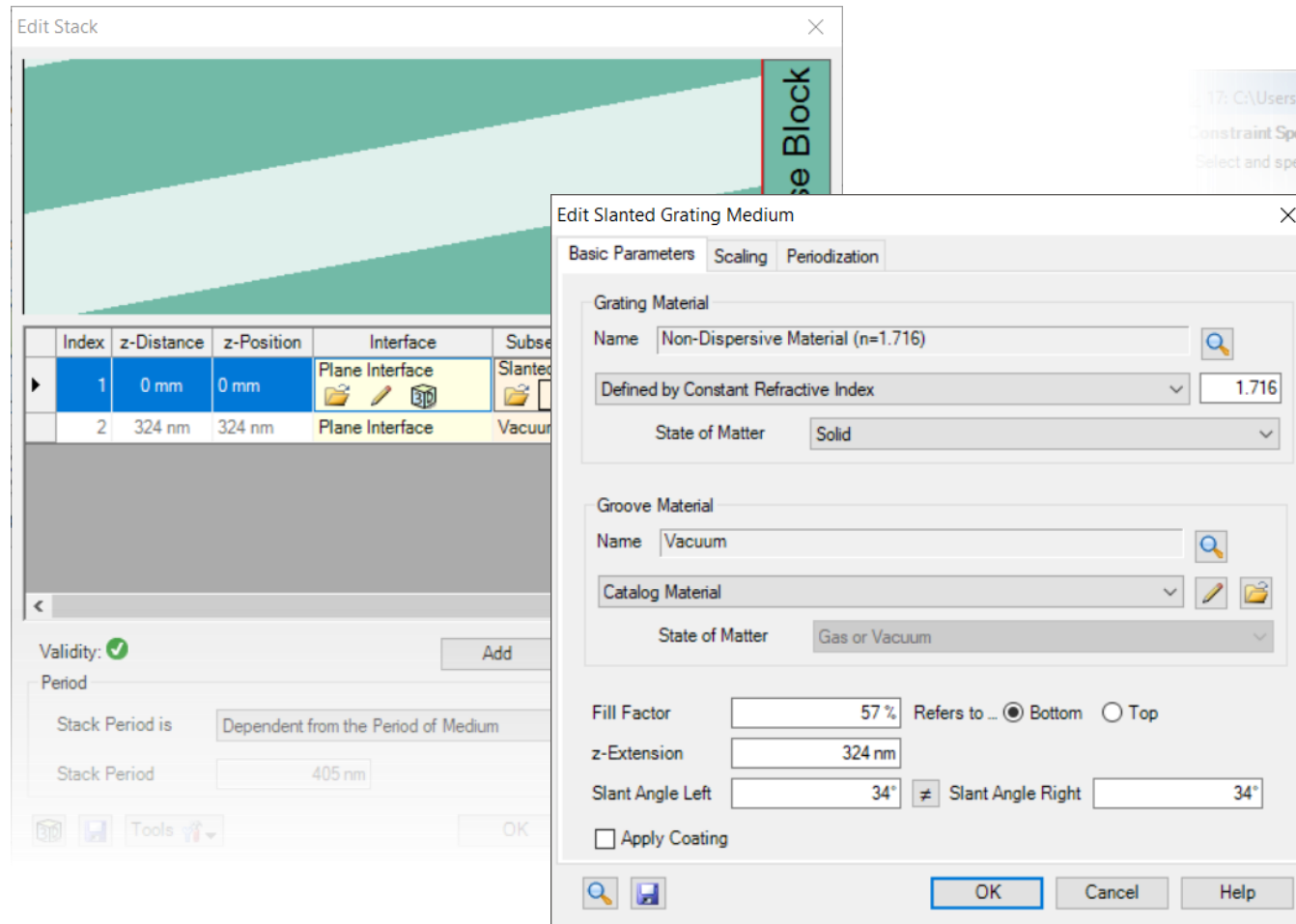
- fixed average slant angle $\varphi = 34^\circ$
- fixed filling factor $c/d = 57\%$
- varying r from 15 nm to 70 nm



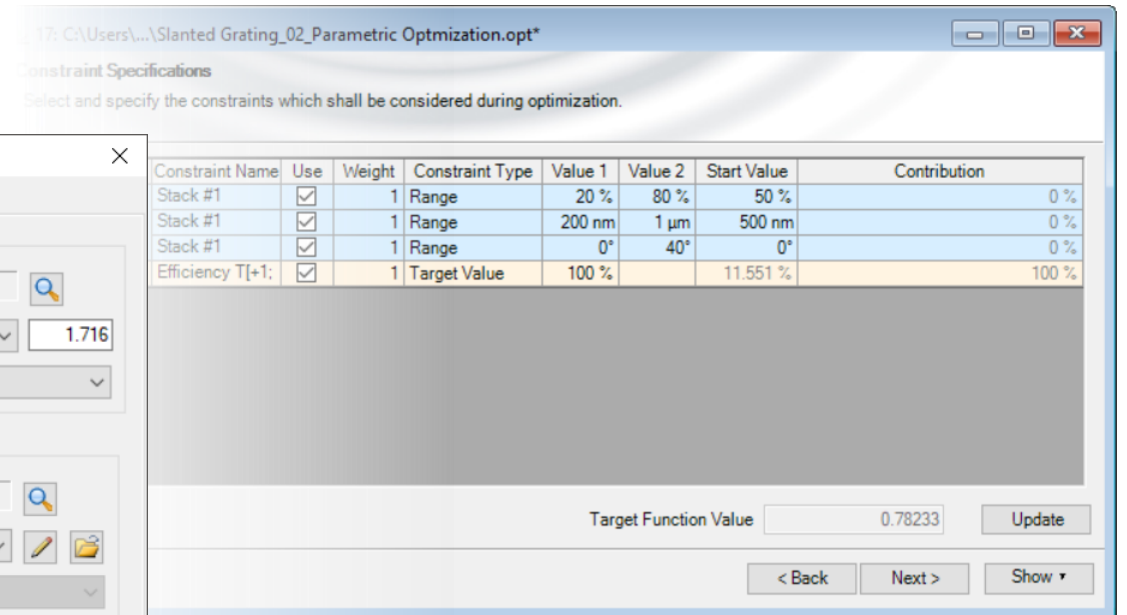
Rigorous simulation with Integral Method (IM), for tolerance analysis over 30 steps, takes 9 seconds.

Peek into VirtualLab Fusion

flexible and easy settings of slanted gratings

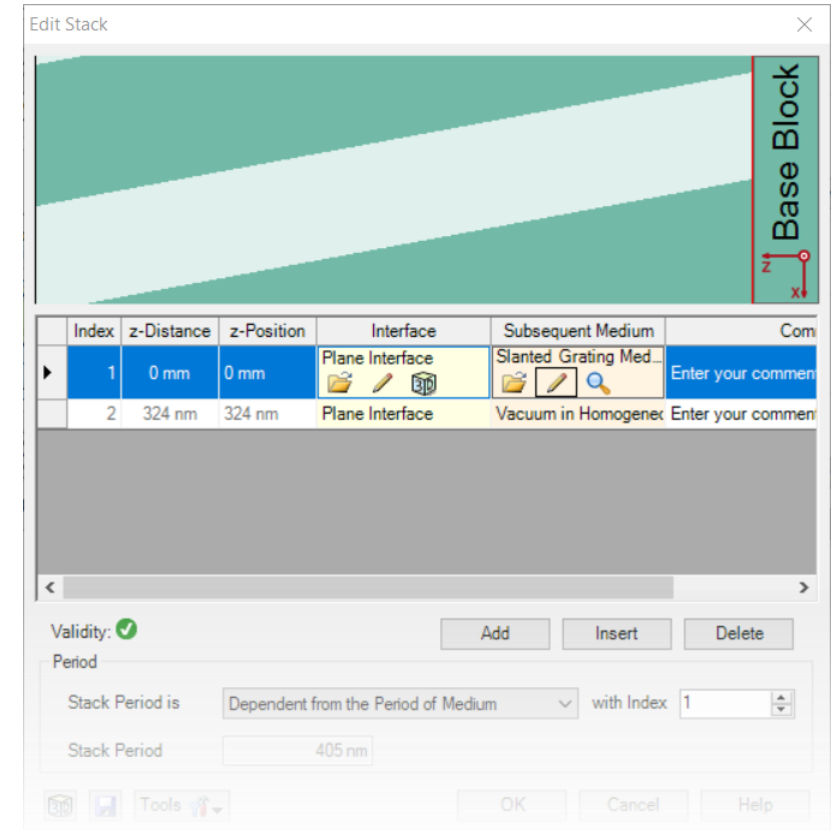


parametric optimization of grating parameters



Workflow in VirtualLab Fusion

- Construct grating structure
 - [Configuration of Grating Structures by Using Special Media](#) [Use Case]
 - [Advanced Configuration of Slanted Gratings](#) [Use Case]
- Analyze grating diffraction efficiency
 - [Grating Order Analyzer](#) [Use Case]
- Optimize grating parameters with Parametric Optimization
- Tolerance analysis with Parameter Run
 - [Usage of the Parameter Run Document](#) [Use Case]

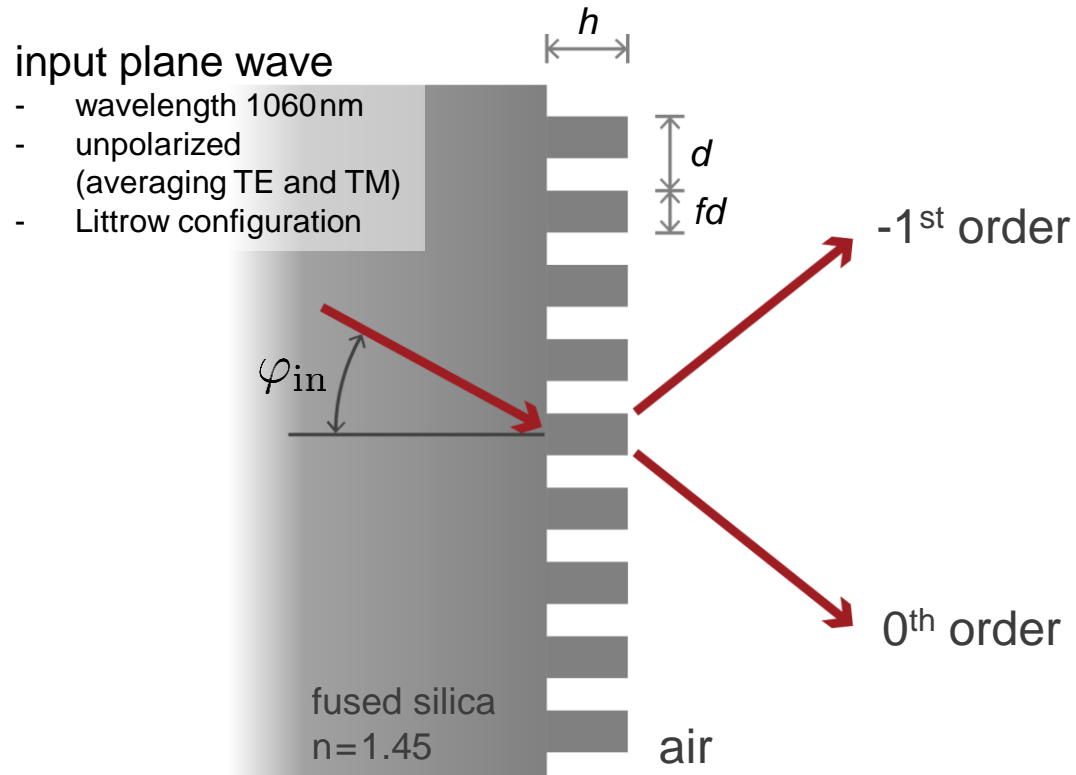


Document Information

title	Parametric Optimization and Tolerance Analysis of Slanted Gratings
document code	GRT.0007
version	1.2
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.202)
category	Application Use Case
further reading	<ul style="list-style-type: none">- <u>Analysis of Slanted Gratings for Lightguide Coupling</u>- <u>Optimization of Lightguide Coupling Grating for Single Incidence Direction</u>

Analysis and Design of Highly Efficient Polarization Independent Transmission Gratings

Design Task



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

?

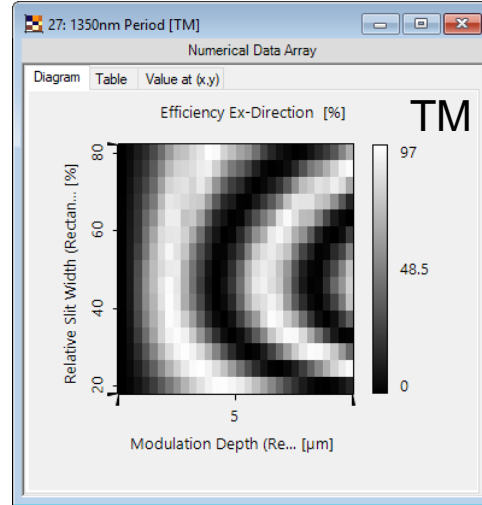
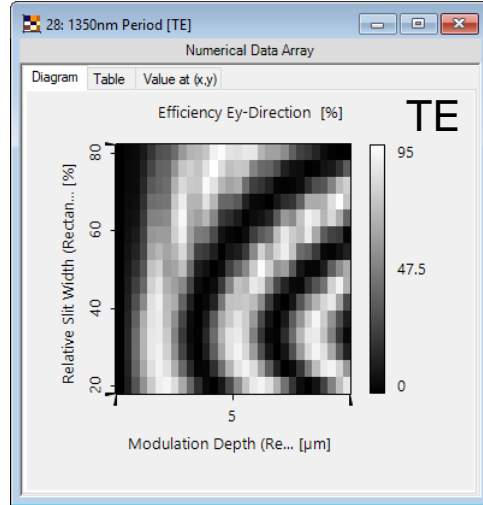
Parameter	Value Range
grating depth h	0.1 - 10 μ m
grating period d	550 - 1350nm
fill factor f	20 - 80%

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

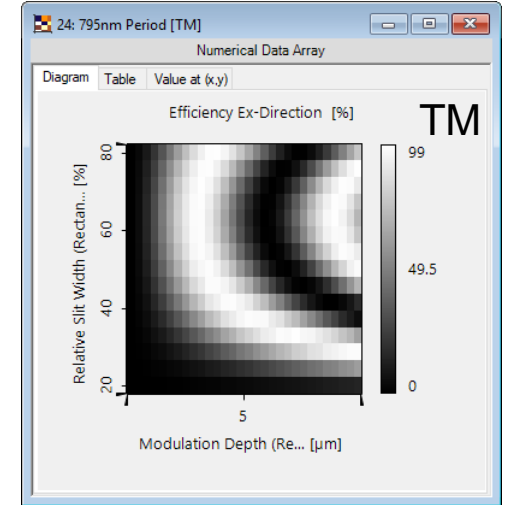
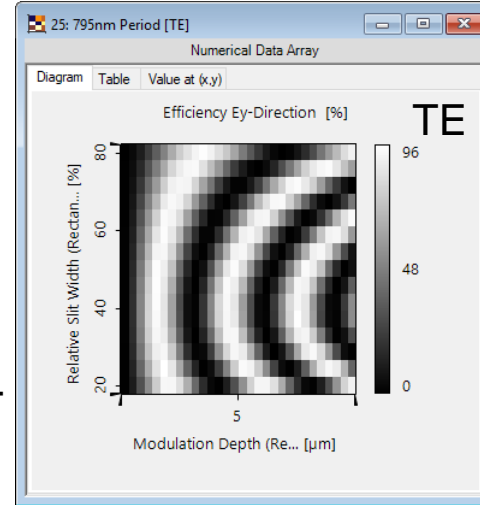
Rigorous Analysis of Grating Property vs. Parameters

Diffraction Efficiency @ Different Grating Periods

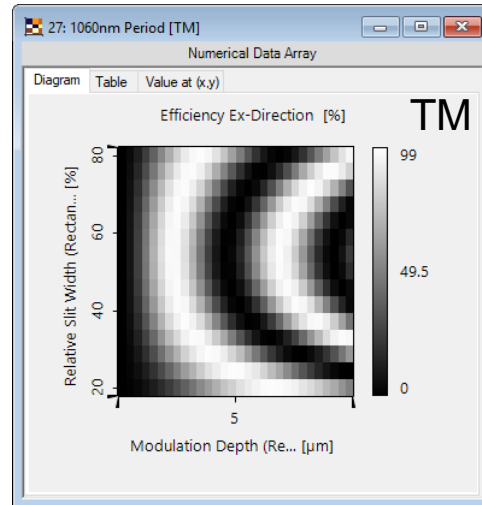
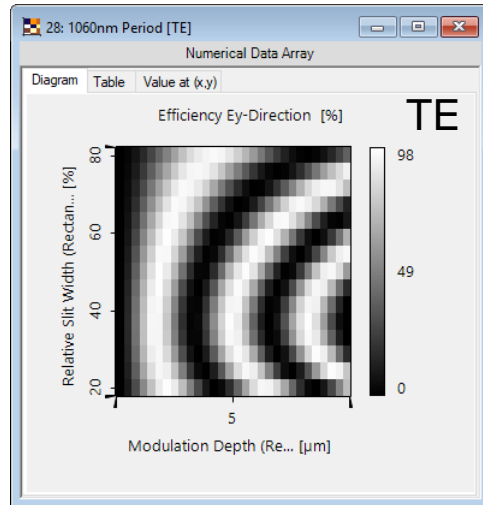
period = 1350 nm



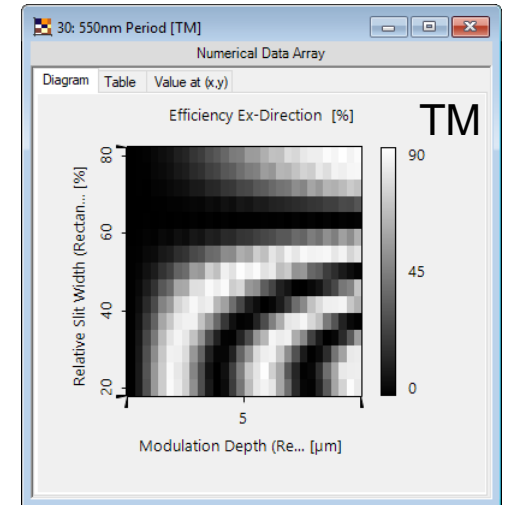
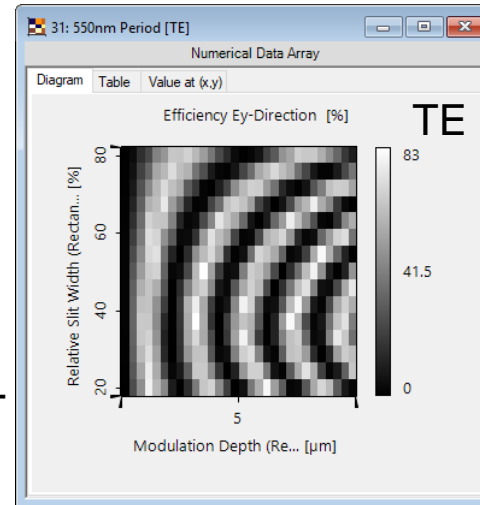
period = 795 nm



period = 1060 nm



period = 550 nm



Considerations on Grating Period Choice

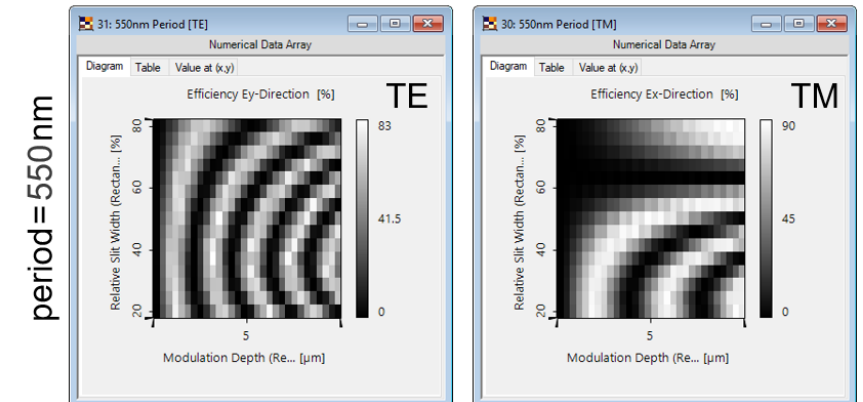
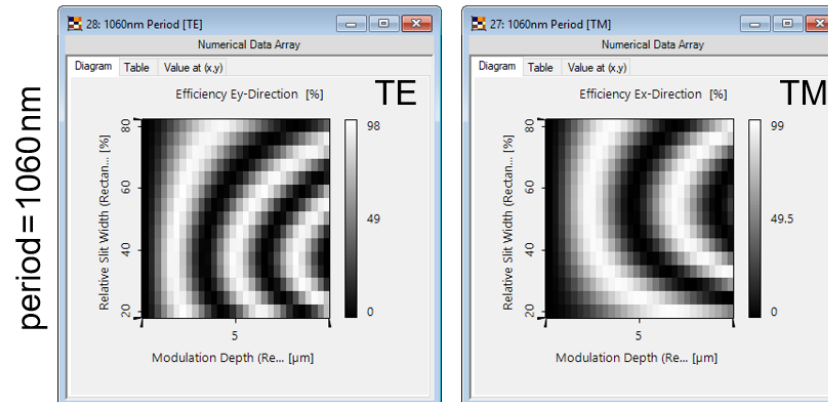
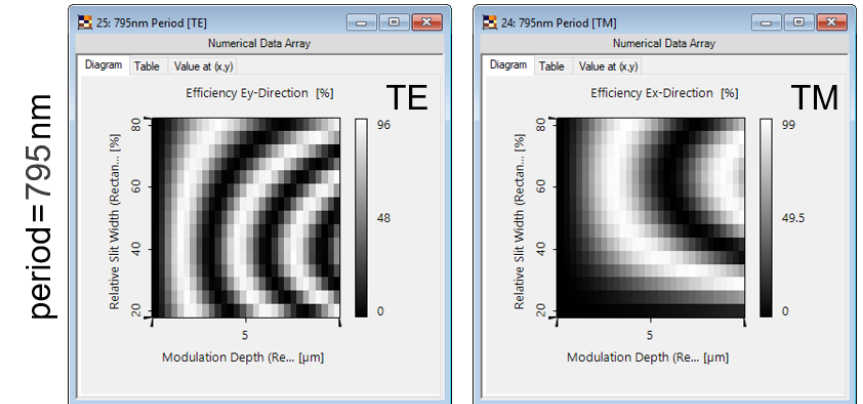
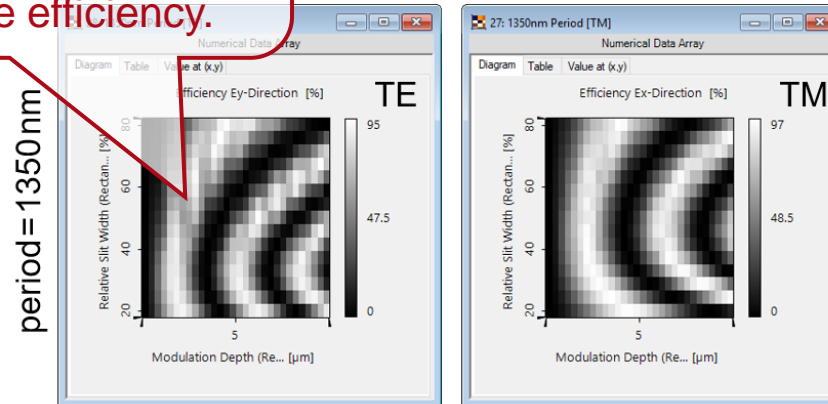
Large period leads to higher diffraction orders in the substrate, and causes additional modulation in the efficiency.

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

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

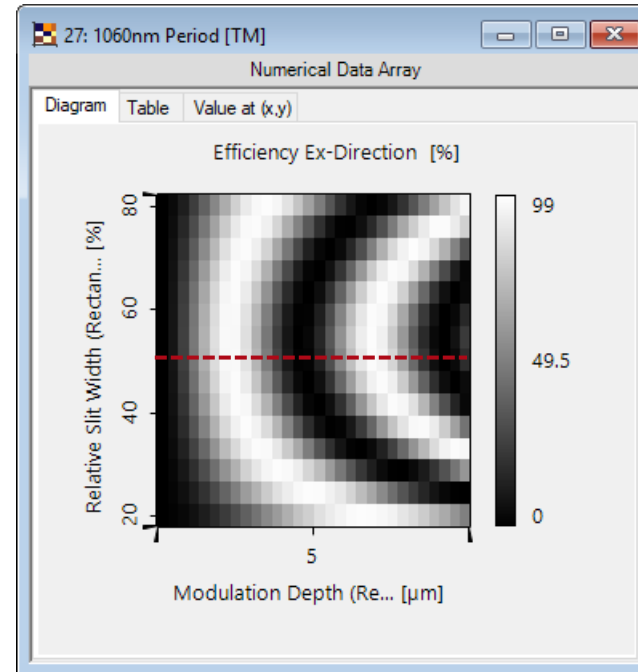
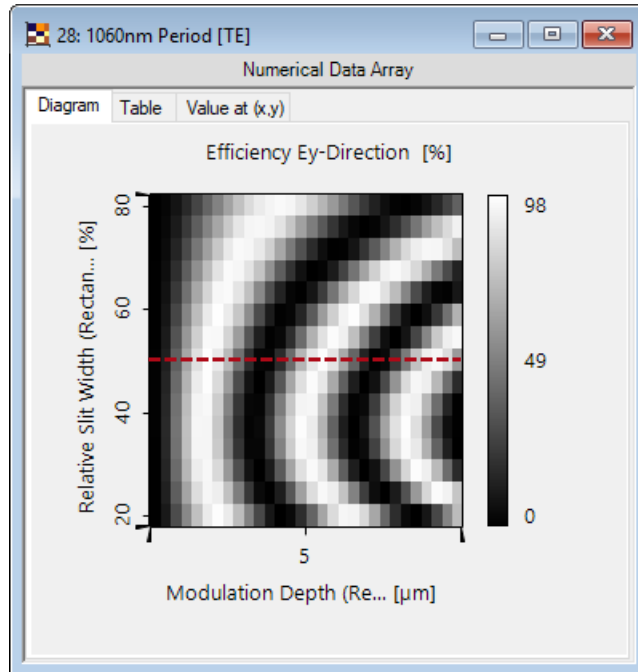
where n is the refractive index of the substrate.

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



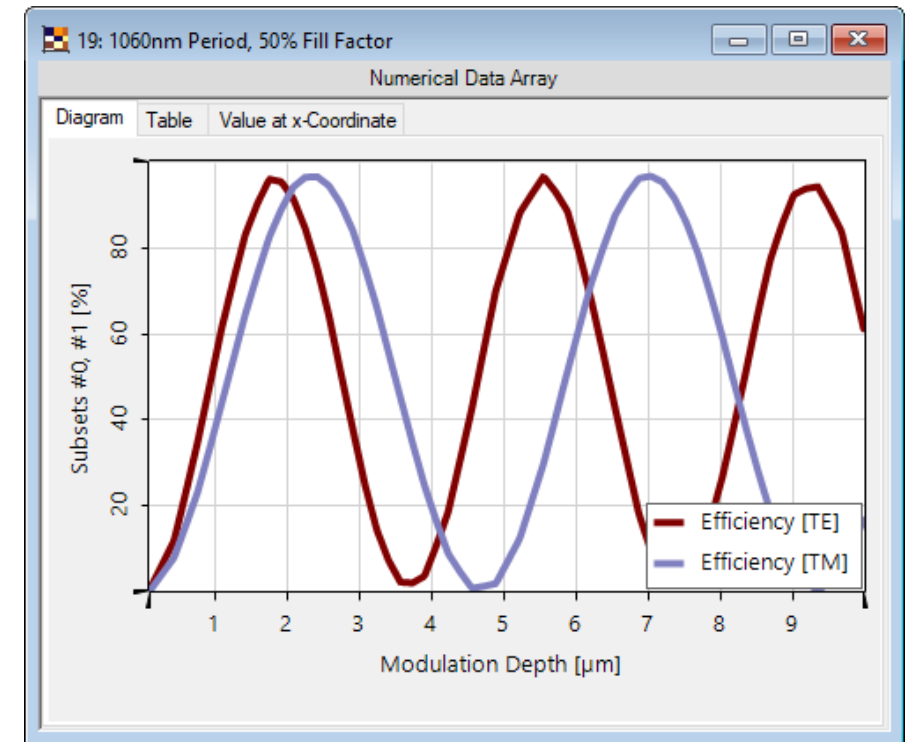
Polarization-Dependent Diffraction Property

diffraction efficiency analysis for given period 1060nm



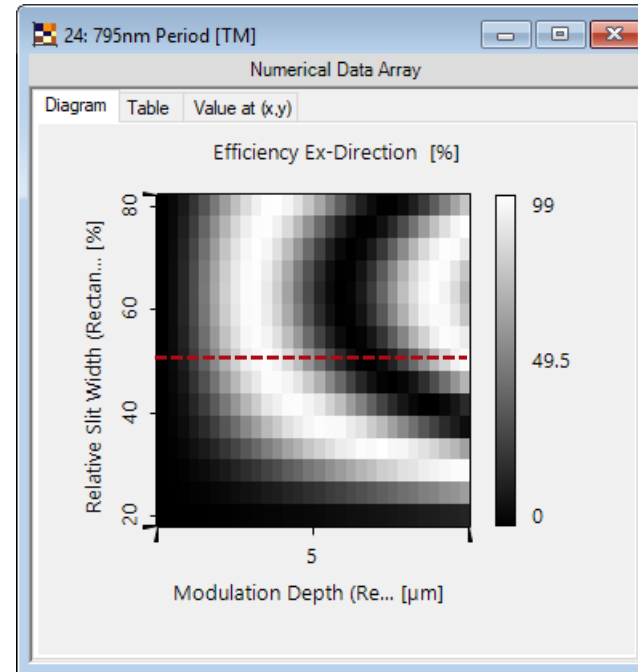
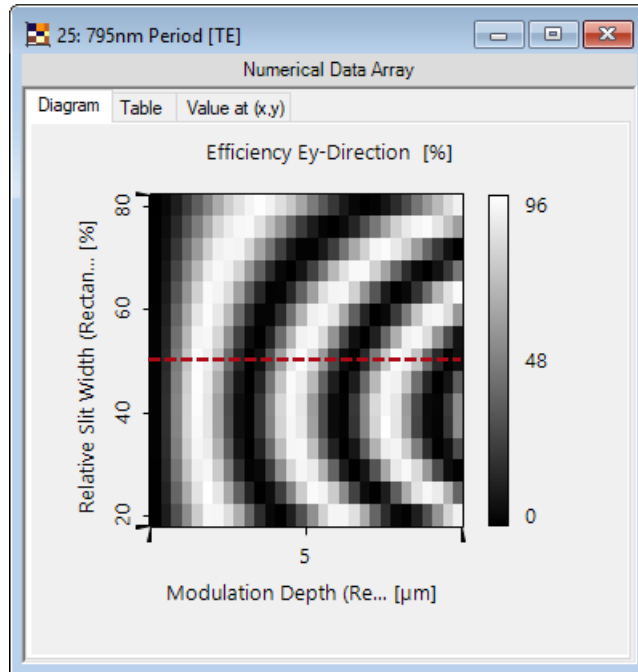
Parameter	Value
grating depth h	0.1-10μm
grating period d	1060nm
fill factor f	20-80%

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



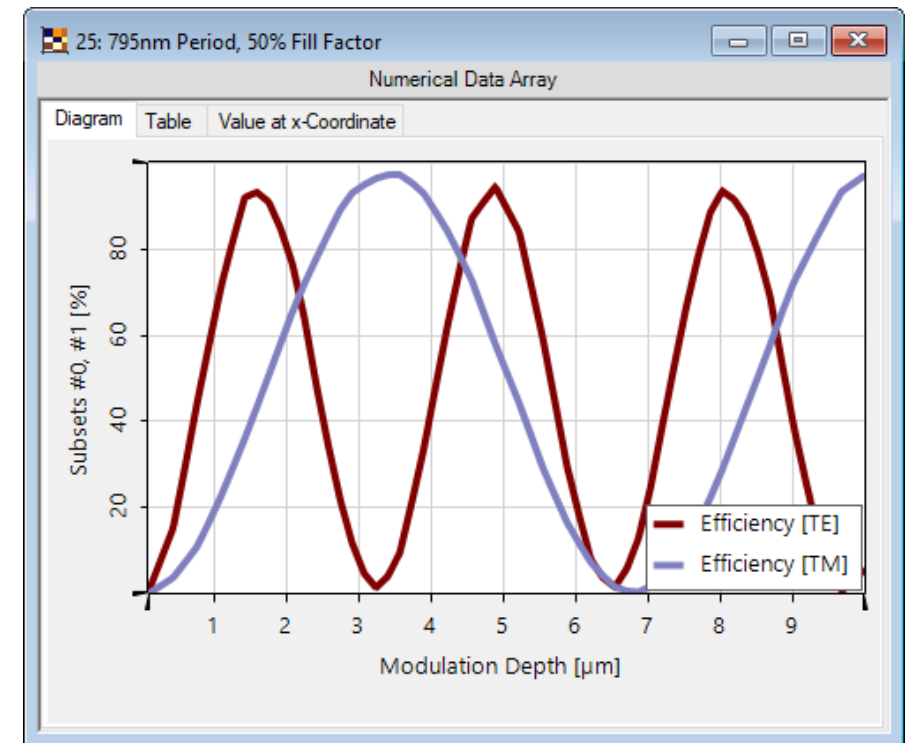
Polarization-Dependent Diffraction Property

diffraction efficiency analysis for given period 795nm



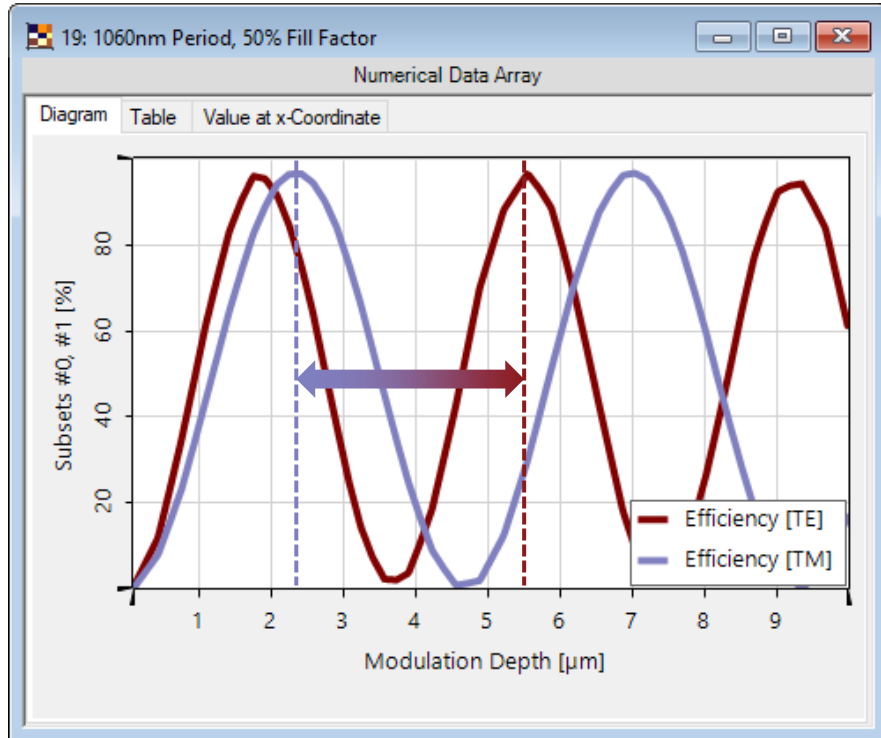
Parameter	Value
grating depth h	0.1-10μm
grating period d	795nm
fill factor f	20-80%

analysis of diffraction efficiency
with fixed fill factor 50%

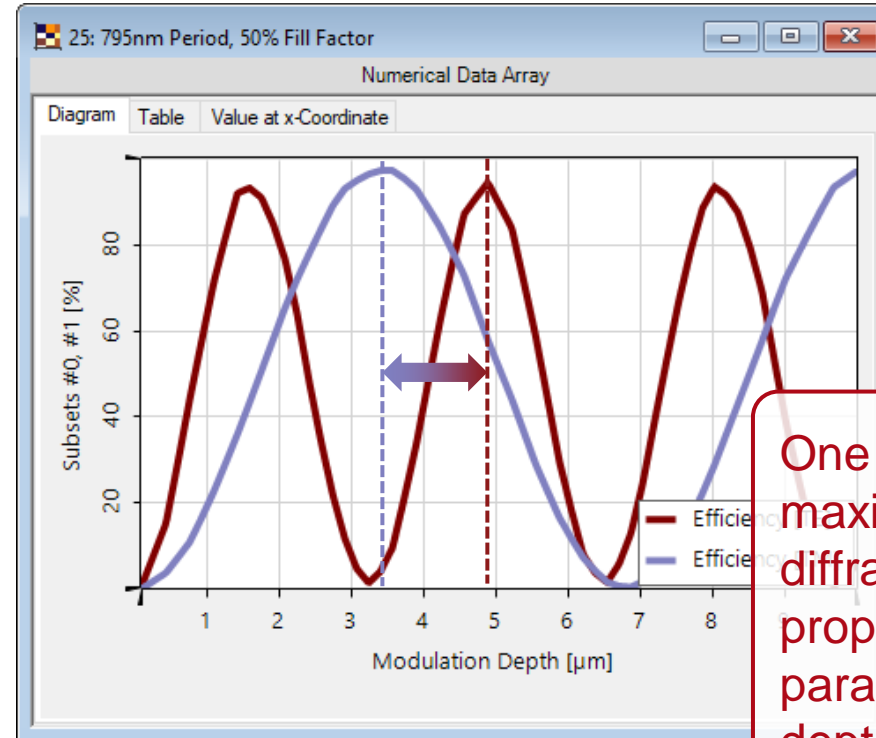


Polarization-Dependent Diffraction Property

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.

