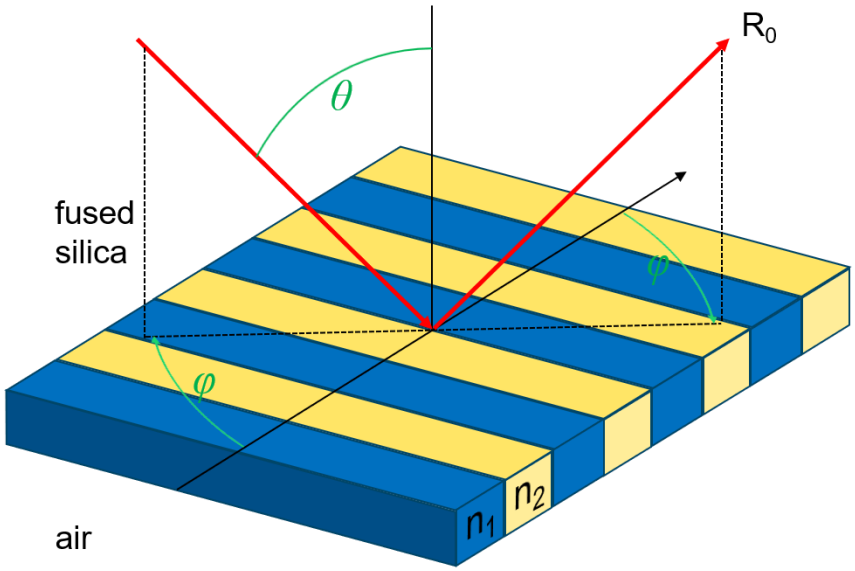
Investigation of Polarization State of Diffraction Orders

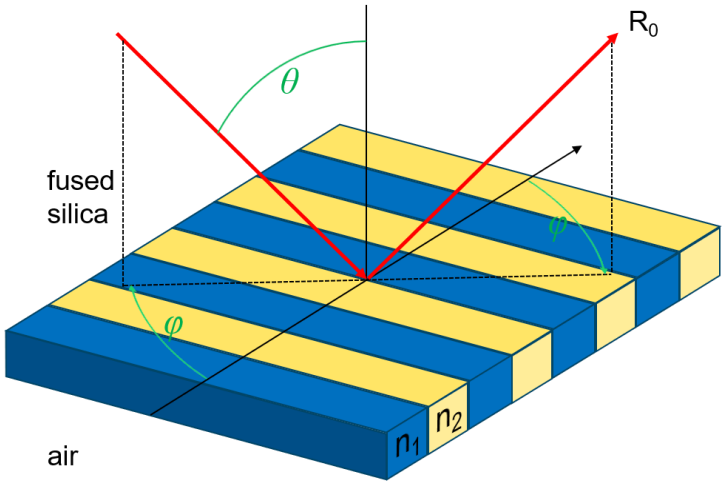
Abstract



Optical grating structures are widely used for several applications such as spectrometers, near-eye display systems, etc. VirtualLab Fusion provides rigorous analysis of arbitrary grating structures in an easy way by applying the Fourier modal method (FMM). In the Grating Toolbox, the periodic structure can be configured by using interfaces or/and media within a stack. The user interface to set up the geometry of a stack is user friendly and allows to generate even more complex gratings easily. In this use case the investigation of the polarization state of the diffracted orders is discussed, which is enabled by the FMM.

Overview

- The topic of this document is the polarization state of light, which was diffracted at a periodic microstructure.
- For this purpose, the reflection of the zeroth order is investigated at an exemplarily binary grating structure and conical incidence, as depicted in the sketch.
- In order to discuss the topic at a particular example, in a second part a grating configuration and the corresponding parameters where chosen according to a work of Passilly *et al*. (2008).



Efficiency & Polarization of Diffraction Orders

- Usually, in order to characterize the performance of an optical grating, the efficiencies (η) of the propagation orders are given.

- This efficiency value is including the energy provided by all the light of this particular order, but does not distinguish between eventually occurring different states of polarization.

- During the rigorous simulation of grating efficiencies, e.g. by using the Fourier modal method, the wave equation for homogeneous media (also called Helmholtz equation) is solved by using complex fields.

