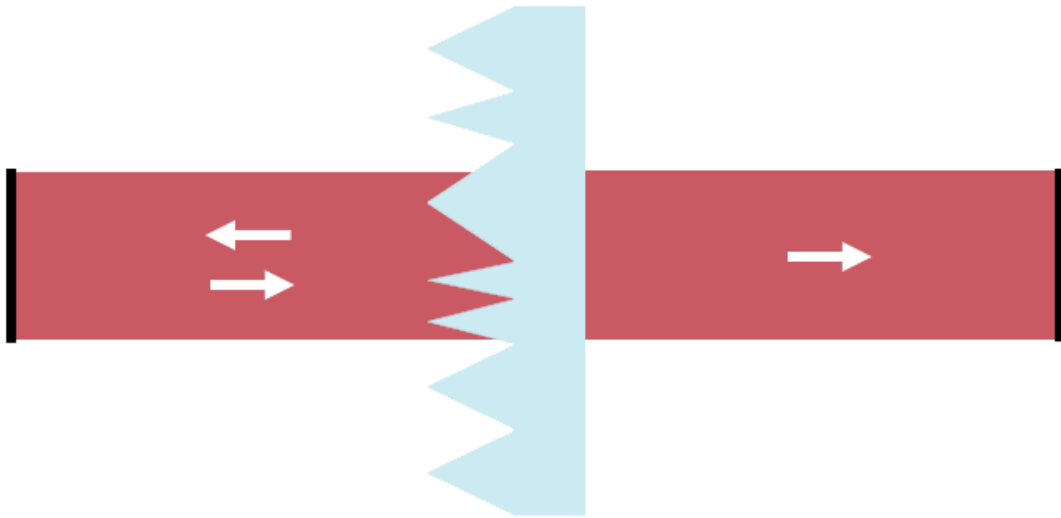


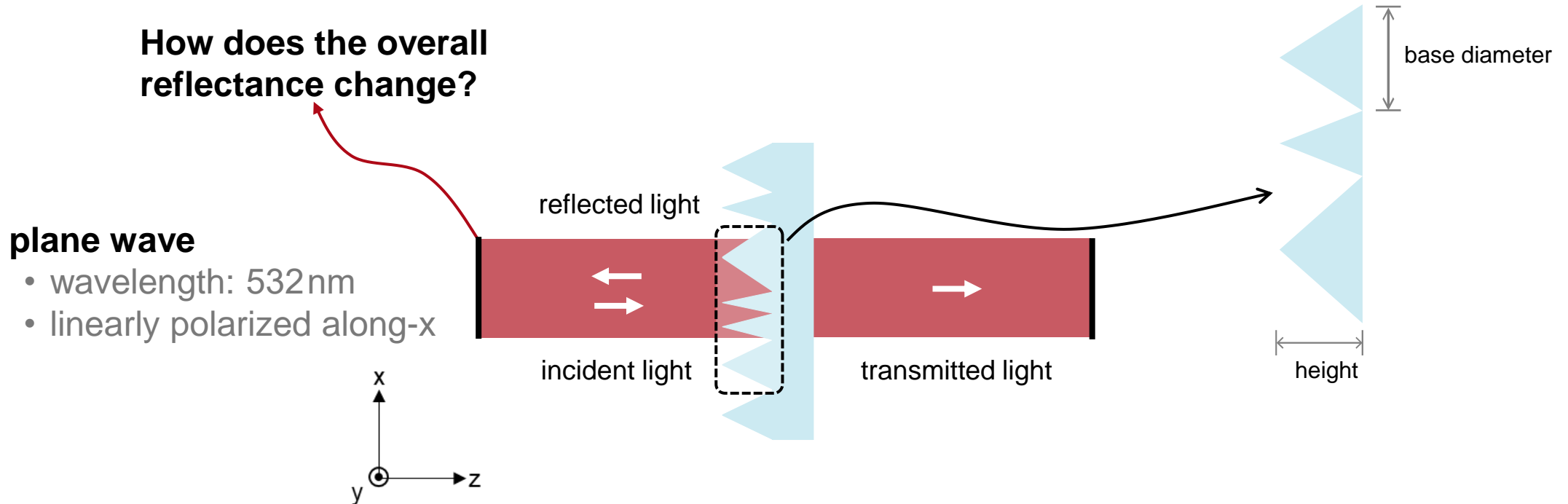
Statistical Anti-reflection Structures (Random Moth-Eye Structures)

Abstract



Minimizing reflection on optical surfaces is of great importance for various optical applications. An intriguing method to mitigate surface reflection involves the employment of nano- and micro-structures designed to counteract reflection, drawing inspiration from natural phenomena such as moth-eye structures. In this use case, we intend to investigate the overall reflection of such a structure by applying tolerance analysis within the framework of VirtualLab Fusion.