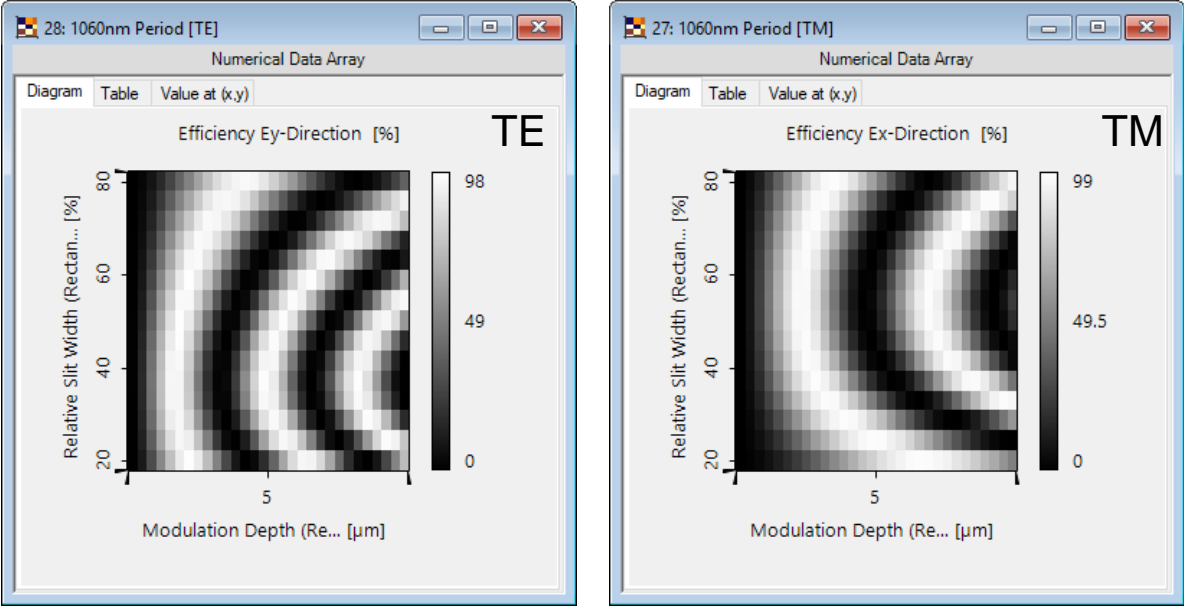
When grating period changes from 1060nm to 795nm

- 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

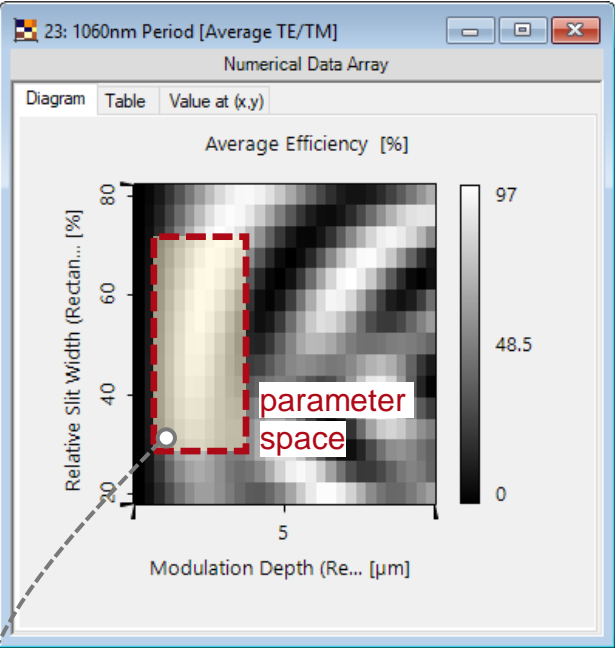
$$\eta^{\text{avg}} = \frac{1}{2} (\eta^{\text{TE}} + \eta^{\text{TM}}) ,$$

and it is to be maximized within the following parameter range

Parameter	Value Range
grating depth h	0.5-3.5 μm
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.

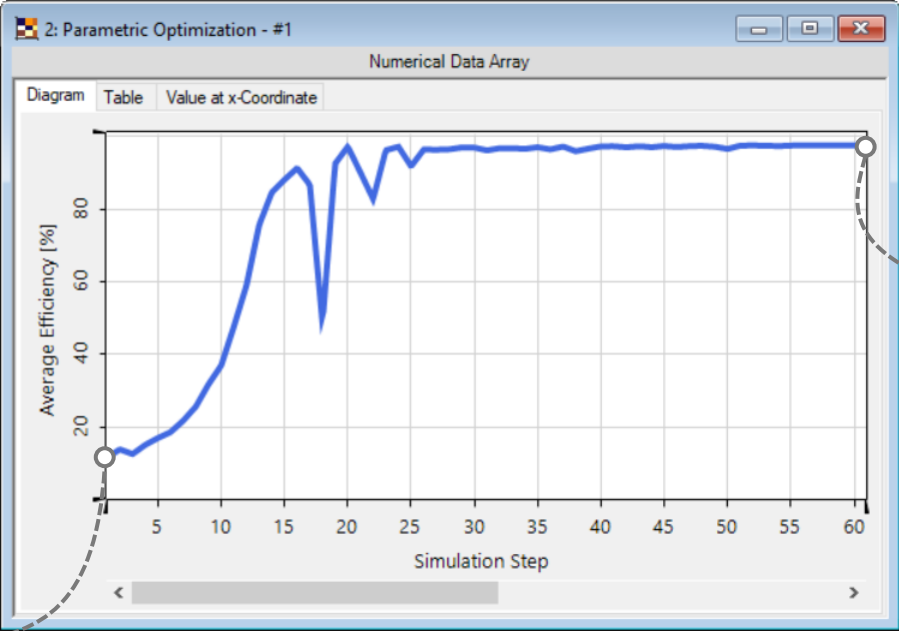
2D Parametric Optimization – Design #1



initial parameters

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

parametric optimization – downhill simplex

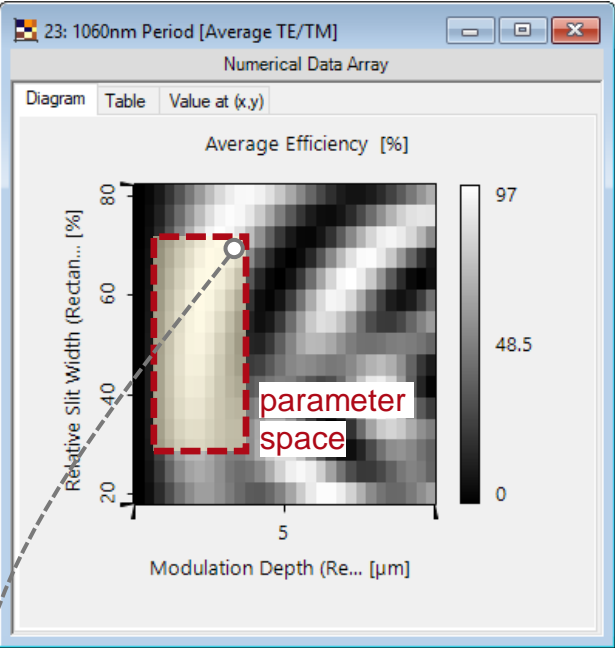


Diffraction efficiency in each optimization step is calculated using Fourier modal method (FMM, also known as RCWA).

optimized parameters

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

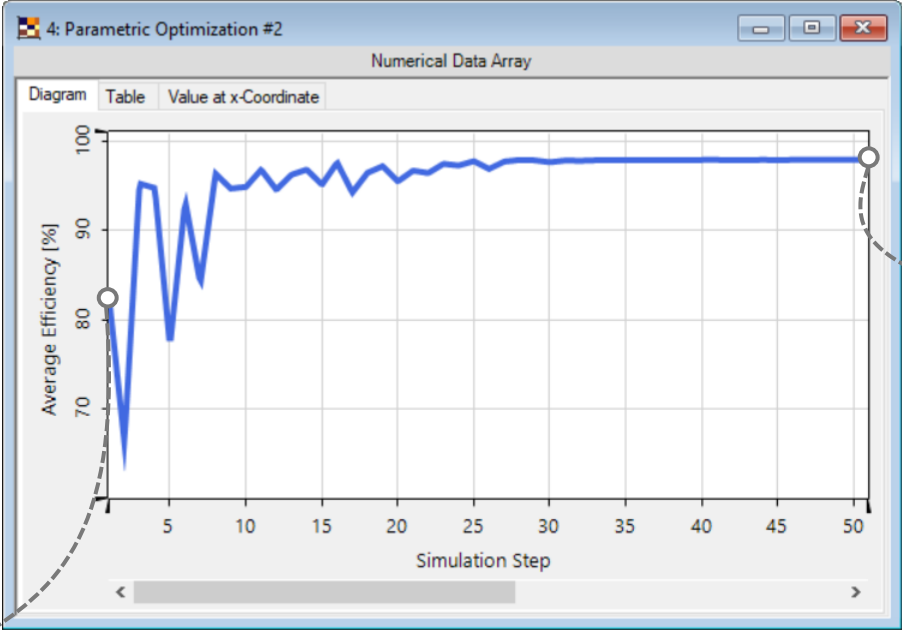
2D Parametric Optimization – Design #2



initial parameters

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

parametric optimization – downhill simplex



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

optimized parameters

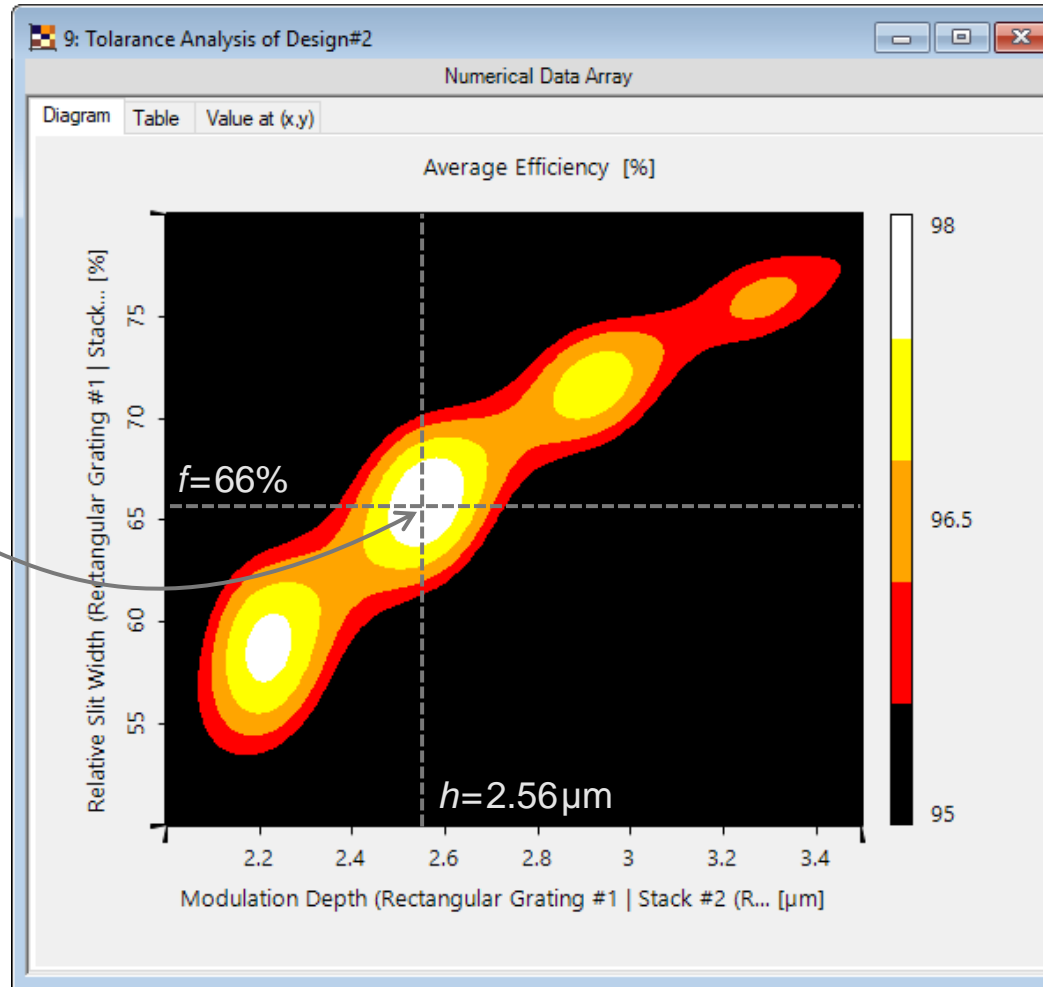
Parameter	Value
grating depth h	2.56 μm
fill factor f	66%
grating period d	1060nm (fixed)

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

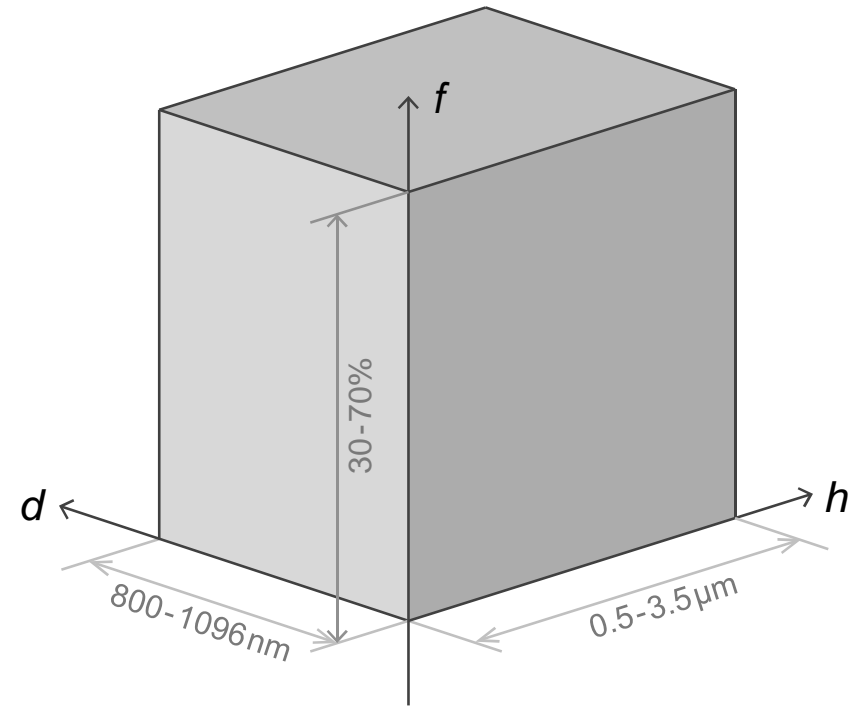
Parameter	Value
grating depth h	$2.56\mu\text{m}$
fill factor f	66%
grating period d	1060nm (fixed)



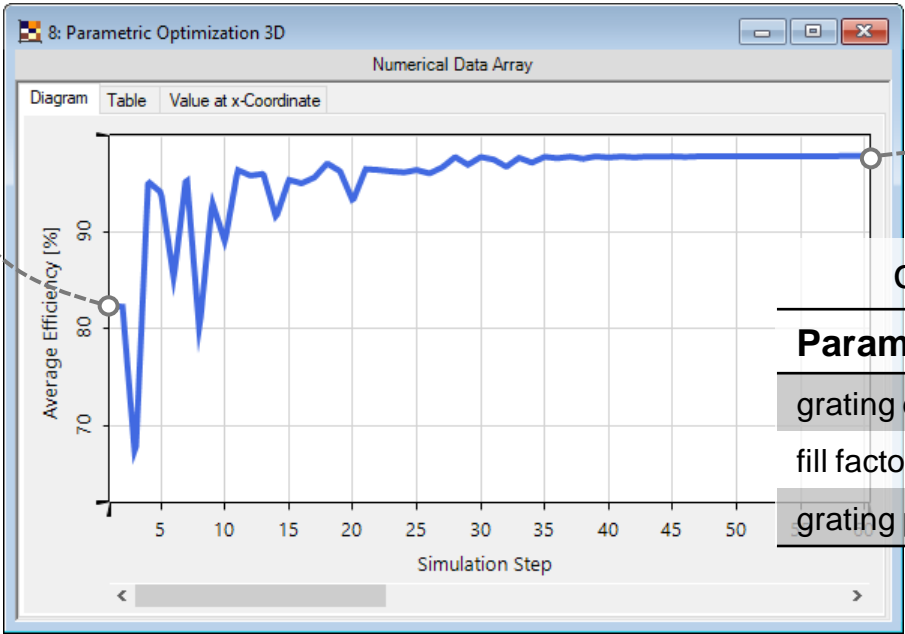
Diffraction efficiency within the region around the design parameters (efficiency value clipped above 95% only)

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



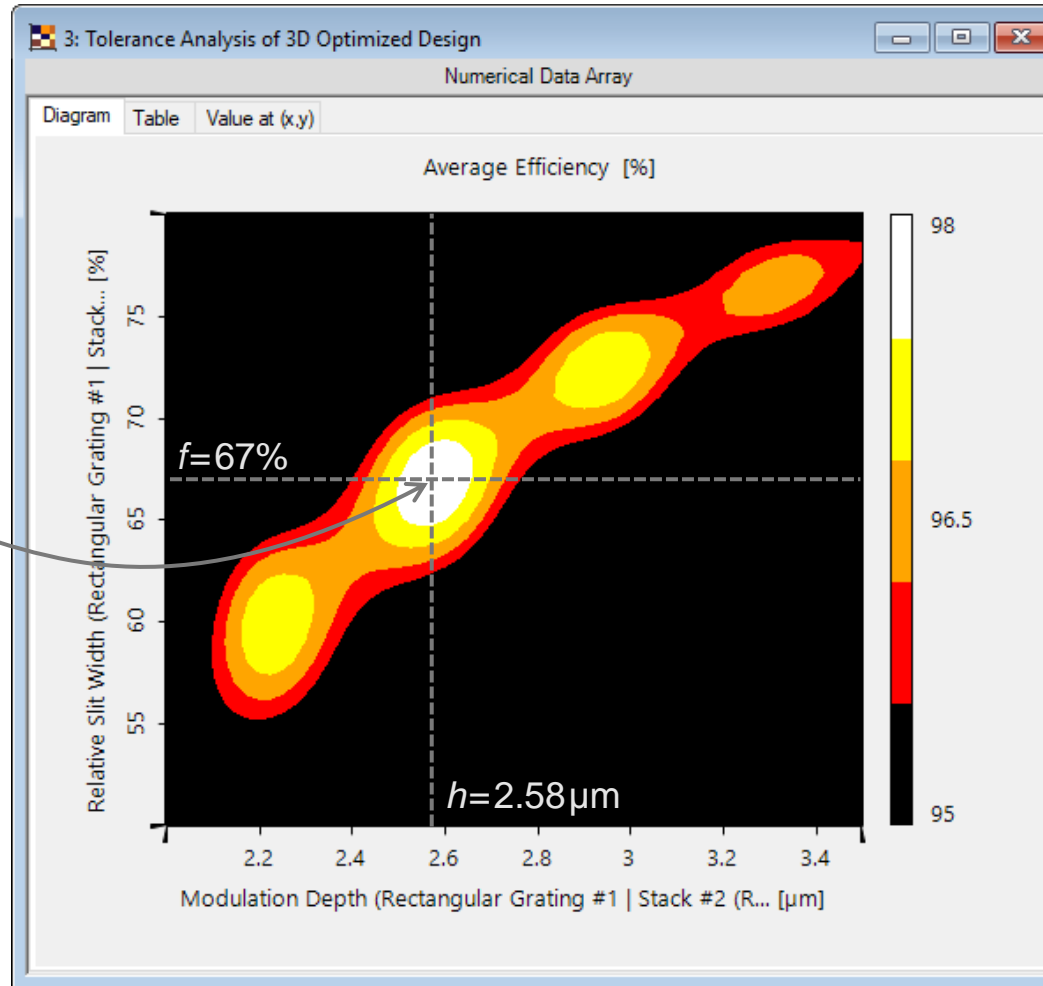
Parameter	Value
grating depth h	2.58 μm
fill factor f	67%
grating period d	1024 nm

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

Fabrication Tolerance Analysis

optimized parameters

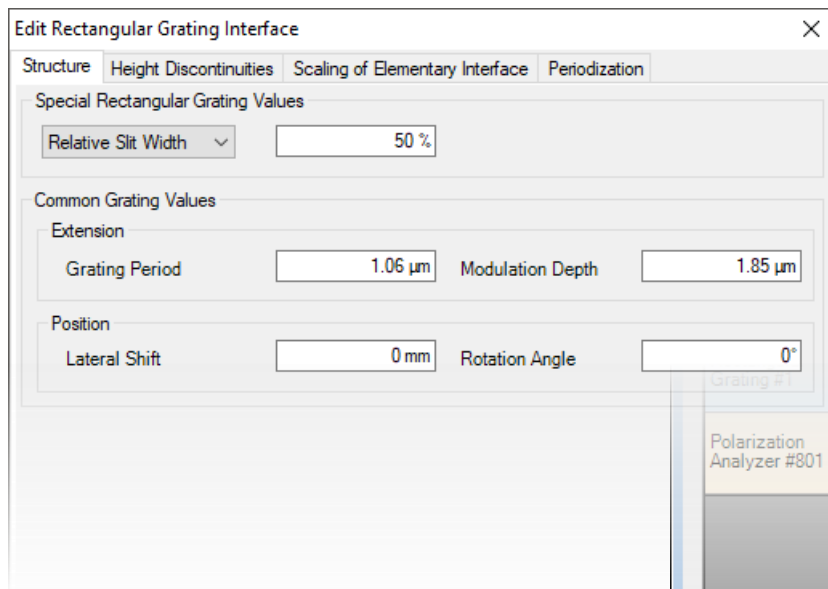
Parameter	Value
grating depth h	$2.58\mu\text{m}$
fill factor f	67%
grating period d	1024nm (fixed)



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

Peek into VirtualLab Fusion

intuitive grating parameters specification



Dialog box titled "Edit Rectangular Grating Interface" with tabs: Structure, Height Discontinuities, Scaling of Elementary Interface, Periodization.

Special Rectangular Grating Values

Relative Slit Width: 50 %

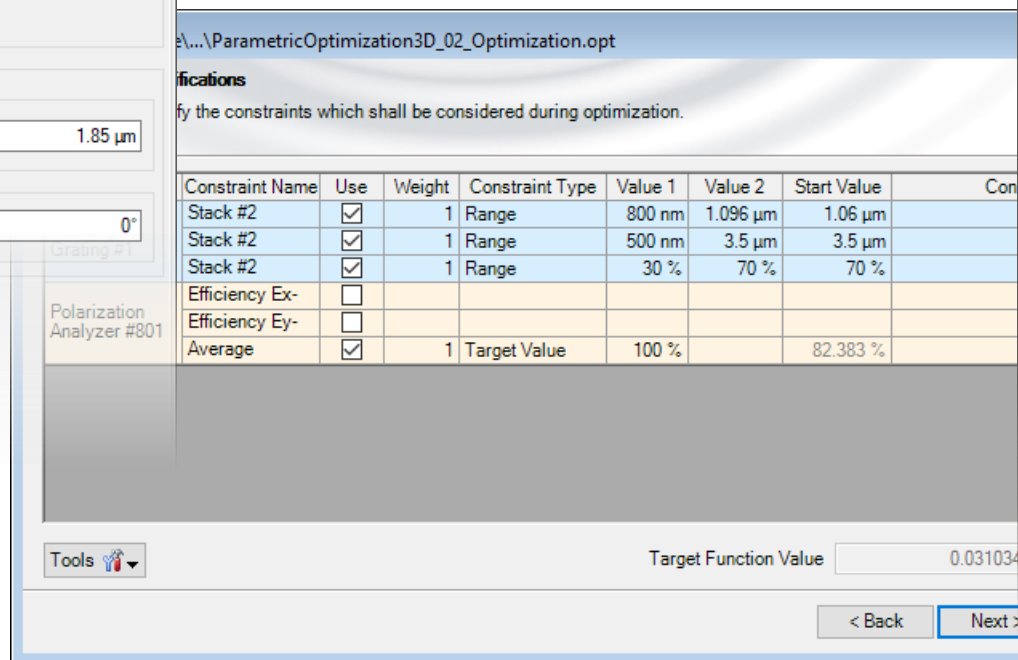
Common Grating Values

Extension

Grating Period: 1.06 μm Modulation Depth: 1.85 μm

Position

Lateral Shift: 0 mm Rotation Angle: 0°



Dialog box titled "Parametric Optimization 3D" with a file path: `\\...\\ParametricOptimization3D_02_Optimization.opt`

Specifications

Specify the constraints which shall be considered during optimization.

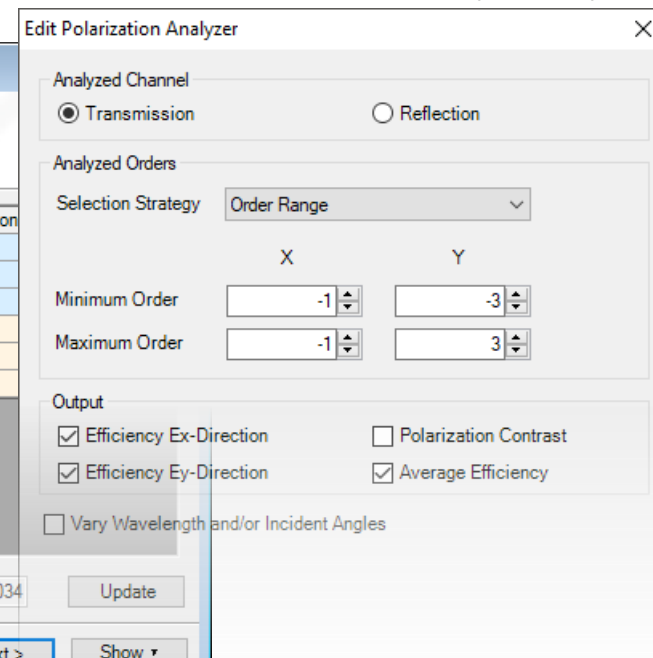
Constraint Name	Use	Weight	Constraint Type	Value 1	Value 2	Start Value	Con
Stack #2	<input checked="" type="checkbox"/>	1	Range	800 nm	1.096 μm	1.06 μm	
Stack #2	<input checked="" type="checkbox"/>	1	Range	500 nm	3.5 μm	3.5 μm	
Stack #2	<input checked="" type="checkbox"/>	1	Range	30 %	70 %	70 %	
Efficiency Ex-	<input type="checkbox"/>						
Efficiency Ey-	<input type="checkbox"/>						
Average	<input checked="" type="checkbox"/>	1	Target Value	100 %		82.383 %	

Tools:

Target Function Value: 0.031034 Update

< Back Next > Show ▾

special detector for polarization-related quantity analysis



Dialog box titled "Edit Polarization Analyzer"

Analyzed Channel

☒ Transmission ☐ Reflection

Analyzed Orders

Selection Strategy: Order Range ▾

X Y

Minimum Order: -1 -3

Maximum Order: -1 3

Output

☒ Efficiency Ex-Direction ☐ Polarization Contrast

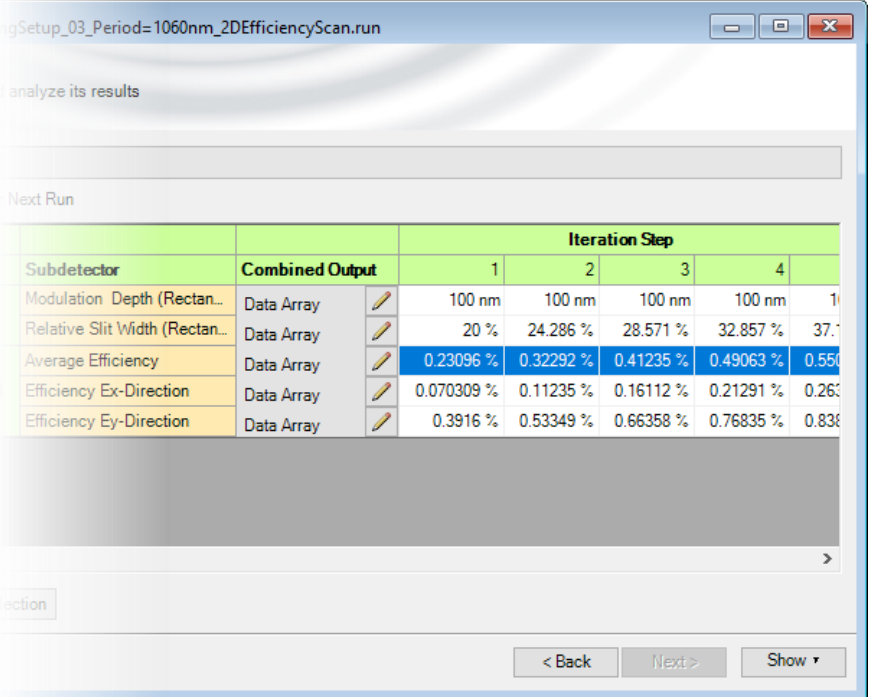
☒ Efficiency Ey-Direction ☒ Average Efficiency

☐ 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 software window titled "Setup_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 has a "Data Array" icon and a pencil icon. 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 %

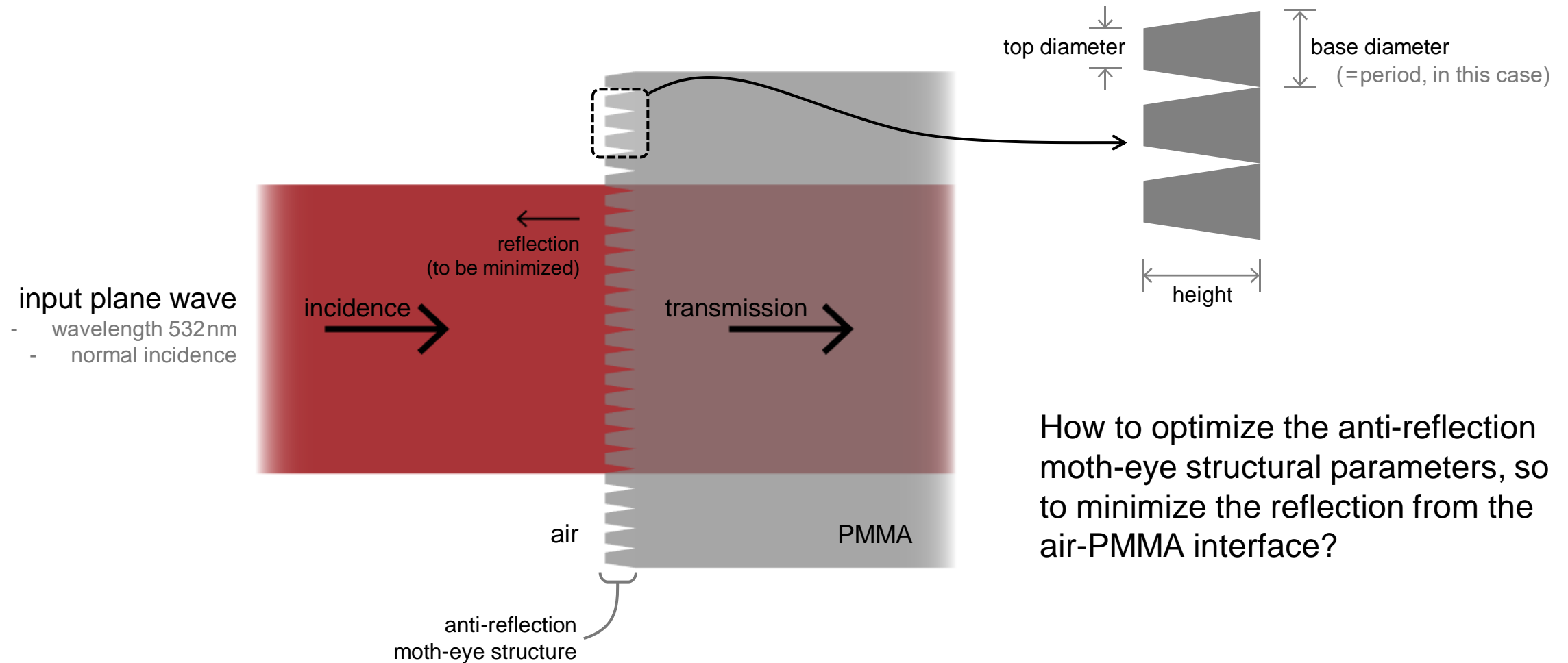
At the bottom of the window, there are buttons for "< Back", "Next >", and "Show ▾".

Document Information

title	Analysis and Design of Highly Efficient Polarization Independent Transmission Gratings
document code	GRT.0015
version	1.2
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.202)
category	Application Use Case
further reading	<ul style="list-style-type: none">- Ultra-Sparse Dielectric Nano-Wire Grid Polarizers- Rigorous Analysis of Nanopillar Metasurface Building Block- Parametric Optimization and Tolerance Analysis of Slanted Gratings

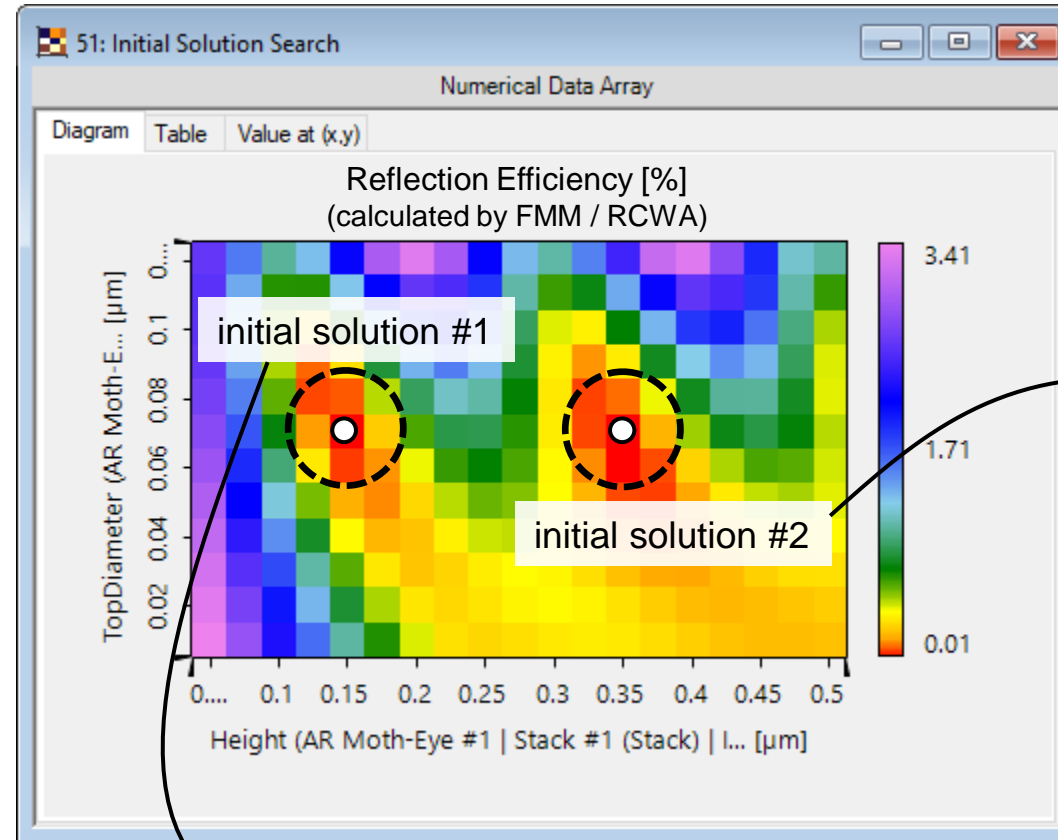
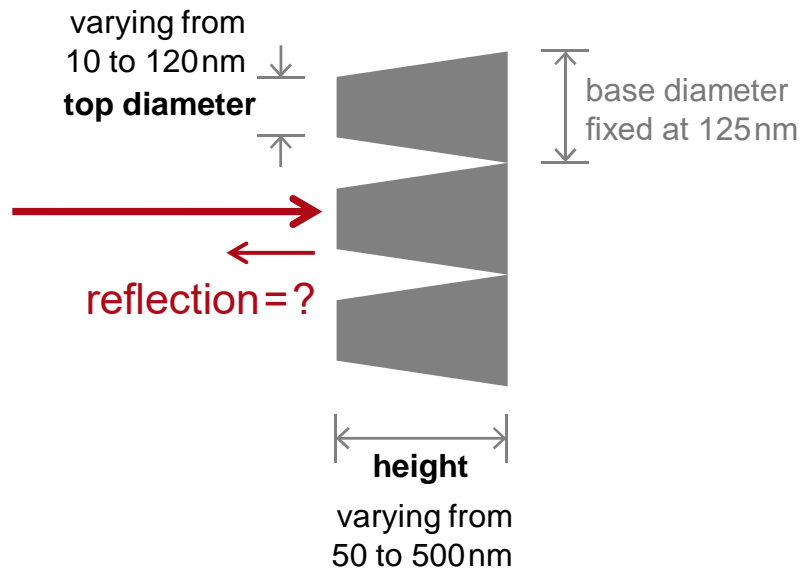
Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures

Design Task



How to optimize the anti-reflection moth-eye structural parameters, so to minimize the reflection from the air-PMMA interface?

