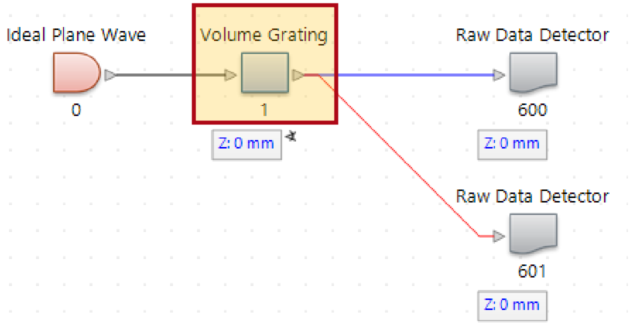
Holographically Generated Volume Grating

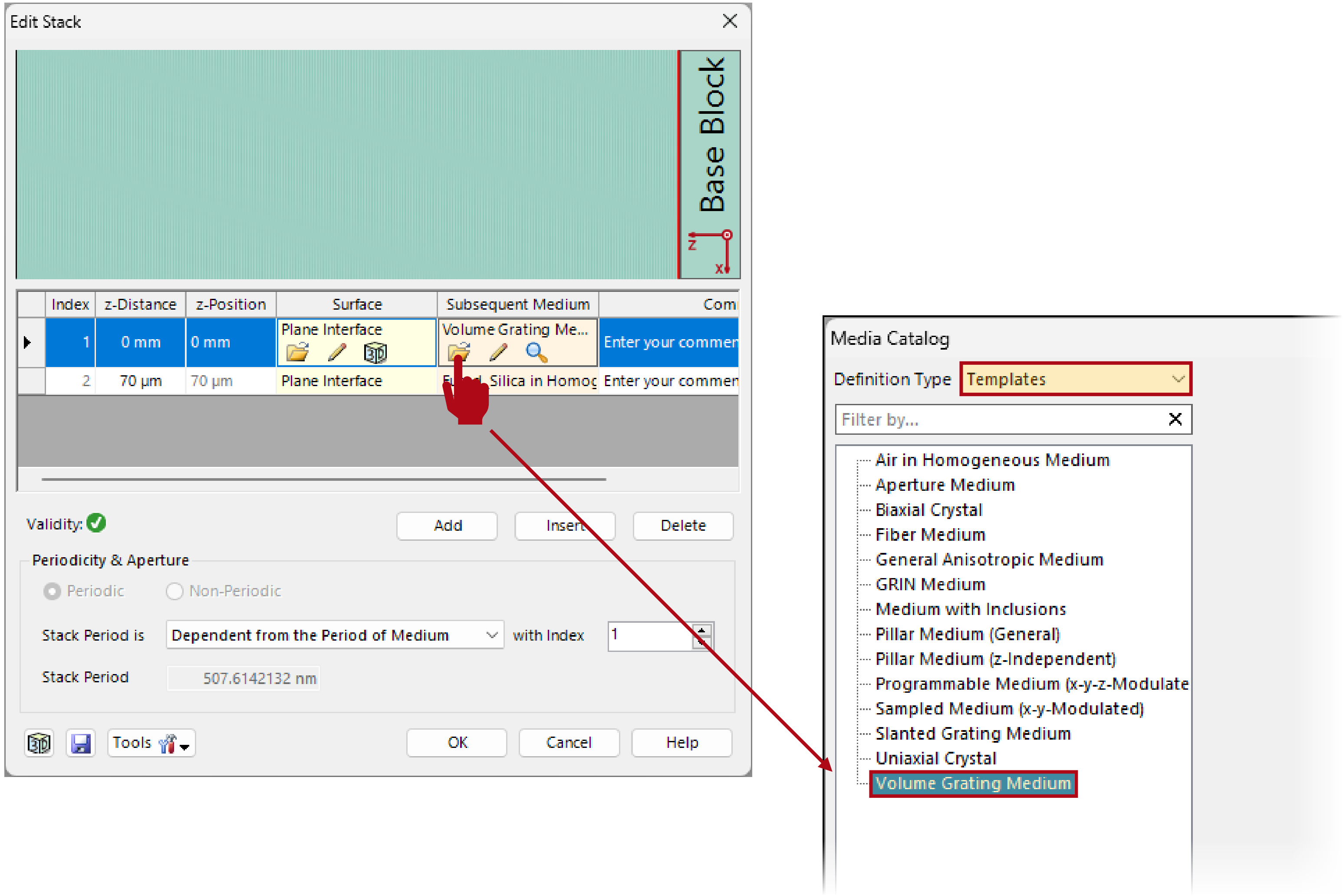
Abstract

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.

