

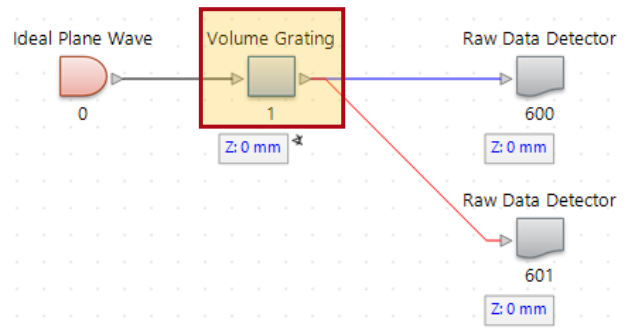
# Holographically Generated Volume Grating

# Abstract



Holographic generated volume gratings, with a thickness much larger than the wavelength, normally exhibit a narrow bandwidth for the particular designed 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.

# Holographic Volume Grating



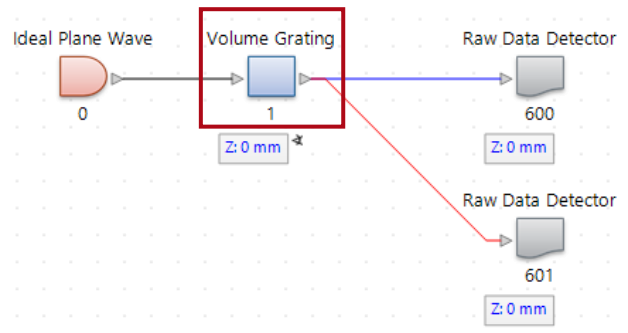
The holographic volume grating is generated by a specialized medium defined between two plane interfaces. It allows to configure the modulations of the refractive index, which was e.g., generated by holographic exposure. It can be found via *Templates > Volume Grating Medium*.

The 'Edit Stack' window displays a table of media layers. The first layer (Index 1) is a 'Volume Grating Medium' defined between two 'Plane Interface' surfaces. The second layer (Index 2) is 'Silica in Homog' medium. Below the table, there are configuration options for 'Validity' (checked), 'Periodicity & Aperture' (set to 'Periodic'), and 'Stack Period' (set to 'Dependent from the Period of Medium' with an index of 1, resulting in a stack period of 507.6142132 nm). Buttons for 'Add', 'Insert', 'Delete', 'OK', 'Cancel', and 'Help' are visible.

Index	z-Distance	z-Position	Surface	Subsequent Medium	Com
1	0 mm	0 mm	Plane Interface	Volume Grating Me...	Enter your commen
2	70 $\mu$ m	70 $\mu$ m	Plane Interface	Silica in Homog	Enter your commen

The 'Media Catalog' window shows a list of media types under the 'Templates' definition type. The 'Volume Grating Medium' is highlighted in blue. Other media types include 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, and Uniaxial Crystal.

# 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 Me...	Enter your commen
2	70 $\mu$ m	70 $\mu$ 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 1

Stack Period 507.6142132 nm

OK Cancel

Lateral View Settings

Show z-x-Plane  Show z-y-Plane

Color Table Midnight Sun

Media Visualization

Draw Media

Preview Wavelength 640 nm

Minimum Shown Refractive Index 1.42

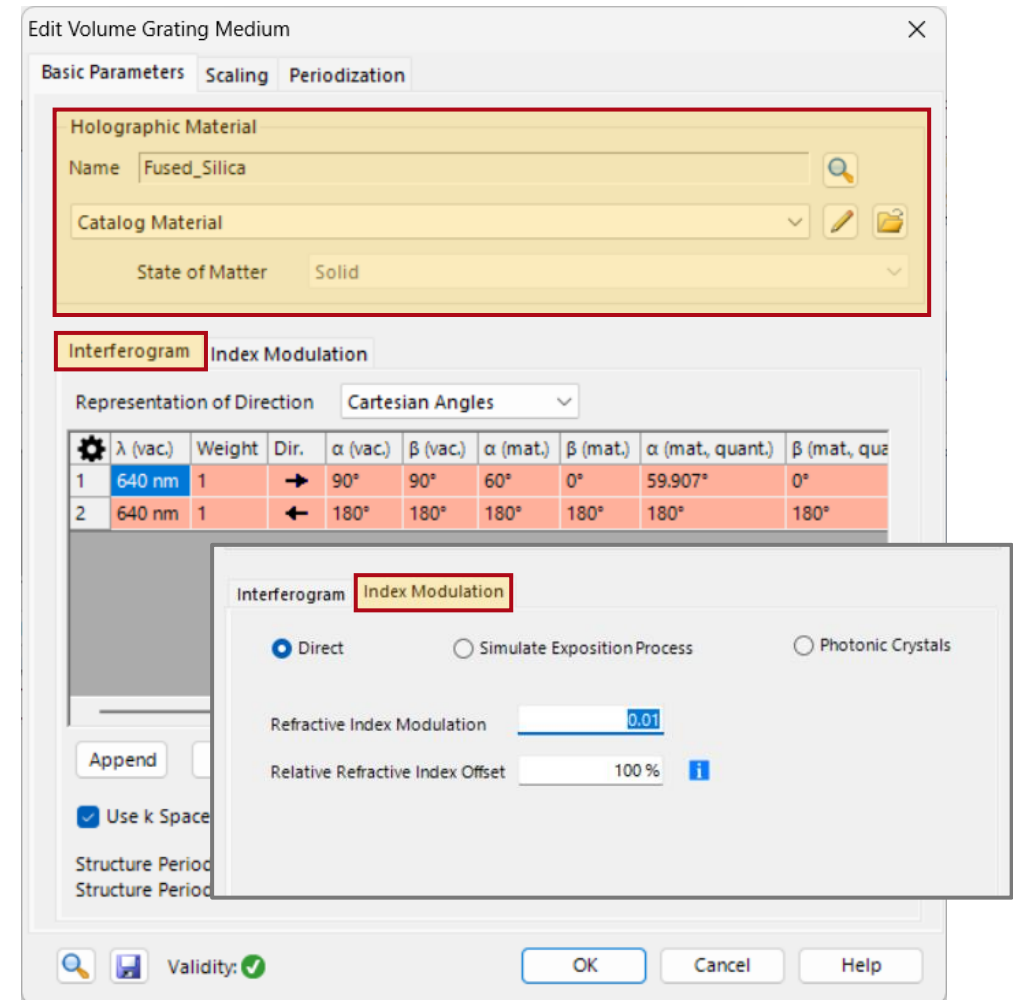
Maximum Shown Refractive Index 1.47

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 $\mu$ m	1 $\mu$ m	Plane Interface	Fused_Silica in Hom ...	Enter your commen

