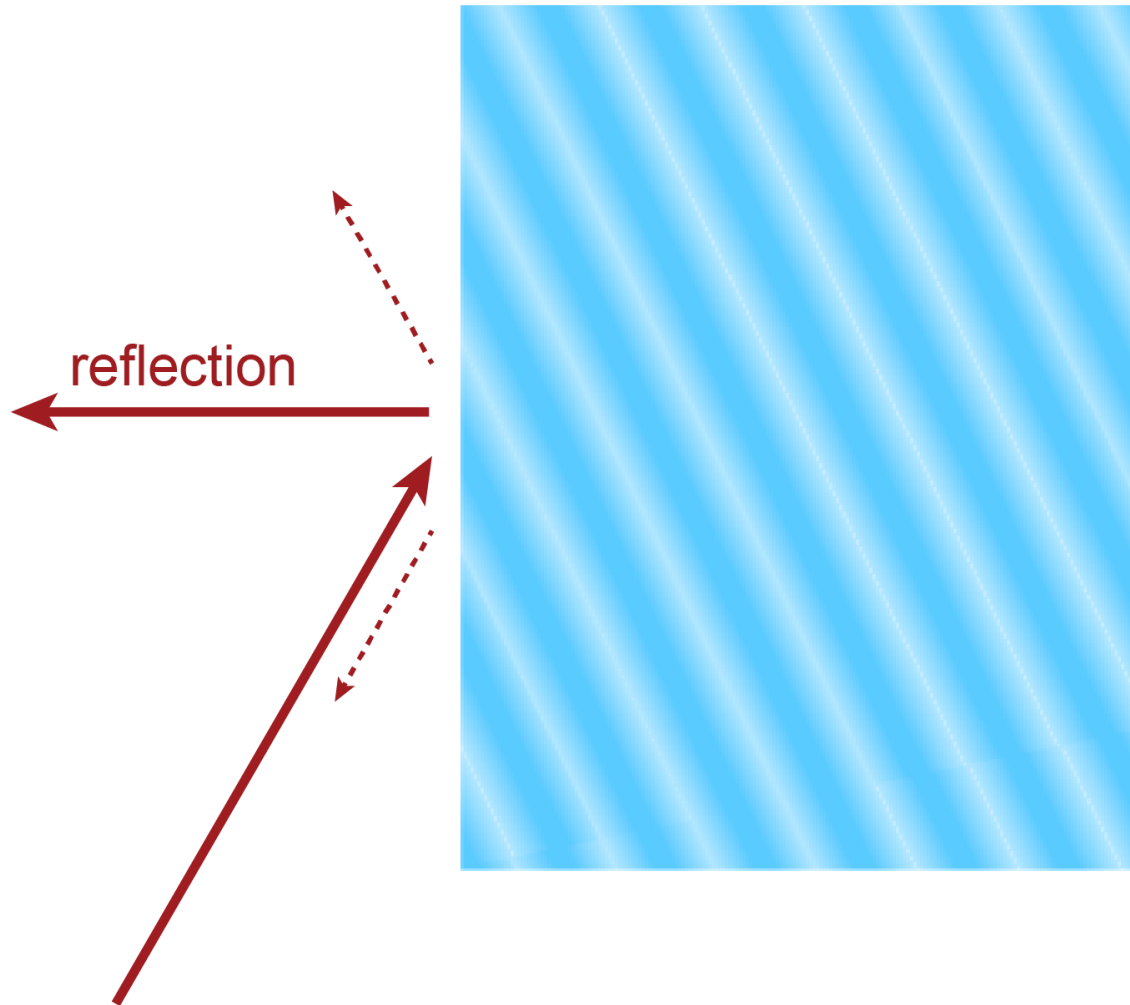


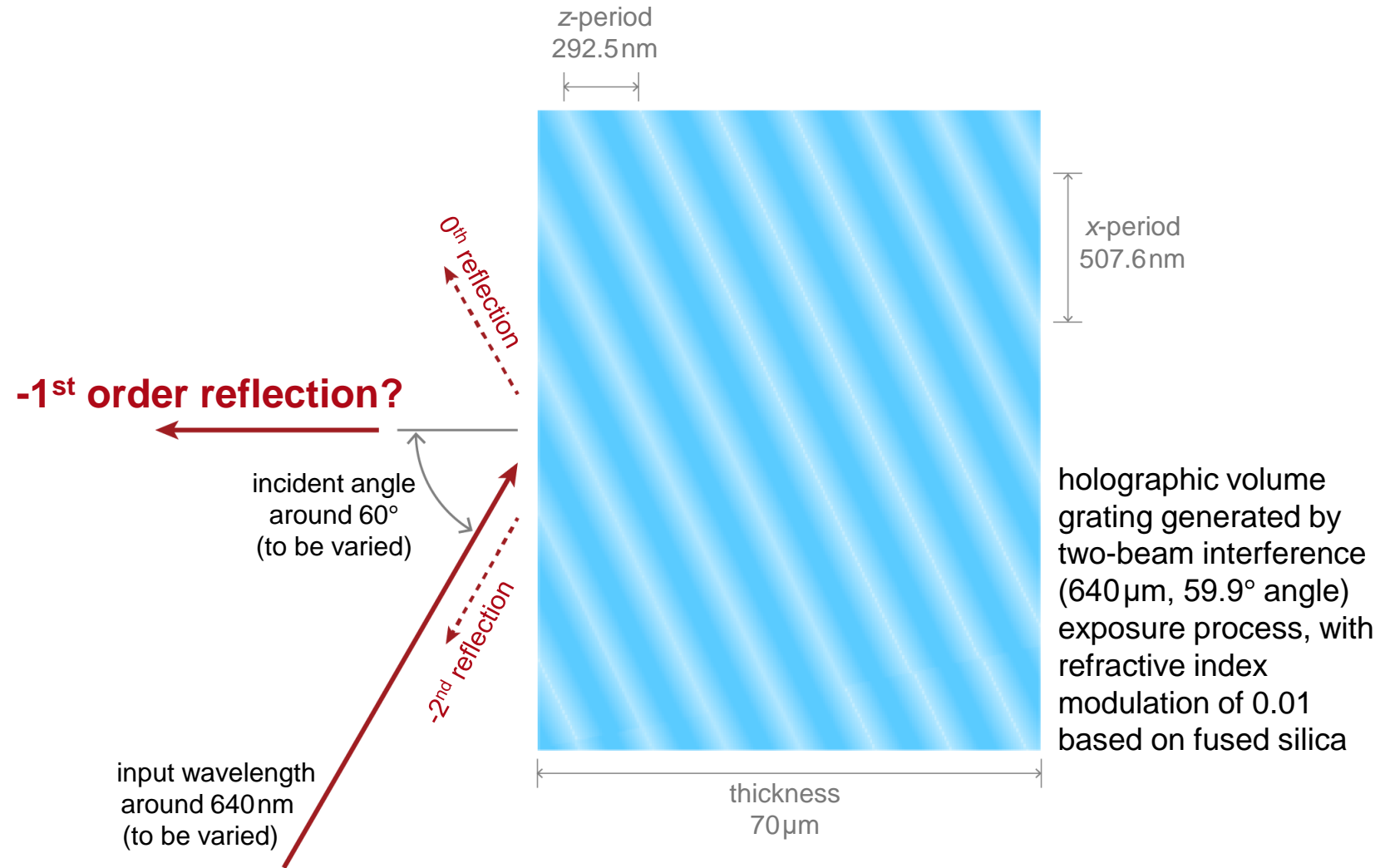
Holographically Generated Volume Grating

Abstract

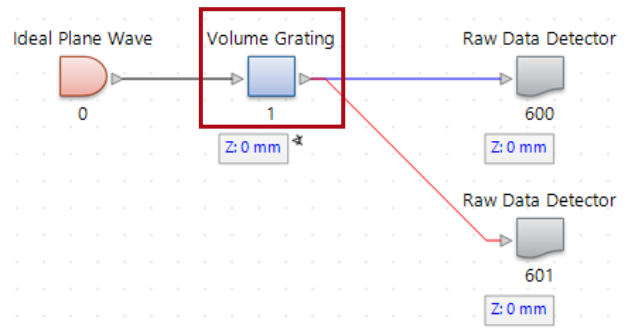


Holographic generated volume gratings, with a thickness much larger than the wavelength, normally exhibit a narrow bandwidth for the particular design wavelength and angle. Following the two-beam interference exposure process, a volume grating inside fused silica is generated and simulated with the rigorous Fourier modal method (FMM) in VirtualLab Fusion. Both the spectral and angular dependent reflection property of the grating are analyzed.

Modeling Task



Holographic Volume Grating



The holographic volume grating is generated by a specialized medium defined between two plane interfaces. It allows to configure the modulations of the refractive index, which was e.g., generated by holographic exposure. It can be found via *Templates > Volume Grating Medium*.

Index	z-Distance	z-Position	Surface	Subsequent Medium	Com
1	0 mm	0 mm	Plane Interface	Volume Grating Me...	Enter your commen
2	70 µm	70 µm	Plane Interface	Film 1, Silica in Homog	Enter your commen

Validity: ✔

Periodicity & Aperture

Periodic Non-Periodic

Stack Period is: Dependent from the Period of Medium with Index: 1

Stack Period: 508 nm

Buttons: Add, Insert, Delete, OK, Cancel, Help

Media Catalog

Definition Type: Templates

Filter by...