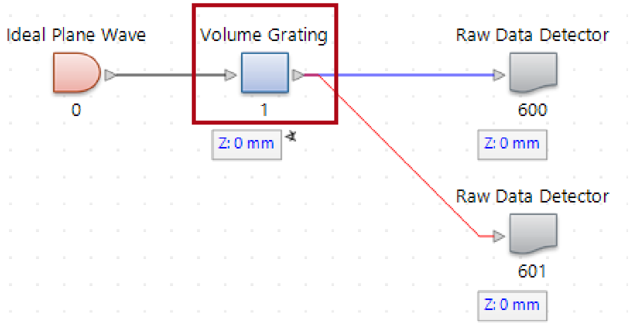
Holographic Volume Grating



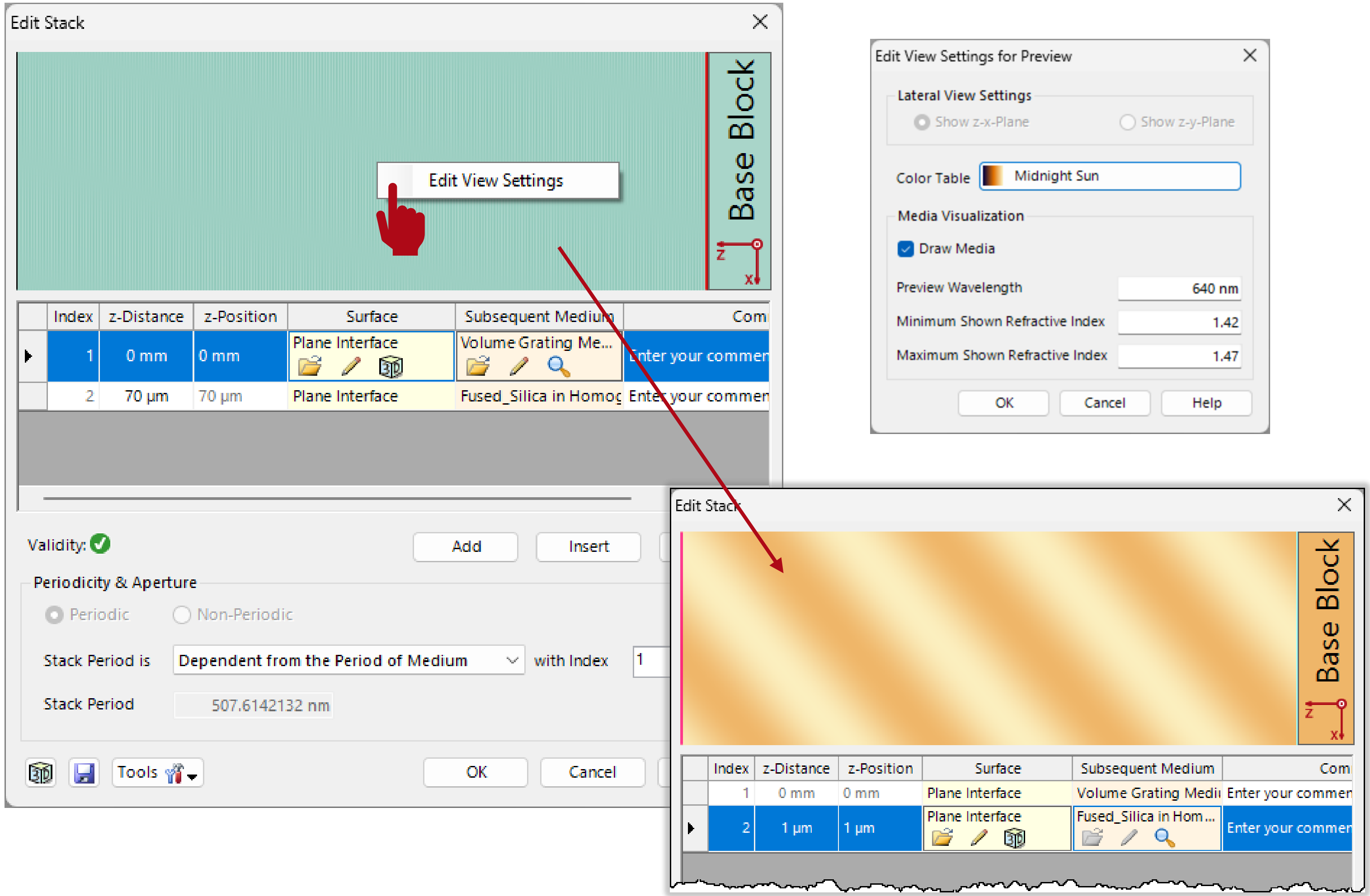
The holographic volume grating is generated by a specialized medium defined between two plane interfaces. It allows to configure the modulations of the refractive index, which was e.g., generated by holographic exposure. It can be found via *Templates > Volume Grating Medium*.



Holographic Volume Grating

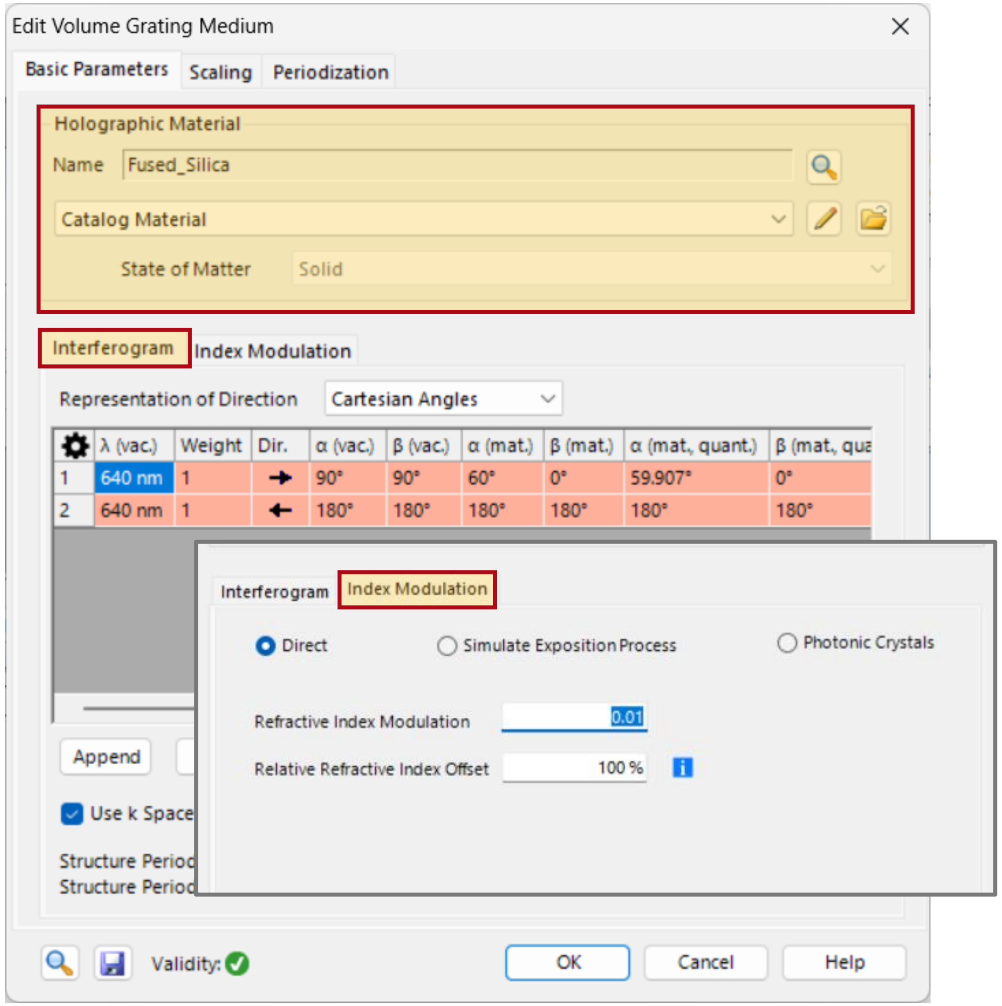


After adjusting the thickness and editing the view settings appropriately, the preview of the periodic grating structure can be seen.



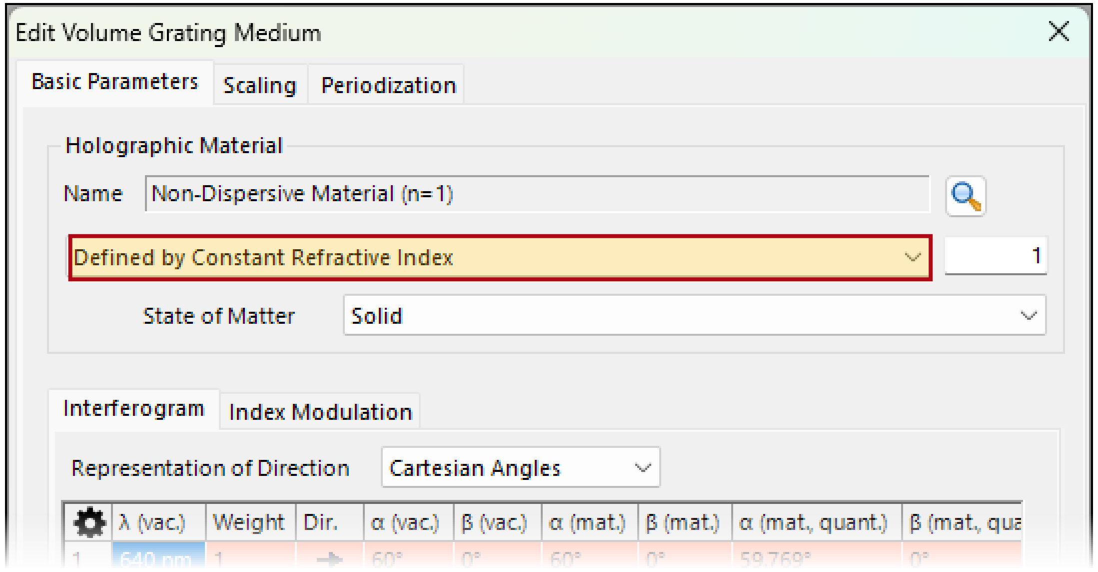
Construction of the Volume Grating Medium

