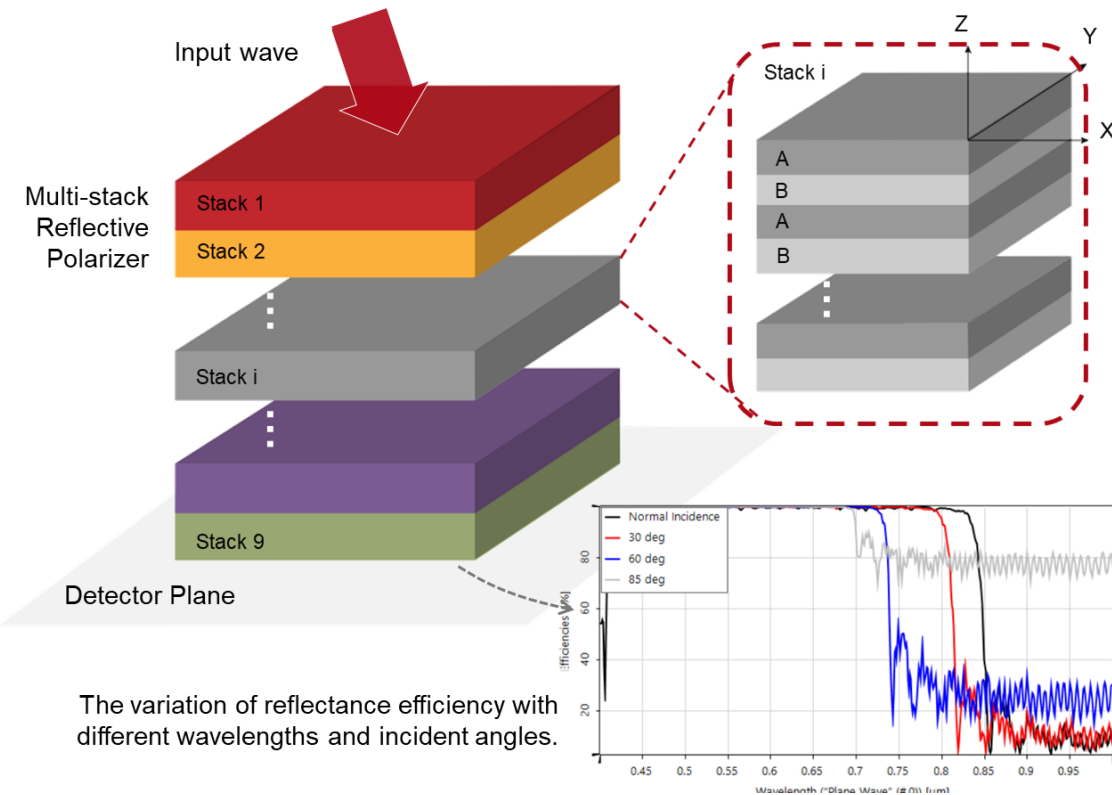


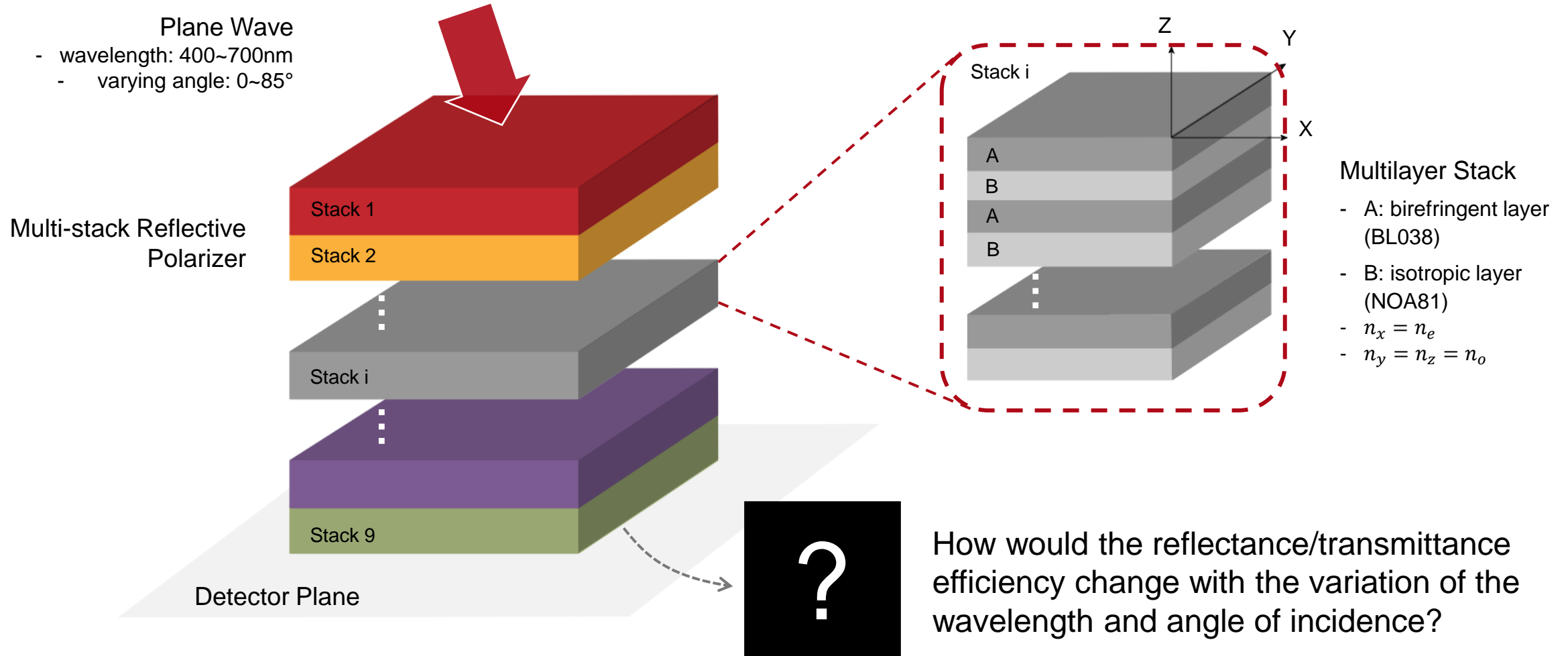
# **Simulation of Multilayer Birefringent Reflective Polarizer with VirtualLab Fusion**