Modeling Task



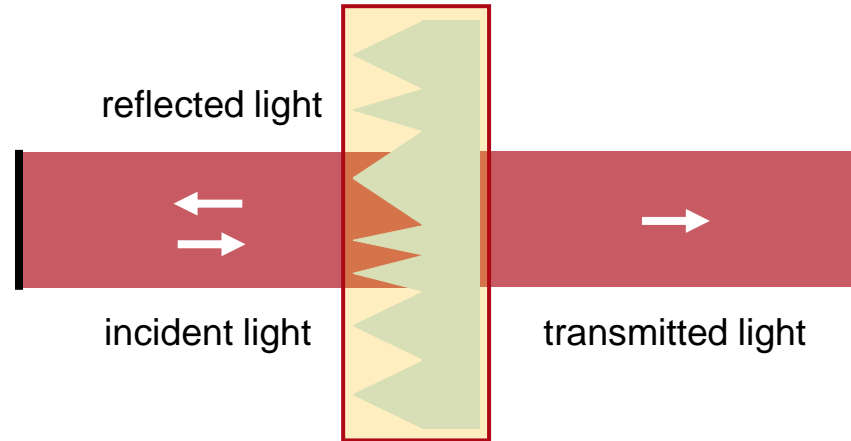
AR moth-eye structure [fixed values]

- base material: fused silica
- base thickness: 1 mm
- surrounding medium: air
- cone base diameter variance: 100 nm

AR moth-eye structure [varying parameters]

- number of cones: (50 – 500)
- cone height: (100 nm – 1 μ m)
- cone base diameter: (50 nm – 500 nm)

