

The background features a large, light blue watermark of the Yonsei University logo. The logo is circular with the text 'YONSEI UNIVERSITY' around the top and '1885' at the bottom. In the center is a shield with a white circle and a white triangle.

Waveguide and Directional Coupler 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 omnidirectional broadband propagator design software.

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



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

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



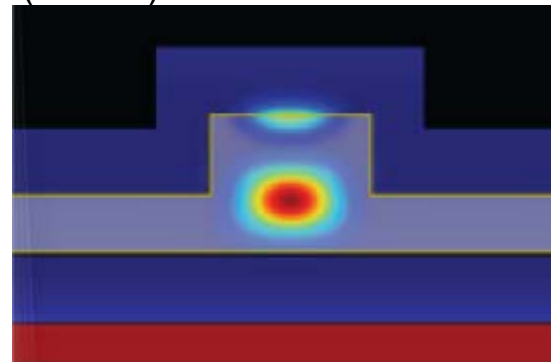
DEVICE: Powerful semiconductor TCAD device simulation software for silicon-based optoelectronic structures.

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

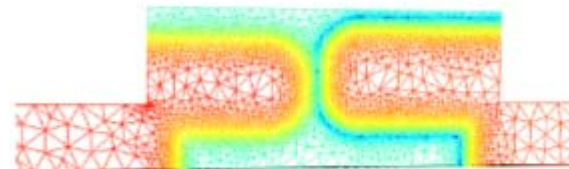
3D Maxwell solver(FDTD)



Modal analysis(MODE)

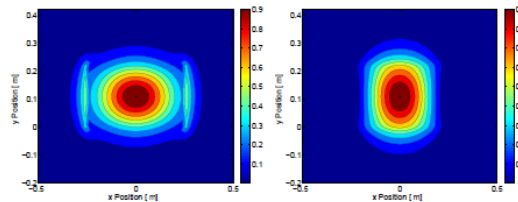


Charge transport & heat transfer(DEVICE)

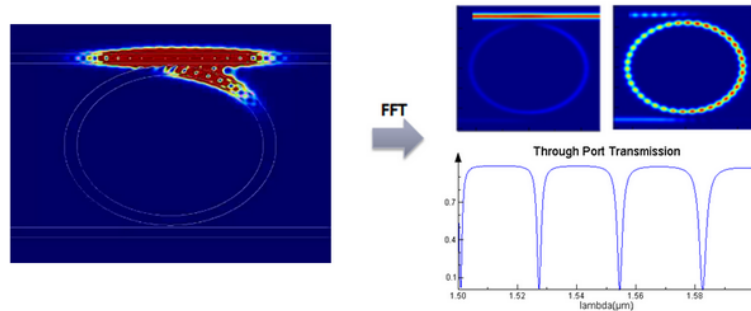


Lumerical MODE Solution

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



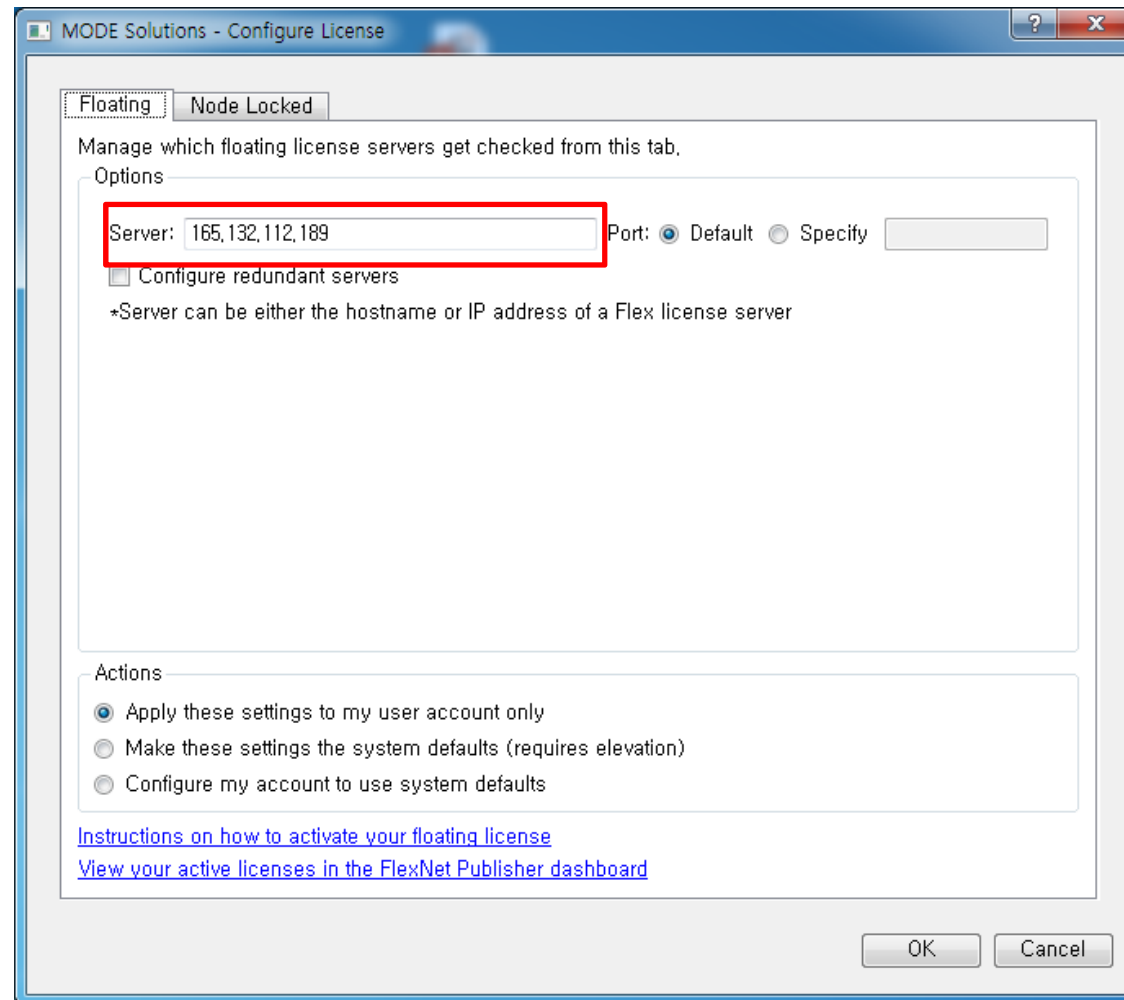
- **2.5D varFDTD(Finite Difference Time Domain)**
 - Time domain simulation with approximation**
 - 2D simulation speed with 3D accuracy



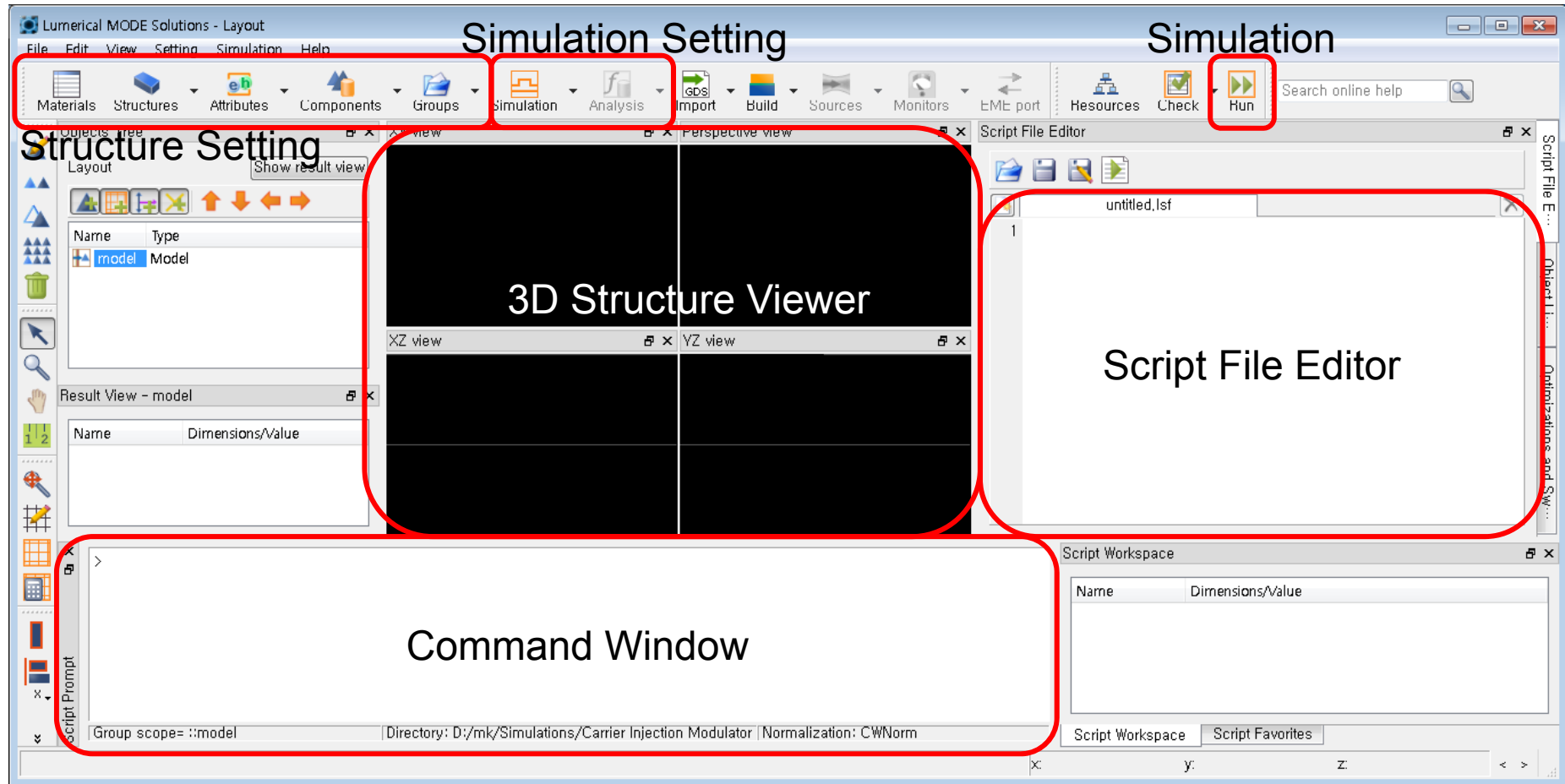
- **EME(Eigenmode Expansion) solver**
 - Frequency domain simulation

