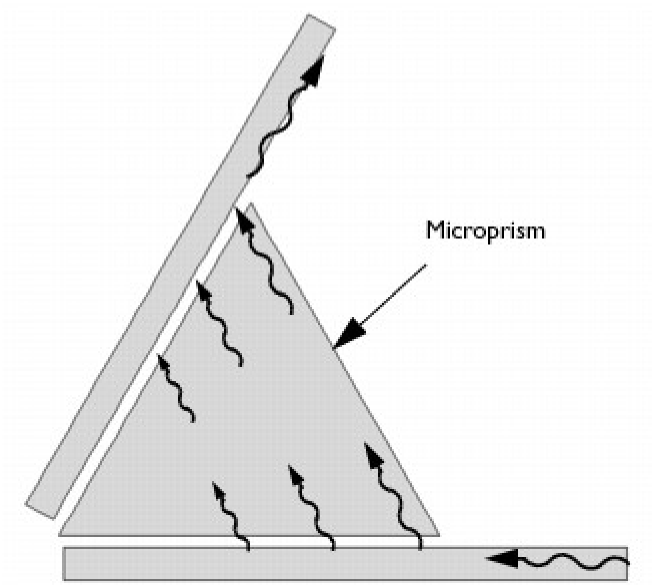
Photonic Microprism

Introduction

A microprism is used for reducing radiative losses in photonic waveguide bends. If you place a microprism between two waveguides forming a sharp bend, light will be guided between the waveguides through the prism.



For a certain refractive index of the prism, the light propagating through the prism couples to the respective mode under just the appropriate resonance angle (see Ref. 1). If the initial field distribution does not diffract while propagating through the prism, the coupling from the prism to the guide is the inverse to the light transfer from the guide to the prism. Therefore, the efficiency of the process is very high.

The interface between the guide and the prism must be sufficiently long to allow almost all the power to exit from the guide into the prism and vice versa. On the other hand, to avoid diffraction, the size of the prism should be kept as small as possible.

This model also makes use of *perfectly matched layers*, PMLs. These are domains with artificial absorption that reduce nonphysical reflections. For more information on PMLs, see Ref. 2 and the section "Perfectly Matched Layers (PMLs)" on page 44 in the *RF Module User's Guide*.

Model Definition

The model is built using the 2D In-Plane TE Waves application mode. The modeling takes place in the *xy*-plane.

DOMAIN EQUATIONS

The dependent variable in this application mode is the z component of the electric field $\mathbf{E}$. It obeys the following relation:

$$\nabla \times (\mu_r^{-1} \nabla \times E_z) - \left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon_0}\right) k_0^2 E_z = 0$$

where μ_r denotes the relative permeability, ω the angular frequency, σ the conductivity, ε_0 the permittivity of vacuum, ε_r the relative permittivity, and k_0 the wave number. Different refractive indices are used for the prism and the guides. The wave is dampened by PMLs where the wave enters and exits the setup. The whole geometry is surrounded by another PML, which decreases reflections from the nonphysical exterior boundary. The solution is calculated for IR light with a wavelength in vacuum of 870 nm.

BOUNDARY CONDITIONS

The exterior boundaries in this model use a scattering boundary condition to terminate the PML. Inside the geometry, continuity is applied everywhere except for at the boundary where the wave is entering the structure. This boundary is excited with a cosine function fitted to match the width of the waveguide.

Results and Discussion

Figure 4-1 shows the geometry and the solution of the model. The wave enters the horizontal guide from the right and exits at the top of the vertical guide. The circles surrounding the entry and the exit are PMLs.

