

The background of the slide features a large, light blue watermark of the Yonsei University seal. The seal is circular with the text 'YONSEI UNIVERSITY' around the top and 'YONSEI' at the bottom. In the center is a shield with a book, a torch, and a central circle. Below the shield is a diamond shape containing the year '1885'.

Ring Resonator MODE Simulation

**High-Speed Circuits & Systems Lab.
Dept. of Electrical and Electronic Engineering
Yonsei University**

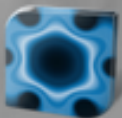
Lumerical Solutions

Our Products



FDTD Solutions: Single and multi-processor finite-difference time-domain optical design software.

[Product Details](#) | [Trial Download](#)



MODE Solutions: Waveguide eigenmode solver and omni-directional broadband propagator design software.

[Product Details](#) | [Trial Download](#)



INTERCONNECT: Optoelectronic and photonic integrated circuit (PIC) design software package.

[Product Details](#) | [Trial Download](#)



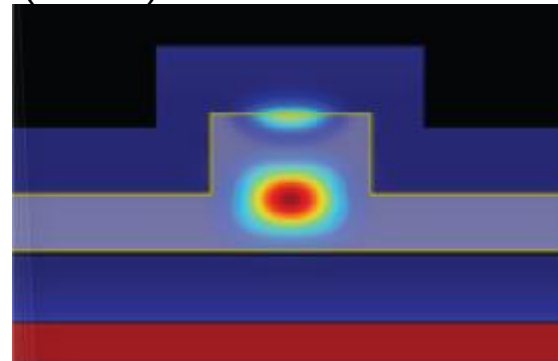
DEVICE: Powerful semiconductor TCAD device simulation software for silicon-based optoelectronic structures.

[Product Details](#) | [Trial Download](#)

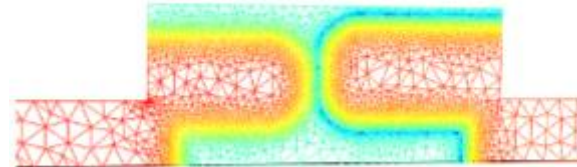
3D Maxwell solver(FDTD)



Modal analysis(MODE)

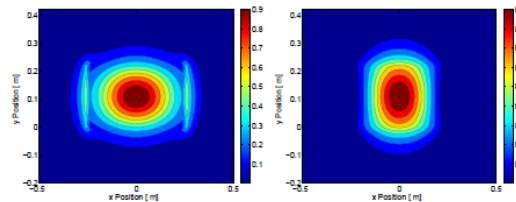


Charge transport & heat transfer(DEVICE)

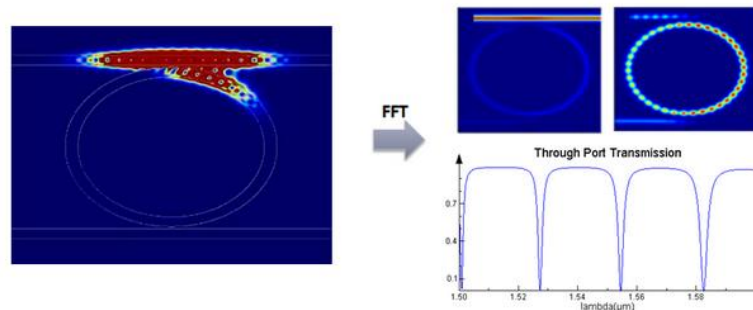


Lumerical MODE Solution

- **FDE(Finite Difference Eigenmode) solver**
 - Calculate physical properties of **waveguide modes**
 - Solve Maxwell's equations for cross-sectional mesh



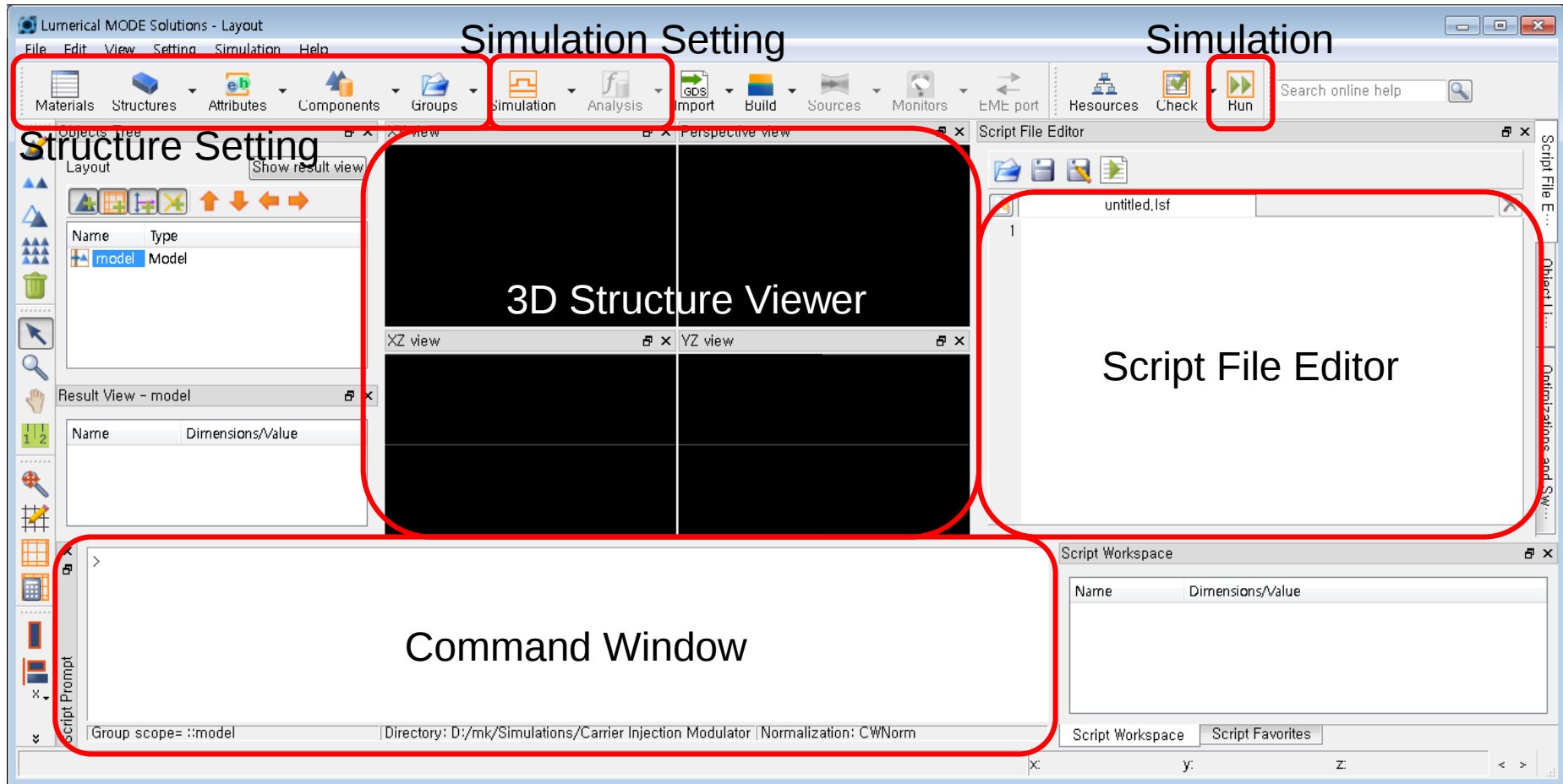
- **2.5D varFDTD(Finite Difference Time Domain)**
 - Time domain simulation with approximation**
 - 2D simulation speed with 3D accuracy



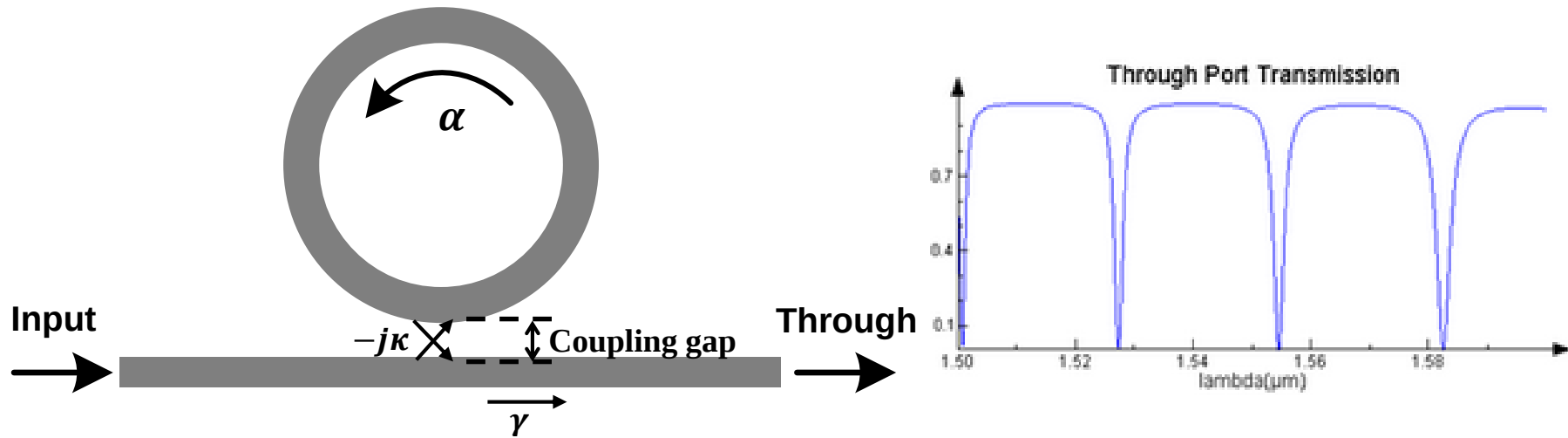
Most simulations will be held with these solvers

- **EME(Eigenmode Expansion) solver**
 - Frequency domain simulation

MODE Window



Ring Resonator

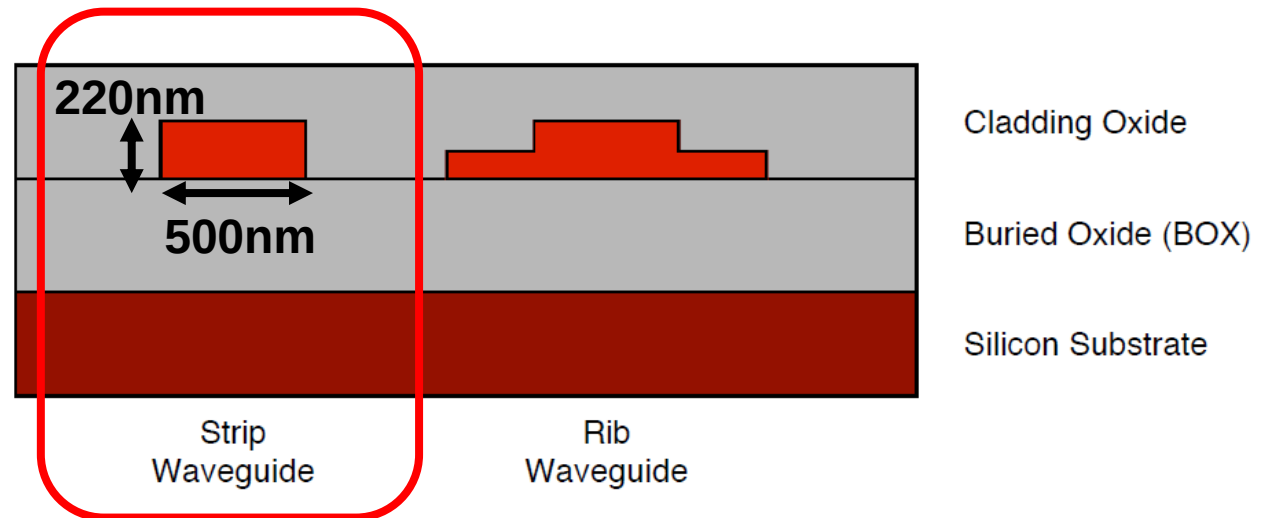


- Resonate on specific wavelength, λ_{res}
& Out of phase at through port
→ Large interference at λ_{res}
- Used in many applications
:Filters, E/O modulators, sensors, RF photonics, etc.
- Waveguide property analysis is necessary