# Abstract

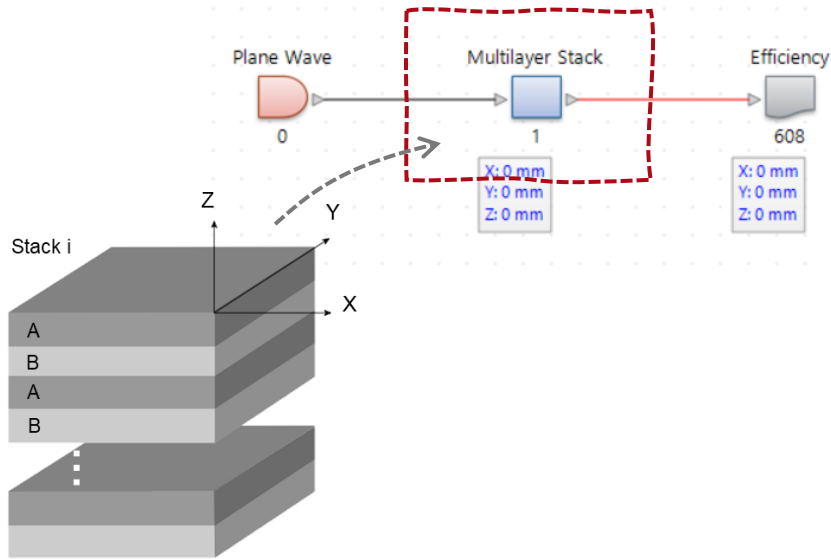


Multilayer birefringent reflective polarizers have big advantages in liquid crystal display (LCD) applications. They can recycle the backlight so as to improve the optical efficiency of LCDs. In this use case, we reproduce the experiments in Li et. al. J. Display Technol. 5, 335-340 (2009) to explore the relationship between the number of alternate birefringent layers and the Bragg reflection condition in VirtualLab Fusion. Then the variation of the reflectance efficiency with different wavelengths and incident angles is further investigated.

# Task Description



# Modeling of the Multilayer Stack



A Stratified Media Component is used to model the multilayer stack.

Component Size: 20 mm × 20 mm

Reference Surface (all Channels): Plane Surface

Aperture:  Yes  No

Coating Name: Anisotropic Layer Stack

Coating Orientation: Front Side Application

Homogeneous Medium Behind Surface: NOA81 in Homogeneous Medium

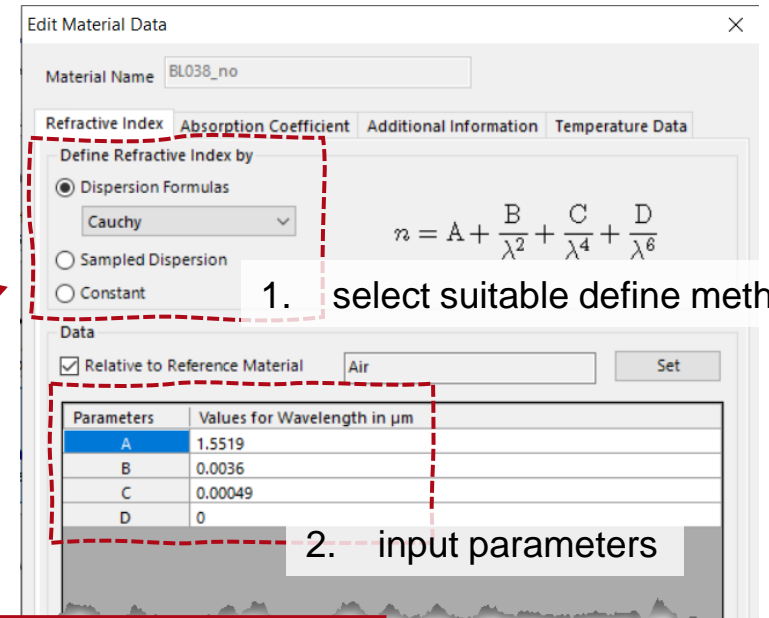
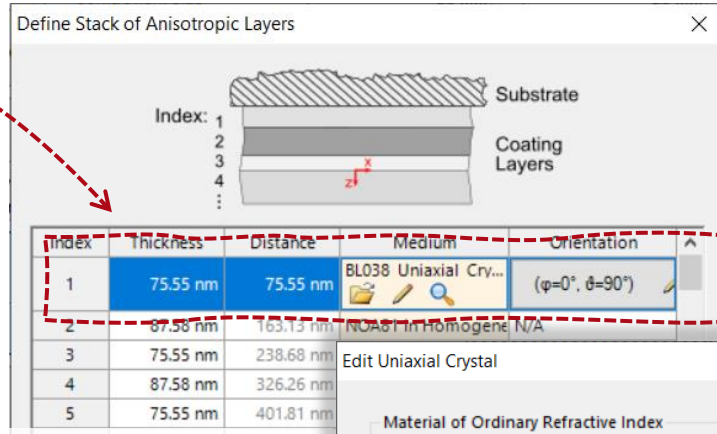
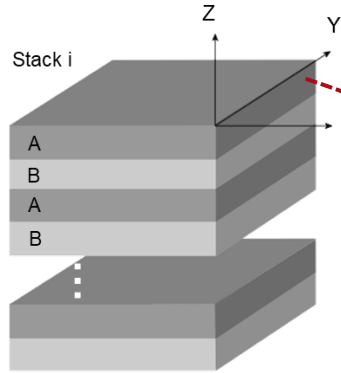
Define Stack of Anisotropic Layers

Index	Thickness	Distance	Medium	Orientation
1	75.55 nm	75.55 nm	BL038_Uniaxial_Cryst	( $\phi=0^\circ, \theta=90^\circ$ )
2	87.58 nm	163.13 nm	NOA81 in Homogene	N/A
3	75.55 nm	238.68 nm	BL038_Uniaxial_Cryst	( $\phi=0^\circ, \theta=90^\circ$ )
4	87.58 nm	326.26 nm	NOA81 in Homogene	N/A
5	75.55 nm	401.81 nm	BL038_Uniaxial_Cryst	( $\phi=0^\circ, \theta=90^\circ$ )
6	87.58 nm	489.39 nm	NOA81 in Homogene	N/A
7	75.55 nm	564.94 nm	BL038_Uniaxial_Cryst	( $\phi=0^\circ, \theta=90^\circ$ )
8	87.58 nm	652.52 nm	NOA81 in Homogene	N/A

Wavelength Range of Materials: Minimum Wavelength: 400.1111667 nm, Maximum Wavelength: 1.000269477  $\mu$ m

Select *Anisotropic Layer Stack* from the *Template* catalog and use the tool tabs to edit the layers.