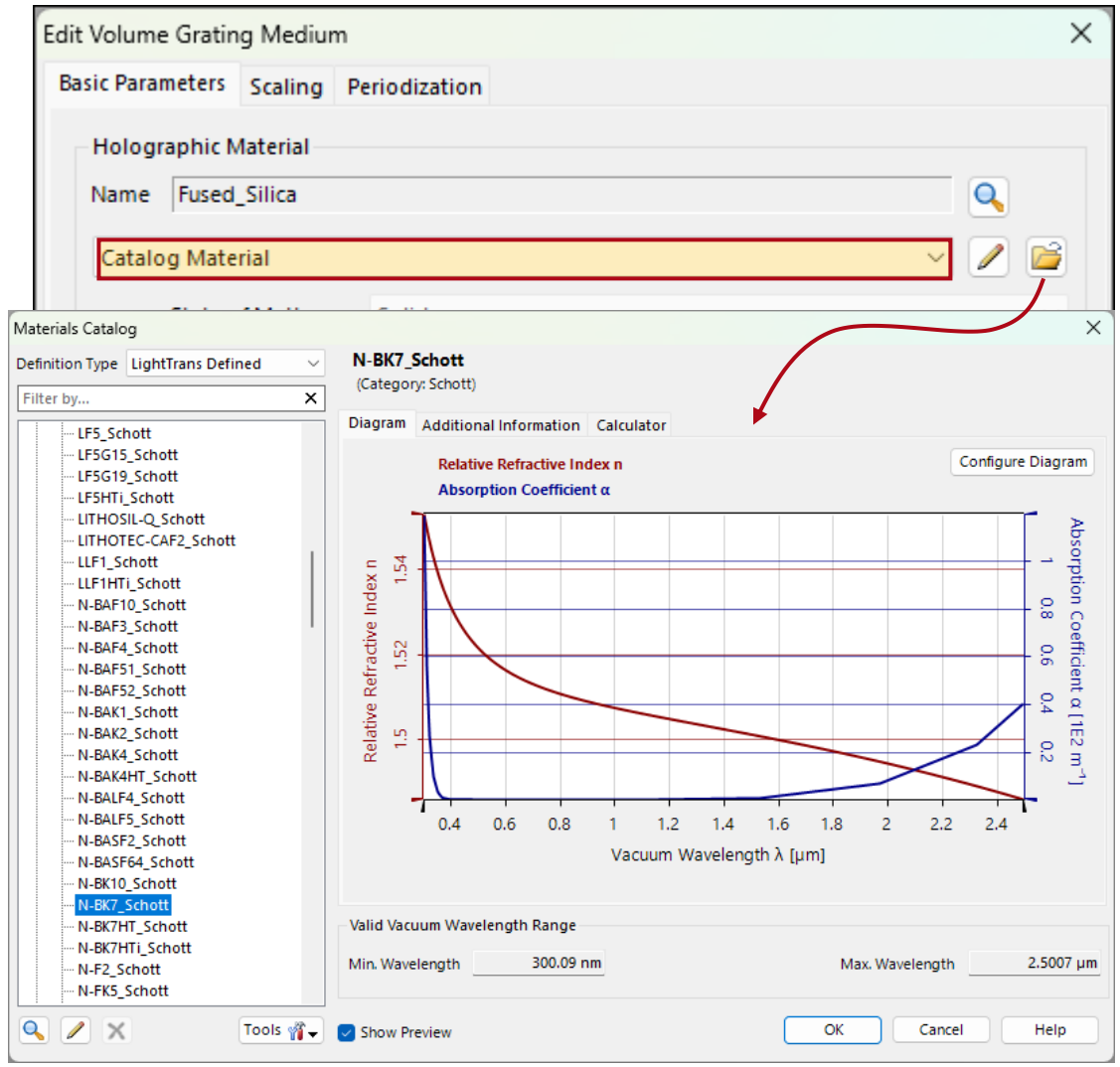
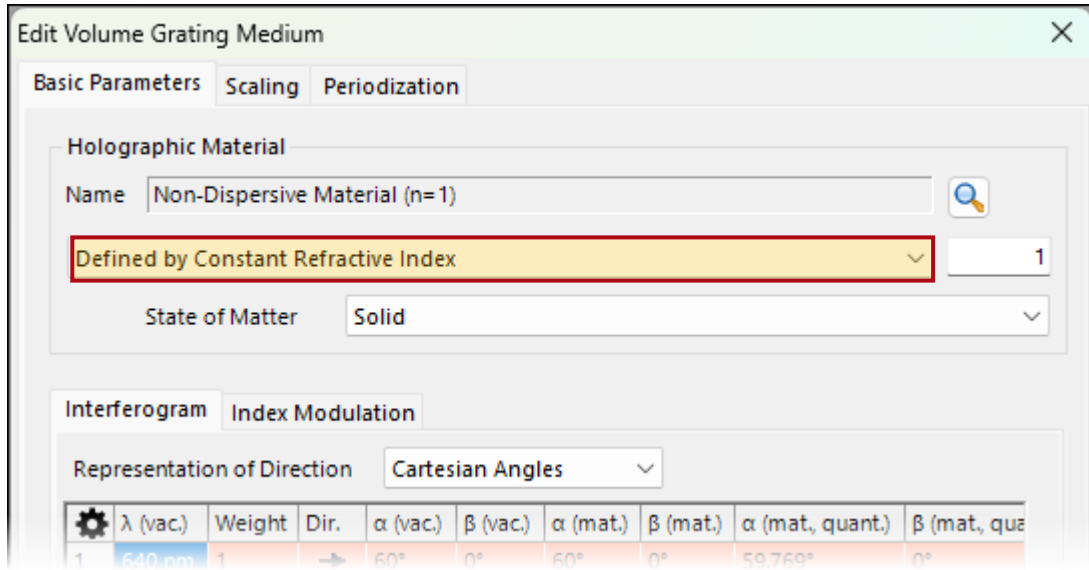
# Construction of the Volume Grating Medium