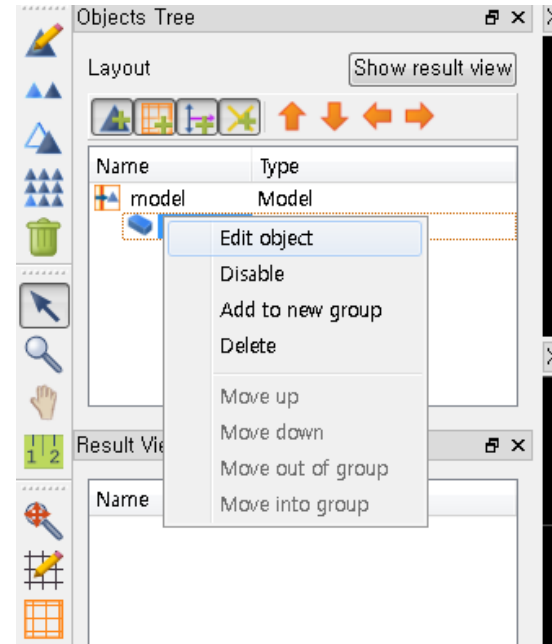
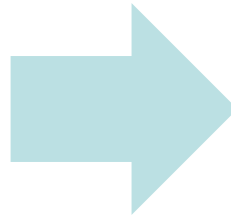
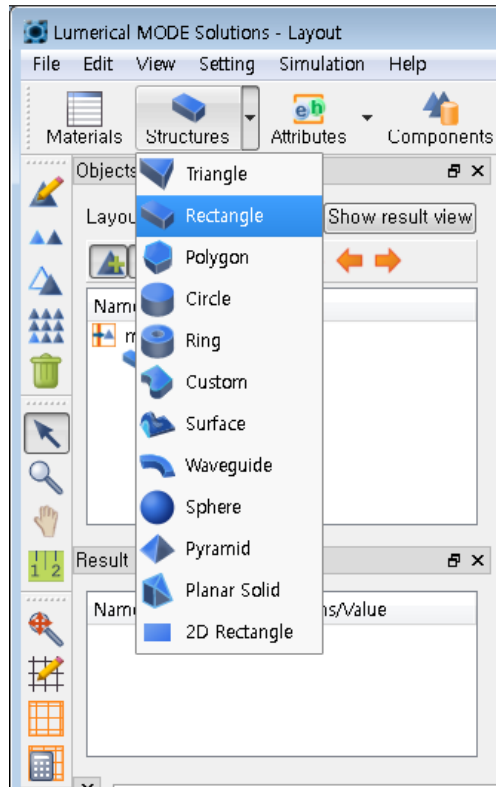
Waveguide Structure

- **Drawing structure**

- Example) Make strip waveguide
- Height: 220 nm
- Width: 500 nm
- Length: 30 μm
- Core material: Si
- Cladding material: SiO_2



Structure Build(GUI)



Structure Build(GUI)

- Cladding

name test_clad

Geometry Material Rotations Graphical rendering

x (μm) 0 x min (μm) -2
x span (μm) 4 x max (μm) 2

y (μm) 0 y min (μm) -15
y span (μm) 30 y max (μm) 15

z (μm) 0 z min (μm) -2
z span (μm) 4 z max (μm) 2

☒ use relative coordinates

OK Cancel

You can use both (x & span)
or (x min & max) for setup

name test_clad

Geometry Material Rotations Graphical rendering

Optical material

material SiO2 (Glass) - Palik
index see material database
index units microns
☒ override mesh order from material database
mesh order 3

Grid attributes

grid attribute name

OK Cancel

Mesh order: If material is folded, choose material which has smaller mesh order

name test_clad

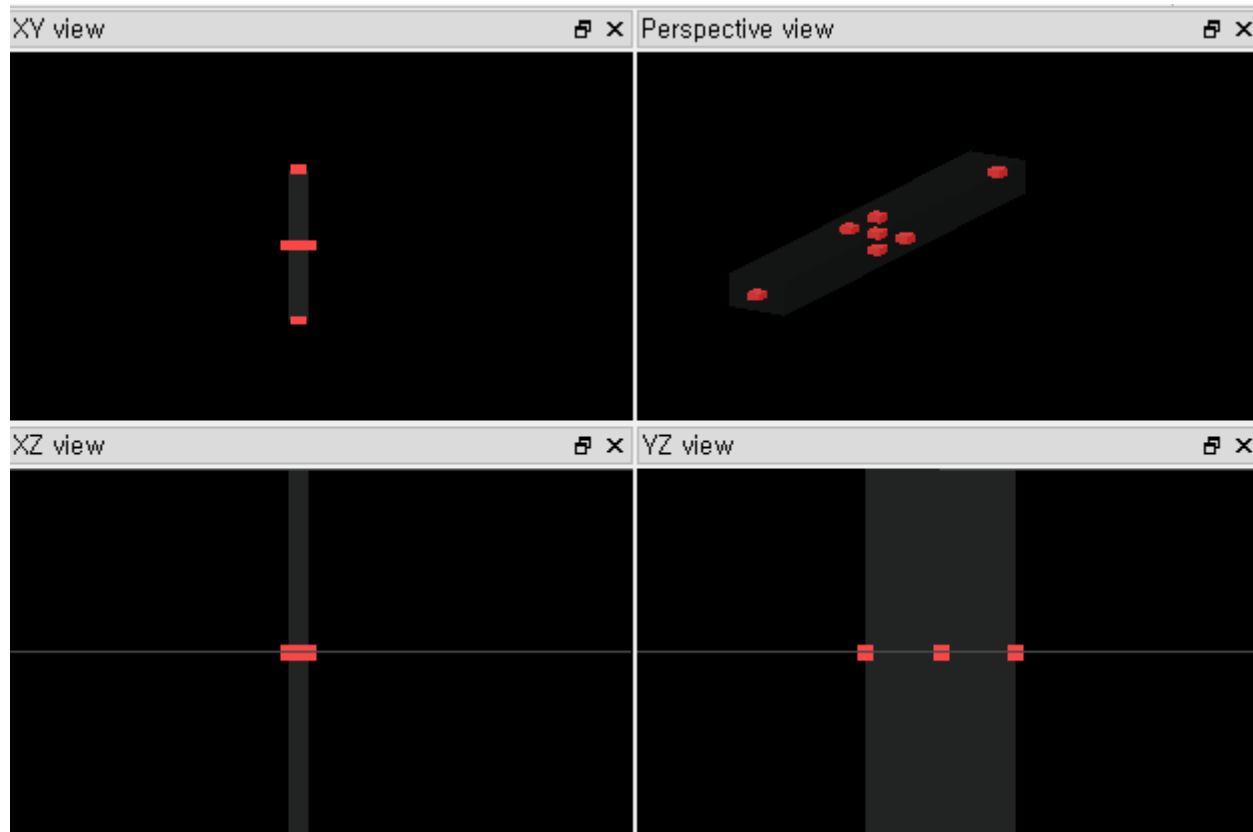
Geometry Material Rotations Graphical rendering

render type detailed
detail
☒ override color opacity from material database
alpha 0.1

OK Cancel

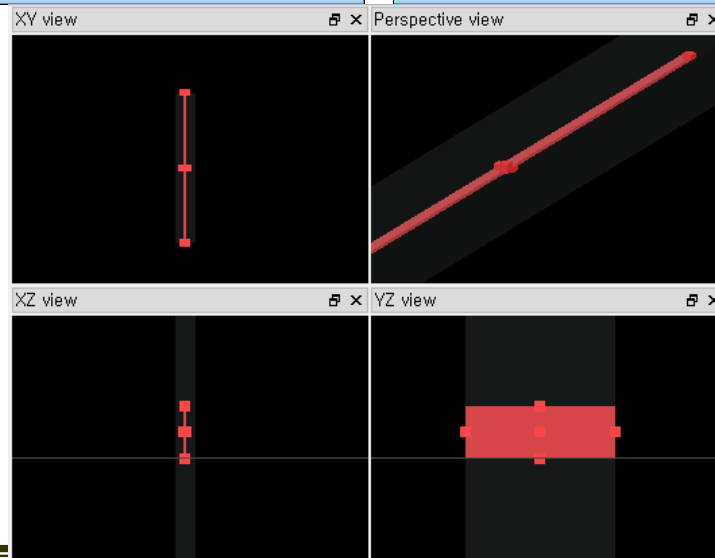
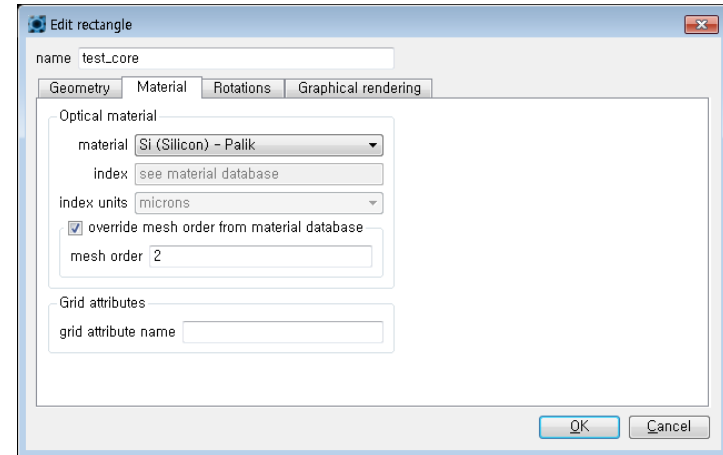
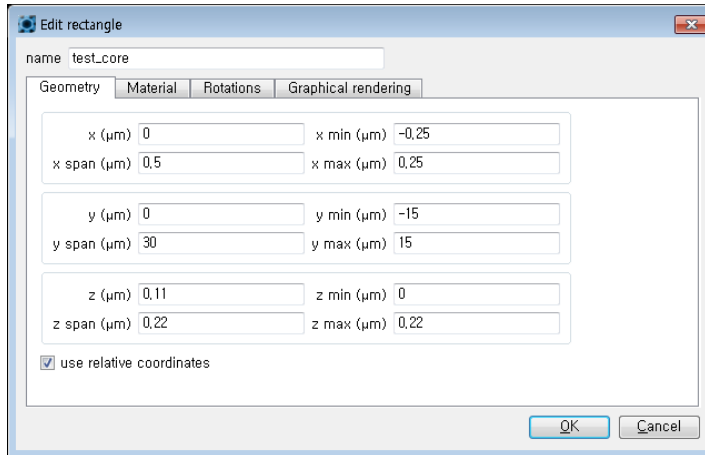
Structure Build(GUI)

- Cladding



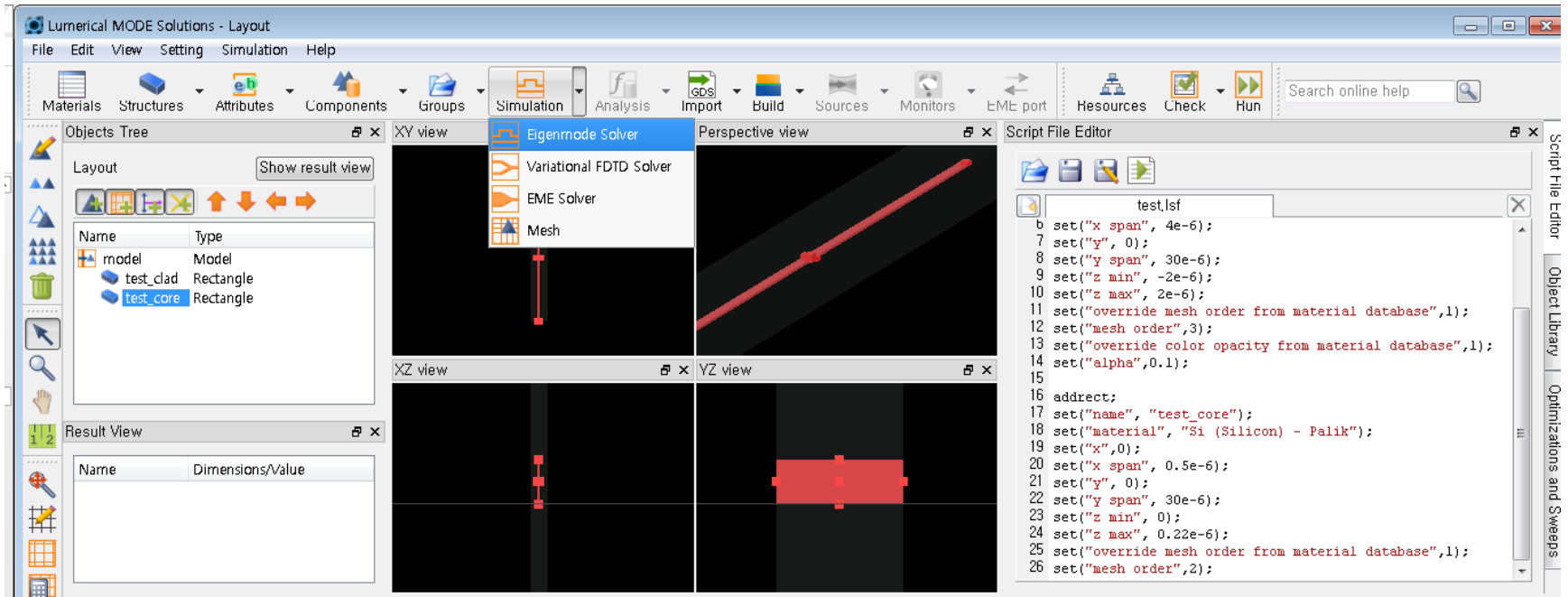
Structure Build(GUI)

