







## Nano-lens and pixel simulations using OptiFDTD

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## Micro Optical Lens and pixel simulations using OptiFDTD

- Micro-lens with dimension compatible with working wavelength is not suitable using the Ray-tracing method.
- Micro-Lens in Pixel layout and image application can be simulated using OptiFDTD.
- Layout sweep simulation can scan the Lens' parameters.
- Tools in OptiFDTD can measure the focusing distance, focusing spot size, transmission and more.
- This presentation will explore the extensive simulation and post processing tools included with OptiFDTD.





## (1) Example1---4\*4 Lens array

Lens dimension







## Example1---4\*4 Lens array in OptiFDTD





## Example1---4\*4 Lens array in OptiFDTD

(3) XY plane at z=0.7

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Simulation domain

4.6um\*4.6\*5.0um

- X: -2.3---2.3um
- Y: 0.0--- 4.6um
- Z: 0.0---5.0um







## Example1---4\*4 Lens array---input wave

- (a) Input transverse is set as y-polarized plane wave in the whole xy plane.
   Boundary condition makes the plane wave straight forward propagate to the lens.
- (b) Select from a variety of input transverse beam formats: Modal, Gaussian, or user defined.

Input Field Properties	×
Continuous Wave C Gaussian Modulated Continuous Wave	
Wavelength (um) 0.248	
General 2D Transverse 3D Transverse	
Rectangular Transverse	
Center Position (um) X 00 · Auto Y 2.3 · Auto Half Width (um) X 2.3 · Auto Tilting Angle (deg) 0 · Auto	
Effective Refractive Index	
C Modal Select Mode C Local C User Real 1.5 Imaginary 0	
Polarization C Linear X C Right Hand Circular	
Linear Y     Linear Theta[deg) = 0.0	
Input Amplitude or Power	
• Amplitude (V/m2) 1.0 • • • • • • • • • • • • • • • • • • •	
OK Cancel Help	

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## Example1---4\*4 Lens array---Simulation parameters

- (5) Simulation Parameters
- (a) Mesh size
- 0.02um\*0.02um\*0.02um
- (b) Run for 1248 time step +
- 10 additional cycle to get the steady state field
- (c) Calculate steady statefield for Ey and Hx(Disretized Fourier transform)
- (d) x-y boundary use the upper-lower symmetric boundary condition. Zdirection user the APML as the boundary condition

3D Simulation Parameters
Mesh Parameters
Mesh Delta X (um) 0.02 Number of Mesh Cells X 229 CAuto
Mesh Delta Y (um) 0.02 Number of Mesh Cells Y 229 🗖 Auto
Mesh Delta Z (um) 0.02 Number of Mesh Cells Z 250 Auto
Wafer Dimensions: 5.00 um (length) * 4.60 um (width) * 4.60 Advanced um (depth) Actual Mesh Used = 0.0200873 um (delta X) * 0.0200873
Time Step Size: 3.33564095198152e-017 🔽 Auto
Run for 1248 Time Steps (Results Finalized)  Auto
C Run Until User Stops Execution, then Finalize Results
Script Option: 🔲 Simulate Using Script
Key Input Field: InputPlane1 and wavelength: 0.248
DFT Options
Components for Post-Simulation Analysis.
Electric Components Magnetic Components
I Ex M Ey I Ez
Time Sampling Interval: 1
<u>R</u> un S <u>u</u> mmary <u>Q</u> K <u>C</u> ancel <u>H</u> elp



#### Simulation --- Observe the time domain response (time step around 310)



Ey at xz plane at y=0.5 ( the center of first row)



Ey at xz plane at y=2.9 ( the center of third row)



Ey at xz plane at y=1.7 ( the center of second row)



Ey at xz plane at y=4.1 ( the center of third row)

**D m D** 

+0+





#### Simulation --- Observe the time domain response (time step around 310)



Ey at xz plane at y=1.8 (the center of domain)

Simulation uses 761.58MB RAM and CPU time 1:33:49





#### Simulation --- Observe the time domain response (time step 360)



Ey at xy plane at z=1.1 ( 300nm from lens edge z=0.8um)





#### Analyzer --- Observe the steady state response



\*steady state response can be observed in any xy, yz, zx slice





#### Analyzer --- Observe the steady state response



Ey along z direction at x=-1.8, y=0.5

It can be read that ach lens focus at z=1.26, focus distance 1.26-0.8=0.46um





#### Analyzer --- Observe the steady state response







#### Analyzer --- Observe the steady state response--- Poynting vector



Poynting Vector at z=1.26um





#### Analyzer --- Observe the steady state response--- Poynting vector



Poynting vector vs. y at x=0.6um, z=1.26um

Focus beam size can be measured at half width of the peak value, which is 0.1613





Discussion

- All data can be exported to an ASCII file for further analysis by using third party packages such as Code V (ORA) and ZEMAX.
- OptiFDTD includes an interface for users to convert OptiFDTD data to an output file which can be used directly in Code V or ZEMAX.