- Air in Homogeneous Medium
- Aperture Medium
- Biaxial Crystal
- Fiber Medium
- General Anisotropic Medium
- GRIN Medium
- Medium with Inclusions
- Pillar Medium (General)
- Pillar Medium (z-Independent)
- Programmable Medium (x-y-z-Modulate
- Sampled Medium (x-y-Modulated)
- Slanted Grating Medium
- Uniaxial Crystal
- Volume Grating Medium**

Extension and Section E

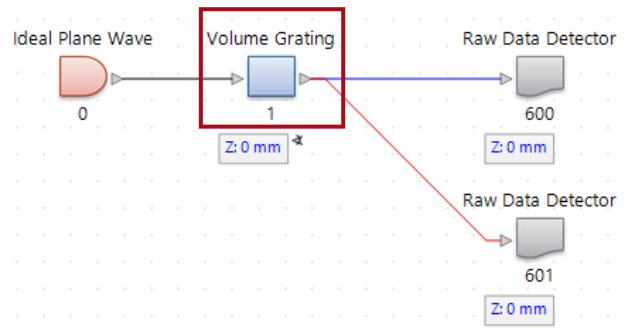
View Range (x, y, z)

Section Plane

y-Position of Section Pla

Diagram Table

Holographic Volume Grating



After adjusting the thickness and editing the view settings appropriately, the preview of the periodic grating structure can be seen.

Index	z-Distance	z-Position	Surface	Subsequent Medium	Com
1	0 mm	0 mm	Plane Interface	Volume Grating Medi	Enter your commen
2	70 μ m	70 μ m	Plane Interface	Fused_Silica in Homog	Enter your commen

Validity: Add Insert

Periodicity & Aperture
 Periodic Non-Periodic

Stack Period is: Dependent from the Period of Medium with Index

Stack Period: 508 nm

OK Cancel

Lateral View Settings
 Show z-x-Plane Show z-y-Plane

Media Visualization
 Draw Media

Preview Wavelength: 640 nm

Minimum Shown Refractive Index: 1.42

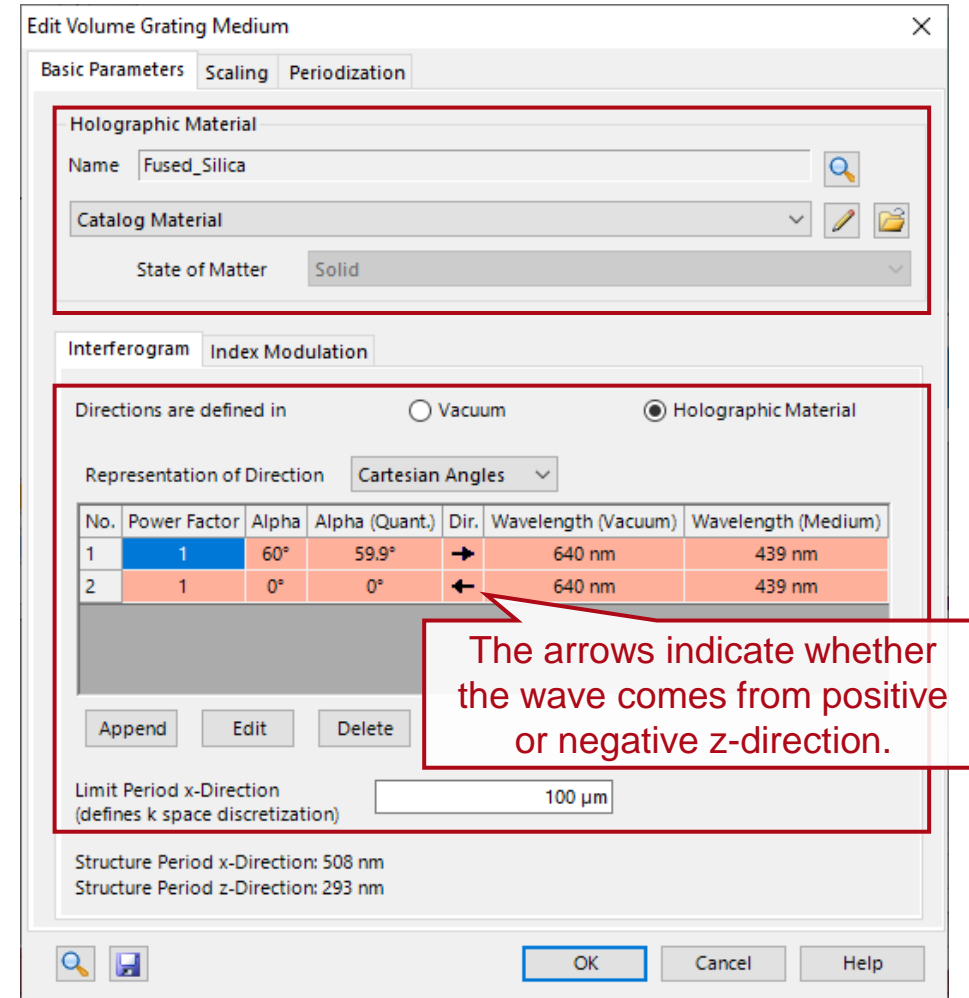
Maximum Shown Refractive Index: 1.5

OK Cancel Help

Index	z-Distance	z-Position	Surface	Subsequent Medium	Com
1	0 mm	0 mm	Plane Interface	Volume Grating Medi	Enter your commen
2	1 μ m	1 μ m	Plane Interface	Fused_Silica in Homog	Enter your commen

Volume Grating Medium

- In order to describe the volume grating VirtualLab simulates the interference pattern of a certain number on impinging waves.
- First, a *Holographic Material* 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), the wavelength of reference and signal wave.
- Moreover, by introducing a quantized k-space respectively incidence angle, the numerical effort can be reduced significantly.