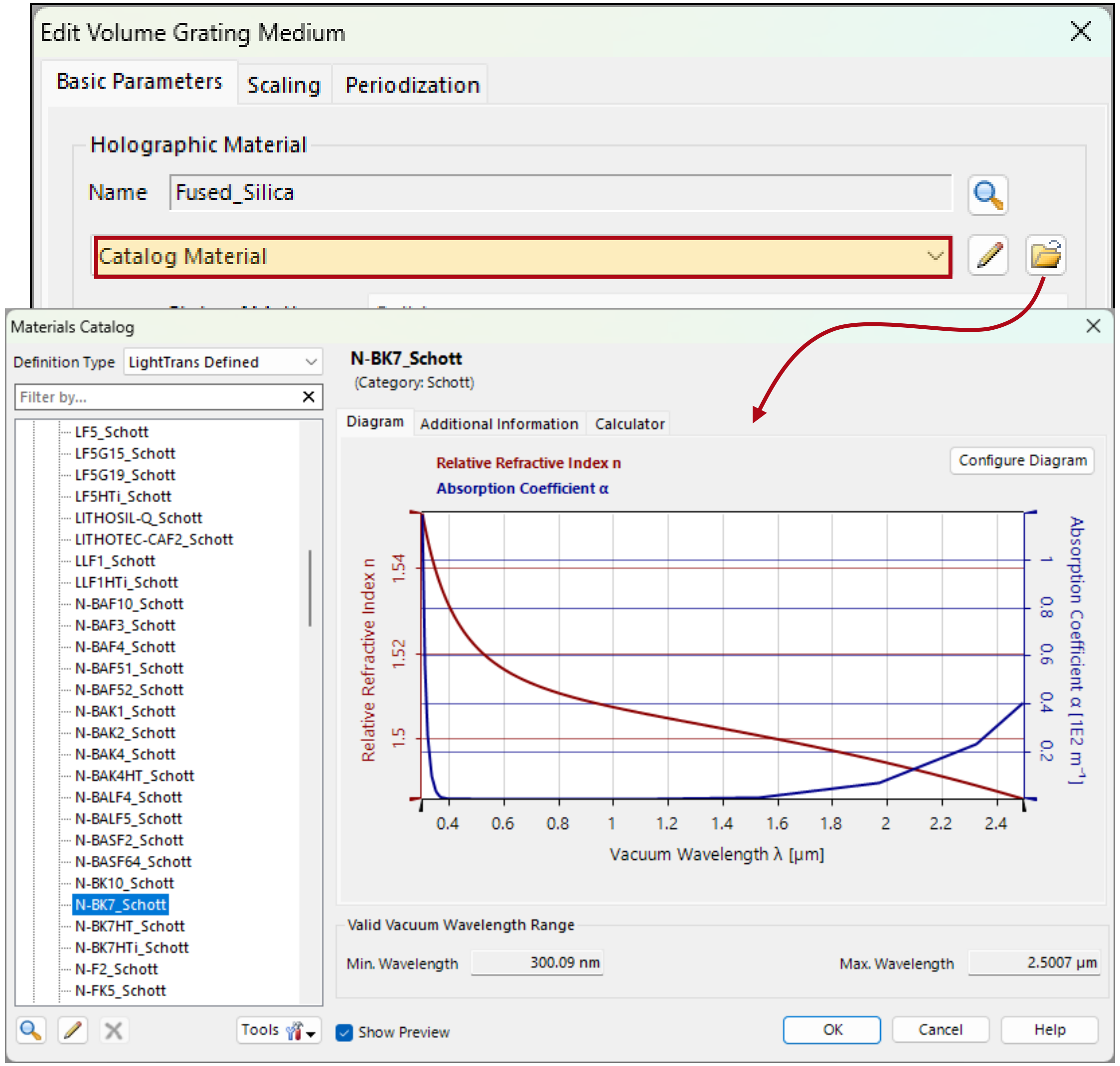
- To describe the volume grating VirtualLab simulates the interference pattern of a certain number of impinging waves.
- First, a *Holographic Material* has to be chosen, that provides the initial index of refraction.
- Next, an interference pattern is constructed by calculating the local time-averaged 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

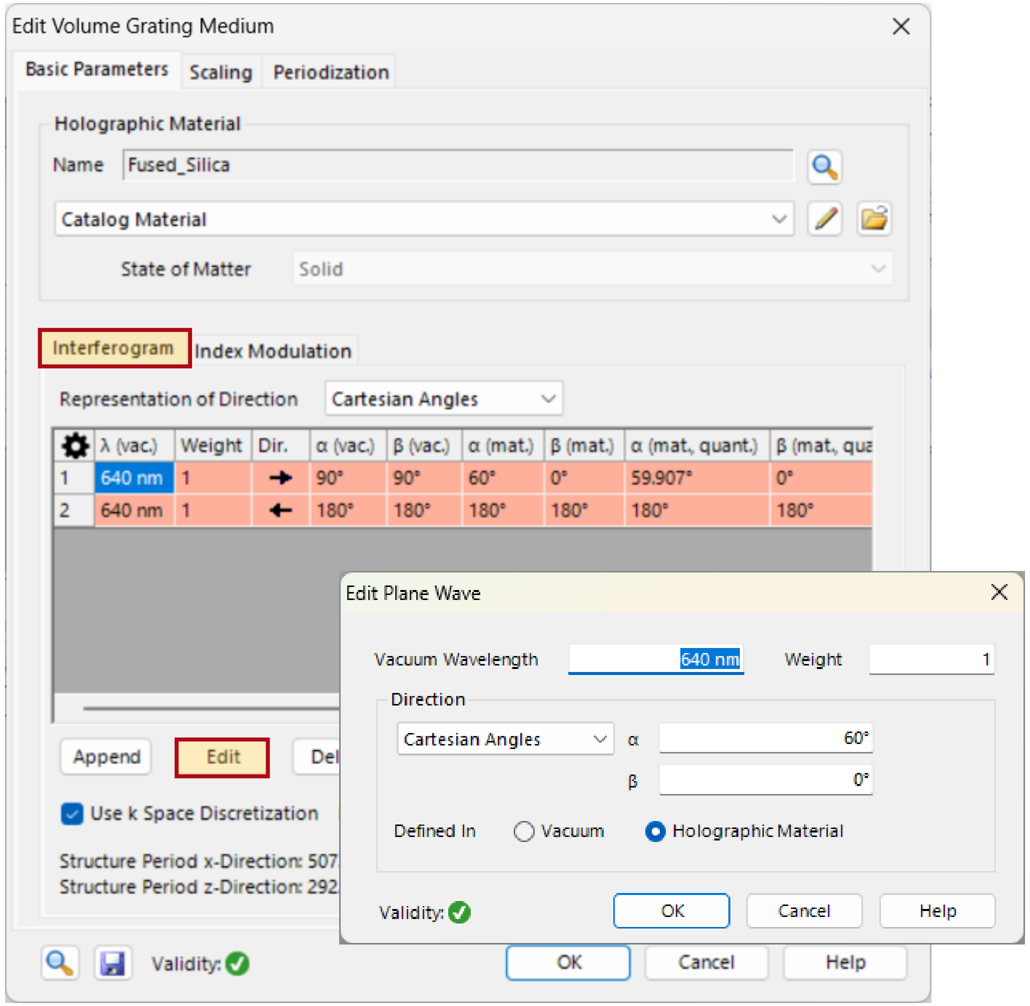
- To generate an interference pattern, user can specify weights, wavelengths and direction of an arbitrary number of plane waves.
- The locally averaged energy density is then calculated as

