Model created in COMSOL Multiphysics 6.4

Distributed Bragg Reflector

Introduction

A distributed Bragg reflector, or dielectric mirror, is a reflector used in waveguides and optical fibers. A distributed Bragg reflector has extremely low losses at optical and infrared frequencies compared to ordinary metallic mirrors. Its structure is formed from periodic thin layers of alternating materials with high and low refractive indices. Typically the stack would be made up of an odd number of layers where the first and last layers are chosen to have high refractive index.

Each layer boundary causes a partial reflection of an optical wave. When the wavelength is close to four times the optical thickness of the layers, the many reflected waves tend to interfere constructively, causing the layers to act as a high-quality reflector. The range of wavelengths in which most of the incident intensity is reflected is called the photonic stopband. In the limit in which the reflector contains a very large number of layers, radiation in this range of wavelengths cannot propagate into the structure.

Distributed Bragg reflectors are critical components in vertical cavity surface emitting lasers and other types of narrow-linewidth laser diodes such as distributed feedback lasers.

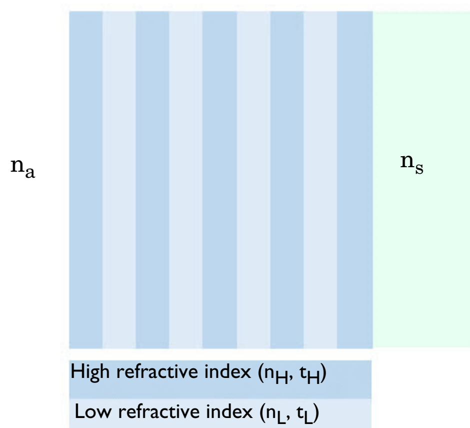

Figure 1: Bragg reflector with 9 layers (N = 4).

Model Definition

The model consists of a single domain containing a substrate with refractive index $n_s = 1.5$. The exterior of the modeling domain is air with refractive index $n_a = 1.0$. At the default **Material Discontinuity** boundary condition on the surfaces of the substrate, a number of **Thin Dielectric Film** features are added to represent the alternating layers.

The layers of greater refractive index are made of ZnS with $n_H = 2.32$, and the layers of lower refractive index contain MgF_2 with $n_L = 1.38$. The thicknesses of the layers are calculated such that $n_H t_H = n_L t_L = \lambda_0/4$.

To show the response of the mirror across a span of wavelengths, a range of wavelengths (or frequencies) can be specified using the **Release from Grid** feature.

Of particular interest in this device is the reflectance R of the device and what range of wavelengths it is effective over, $\Delta\lambda$. The reflectance for the distributed Bragg reflector is given by

$$R = \left(\frac{1 - \left(\frac{n_H}{n_L}\right)^{2N} \frac{n_H^2}{n_a n_b}}{1 + \left(\frac{n_H}{n_L}\right)^{2N} \frac{n_H^2}{n_a n_b}} \right)^2 \tag{1}$$

where N is the number of pairs of dielectric layers; for example, $N = 5$ implies that the reflector consists of 11 layers (five pairs plus an additional layer of high refractive index on top).

The bandwidth $\Delta\lambda$ of the photonic stopband is given by

$$\Delta\lambda_0 = \frac{4\lambda_0}{\pi} \operatorname{asin}\left(\frac{n_H - n_L}{n_H + n_L}\right) \tag{2}$$

where λ_0 is the central wavelength of the band.

Results and Discussion

Figure 2 shows the response of the dielectric mirror across a range of wavelengths from 400 nm to 800 nm. The vacuum wavelength λ_0 used in the specification of the layers is 550 nm. At this wavelength, a configuration with 2 unit cells (5 total layers) gives roughly 87% reflectance whereas a configuration with 5 unit cells (11 total layers) gives roughly 99.5% reflectance. The computed values of R agree with Equation 1.

The calculated stopband is 180 nm using Equation 2. As shown in Figure 2 the reflectance approaches 100% within the stopband as the number of layers increases. For the maximum number of layers the reflectance is about 100% for a range of free-space wavelengths from 475 nm to 655 nm for a stopband of about 180 nm.