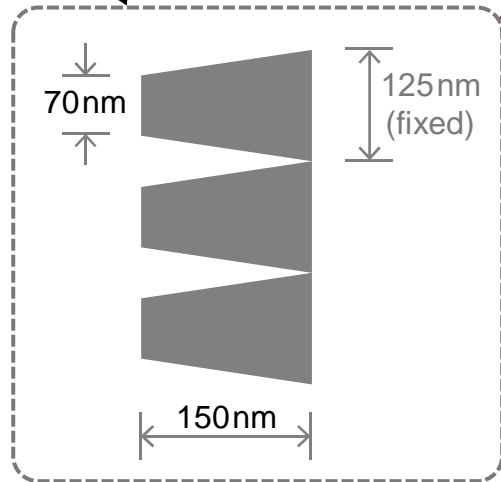
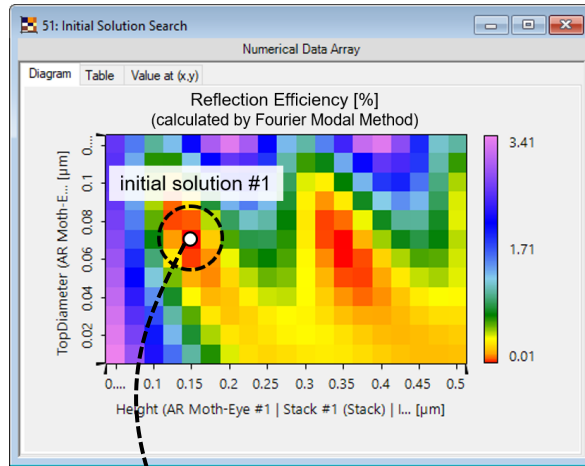
Scanning over Parameter Space for Initial Solutions



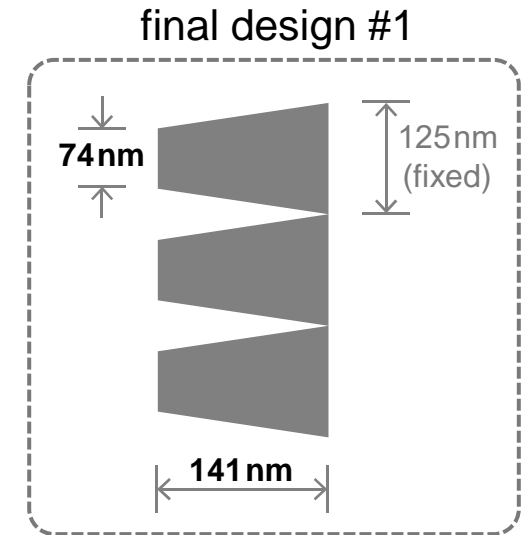
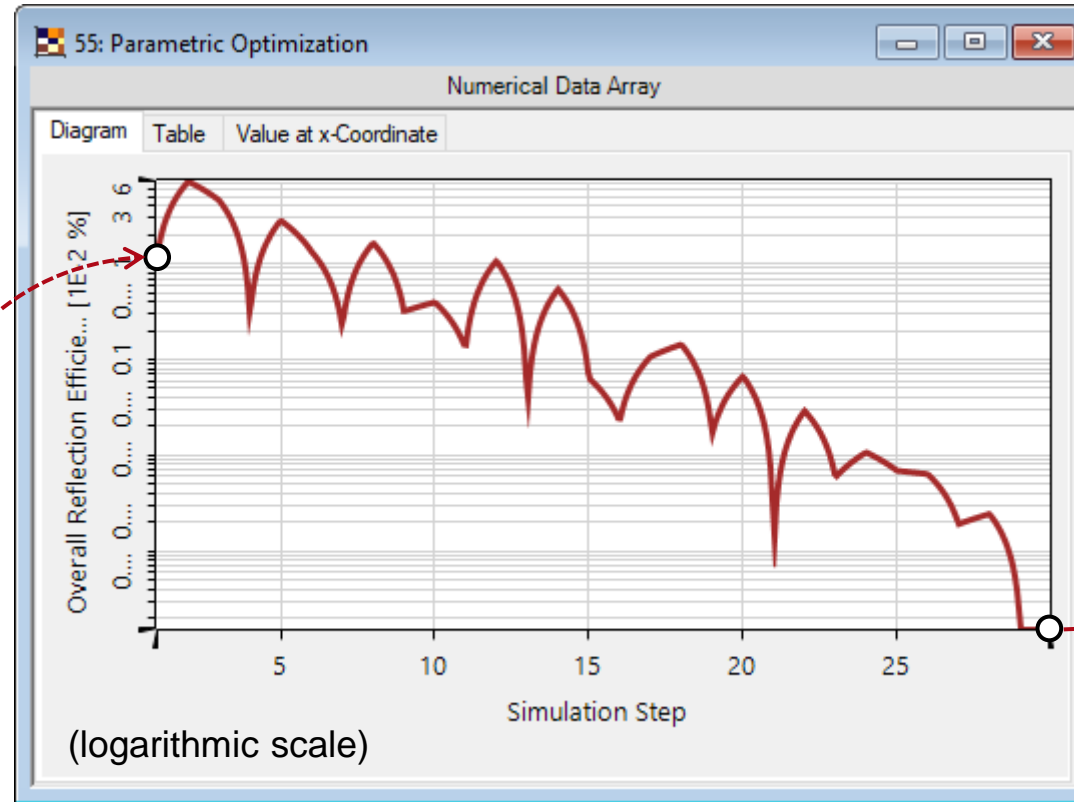
relatively higher aspect ratio and maybe not the first choice for fabrication

relatively smaller aspect ratio and therefore preferable for fabrication

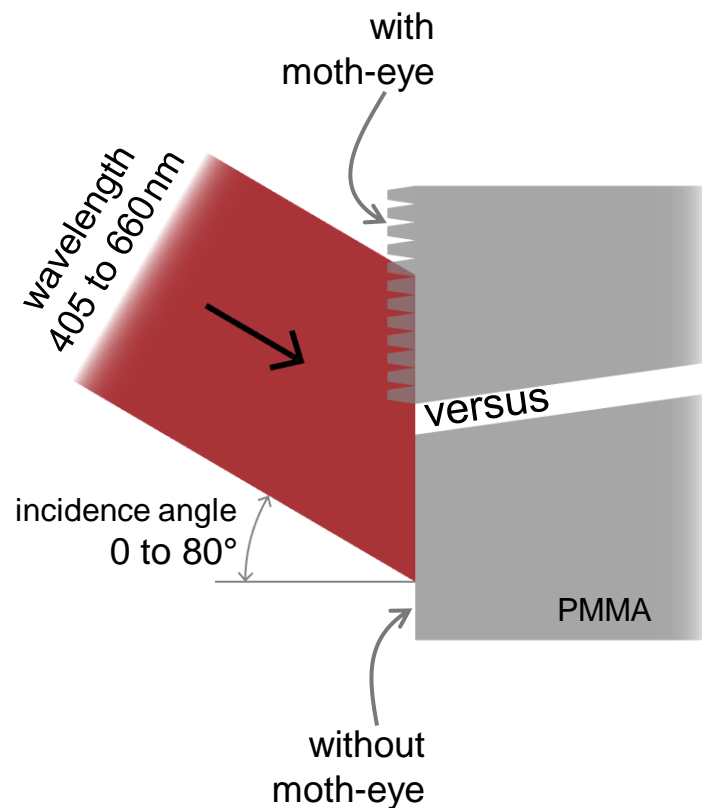
Parametric Optimization for Initial Solution #1



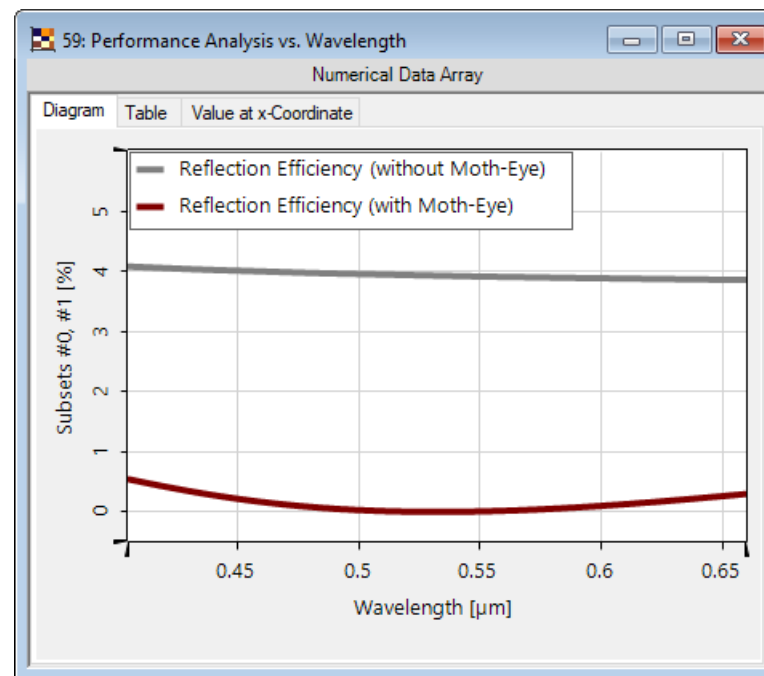
parametric optimization by downhill simplex method
(each iteration calculated by FMM / RCWA)



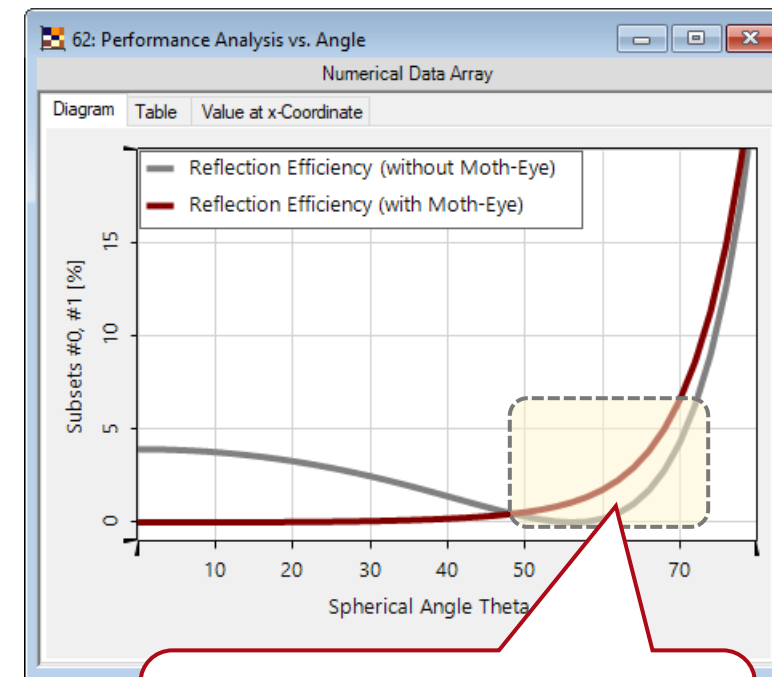
Performance Analysis of Final Design #1



reflection efficiency vs. wavelength
(at normal incidence)

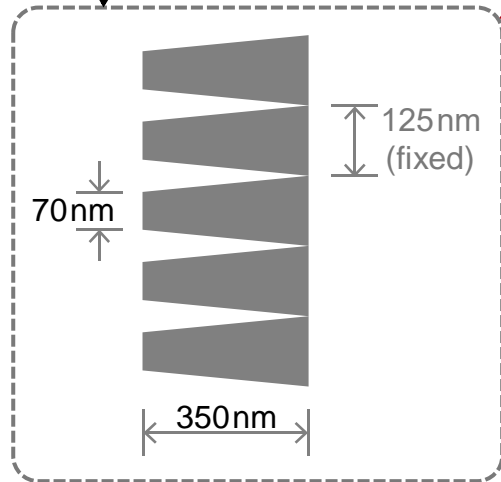
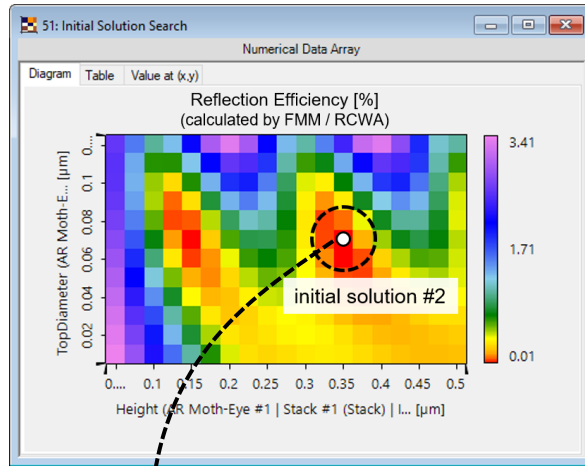


reflection efficiency vs. angle
(at 532nm wavelength)

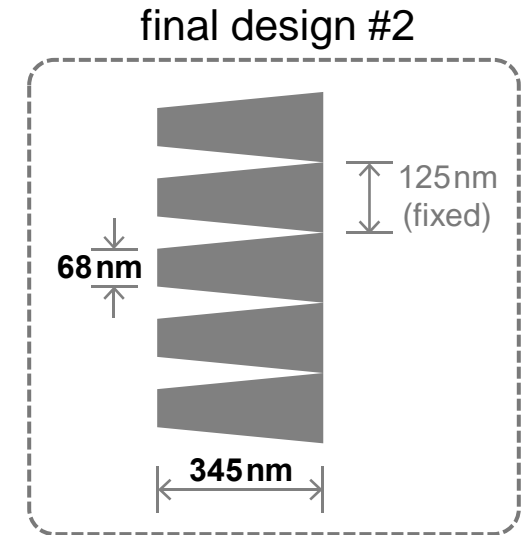
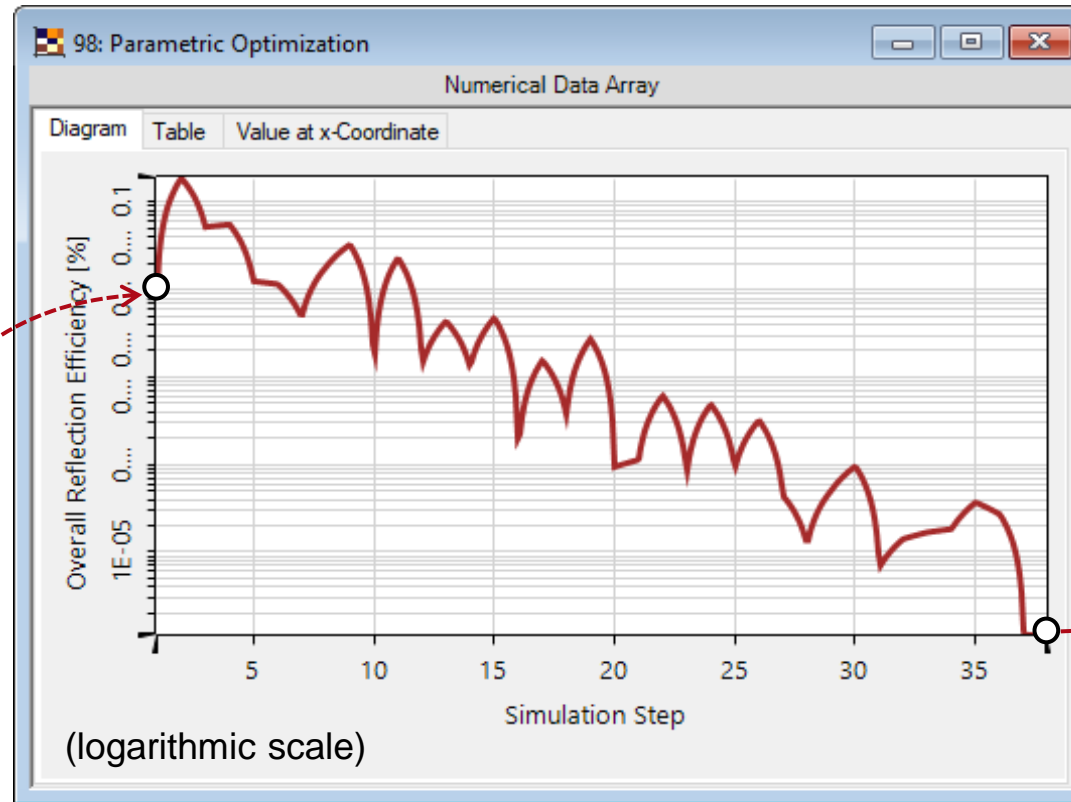


Design #1 does not suppress reflection effectively for incidence over 50°.

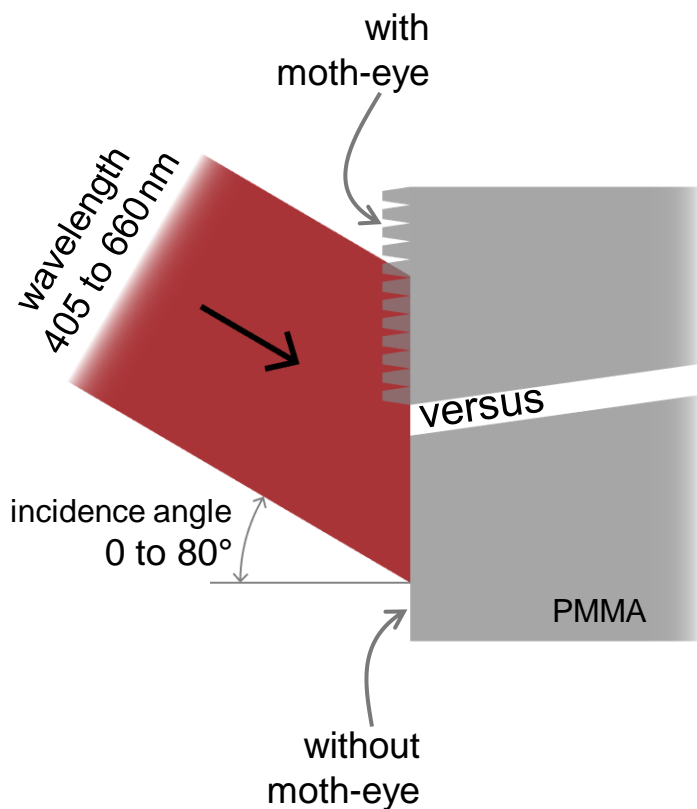
Parametric Optimization for Initial Solution #2



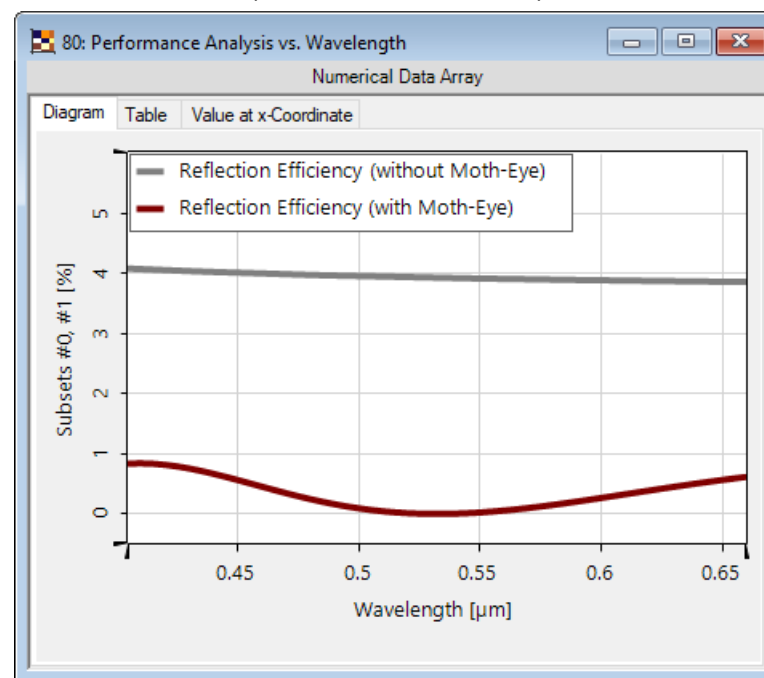
parametric optimization by downhill simplex method
(each iteration calculated by FMM / RCWA)



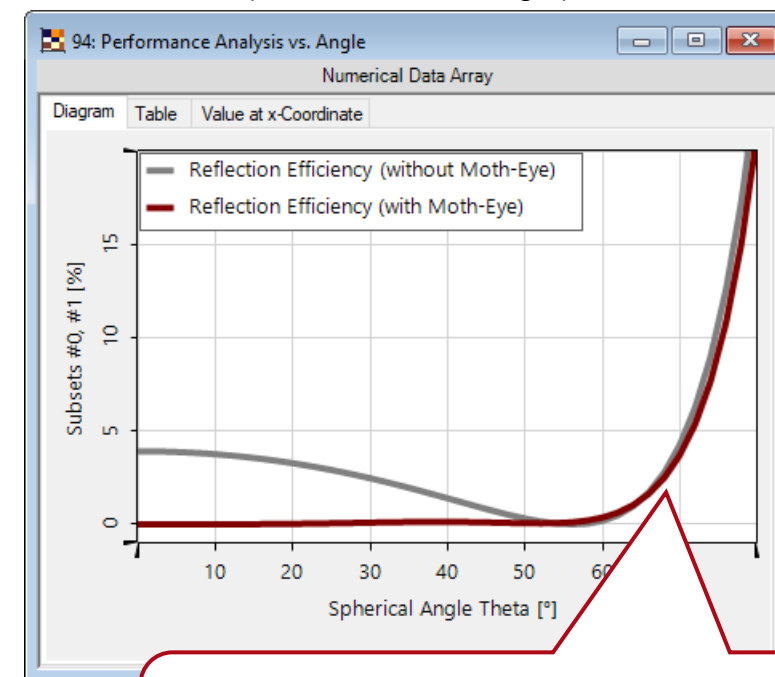
Performance Analysis of Final Design #2



reflection efficiency vs. wavelength
(at normal incidence)



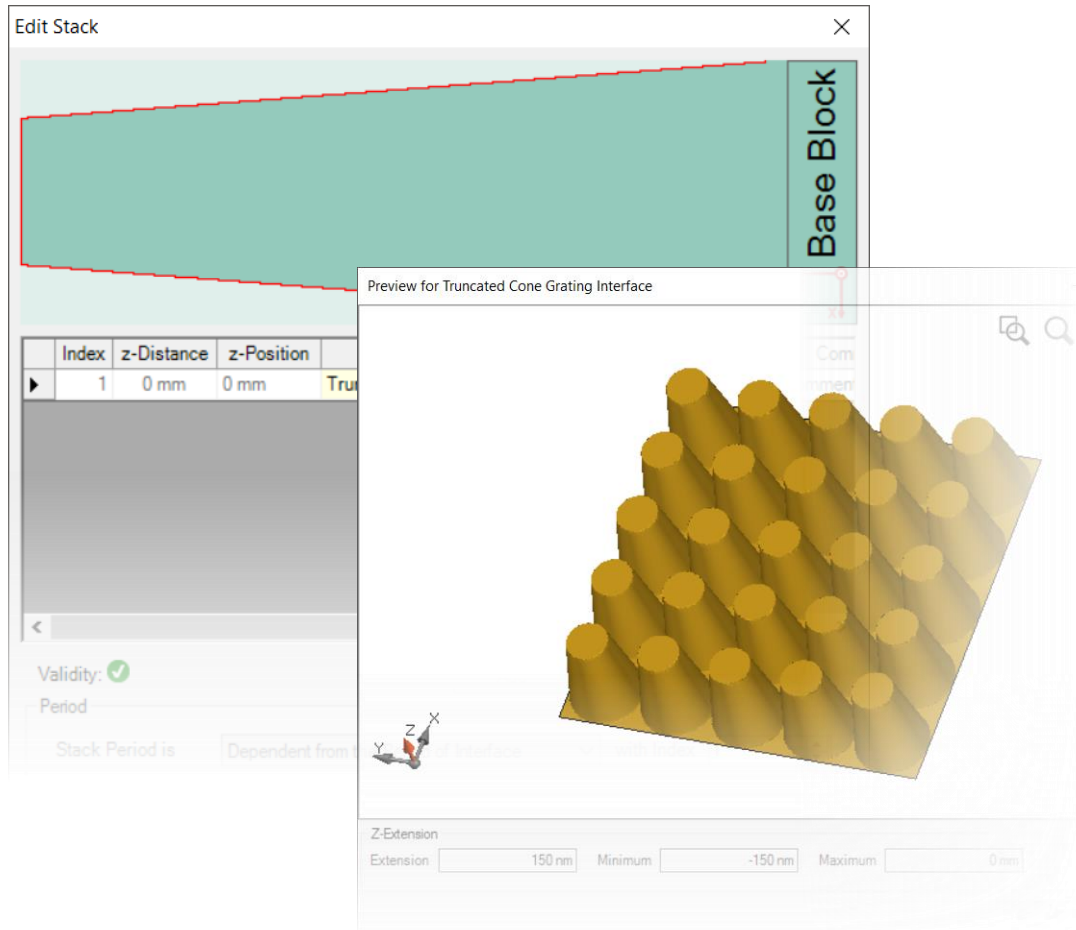
reflection efficiency vs. angle
(at 532nm wavelength)



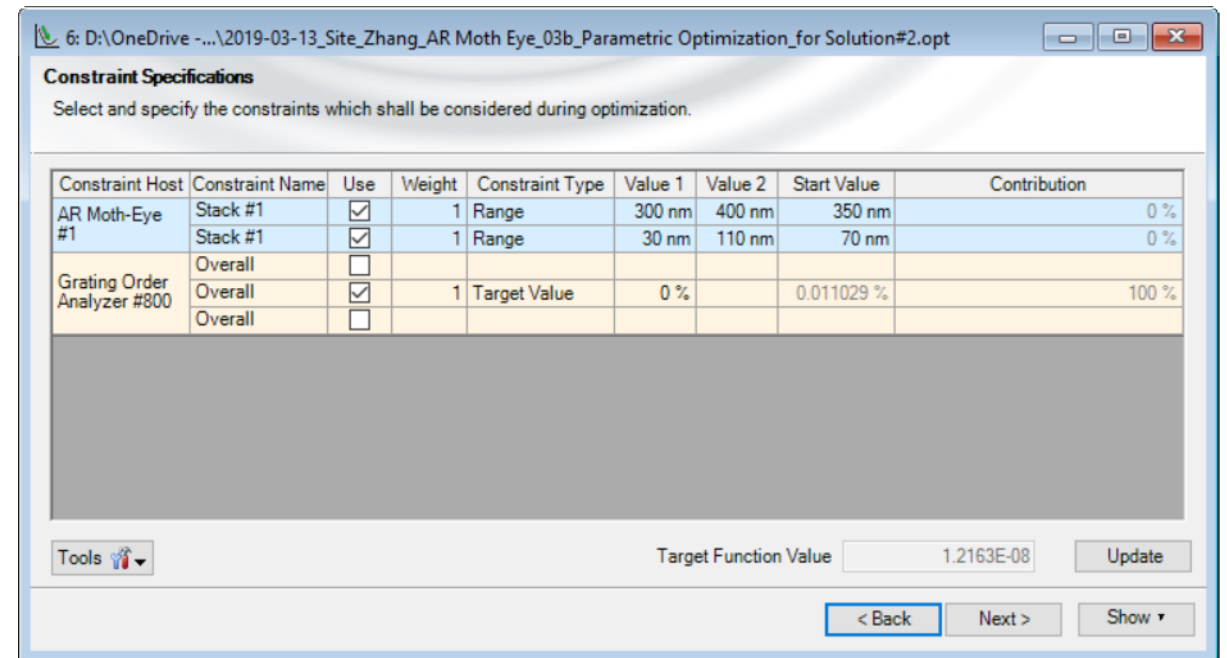
Despite of the higher aspect ratio,
design #2 suppresses reflection
better for higher incidence angles.

Peek into VirtualLab Fusion

grating structure editor with preview

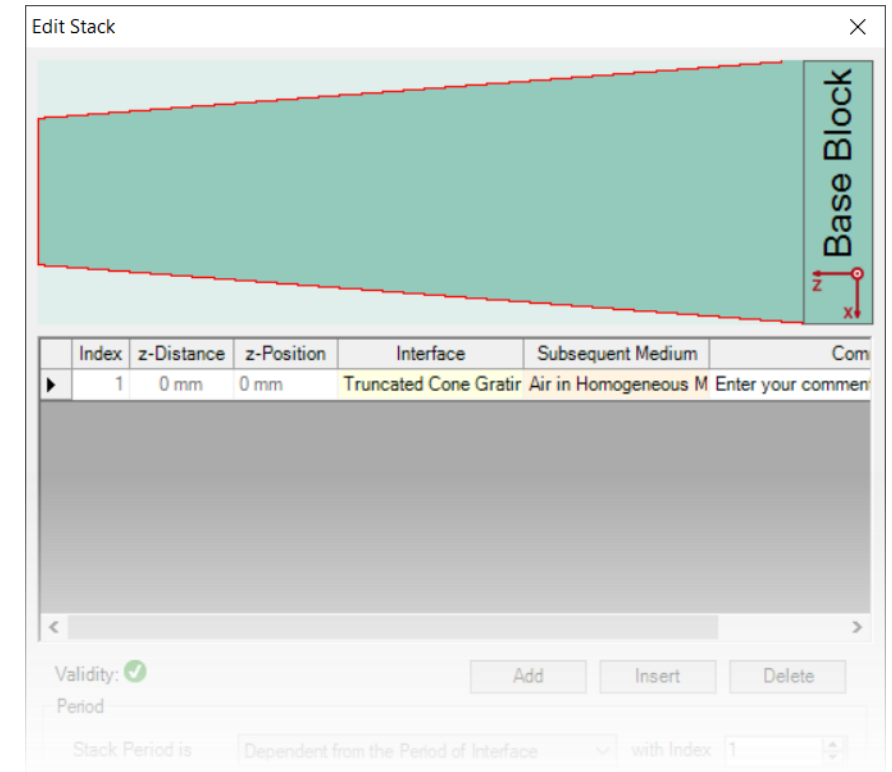


parametric optimization tools
with flexible variable and merit function definition



Workflow in VirtualLab Fusion

- Construct grating structure
 - [Configuration of Grating Structures by Using Interfaces](#) [Use Case]
 - [Configuration of Grating Structures by Using Special Media](#) [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



Document Information

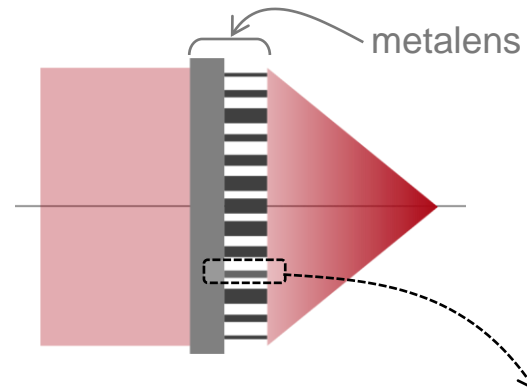
title	Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures
document code	GRT.0011
version	1.0
toolbox(es)	Grating Toolbox
VL version used for simulations	7.4.0.49
category	Application Use Case
further reading	<ul style="list-style-type: none">- <u>Parametric Optimization and Tolerance Analysis of Slanted Gratings</u>- <u>Optimization of Lightguide Coupling Grating for Single Incidence Direction</u>

Part IV

- Rigorous analysis of nanopillars as metasurface building blocks
- Design of a blazed metagrating
- Beam-splitting metagrating design
- IFTA for phase profile generation

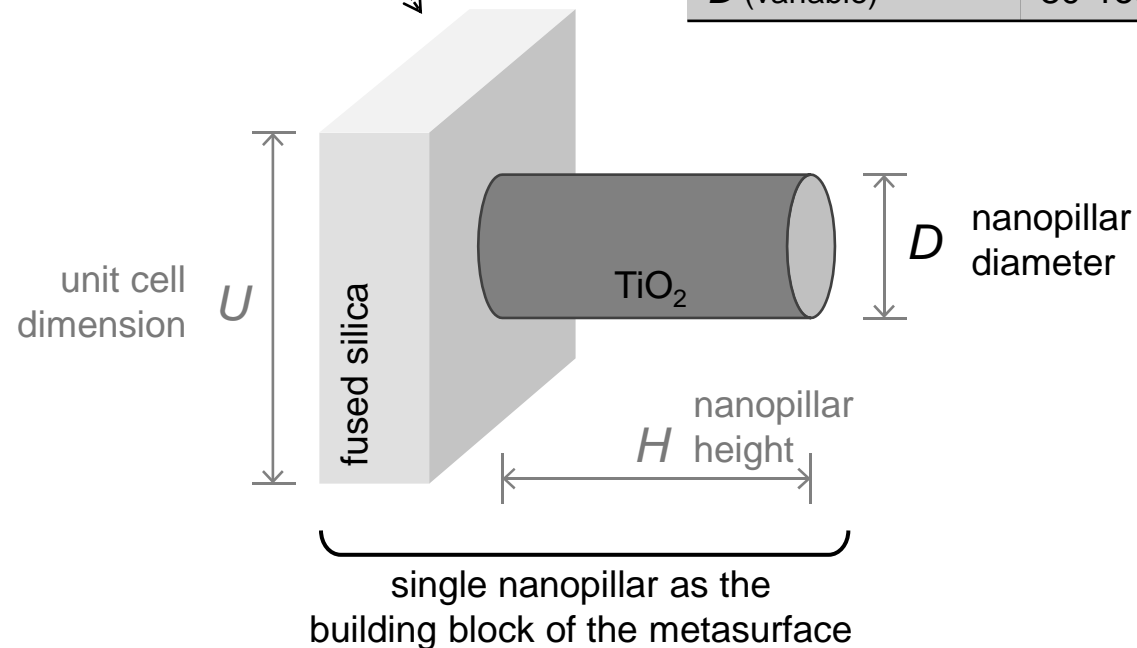
Rigorous Analysis of Nanopillar Metasurface Building Block

Modeling Task



parameters from M. Khorasaninejad,
Nano Lett. 2016, 16, 7229-7234

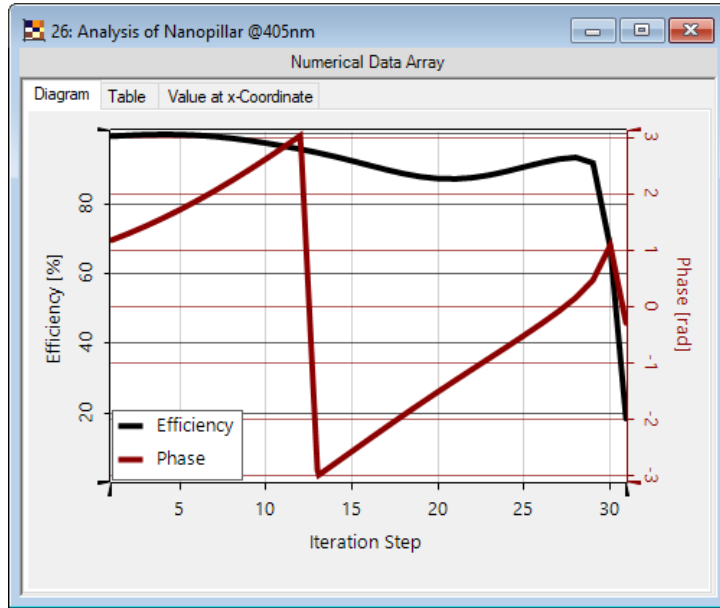
Nanopillars No.	#1 (405nm)	#2 (532nm)	#3 (660nm)
U	180nm	250nm	350nm
H	400nm	600nm	600nm
D (variable)	80-155nm	100-220nm	100-320nm



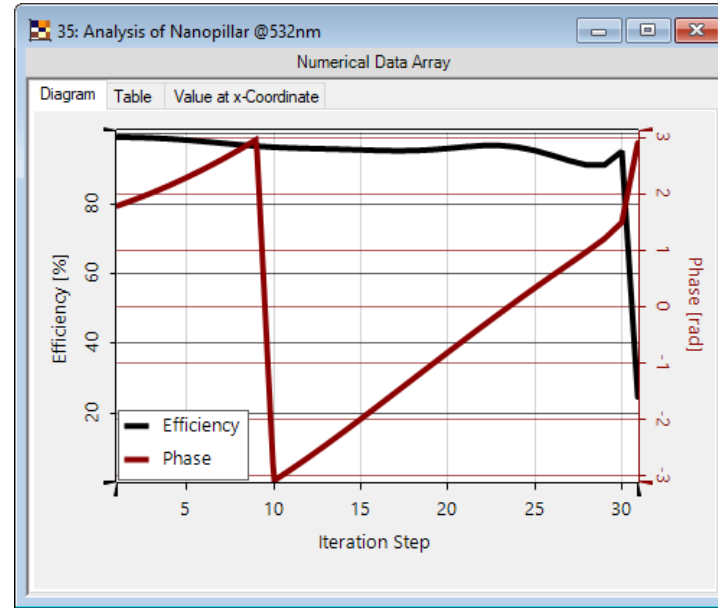
By varying the nanopillar diameter, the metasurface building block is supposed to have phase modulation covering 2π . How to evaluate such nanopillar structure rigorously?