Most simulations will be held with these solvers

License Setting



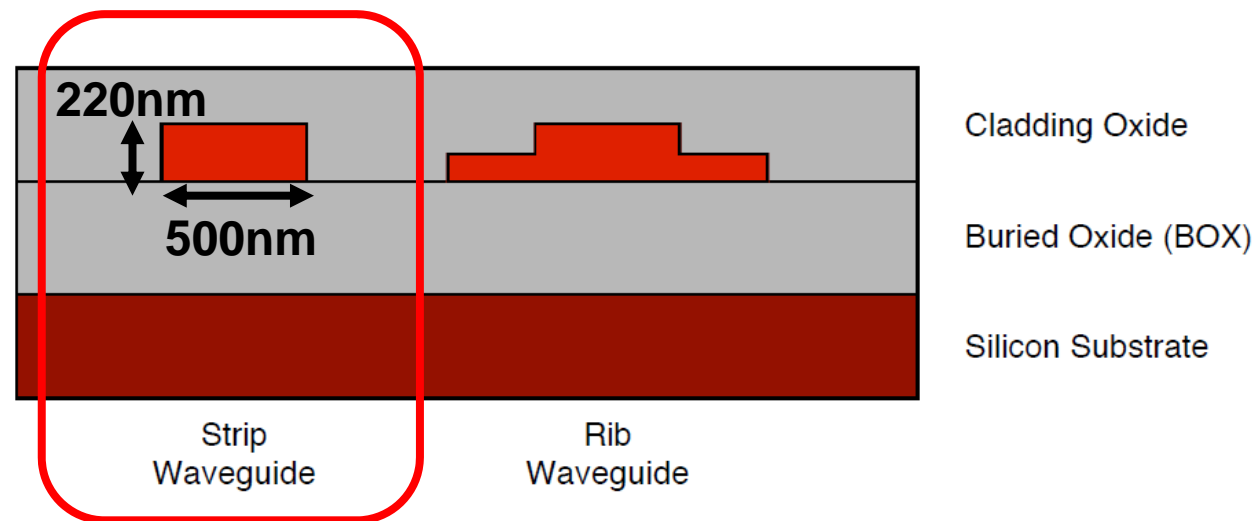
MODE Window



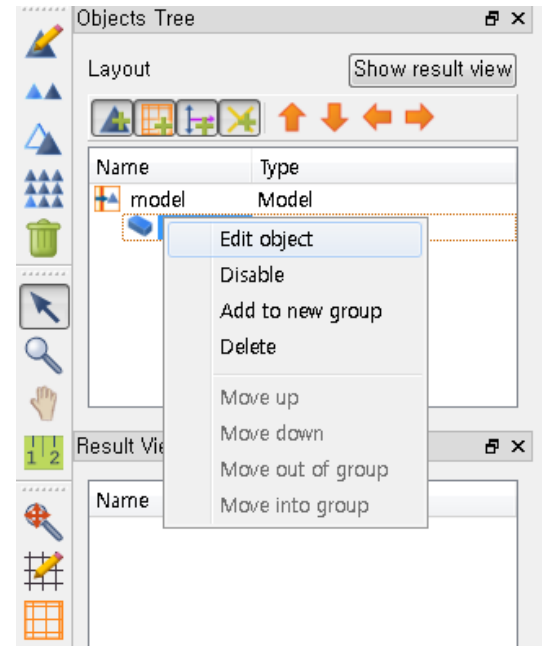
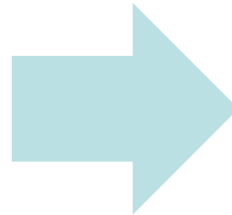
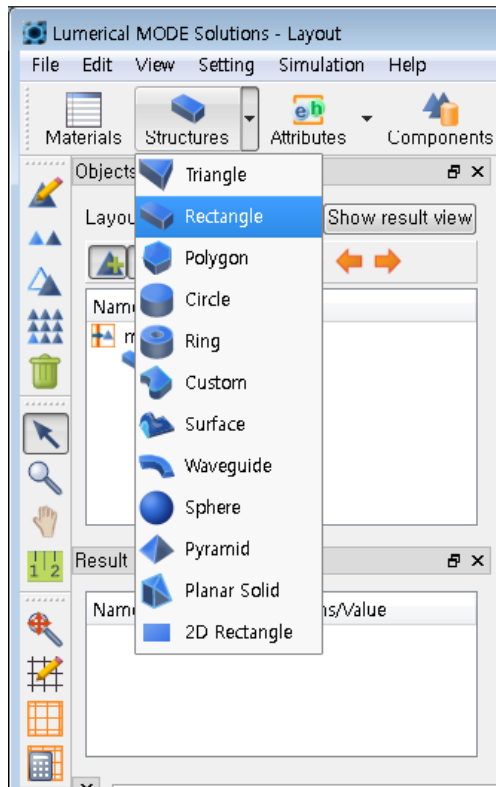
Waveguide Structure

- **Drawing structure**

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

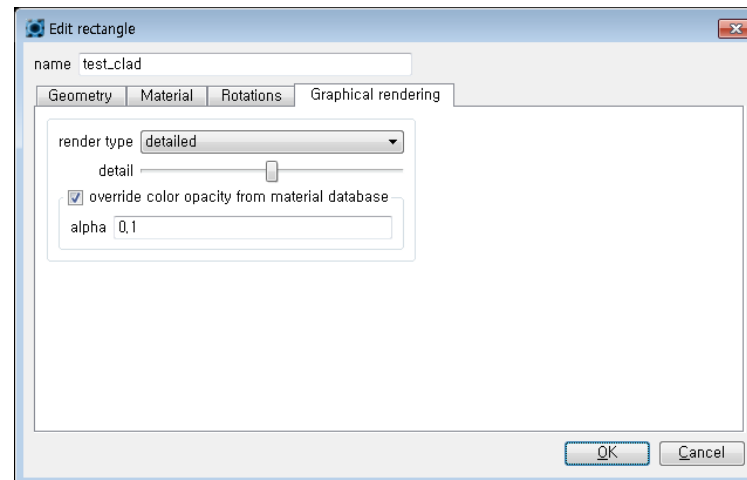
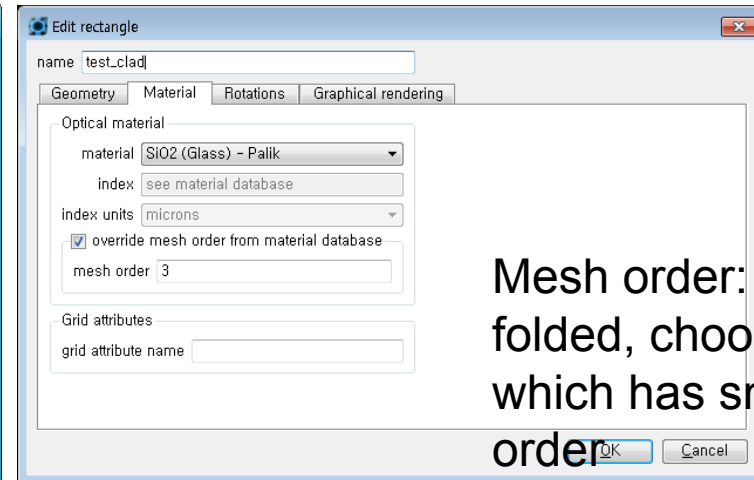
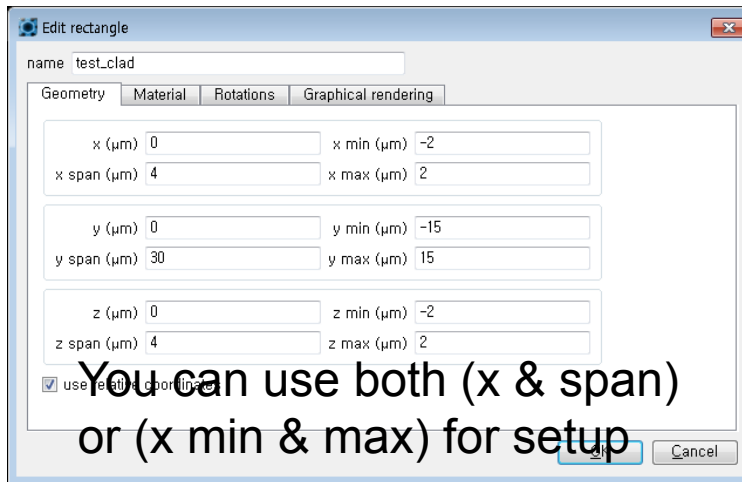