- To describe the volume grating VirtualLab simulates the interference pattern of a certain number of impinging waves.
- First, a *Holographic Material* has to be chosen, that provides the initial index of refraction.
- Next, an interference pattern is constructed by calculating the local time-averaged energy density of an arbitrary number of *Plane Waves*.
- Lastly, this interference pattern is transferred into a refractive index modulation that represents the volume grating.



# Holographic Material

- The *Holographic Material* can be specified either using our extensive material library or by specifying the refractive index directly.



# Construction of the Volume Grating Medium

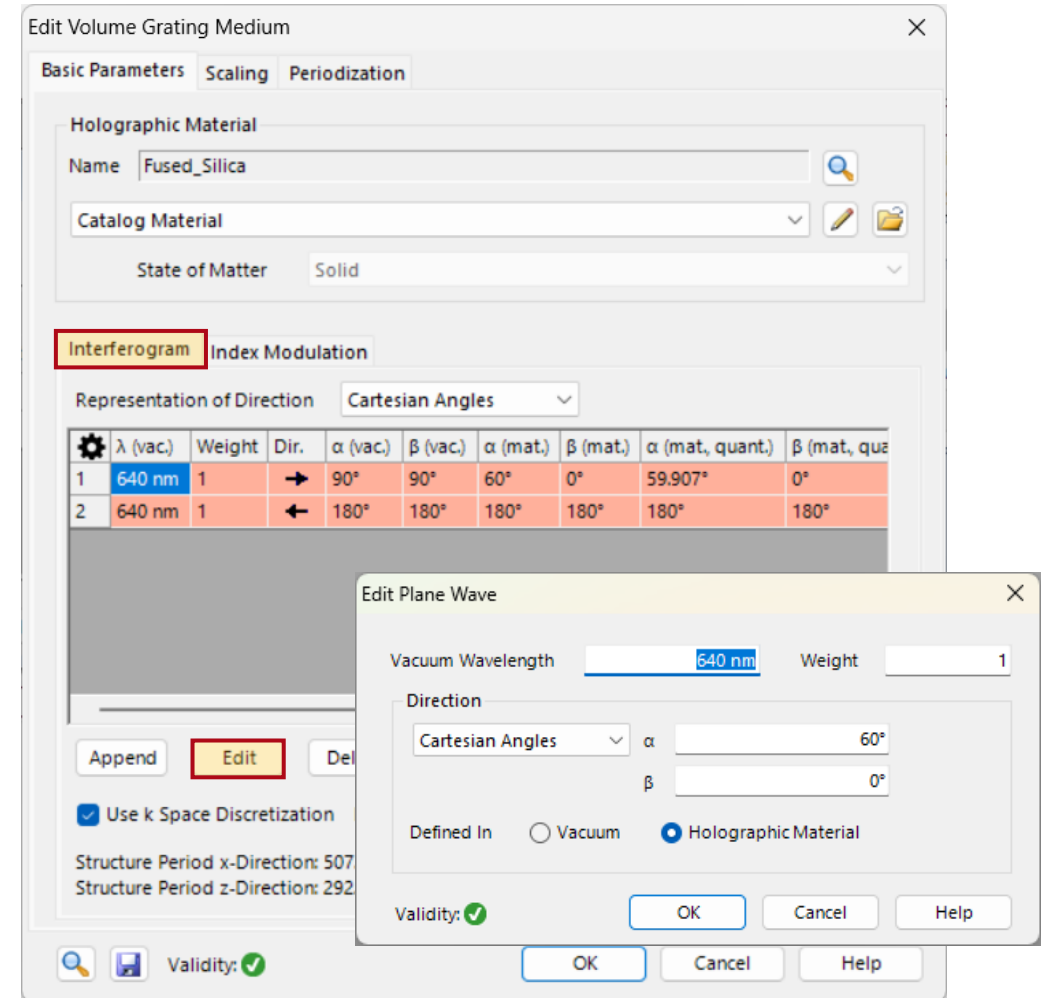
- To generate an interference pattern, user can specify weights, wavelengths and direction of an arbitrary number of plane waves.
- The locally averaged energy density is then calculated as

$$\bar{\omega}(x, y, z) = \epsilon_0 n_{\text{base}}^2 \left( \sum_n E_n e^{i\Phi_n(x,y,z)} \right)^2$$

$$E_n = \sqrt{\frac{F_n}{\sum_n F_n} \frac{\omega_{\text{max}}}{\epsilon_0 n_{\text{base}}^2}}$$

With  $F_n$  being the customizable weights.

- Here,  $\omega_{\text{max}}$  describes a weighting factor, which will be specified in the next section.