# Layer A: Birefringent Uniaxial Layers (BL038)



## Layer A: birefringent uniaxial layer (BL038)

- Layer thickness: 75.55nm
- Ordinary refractive index

$$n_o = n_y = n_z$$

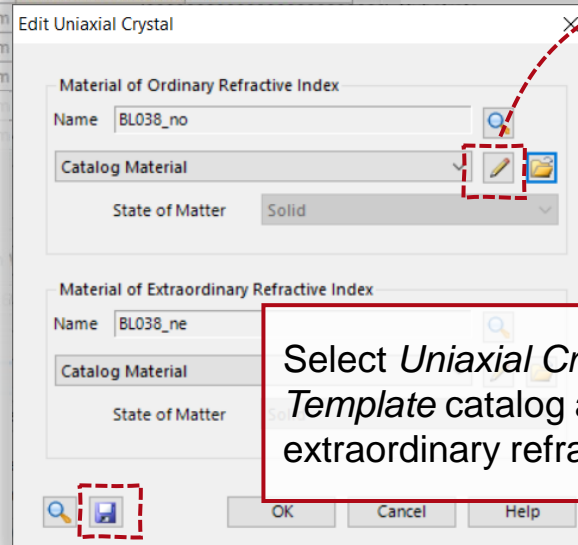
- Extraordinary refractive index

$$n_e = n_x$$

- According to the extended Cauchy model:

$$n_{o,e} = A_{o,e} + \frac{B_{o,e}}{\lambda^2} + \frac{C_{o,e}}{\lambda^4}$$

and  $A_o = 1.5519$ ,  $B_o = 0.0036\mu\text{m}^2$ ,  $C_o = 0.00049\mu\text{m}^4$ ;  
 $A_e = 1.74775$ ,  $B_e = 0.01184\mu\text{m}^2$ ,  $C_o = 0.00303\mu\text{m}^4$

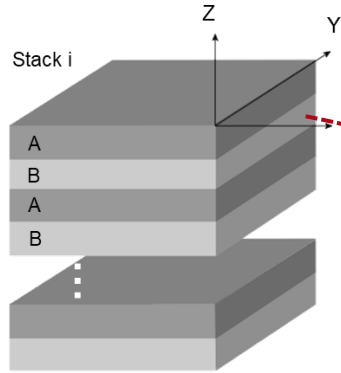


Select *Uniaxial Crystal* media from the *Template* catalog and define the ordinary and extraordinary refractive indices, respectively.

Tips: after configuring the material, use the Save tab to save the new material to the *User Defined* material catalog and load it easily for the next simulation.

Parameters follow from Li et. al. J. Display Technol. 5, 335-340 (2009)

# Layer B: Isotropic Layers (NOA81)



Define Stack of Anisotropic Layers

Index	Thickness	Distance	Medium	Orientation
1	75.55 nm	75.55 nm	BL038 Uniaxial Cryst. ( $\phi=0^\circ, \theta=90^\circ$ )	
2	87.58 nm	163.13 nm	NOA81 in Homoge...	N/A
3	75.55 nm	150.66 nm	BL038 Uniaxial Cryst. ( $\phi=0^\circ, \theta=90^\circ$ )	
4	87.58 nm	326.26 nm		
5	75.55 nm	401.81 nm		
6	87.58 nm	489.39 nm		
7	75.55 nm	564.94 nm		

Edit Homogeneous Medium

Material Name: NOA81

Catalog Material: [selected]

State of Matter: Solid

Edit Material Data

Material Name: NOA81

Refractive Index | Absorption Coefficient | Additional Information | Temperature Data

Define Refractive Index by:

- Dispersion Formulas
  - Cauchy
- Sampled Dispersion
- Constant

$$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \frac{D}{\lambda^6}$$

1. select suitable define method

Data

Relative to Reference Material: Air

Parameters	Values for Wavelength in $\mu\text{m}$
A	1.5519
B	0.0036
C	0.00049
D	0

2. input parameters

## Layer B: isotropic layer (NOA81)

- Layer thickness: 87.58nm
- Refractive index

$$n = n_o = n_y = n_z$$

- According to the extended Cauchy model:

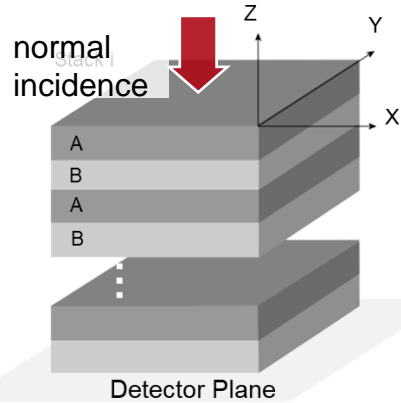
$$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$$

and  $A = 1.5519$ ,  $B = 0.0036\mu\text{m}^2$ ,  $C = 0.00049\mu\text{m}^4$ .

Select *Homogeneous* medium from the catalog and define the refractive index according to the Cauchy formula. Here, the designated isotropic material's refractive index is the same as the uniaxial material's ordinary refractive index.

Parameters follow from Li et. al. J. Display Technol. 5, 335-340 (2009)

# Number of Periodic Layers to Establish Bragg Condition



- When the unpolarized plane wave hits the reflective polarizer, one direction of linear polarized light will pass through while the other component will be reflected back and depolarized, then it will be reflected again for another cycle. After several cycles, more and more light will be able to pass through the polarizer and therefore the energy efficiency is enhanced.
- In order to achieve the highest possible efficiency, the aim is to fulfill the Bragg reflection condition. Therefore, a minimum number of periodic layers is required. We used a *Parameter Run* to scan the wavelength range and calculate the efficiency with 20 layers, 50 layers, and 100 layers respectively.