Structure Build(GUI)



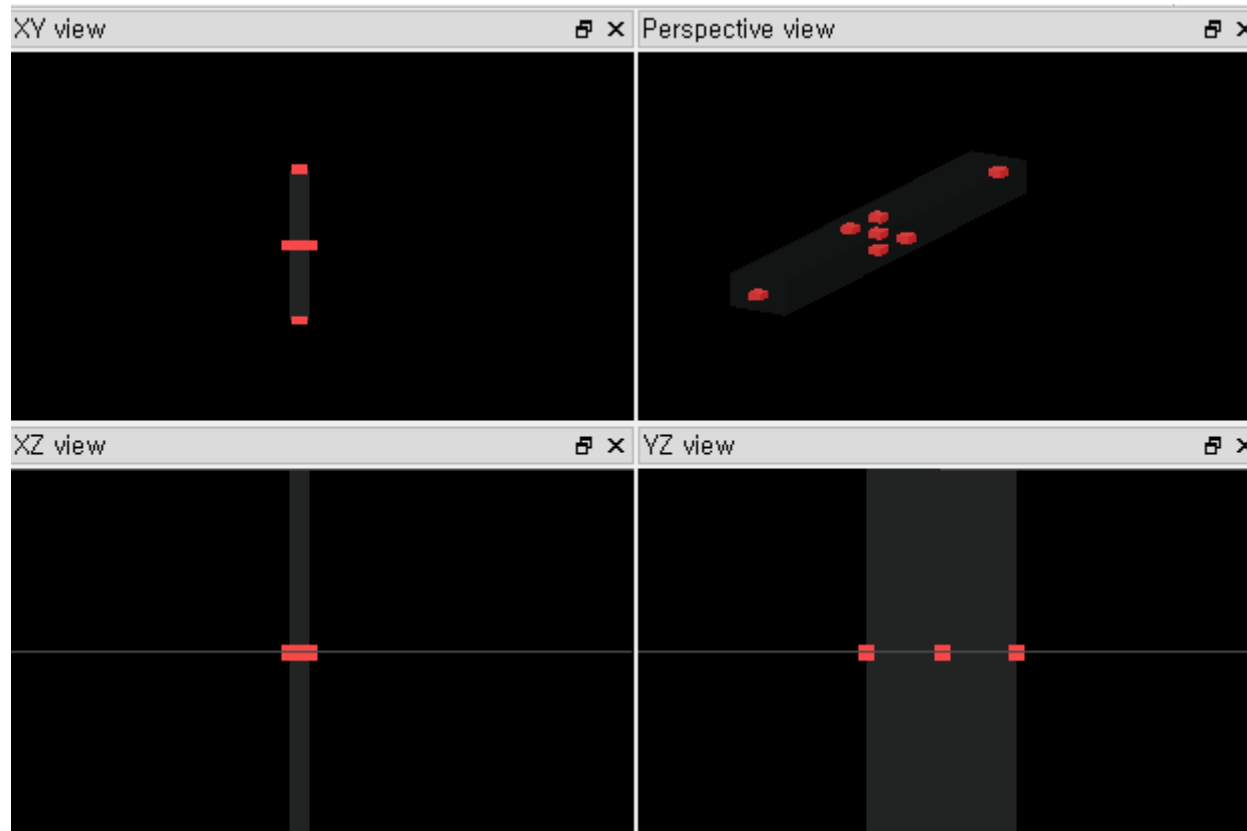
Structure Build(GUI)

- Cladding



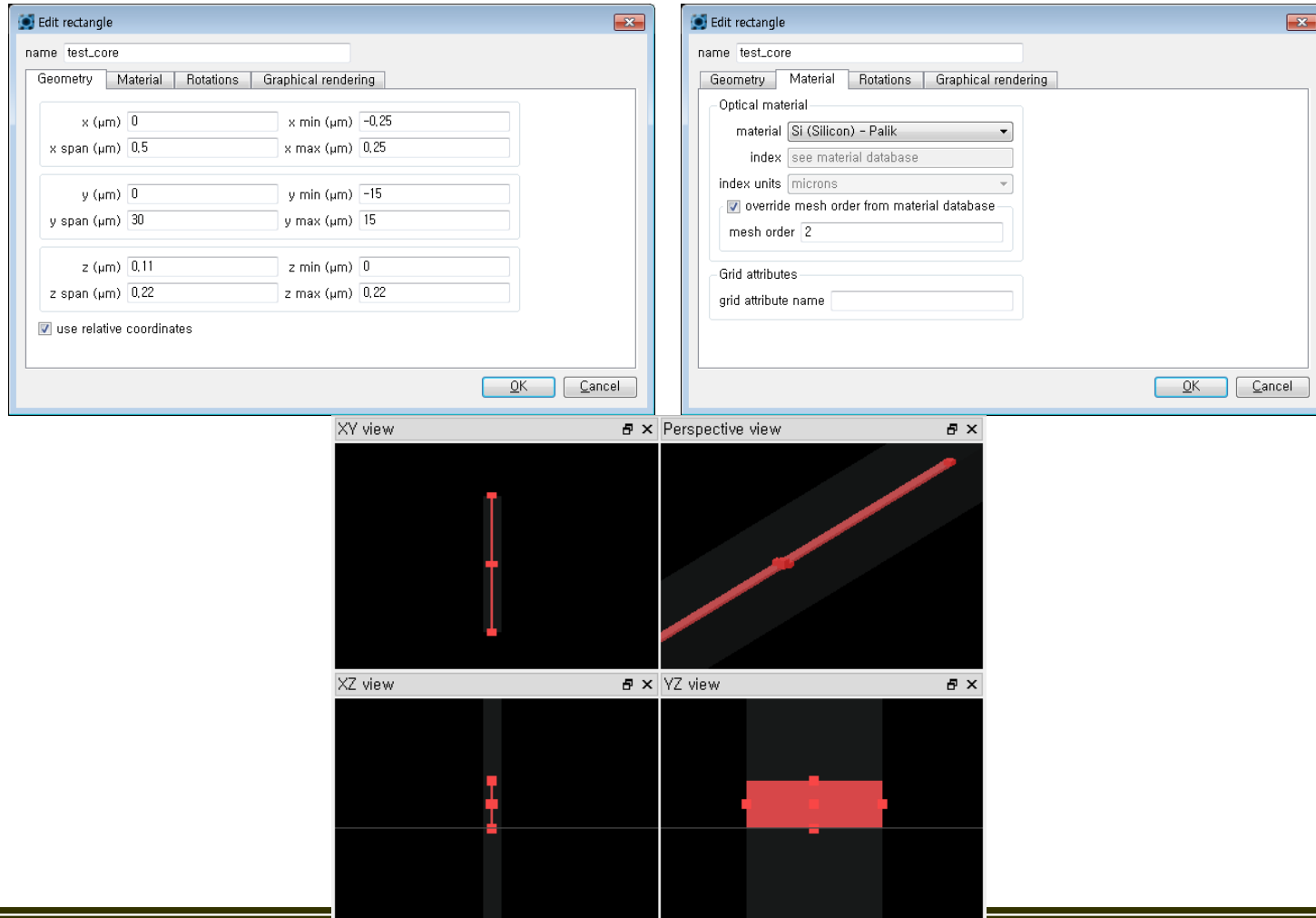
Structure Build(GUI)

- Cladding



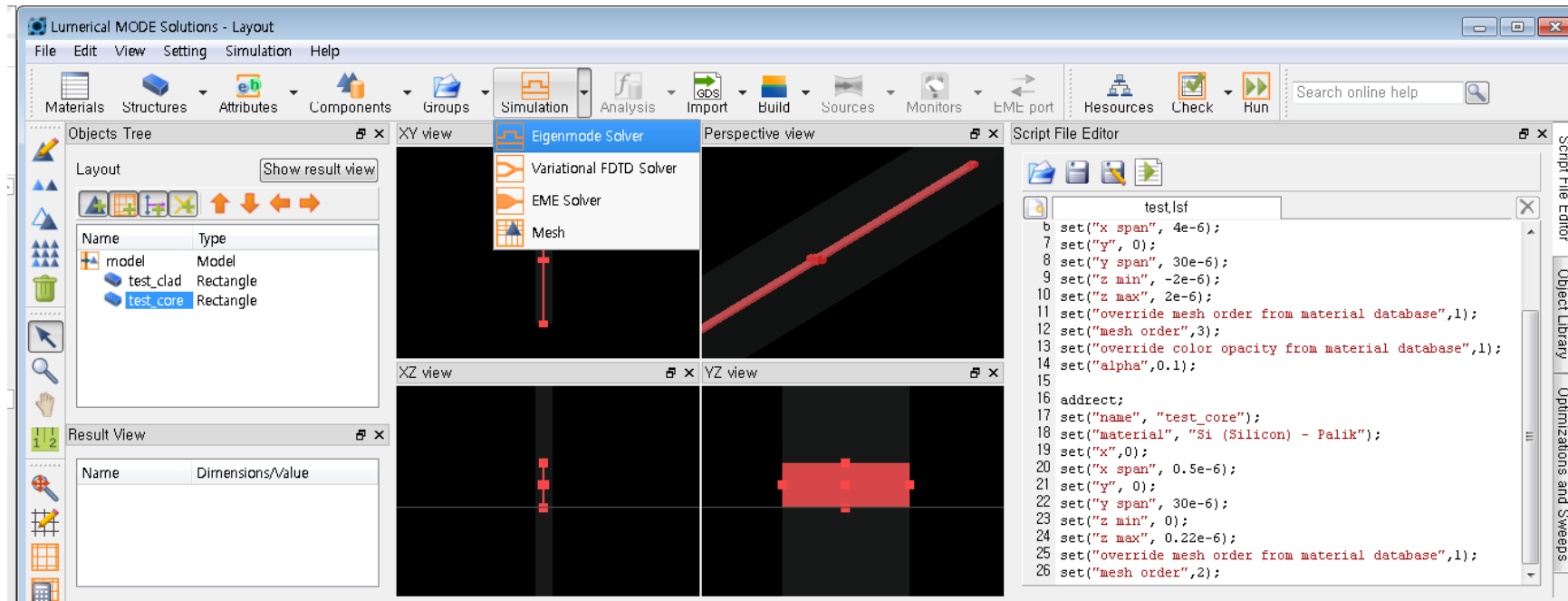
Structure Build(GUI)