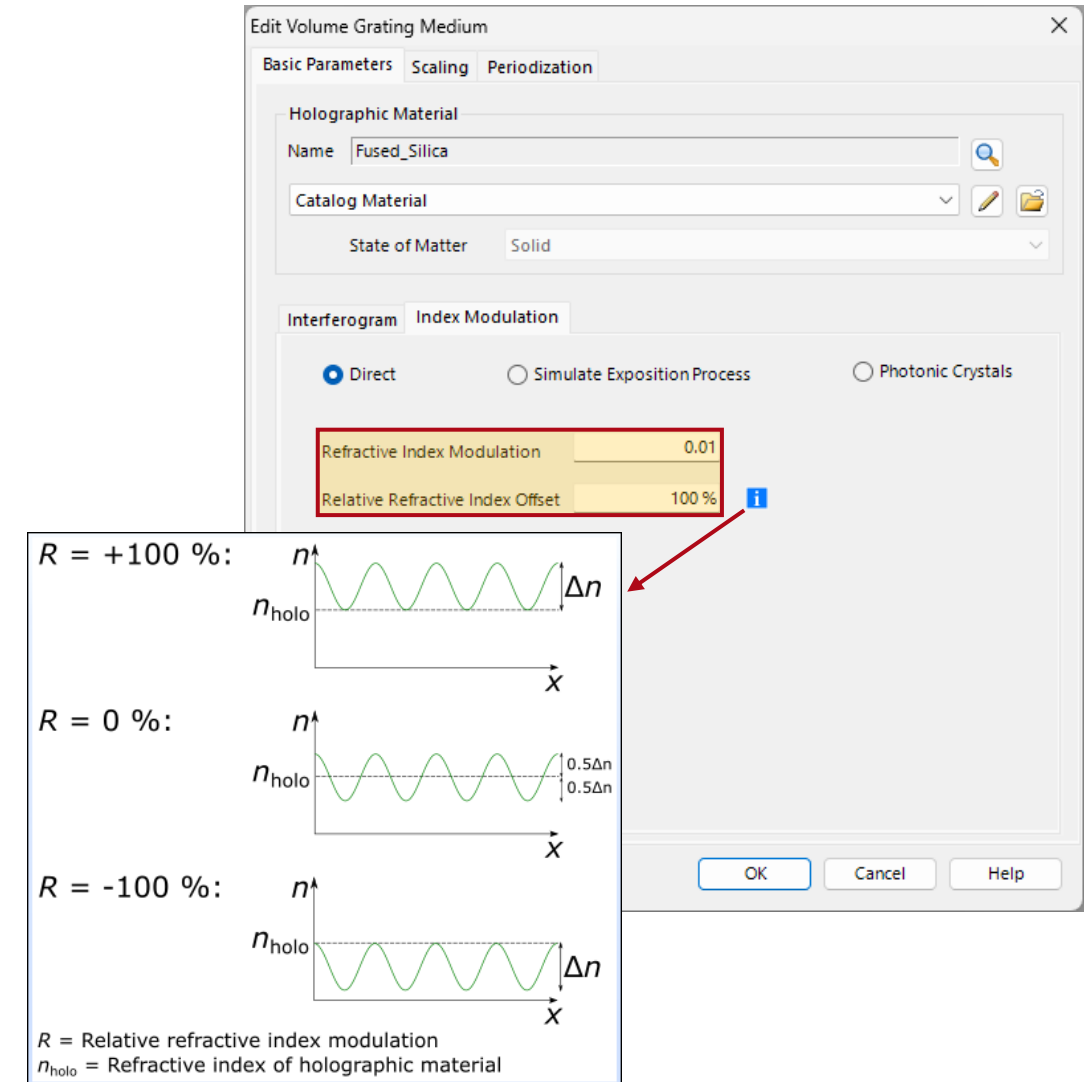
# Refractive Index Modulation – Direct

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

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

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

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





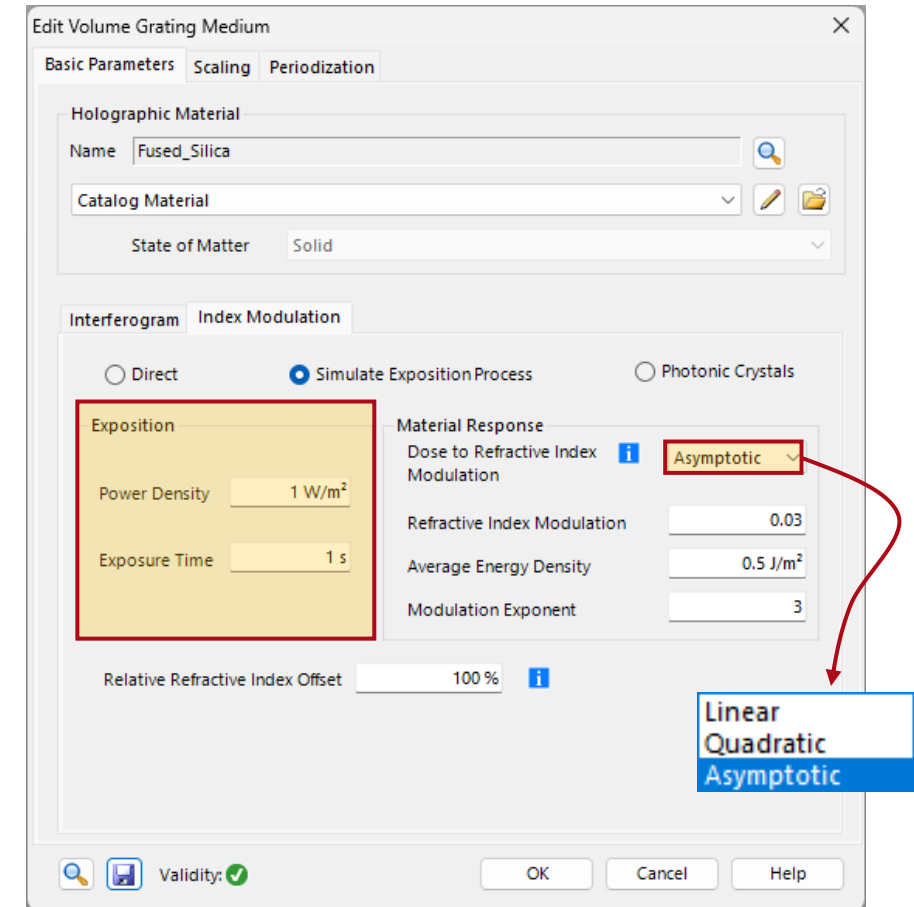
# Refractive Index Modulation – Simulate Exposition Process