Connected Modeling Techniques: Moth-Eye Structure



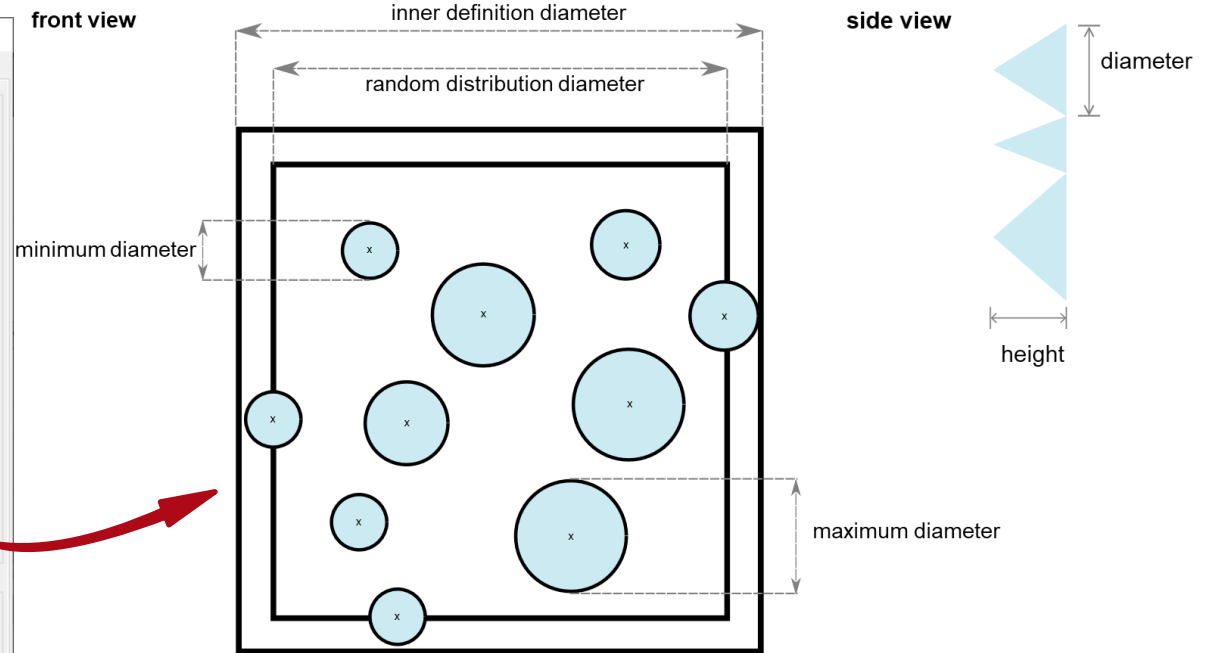
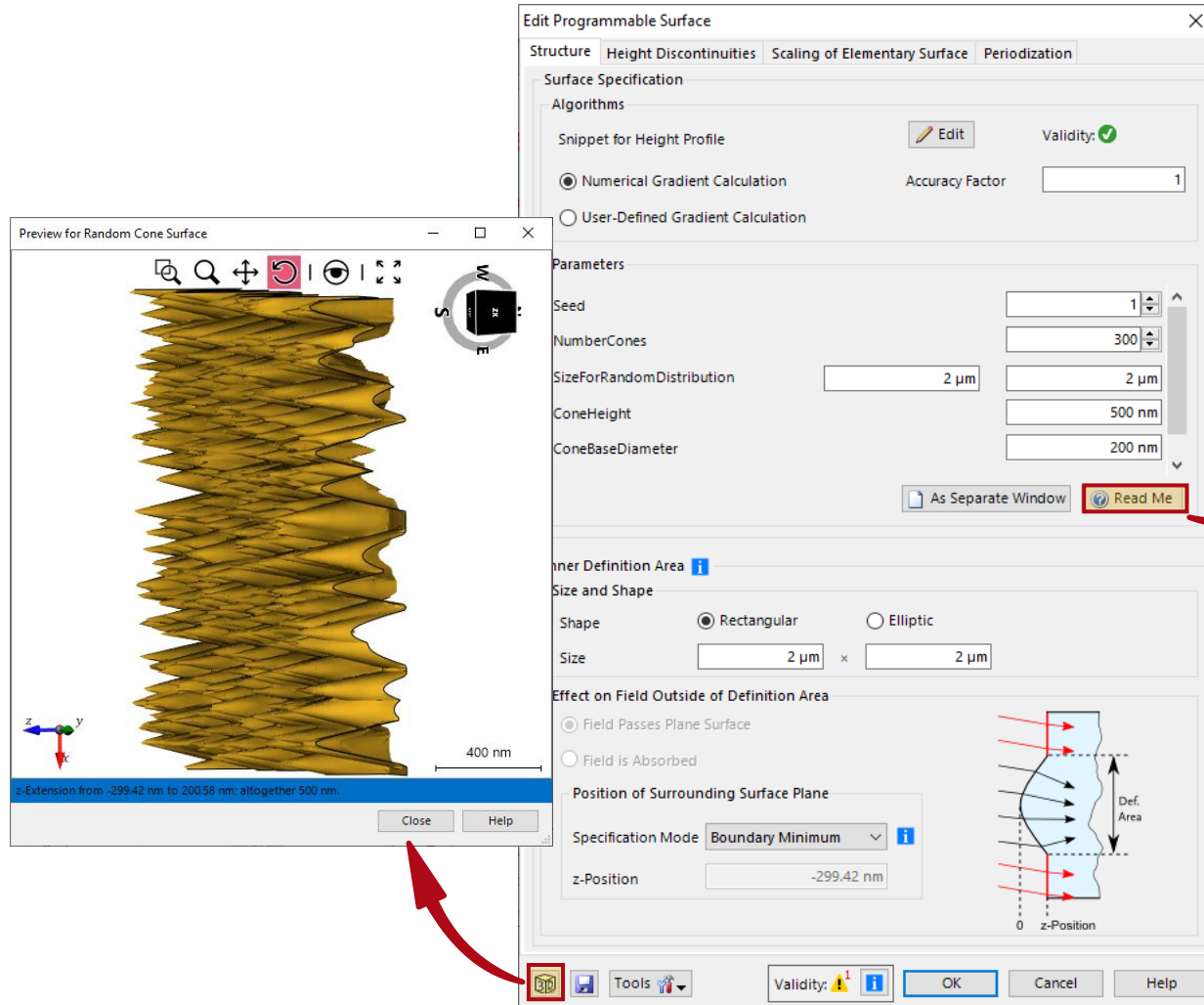
Available modeling techniques for microstructures:

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



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

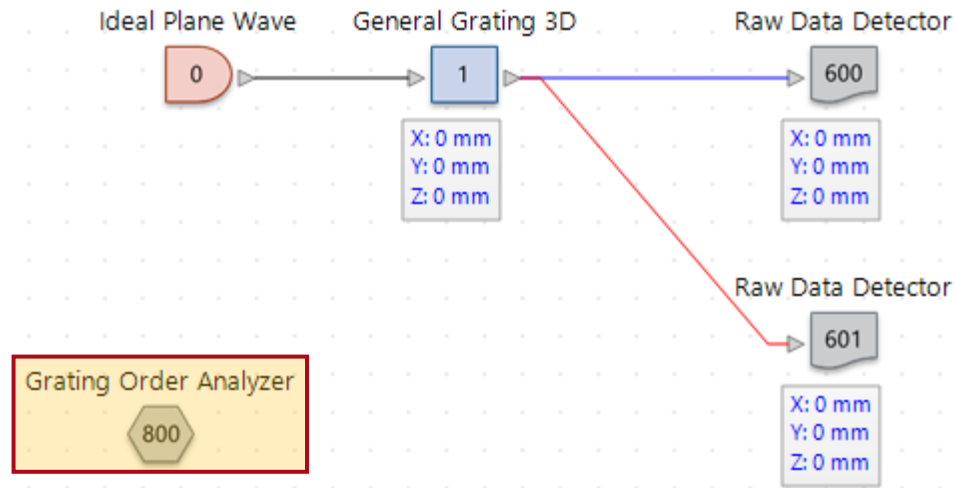
Random Cone Interface



This programmable surface allows to randomly distribute cones with various base diameters. The user can define the number, max. height and size of the cones. Cone base diameter will vary according to:

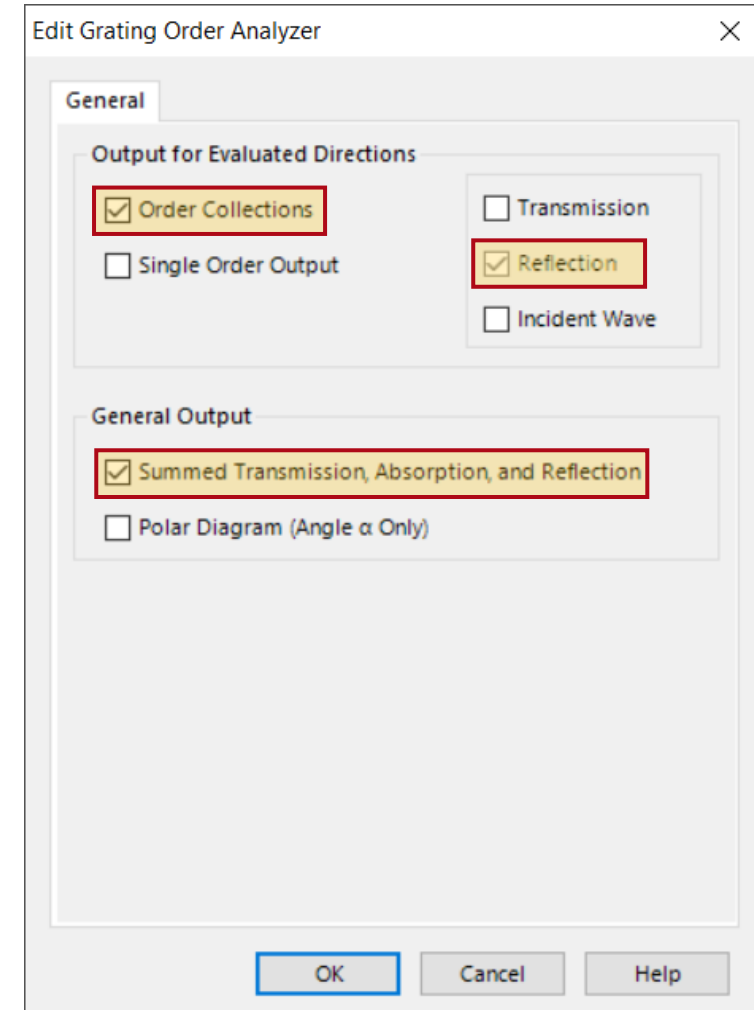
$$\begin{aligned} \text{maximum diameter} &= \text{base diameter} + 0.5 \cdot \text{base diameter variance} \\ \text{minimum diameter} &= \text{base diameter} - 0.5 \cdot \text{base diameter variance} \end{aligned}$$