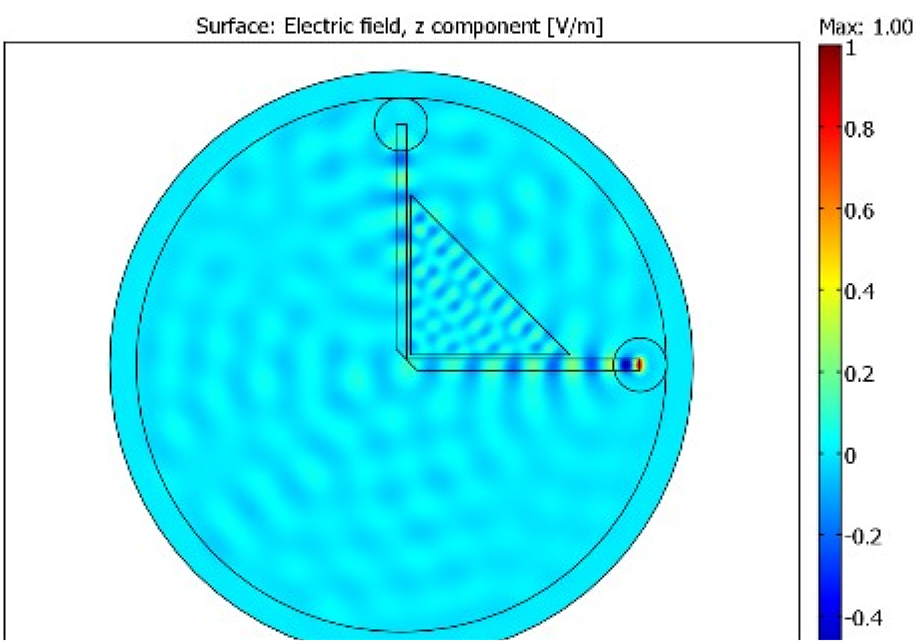


Figure 4-1: The z component of the electric field.

Several variables govern the transmission of the wave through the bend: for example, the relation between the refractive indices of the guide and the prism, the size of the prism, and the gap between the guides and the prism. The optimal values of the parameters also depend on the angle of the bend.

References

1. CLEO 2001, *Conference on Lasers and Electro-Optics*, OSA-Optical Society of America, pp. 129–130.

2. Jianming Jin: *The Finite Element Method in Electromagnetics*, Second Edition, Wiley-Interscience.

Model Library path:
`RF_Module/Optics_and_Photonics/photonic_micro_prism`

Modeling Using the Graphical User Interface

MODEL NAVIGATOR

1 Select **2D** from the **Space dimension** list.

2 In the list of application modes, select **RF Module>In-Plane Waves> TE Waves>Harmonic propagation**.

3 Click **OK**.

OPTIONS AND SETTINGS

1 In the **Axes/Grid Settings** dialog box, set axis and grid settings according to the following table; when done, click **OK**.

AXIS		**GRID**	
x min	-6	x spacing	0.5
x max	6	Extra x	-0.1 0.1 0.18 0.3 3.18
y min	-6	y spacing	0.5
y max	6	Extra y	-0.1 0.1 0.18 0.3 3.18

2

In the **Constants** dialog box, enter the following variable names, expressions, and descriptions (optional); when done, click **OK**.

NAME	EXPRESSION	DESCRIPTION
n_Guide	1.5	Refractive index, waveguide
n_Prism	2.5	Refractive index, microprism

GEOMETRY MODELING

Start by defining the solid objects for the two guides and the prism.

1 Select **Draw Line** and click at (0.3, −0.1), (4.5, −0.1), (4.5, 0.1), and (0.1, 0.1). Create a solid object CO1 by clicking the right mouse button.

2 Select **Draw Line** and click at (0.1, 0.1), (0.1, 4.5), (−0.1, 4.5), and (−0.1, 0.3). Create a solid object CO2 by clicking the right mouse button.

3 Select **Draw Line** and click at (0.18, 3.18), (0.18, 0.18), and (3.18, 0.18). Create a solid object CO3 by clicking the right mouse button.

Then, define circular domains for the absorbing layers.

1 Draw a circle C1 with radius 5 and a circle C2 with radius 5.5, both centered at (0,0).

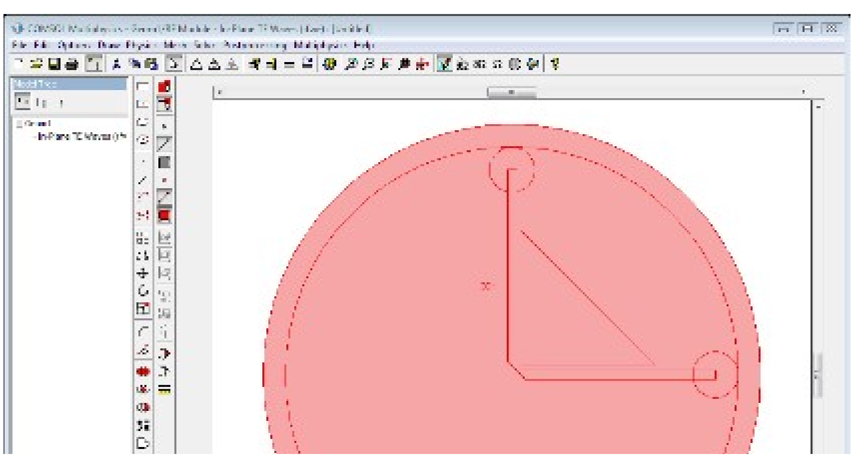
2 Draw a circle C3 centered at (4.5, 0) and a circle C4 centered at (0, 4.5), both with radius 0.5.