- There is also the option to simulate an exposition process, in this case the weighting factor is defined by the *Power Density*  $P$  and the *Exposure Time*  $t_{\text{exp}}$  as

$$\bar{w}(x, y, z) = P \cdot t_{\text{exp}}$$

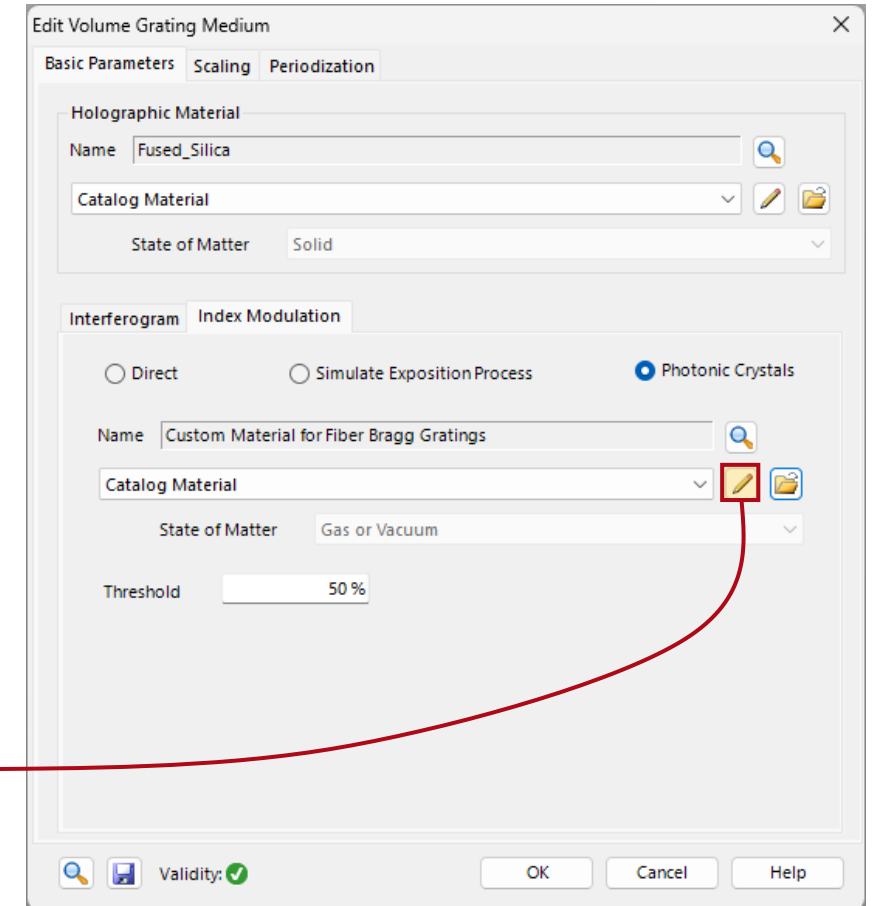
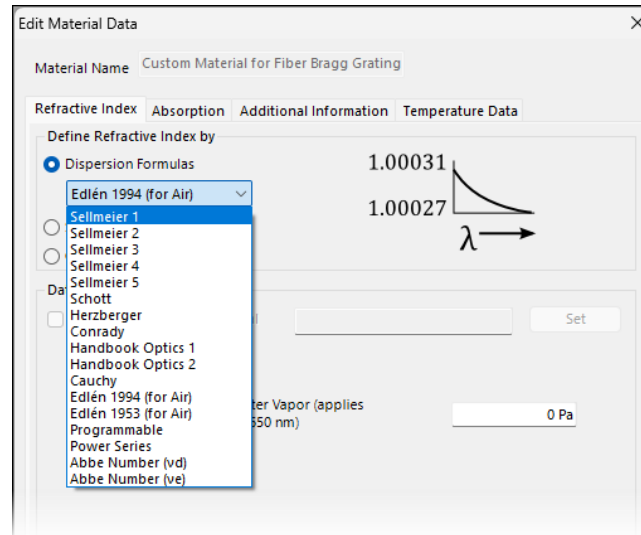
- For the actual refractive index modulation three options are available which are as following:

DOSE TO REFRACTIVE INDEX MODULATION	EQUATION	PARAMETERS
<b>Linear</b>	$n(x, y, z) = n_{\text{holo}} + l\bar{w}(x, y, z)$	$l$ : Linear Factor
<b>Quadratic</b>	$n(x, y, z) = n_{\text{holo}} + l\bar{w}(x, y, z) + p\bar{w}(x, y, z)^2$	$l$ : Linear Factor $p$ : Squared Factor
<b>Asymptotic</b>	$n(x, y, z) = n_{\text{holo}} + \Delta n - \frac{\Delta n}{1 + (\bar{w}(x, y, z)/w_0)^\gamma}$	$\Delta n$ : Refractive Index Modulation $w_0$ : Average Energy Density $\gamma$ : Modulation Exponent →Fig. 787



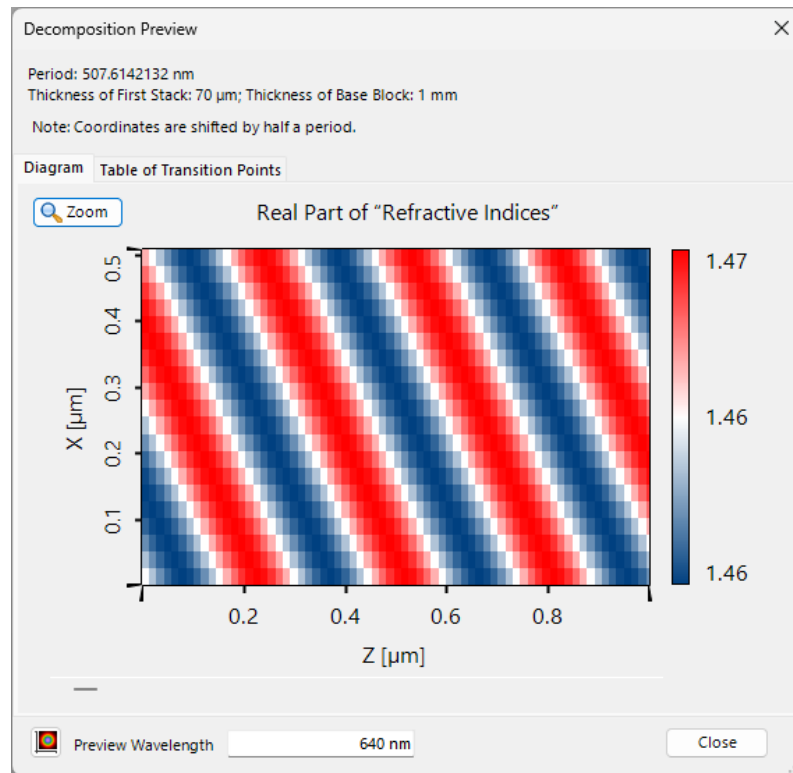
# Refractive Index Modulation – Photonic Crystal

- When using the *Photonic Crystal* options, users can specify a second material using or importing one from our extensive data base. VirtualLab will then assume the base material if the local averaged energy density of the interference pattern is below the specified threshold and the second material when it is above.