Volume Grating Medium

- In this case the desired *Refractive Index Modulation* Δn and the *Relative Refractive Index Offset* R is defined by direct modulation mode. The refractive index $n(x, y)$ at a certain position is then calculated via

$$n(x, z) = n_{holo} + \left(\frac{\bar{w}(x, y)}{w_{max}} + \frac{R - 1}{2} \right) \cdot \Delta n$$

w_{max} can be an arbitrary value, as it cancels out in this case. n_{holo} is the refractive index of the holographic material.

- For $R = +100\%$, the refractive index modulation is added to n_{holo} , for $R = -100\%$, it is subtracted from n_{holo} and for intermediate values it is something in between. In particular, the case $R = 0$ means that the refractive indices range from $n_{holo} - \frac{\Delta n}{2}$ to $n_{holo} + \frac{\Delta n}{2}$.
- The effect of the *Relative Refractive Index Offset* R is shown in the following experiment (Diffraction Efficiency vs. Wavelength)

The screenshot shows the 'Edit Volume Grating Medium' window with the following settings:

- Basic Parameters: Holographic Material Name: Fused_Silica, Catalog Material: (dropdown), State of Matter: Solid
- Interferogram: Direct (selected), Simulate Exposition Process (unselected), Photonic Crystals (unselected)
- Index Modulation: Refractive Index Modulation: 0.01, Relative Refractive Index Offset: 0%

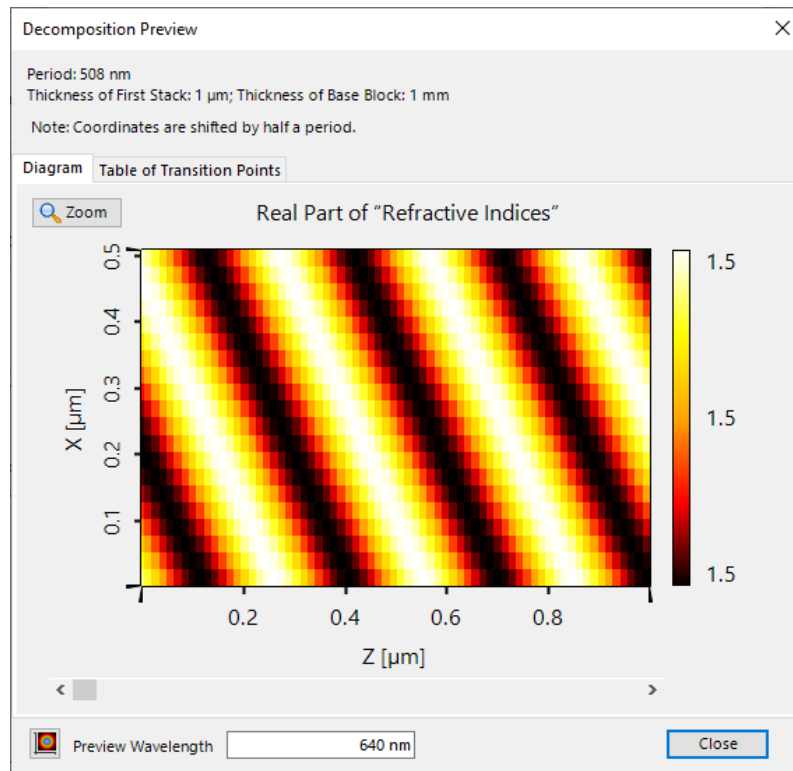
The diagram below the screenshot illustrates the effect of the Relative Refractive Index Offset (R) on the refractive index modulation. It shows three plots of refractive index n versus position x for different values of R :

- $R = +100\%$: The refractive index modulation is added to n_{holo} , resulting in a range of $n_{holo} - \Delta n$ to $n_{holo} + \Delta n$.
- $R = 0\%$: The refractive index modulation is centered around n_{holo} , resulting in a range of $n_{holo} - 0.5\Delta n$ to $n_{holo} + 0.5\Delta n$.
- $R = -100\%$: The refractive index modulation is subtracted from n_{holo} , resulting in a range of $n_{holo} - \Delta n$ to $n_{holo} + \Delta n$.