Define Stack of Anisotropic Layers

Index	Thickness	Distance	Medium
1	75.55 nm	75.55 nm	BL038_Uniaxial_Cryst
2	87.58 nm	163.13 nm	NOA81 in Homogene N/A
3	75.55 nm	238.68 nm	BL038_Uniaxial_Cryst
4	87.58 nm	326.26 nm	NOA81 in Homogene N/A
5	75.55 nm	401.81 nm	BL038_Uniaxial_Cryst
6	87.58 nm	489.39 nm	NOA81 in Homogene N/A

Configure Layer Sequence Replication

Layer Sequence

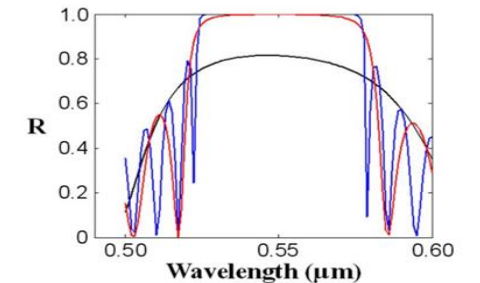
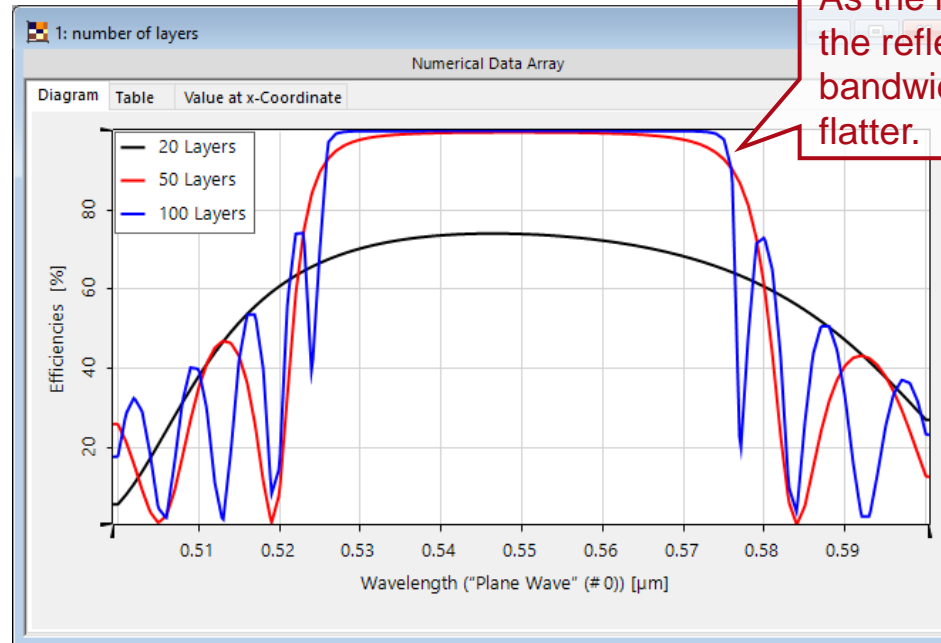
Index of First Layer: 1

Index of Last Layer: 2

No. of Replications: 10

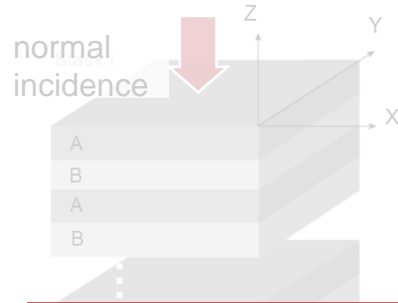
Append Repeated Layer Sequence

layer 1 and layer 2 repeated 10 times, i.e., 20 layers are used overall.



simulation result compare with Li et. al. J. Display Technol. 5, 335-340 (2009)

# Number of Periodic Layers to Establish Bragg Condition



- When the unpolarized plane wave hits the reflective polarizer, one direction of linear polarized light will pass through while the other component will be reflected back and depolarized, then it will be reflected again for another cycle. After several cycles, more and more light will be able to pass through the polarizer and therefore the energy efficiency is enhanced.
- In order to achieve the highest efficiency, the Bragg reflection condition is aimed to establish here. Therefore, a minimum number of periodic layers is required. We used *Parameter Run* to scan within the wavelength range and calculate the efficiency with 20 layers, 50 layers, and 100 layers respectively.

Considering the material cost and fabrication complexity will also increase with more layers, a minimum of 50 layers can be used to achieve acceptable reflectivity and bandwidth.  
- Li2009

Define Stack

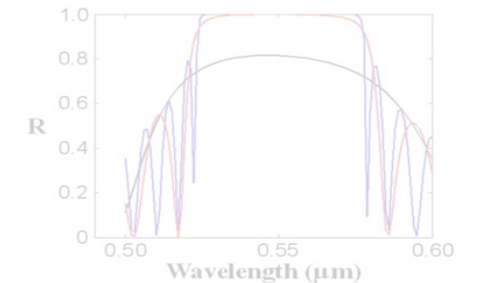
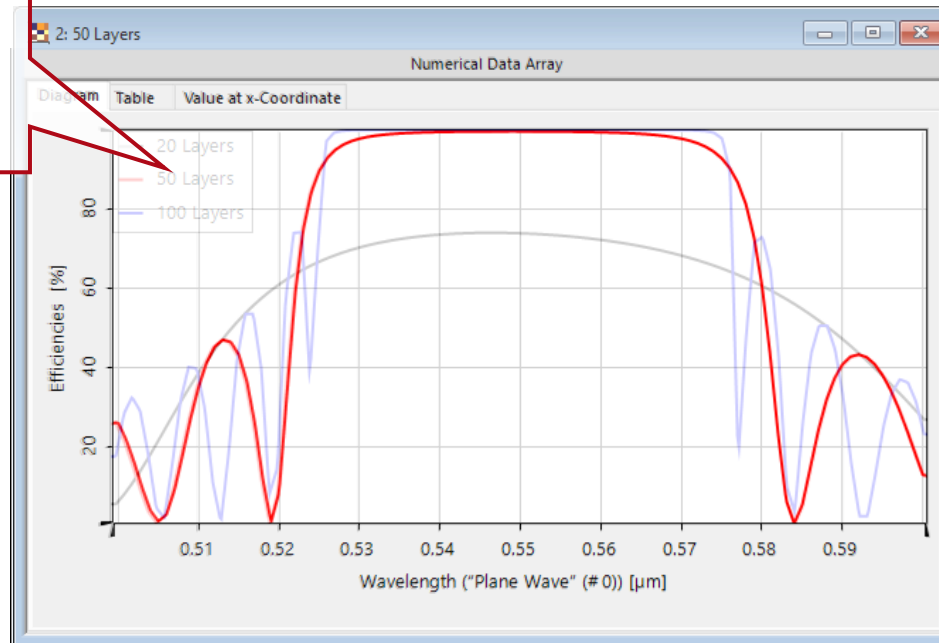
Index	Thickness	Distance	Medium
1	75.55 nm	75.55 nm	BL038_Uniaxial_Cryst
2	87.58 nm	163.13 nm	NOA81 in Homogene N
3	75.55 nm	238.68 nm	BL038_Uniaxial_Cryst
4	87.58 nm	326.26 nm	NOA81 in Homogene N
5	75.55 nm	401.81 nm	BL038_Uniaxial_Cryst
6	87.58 nm	489.39 nm	NOA81 in Homogene N