- Core

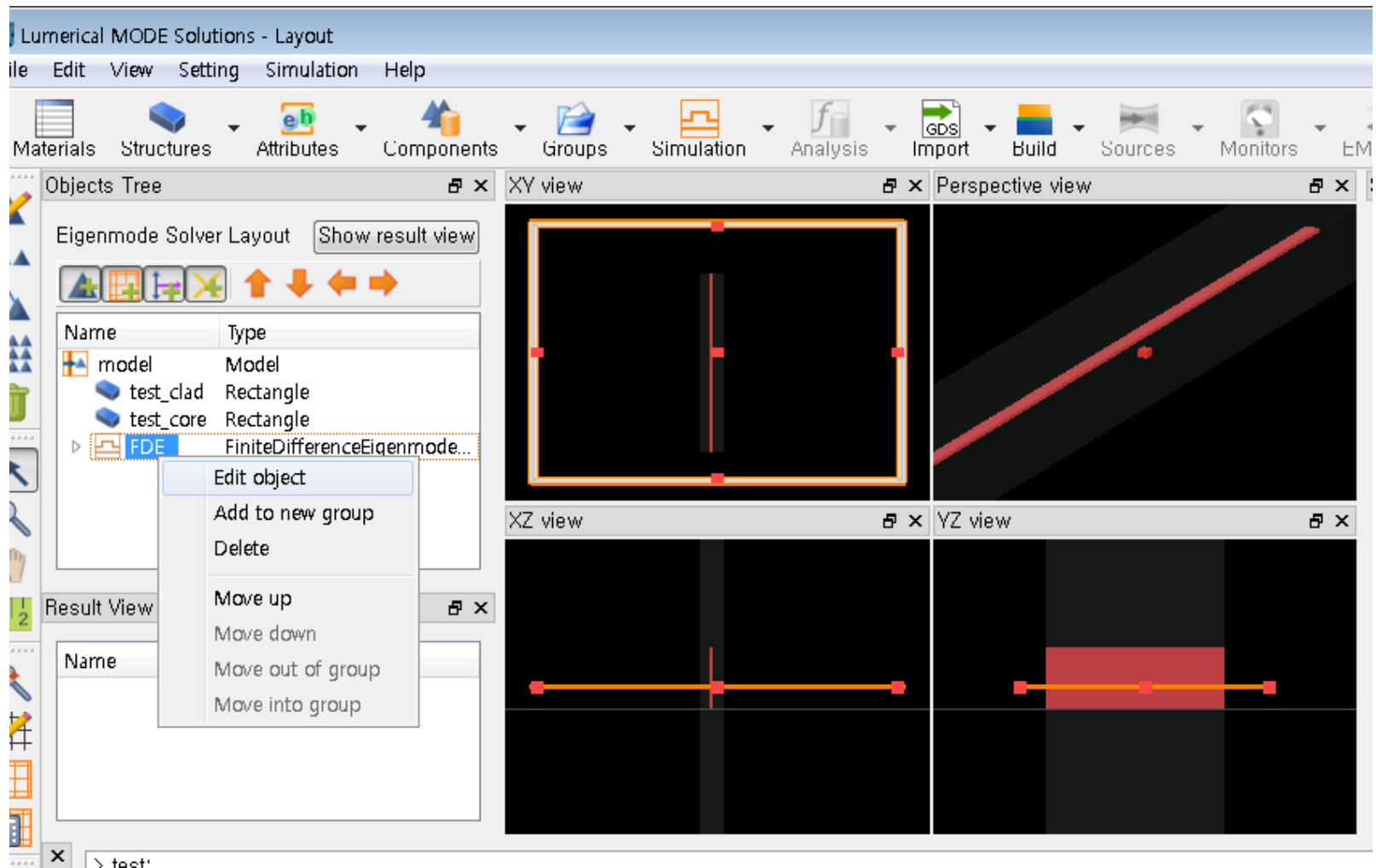


Simulation Setup(GUI)

- Eigenmode Solver



Simulation Setup(GUI)



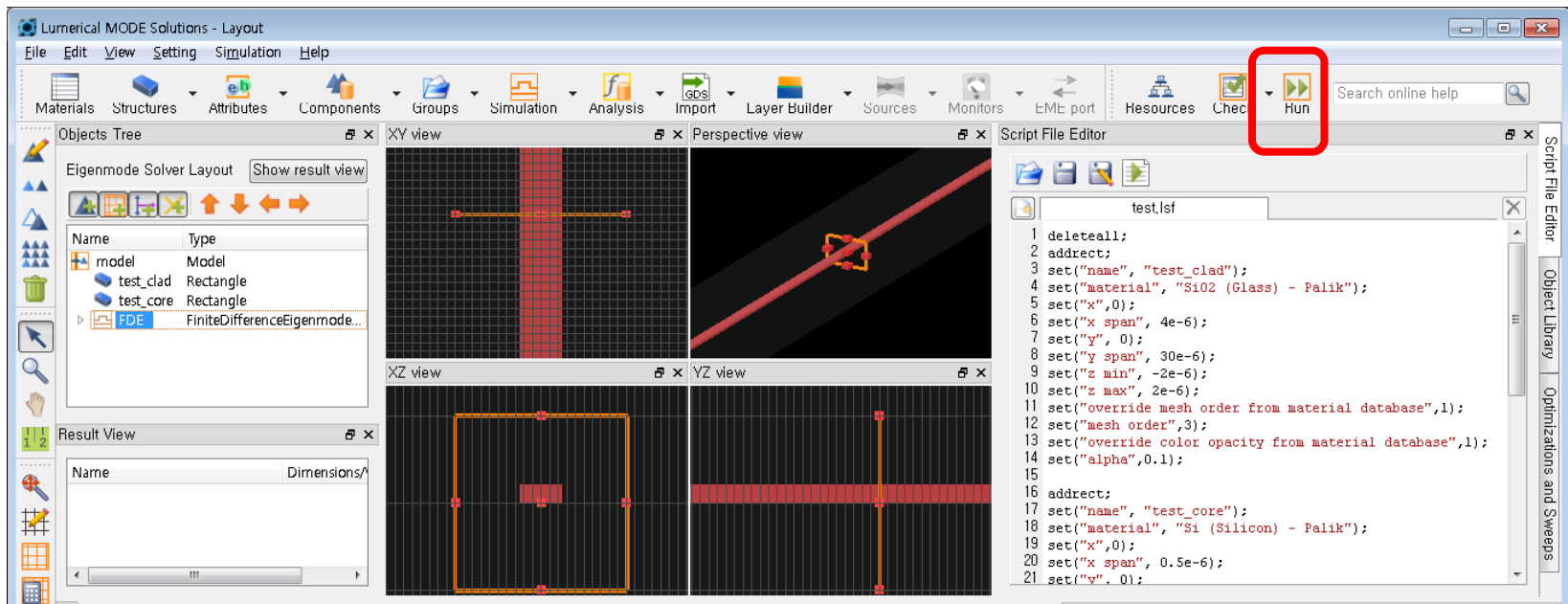
Simulation Setup(GUI)

The image displays four screenshots of the 'Edit finite difference eigenmode solver' GUI, arranged in a 2x2 grid. Each window has a title bar with a close button and a name field set to 'FDE'. The tabs are 'General', 'Geometry', 'Mesh settings', 'Boundary conditions', 'Material', and 'Advanced options'.

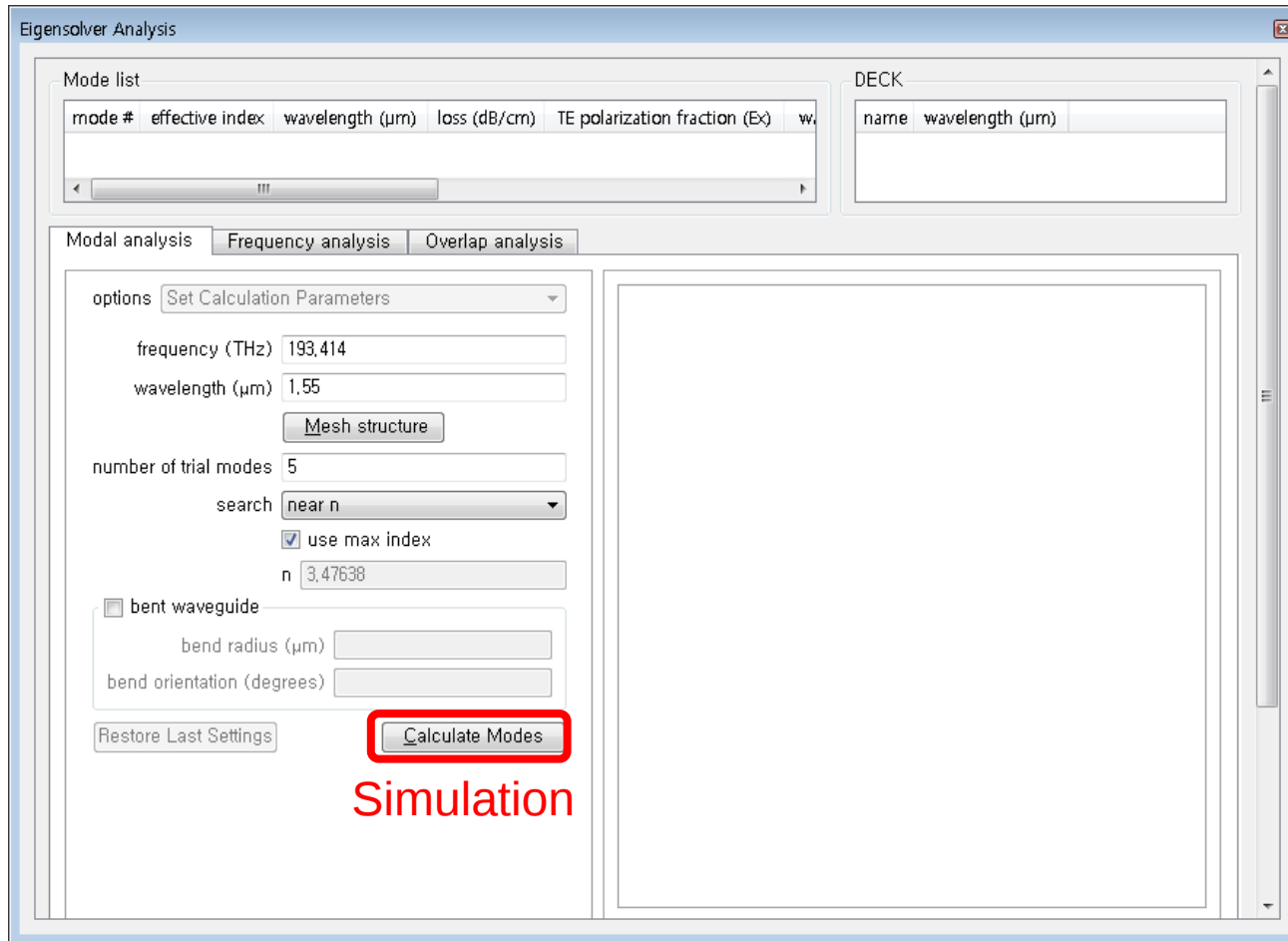
- Top-left (General tab):** Shows 'background index' set to 1, 'simulation temperature (K)' set to 300, and 'solver type' set to '2D Y normal'.
- Top-right (Geometry tab):** Shows spatial dimensions in micrometers. x: 0 to 1, x span: 2. y: 0 to 0, y span: 0. z: 0 to 1, z span: 2.
- Bottom-left (Mesh settings tab):** Shows mesh definition options. 'define x mesh by' is 'maximum mesh step', 'define y mesh by' is 'number of mesh cells', and 'define z mesh by' is 'maximum mesh step'. It also shows 'Actual number of mesh cells used' (x: 200, y: 0, z: 200) and 'Maximum mesh step settings' (dx: 0.01, dy: 0, dz: 0.01).
- Bottom-right (Boundary conditions tab):** Shows boundary conditions for all six faces (x min, x max, y min, y max, z min, z max) set to 'Metal'. There is an unchecked checkbox for 'allow symmetry on all boundaries'.

Each window has 'OK' and 'Cancel' buttons at the bottom.

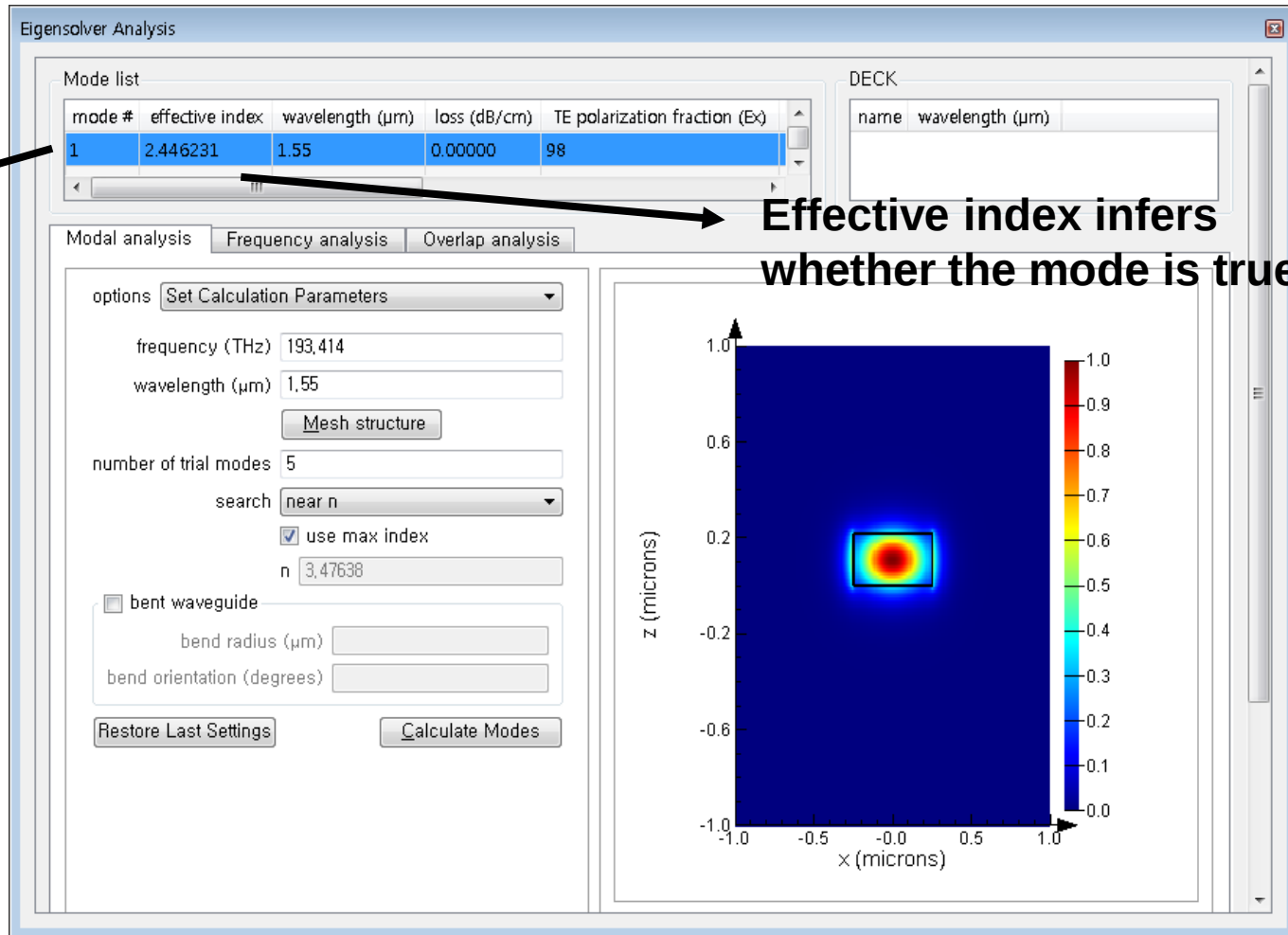
Simulation Setup(GUI)