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

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

With F_n being the customizable weights.

- Here, ω_{max} describes a weighting factor, which will be specified in the next section.

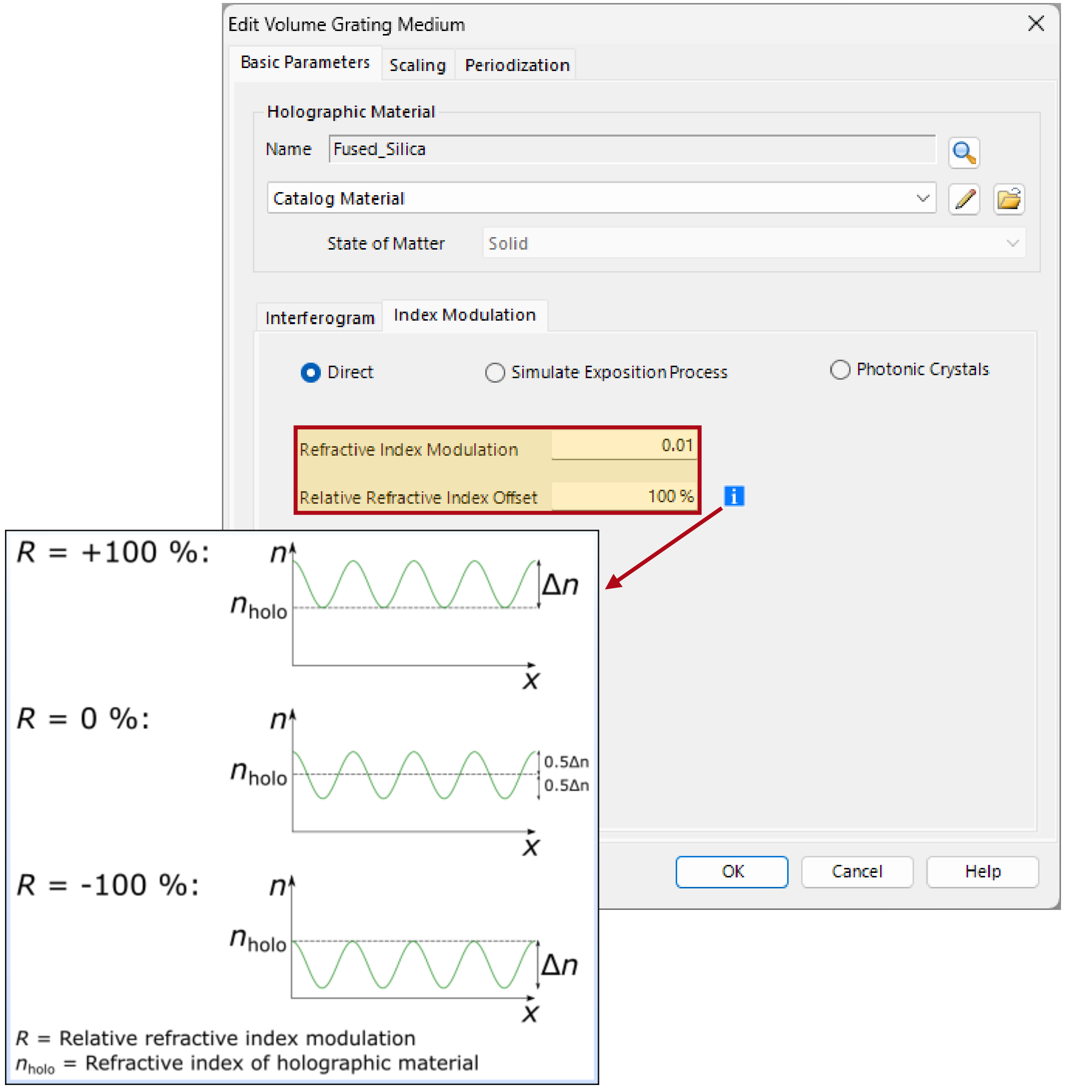


Refractive Index Modulation – Direct

- In this case the desired *Refractive Index Modulation* Δn 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

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

  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)



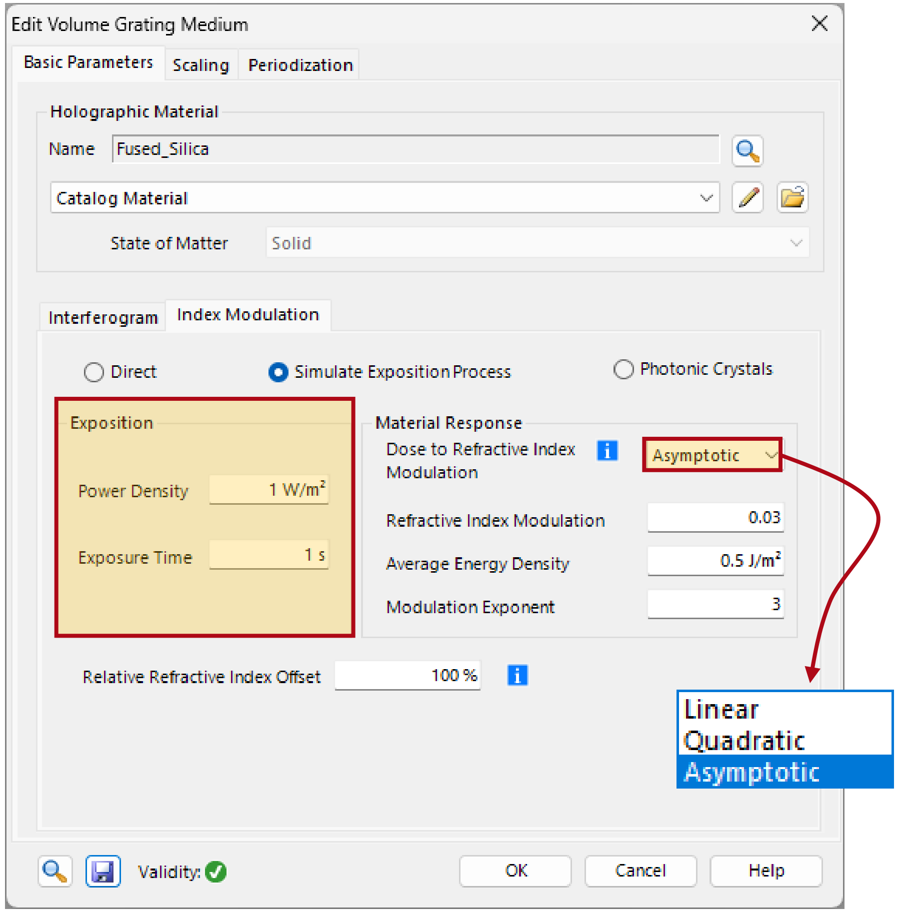
Refractive Index Modulation – Simulate Exposition Process