Layer Sequence

Index of First Layer: 1  
Index of Last Layer: 2  
No. of Replications: 10

Layer Tools  
Append Repeated Layer Sequence

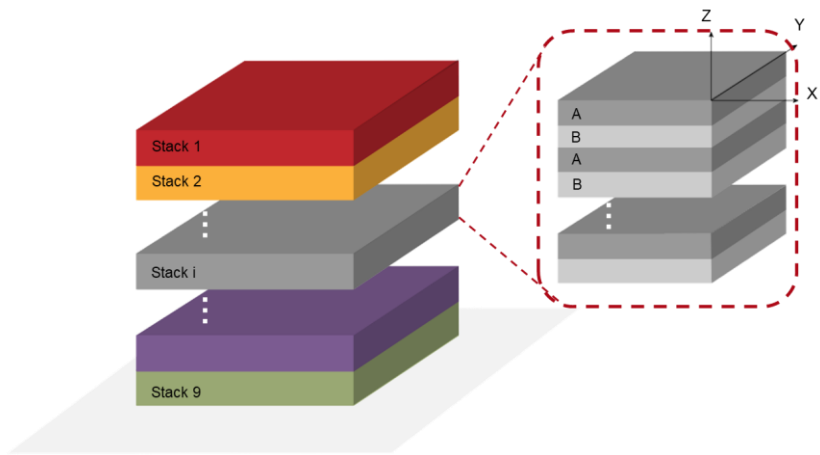
layer 1 and layer 2 repeated 10 times, i.e., 20 layers are constructed



simulation result compare with Li et. al. J. Display Technol. 5, 335-340 (2009)



# Modeling of Multi-Stack Reflective Polarizer



Nine stacks in the reflective polarizer, each stack with 50 alternate layers, hence 450 layers in total.

**Edit Stratified Media Component**

Component Size: 20 mm × 20 mm

Reference Surface (all Channels): Plane Surface

Aperture:  Yes  No

Coating Name: Anisotropic Layer Stack

Coating Orientation: Front Side Application

Homogeneous Medium Behind Surface: NOA81 in Homogeneous Medium

**Define Stack of Anisotropic Layers**

Index	Thickness	Distance	Medium	Orientation
443	112.64 nm	39.6253 μm	BL038_Uniaxial_Cryst	( $\varphi=0^\circ, \theta=90^\circ$ )
444	130.57 nm	39.75587 μm	NOA81 in Homogene	N/A
445	112.64 nm	39.86851 μm	BL038_Uniaxial_Cryst	( $\varphi=0^\circ, \theta=90^\circ$ )
446	130.57 nm	39.99908 μm	NOA81 in Homogene	N/A
447	112.64 nm	40.11172 μm	BL038_Uniaxial_Cryst	( $\varphi=0^\circ, \theta=90^\circ$ )
448	130.57 nm	40.24229 μm	NOA81 in Homogene	N/A
449	112.64 nm	40.35493 μm	BL038_Uniaxial_Cryst	( $\varphi=0^\circ, \theta=90^\circ$ )
450	130.57 nm	40.4855 μm	NOA81 in Homogene	N/A

**Append Repeated Layer Sequence**

Wavelength Range of Materials: Minimum Wavelength: 400.1111667 nm, Maximum Wavelength: 1.000269477 μm