Nanopillar Analysis vs. Pillar Diameter

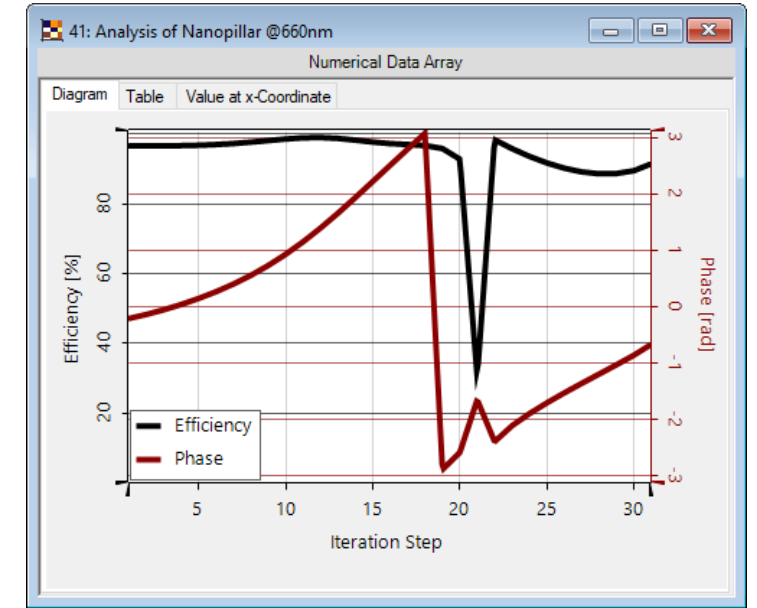
nanopillar #1



nanopillar #2



nanopillar #3



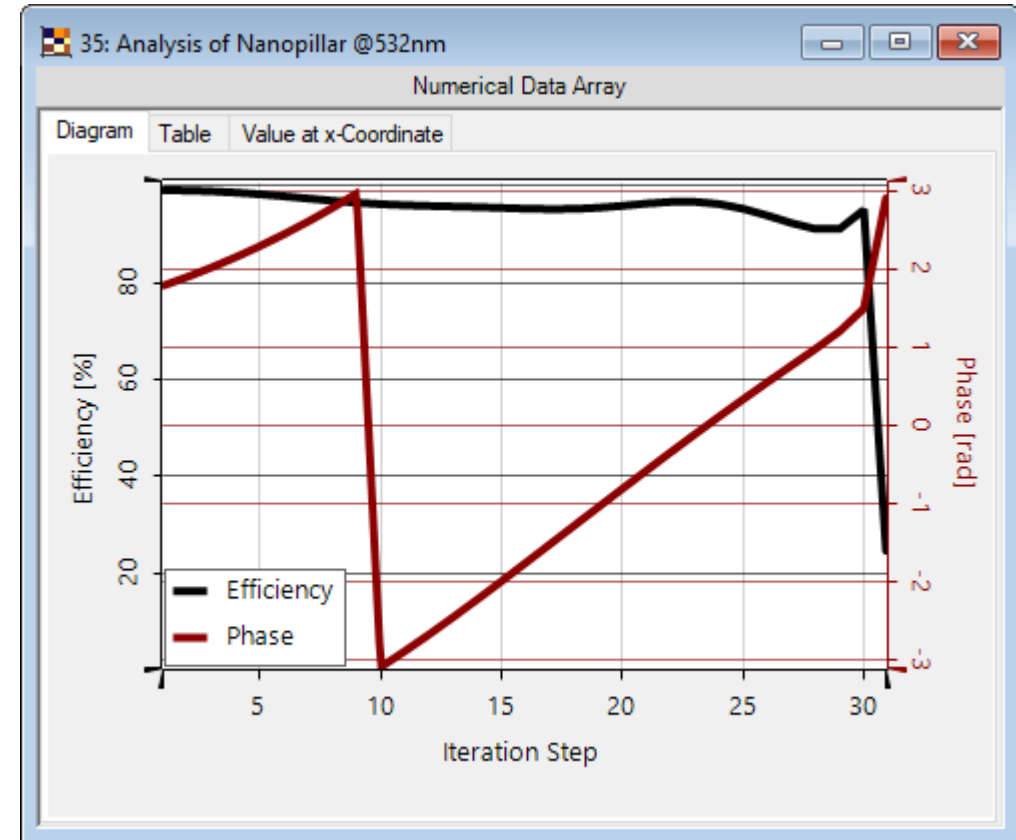
Nanopillars No.	#1 (405nm)	#2 (532nm)	#3 (660nm)
<i>U</i>	180nm	250nm	350nm
<i>H</i>	400nm	600nm	600nm
<i>D</i> (variable)	80-155nm	100-220nm	100-320nm

Nanopillar Analysis vs. Pillar Diameter

- The phase modulation covers 2π range, and it changes almost linearly with pillar diameter, which enables convenient phase control.
- The transmission efficiency remains above 90% for varying pillar diameter over the design range.

Nanopillars No.	#1 (405nm)	#2 (532nm)	#3 (660nm)
<i>U</i>	180nm	250nm	350nm
<i>H</i>	400nm	600nm	600nm
<i>D</i> (variable)	80-155nm	100-220nm	100-320nm

nanopillar #2



Appendix: Refractive Index of TiO_2

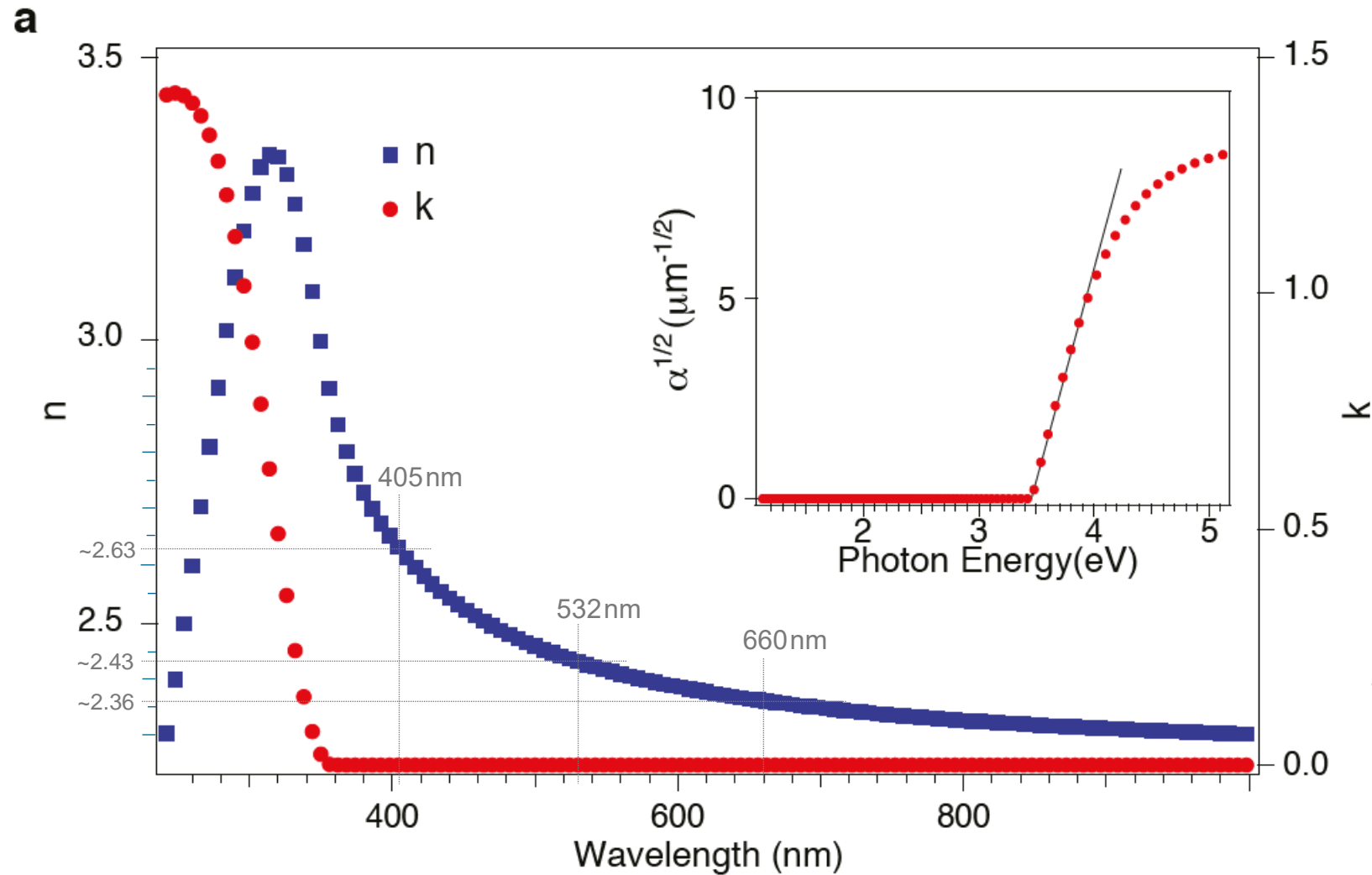


figure from R. C. Devlin, M. Khorasaninejad, W.-T. Chen, J. Oh, F. Capasso, arXiv:1603.02735 (2016)

Peek into VirtualLab Fusion

flexible pillar structure definition

The 'Edit Stack' window displays a cross-section of a pillar structure. A green rectangular block is labeled 'Base Block' on the right. Below the stack, a table lists the layers:

Index	z-Distance	z-Position	Interface	Subsequent Medium	Comments
1	0 mm	0 mm	Plane Interface	Non-Dispersive Material	Enter your comment
2	600 nm	600 nm	Programmable Interface	Air in Homogeneous Medium	Enter your comment

The 'Source Code Editor' window shows a C# script for defining the pillar structure:

```
1 double height = 0.0;
2
3 // convert to radial distance
4 double rho = Math.Sqrt(x * x + y * y);
5 if(rho <= 0.5 * Diameter)
6 {
7     height = Height;
8 }
9
10 return height;
```

Customized structure via programming

The 'Edit Grating Order Analyzer' window shows the 'General' tab with the following settings:

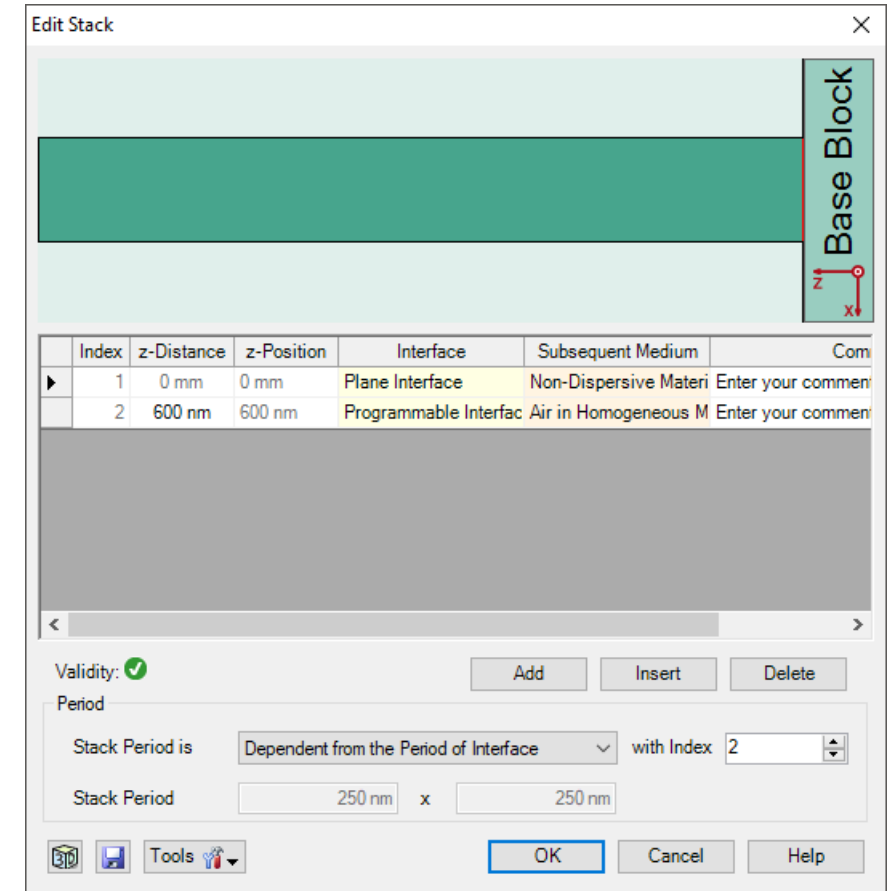
- Order Selection Strategy: Order Range
- Minimum Order: 0
- Maximum Order: 0
- Coordinates: ☐ Spherical Angles, ☐ Cartesian Angles, ☐ Wave Vector Components, ☐ Positions
- Efficiencies: ☒ Efficiencies
- Rayleigh Coefficients: ☒ Ex, ☒ Ey, ☐ Ez, ☐ TE, ☐ TM

The 'Numerical Data Array' window shows a plot of Amplitude [V/m] (black line) and Phase [rad] (red line) versus Diameter (Nanopillar @532nm #1 | Stack #1 (Program... [μm]). The Amplitude is constant at approximately 0.8 V/m, while the Phase increases linearly from approximately -2.5 rad to 2.5 rad as the Diameter increases from 0.12 μm to 0.2 μm.

access to full vectorial and complex-valued information

Workflow in VirtualLab Fusion

- Construct grating structure
 - [Configuration of Grating Structures by Using Interfaces](#) [Use Case]
 - [Configuration of Grating Structures by Using Special Media](#) [Use Case]
- Analyze grating diffraction efficiency
 - [Grating Order Analyzer](#) [Use Case]
- Check influence from specific parameters with Parameter Run
 - [Usage of the Parameter Run Document](#) [Use Case]



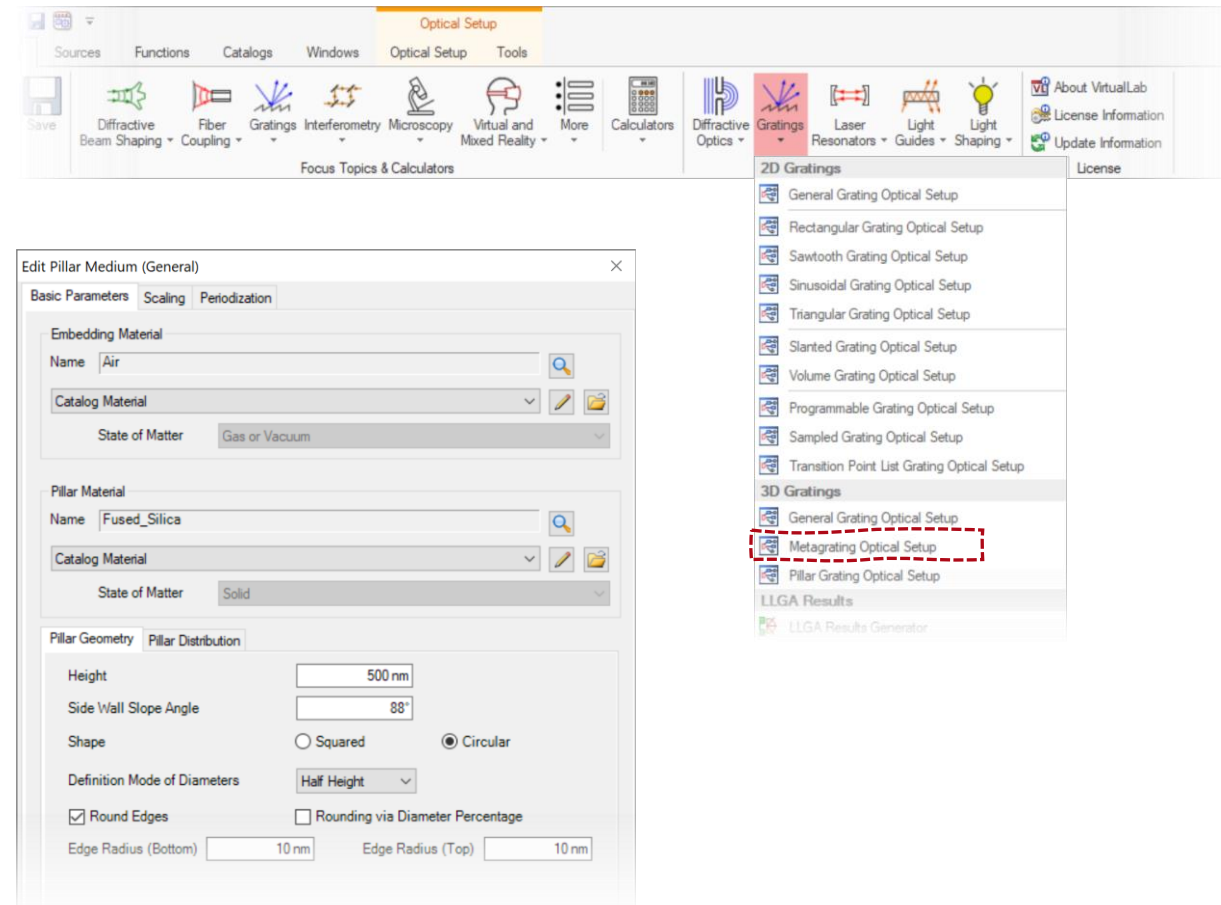
Document Information

title	Rigorous Analysis of Nanopillar Metasurface Building Block
document code	GRT.0012
version	1.2
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.202)
category	Application Use Case
further reading	<ul style="list-style-type: none">- Ultra-Sparse Dielectric Nano-Wire Grid Polarizers- Investigation of Polarization State of Diffraction Orders- Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures

Metagrating Construction – Discussion at Examples

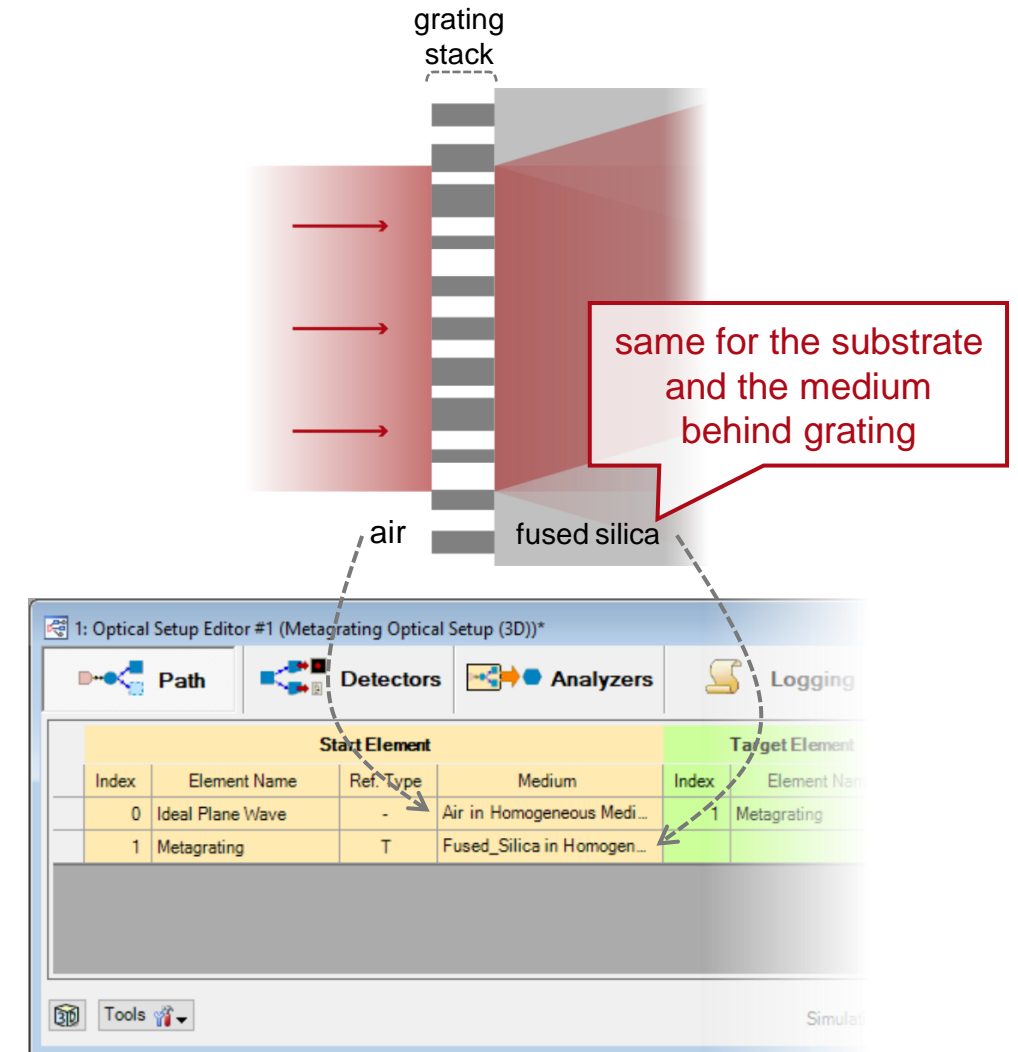
Metagrating Construction and Modeling

- VirtualLab Fusion provides
 - **Pillar Medium (General)** for the construction of metagrating – and other proper structures – by the composition of circular / rectangular nanopillars;
 - **Fourier modal method (FMM)** for the rigorous analysis of the performance of the composed metagratings, in terms of diffraction efficiency, polarization sensitivity, and so on.



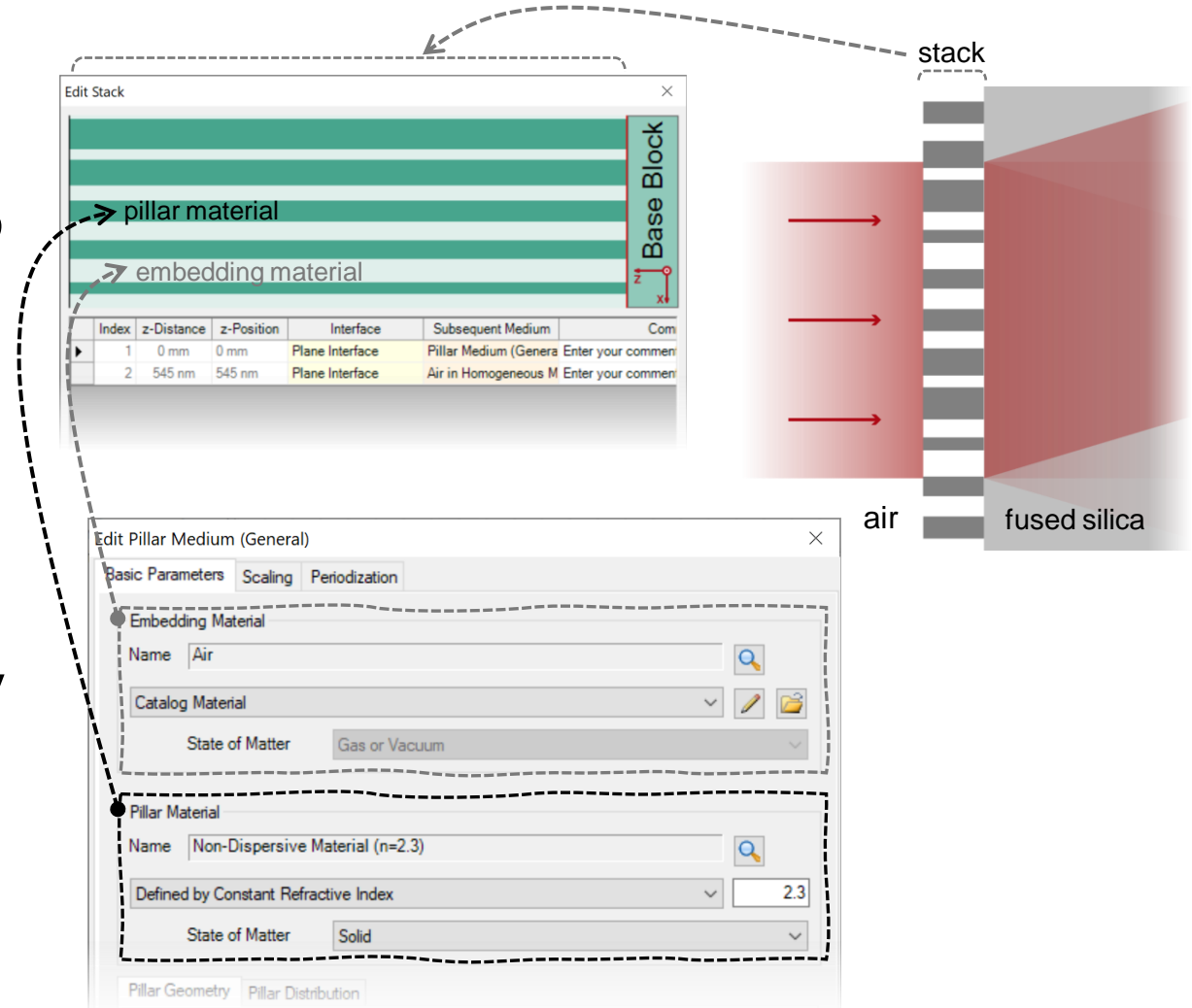
Media around Grating Component

- Media in front and behind grating
 - The medium in front and that behind the grating shall be set in the optical setup editor.
 - The media shall be configured according the actual situation under investigation.
 - As a convention for grating efficiency analysis, the Fresnel loss between the substrate and the surrounding medium is usually neglected.

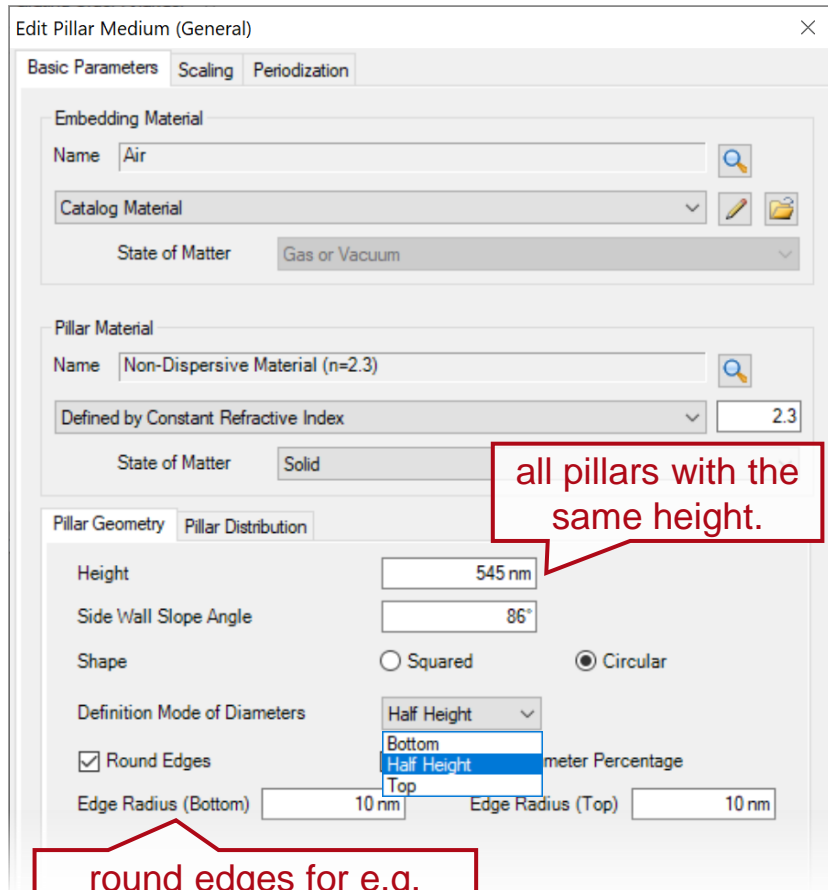


Materials inside Grating Stack

- Grating stack
 - The metagrating stack is constructed by the Pillar Medium (General) and two plane interfaces that press it from both sides.
 - The pillar regions are filled by the specified pillar material, while the rest filled by the embedding material.
 - Both the pillar and embedding materials can be defined independently from the media in front or behind the grating.

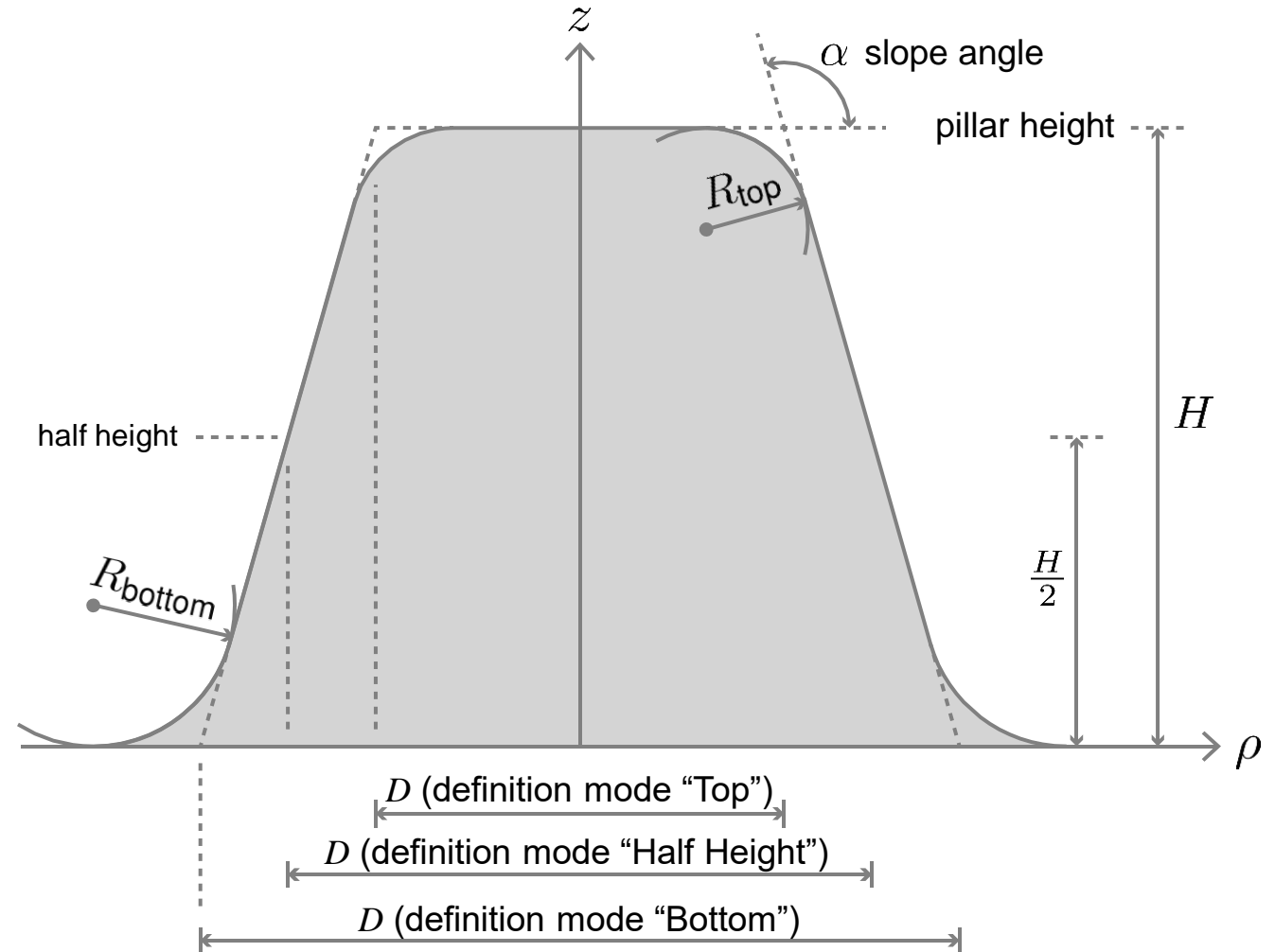


Single Pillar Geometry Configuration

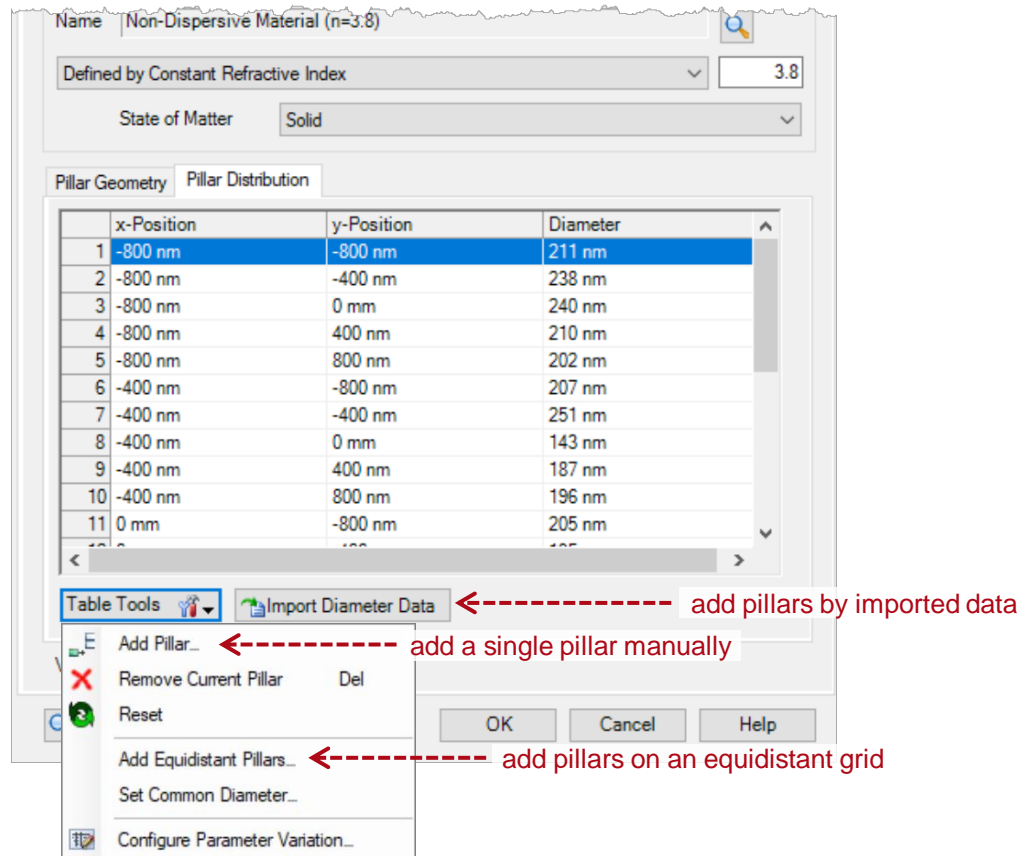


all pillars with the same height.

round edges for e.g. tolerance consideration



Distribution of Pillars

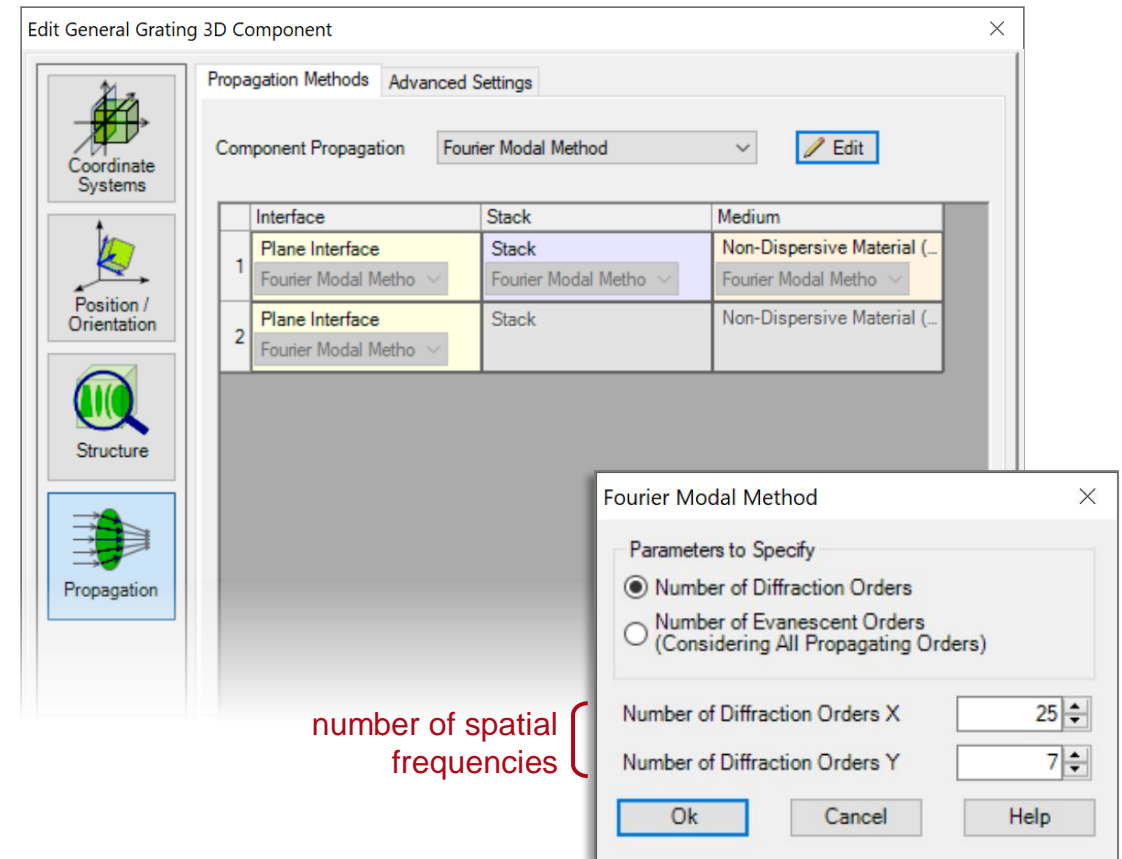


- Pillar Distribution

- One can specify the pillar diameter at an arbitrary lateral position (x, y).
- Pillars can be added
 - one by one manually;
 - on an equidistant grid at once;
 - According to an imported array that defines the lateral position and diameter of each pillar.
- Pillar positions can be arbitrarily varied either directly, or as deviations from their original positions.