- 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_{exp} as

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

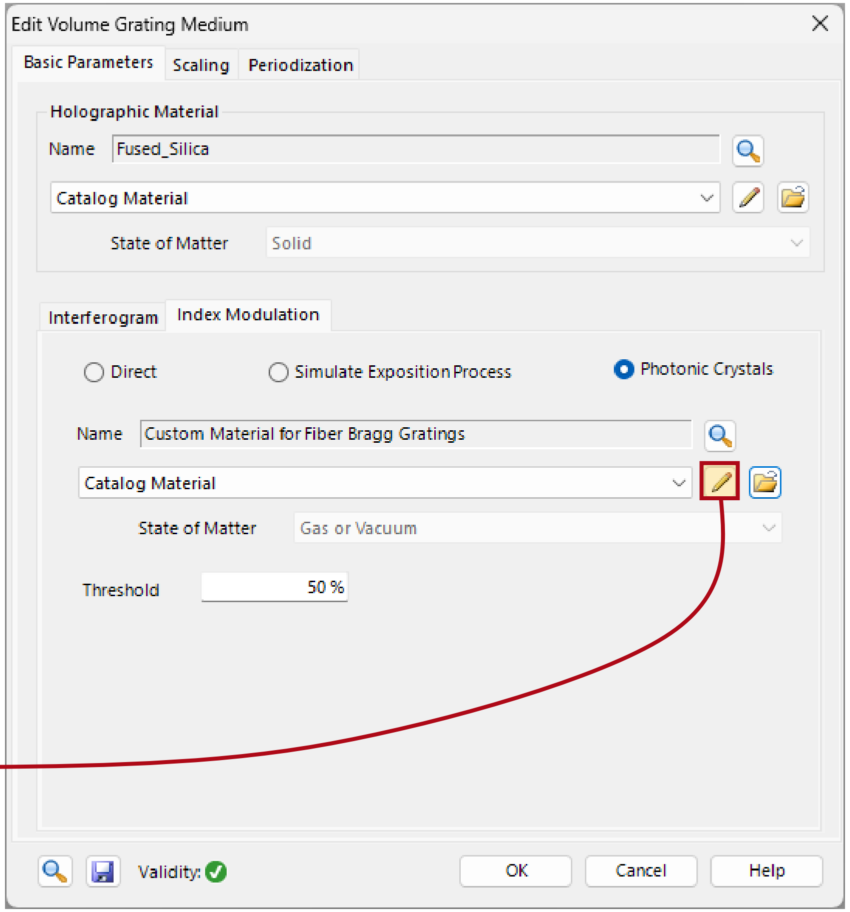
- For the actual refractive index modulation three options are available which are as following:

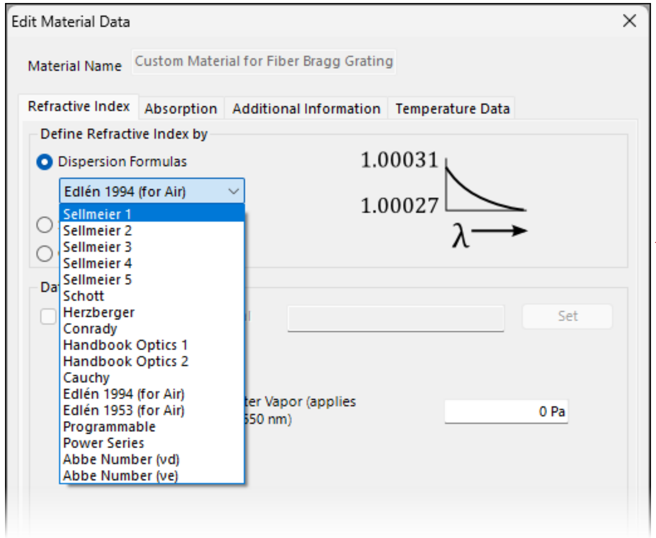
DOSE TO REFRACTIVE INDEX MODULATION	EQUATION	PARAMETERS
Linear	$n(x,y,z) = n_{\text{holo}} + l\overline{w}(x,y,z)$	l: *Linear Factor*
Quadratic	$n(x,y,z) = n_{\text{holo}} + l\overline{w}(x,y,z) + p\overline{w}(x,y,z)^2$	l: *Linear Factor* p: *Squared Factor*
Asymptotic	$n(x,y,z) = n_{\text{holo}} +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



Refractive Index Modulation – Photonic Crystal

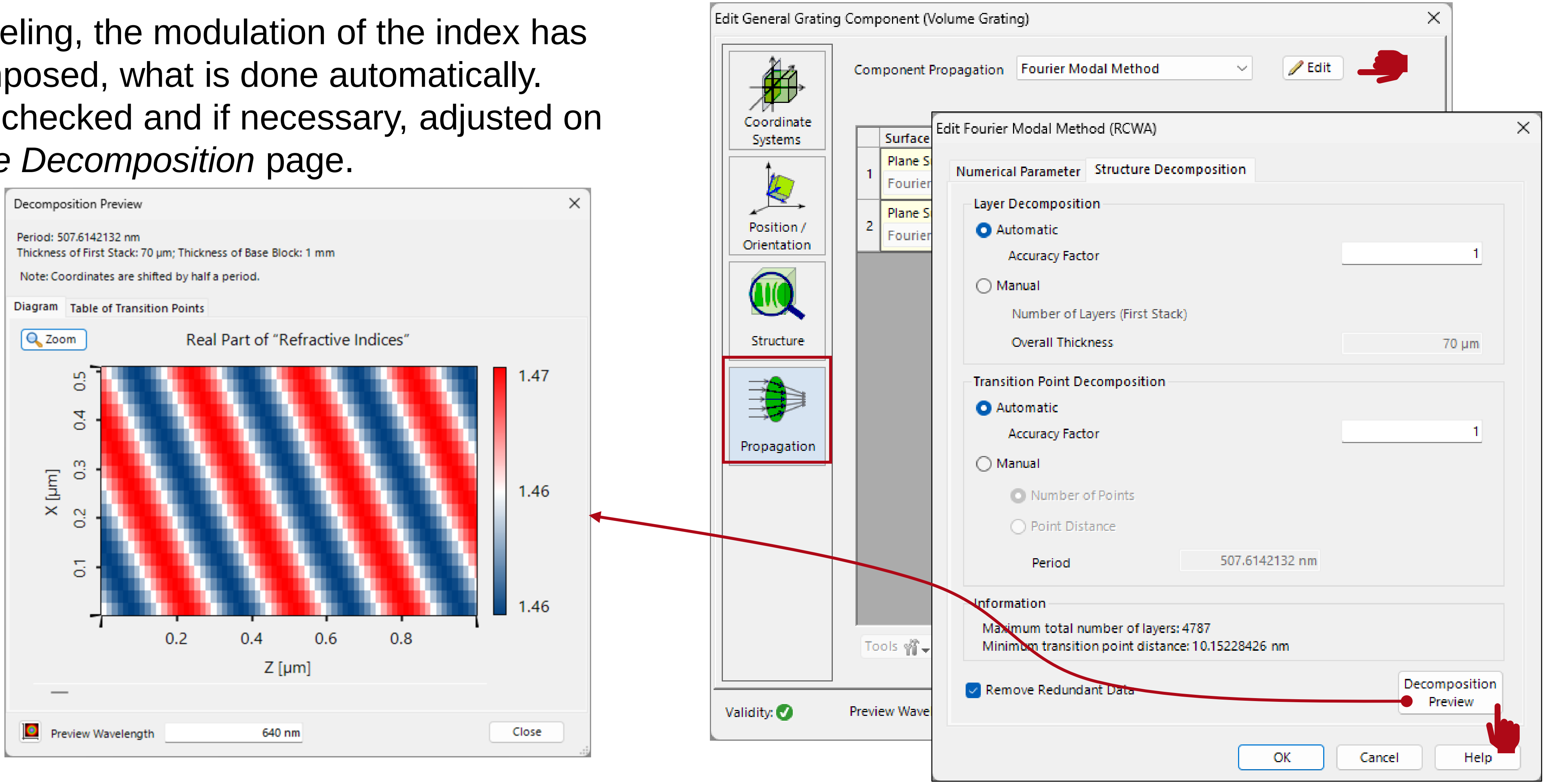
- When using the *Photonic Crystal* options, users can specify a second material using or importing one from our extensive data base. VirtualLab will then assume the base material if the local averaged energy density of the interference pattern is below the specified threshold and the second material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