3 Unite all objects into one solid object by selecting all objects and clicking the **Union** toolbar button.

The model geometry is now ready, except for the size. The dimensions should be given in μm.

1 Click the **Scale** button on the Draw toolbar, and give the value `1e-6` for both scaling factors.

2 Click the **Zoom Extents** button on the Main toolbar to see the resulting object.



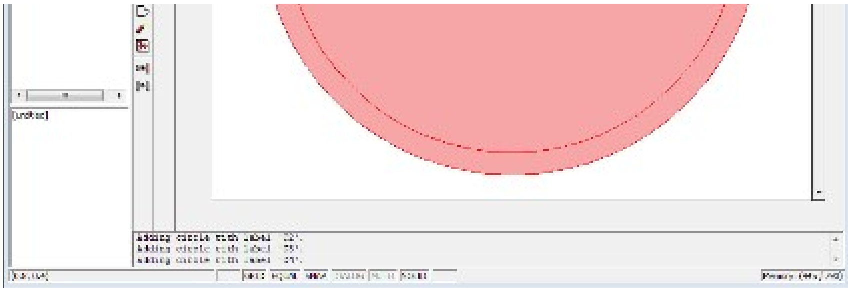


Figure 4-2: Model geometry.

PHYSICS SETTINGS

Scalar Variables

Set the frequency to `3e8/870e-9` in the **Scalar Variables** dialog box.

Boundary Conditions

Enter the boundary conditions according to the following table. To apply boundary conditions to interior boundaries, it is necessary to select the **Interior boundaries** check box.

SETTINGS	BOUNDARY 15	BOUNDARIES 16, 17, 23, 28	ALL OTHERS
Boundary condition	Electric field	Scattering boundary condition	Continuity
E_{0z}	cos(y*pi/0.4 [um])	0	
Wave type		Cylindrical wave	

Subdomain Settings

1 Subdomains 1 and 5 represent air or vacuum. This is the default setting.

2 Subdomain 7 is the prism. Choose to represent the material properties in terms of the refractive index, and enter `n_Prism` in the text field.

3 Subdomains 2, 4, and 6 are the free part of the waveguide. Use `n_Guide` as the refractive index here.

4 Subdomains 3, 8, and 9 are used for damping the wave. Choose to represent the material properties in terms of ε_r, μ_r, and σ. Enter `n_Guide^2*Izz` for the **Relative permittivity** and `Ixx 0 0 Iyy` for the **Relative permeability**, which is anisotropic.

5 Subdomain 10 also damps the wave to reduce the effect of the exterior boundary. Enter `Izz` for the **Relative permittivity** and `Ixx 0 0 Iyy` for the **Relative permeability**.

Expression Variables

1 Open the **Subdomain Expressions** dialog box from the **Options** menu. Mark all subdomains and specify the expressions for diagonal indices of the PML tensor.

NAME	EXPRESSION
Ixx	sy*sz/sx
Iyy	sx*sz/sy
Izz	sx*sy/sz

2 For best results, the wave is damped along the expected direction of propagation, except for in the beginning of the waveguide, where it is damped in the perpendicular direction. To achieve this effect, use the following expressions.

SETTINGS	SUBDOMAINS 3, 4, 8	SUBDOMAINS 9, 10	ALL OTHERS
sx	1	1-i	1
sy	1-i	1-i	1
sz	1	1	1

MESH GENERATION

1 Change the default mesh parameters to get an applicable mesh. Open the **Free Mesh Parameters** dialog box. On the **Global** page, click the **Custom mesh size** button and set **Maximum element size** to `250e-9`. On the **Subdomain** page, select Subdomains 2, 4, and 6–8, and set **Maximum element size** to `100e-9`.