Simulation Setup(GUI)



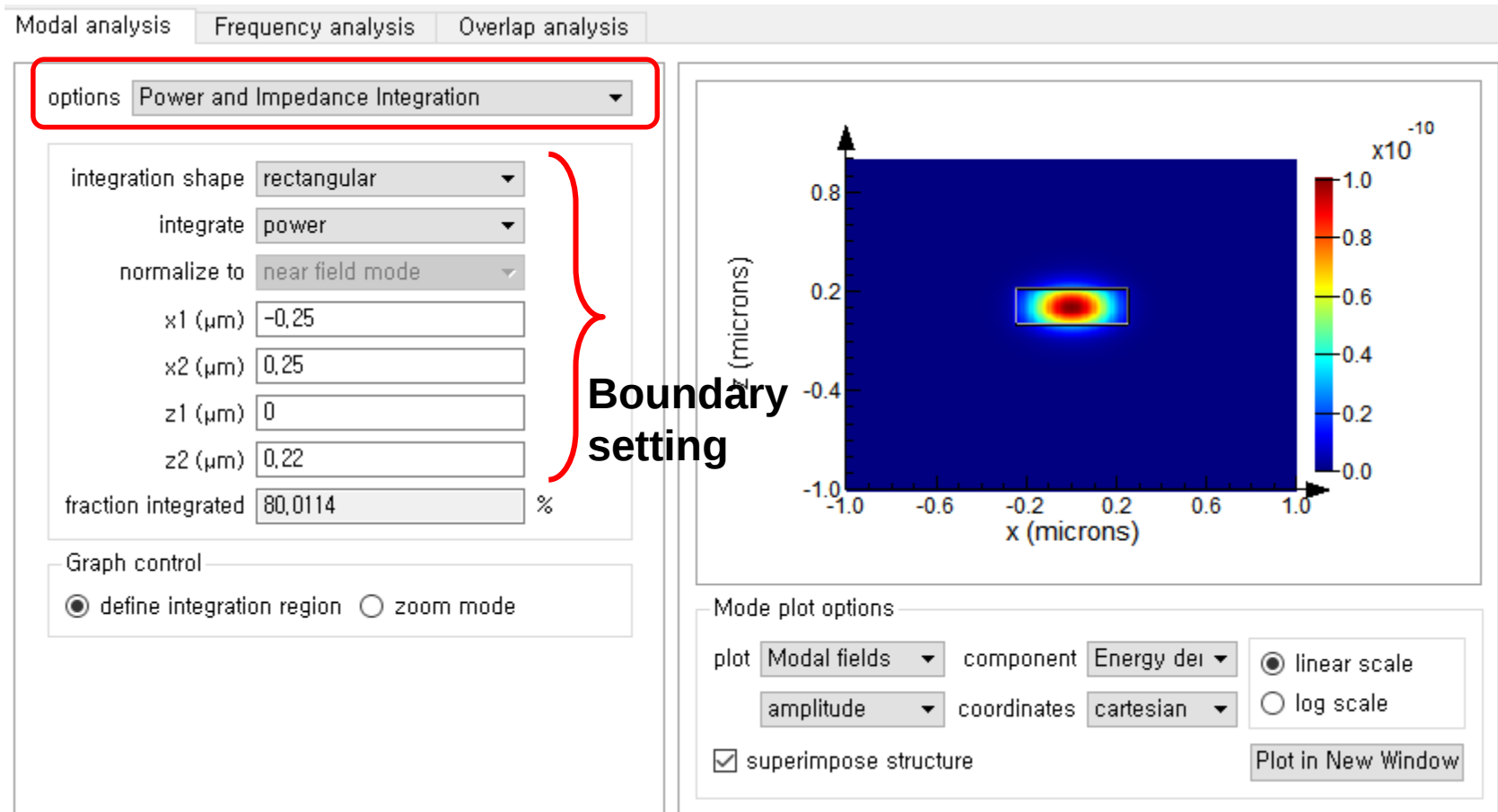
MODE Solutions



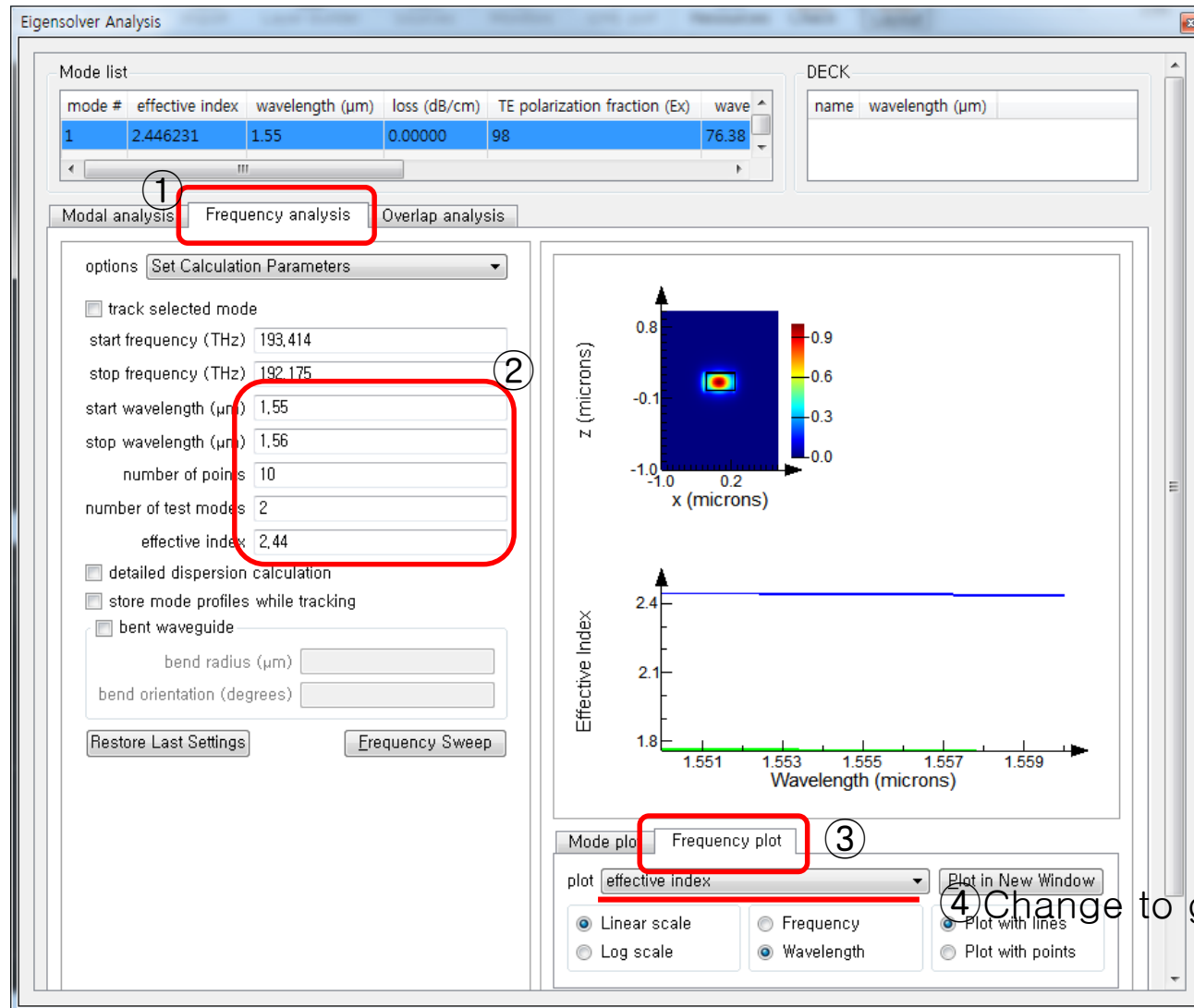
Calculated modes

Effective index infers whether the mode is true or not

Confinement Factor



Group Index(n_g)



Sweep Width

Sweep waveguide width from 100nm to 300nm with 50nm step

Name:

Parameters

Type: Number of points:

Name	Parameter	Type	Start	Stop	Units
width	::model::core::x span	Length	0.1	0.3	microns

Results

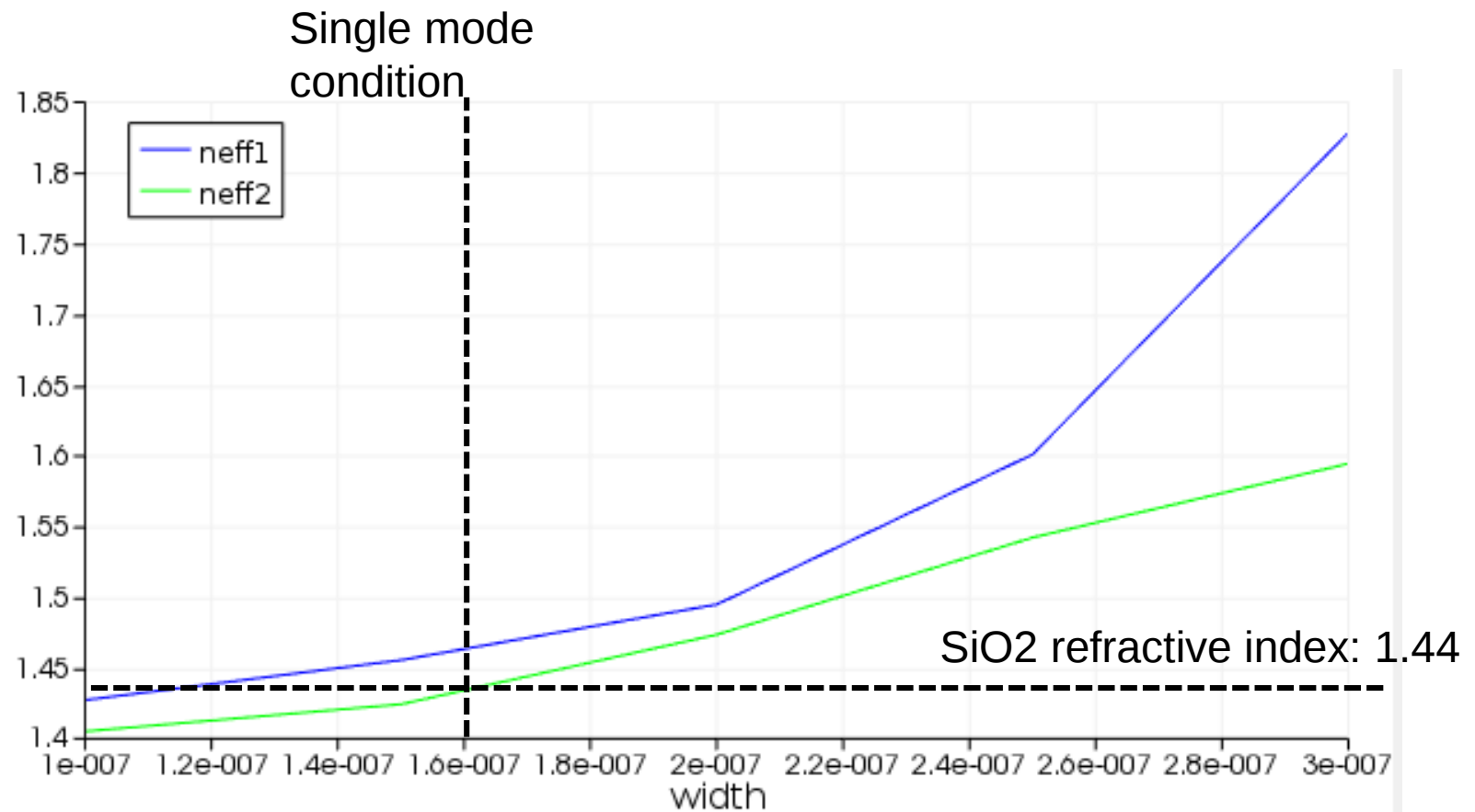
Name	Result	Operation
neff1	::model::FDE::data::mode1::neff	
neff2	::model::FDE::data::mode2::neff	