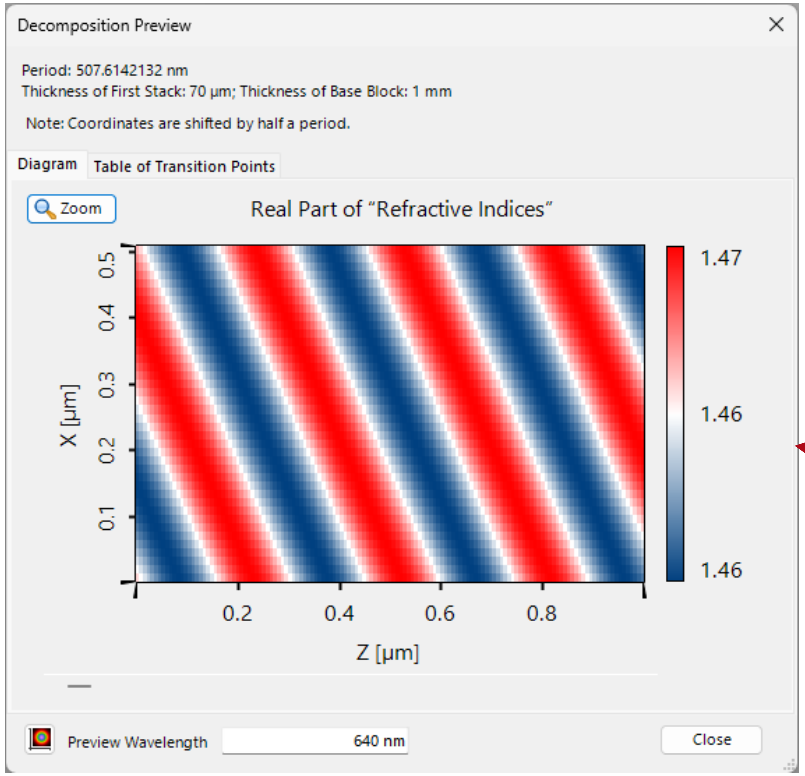
Advanced Options & Information

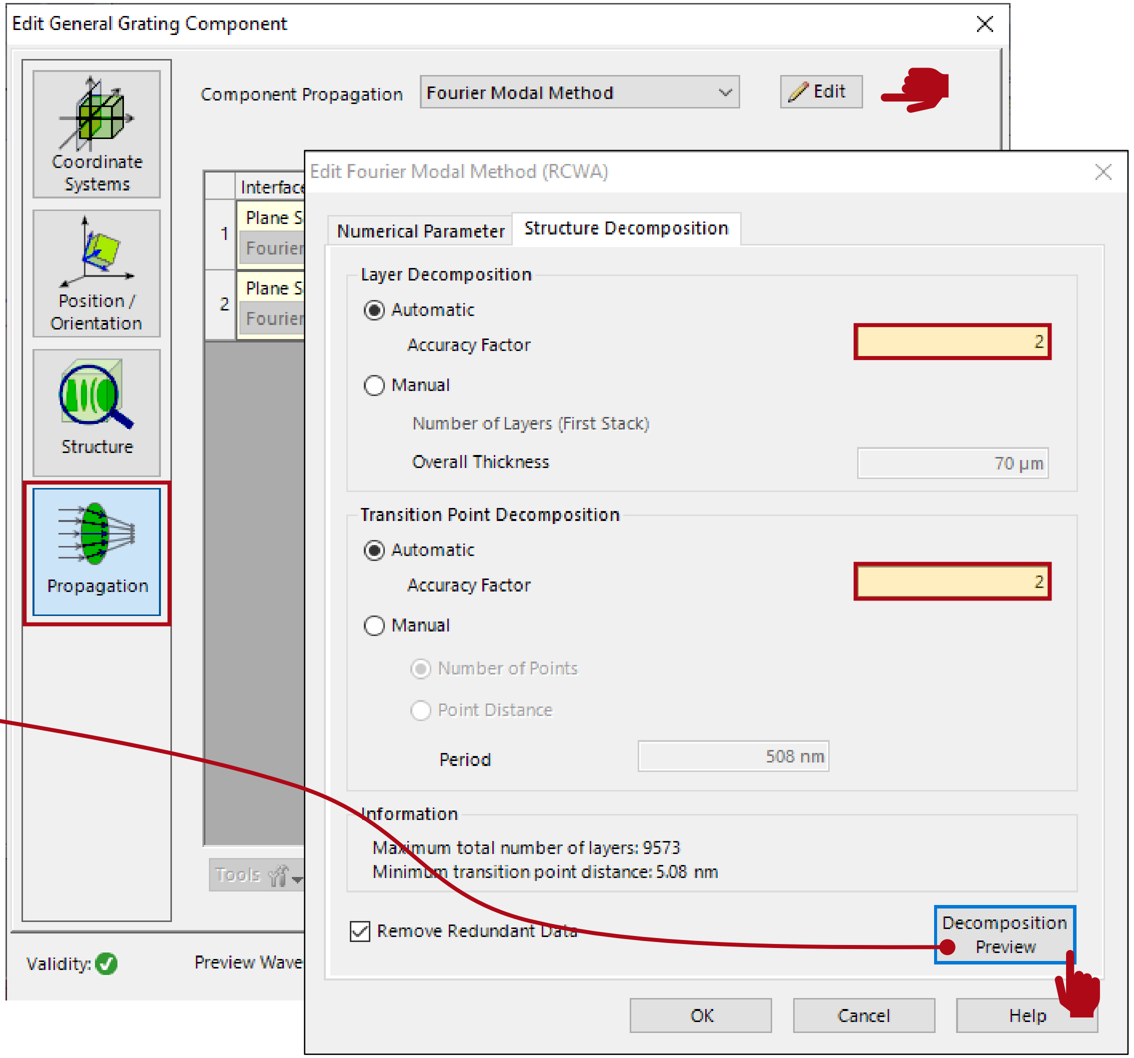
For the modeling, the modulation of the index has to be decomposed, what is done automatically. This can be checked and if necessary, adjusted on the *Structure Decomposition* page.