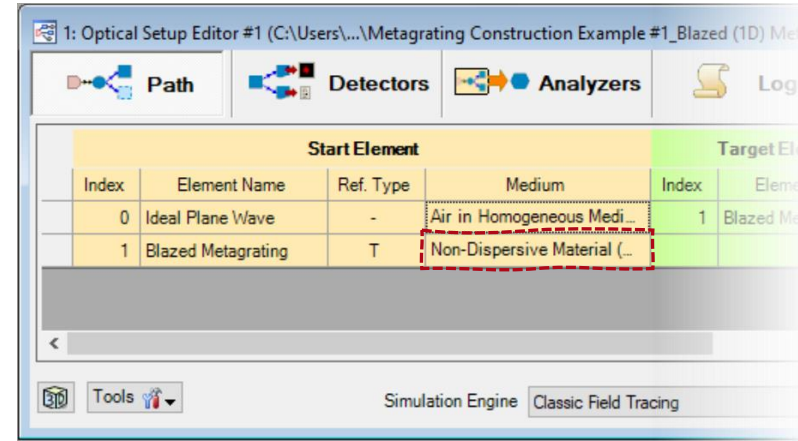
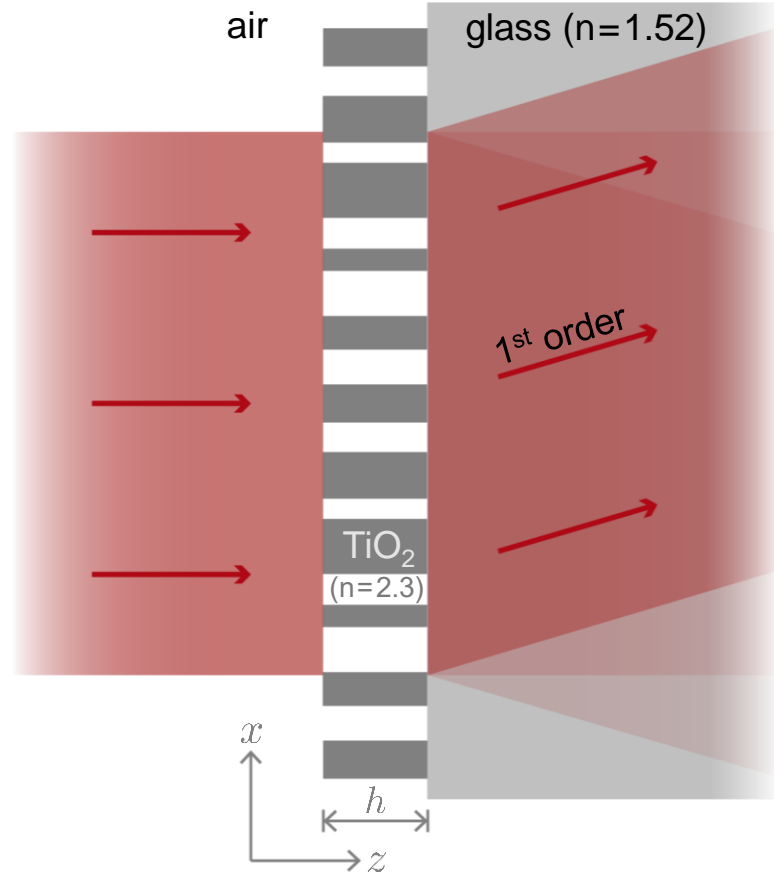
Numerical Parameter Setting

- Number of spatial frequencies
 - To obtain converged result from FMM / RCWA simulation, enough number of spatial frequencies should be used.
 - For metagratings, which is usually composed by an array (1D or 2D) of pillars, we recommend to perform convergence test to ensure the numerical convergence.
 - For 1D metagratings (e.g. blazed metagrating), the required number of spatial frequencies should be check separated for x and y directions.

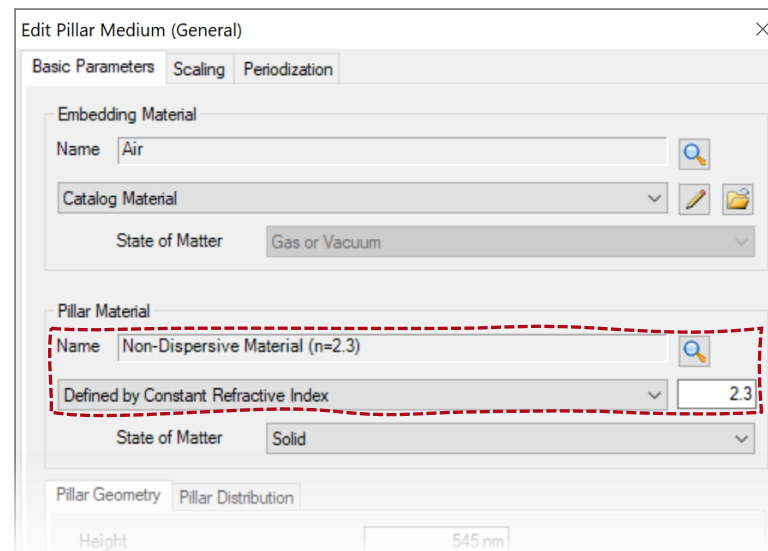


Example #1: One-Dimensional Blazed Metagrating

Media and Materials Configuration



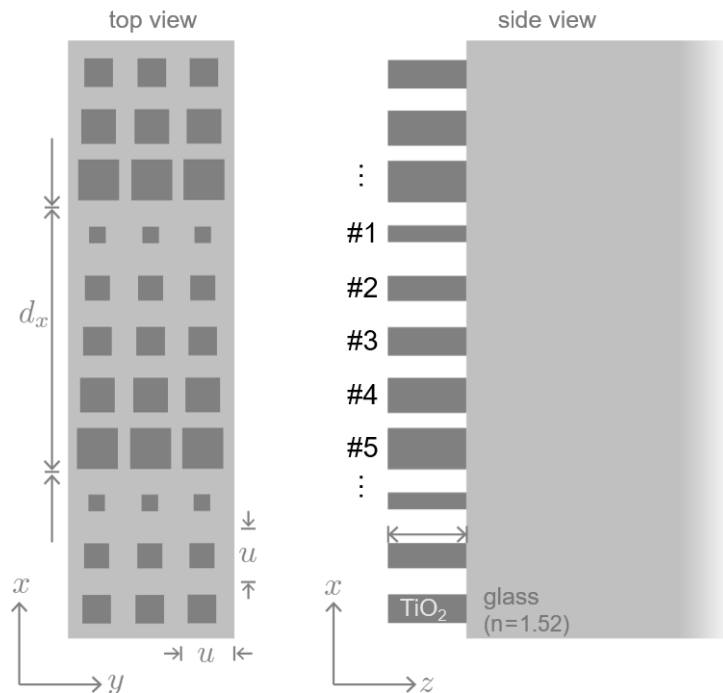
The medium behind grating is set the same as the glass substrate, with $n=1.52$.



The pillar material is set with $n=2.3$ for TiO_2 at the given wavelength.

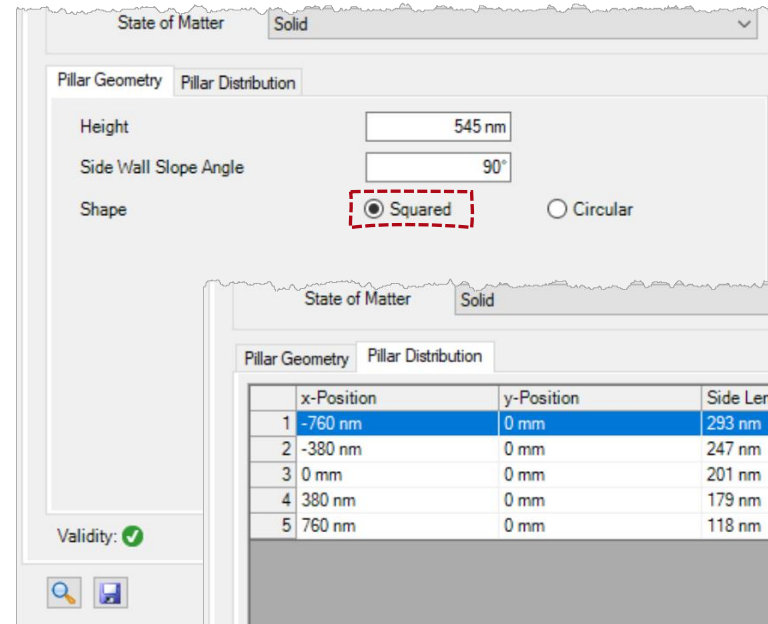
 [see the full Application Use Case](#)

Pillar Geometry and Distribution

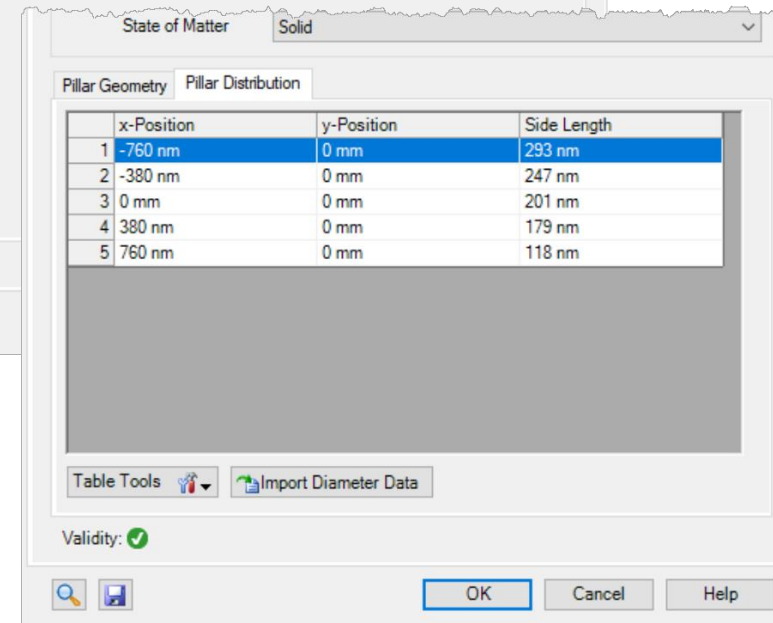


	#1	#2	#3	#4	#5
D	118nm	179nm	201 nm	247nm	293nm
$f=D/u$	0.31	0.47	0.53	0.65	0.77
$\Delta\psi$	0.20π	0.69π	0.98π	1.40π	1.73π

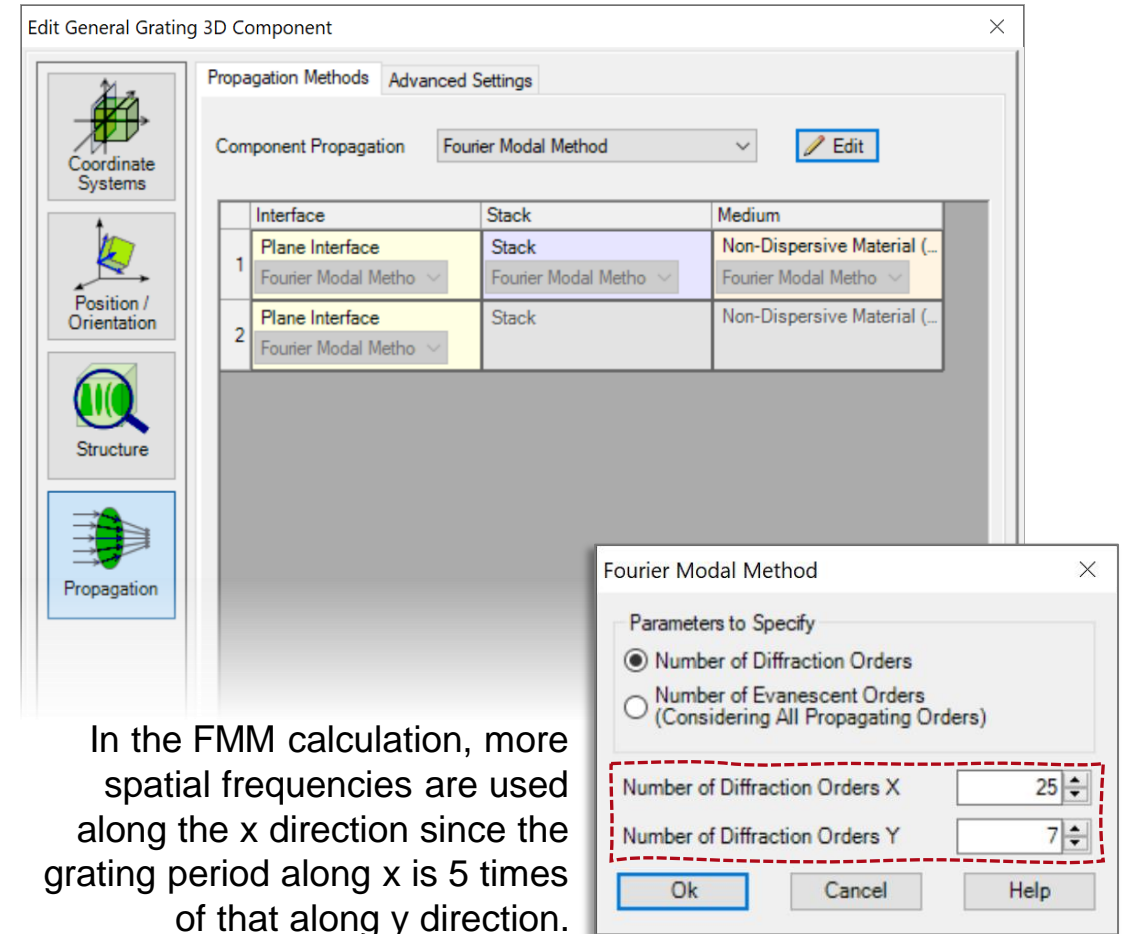
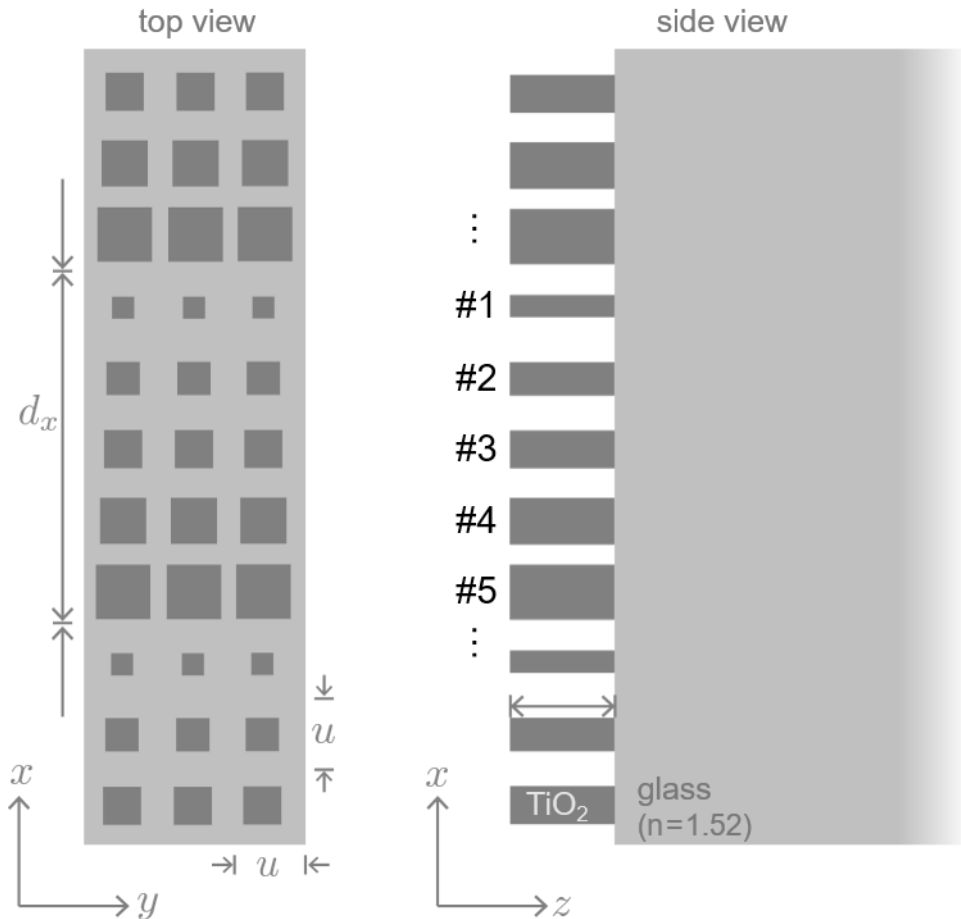
Selection of pillar diameters follows from P. Lalanne, *et al.*, Opt. Lett. 23, 1081-1083 (1998)



In this case, following the reference, we use square pillars with pre-calculated height, and defined their positions and diameters manually.



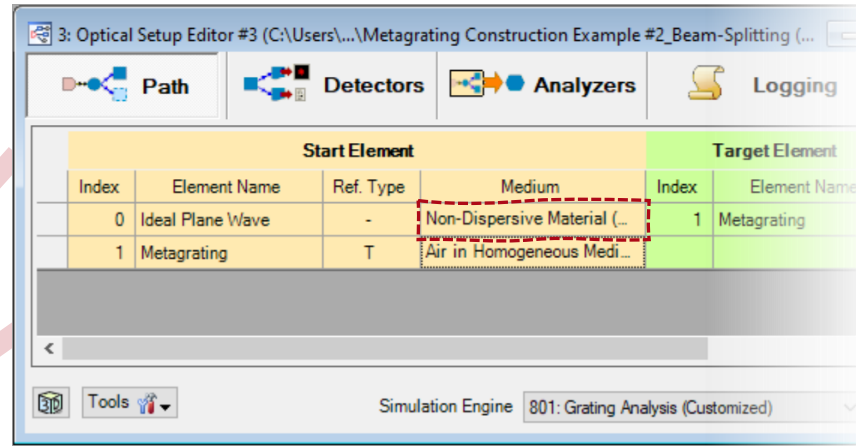
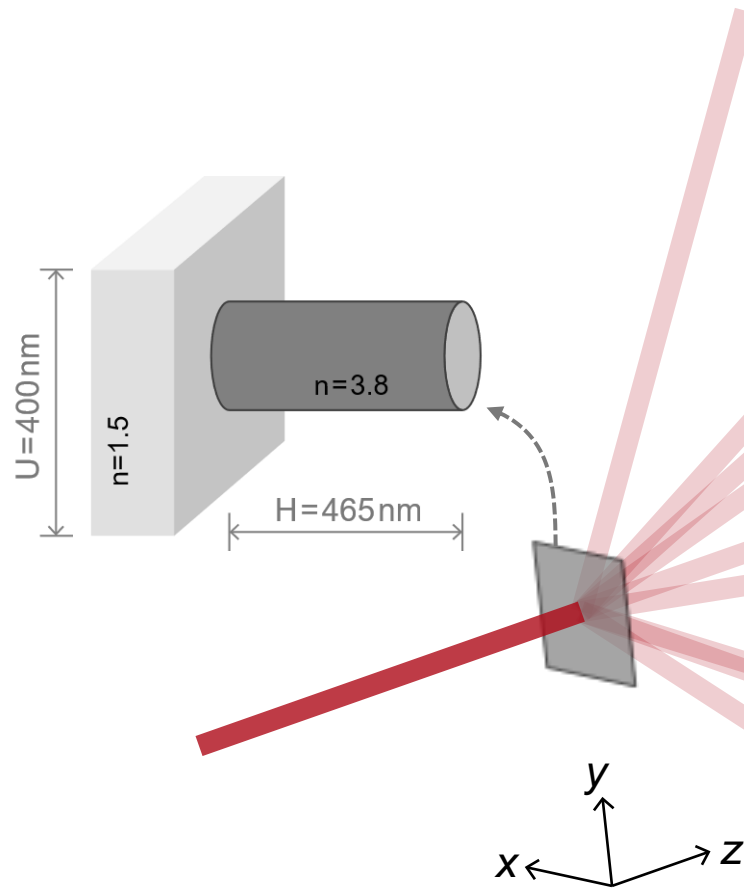
Number of Spatial Frequencies



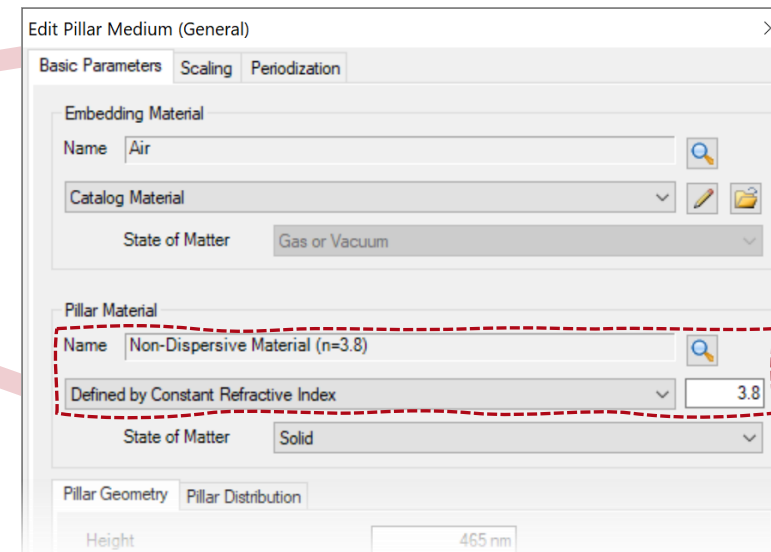
In the FMM calculation, more spatial frequencies are used along the x direction since the grating period along x is 5 times of that along y direction.

Example #2: Two-Dimensional Beam-Splitting Metagrating

Media and Materials Configuration



The medium in front of the grating is set the same as the substrate, with $n=1.5$, and, in this way, the incident light is assumed from inside the substrate.



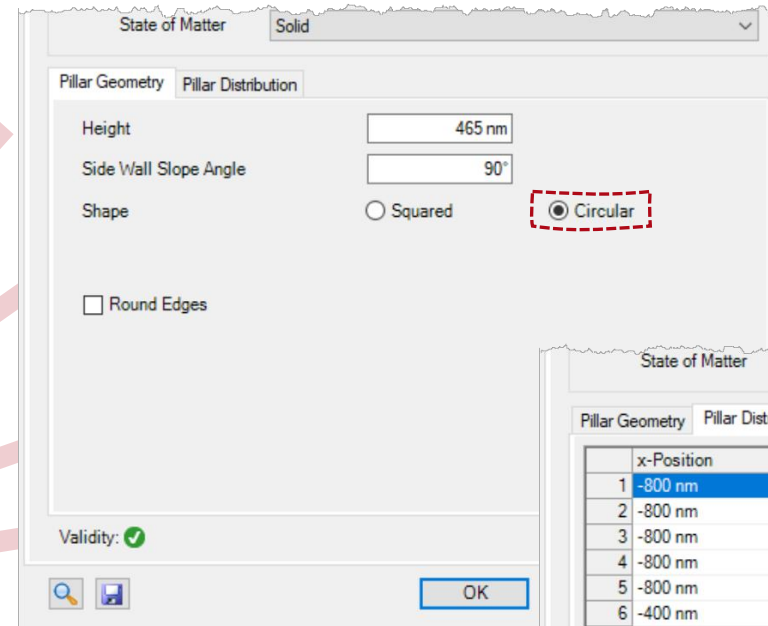
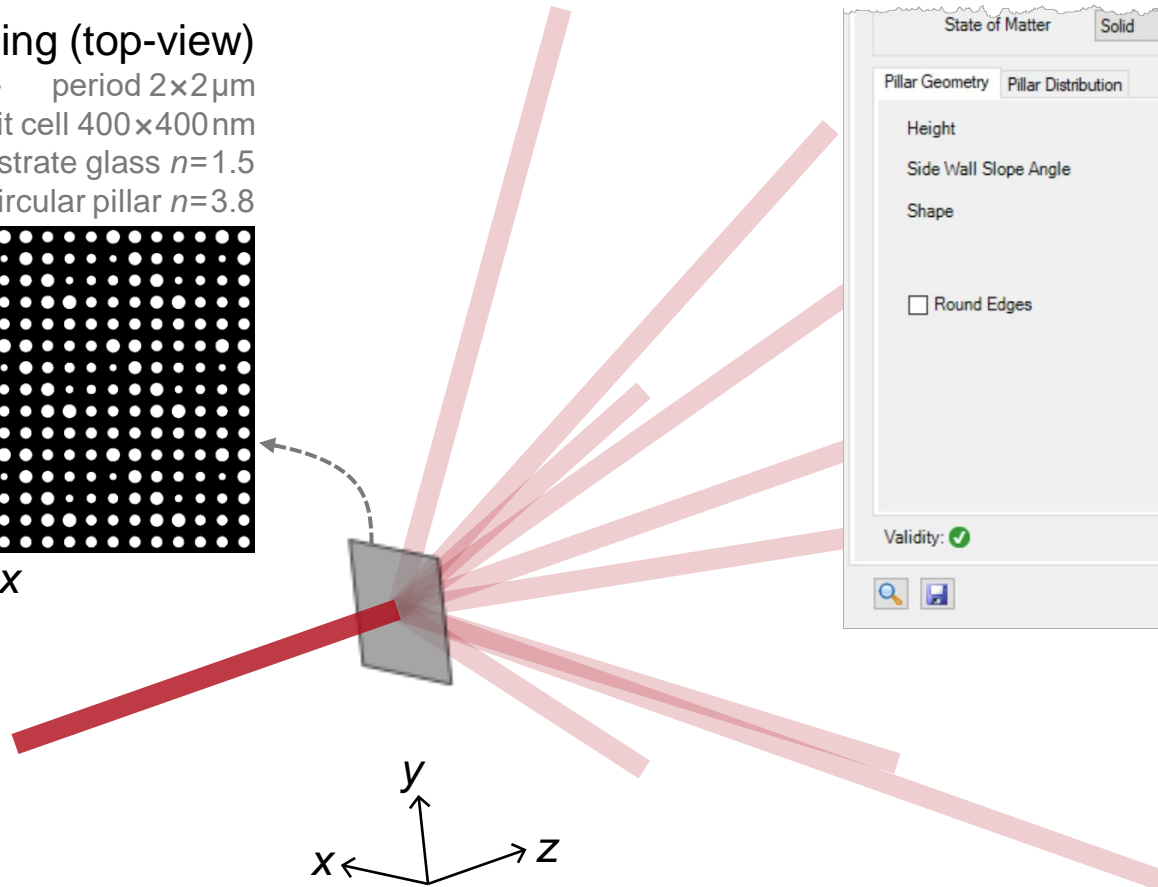
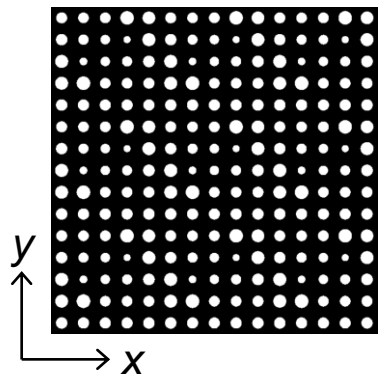
The pillar material is set with $n=3.8$ for the given wavelength.

[see the full Application Use Case](#)

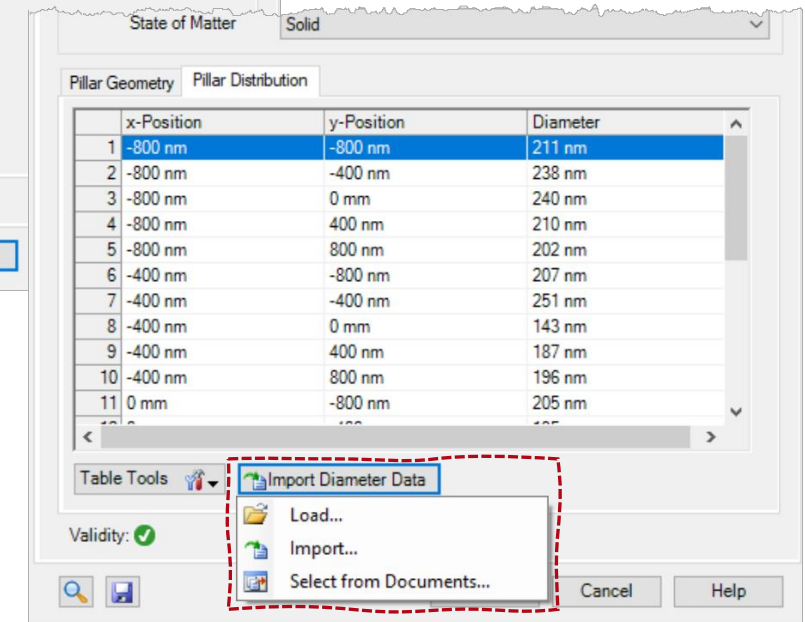
Pillar Geometry and Distribution

metagrating (top-view)

- period $2 \times 2 \mu\text{m}$
- unit cell $400 \times 400 \text{ nm}$
- substrate glass $n=1.5$
- circular pillar $n=3.8$



Circular pillars are chosen for this case, and their positions and diameters are defined by imported data (calculated based on IFTA design).

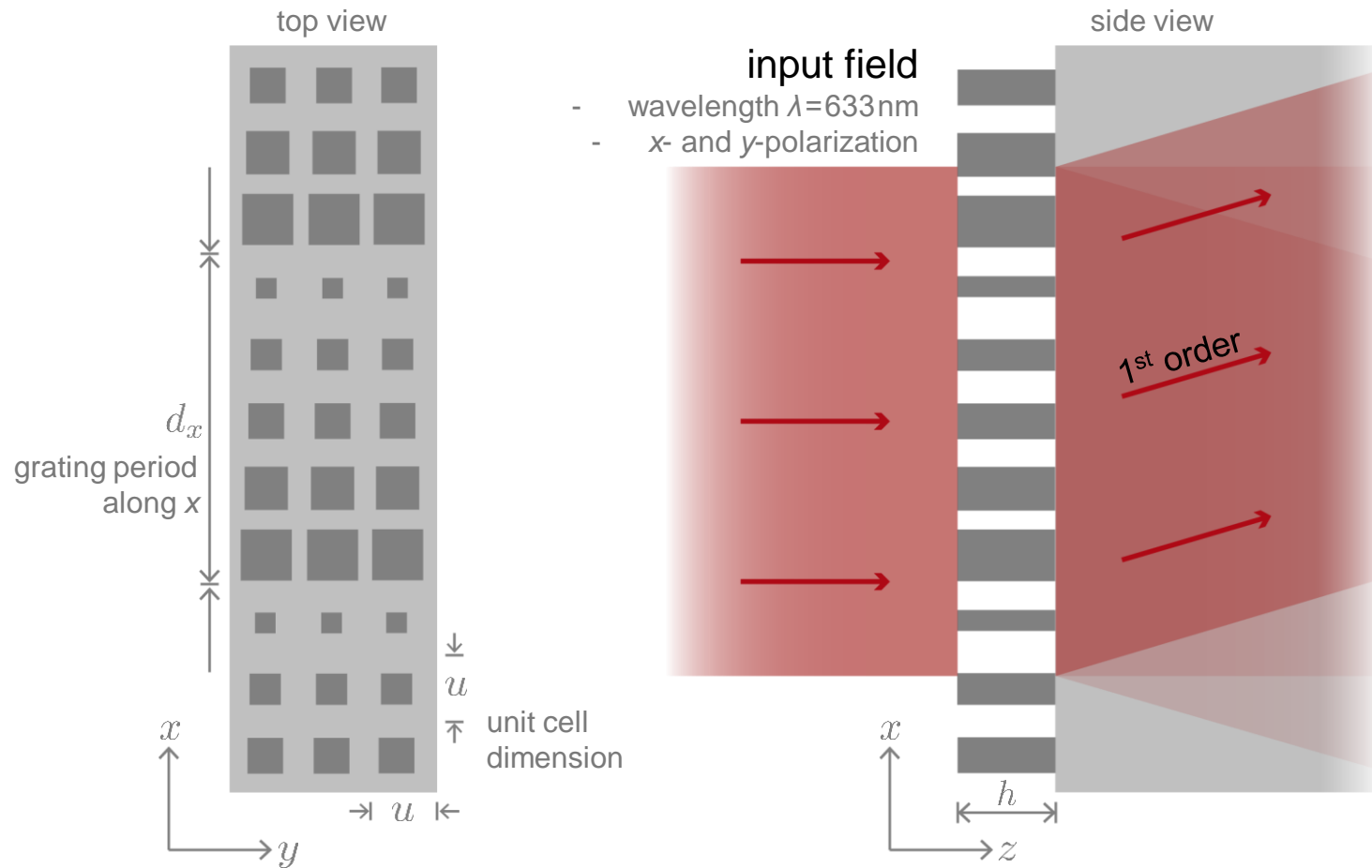


Document Information

title	Metagrating Construction – Discussion at Examples
document code	GRT.0022
version	1.0
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 2.8)
category	Feature Use Case
further reading	<ul style="list-style-type: none">- Configuration of Grating Structures by Using Interfaces- Configuration of Grating Structures by Using Special Media- VirtualLab Fusion Technology – FMM / RCWA [S-Matrix]

Modeling and Design of Blazed Metagratings

Modeling Task



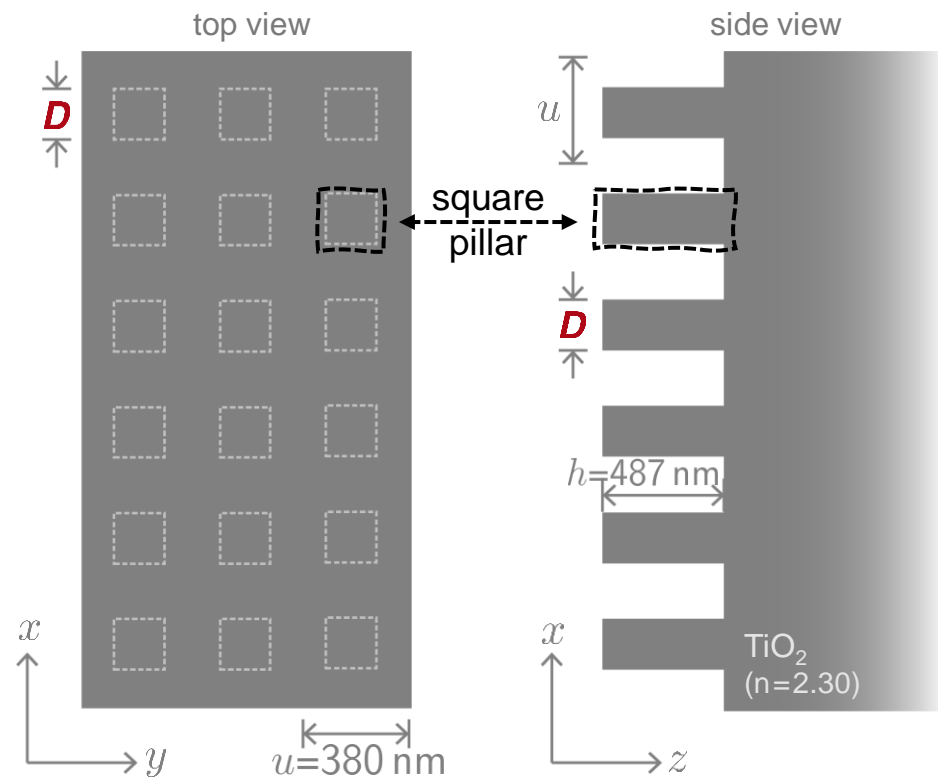
How to design a metagrating with optimized 1st order diffraction efficiency, by

- selecting the proper unit cells / building blocks, and
- arranging them and optimize their positions within one grating period?