To verify single mode condition

Advanced

☐ resave files after analysis

Sweep Results

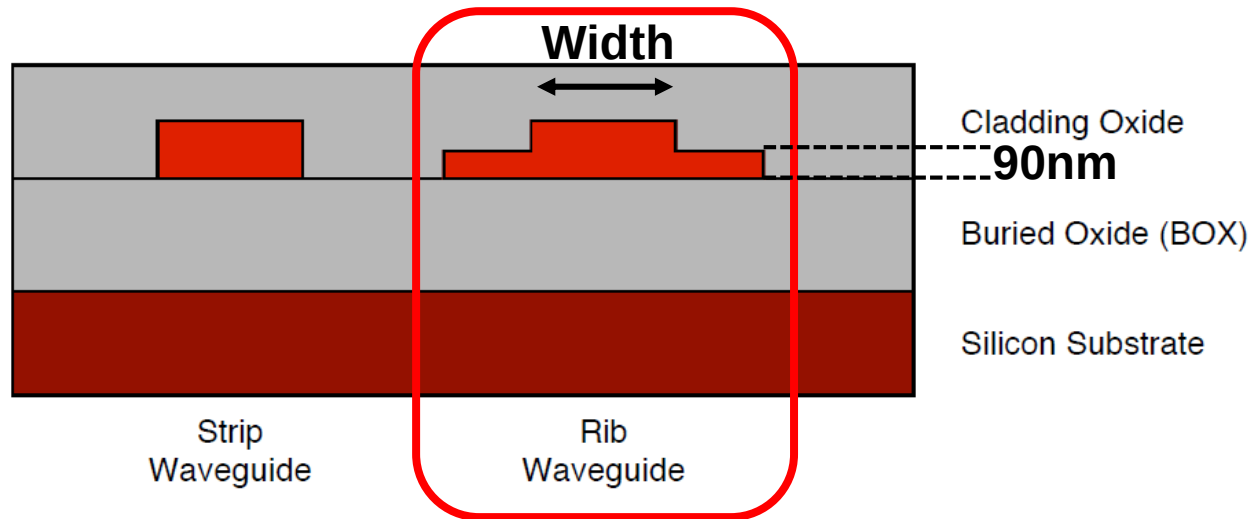


Design Exercise 2-1

What is the single-mode condition for the given thickness of rib waveguide? Also, calculate group index(n_g) for the single-mode rib waveguide.

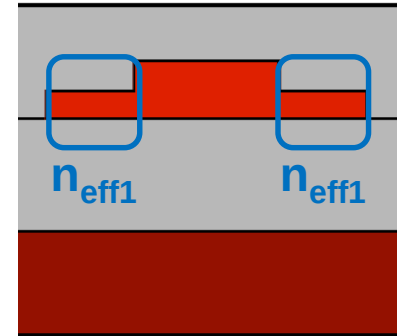
-220nm thick & 90nm slab at 1550nm

Due: 30 Nov. in class

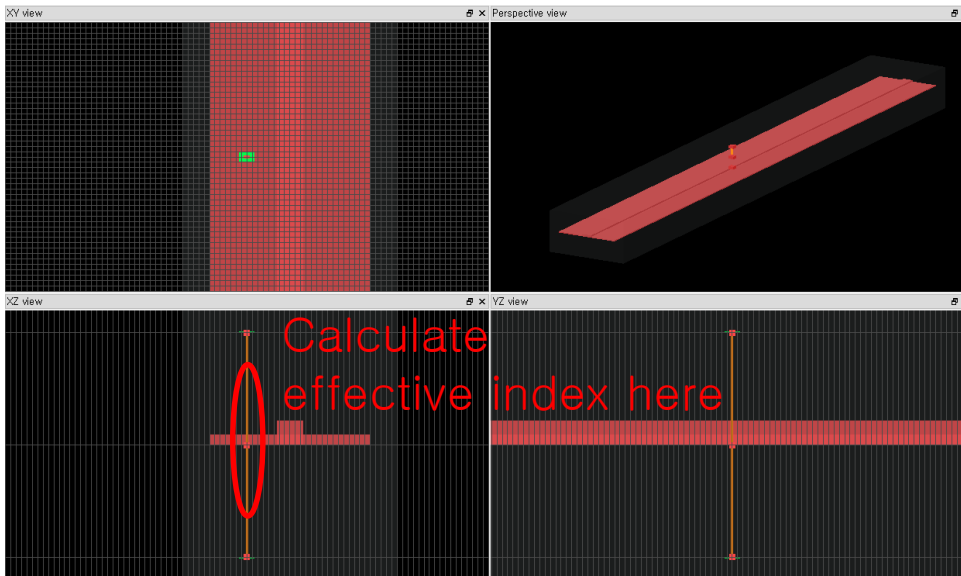


Design Exercise 2-1

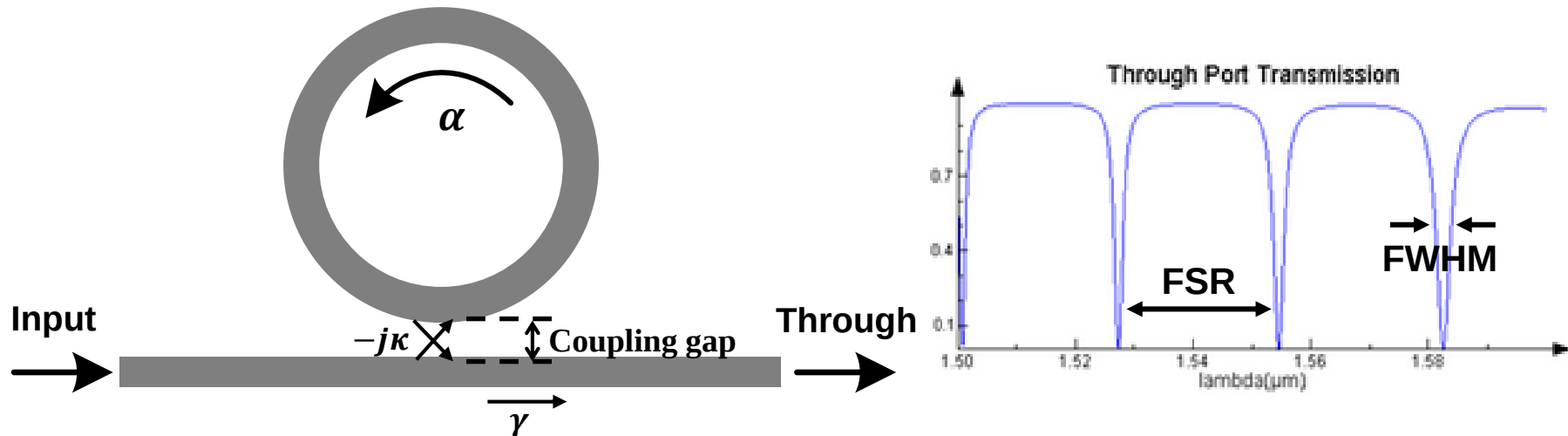
- Condition for guidance of rib waveguide
: $n_{\text{eff_total}} > n_{\text{eff1}}$
: Making same environment as strip waveguide
- How to get n_{eff1}
: Use 1-D Z:X prop simulation in FDE solver



Rib
Waveguide

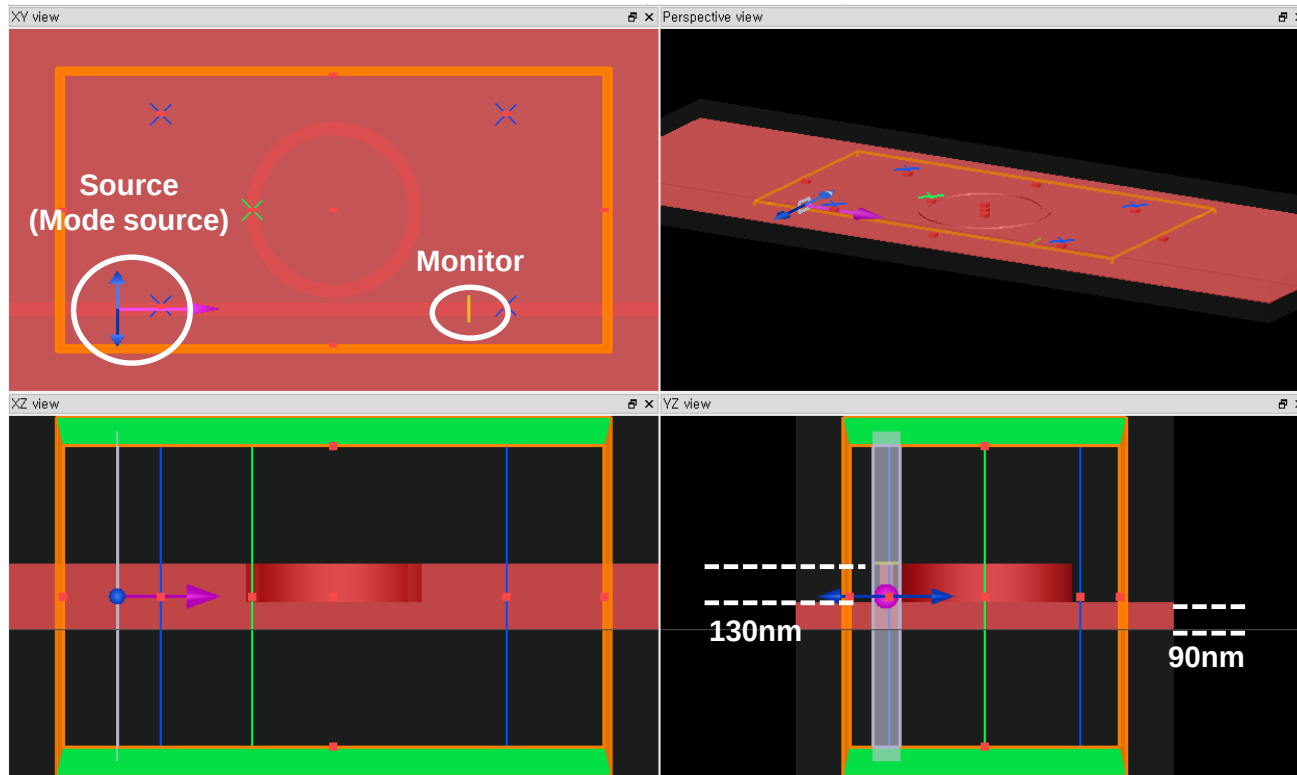


Ring Resonator



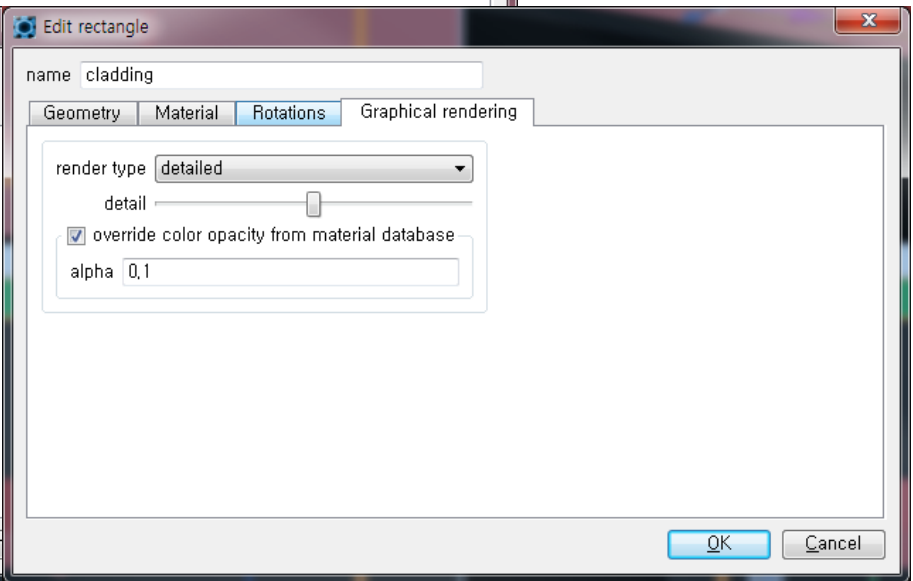
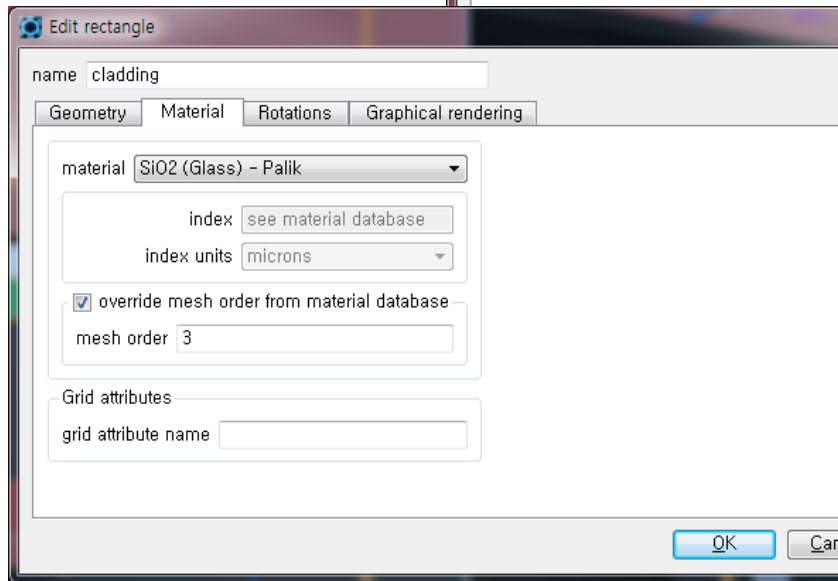
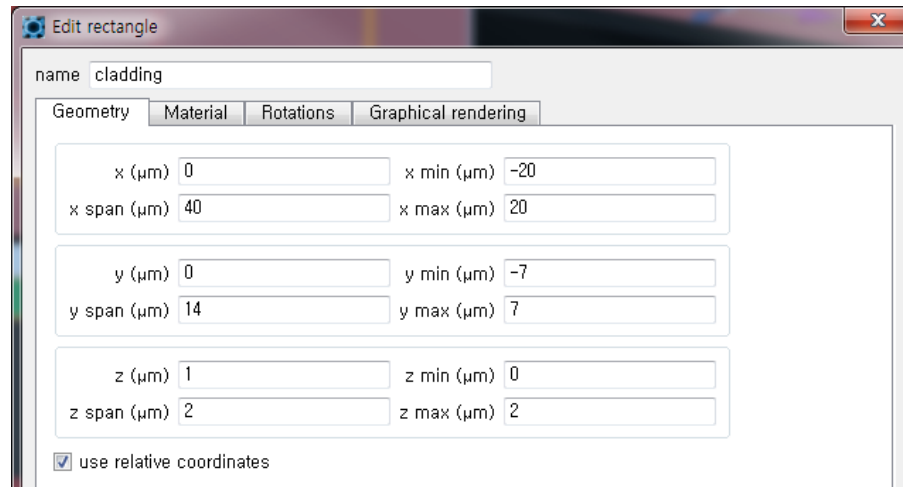
- Resonate on specific wavelength, λ_{res}
- Key parameters : α, γ, κ and assume $|\gamma|^2 + |\kappa|^2 = 1$
- $FSR = \frac{\lambda_{res}^2}{n_g L}$, $FWHM = \frac{(1-\alpha)\lambda_{res}^2}{\pi n_{eff} L \sqrt{\alpha\gamma}}$
- $\alpha, \gamma, n_{eff}, n_g$ are determined by simulation
- ➔ FSR, FWHM(Full-Width Half Maximum) can be calculated