- Core

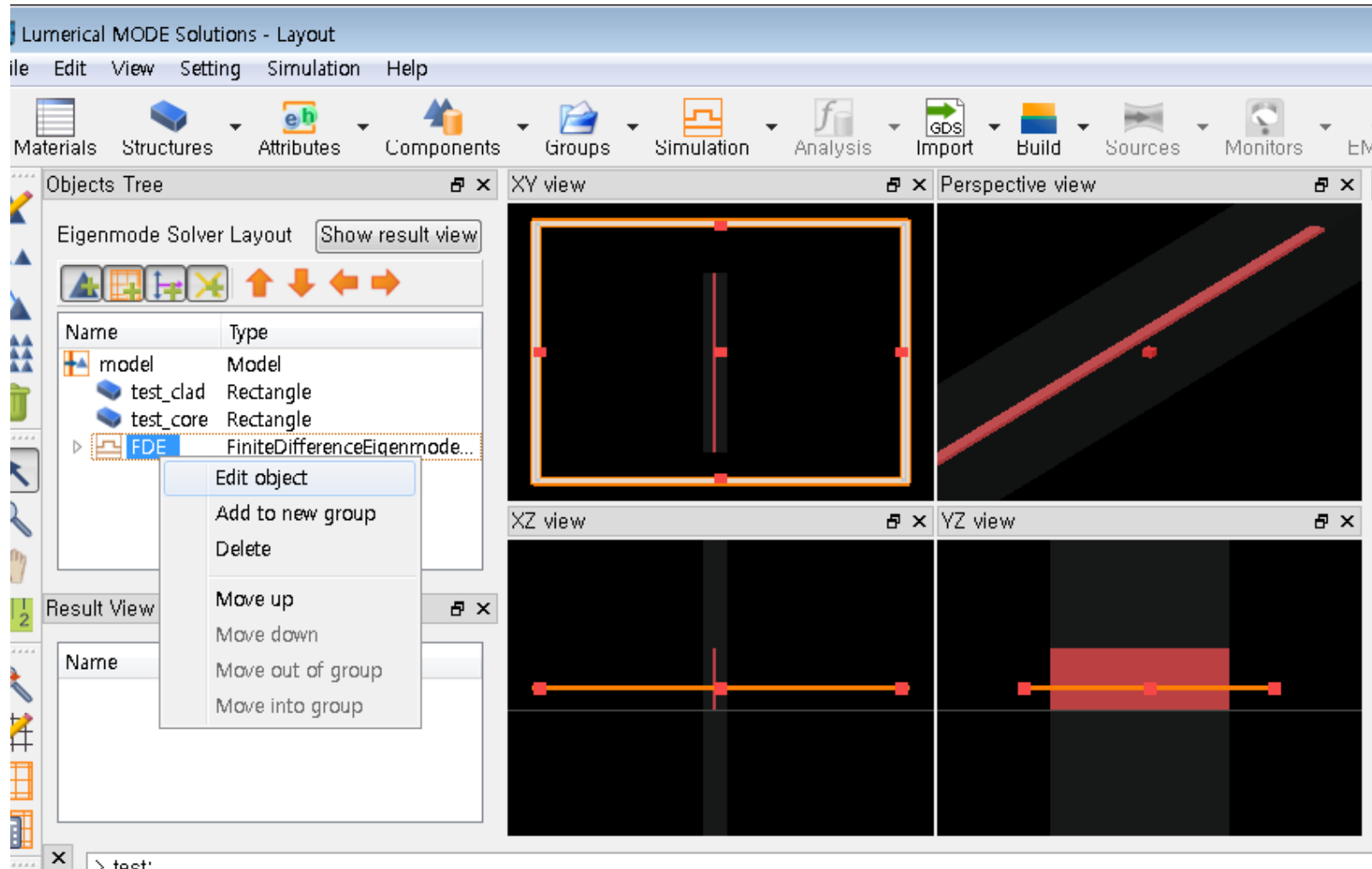


Simulation Setup(GUI)

- Eigenmode Solver



Simulation Setup(GUI)

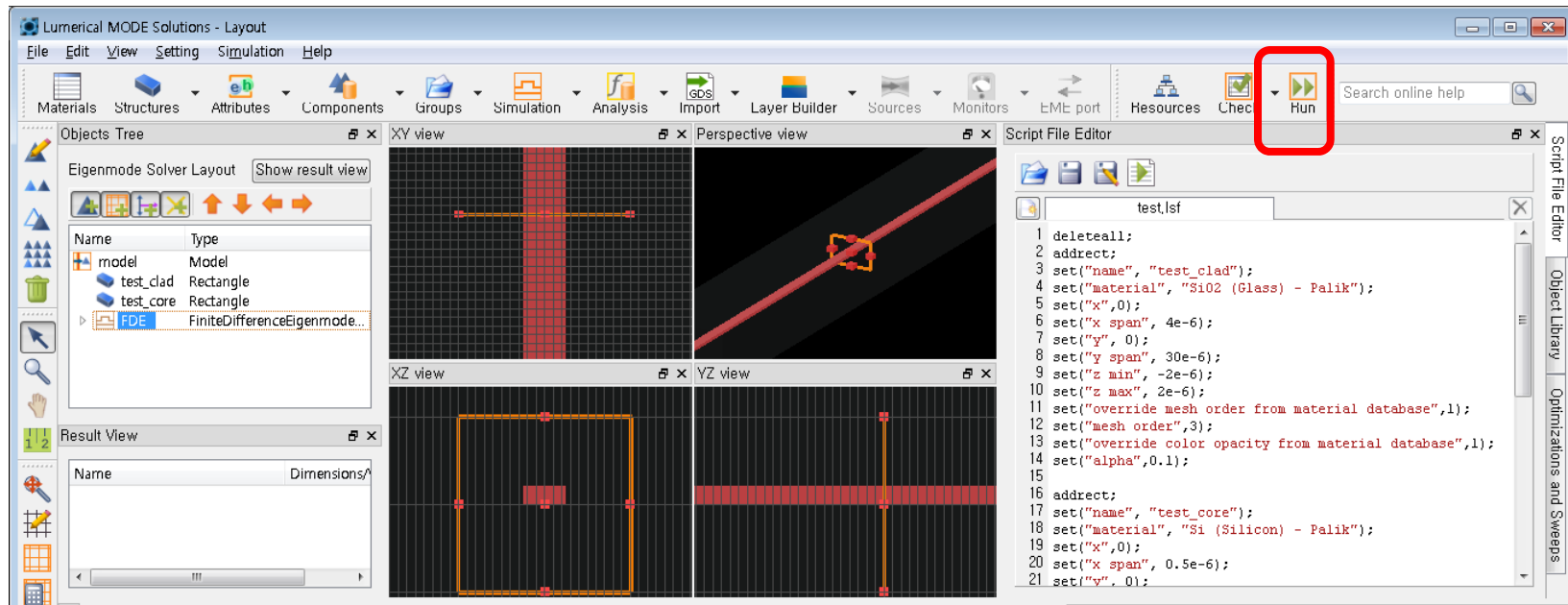


Simulation Setup(GUI)