R = Relative refractive index modulation
 n_{holo} = Refractive index of holographic material

Advanced Options & Information

For the modeling, the modulation of the index has to be decomposed, what is done automatically. This can be checked and if necessary adjusted on the Structure Decomposition page.



Edit General Grating Component

Component Propagation Fourier Modal Method Edit

Coordinate Systems

Position / Orientation

Structure

Propagation

Interface

Plane S

Fourier

Plane S

Fourier

Tools

Validity: Preview Wave

Edit Fourier Modal Method (RCWA)

Numerical Parameter Structure Decomposition

Layer Decomposition

Automatic Accuracy Factor 1

Manual

Number of Layers (First Stack)

Overall Thickness 70 μm

Transition Point Decomposition

Automatic Accuracy Factor 1

Manual

Number of Points

Point Distance

Period 508 nm

Information

Maximum total number of layers: 4787

Minimum transition point distance: 10.2 nm

Remove Redundant Data

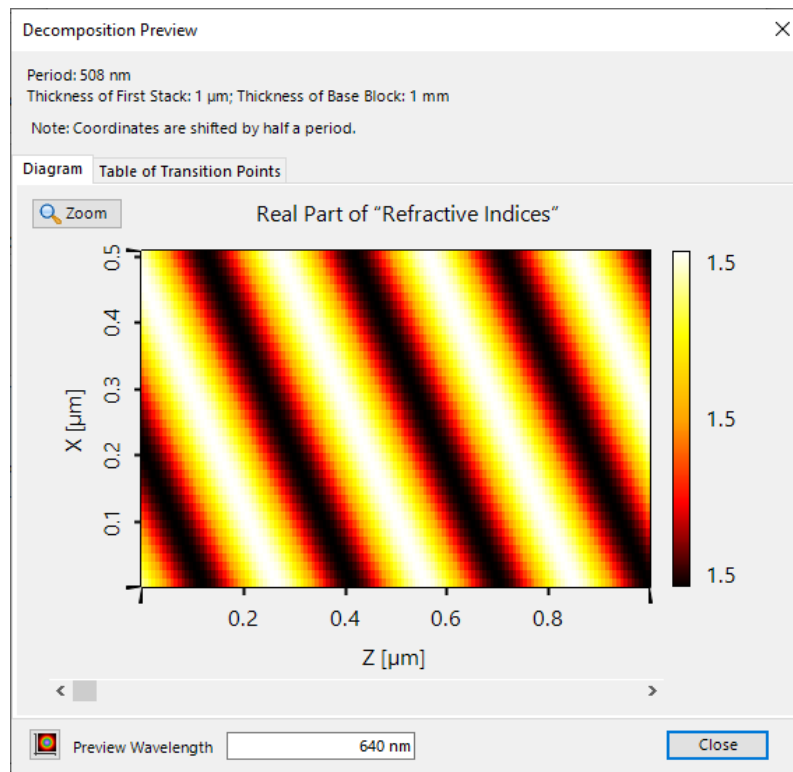
Decomposition Preview

OK Cancel Help

The screenshot shows the software interface for editing a grating component. The "Edit General Grating Component" dialog box is open, with the "Component Propagation" set to "Fourier Modal Method". The "Structure" tab is selected, and the "Propagation" icon is highlighted with a red box. A red arrow points from the "Propagation" icon to the "Decomposition Preview" button in the "Edit Fourier Modal Method (RCWA)" dialog box. The "Edit Fourier Modal Method (RCWA)" dialog box has two tabs: "Numerical Parameter" and "Structure Decomposition". The "Structure Decomposition" tab is active, showing options for "Layer Decomposition" and "Transition Point Decomposition". Both are set to "Automatic". The "Period" is set to 508 nm. The "Remove Redundant Data" checkbox is checked. The "Decomposition Preview" button is highlighted with a red box, and a red arrow points to it from the "Propagation" icon in the "Edit General Grating Component" dialog box.

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.



Edit General Grating Component

Component Propagation Fourier Modal Method Edit

Coordinate Systems

Position / Orientation

Structure

Propagation

Interface

1 Plane S Fourier

2 Plane S Fourier

Tools

Validity: Preview Wave

Edit Fourier Modal Method (RCWA)

Numerical Parameter Structure Decomposition

Layer Decomposition

Automatic Accuracy Factor 2

Manual

Number of Layers (First Stack)