# 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 (Volume Grating)

Component Propagation Fourier Modal Method Edit

Coordinate Systems

Position / Orientation

Structure

Propagation

Surface

1 Plane S Fourier

2 Plane S Fourier

Edit Fourier Modal Method (RCWA)

Numerical Parameter Structure Decomposition

Layer Decomposition

Automatic Accuracy Factor 1

Manual

Number of Layers (First Stack)

Overall Thickness 70  $\mu\text{m}$

Transition Point Decomposition

Automatic Accuracy Factor 1

Manual

Number of Points

Point Distance

Period 507.6142132 nm

Information

Maximum total number of layers: 4787  
Minimum transition point distance: 10.15228426 nm

Remove Redundant Data

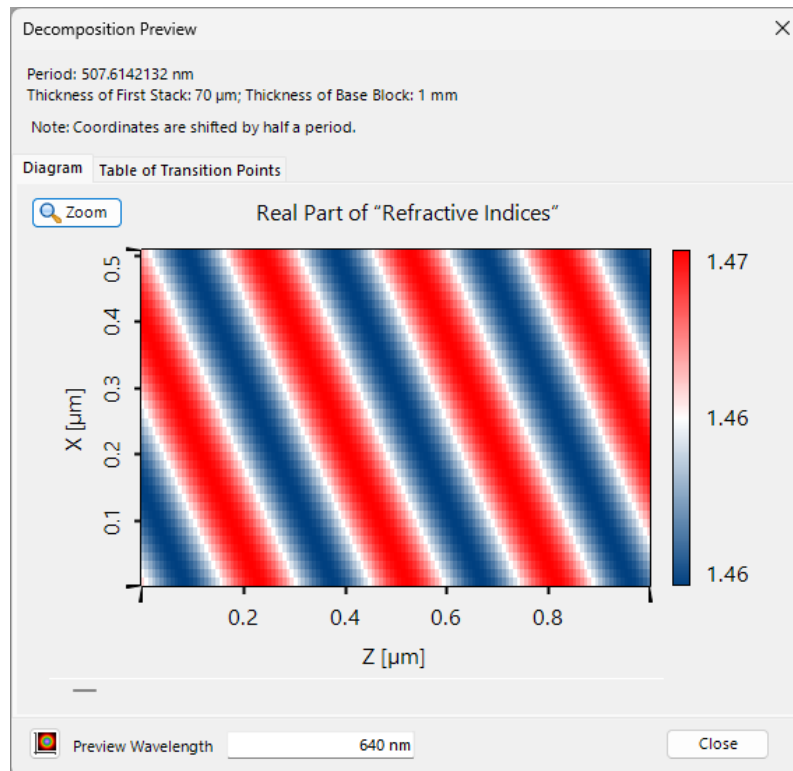
Decomposition Preview

OK Cancel Help

The screenshot shows the 'Edit General Grating Component (Volume Grating)' dialog box. The 'Component Propagation' is set to 'Fourier Modal Method'. The 'Structure Decomposition' tab is active, showing 'Layer Decomposition' and 'Transition Point Decomposition' sections. Both are set to 'Automatic'. The 'Overall Thickness' is 70  $\mu\text{m}$  and the 'Period' is 507.6142132 nm. The 'Information' section shows 'Maximum total number of layers: 4787' and 'Minimum transition point distance: 10.15228426 nm'. The 'Remove Redundant Data' checkbox is checked. A red arrow points from the 'Decomposition Preview' button in the bottom right to the 'Decomposition Preview' window on the left. Another red arrow points from the 'Edit' button in the top right to the 'Edit Fourier Modal Method (RCWA)' 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  $\mu\text{m}$