- Thus, the result of the algorithm are given as complex values, the Rayleigh coefficients, for each diffraction order (n) and polarization state.

Efficiency & Polarization of Diffraction Orders

- The efficiency of the particular order (n) represents the relation between the power of the incoming light and the amount of light of an outgoing diffraction order. It is calculated from the Rayleigh coefficients.

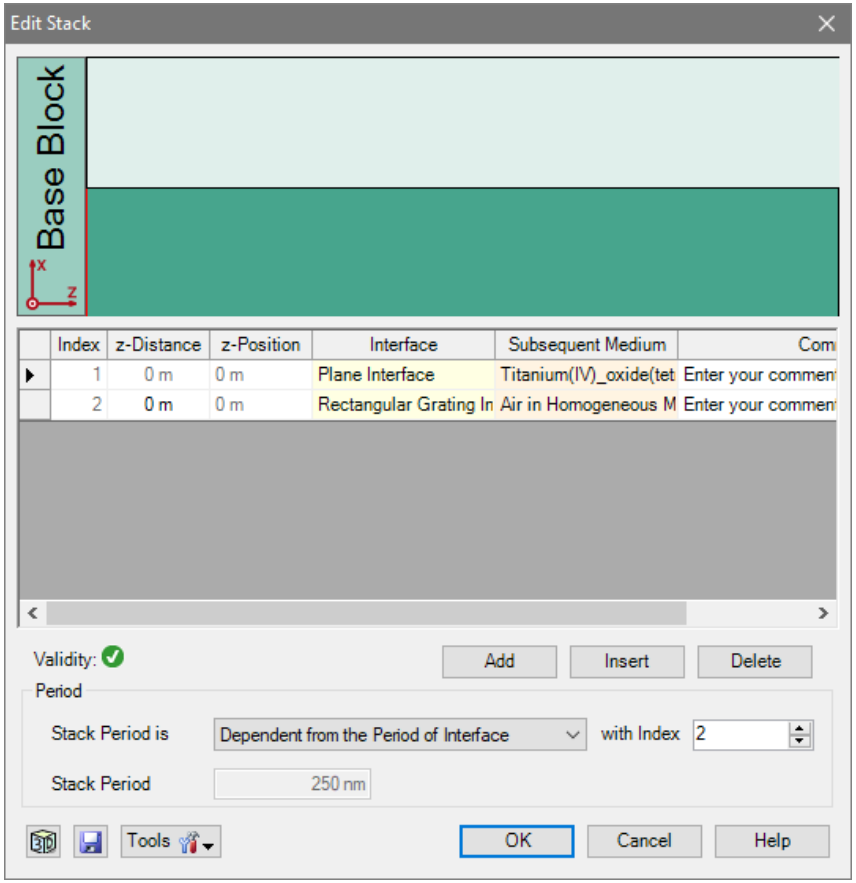
- In case of the Rayleigh coefficients are given in TE/TM, the efficiency can be calculated by $\eta = \left|R_n^{\mathrm{TE}}\right|^2 + \left|R_n^{\mathrm{TM}}\right|^2$ for normalized input.

- If the Rayleigh coefficients are given along x, y and z, the following equation has to be applied: $\eta = \frac{n_{\mathrm{out}}}{A^2 n_{\mathrm{in}} \cos\vartheta_{\mathrm{in}}} \cos\vartheta_{\mathrm{out}} \left[|R_n^x|^2 + \left|R_n^y\right|^2 + |R_n^z|^2\right]$, where n_{in}/ n_{out} are the refractive indices of the superstrate and substrate and ϑ_{in}/ ϑ_{out} the incidence and diffraction angles of the particular order. Further A represents the amplitude of the impinging wave.

- This means the coordinate system (CS) of the provided Rayleigh coefficients has to be regarded. Otherwise it has to be rotated to the appropriate CS. By default R_n^x, R_n^y, R_n^z are provided in the CS of the grating.