Structure

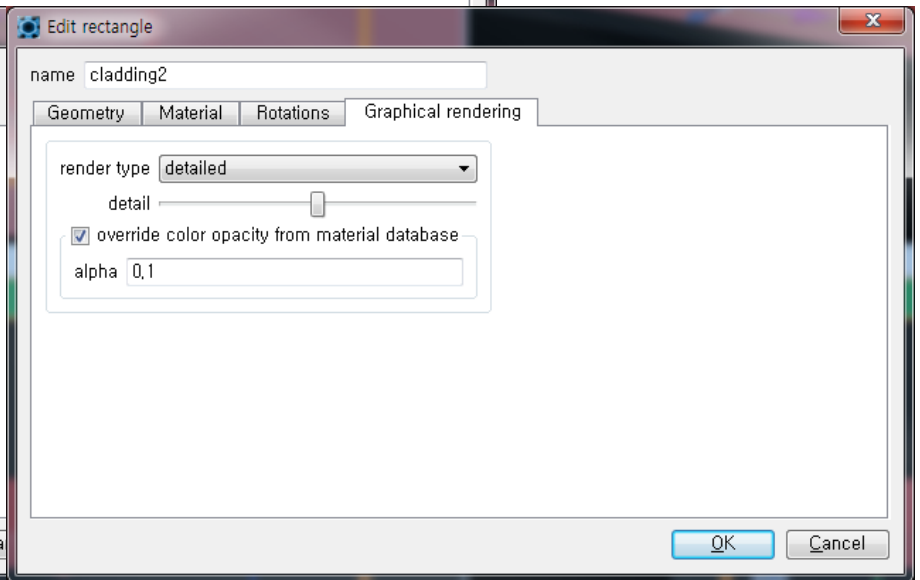
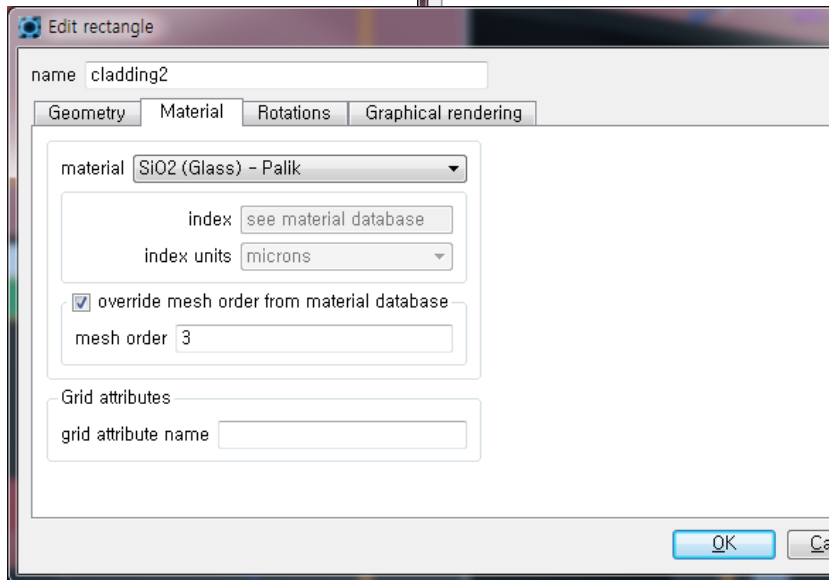
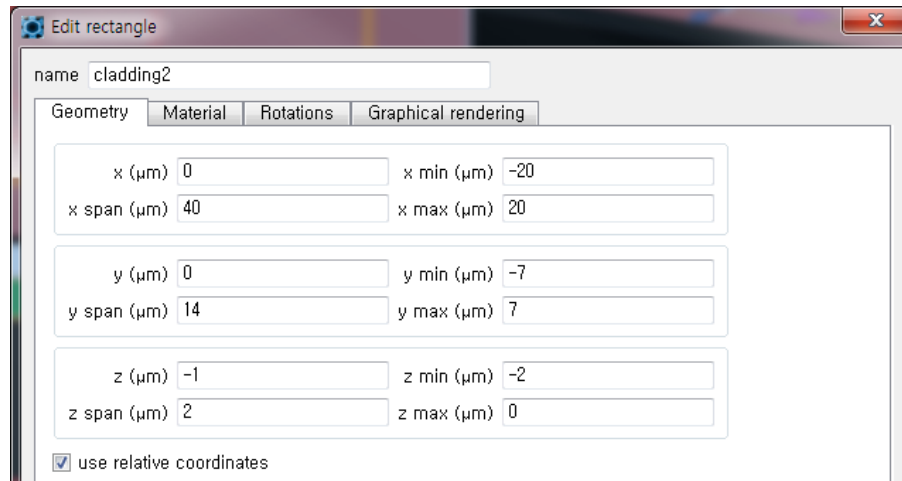


- Rib waveguide
 - Width : 500nm
 - Thick : 220nm
 - Slab : 90nm
- Resonator
 - gap : 150nm
 - radius : 3 μ m

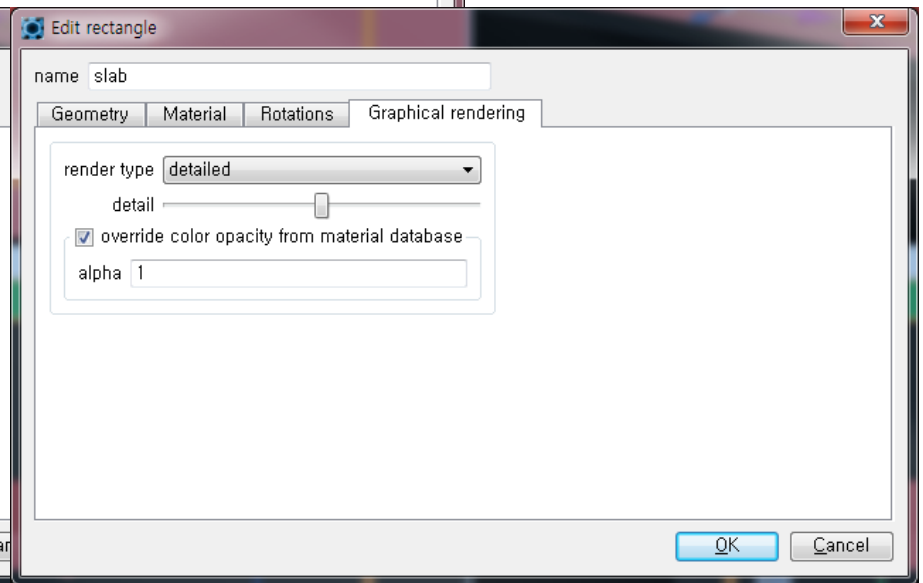
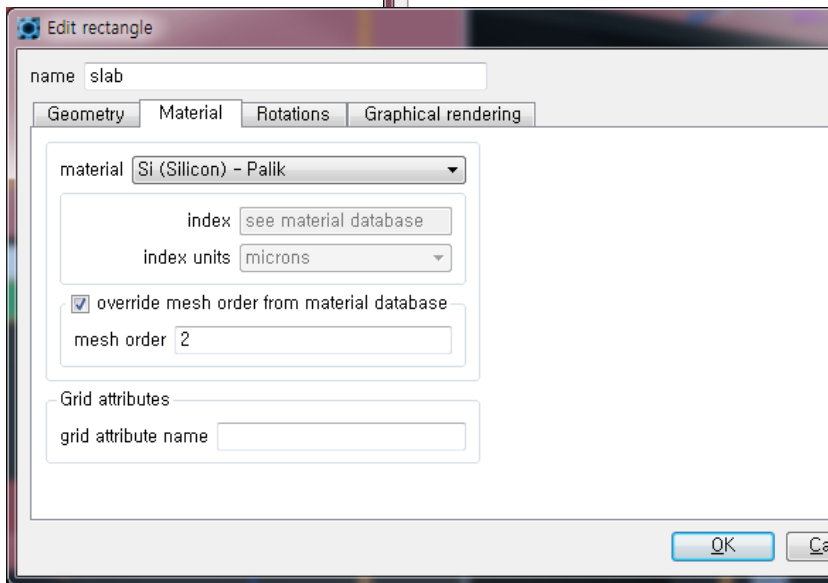
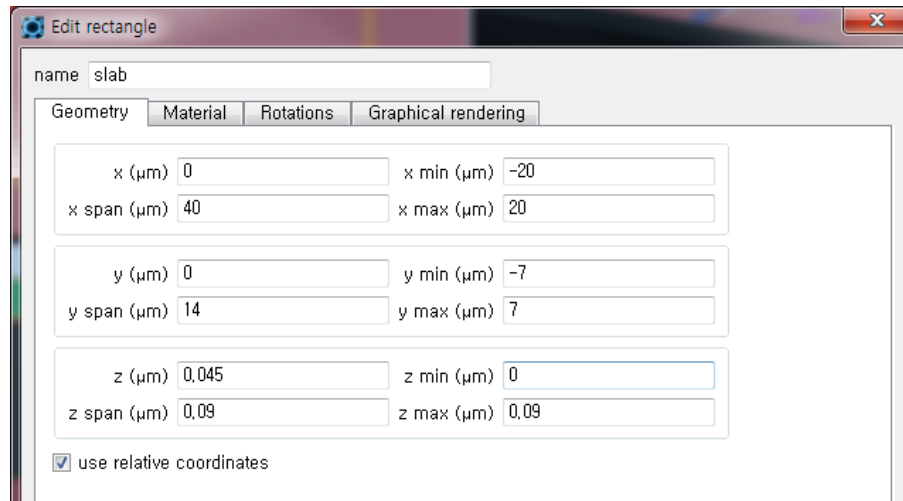
Structure(Cladding)



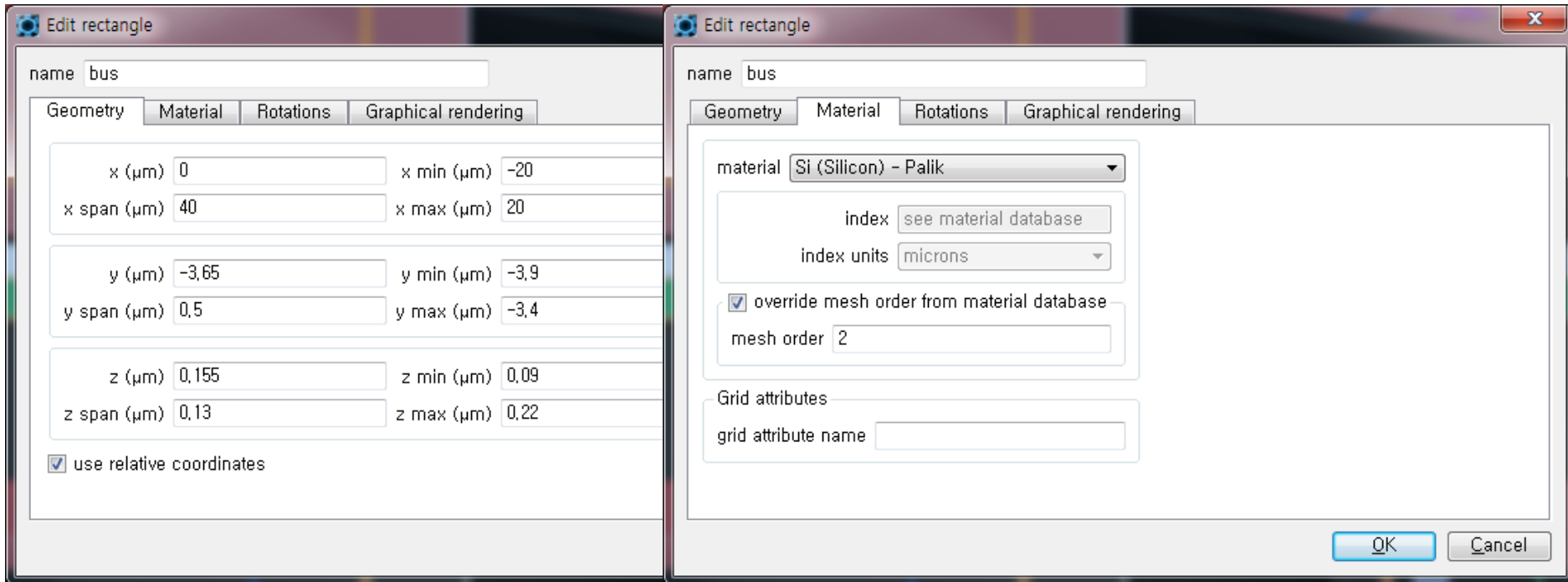
Structure(Cladding2)