Grating Order Analyzer

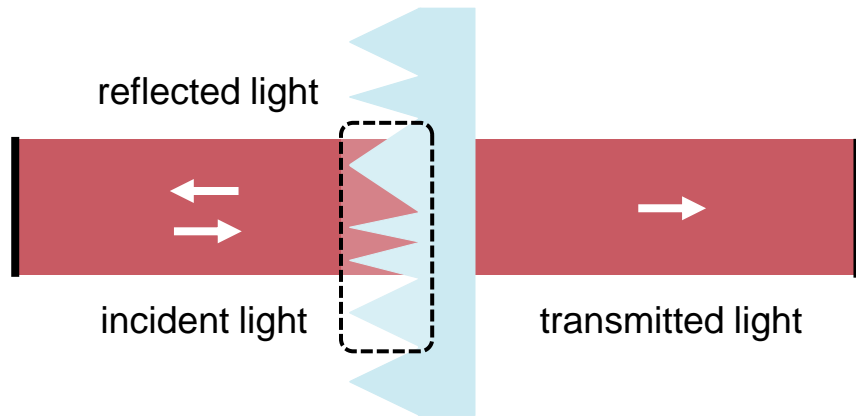


The *Grating Order Analyzer* can be used to investigate the efficiency of the diffraction orders of a given grating. Find more information under:

[Grating Order Analyzer](#)



Parameter Run



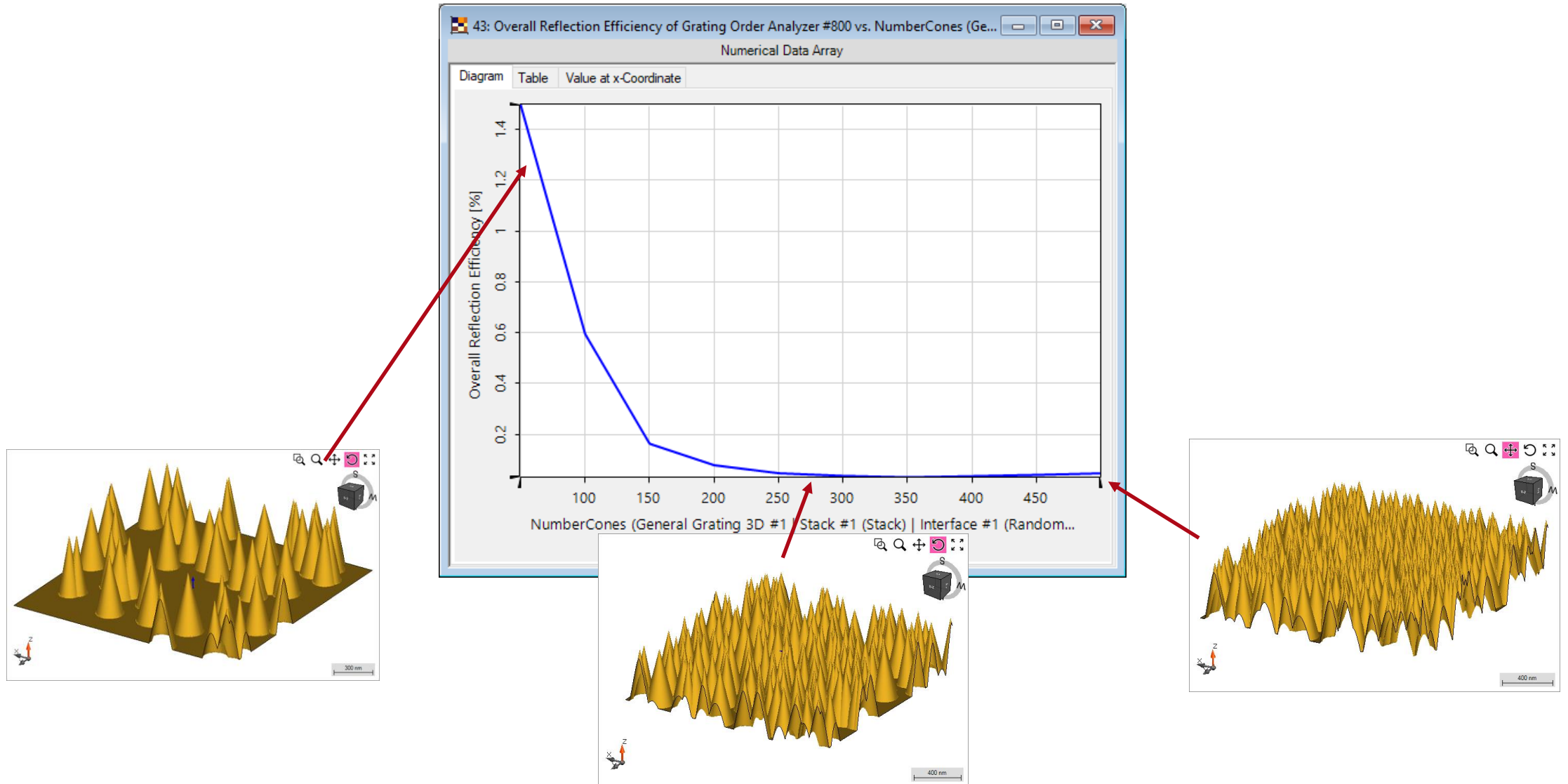
The overall reflectance is evaluated by varying the number of cones, height of cones and base diameter of the cones separately. Such a variation of parameters can be achieved by a *Parameter Run*.