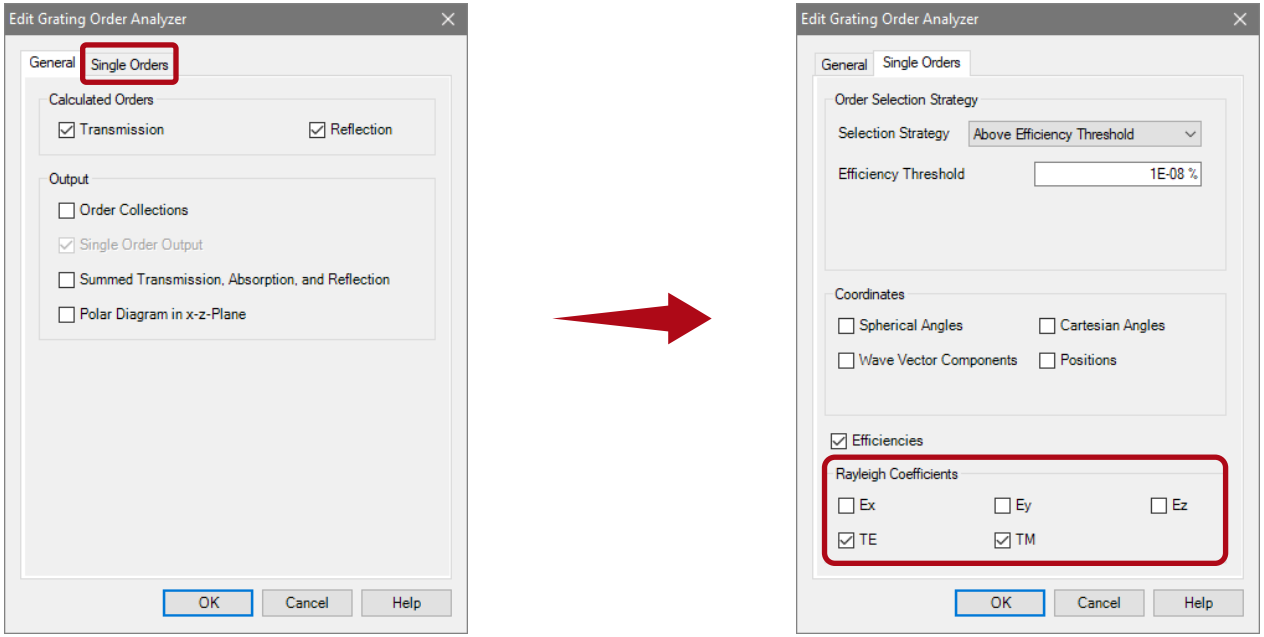
Grating Structure Parameters

- A grating structure with a rectangular shape is investigated.
- For sake of simplicity the configuration of the grating is chosen such, that only the zeroth order in reflection (R_0) is propagating.
- Thus, the following grating parameters are chosen:
  - grating period: 250 nm
  - fill factor: 0.5
  - grating height: 200 nm
  - material n_1: fused silica
  - material n_2: TiO_2 (from catalog)



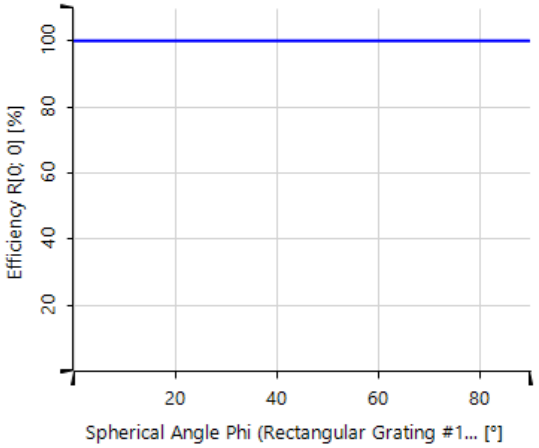
Analysis of Polarization State

- Now, the grating is illuminated with TE-polarized light and a variation of the angle of conical incidence (φ) is applied.
- As mentioned, the squared amplitudes of the Rayleigh coefficients will provide information about the polarization state of the particular order.
- In order to receive the Rayleigh coefficients, please activate the single order output in the grating order analyzer and choose the desired coefficients.