**Configure Layer Sequence Replication**

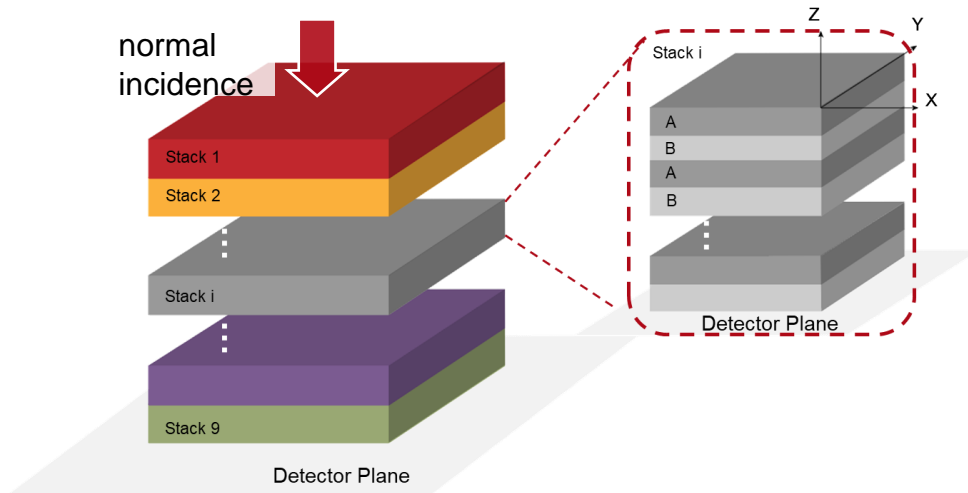
Layer Sequence

Index of First Layer: 1

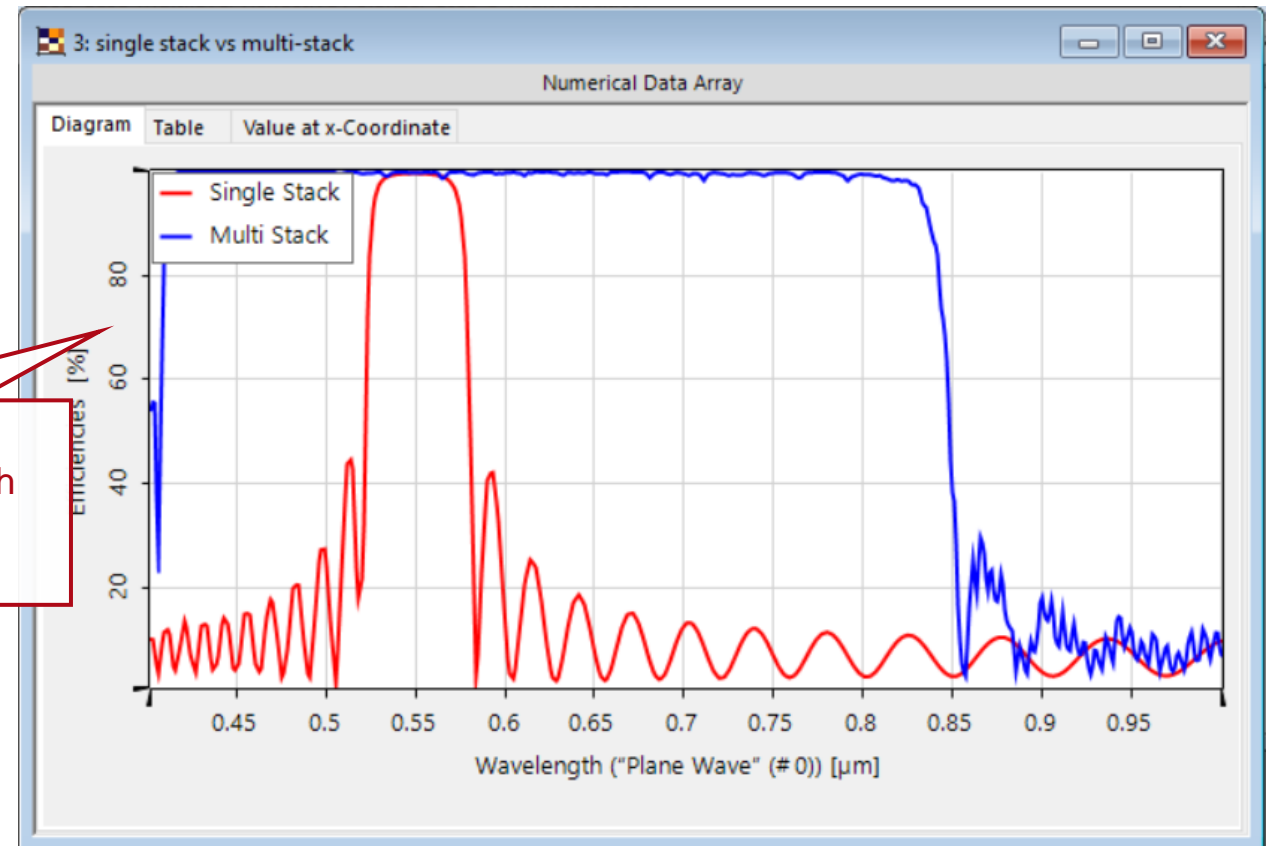
Index of Last Layer: 50

No. of Replications: 9

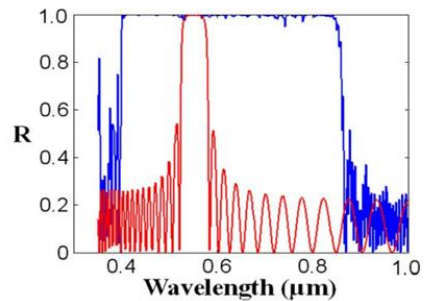
# Expanded Bandwidth by the Multi-Stack Method



The reflection efficiencies of single-stack and multi-stack structures were calculated under wavelength scanning. The simulation shows that, compared with the single stack, an expanded bandwidth is achieved through the multi-stack method.

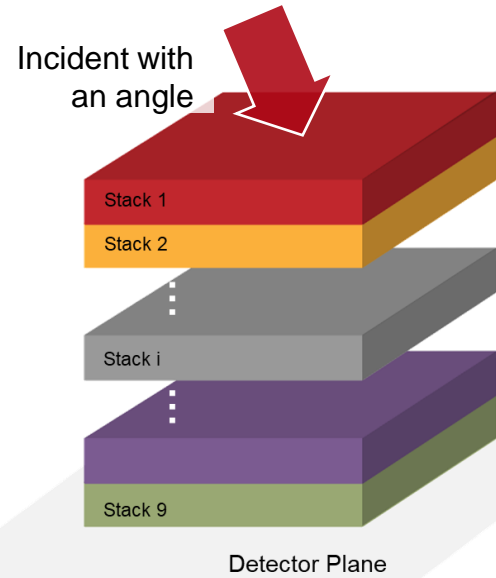


Multi-stack structure achieves reflectance ~ 100% for a much broader bandwidth when compared to a single stack.

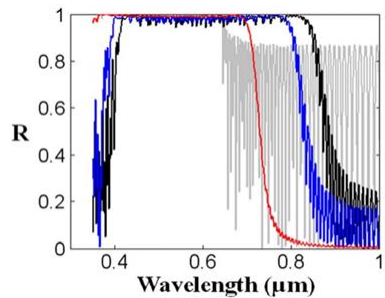


simulation result compare with Li et. al. J. Display Technol. 5, 335-340 (2009)