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

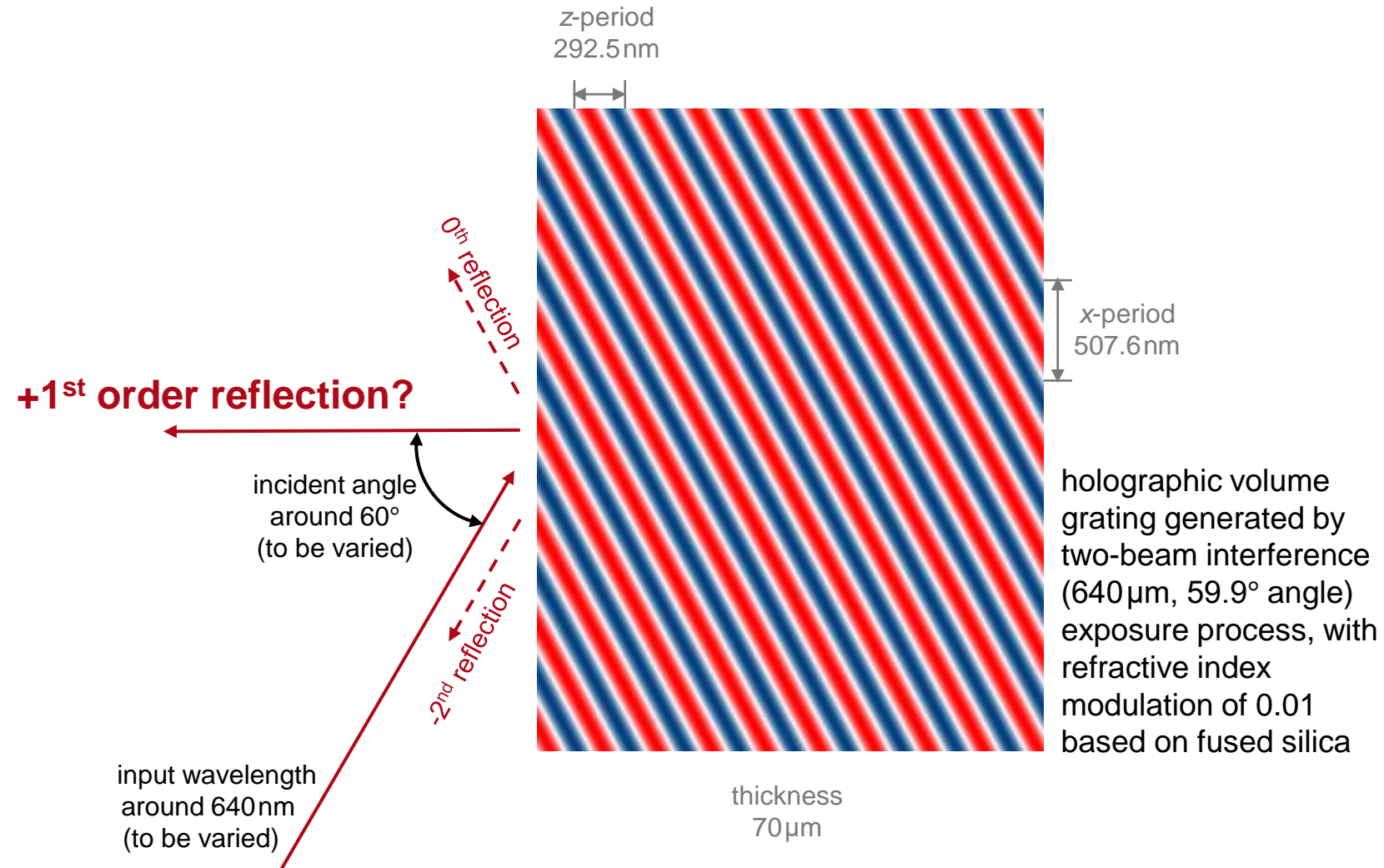
Decomposition Preview

OK Cancel Help

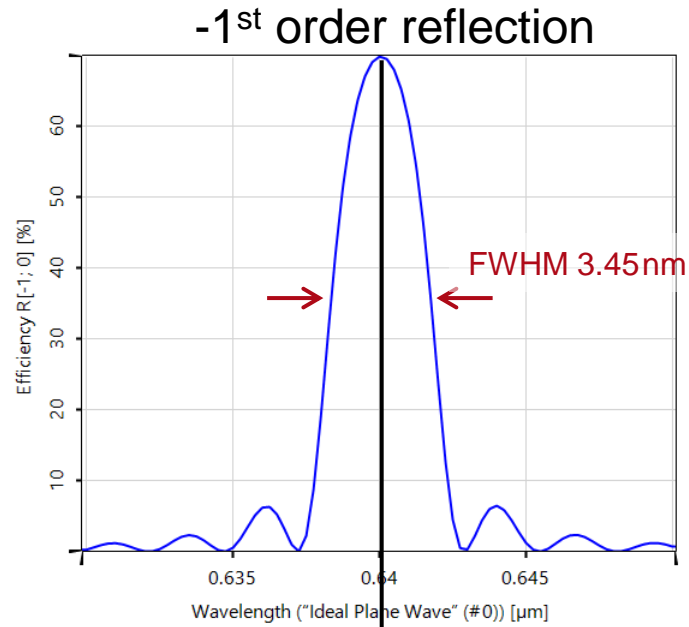
The screenshot shows the software interface for editing a grating component. The "Edit General Grating Component" dialog is open, with the "Propagation" option selected in the left sidebar. The "Edit Fourier Modal Method (RCWA)" dialog is also open, showing the "Structure Decomposition" tab. The "Layer 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 "Decomposition Preview" window in the previous figure.