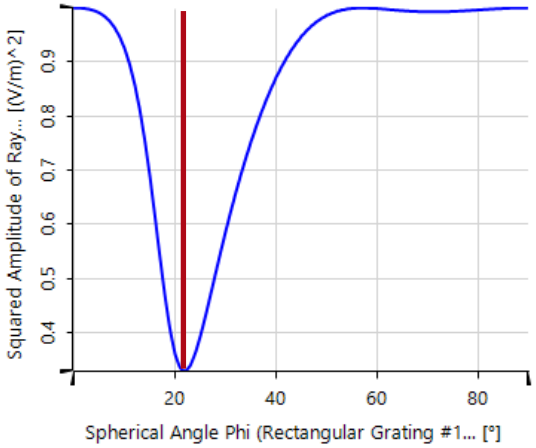


Resulting Polarization States

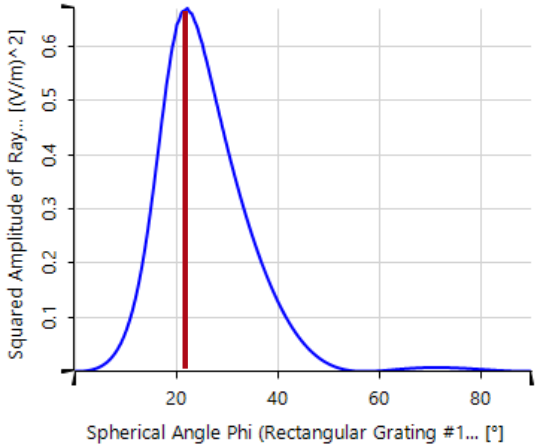
efficiency η



$\left|R_0^{\mathrm{TE}}\right|^2$



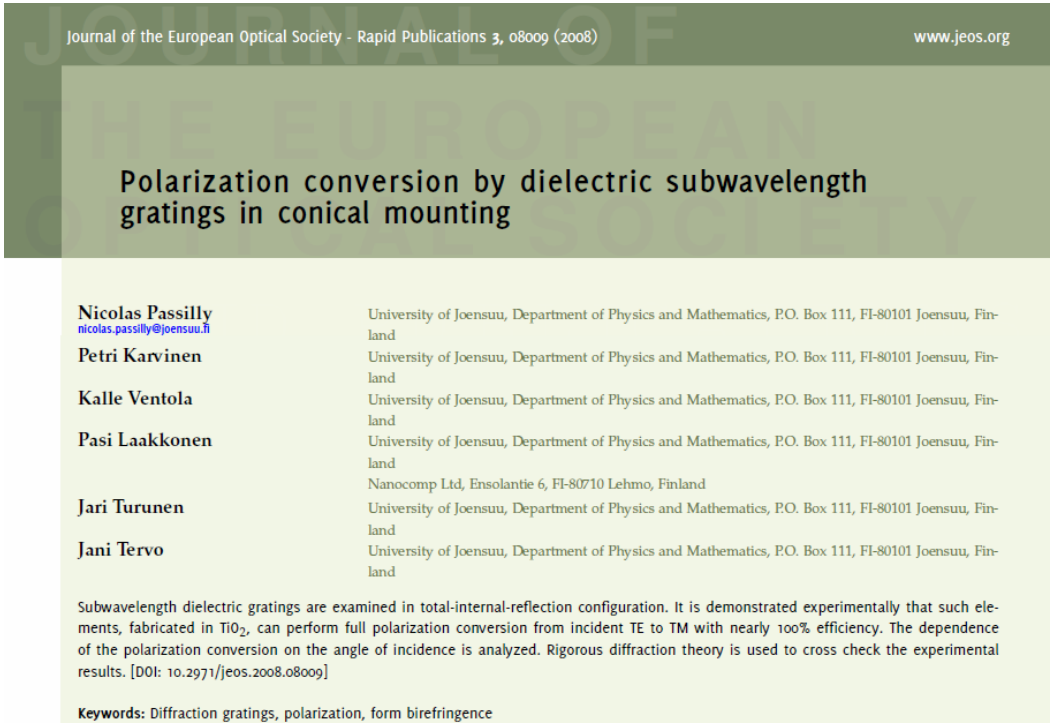
$\left|R_0^{\mathrm{TM}}\right|^2$



- The efficiency of the reflected zeroth order is 100% (left figure).
- The Rayleigh coefficients now disclose the polarization information:
  - In case of non-conical incidence (φ = 0), $\left|R_0^{\mathrm{TE}}\right|^2$ is 1 (V/m)², whereas $\left|R_0^{\mathrm{TM}}\right|^2$ is 0. This means the diffracted light is TE-polarized, entirely.
  - For φ = 22° there is a minimum of $\left|R_0^{\mathrm{TE}}\right|^2$ yielding a value of 0.33 (V/m)² and a maximum of $\left|R_0^{\mathrm{TM}}\right|^2$ with 0.67 (V/m)². In this case, 67% of the light are TM polarized.
  - For φ > 50° the coefficients are almost constant, and thus the polarization as well.

Further Example

- In the work by Passilly *et al*. the polarization state of light diffracted at a subwavelength grating was investigated and optimized in order to receive a high conversion between different states.
- Thus they compared simulated results with measurement data of fabricated sample.



Journal of the European Optical Society - Rapid Publications 3, 08009 (2008) www.jeos.org