Usage of the Parameter Run Document

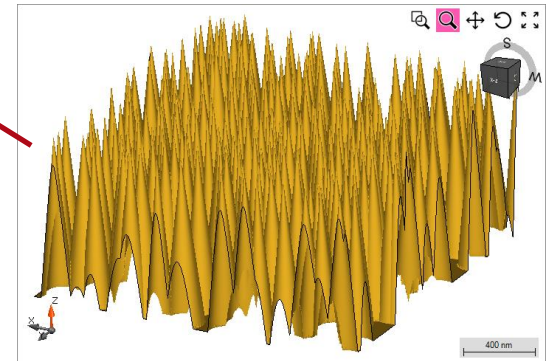
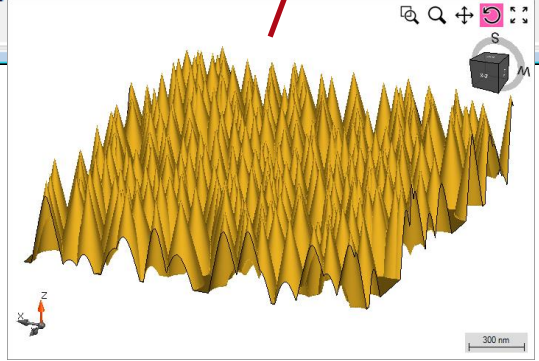
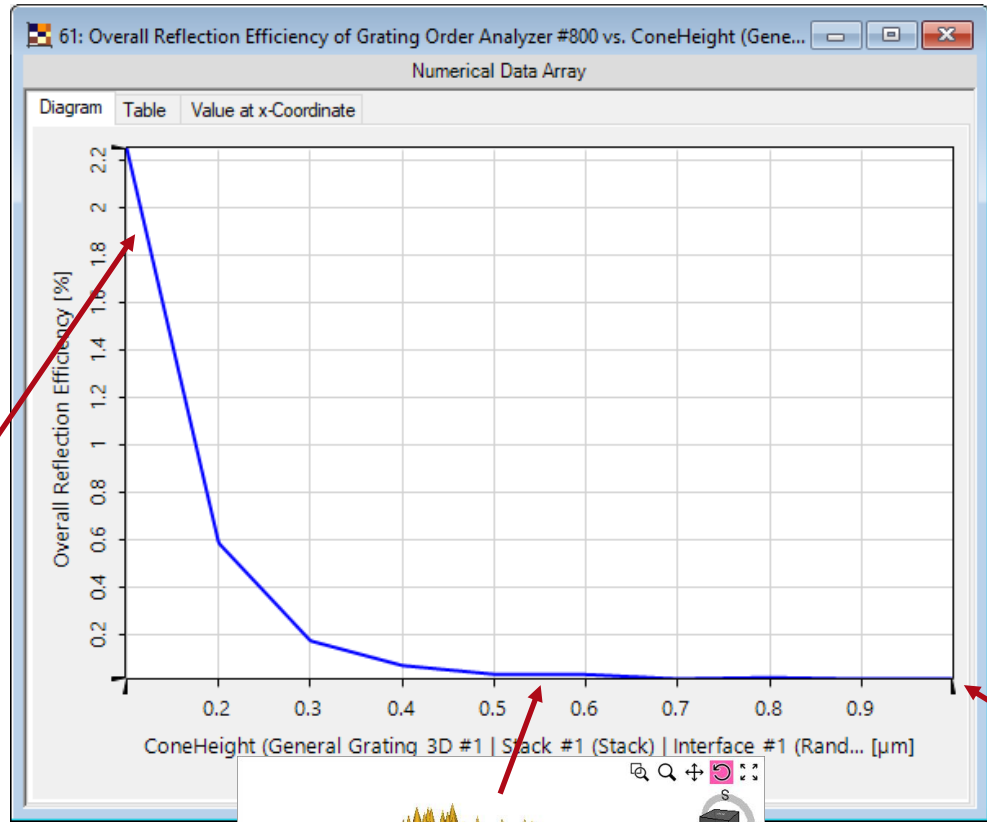
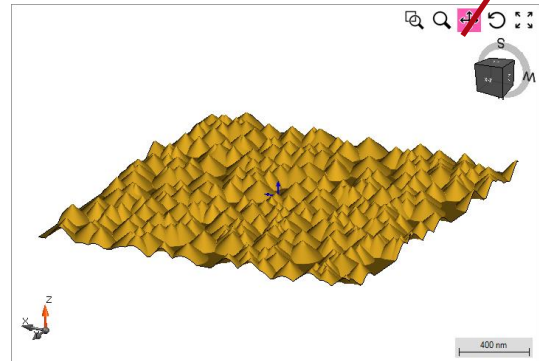
The screenshot shows the '7: Parameter Run' dialog box. The title bar reads '7: Parameter Run'. The main area is titled 'Parameter Specification' and contains the instruction 'Set up the parameter(s) to be varied.' Below this, there is a text block: 'You can select one or more parameters which shall be varied as well as the resulting number of iterations. Several [modes](#) are available specifying how the parameters are varied per iteration.' A 'Usage Mode' dropdown menu is set to 'Standard'. A search filter 'Filter by...' is present, along with a checkbox for 'Show Only Varied Parameters'. A table lists various parameters for a 'General Grating 3D* (#1)' object, categorized under 'Stack #1 (Stack)' and 'Fourier Modal Method'. The table has columns for 'Object', 'Category', 'Parameter', 'Vary', 'From', 'To', 'Steps', 'Step Size', and 'Original Value'. The 'Vary' column contains checkboxes, and the 'From', 'To', 'Steps', and 'Step Size' columns contain numerical values. The row for 'Surface #1 (Ran...)' with 'Vary' checked and values '50', '500', '10', and '50' is highlighted in blue.