Overall Thickness 70 μm

Transition Point Decomposition

Automatic Accuracy Factor 2

Manual

Number of Points

Point Distance

Period 508 nm

Information

Maximum total number of layers: 9573
Minimum transition point distance: 5.08 nm

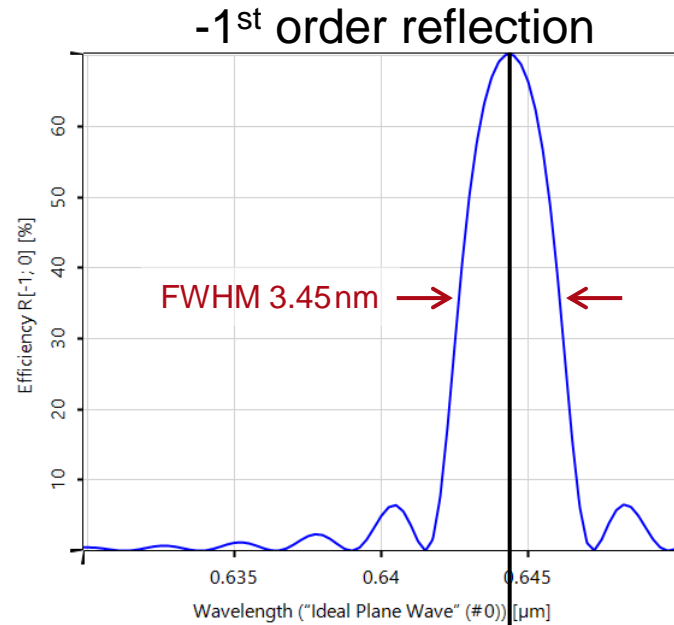
Remove Redundant Data

Decomposition Preview

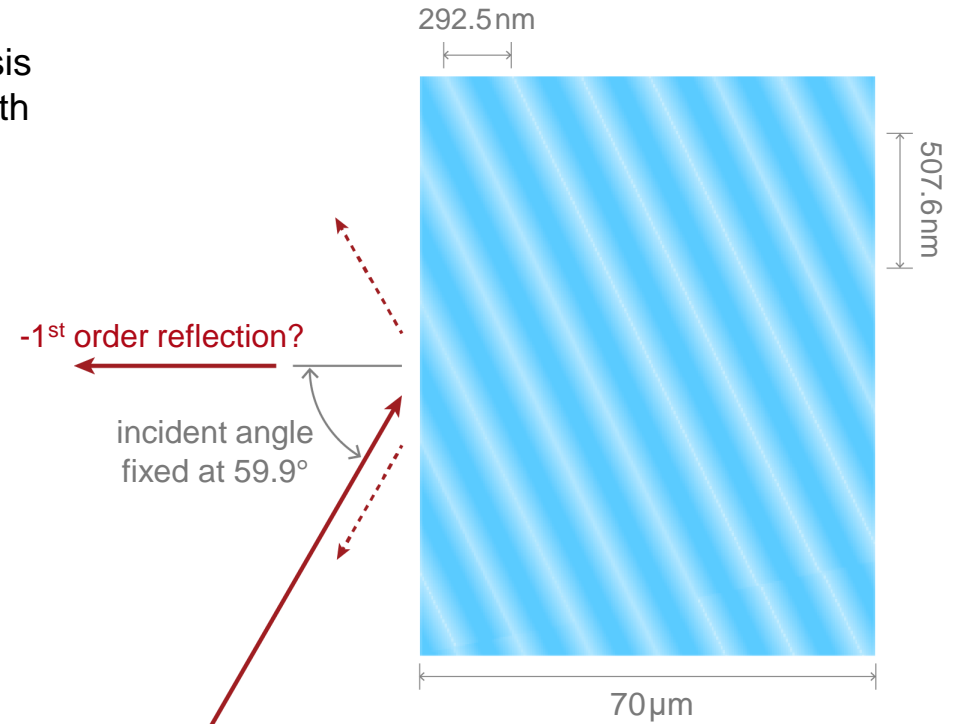
OK Cancel Help

The screenshot shows the software interface for editing a grating component. The "Edit General Grating Component" dialog box is open, with the "Component Propagation" set to "Fourier Modal Method". The "Edit Fourier Modal Method (RCWA)" dialog box is also open, showing the "Structure Decomposition" tab. The "Layer Decomposition" section has "Automatic" selected, and the "Accuracy Factor" is set to 2. The "Transition Point Decomposition" section also has "Automatic" selected, and the "Accuracy Factor" is set to 2. The "Period" is set to 508 nm. The "Information" section shows "Maximum total number of layers: 9573" and "Minimum transition point distance: 5.08 nm". The "Remove Redundant Data" checkbox is checked. The "Decomposition Preview" button is highlighted with a red box and a red arrow pointing to the heatmap in the previous figure. The "OK", "Cancel", and "Help" buttons are at the bottom.

Diffraction Efficiency vs. Wavelength



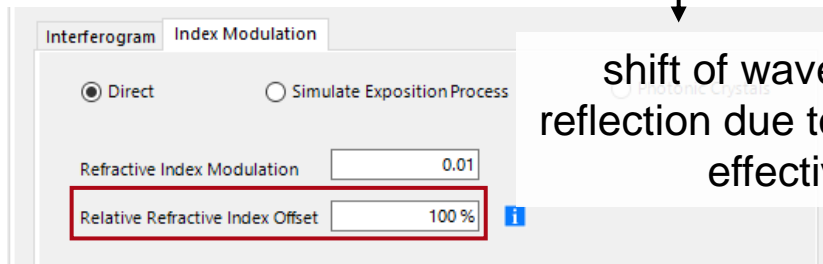
rigorous FMM analysis for varying wavelength



-1st order reflection?