Polarization conversion by dielectric subwavelength gratings in conical mounting

Nicolas Passilly
nicolas.passilly@joensuu.fi
University of Joensuu, Department of Physics and Mathematics, P.O. Box 111, FI-80101 Joensuu, Finland

Petri Karvinen
University of Joensuu, Department of Physics and Mathematics, P.O. Box 111, FI-80101 Joensuu, Finland

Kalle Ventola
University of Joensuu, Department of Physics and Mathematics, P.O. Box 111, FI-80101 Joensuu, Finland

Pasi Laakkonen
University of Joensuu, Department of Physics and Mathematics, P.O. Box 111, FI-80101 Joensuu, Finland
Nanocomp Ltd, Ensolantie 6, FI-80710 Lehmo, Finland

Jari Turunen
University of Joensuu, Department of Physics and Mathematics, P.O. Box 111, FI-80101 Joensuu, Finland

Jani Tervo
University of Joensuu, Department of Physics and Mathematics, P.O. Box 111, FI-80101 Joensuu, Finland

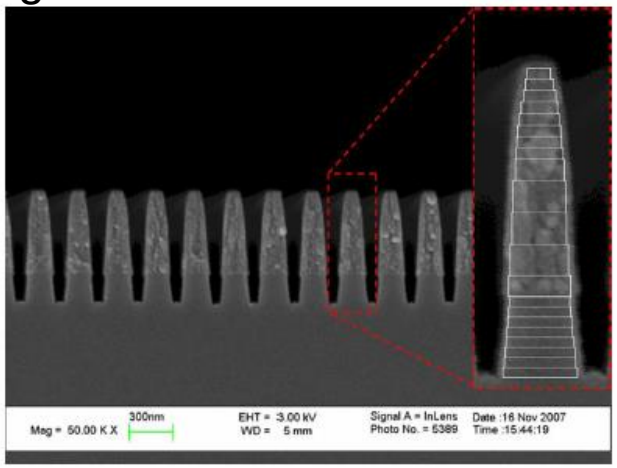
Subwavelength dielectric gratings are examined in total-internal-reflection configuration. It is demonstrated experimentally that such elements, fabricated in TiO_2, can perform full polarization conversion from incident TE to TM with nearly 100% efficiency. The dependence of the polarization conversion on the angle of incidence is analyzed. Rigorous diffraction theory is used to cross check the experimental results. [DOI: 10.2971/jeos.2008.08009]