2 Initialize the mesh.

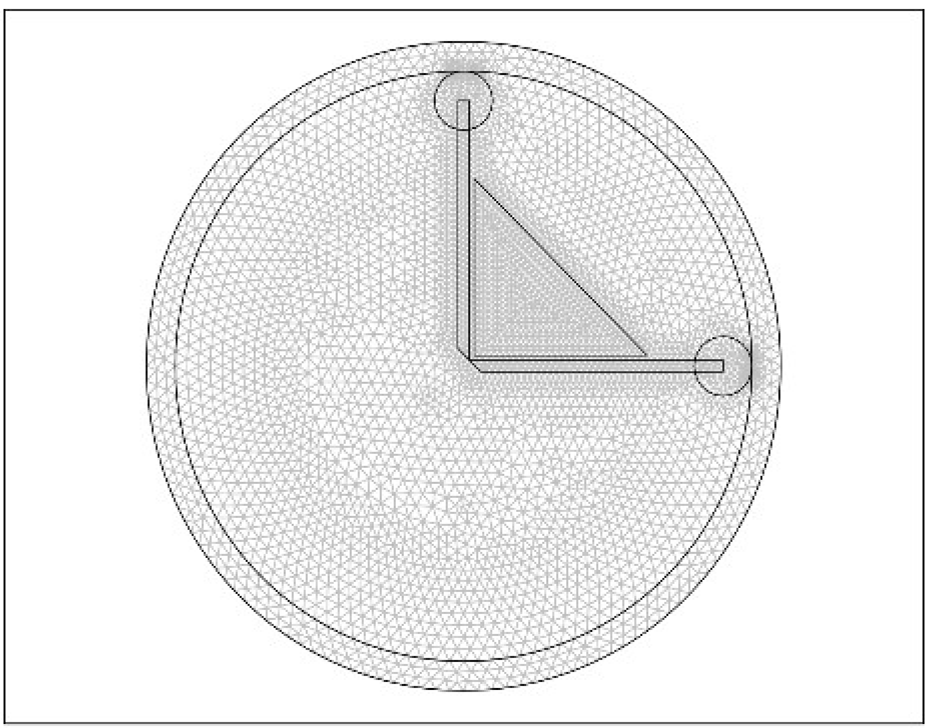


Figure 4-3: Mesh

COMPUTING THE SOLUTION

1 Click the **Solve** button on the Main toolbar to compute the solution.

POSTPROCESSING AND VISUALIZATION

By default, the z component of the electric field is visualized. It shows clearly that the wave propagates between the two guides, through the prism; see Figure 4-1. Another interesting entity for visualization is the electric energy density. Select **Electric energy density, time average** on the **Surface** page of the **Plot Parameters** dialog box, and use the **WaveLight** color table. The resulting plot (Figure 4-4) shows that the energy density is mainly localized to the waveguide and the prism, and that there are signs of resonances in the prism.

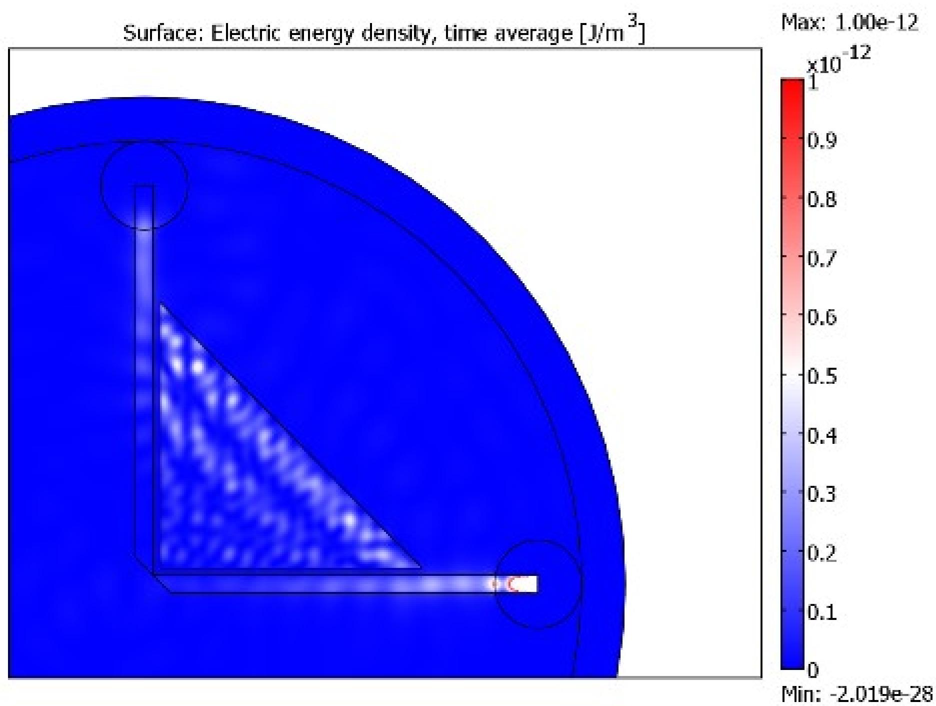


Figure 4-4: Electric energy density.