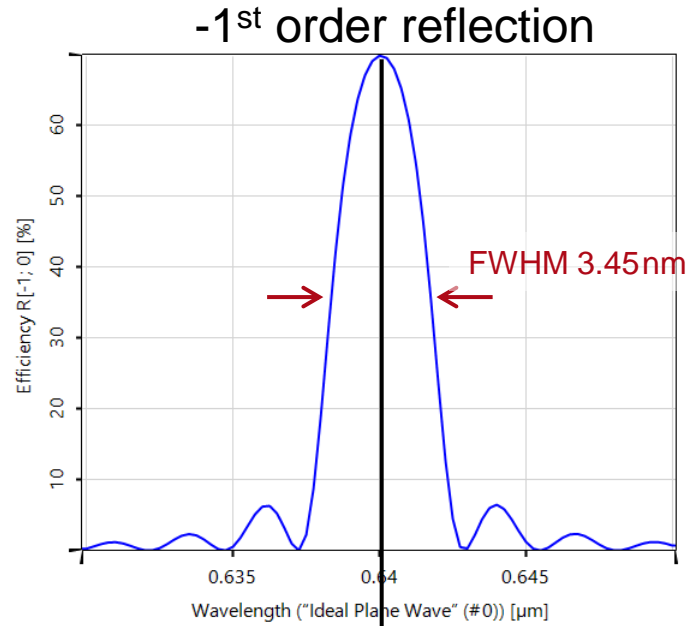
incident angle fixed at 59.9°

wavelength varying from 630 to 650 nm

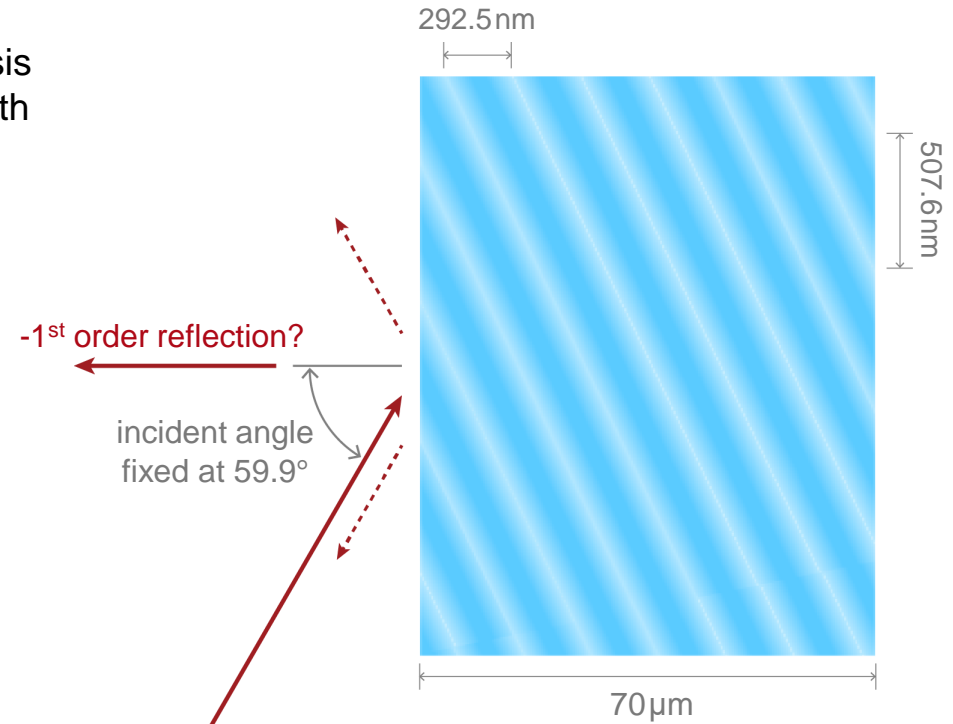


shift of wavelength dependent reflection due to locally increased effective refraction index