Keywords: Diffraction gratings, polarization, form birefringence

Grating Structure Parameters

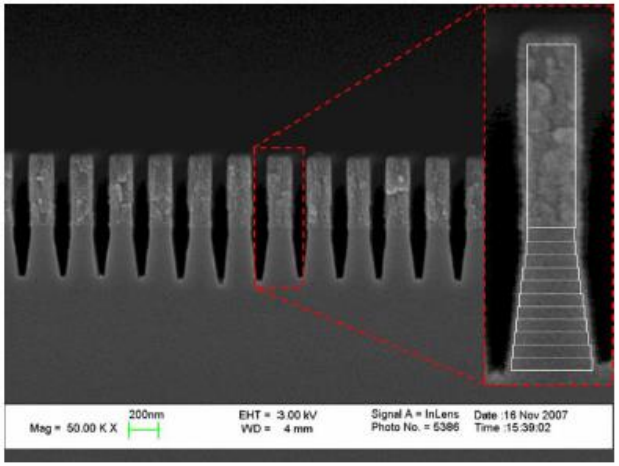
- In the cited work, two different fabricated grating structured were investigated.
- Caused by the applied fabrication strategy, the structures exhibit some deviations compared to the desired binary shape.: under-etching in the substrate and deviating shapes of ridges.
- Due to missing details about the fabricated structure, it is simplified for the realization in VirtualLab.
- Nevertheless, if the data is available, the complex shape of the grating could be analyzed in detail.

Grating #1:



Passilly *et al*. (2008)

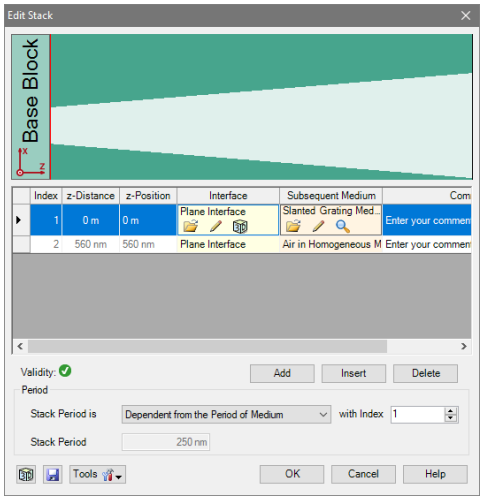
Grating #2:



Passilly *et al*. (2008)

Grating #1

- Just the grating is regarded.
- The sidewalls are assumed to exhibit a linear slope.
- The under-etched part in the substrate is neglected.
- In order to realize the trapezoidal shape of the grating ridges, the slanted grating medium was applied.



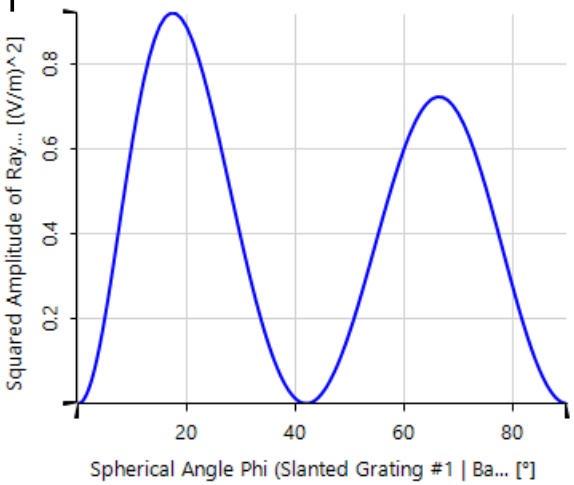
assumed grating parameters:

- grating period: 250 nm
- grating height: 660 nm
- fill factor: 0.75 (bottom)
- angles of sidewalls: ±6°
- n_1: 1.46
- n_2: 2.08

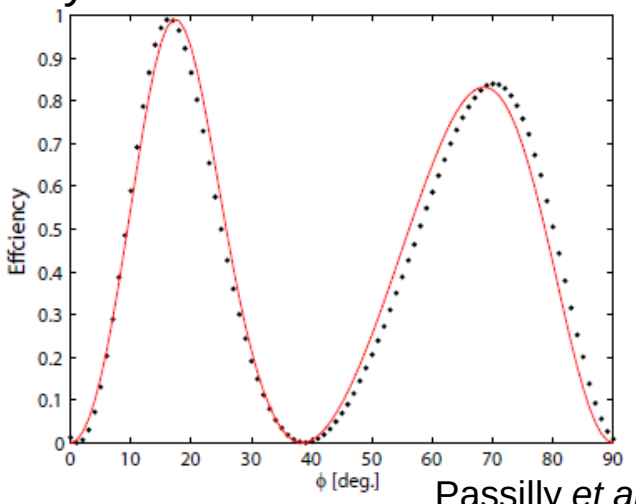
Grating #1 Results

- The figure on the left exhibits the results obtained by using VirtualLab, whereas the result published by Passilly *et al*. is shown on the right.
- In comparison, both figures exhibit a very good match, especially the course of the graph.
- There are some small deviations, caused by the simplification of the grating structure compared to the reference. The simplifications were necessary due to the lack of data of the complex grating structure.