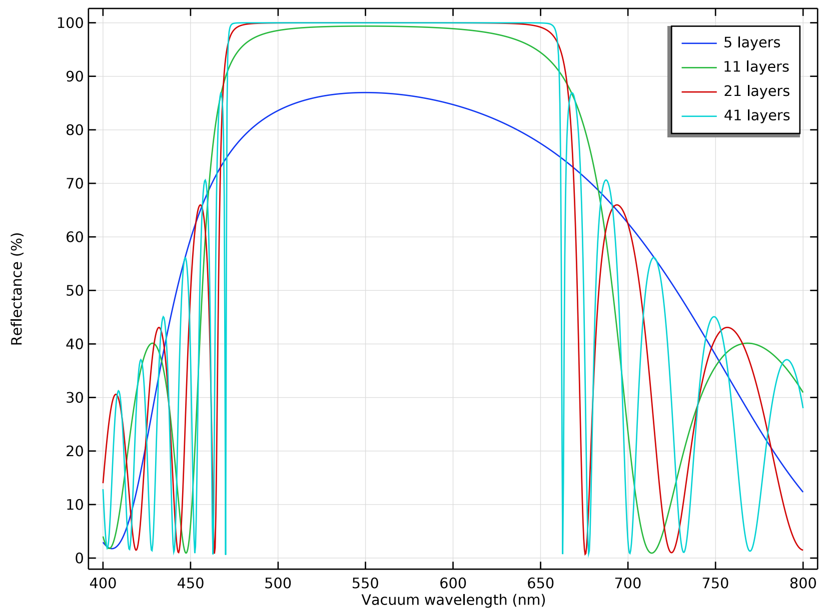

Figure 2: Response of the distributed Bragg grating for different numbers of layers, from a minimum of 5 total layers to a maximum of 41.

Application Library path: `Ray_Optics_Module/Prisms_and_Coatings/distributed_bragg_reflector`

Modeling Instructions

From the **File** menu, choose **New**.

NEW

In the **New** window, click **Model Wizard**.

MODEL WIZARD

1 In the **Model Wizard** window, click **3D**.

2 In the **Select Physics** tree, select **Optics** > **Ray Optics** > **Geometrical Optics (gop)**.

3 Click **Add**.

4 Click **Study**.

5 In the **Select Study** tree, select **Preset Studies for Selected Physics Interfaces > Ray Tracing**.

6 Click **Done**.

GEOMETRY 1

Add some parameters for the refractive indices of the materials and the central wavelength.

GLOBAL DEFINITIONS

Parameters 1

1 In the **Model Builder** window, under **Global Definitions** click **Parameters 1**.

2 In the **Settings** window for **Parameters**, locate the **Parameters** section.

3 In the table, enter the following settings:

Name	Expression	Value	Description
ns	1.5	1.5	Refractive index of substrate
nh	2.32	2.32	Refractive index of ZnS
nl	1.38	1.38	Refractive index of MgF2
lam0	550[nm]	5.5E-7 m	Vacuum wavelength
Nc	2	2	Number of unit cells

GEOMETRY 1

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometry 1**.

2 In the **Settings** window for **Geometry**, locate the **Units** section.

3 From the **Length unit** list, choose **mm**.

Cylinder 1 (cyl1)

1 In the **Geometry** toolbar, click **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type 10.

4 In the **Height** text field, type 5.

5 Click **Build All Objects**.

In the Geometrical Optics interface, enable ray intensity calculation and allow distributions of ray wavelengths to be released. Also set the number of secondary rays to zero as this saves memory when it is not necessary to compute the trajectories of the reflected rays.

GEOMETRICAL OPTICS (GOP)

1 In the **Model Builder** window, under **Component 1 (comp1)** click **Geometrical Optics (gop)**.
2 In the **Settings** window for **Geometrical Optics**, locate the **Intensity Computation** section.
3 From the **Intensity computation** list, choose **Compute intensity**.
4 Locate the **Ray Release and Propagation** section. From the **Wavelength distribution of released rays** list, choose **Polychromatic, specify vacuum wavelength**.
5 In the **Maximum number of secondary rays** text field, type `0`.

Specify the refractive index of the substrate.

MATERIALS

Material 1 (mat1)

1 In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **Blank Material**.
2 In the **Settings** window for **Material**, locate the **Material Contents** section.
3 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Refractive index, real part	n_iso ; nii = n_iso, nij = 0	ns	1	Refractive index

Edit the **Material Discontinuity** settings to allow periodic thin dielectric films to be added to the surface.

GEOMETRICAL OPTICS (GOP)

Material Discontinuity 1

1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometrical Optics (gop)** click **Material Discontinuity 1**.
2 In the **Settings** window for **Material Discontinuity**, locate the **Coatings** section.
3 From the **Thin dielectric films on boundary** list, choose **Add layers to surface, repeating**.
4 In the N text field, type `Nc`.
5 Locate the **Rays to Release** section. From the **Release reflected rays** list, choose **Never**.

Add two **Thin Dielectric Film** features to the **Material Discontinuity** feature. To visualize the arrangement of the thin dielectric layers, show the boundary normal in the **Graphics** window.

6 Click the **Wireframe Rendering** button in the **Graphics** toolbar.

7 Locate the **Advanced Settings** section. Select the **Show boundary normal** checkbox.

The red arrow points in the direction of the stack of layers; the last **Thin Dielectric Film** feature in the Model Builder will be at the top of the stack.