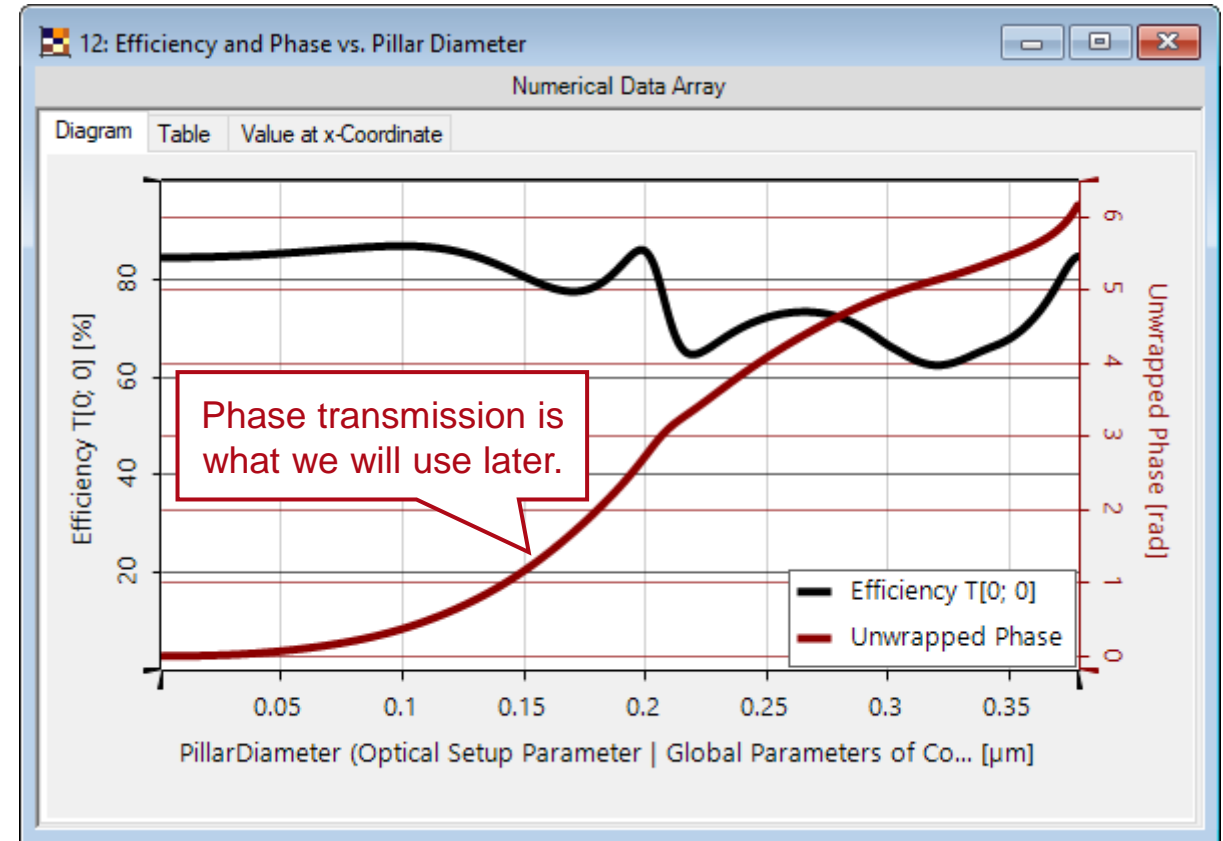
grating parameters and design method follows P. Lalanne, *et al.*, Opt. Lett. 23, 1081-1083 (1998)

Unit Cell Analysis (Index Matched)

First, we assume a periodic replication of the same square pillars and vary the **pillar diameter (D)**.



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



Unit Cell Analysis (Index Matched)

First, we assume a periodic replication of the same square pillars and vary the **pillar diameter (D)**.

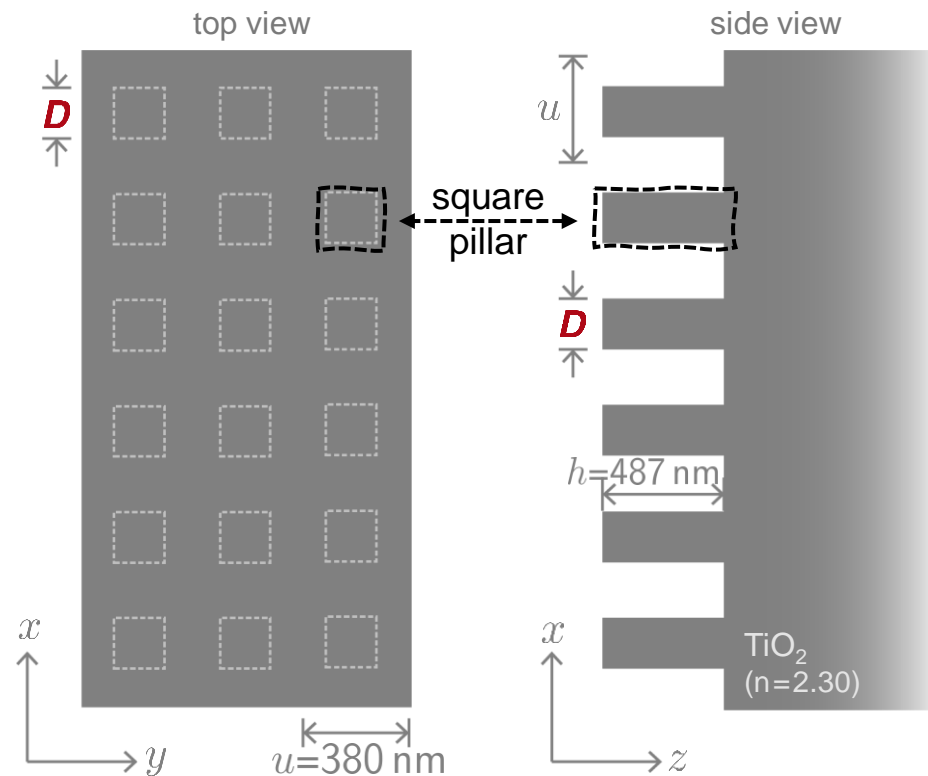


Fig. 1 from P. Lalanne, *et al.*, Opt. Lett. 23, 1081-1083 (1998)

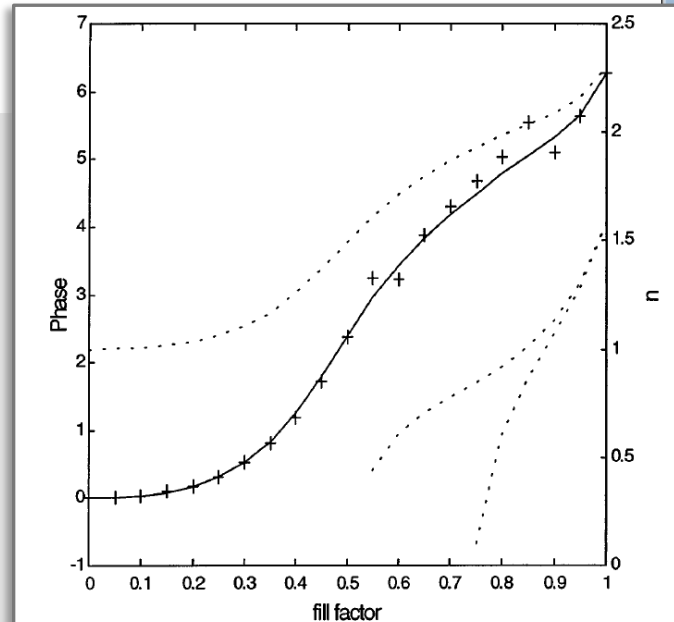
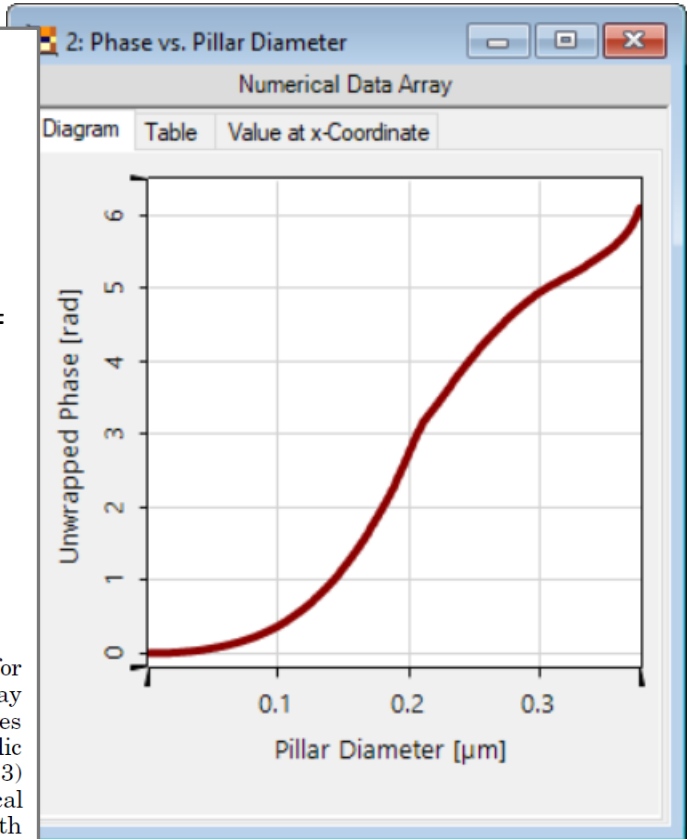


Fig. 1. Crosses, phases of the transmitted zeroth order for a 487-nm-thick grating composed of a 380-nm-period array of square pillars etched in TiO_2 . Dotted curves, n values of all the propagating modes supported by the biperiodic structure. The uppermost curve (n varies from 1 to 2.3) corresponds to the grating effective index. Numerical results were obtained by the modal method of Ref. 10 with square truncation (17 orders are retained along each axis). Solid curve, phases of a plane wave transmitted through a 487-nm-thick homogeneous dielectric film whose refractive index is equal to the n value of the fundamental mode.

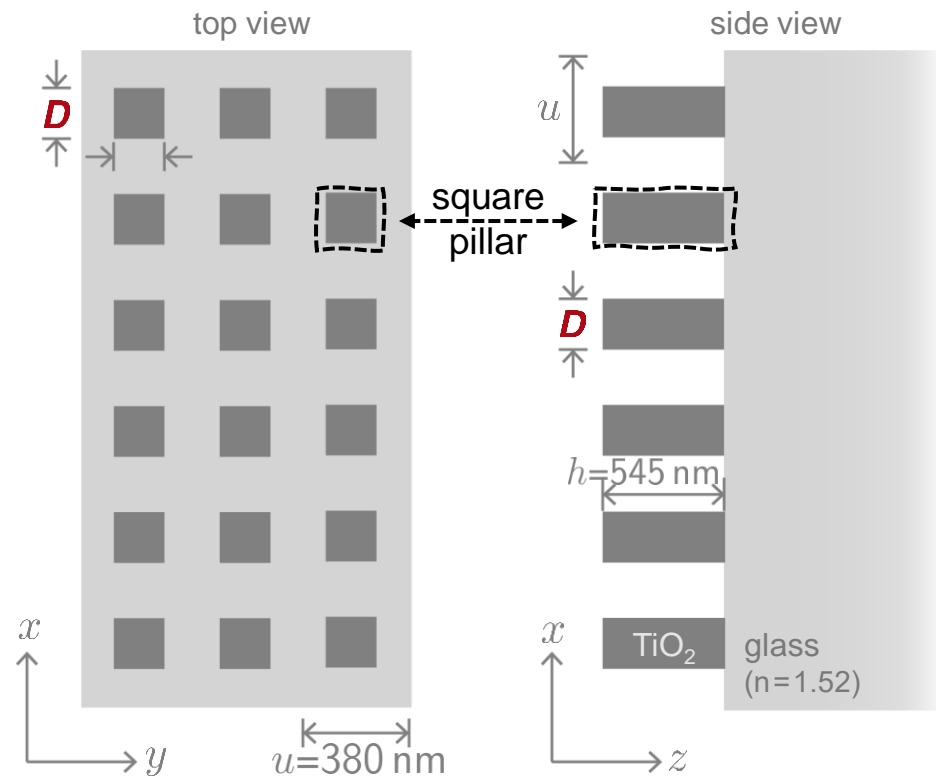
phase vs. pillar diameter (@633nm)



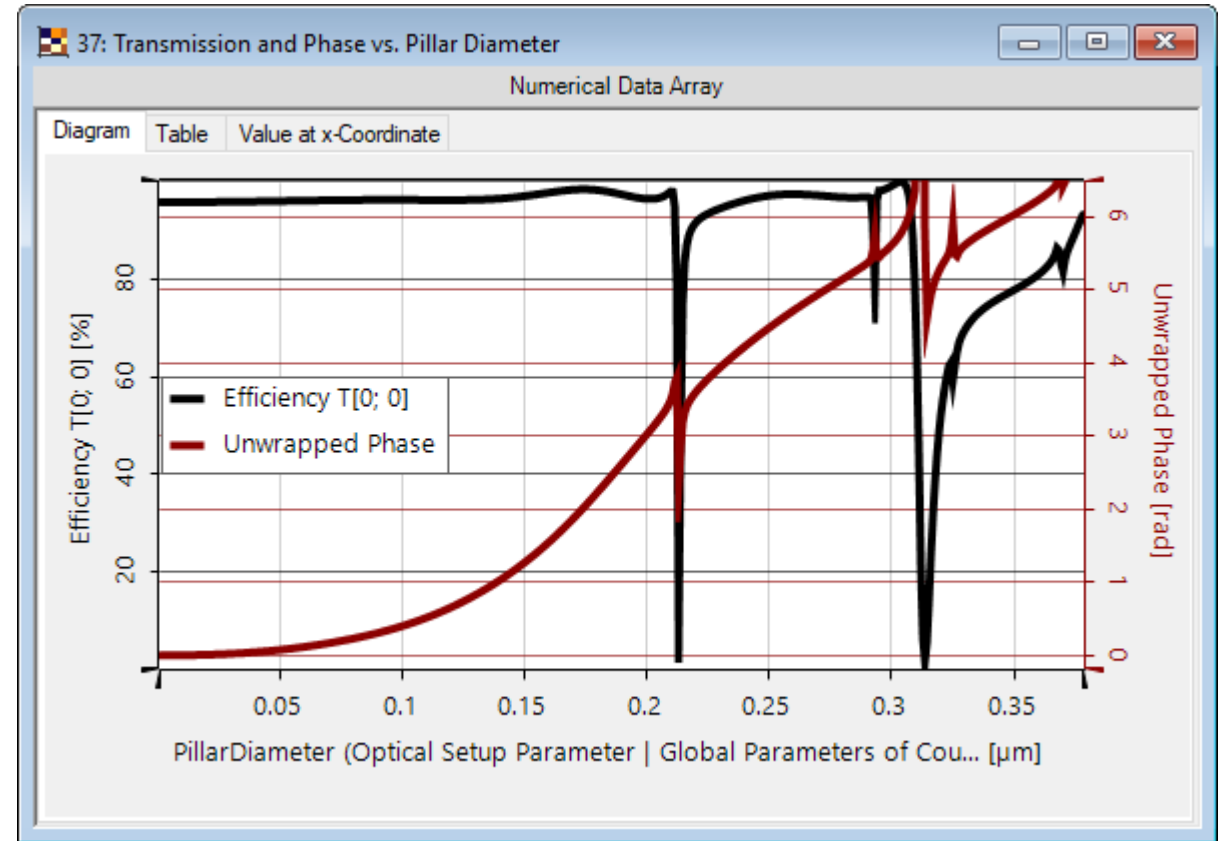
VirtualLab Fusion simulation

Choosing Unit Cell (TiO₂-Glass Interface)

In practice, the substrate is in a different material as the pillars. Here, we consider glass substrate.

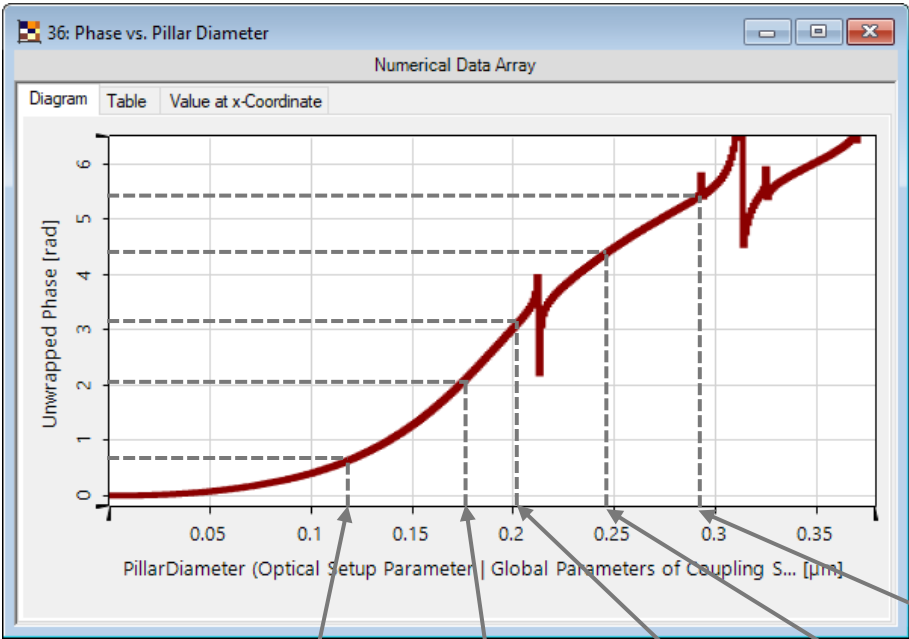
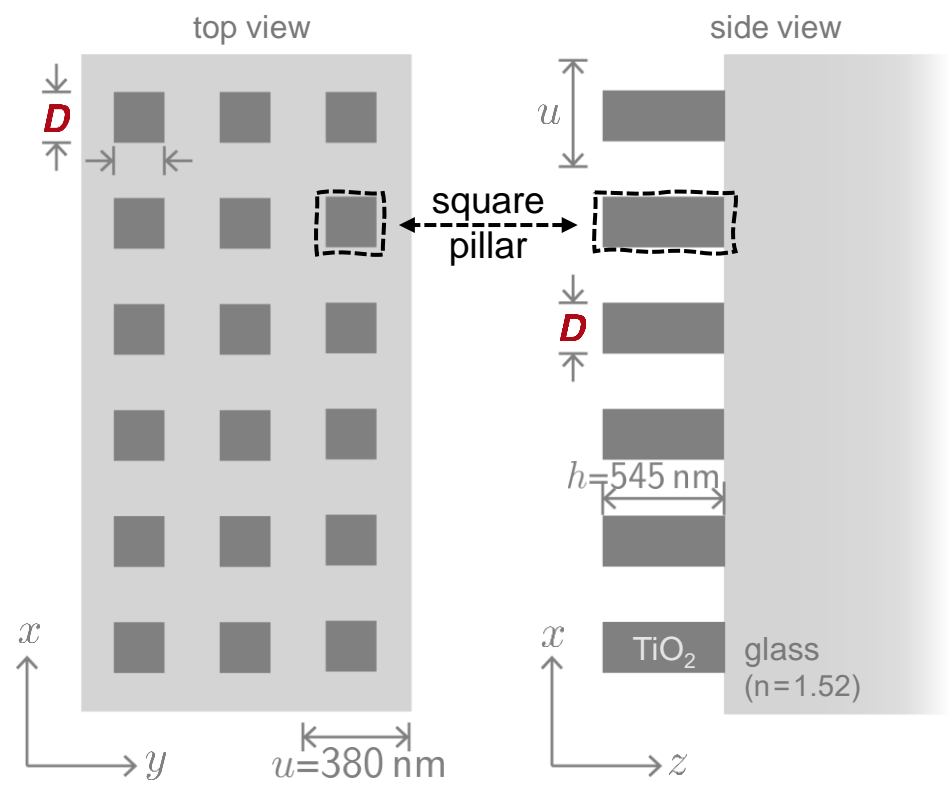


transmission amplitude/phase vs. pillar diameter (@633nm)



Selection of Pillar Diameters

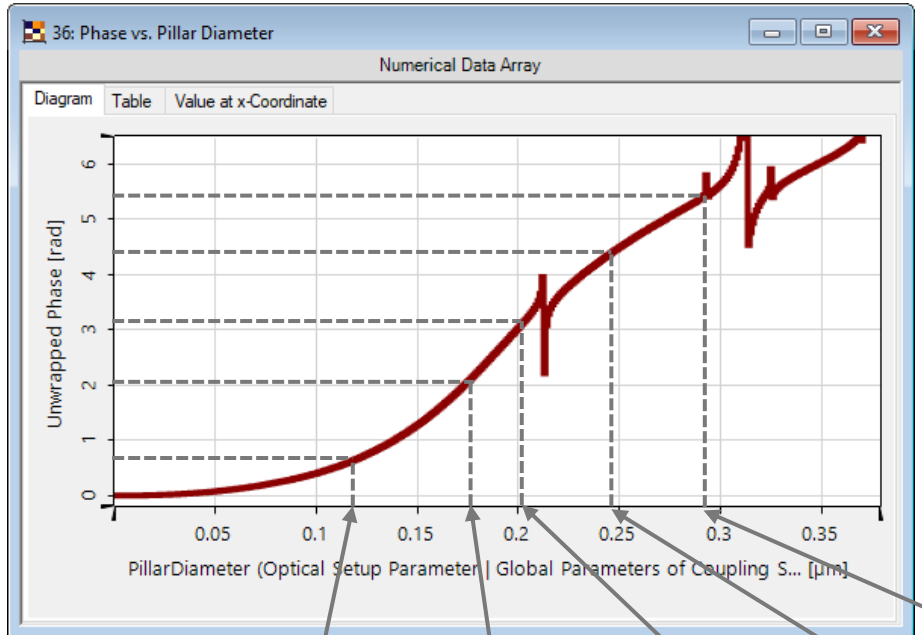
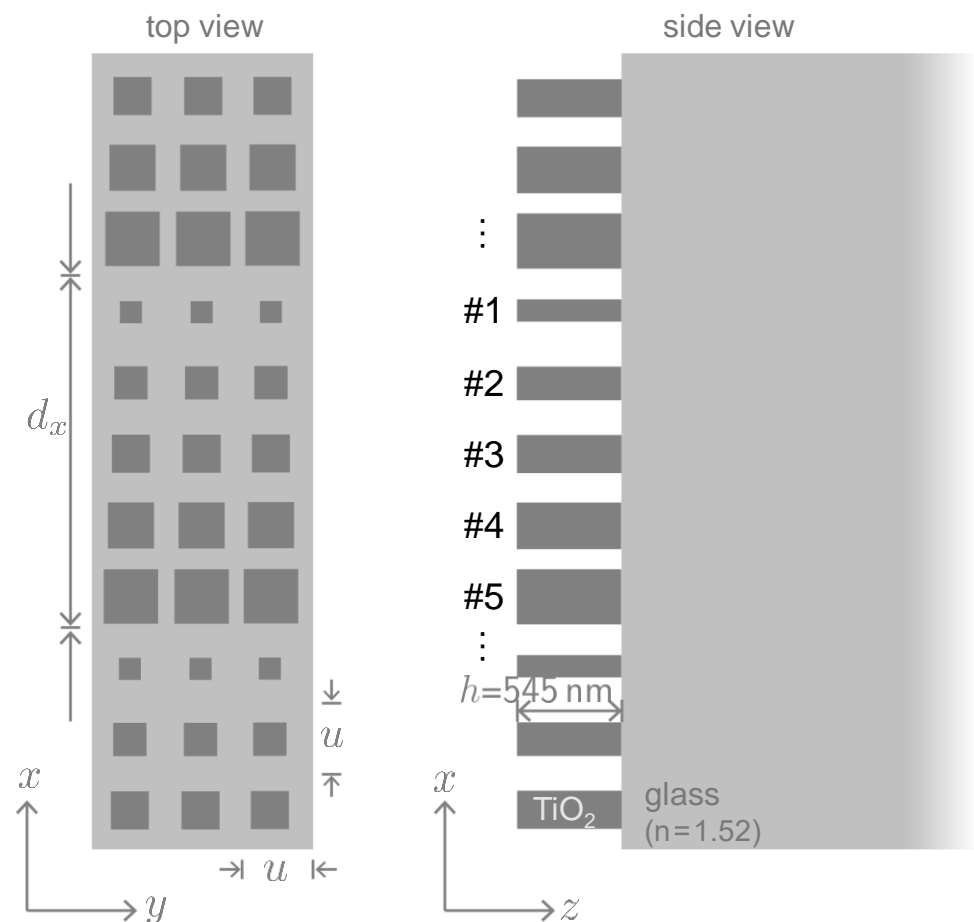
In practice, the substrate is in a different material as the pillars. Here, we consider glass substrate.



	#1	#2	#3	#4	#5
D	118nm	179nm	201nm	247nm	293nm
$f = D/u$	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)

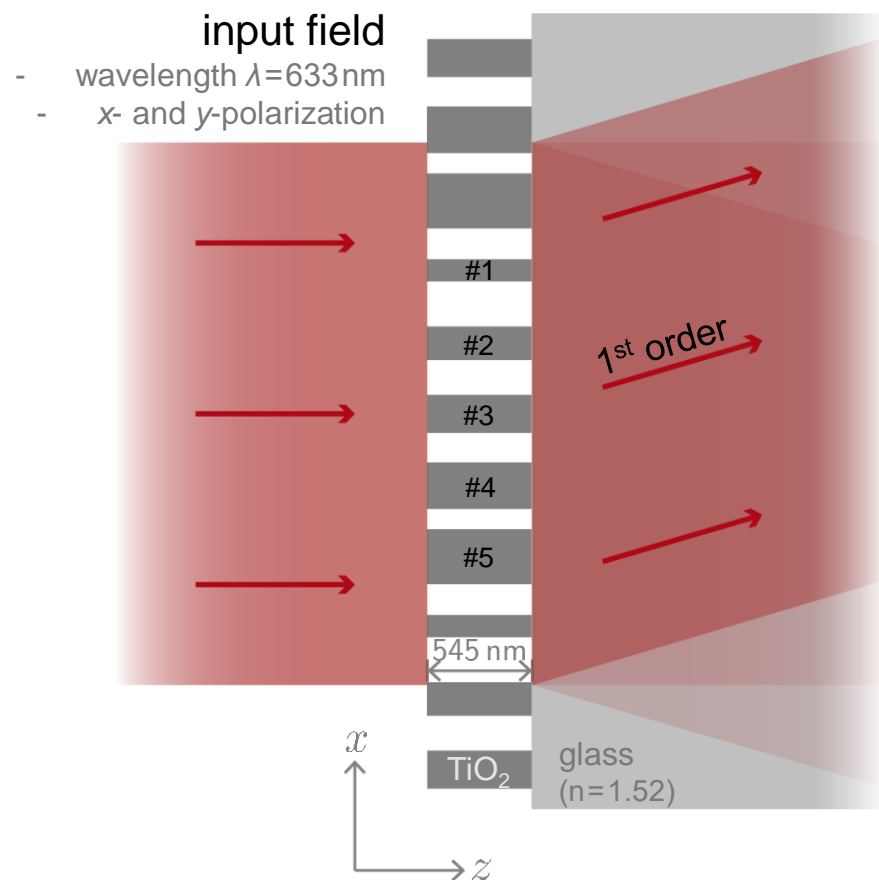
Blazed Metagrating Construction



	#1	#2	#3	#4	#5
D	118nm	179nm	201nm	247nm	293nm
$f = D/u$	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)

Performance Analysis of Initial Design



grating performance evaluation

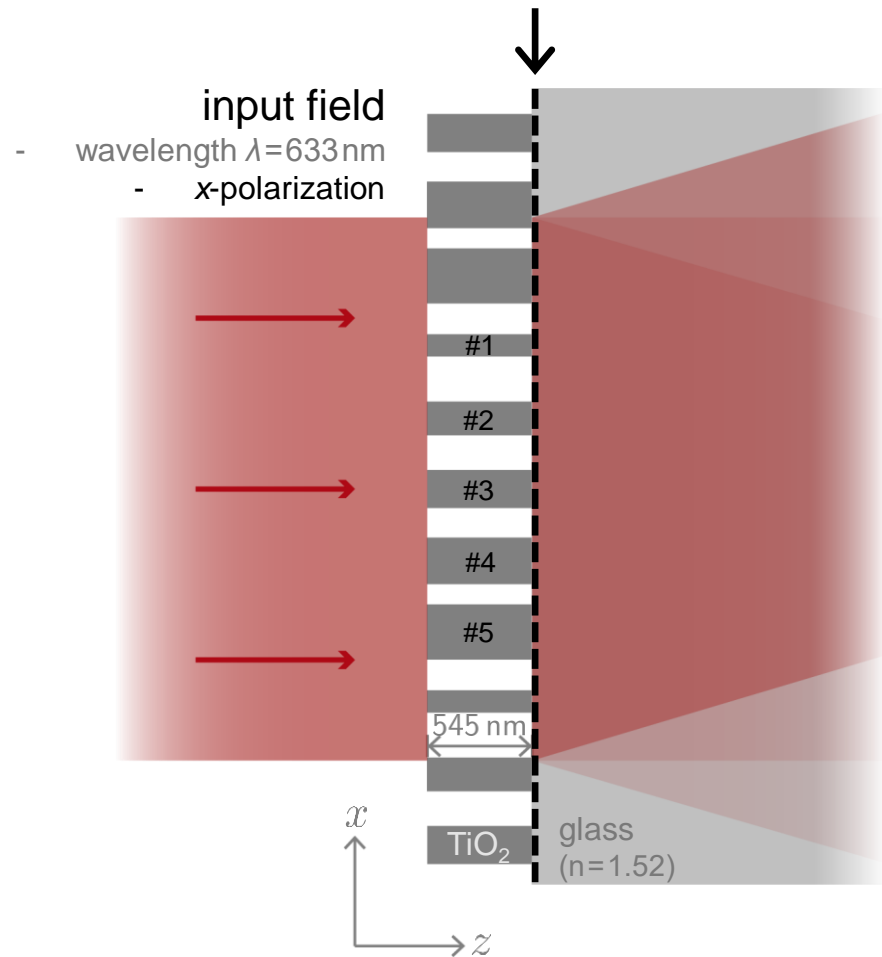
	Efficiency
y-polarization (TE)	80.2%
x-polarization (TM)	74.2%
average	77.2%

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

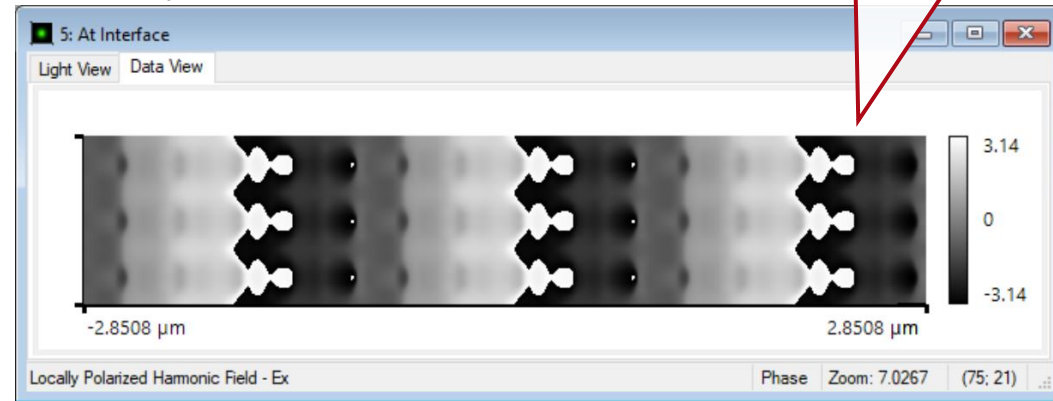
	#1	#2	#3	#4	#5
D	118nm	179nm	201nm	247nm	293nm
$f=D/u$	0.31	0.47	0.53	0.65	0.77
$\Delta\psi$	0.20π	0.69π	0.98π	1.40π	1.73π

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

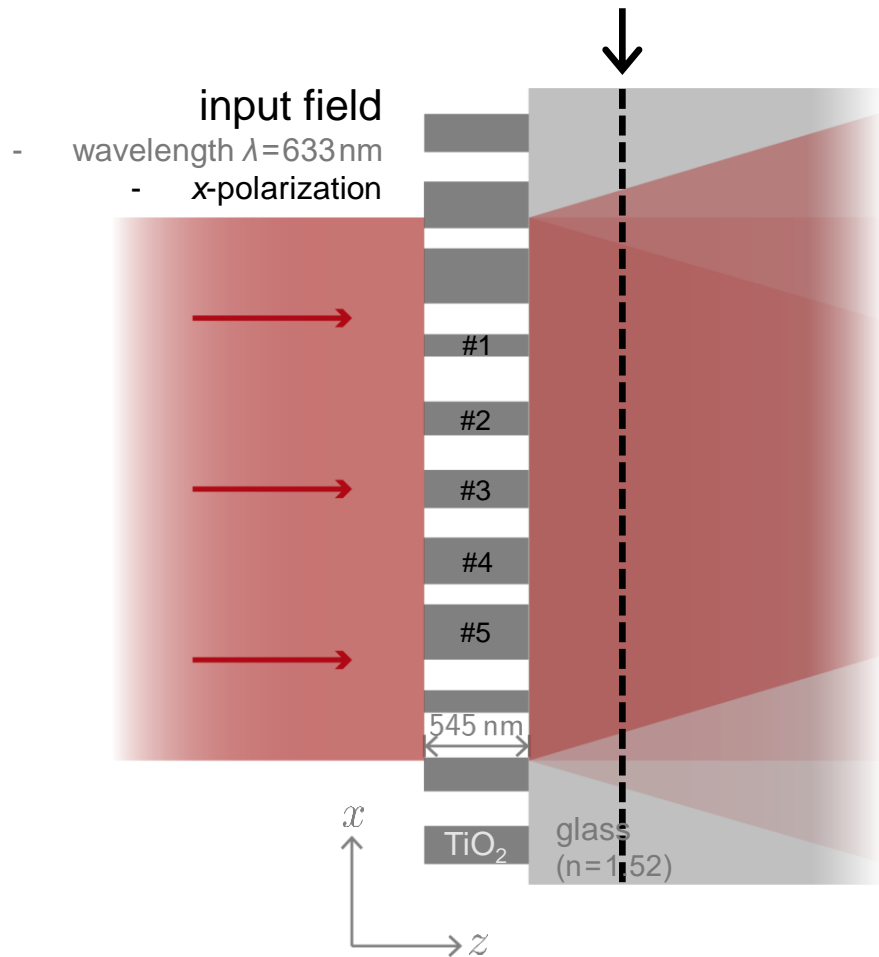
Visualization of Transmitted Field



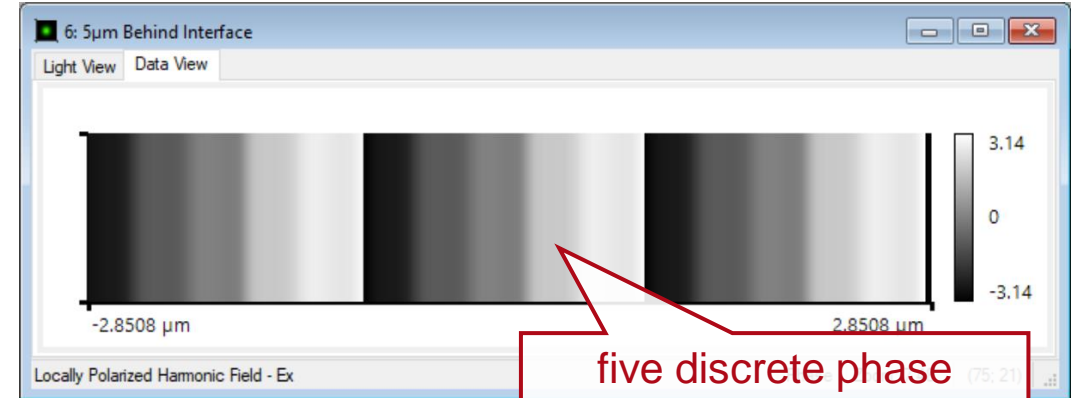
directly at pillar-substrate interface



Visualization of Transmitted Field



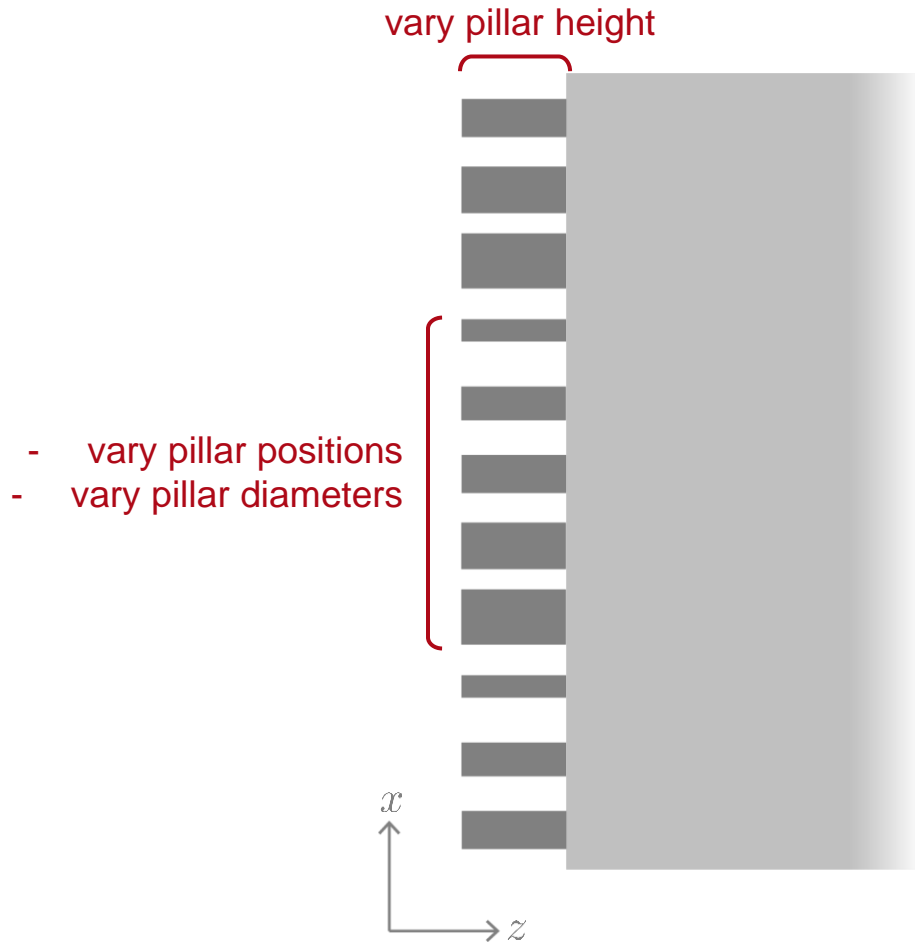
5 μm behind interface (evanescent waves damped)