1	2	*	Object	Category	Parameter	Vary	From	To	Steps	Step Size	Original Value
			"General Grating 3D* (#1)	Stack #1 (Stack)	Surface #1 (Ran...	<input type="checkbox"/>	1e-300	1e+300	1	1e+300	1
					Surface #1 (Ran...	<input type="checkbox"/>	1 pm	1e+297 km	1	1e+297 km	2 μm
					Surface #1 (Ran...	<input type="checkbox"/>	1 pm	1e+297 km	1	1e+297 km	2 μm
					Surface #1 (Ran...	<input type="checkbox"/>	1 pm	1e+297 km	1	1e+297 km	2 μm
					Surface #1 (Ran...	<input type="checkbox"/>	1 pm	1e+297 km	1	1e+297 km	2 μm
					Surface #1 (Ran...	<input type="checkbox"/>	-1	1000	1	1001	1
					Surface #1 (Ran...	<input checked="" type="checkbox"/>	50	500	10	50	300
					Surface #1 (Ran...	<input type="checkbox"/>	1 nm	1 km	1	1 km	2 μm
					Surface #1 (Ran...	<input type="checkbox"/>	1 nm	1 km	1	1 km	2 μm
					Surface #1 (Ran...	<input type="checkbox"/>	1 nm	1 m	1	1000 mm	500 nm
					Surface #1 (Ran...	<input type="checkbox"/>	1 nm	1 m	1	1000 mm	200 nm
					Surface #1 (Ran...	<input type="checkbox"/>	0 mm	1 m	1	1 m	100 nm
			Fourier Modal Method	Number of Eva...	<input type="checkbox"/>	0	23170	1	23170	10	
				Number of Eva...	<input type="checkbox"/>	0	23170	1	23170	10	