Add the layers and specify their refractive indices and thicknesses so that the optical thickness of each layer is equal to 1/4 of the vacuum wavelength.

Thin Dielectric Film 1

1 In the **Physics** toolbar, click **Attributes** and choose **Thin Dielectric Film**.

2 In the **Settings** window for **Thin Dielectric Film**, locate the **Film Properties** section.

3 In the n text field, type `nh`.

4 In the t text field, type `lam0/(4*nh)`.

Material Discontinuity 1

In the **Model Builder** window, click **Material Discontinuity 1**.

Thin Dielectric Film 2

1 In the **Physics** toolbar, click **Attributes** and choose **Thin Dielectric Film**.

2 In the **Settings** window for **Thin Dielectric Film**, locate the **Film Properties** section.

3 In the n text field, type `nl`.

4 In the t text field, type `lam0/(4*nl)`.

The multilayer film will begin and end with the same layer. To allow any number of repeating unit cells to be applied, duplicate the first layer so that three **Thin Dielectric Film** nodes are present, two of which form the repeating unit cell.

Thin Dielectric Film 3

In the **Model Builder** window, under **Component 1 (comp1)** > **Geometrical Optics (gop)** > **Material Discontinuity 1** right-click **Thin Dielectric Film 1** and choose **Duplicate**.

Exclude the first layer from the unit cell of the multilayer film.

Thin Dielectric Film 1

1 In the **Settings** window for **Thin Dielectric Film**, click to expand the **Repeating Multilayer Films** section.

2 Clear the **Repeat layer in multilayer films** checkbox.

Add a **Release from Grid** feature and specify a range of wavelengths to be released.

Release from Grid 1

1 In the **Physics** toolbar, click **Global** and choose **Release from Grid**.

Release rays with a large number of wavelengths within a given range.

2 In the **Settings** window for **Release from Grid**, locate the **Initial Coordinates** section.

3 In the $q_{z,0}$ text field, type 10.

4 Locate the **Ray Direction Vector** section. Specify the $\mathbf{L}_0$ vector as

0	x
0	y
-1	z

5 Locate the **Vacuum Wavelength** section. From the **Distribution function** list, choose **List of values**.

6 Click **Range**.

7 In the **Range** dialog, choose **Number of values** from the **Entry method** list.

8 In the **Start** text field, type 400[nm].

9 In the **Stop** text field, type 800[nm].

10 In the **Number of values** text field, type 1000.

11 Click **Replace**.

STUDY 1

Parametric Sweep

1 In the **Study** toolbar, click **Parametric Sweep**.

Run a **Parametric Sweep** over the number of unit cells in the dielectric mirror in order to observe the changes in the reflectance.

2 In the **Settings** window for **Parametric Sweep**, locate the **Study Settings** section.

3 Click **Add**.

4 In the table, enter the following settings:

Parameter name	Parameter value list	Parameter unit
Nc (Number of unit cells)	2 5 10 20	

Step 1: Ray Tracing

1 In the **Model Builder** window, click **Step 1: Ray Tracing**.

2 In the **Settings** window for **Ray Tracing**, locate the **Study Settings** section.

3 In the **Output times** text field, type `0 0.025`.

4 In the **Study** toolbar, click **Compute**.

To show the reflectance response of the mirror as a function of wavelength, use a **Ray** plot.

RESULTS

Reflectance

1 In the **Results** toolbar, click **1D Plot Group**.

2 In the **Settings** window for **1D Plot Group**, type `Reflectance` in the **Label** text field.

3 Locate the **Data** section. From the **Dataset** list, choose **Ray 1**.

4 From the **Time selection** list, choose **Last**.

5 Click to expand the **Title** section. From the **Title type** list, choose **None**.

6 Locate the **Plot Settings** section.

7 Select the **x-axis label** checkbox. In the associated text field, type `Vacuum wavelength (nm)`.

8 Select the **y-axis label** checkbox. In the associated text field, type `Reflectance (%)`.

Ray 1

1 In the **Reflectance** toolbar, click **More Plots** and choose **Ray**.

Compare the initial and current intensity to plot the reflectance at each wavelength.

2 In the **Settings** window for **Ray**, locate the **y-Axis Data** section.

3 In the **Expression** text field, type `100*(gop.relg1.I0-gop.I)/gop.relg1.I0`.

4 Locate the **x-Axis Data** section. From the **Parameter** list, choose **Expression**.

5 In the **Expression** text field, type `gop.lambda0`.

6 From the **Unit** list, choose **nm**.

7 Click to expand the **Legends** section. Select the **Show legends** checkbox.

8 From the **Legends** list, choose **Evaluated**.

9 In the **Legend** text field, type `eval(2*Nc+1) layers`.

10 In the **Reflectance** toolbar, click **Plot**.

11 Click the **Zoom Extents** button in the **Graphics** toolbar. Compare the computed reflectance values with Figure 2.