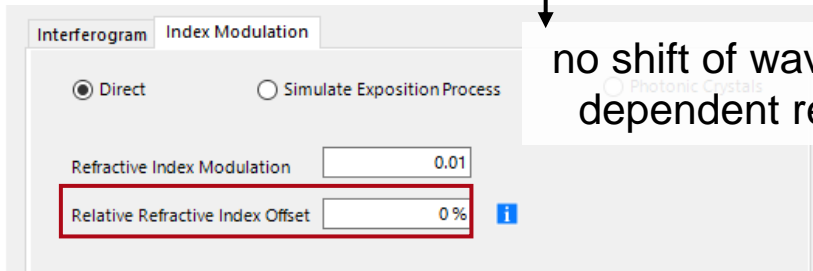
Diffraction Efficiency vs. Wavelength



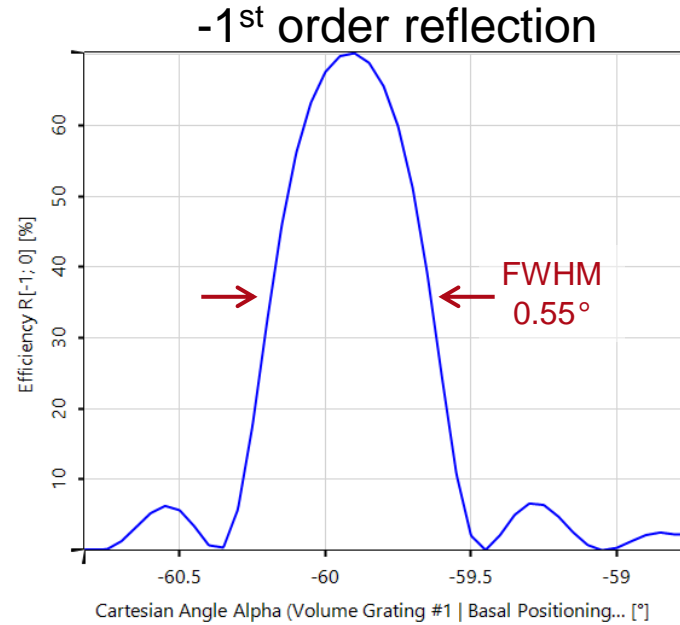
rigorous FMM analysis
for varying wavelength



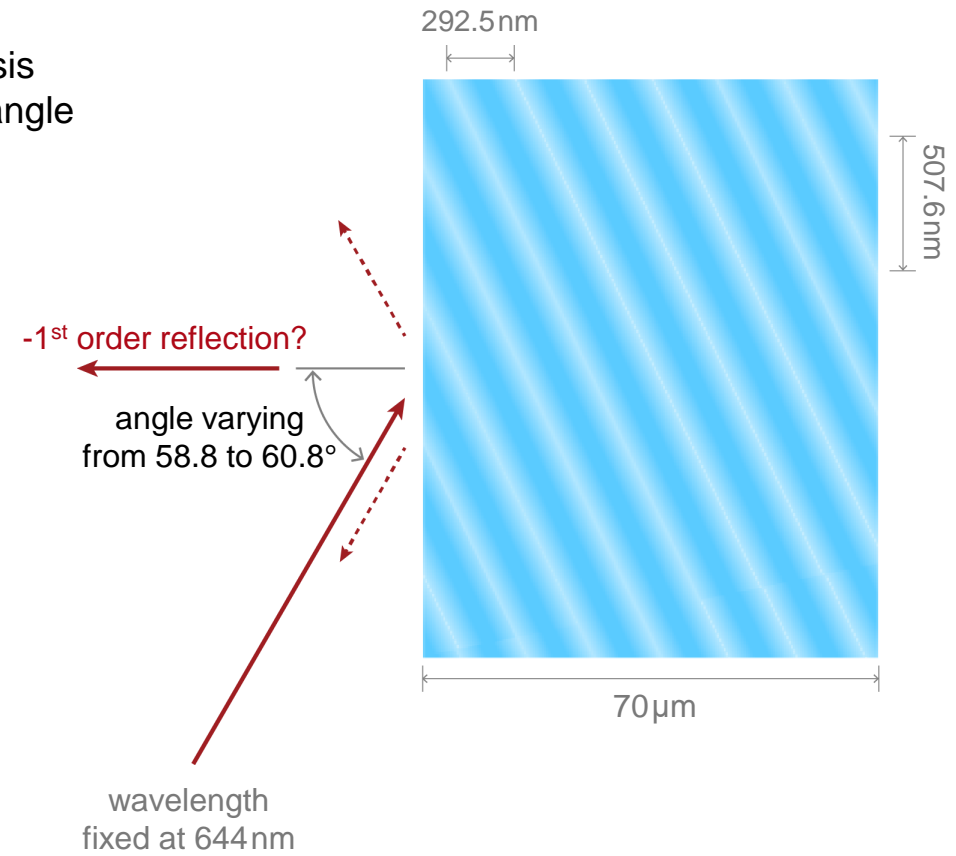
no shift of wavelength
dependent reflection



Diffraction Efficiency vs. Angle of Incidence



rigorous FMM analysis
for varying incident angle



Document Information

title	Holographically Generated Volume Grating
document code	GRT.0003
document version	2.0
software edition	VirtualLab Fusion Advanced
software version	2021.1 (Build 1.180)
category	Feature Use Case
further reading	<ul style="list-style-type: none">- <u>Configuration of Grating Structures by Using Special Media</u>- <u>Grating Order Analyzer</u>- <u>Modeling of Gratings within Optical System - Discussion at Examples</u>