Advanced Options & Information

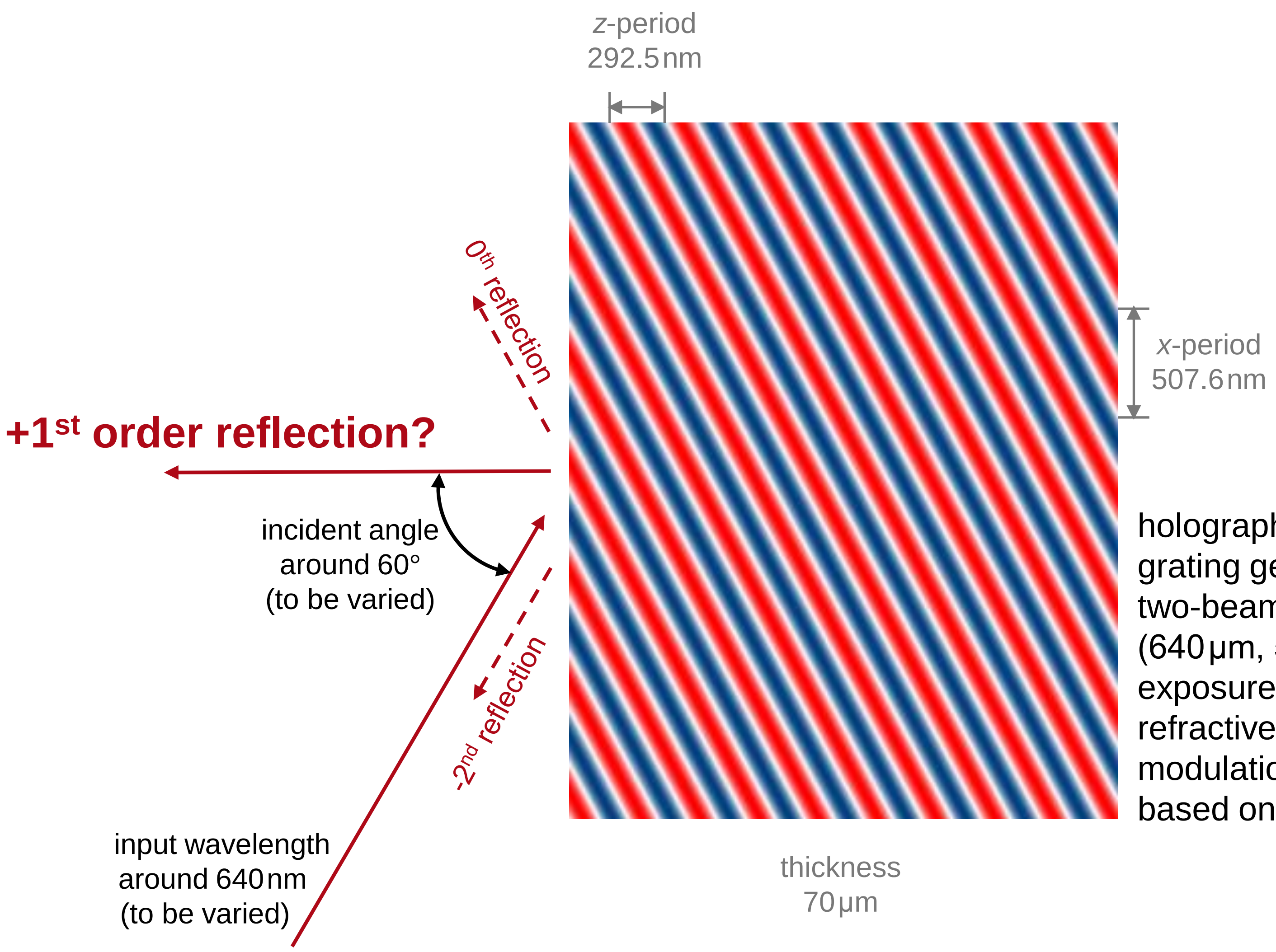
If the numbers of layers and transition points are increased (e.g., by a factor of 2), the discretization becomes smoother, at the expense of an increased numerical effort.





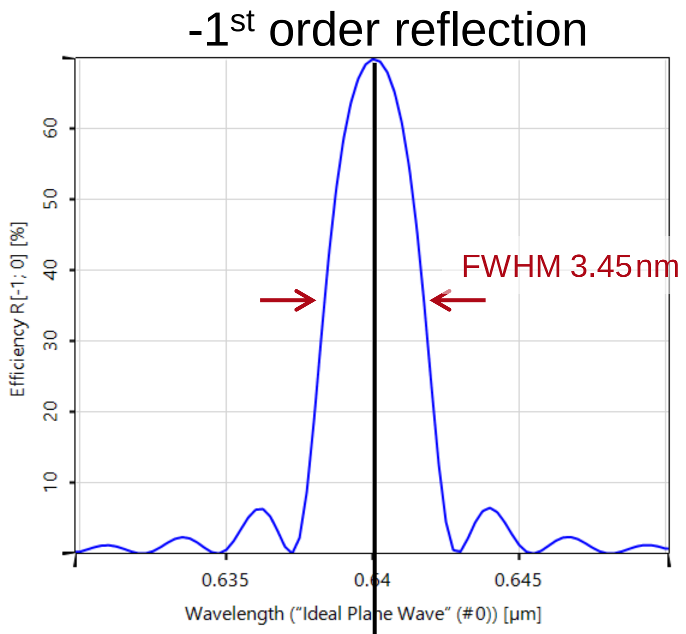
Examples

Modeling Task

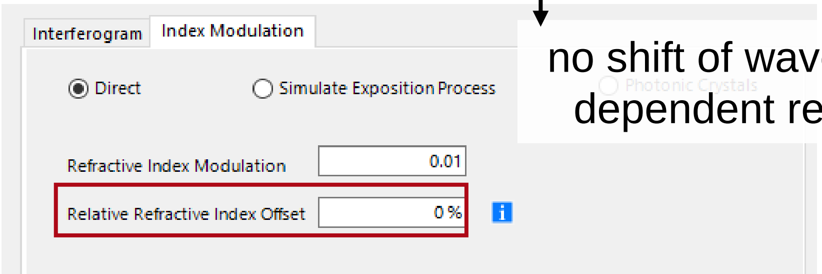


holographic volume grating generated by two-beam interference (640 µm, 59.9° angle) exposure process, with refractive index modulation of 0.01 based on fused silica