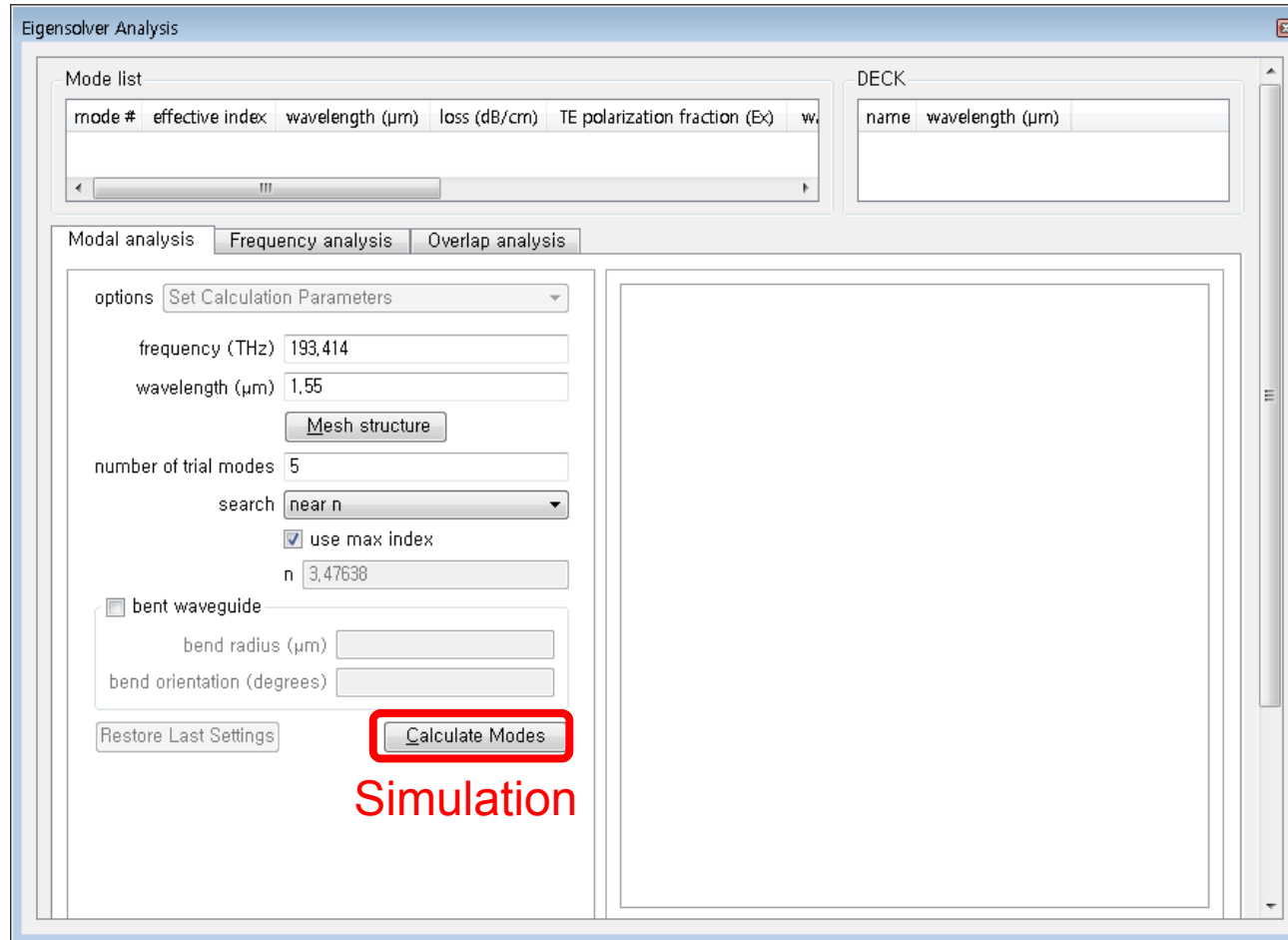
The image displays four sequential screenshots of the 'Edit finite difference eigenmode solver' GUI, showing the configuration process for a simulation. The name of the solver is 'FDE'.

- General Tab:** Shows the background index set to 1, simulation temperature (K) set to 300, and solver type set to '2D Y normal'.
- Geometry Tab:** Shows the geometry dimensions in micrometers (μm):
 - x: 0 to 2, x min: -1, x max: 1
 - y: 0 to 0, y min: 0, y max: 0
 - z: 0 to 2, z min: -1, z max: 1
- Mesh settings Tab:** Shows mesh definition options:
 - define x mesh by: maximum mesh step
 - define y mesh by: number of mesh cells
 - define z mesh by: maximum mesh step
 - Maximum mesh step settings: dx (μm) 0.01, dy (μm) [empty], dz (μm) 0.01
 - Actual number of mesh cells used: actual mesh cells x 200, actual mesh cells y 0, actual mesh cells z 200
 - Number of mesh cells without override regions: mesh cells x 50, mesh cells y 0, mesh cells z 50
 - Minimum mesh step settings: min mesh step (μm) 1e-06
 - Mesh grading: grading factor 1.41421
- Boundary conditions Tab:** Shows boundary conditions for all faces set to 'Metal'. The 'z min bc' dropdown is highlighted. There is an unchecked checkbox for 'allow symmetry on all boundaries'.

Simulation Setup(GUI)



Simulation Setup(GUI)



MODE Solutions

The screenshot displays the 'Eigensolver Analysis' window. At the top, a 'Mode list' table shows the results of the calculation:

mode #	effective index	wavelength (μm)	loss (dB/cm)	TE polarization fraction (Ex)
1	2.446231	1.55	0.00000	98

Below the table, the 'Modal analysis' tab is active, showing various calculation parameters such as frequency (193,414 THz), wavelength (1.55 μm), and number of trial modes (5). A 'Calculate Modes' button is visible at the bottom of this section.

On the right side, a 'DECK' window shows the name 'wavelength (μm)'. Below it, a 2D plot shows the field intensity distribution in the x-z plane. The x-axis ranges from -1.0 to 1.0 microns, and the z-axis ranges from -1.0 to 1.0 microns. A color scale on the right indicates intensity values from 0.0 to 1.0. A bright spot is visible at approximately x = -0.1, z = 0.2.

Annotations on the image include:

- An arrow pointing to the 'Mode list' table with the text 'Calculated modes'.
- An arrow pointing to the 'effective index' column with the text 'Infers whether the mode is true or not from effective index'.

Confinement Factor

Modal analysis | Frequency analysis | Overlap analysis

options: Power and Impedance Integration

integration shape: rectangular

integrate: power

normalize to: near field mode

x1 (μm): -0,25

x2 (μm): 0,25

z1 (μm): 0

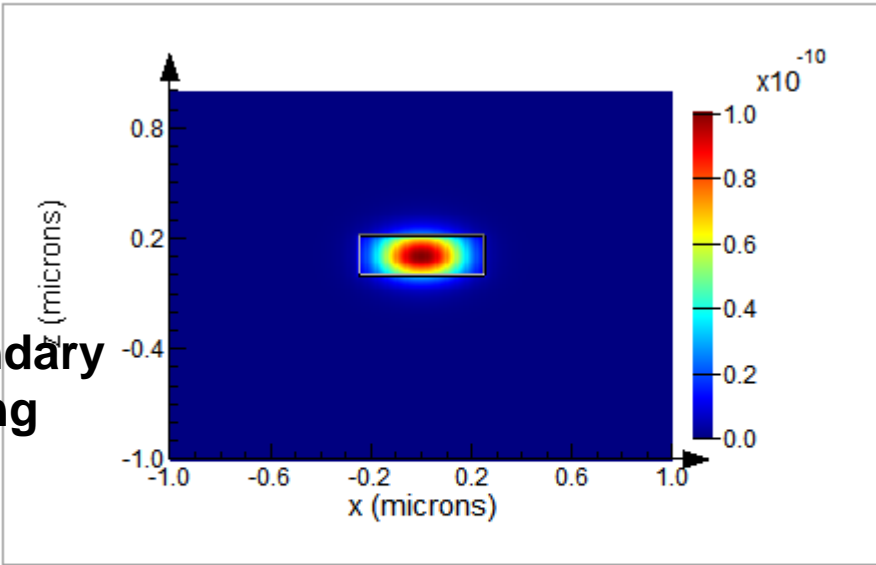
z2 (μm): 0,22

fraction integrated: 80,0114 %

Graph control

define integration region zoom mode

Boundary setting



z (microns)

x (microns)

Mode plot options

plot: Modal fields | component: Energy dei | linear scale

amplitude | coordinates: cartesian | log scale

superimpose structure | Plot in New Window

The figure shows a 2D heatmap plot of the confinement factor. The x-axis is labeled 'x (microns)' and ranges from -1.0 to 1.0. The y-axis is labeled 'z (microns)' and ranges from -1.0 to 0.8. A color bar on the right indicates the magnitude of the confinement factor, ranging from 0.0 (dark blue) to 1.0 (dark red), with a multiplier of $\times 10^{-10}$. The plot shows a localized region of high confinement factor (red/yellow) centered around x = 0 and z = 0.2, which corresponds to the integration region defined in the settings.

Group Index(n_g)

Eigensolver Analysis

Mode list

mode #	effective index	wavelength (μm)	loss (dB/cm)	TE polarization fraction (Ex)	wave
1	2.446231	1.55	0.00000	98	76.38

DECK

name wavelength (μm)

Modal analysis **Frequency analysis** Overlap analysis

options Set Calculation Parameters

track selected mode

start frequency (THz) 193.414

stop frequency (THz) 192.175

start wavelength (μm) 1.55

stop wavelength (μm) 1.56

number of points 10

number of test modes 2

effective index 2.44

detailed dispersion calculation

store mode profiles while tracking

bent waveguide

bend radius (μm)

bend orientation (degrees)

Restore Last Settings Frequency Sweep

z (microns)

x (microns)

Effective Index

Wavelength (microns)