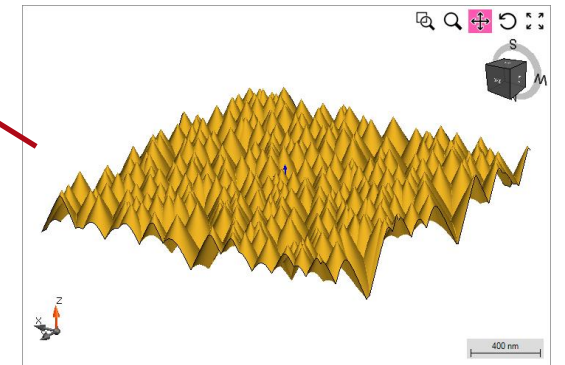
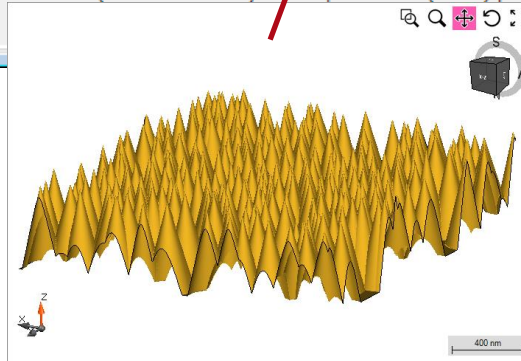
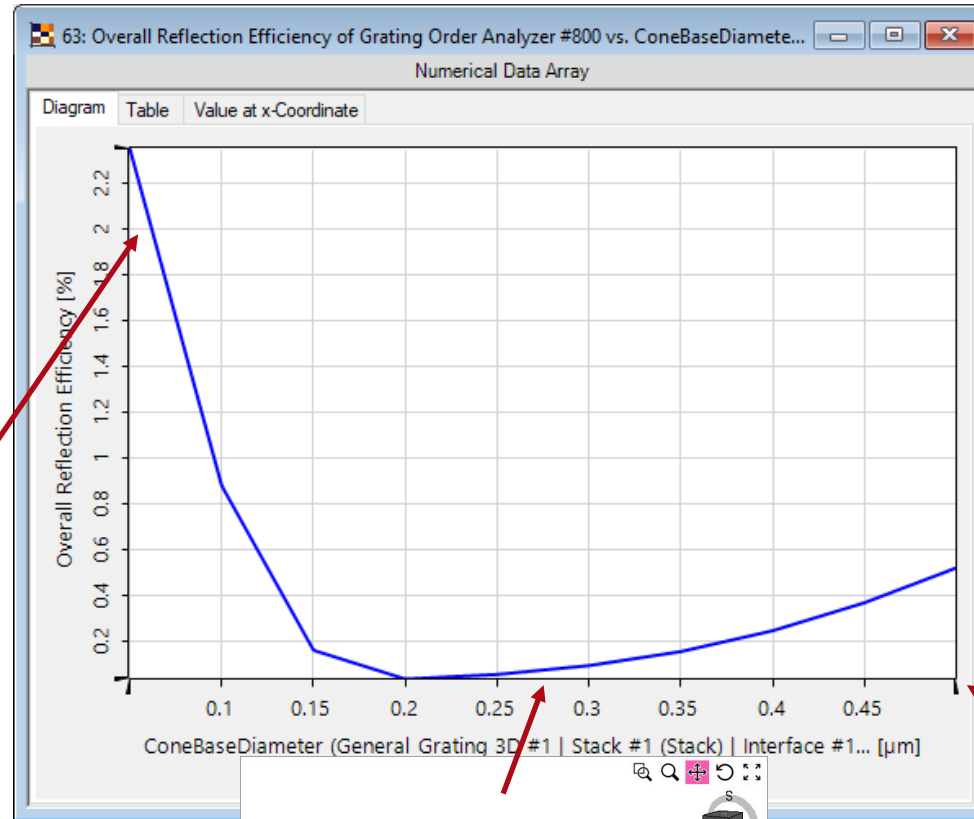
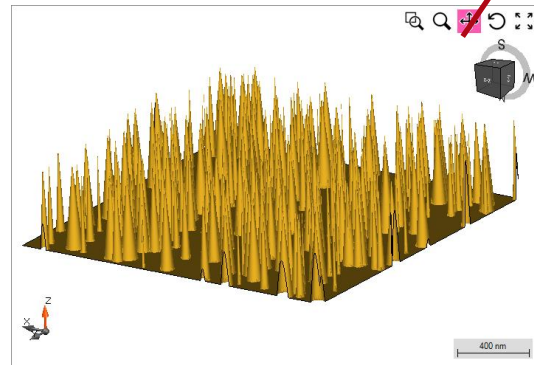
Overall Reflectance vs. Number of Cones



Overall Reflectance vs. Height of Cones



Overall Reflectance vs. Base Diameter of Cones



Document Information

title	Statistical Anti-reflection Structures (Random Moth-Eye Structures)
document code	GRT.0038
document version	1.1
required packages	Grating Package
software version	2023.2 (Build 2.30)
category	Application Use Case
further reading	<ul style="list-style-type: none">• <u>Rigorous Analysis and Design of Anti-Reflective Moth-Eye Structures</u>• <u>Grating Order Analyzer</u>• <u>Usage of the Parameter Run Document</u>