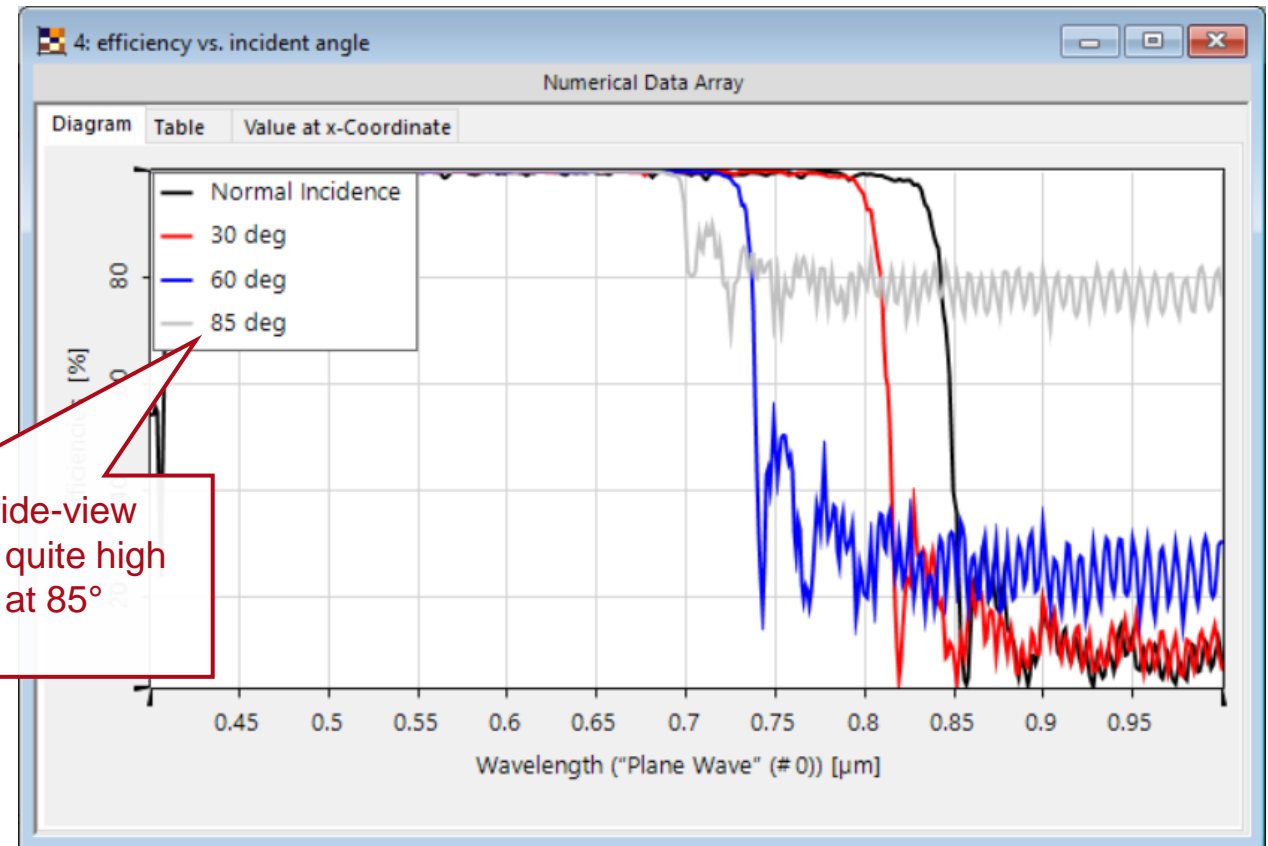
# Investigation of Reflectance Efficiency with Different Incident Angle



To achieve a wide-view LCD, the reflective polarizer should also be designed for oblique incidence. Therefore, the performance of the reflective polarizer at different incident angles is further investigated.

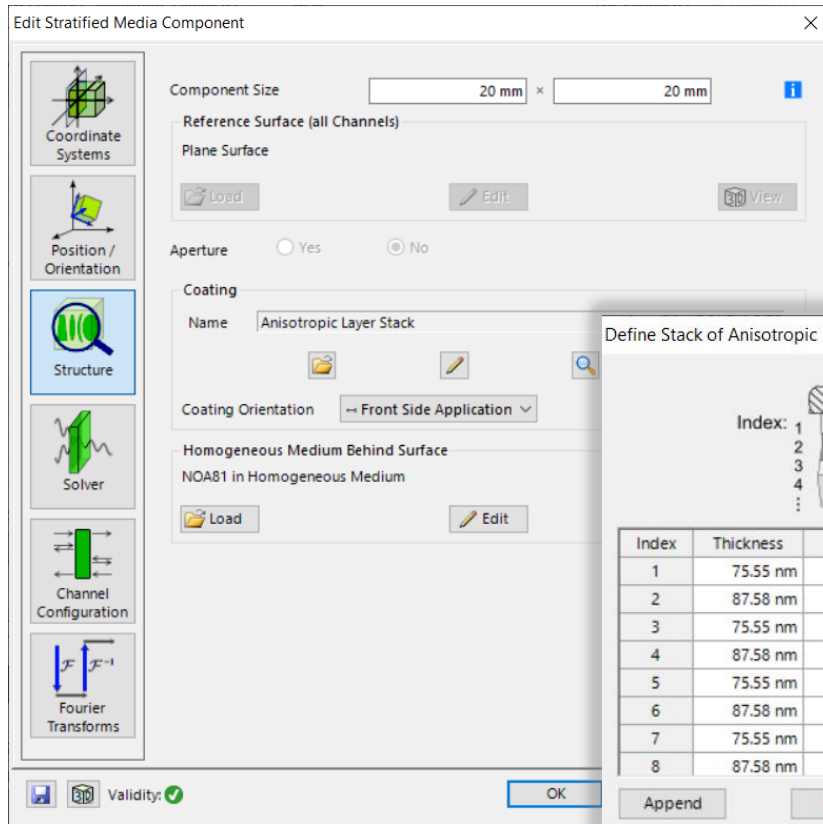


simulation result compare with Li et. al. J. Display Technol. 5, 335-340 (2009)