Mode plot **Frequency plot**

plot effective index

Linear scale Log scale Frequency Wavelength

Plot in New Window

Plot with lines Plot with points

①

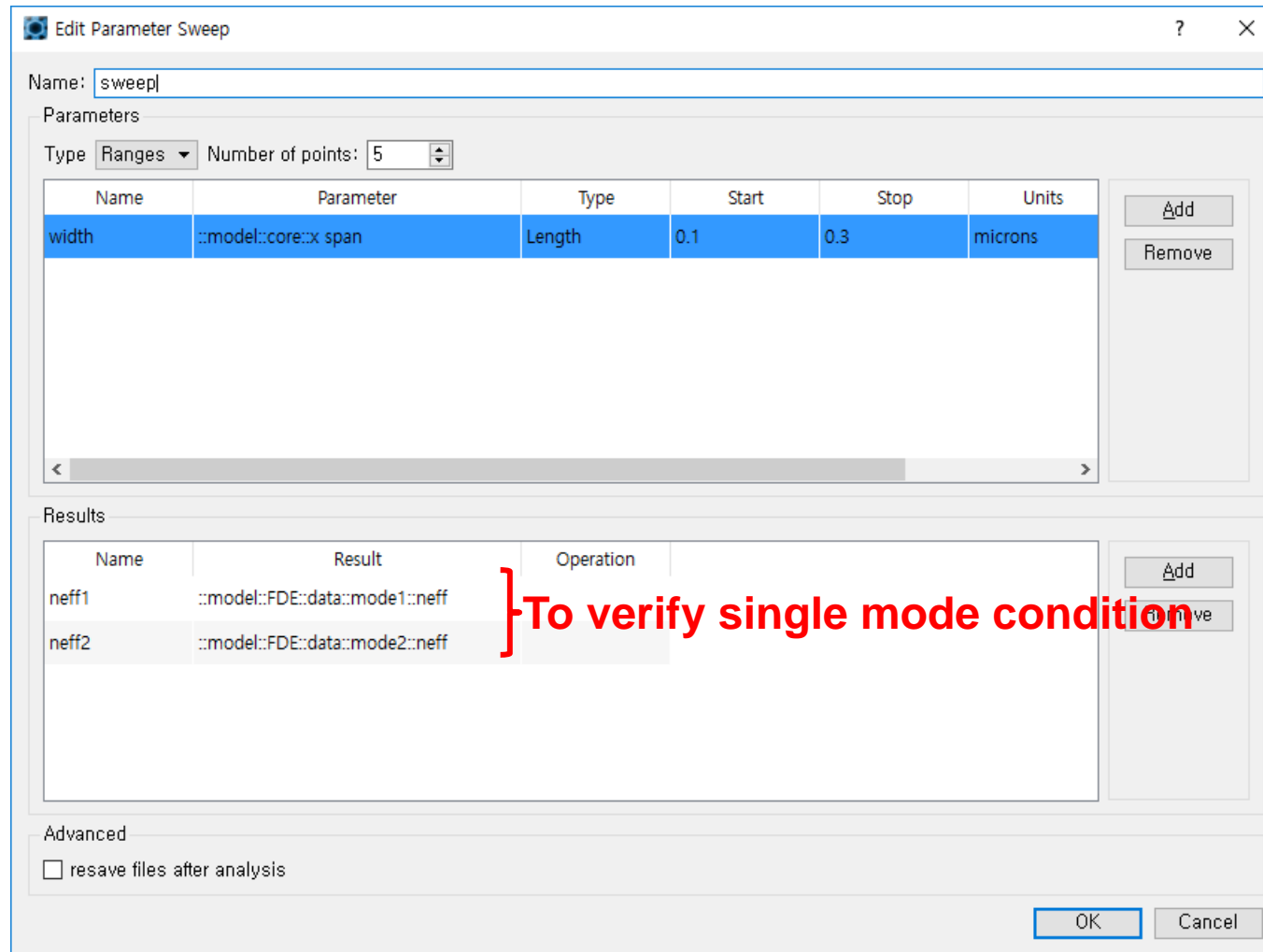
②

③

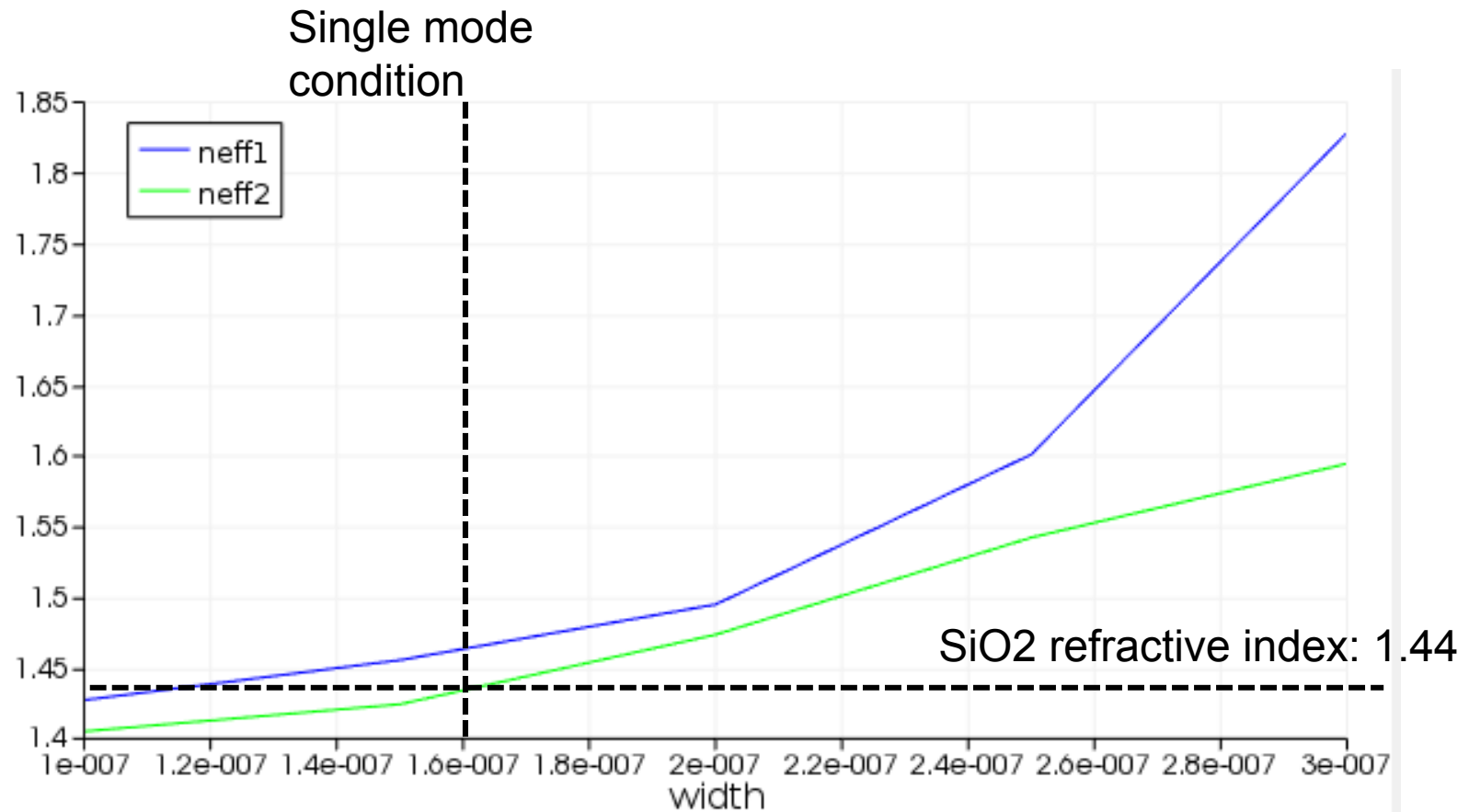
④ Change to group index

Sweep Width

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



Sweep Results

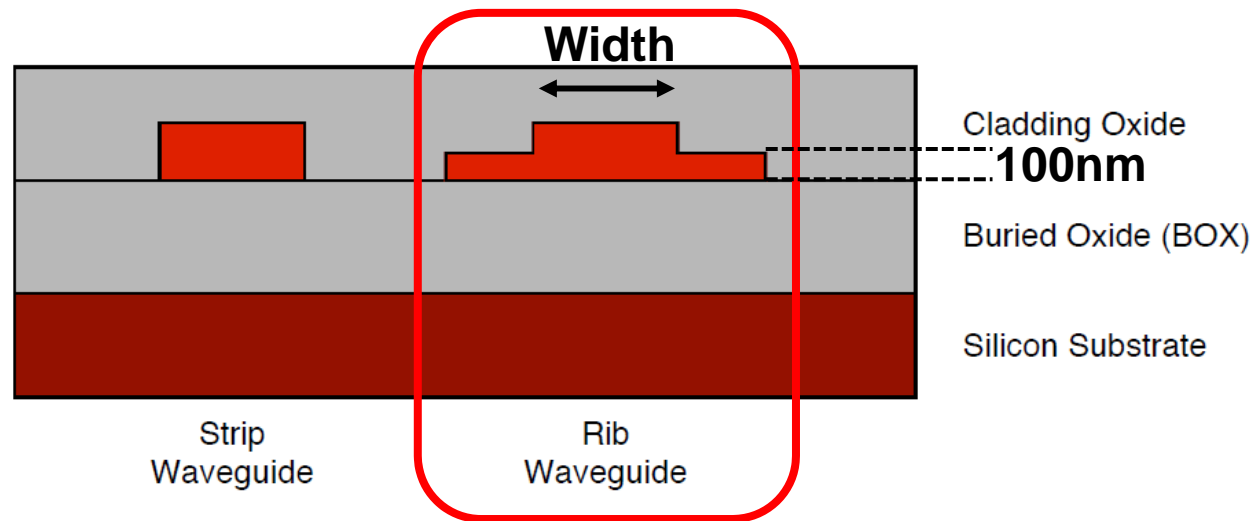


Design Exercise 2-1

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 & 100nm slab at 1550nm

Due: 27 Nov. in class



Tips for Design Exercise 2-1

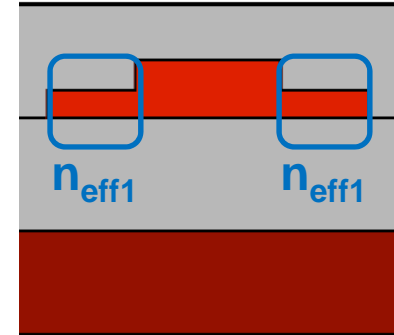
- **Condition for guidance of rib waveguide**