$\left|R_0^{\mathrm{TM}}\right|^2$



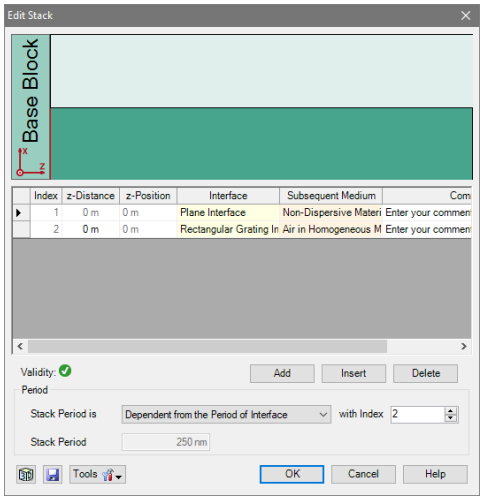
efficiency of TM:



Passilly *et al*. (2008)

Grating #2

- Again, just the grating is regarded.
- The grating is to be assumed to have a rectangular shape.
- The under-etched part in the substrate is neglected.



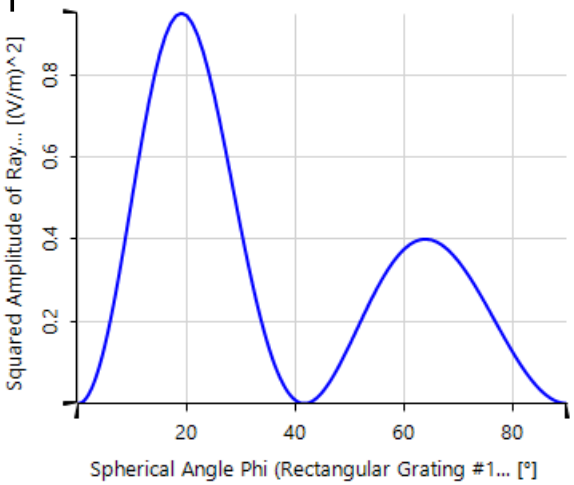
assumed grating parameters:

- grating period: 250 nm
- grating height: 490 nm
- fill factor: 0.5
- n_1: 1.46
- n_2: 2.08

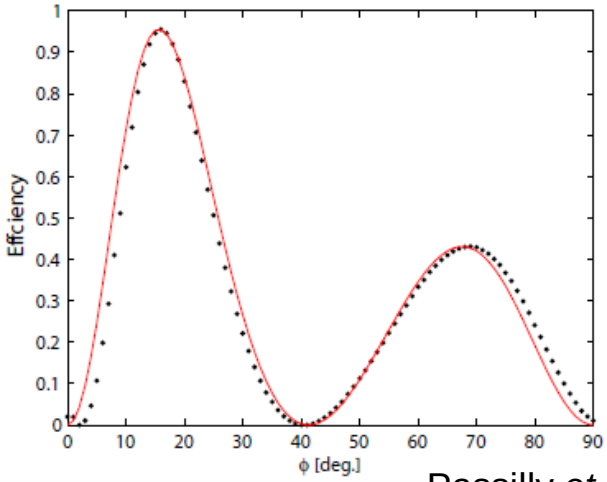
Grating #2 Results

- Again, figure on the left exhibits the results obtained by using VirtualLab, the result published by Passilly *et al*. is shown on the right.
- In comparison, both figures show again a very good match, especially the course of the graph.
- There are some small deviations, caused by the simplification of the grating structure compared to the reference and the lack of some grating parameters.

$\left|R_0^{\mathrm{TM}}\right|^2$



efficiency of TM:



Passilly *et al*. (2008)

Document Information

title	Investigation of Polarization State of Diffraction Orders
version	1.0
VL version used for simulations	7.3.0.50
category	Feature Use Case