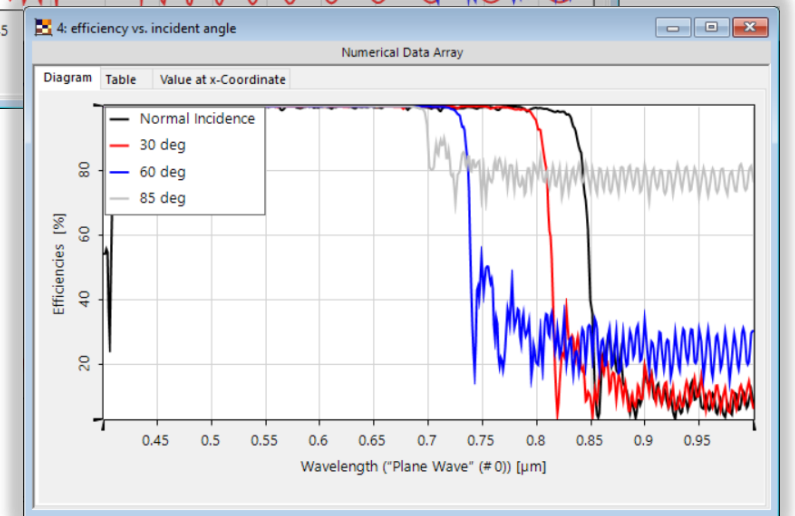
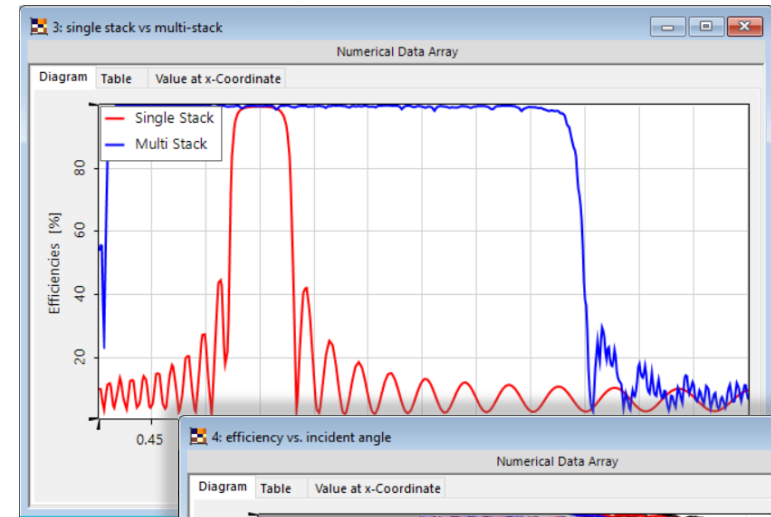
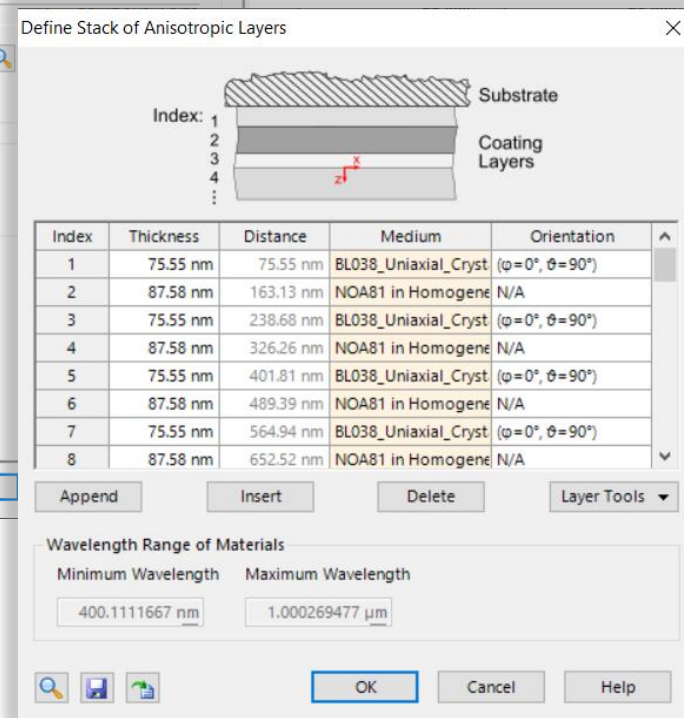


For the application of a wide-view LCD reflectance remains quite high in the visible region even at 85° incident angle.

# Peek into VirtualLab Fusion



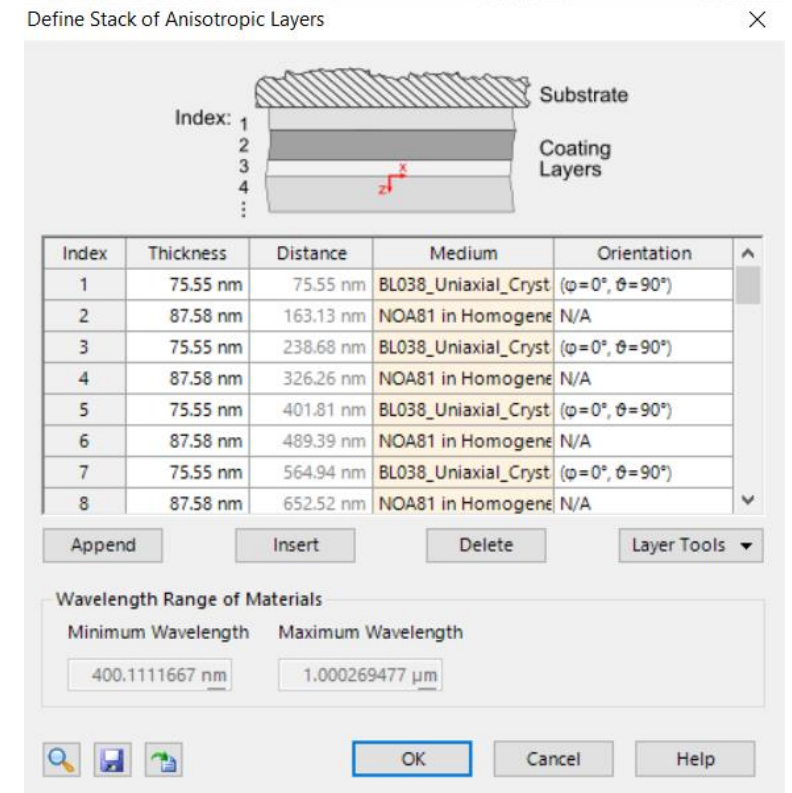
realization of anisotropic layer settings



convenient parameter scanning and result comparison

# Workflow in VirtualLab Fusion

- Set the plane wave light source
  - [Basic Source Models](#) [Tutorial Video]
- Set the anisotropic layer component
  - [Optically Anisotropic Media in VirtualLab Fusion](#) [Use Case]
- Use Parameter Run to investigate the variation of reflectance efficiency with different wavelengths and incident angles



# Document Information

title	Simulation of Multilayer Birefringent Reflective Polarizer with VirtualLab Fusion
document code	CRO.0001
version	1.0
edition	VirtualLab Fusion Basic
software version	2021.1 (Build 1.176)
category	Application Use Case
further reading	<ul style="list-style-type: none"><li>- <a href="#">Optically Anisotropic Media in VirtualLab Fusion</a></li><li>- <a href="#">Conical Refraction in Biaxial Crystals</a></li><li>- <a href="#">Polarization Conversion in Uniaxial Crystals</a></li></ul>