$n_{\text{eff_total}} > n_{\text{eff1}}$

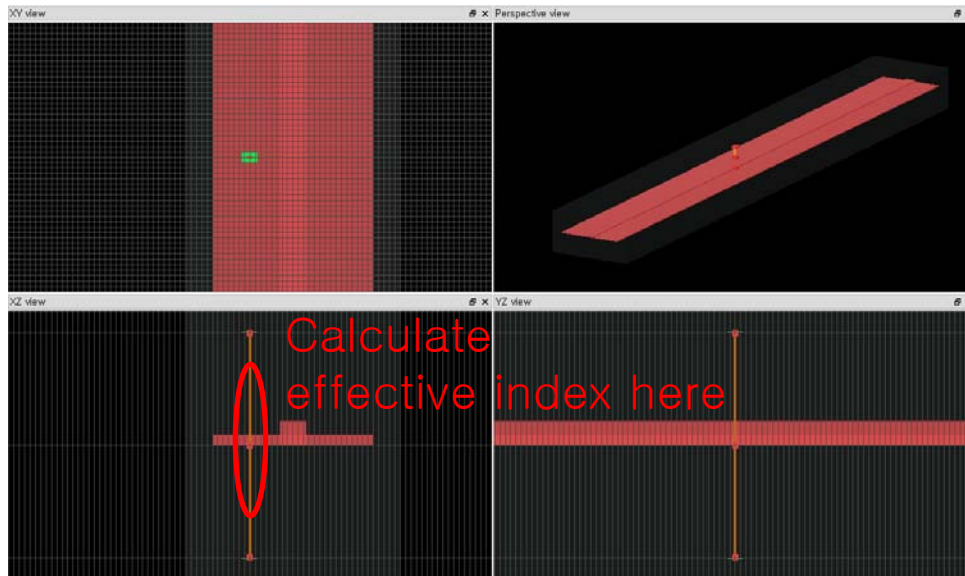
:Making same environment as strip waveguide

- **How to get n_{eff1}**

:Use 1-D Z:X prop simulation in FDE solver

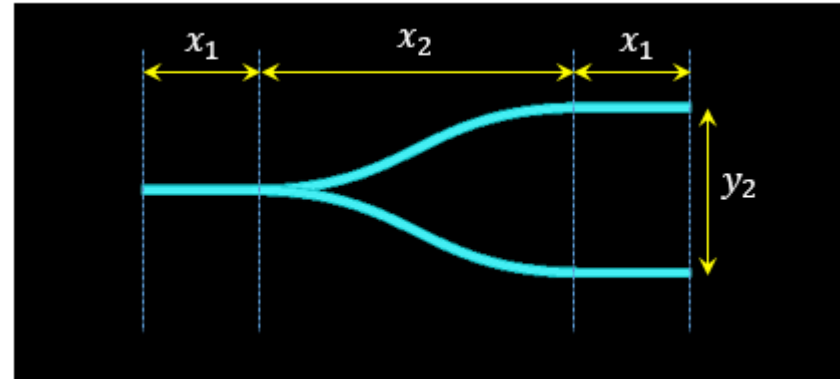
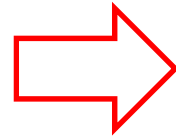
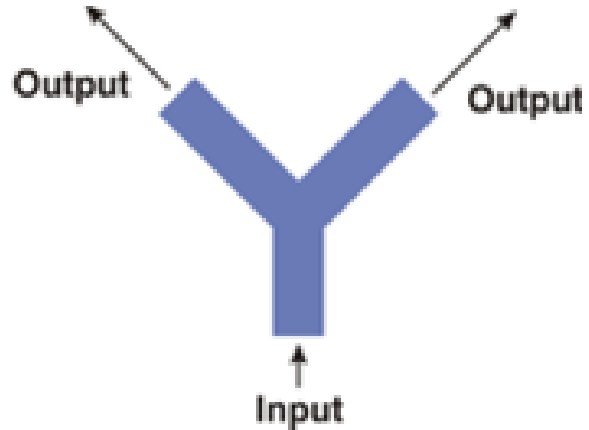


Rib Waveguide



Waveguide coupler

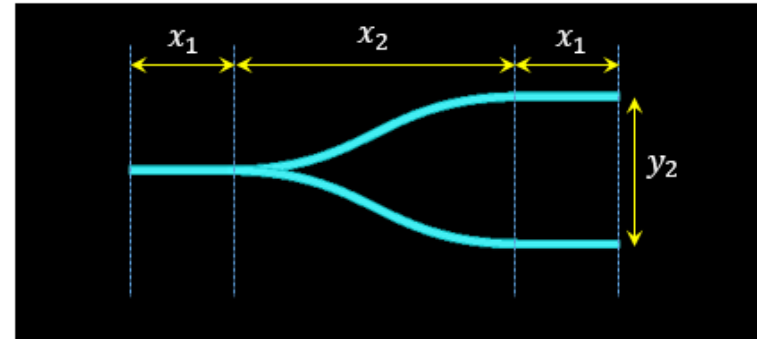
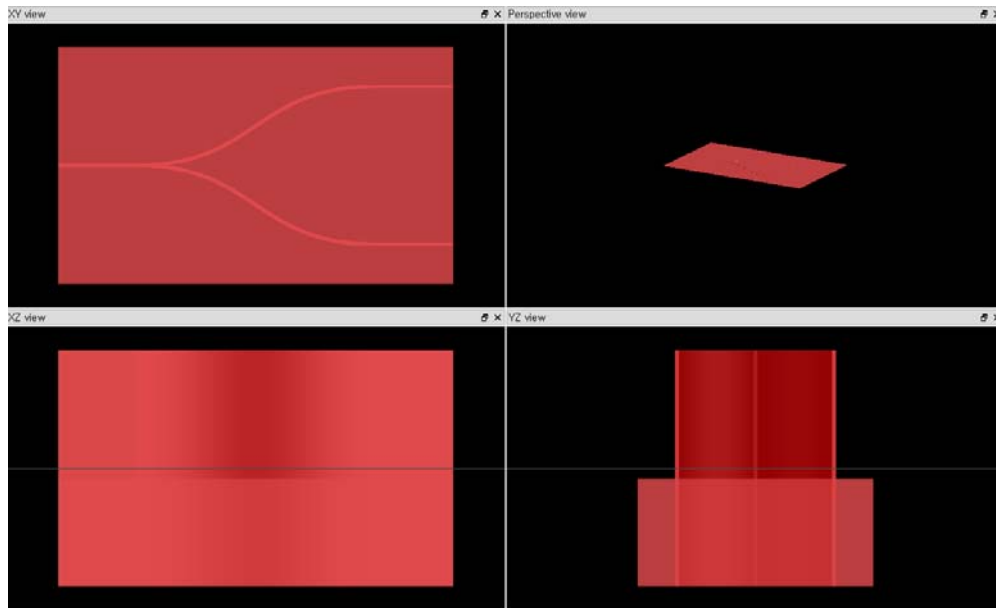
- Y-branch coupler



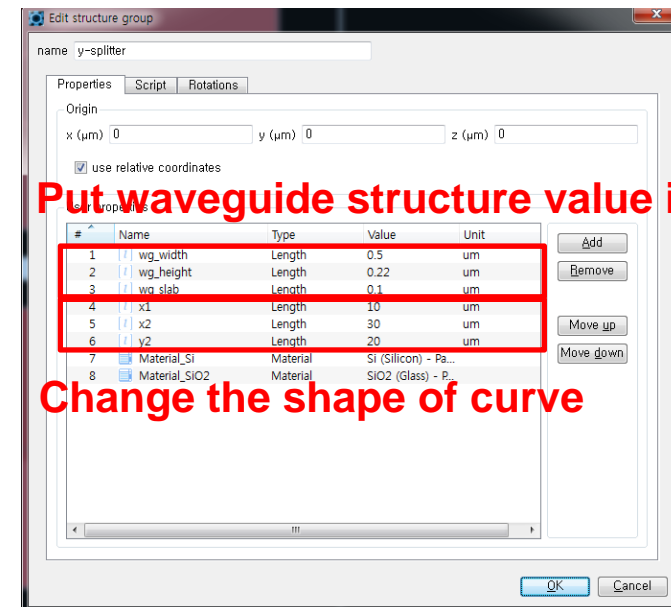
- Ideally 50:50 power splitter
- Bezier Curve
- Curve shape change due to x_2 , y_2