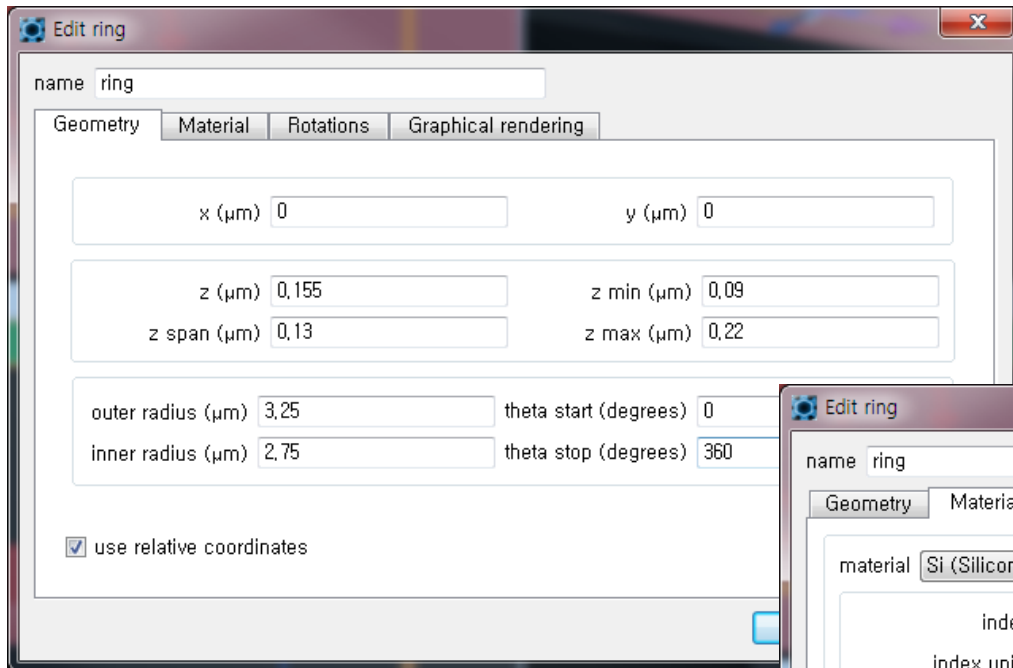
Structure(Slab)



Structure(Bus Waveguides)



Structure(Ring)



name ring

Geometry Material Rotations Graphical rendering

x (μm) 0 y (μm) 0

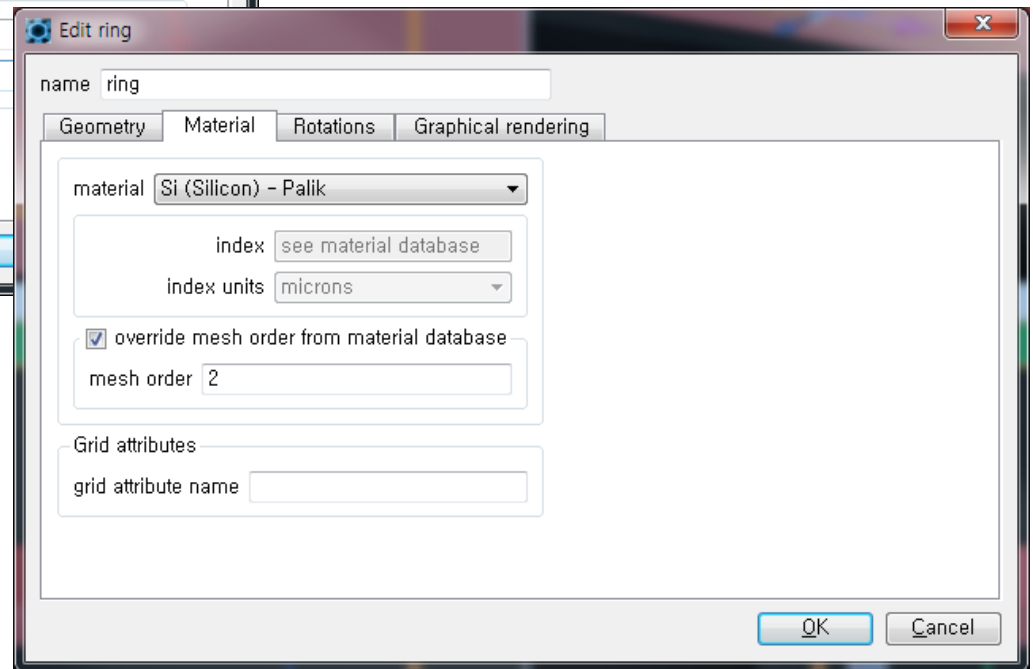
z (μm) 0.155 z min (μm) 0.09

z span (μm) 0.13 z max (μm) 0.22

outer radius (μm) 3.25 theta start (degrees) 0

inner radius (μm) 2.75 theta stop (degrees) 360

☒ use relative coordinates



name ring

Geometry Material Rotations Graphical rendering

material Si (Silicon) - Palik

index see material database

index units microns

☒ override mesh order from material database

mesh order 2

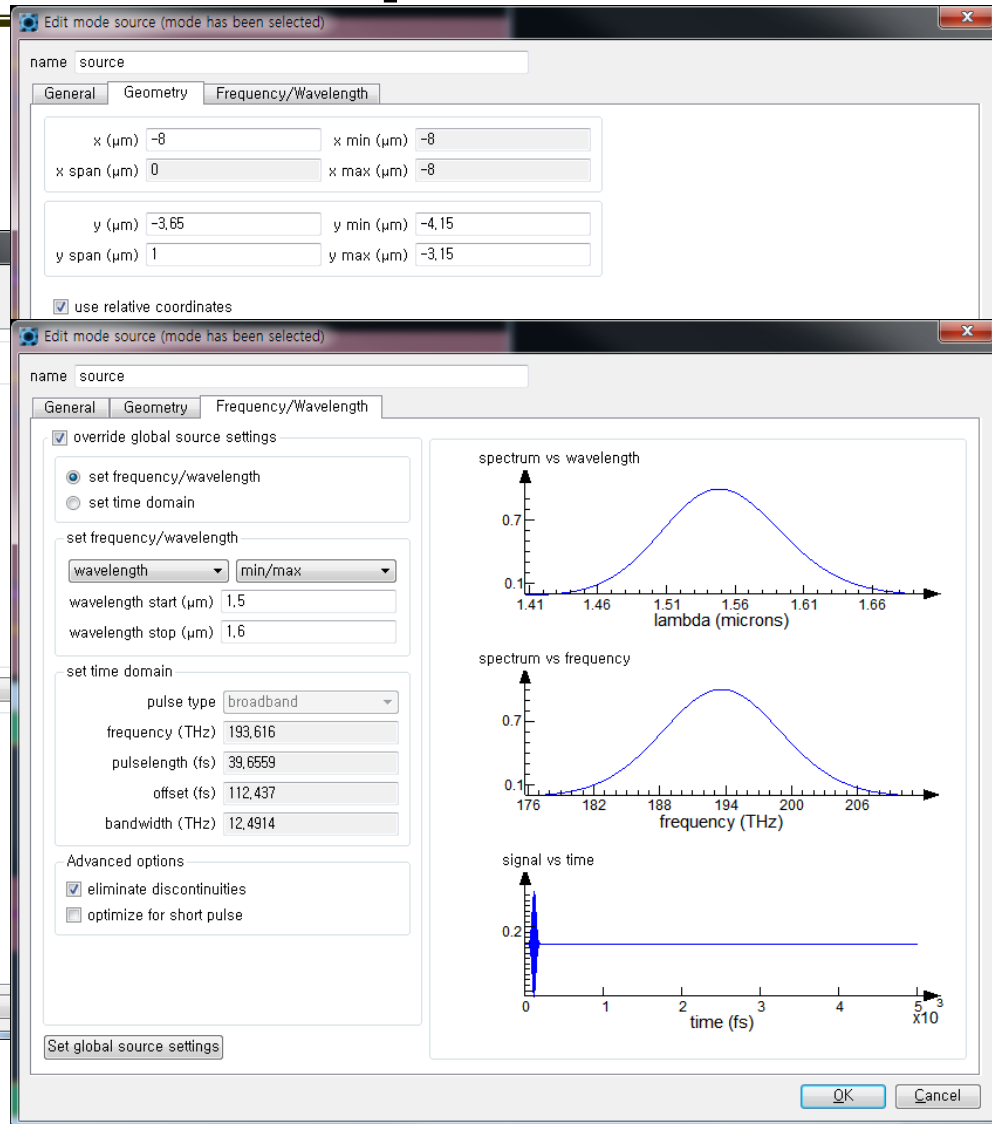
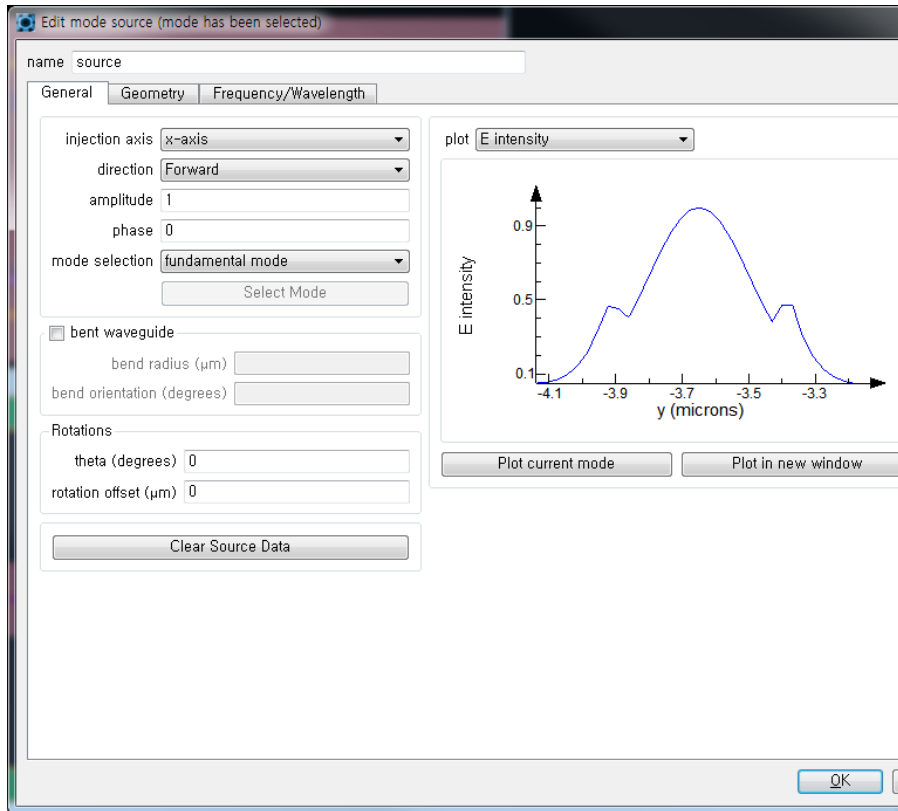
Grid attributes