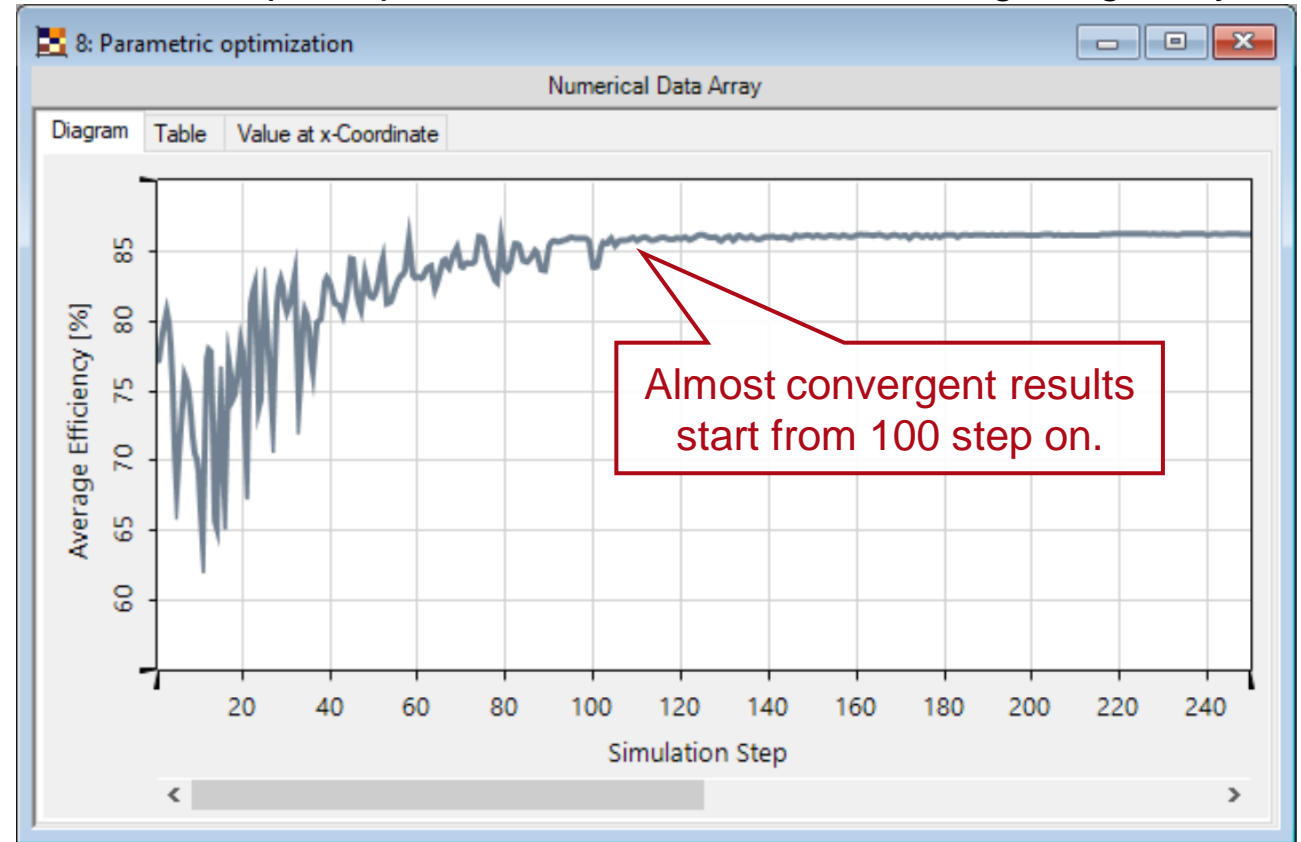
directly at pillar-substrate interface



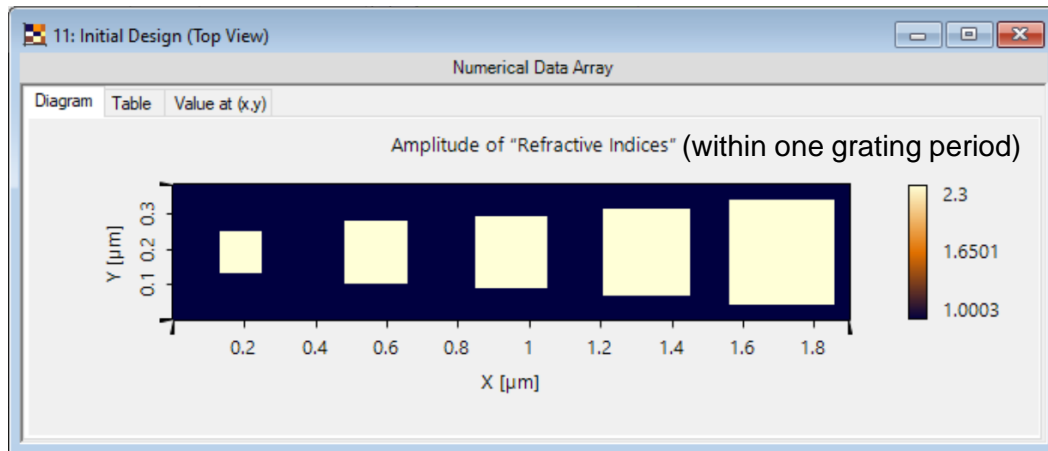
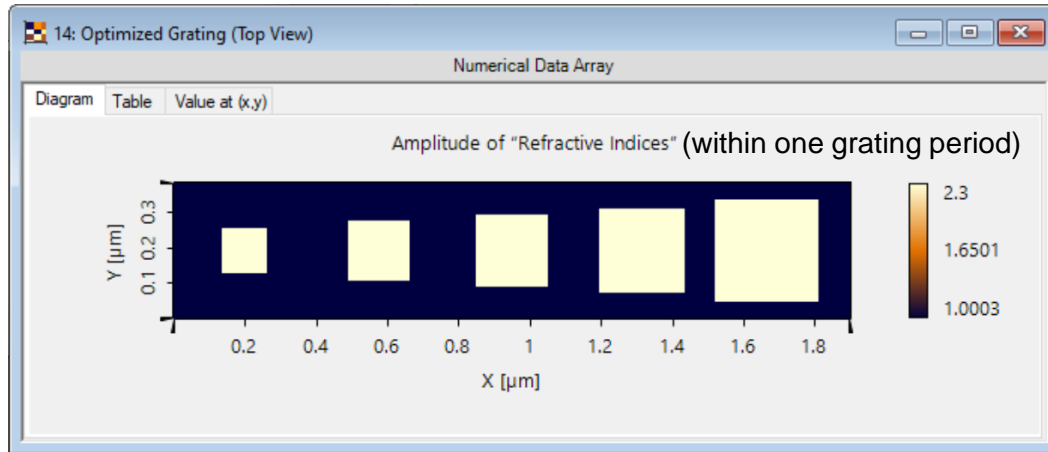
Further Optimization of Metagrating



downhill simplex optimization with FMM/RCWA for grating analysis



Performance Analysis of Optimized Design



optimized grating

Efficiency

y-polarization (TE)	87.0%
x-polarization (TM)	85.5%
average	86.3%

After optimization, the resulting grating shows almost 10 percentage points increase in the 1st order diffraction efficiency.

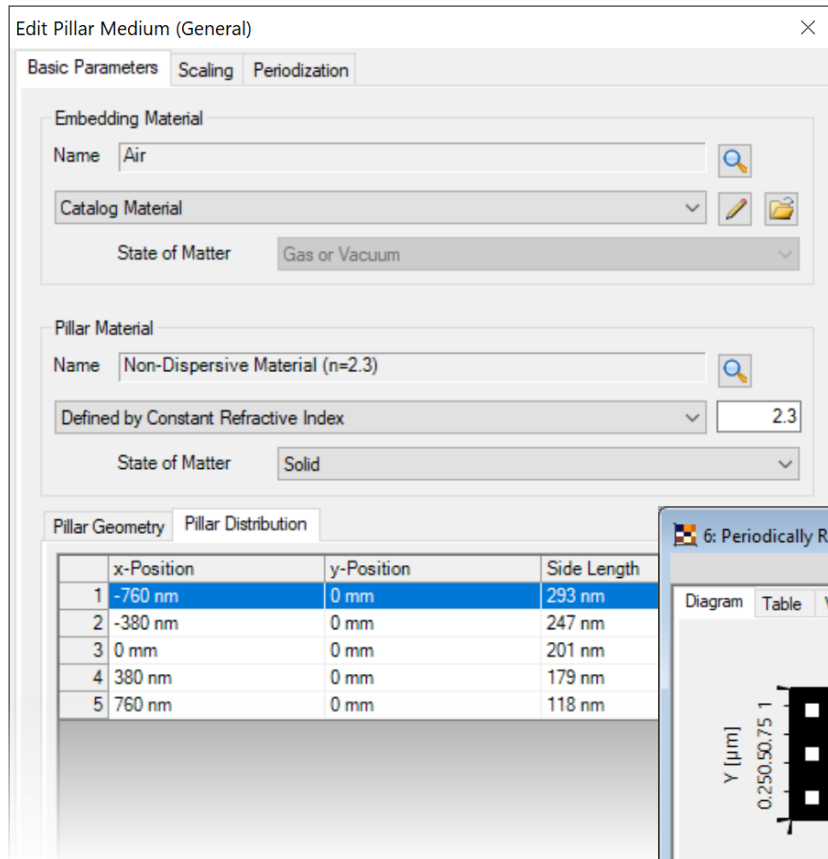
initial grating design

Efficiency

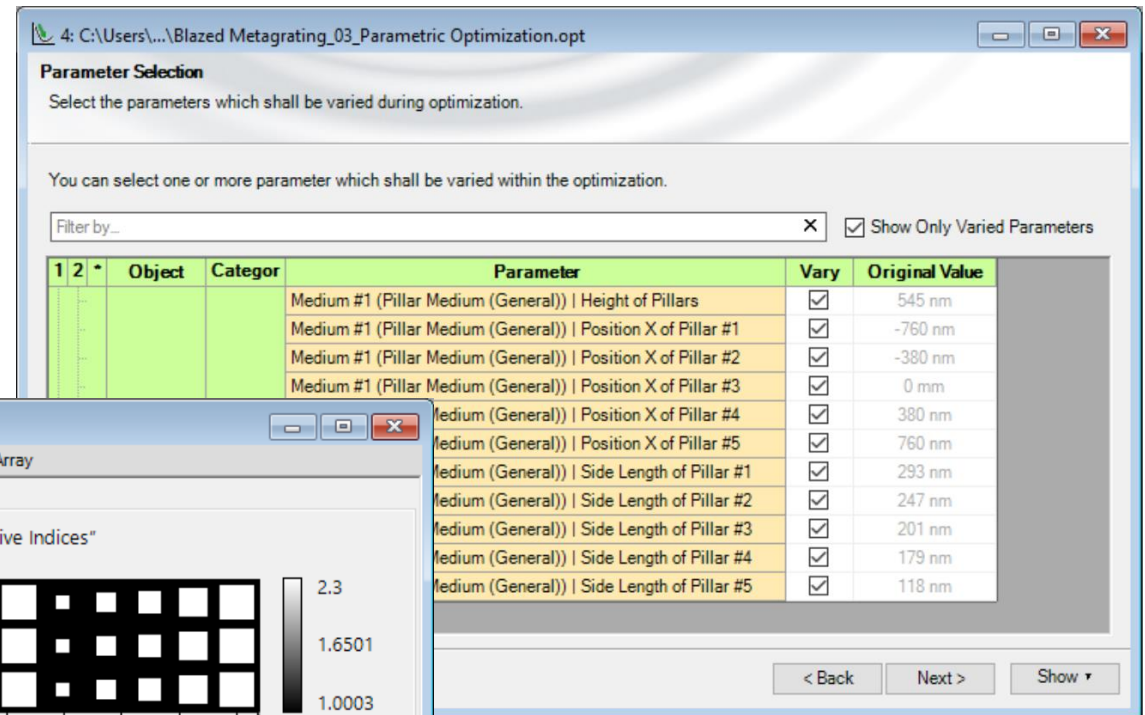
y-polarization (TE)	80.2%
x-polarization (TM)	74.2%
average	77.2%

Peek into VirtualLab Fusion

flexible distribution of unit cells / pillars

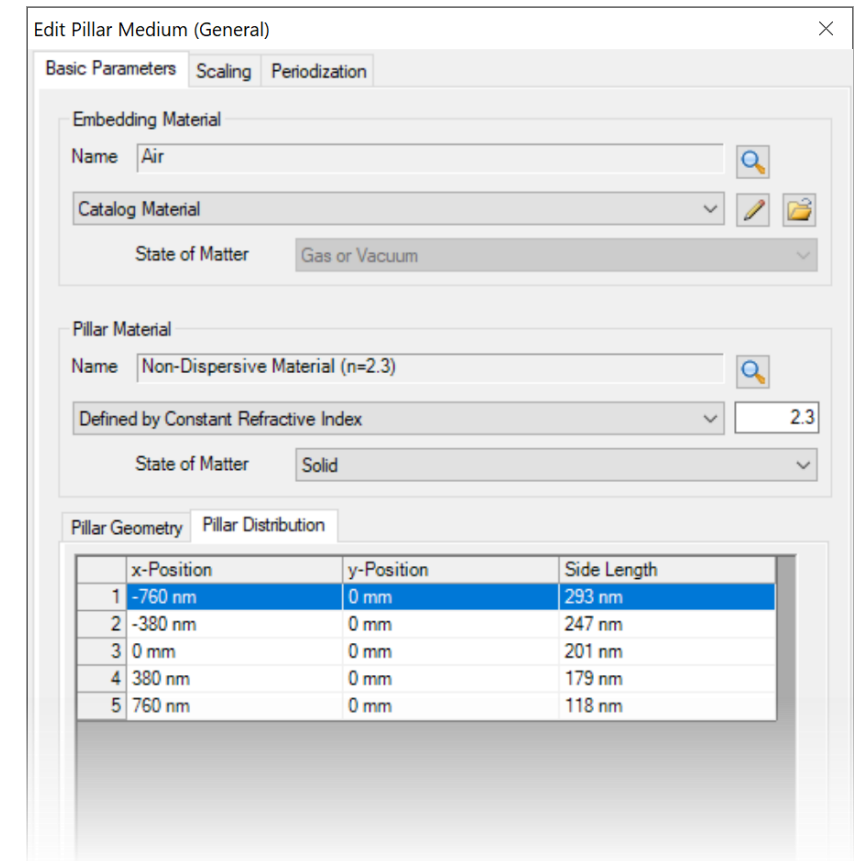


inbuilt parametric optimization tools



Workflow in VirtualLab Fusion

- Analyze metasurface unit cell
 - [Rigorous Analysis of Nanopillar Metasurface Building Block](#) [Use Case]
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 - [Metagrating Construction - Discussion at Examples](#) [Use Case]
- Analyze grating diffraction efficiency
 - [Grating Order Analyzer](#) [Use Case]
- Parametric optimization of grating structure
 - [Parametric Optimization](#) [Tutorial Video]

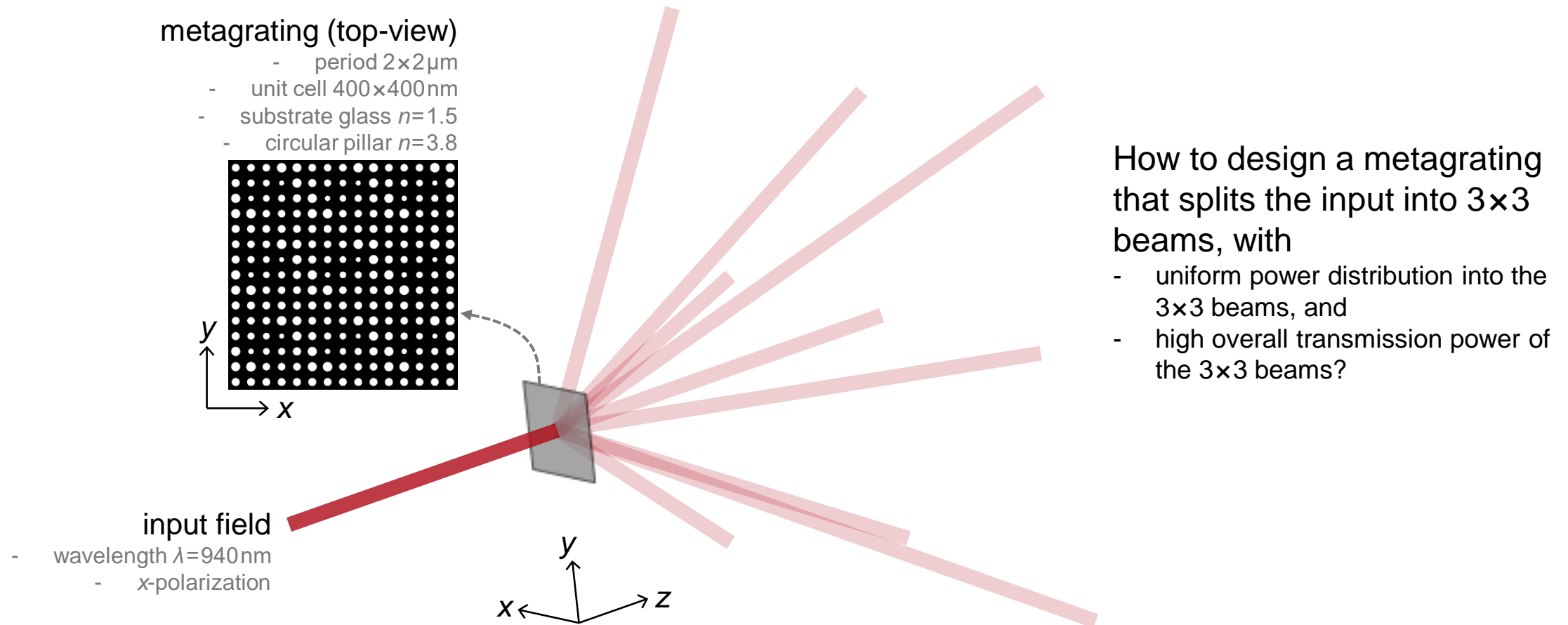


Document Information

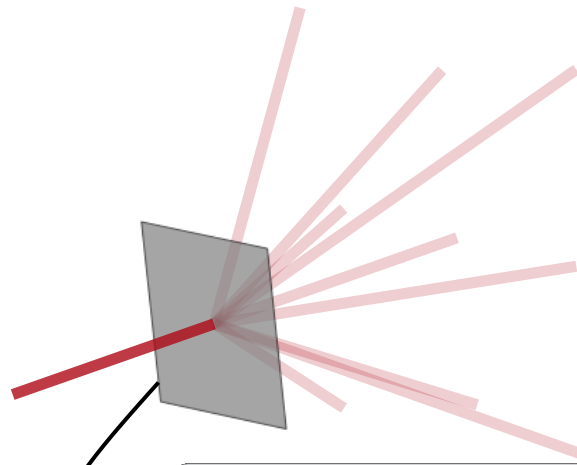
title	Modeling and Design of Blazed Metagratings
document code	GRT.0020
version	1.0
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.238)
category	Application Use Case
further reading	<ul style="list-style-type: none">- <u>Rigorous Analysis of Nanopillar Metasurface Building Block</u>- <u>Design of 2D Non-Paraxial Beam-Splitting Metagrating</u>- <u>Analysis and Design of Highly Efficient Polarization Independent Transmission Gratings</u>

Design of 2D Non-Paraxial Beam-Splitting Metagrating

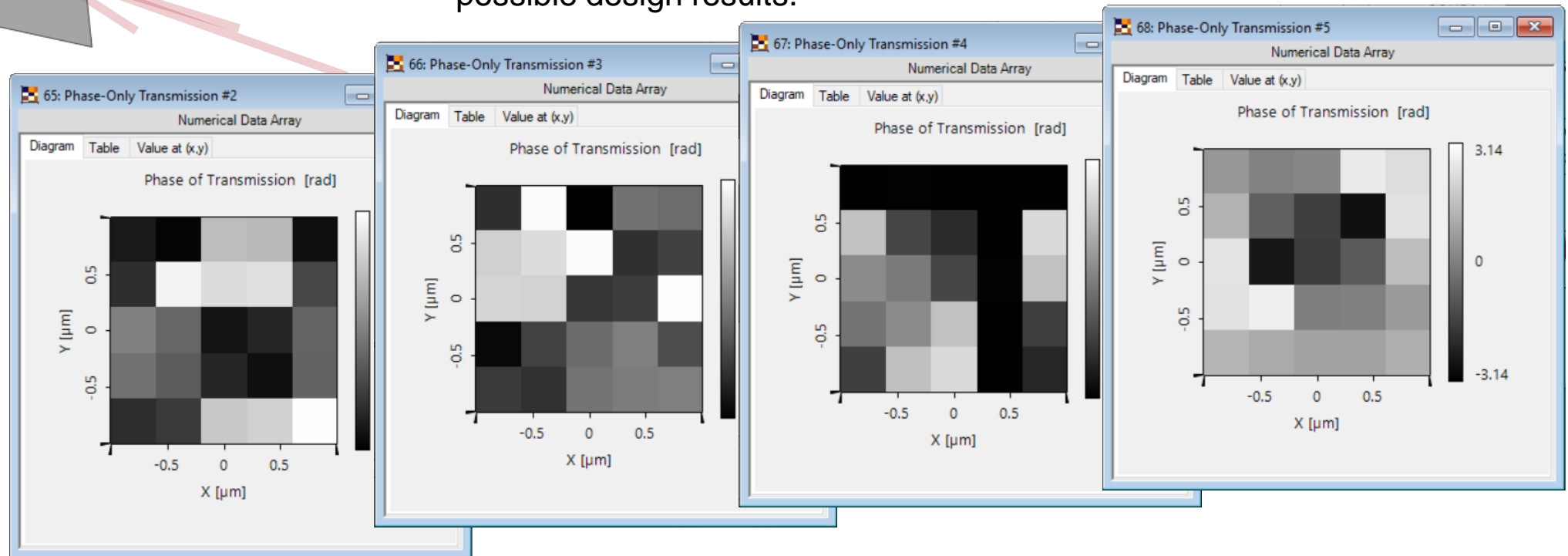
Design Task



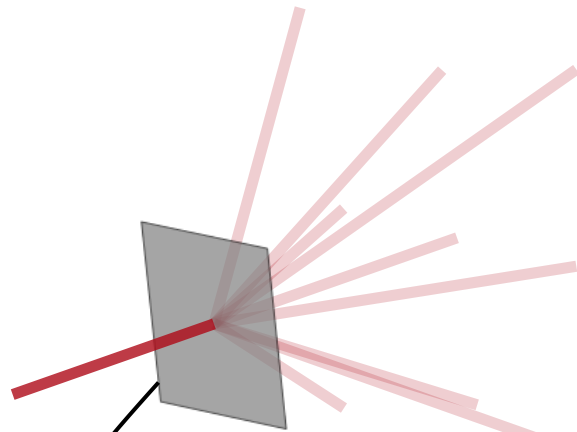
Phase-Only Transmission Design (IFTA)



With differently random phase distributions as starting points, IFTA (iterative Fourier transform algorithm) calculates different possible design results.

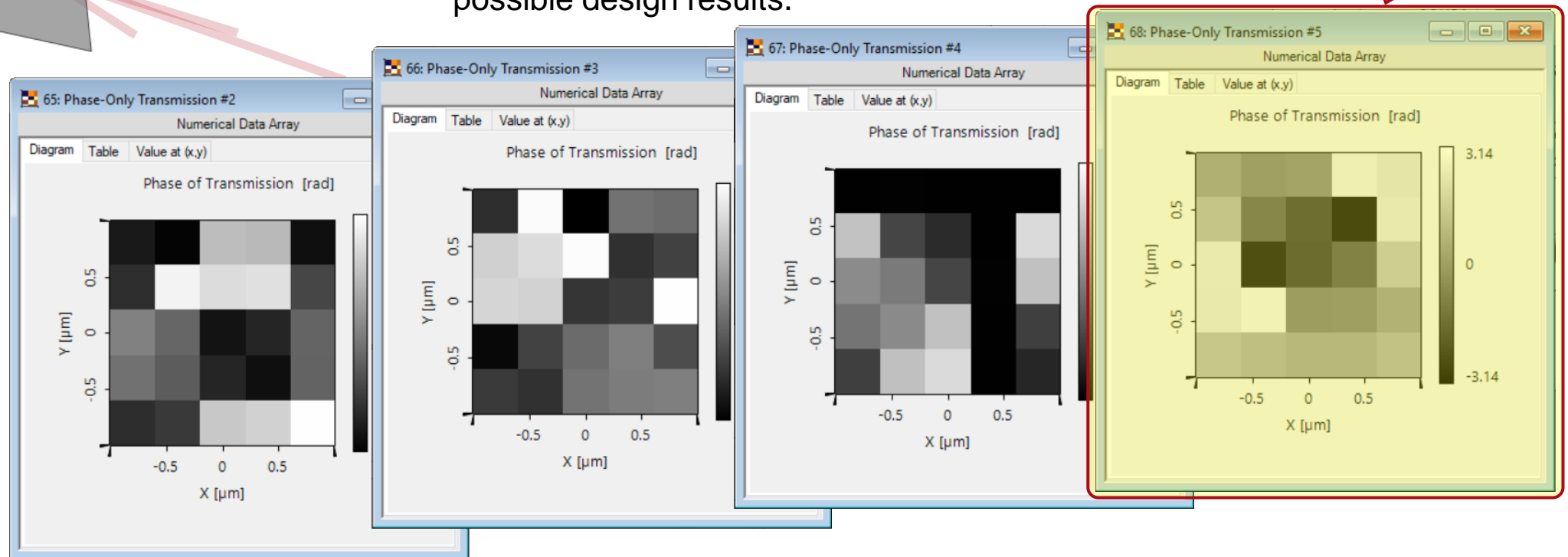


Phase-Only Transmission Design (IFTA)

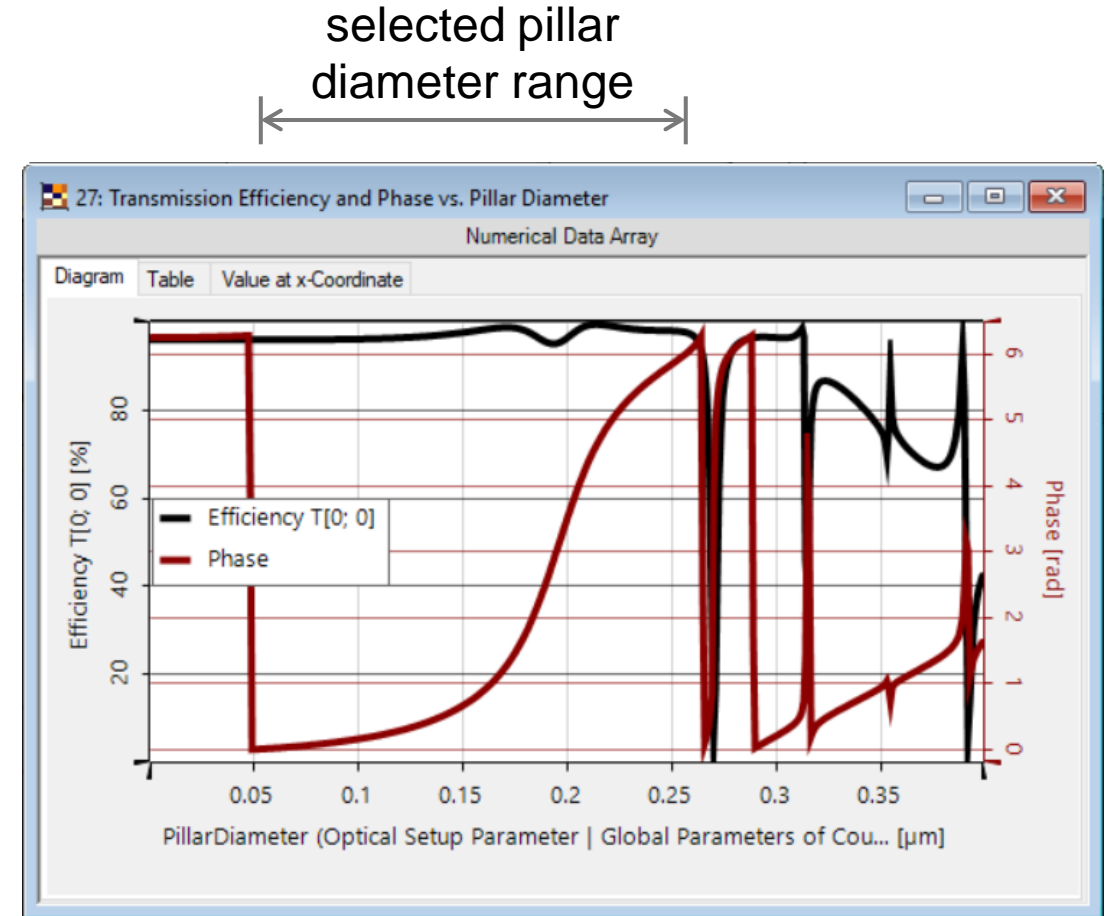
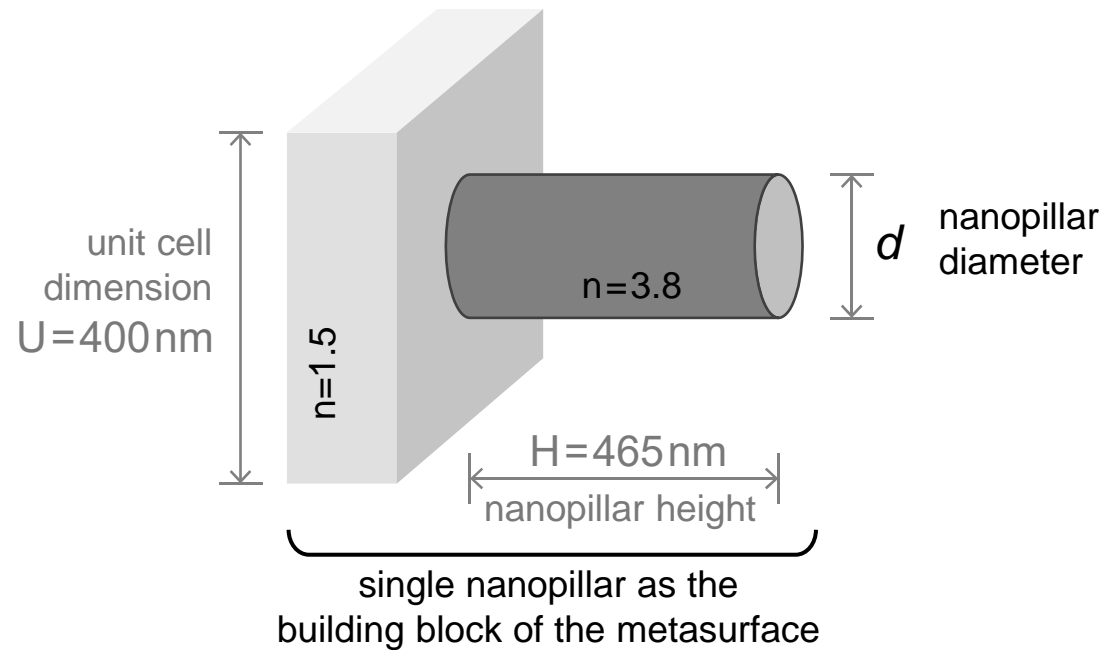


With differently random phase distributions as starting points, IFTA (iterative Fourier transform algorithm) calculates different possible design results.