# Examples

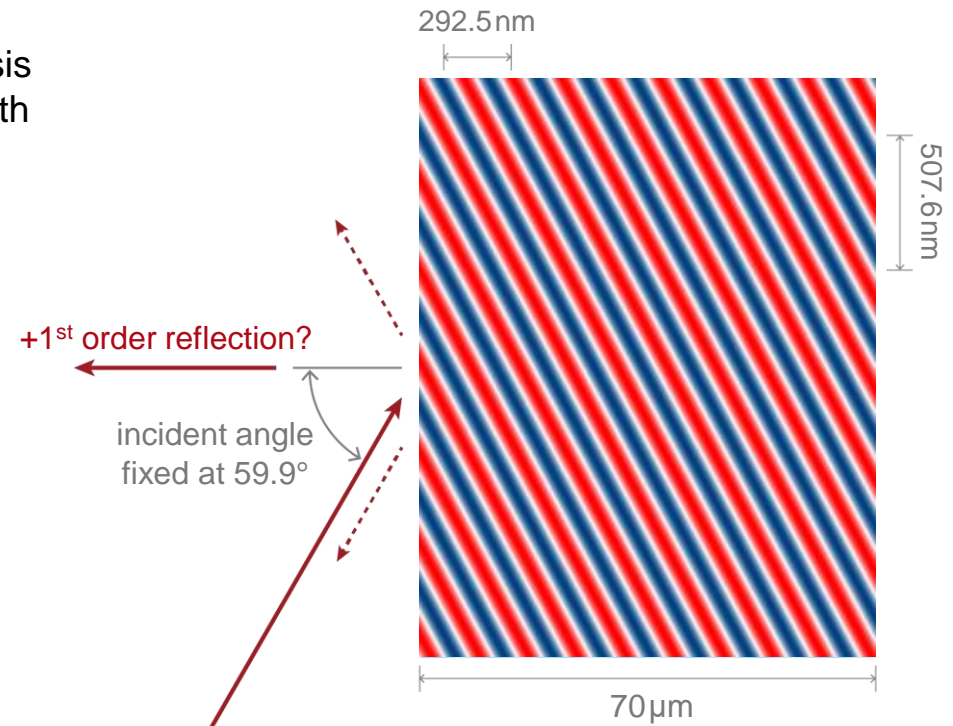
# Modeling Task



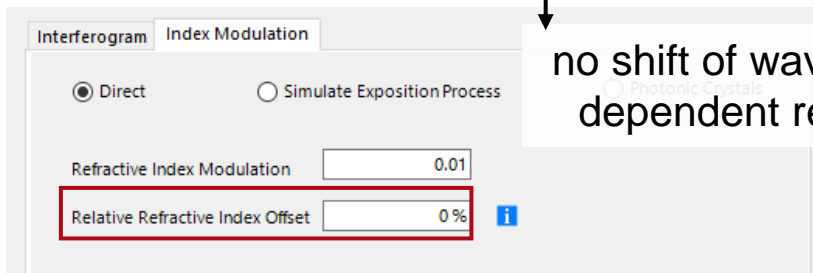
# Diffraction Efficiency vs. Wavelength



rigorous FMM analysis  
for varying wavelength

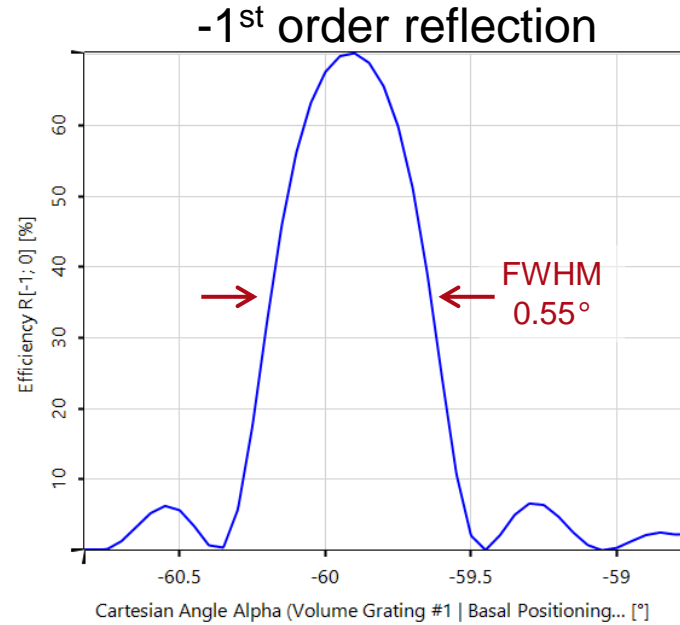


no shift of wavelength  
dependent reflection

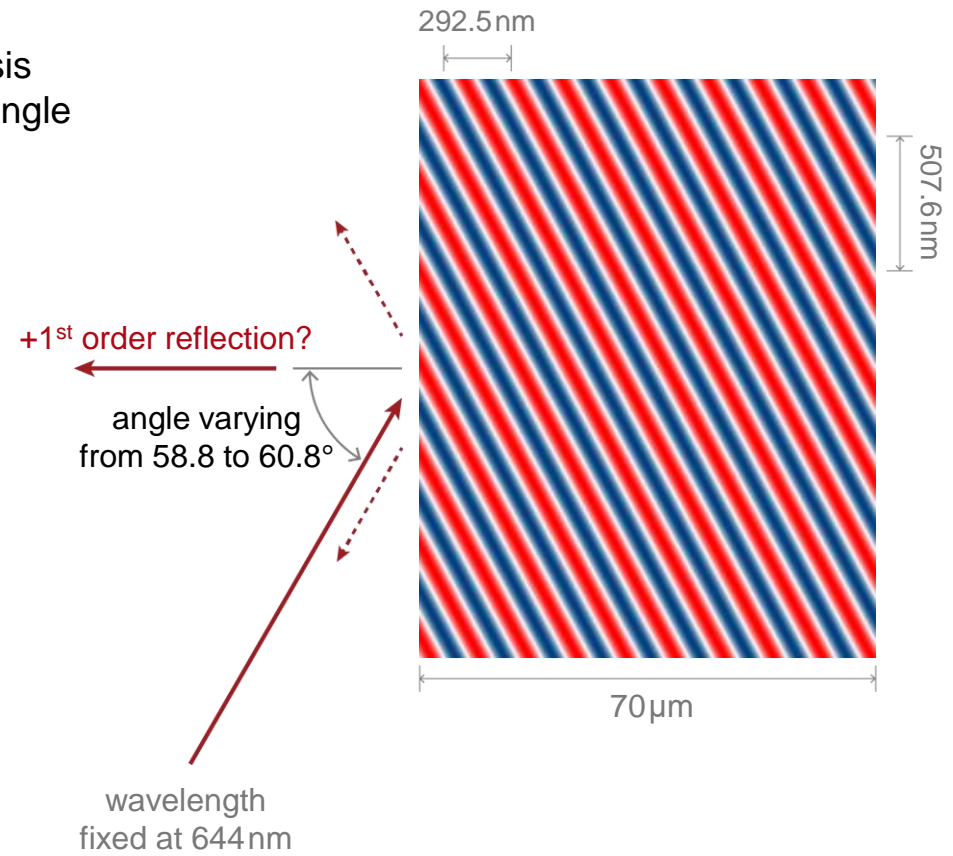




# Diffraction Efficiency vs. Angle of Incidence



rigorous FMM analysis  
for varying incident angle



# Document Information

title	Holographically Generated Volume Grating
document code	GRT.0003
document version	2.0
required packages	VirtualLab Fusion Advanced
software version	2024.1 (Build 1.134)
category	Feature Use Case
further reading	<ul style="list-style-type: none"><li>- <a href="#">Configuration of Grating Structures by Using Special Media</a></li><li>- <a href="#">Grating Order Analyzer</a></li><li>- <a href="#">Modeling of Gratings within Optical System - Discussion at Examples</a></li></ul>