grid attribute name

OK Cancel

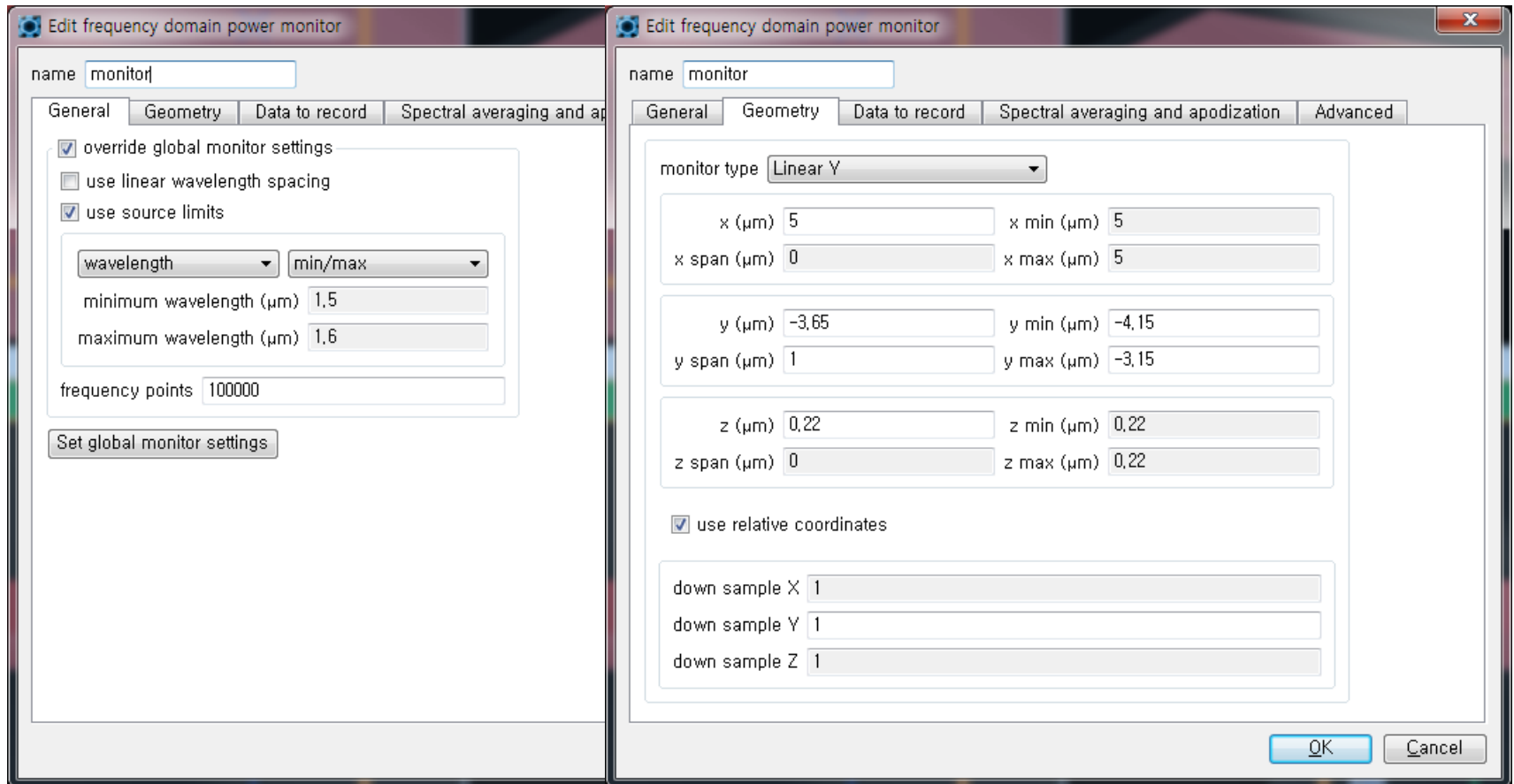
Simulation setup

- Source Setting (MODE source)



Simulation Setup

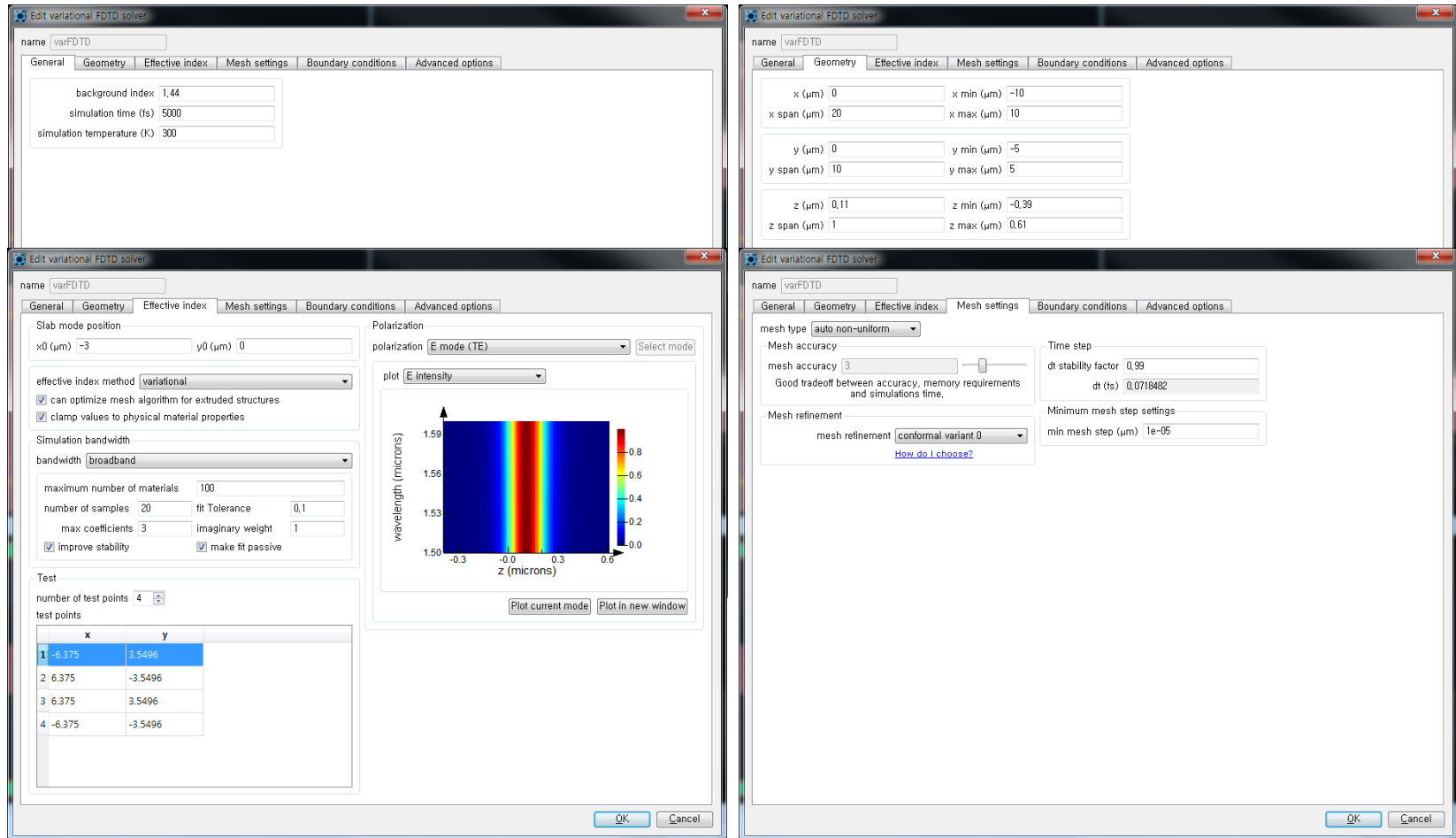
- **Monitor Setting(Frequency domain field and power)**



-Frequency point should be large enough

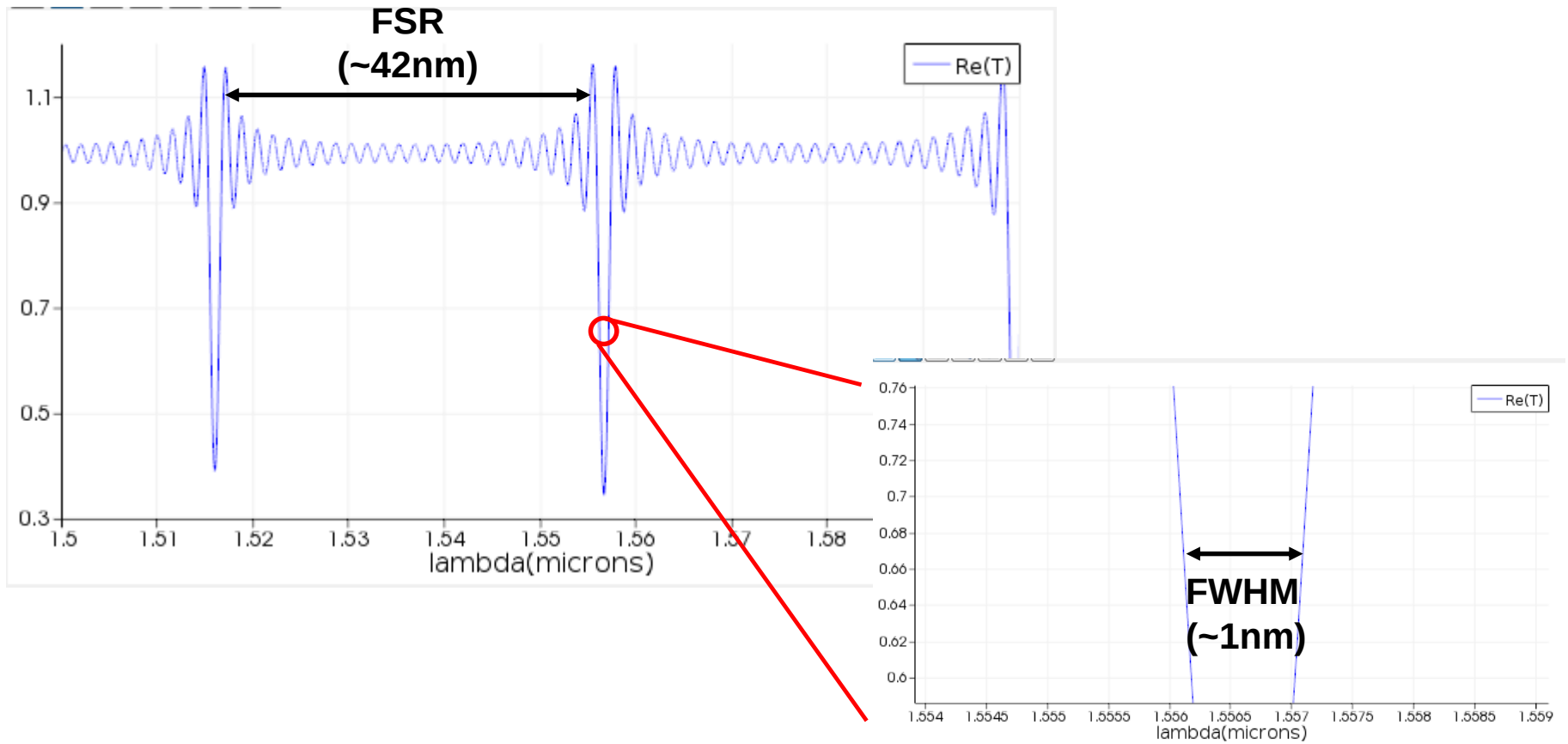
Simulation Setup

- 2.5D FDTD Solver Setting(Variational FDTD Solver)



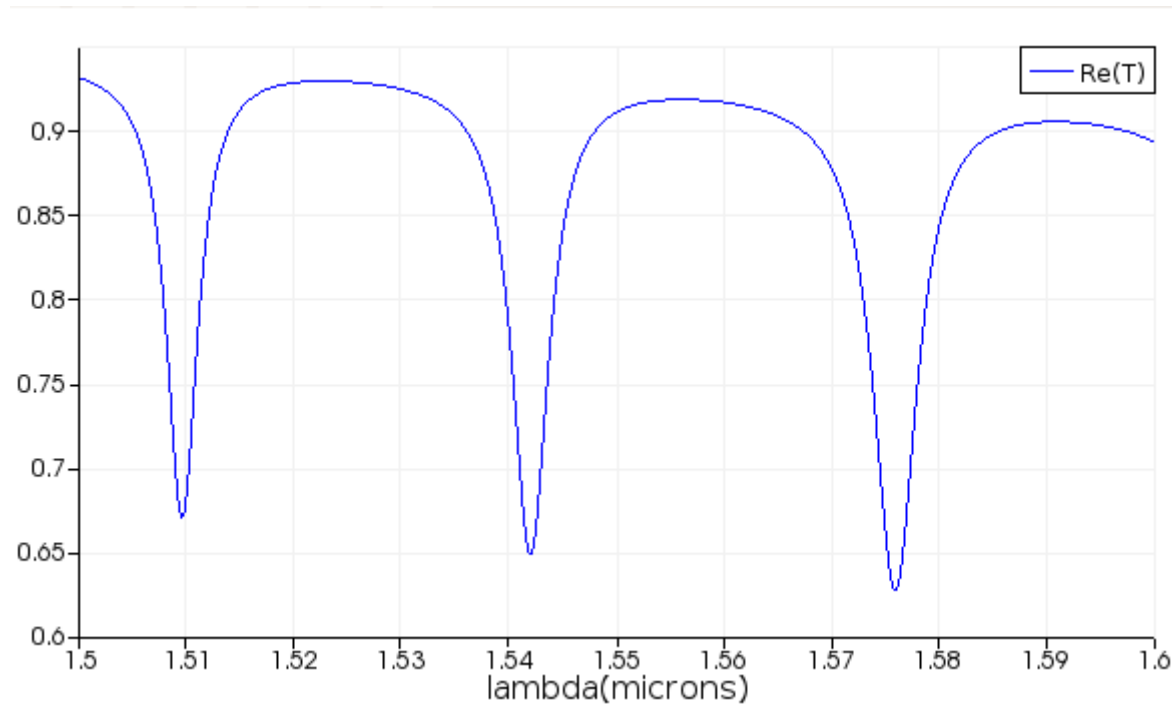
Transmission Curve

- Simulation Result



FDTD Simulation Comparison

- Same simulation condition
- Source: z span 500nm, z center 110nm
- Monitor: 2D X-normal monitor, z span 500nm, z center 110nm
- Simulation: 3D, 5000fs simulation time



Design Exercise 2-2

Use the rib waveguide designed in Design Exercise 2-1, and design & analyze ring resonator with MODE to satisfy specification below. Also, compare & analyze the result with FDTD simulation.

$$FSR > 40nm$$

$$FWHM < 0.8nm$$

$$1.55\mu m \text{ wavelength}$$

Due: 30 Nov. in class