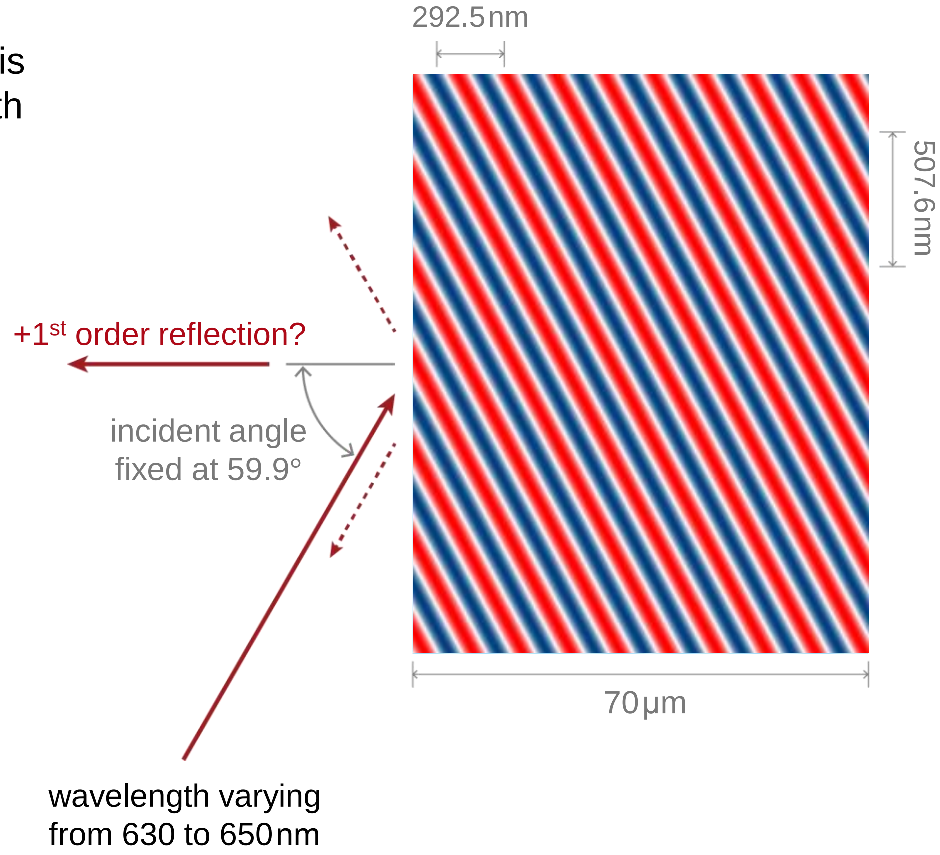
Diffraction Efficiency vs. Wavelength



rigorous FMM analysis
for varying wavelength

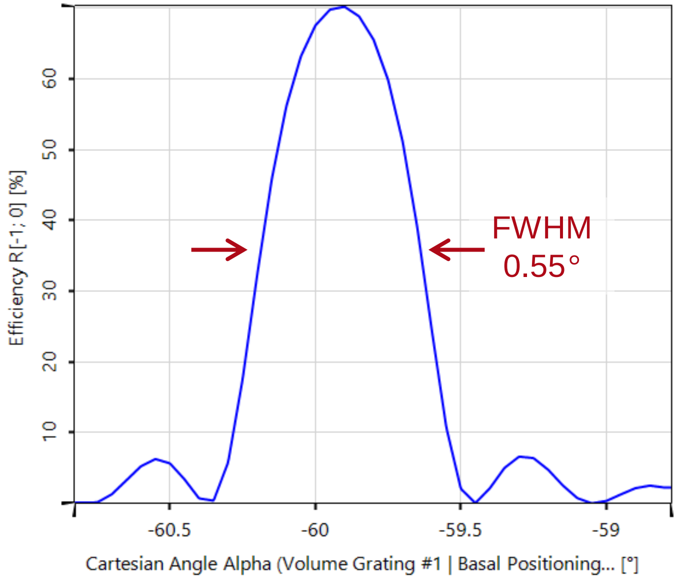


no shift of wavelength
dependent reflection

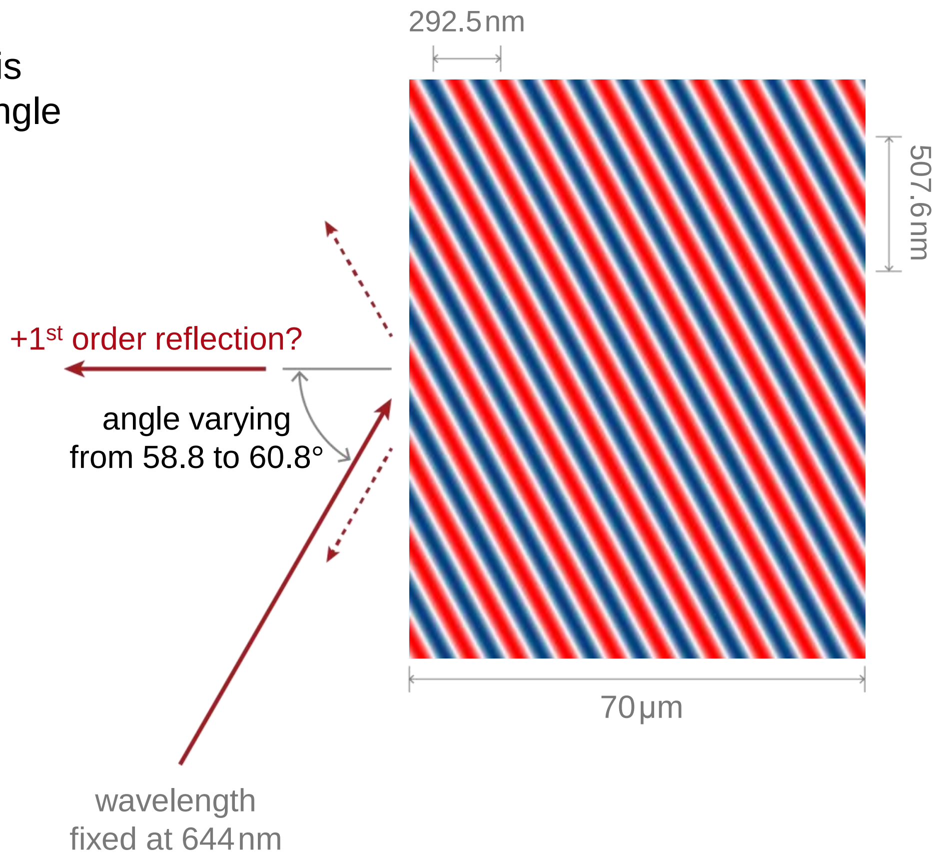


Diffraction Efficiency vs. Angle of Incidence

-1st order reflection



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	- Configuration of Grating Structures by Using Special Media - Grating Order Analyzer - Modeling of Gratings within Optical System - Discussion at Examples