#### Analyzer ---Far field transform



#### Far field pattern based near field at xy plane z=1.26





## Example2----

1. 3\*3 Pixels in layout designer

	000
1,250	
-1.250 	





#### 2. Refractive index distribution in one x-y slice







3D Simulation Parameters
Mesh Parameters
Mesh Delta X (um) 0.01 Number of Mesh Cells X 600 Auto
Mesh Delta Y (um) 0.01 Number of Mesh Cells Y 600 🗖 Auto
Mesh Delta Z (um) 0.02 Number of Mesh Cells Z 459 Auto
Wafer Dimensions: 9.19 um (length) * 6.00 um (width) * 6.00 um (depth) Actual Mesh Used = 0.01 um (delta X) * 0.01 um (delta Y) *
_ <u>I</u> ime Parameters
Time Step Size: 1.66782047599076e-017 🔽 Auto
Run for 9000 Time Steps (Results Finalized) Auto
C Run Until User Stops Execution, then Finalize Results
Script Option: 🔲 Simulate Using Script
Key Input Field: InputPlane1 and wavelength: 0.55
DFT Options
Choose The Components Needed For Future Analysis.
Electric Components Magnetic Components
Time Sampling Interval: 1
<u>R</u> un Summary <u>O</u> K <u>C</u> ancel <u>H</u> elp

### 3. Simulation Parameters

- x, y –direction mesh is set to 0.01um
- Z direction mesh is set to 0.02um
- x, y, z boundary is set as PML boundary condition.
- Total mesh is 600\*600\*459, plus 12 PML layer in each side.
- The total problem size is 190 million nodes (71% of the 16GB memory).
- Initialization Time: 5.6 minutes
- Computation Time: 14.6 hours
- Finalization: 5 minutes
- Computation Rate (average): 32.8 Mnps (million nodes per second)





## 4. Simulation results



Y-Polarization Poynting vector in xy Plane, 100nm under Silicon layer





## 5. Simulation results



Total Poynting vector in xy Plane, 250nm behind input wave

This is the reflected wave. Because reflected wave propagate to negative z direction, so Poynting vector has negative symbol.





## 6. Simulation results



Ey in yz Plane at x=0

(the center pixel)





#### Example 3--- SMF28 fiber lens

#### ----Sample 22 in OptiFDTD (can be used as Live demo)







#### Example 3--- SMF28 fiber lens---sample 28



• Open Sample22 in the OptiFDTD sample folder

• Click "2D\_ref\_ldx\_re(y) button under the layout sub-window to observe index distribution, (Click "Height" plot shortcut toolbar and Drag the graph can change the view angle.)

• The layout is a center cut of the SMF28 Fiber with termination tapered and polished as Lens. When Lens radius is changing, the taper length will be changed too, and the wave focusing distance and size will be also changed. The simulation will check the focusing distance and focusing size.





#### Example 3--- SMF28 fiber lens---sample 28 ---Checking how to sweep the Lens radius



Click Layout button

• Double click on the Lens Object, you will see Lens Radius is defined by an variable "R", Other objects positions are also associated with this R when R is changing.

• Click Simulation Menu and Click on "Editor parameters:, you will find we defined variable R and Some other parameters associate with "R"

• Click "Test Script" or the Play short cut toolbar, you will find the radius and the taper length is changing in the layout.

• Click "VB script" button under the layout graph sub-window, you will find the VB scripting code. This is the code to control scanning parameters. When "R" is re-defined, All the associate parameters will be changed.



#### Example 3--- SMF28 fiber lens (Simulation using Script)

imulation Parameters
© TE C TM
Mesh Parameters
Mesh Delta X (um) 0.075 Number of Mesh Cells X 400   Auto
Mesh Delta Z (um) 0.075 Number of Mesh Cells Z 650 🗖 Auto
Wafer Dimensions: 48.75 um (length) × 30.00 um (width) Actual Mesh Used = 0.075 um (delta ×) × 0.075 um (delta Z)
Time Parameters
Time Step Size 1.66782047599076e-016 🔽 Auto
Run for 4000 Time Steps (Results Finalized) Auto
C Run Until User Stops Execution, then Finalize Results
Script Option: 🔽 Simulate Using Script
Key Input Information: InputPlane1 and wavelength: 1.55
Run Summary OK Cancel Help

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- Click 2D simulation Parameters, Please note "Simulation using Script" is selected
- The scanning simulation will call FDTD Engine 12 times corresponding the iteration number for Lens Radius R
- Simulation will generate 12 results file, open each results file can measure the focusing distance and focusing size.
- Or advanced user can call the final results with VB without open each results file ( please Check tutorial lesson 16 for this feature)





Sample 3---Lens in Sample22, post-data analysis



Click field components of Poynting vector to check the steady state response.









Click Crosscut viewer and right on the graph to select graph tools to measure the focusing distance and size.