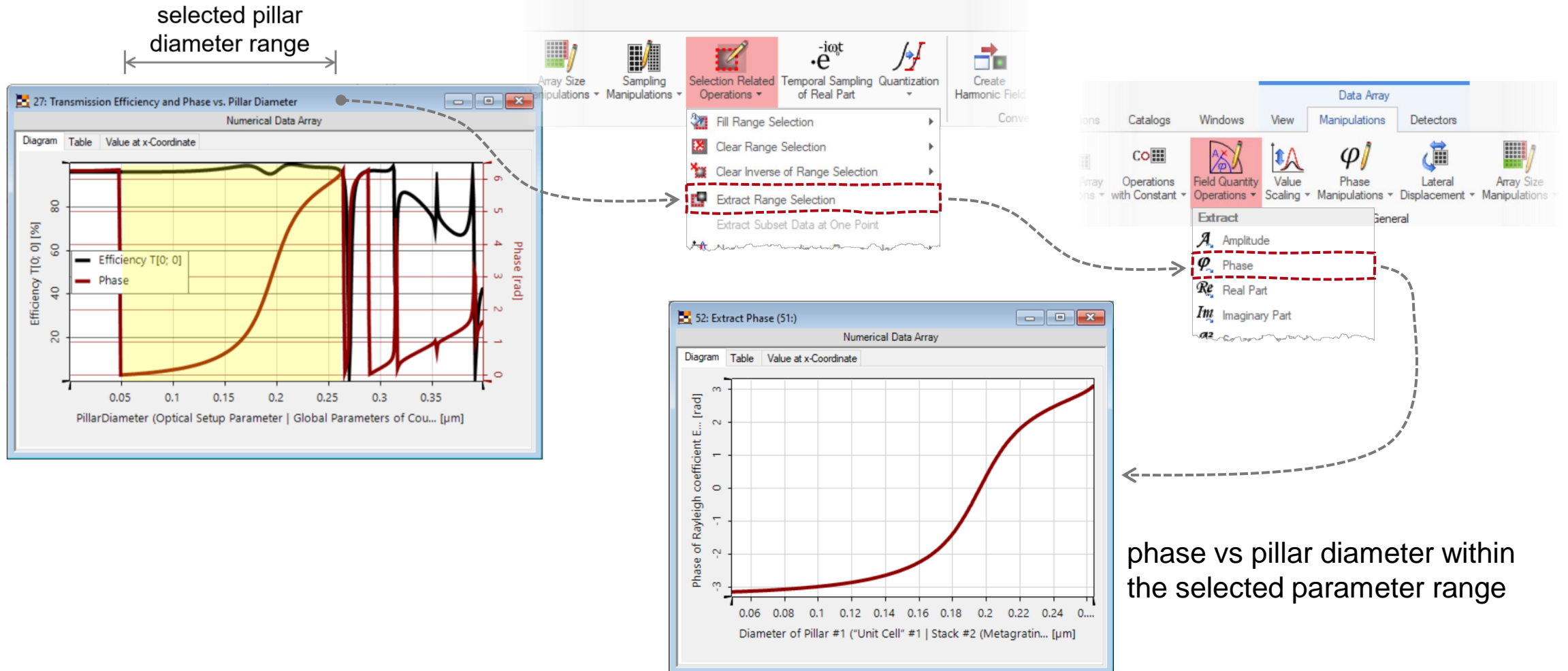
Select one of the results for further design



Metasurface Unit Cell Analysis

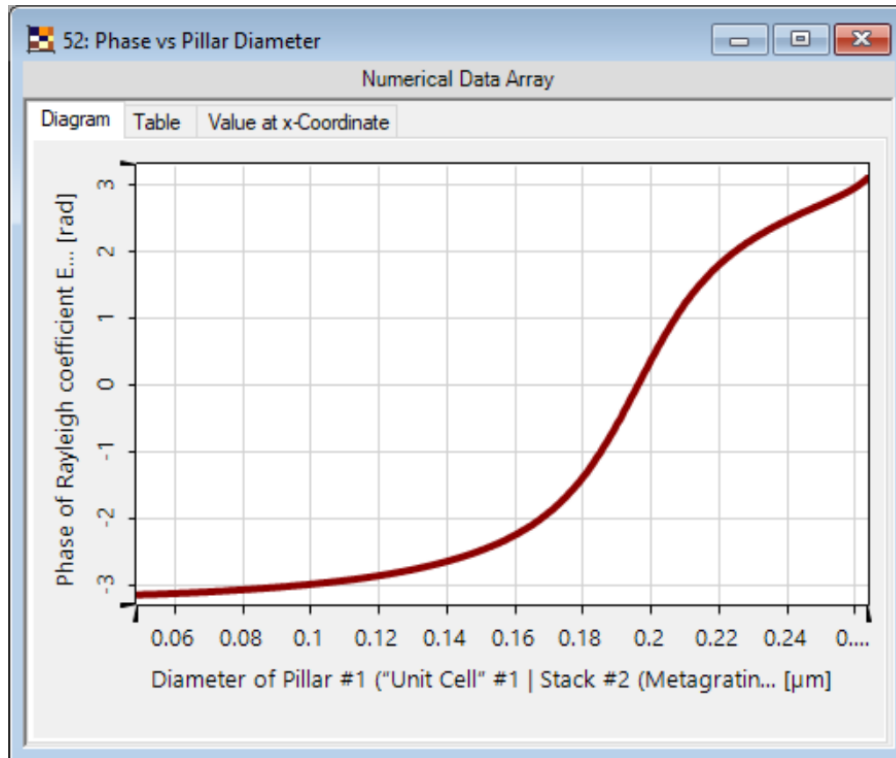


Unit Cell Parameter Range Selection



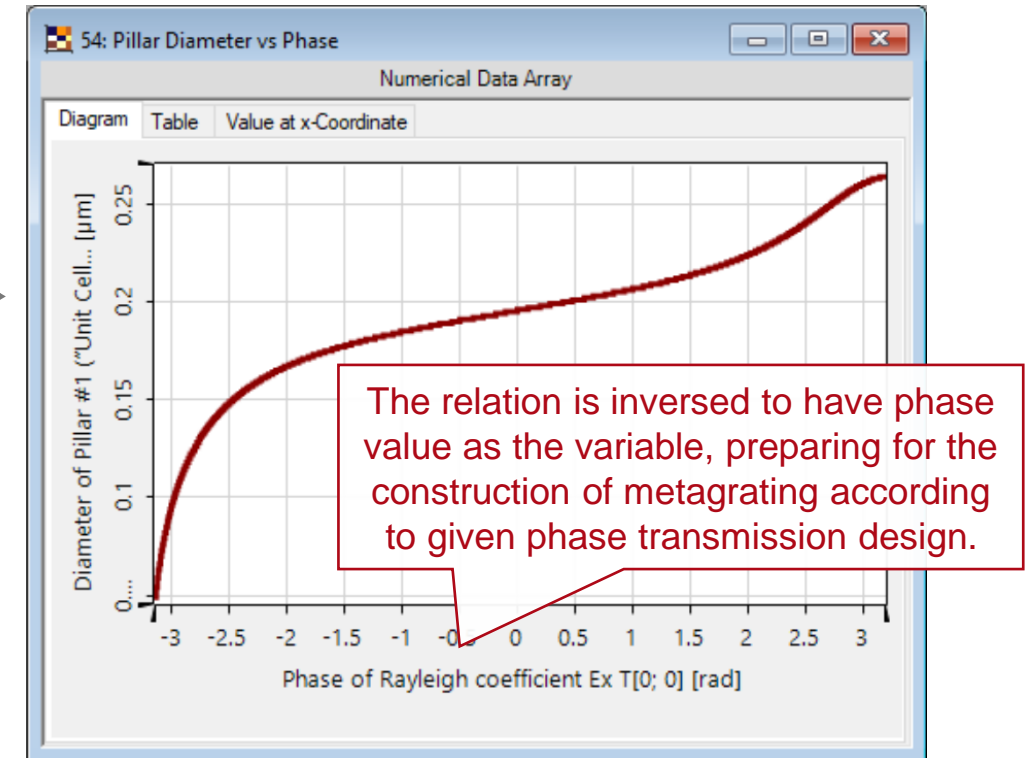
Phase vs Pillar Diameter and Its Inverse

phase value vs pillar diameter
(result from last step)



inverse

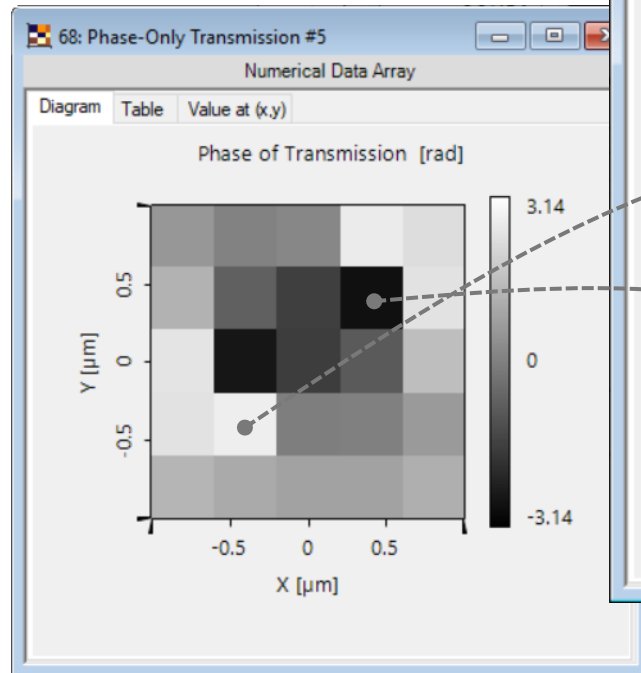
pillar diameter vs phase value



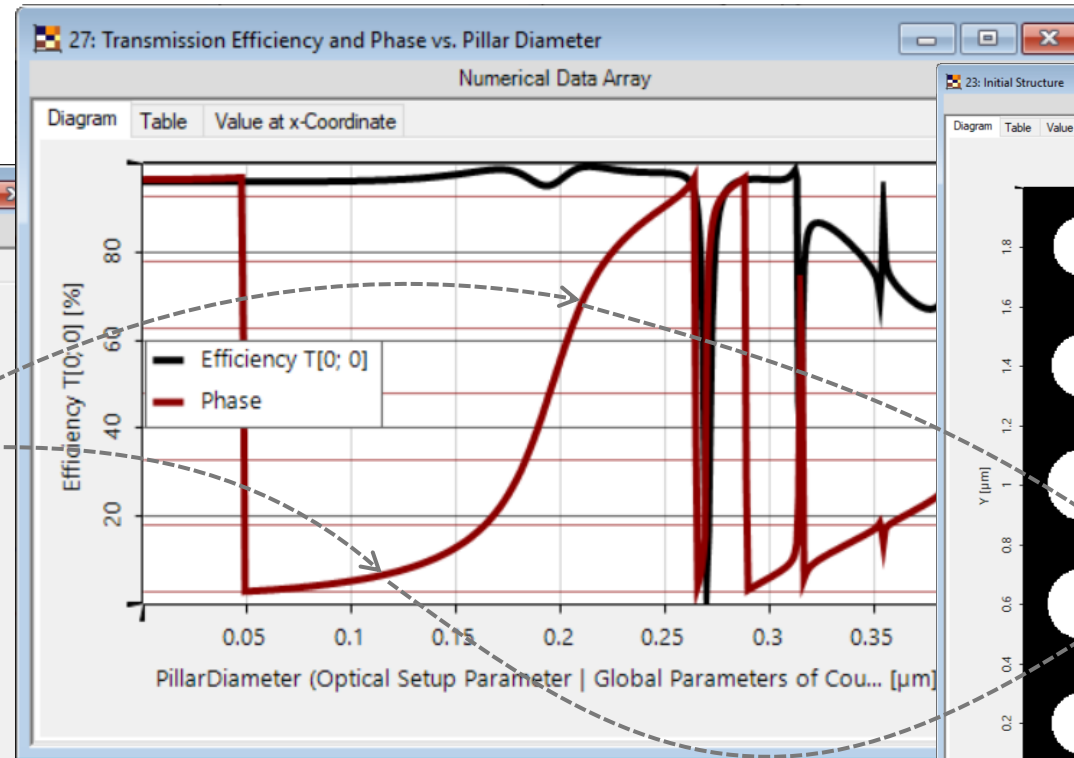
In this example, function inversion can be done with the VirtualLab C# Module: Appx_01_Calculate Inverse of 1D Function.cs

Metagrating Construction

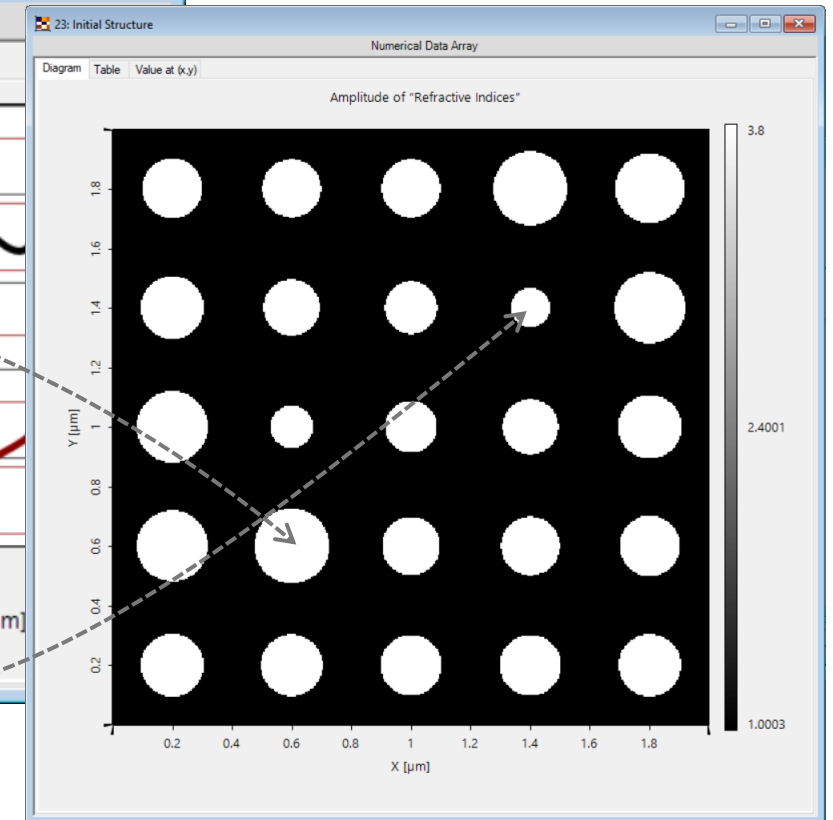
phase-only transmission



phase-diameter map / library



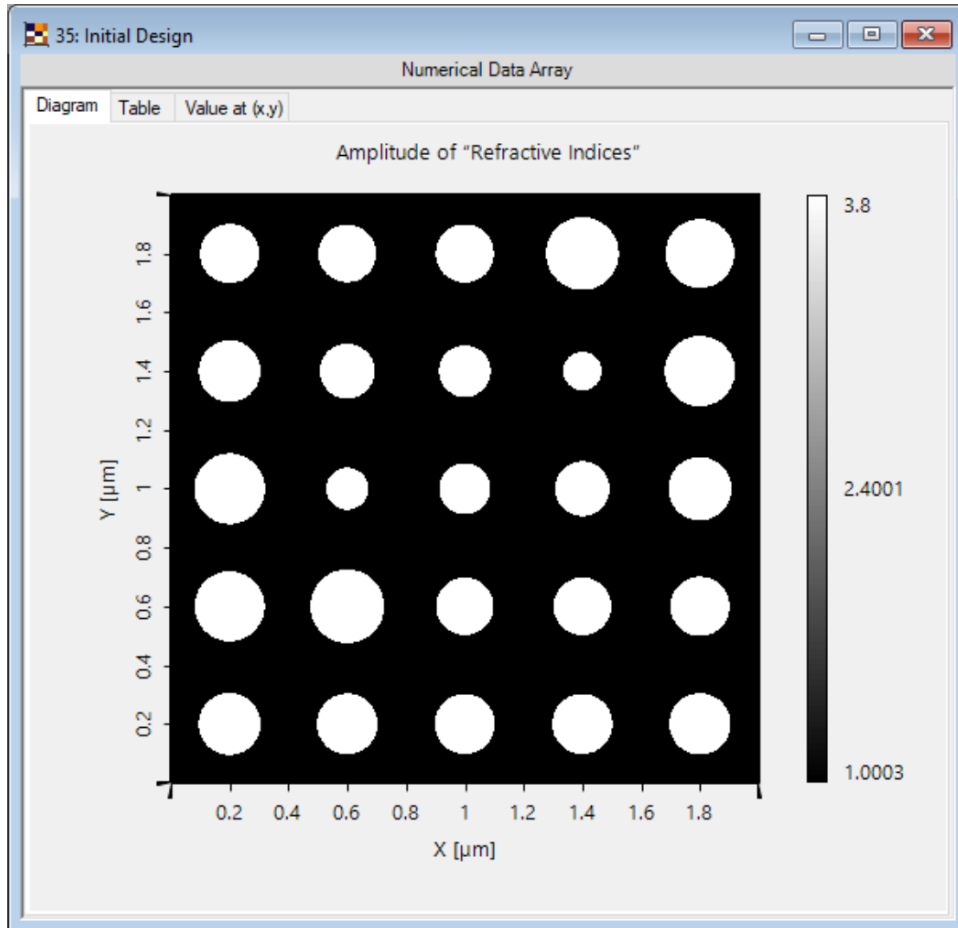
metagrating (top view)



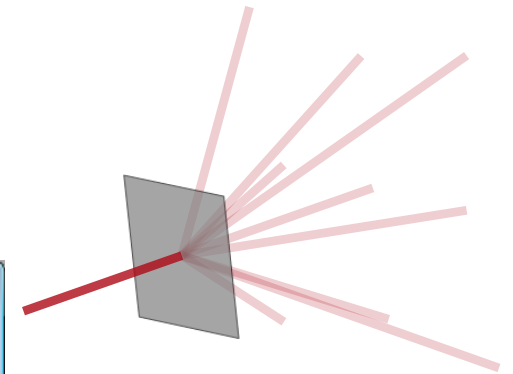
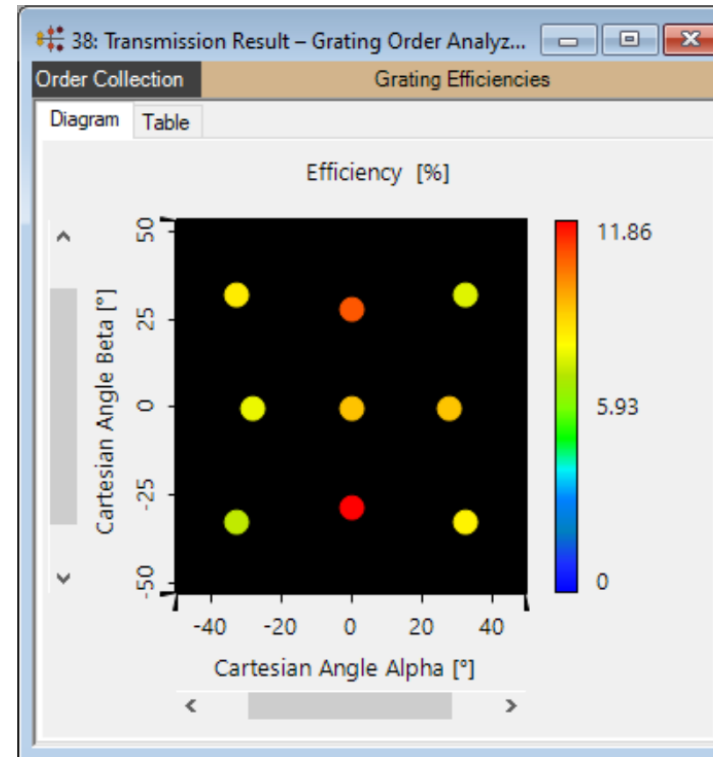
In this example, pillar distribution can be done with the VirtualLab C# Module: Appx_02_Calculate Pillar Diameters from Phase Profile.cs

Evaluation of Initial Metasurface Design

initial metagrating (top-view)



diffraction efficiencies



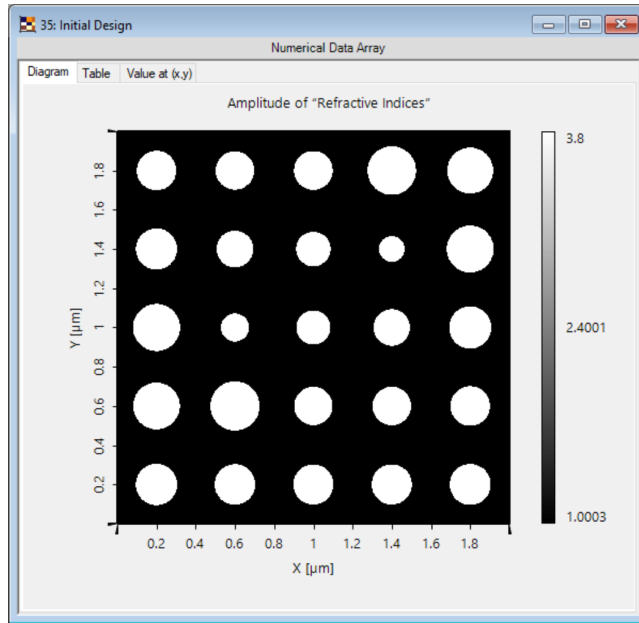
overall efficiency	79.6%
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uniformity error (PV)	25.3%
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uniformity error (RMS)	16.9%
------------------------	-------

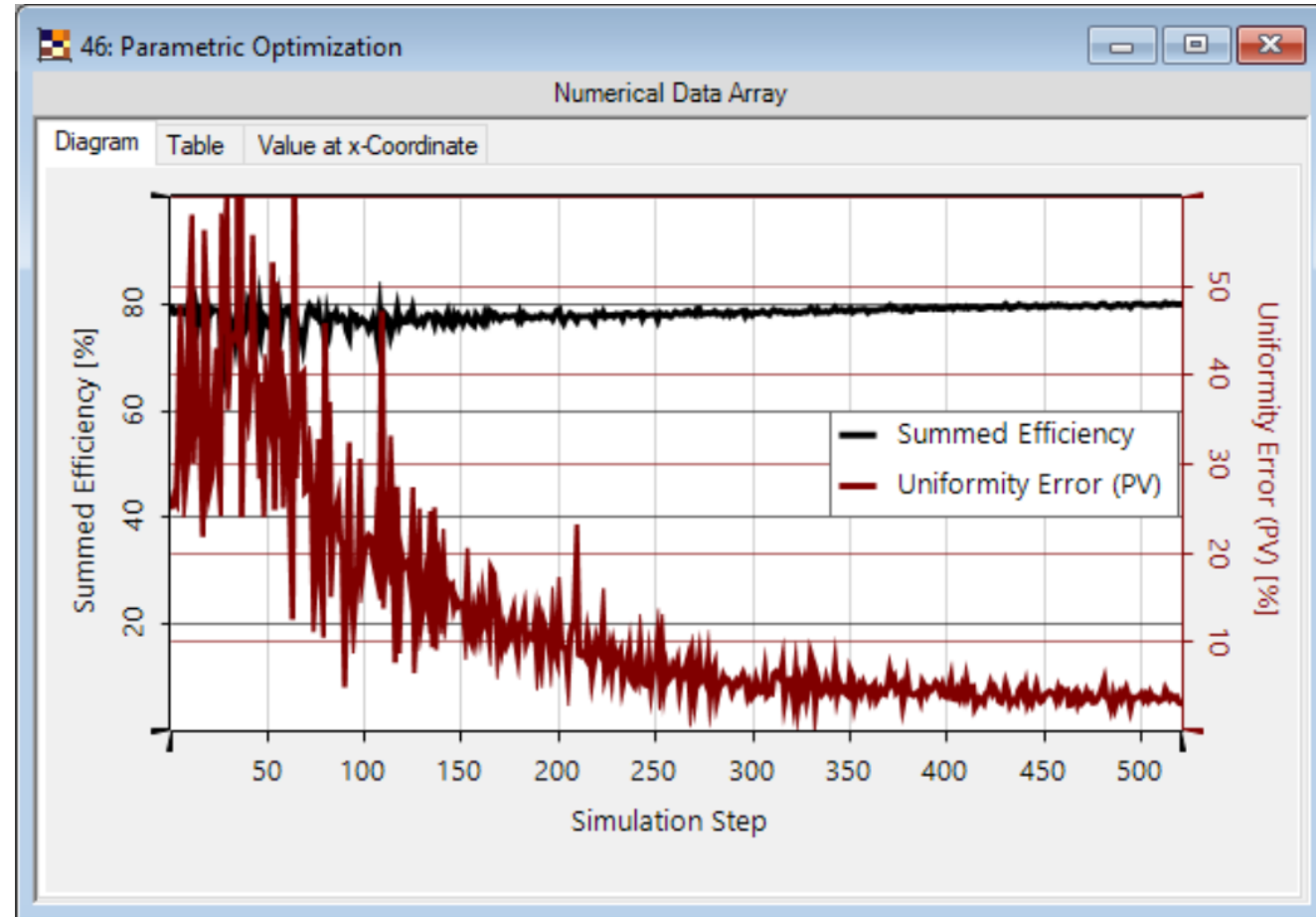
Parametric Optimization

initial metagrating



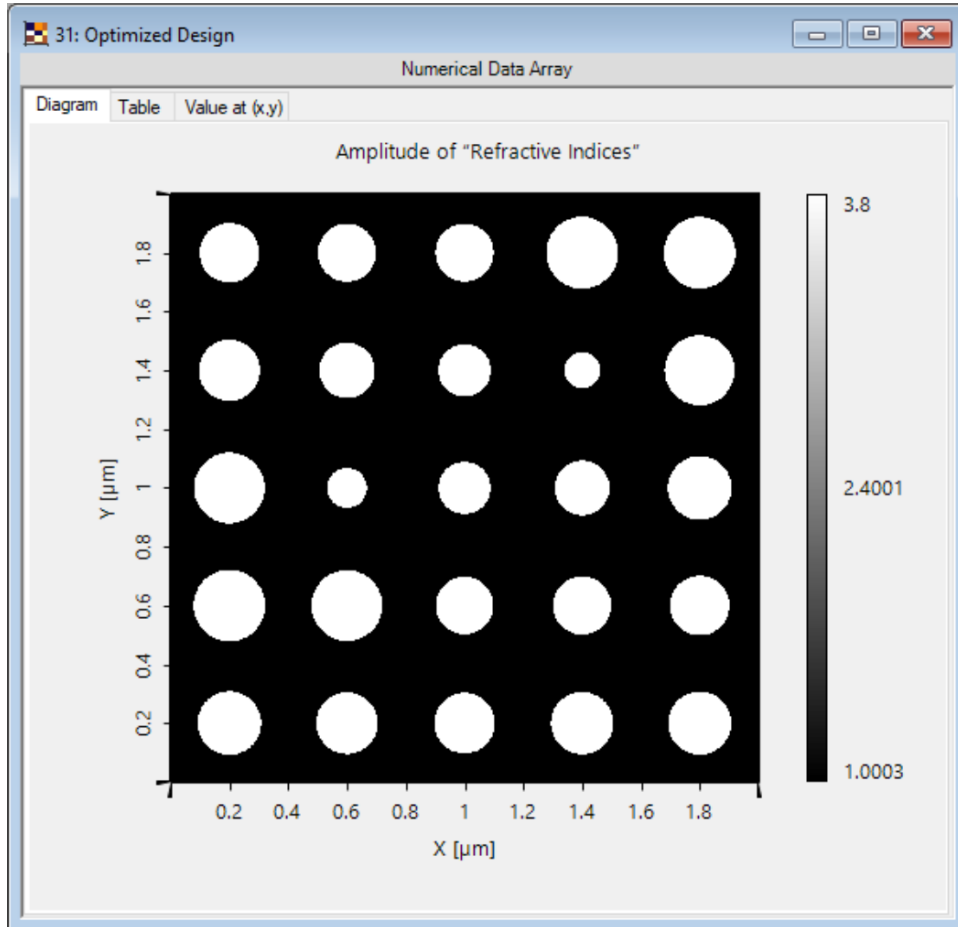
- keep pillar positions
- **vary** pillar diameters (25 variables)

downhill simplex optimization with FMM/RCWA for grating analysis

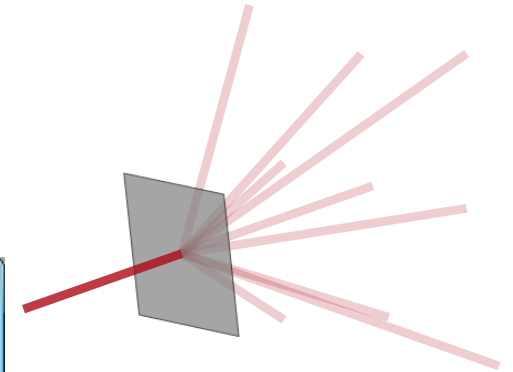
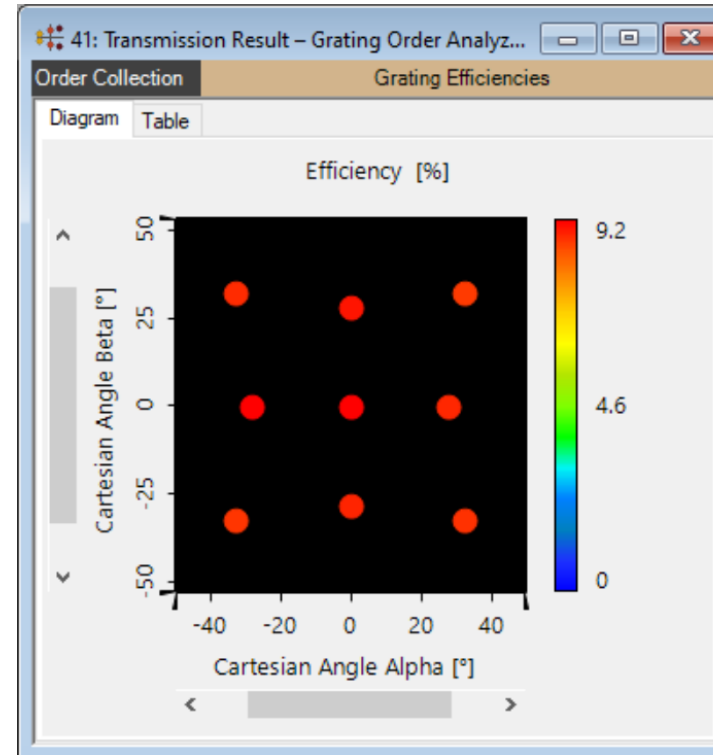


Evaluation of Optimized Metagrating Design

optimized metagrating (top-view)



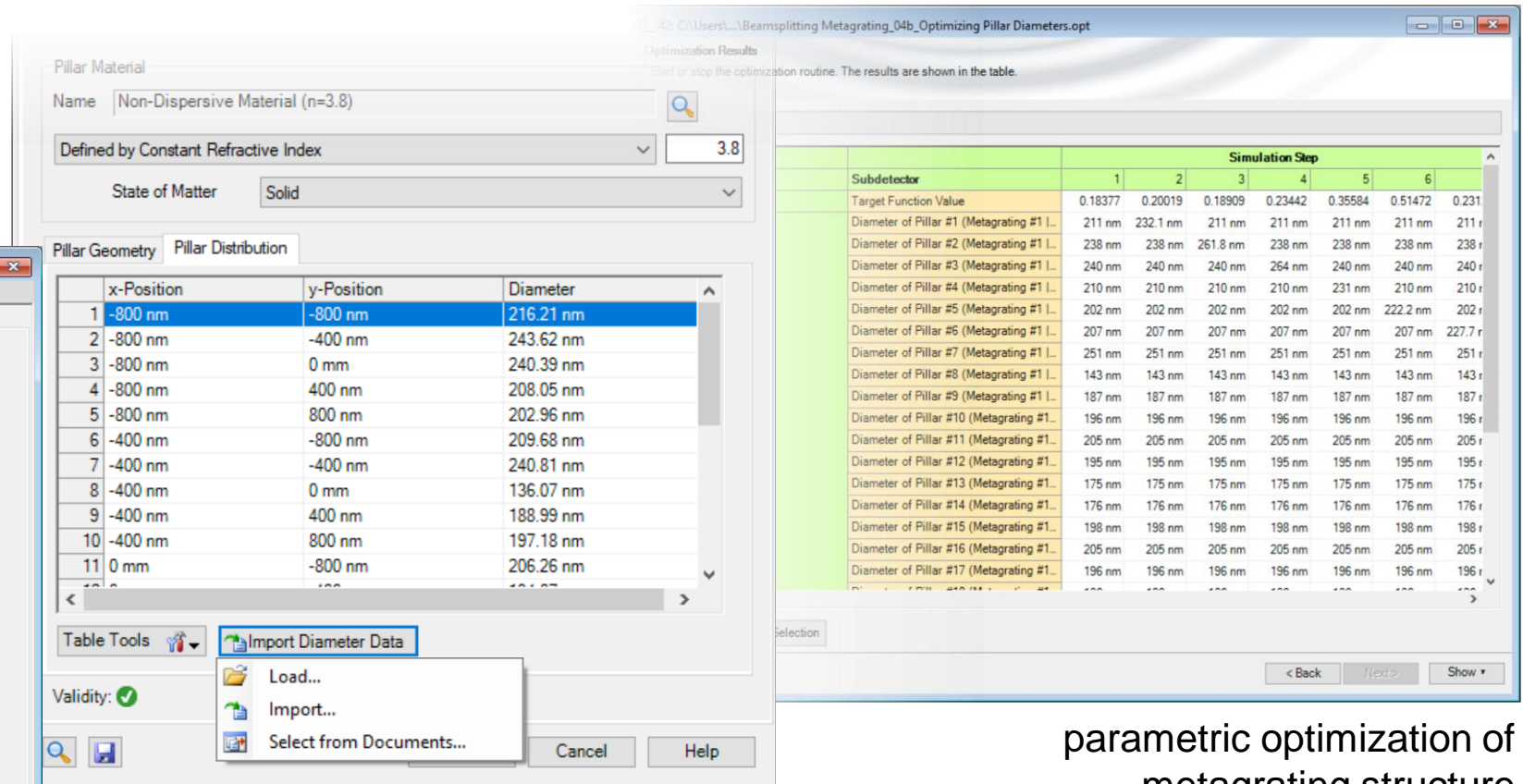
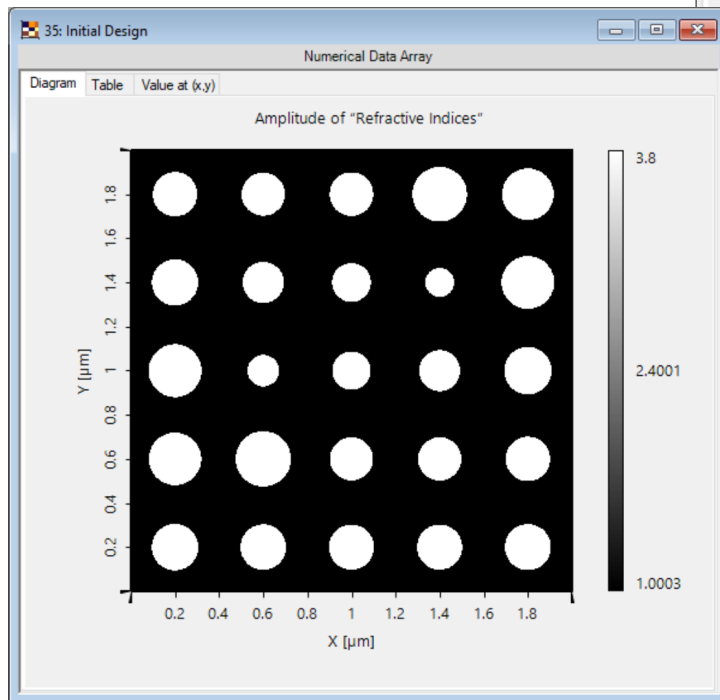
diffraction efficiencies



overall efficiency	80.0%
uniformity error (PV)	3.1%
uniformity error (RMS)	2.2%

Peek into VirtualLab Fusion

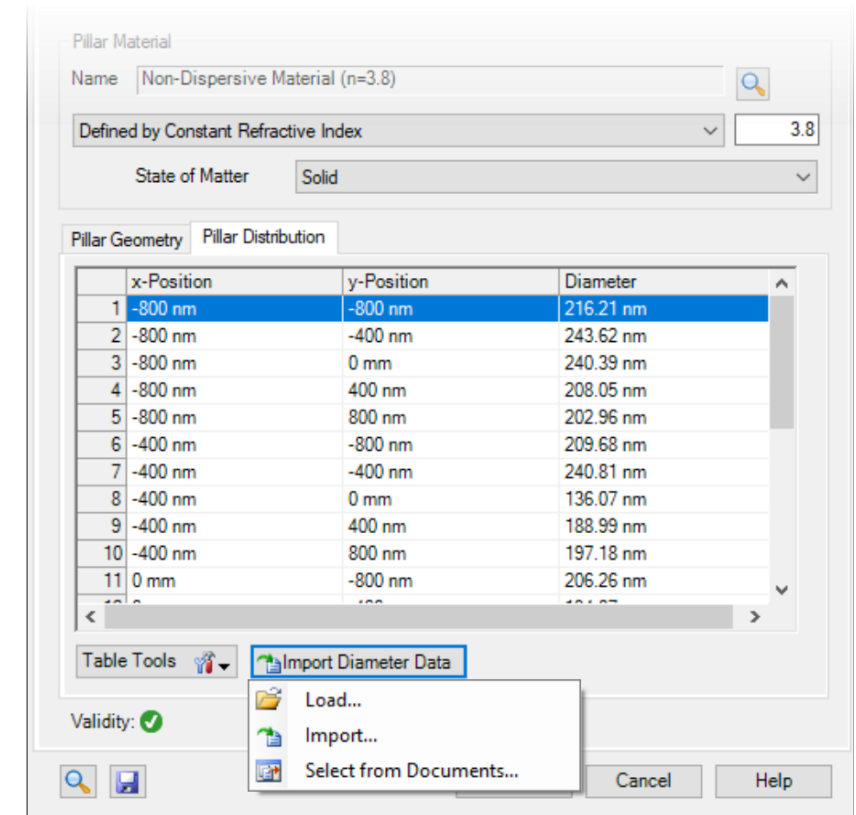
flexible definition of 2D
metagrating surface



parametric optimization of
metagrating structure

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Document Information

title	Design of 2D Non-Paraxial Beam-Splitting Metagrating
document code	GRT.0021
version	1.0
edition	VirtualLab Fusion Advanced
software version	2020.1 (Build 1.238)
category	Application Use Case
further reading	<ul style="list-style-type: none">- Rigorous Analysis of Nanopillar Metasurface Building Block- Modeling and Design of Blazed Metagratings

General Q&A

-
- Materials used for the course
***VirtualLab Fusion Applications, Technology & Workflows:
Grating Modeling and Design***
February 2021, online
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