Y-branch coupler

- Waveguide structure group

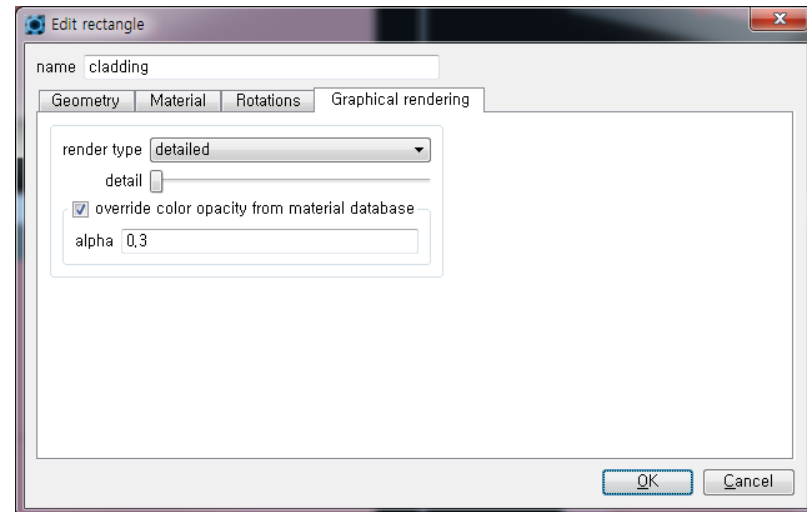
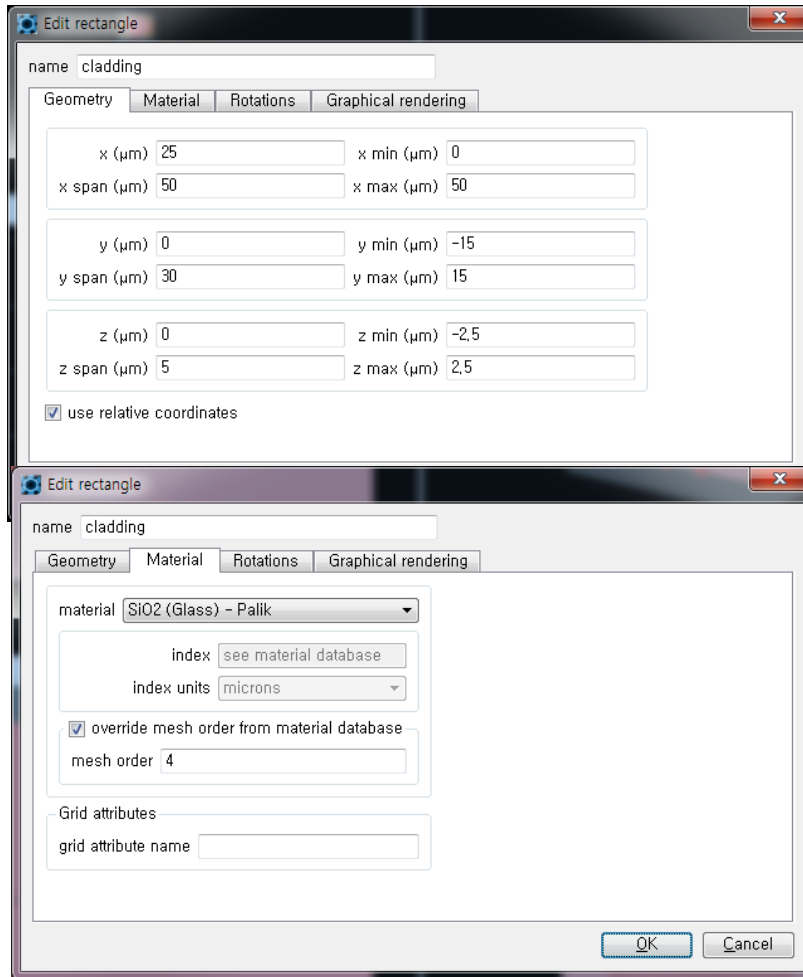


- Download `y_splitter.lms` file at YSCEC



Structure (cladding)

- Rectangular



Simulation Setup

- 2.5D FDTD Solver Setting(Variational FDTD Solver)

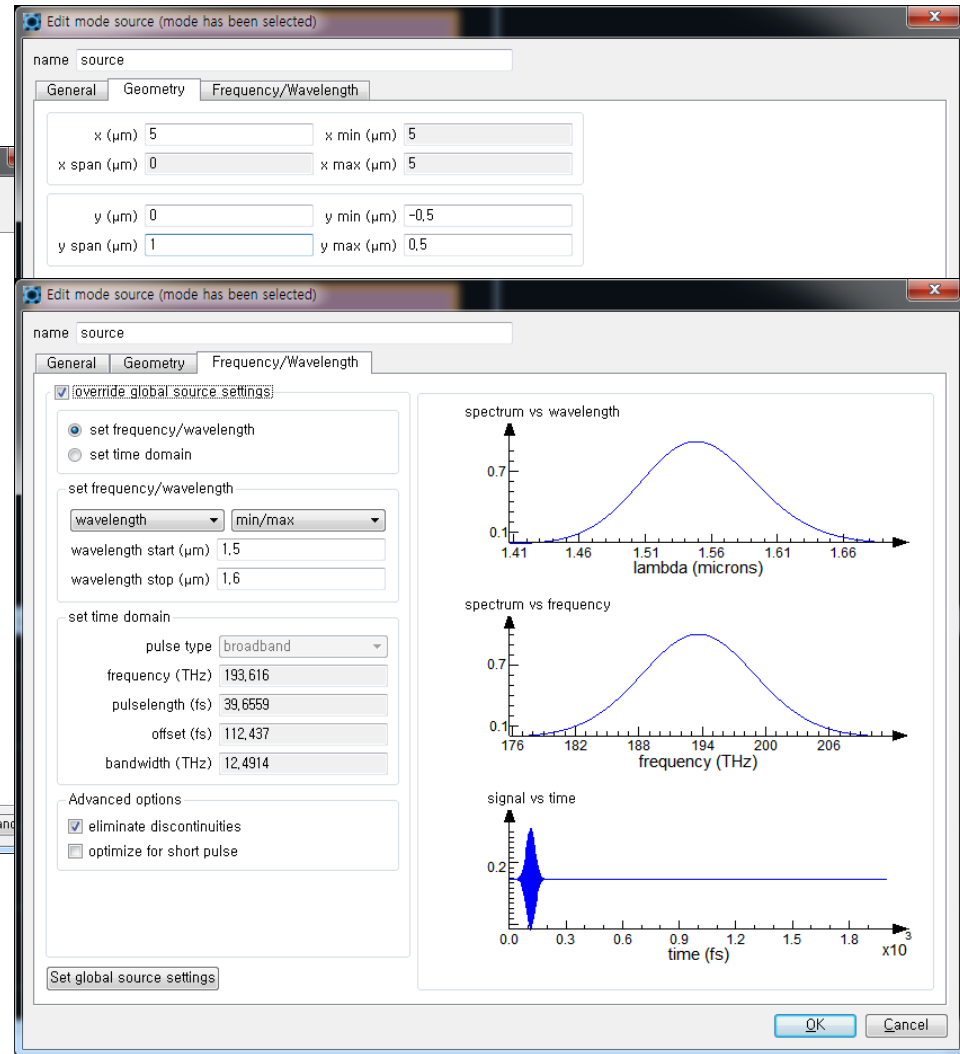
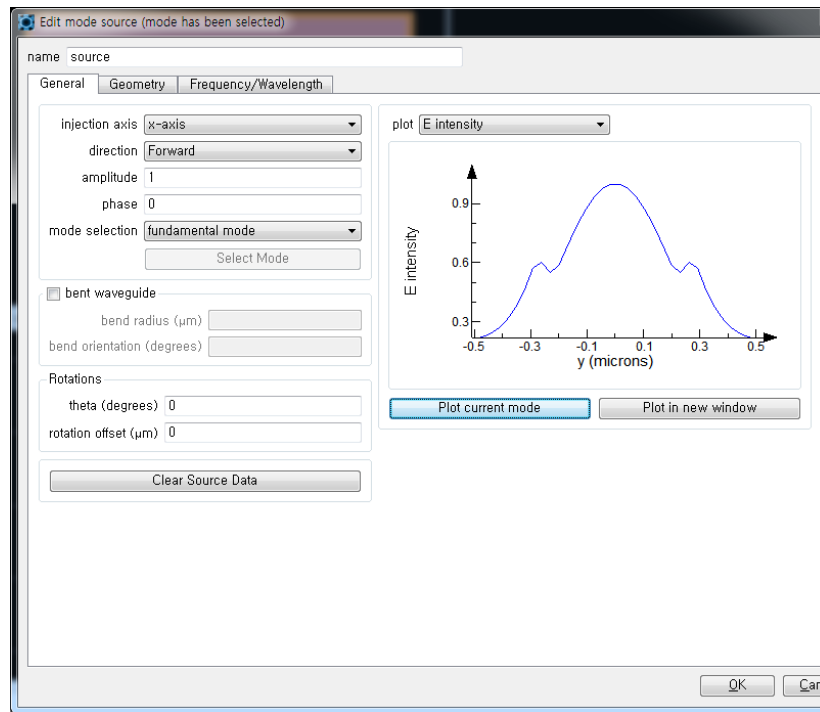
The image displays three overlapping screenshots of the 'Edit variational FDTD solver' dialog box, showing different configuration tabs:

- General Tab (Top Left):**
 - name: varFDTD
 - background index: 1.44
 - simulation time (fs): 2000
 - simulation temperature (K): 300
- Geometry Tab (Top Right):**
 - x (μm): 25, x min (μm): 0, x span (μm): 50, x max (μm): 50
 - 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
- Effective index Tab (Bottom Left):**
 - Slab mode position: x0 (μm): 0, y0 (μm): 0
 - Polarization: E mode (TE)
 - effective index method: variational
 - can optimize mesh algorithm for extruded structures
 - clamp values to physical material properties
 - Simulation bandwidth: bandwidth: broadband
 - maximum number of materials: 100
 - number of samples: 20, fit Tolerance: 0.1
 - max coefficients: 3, imaginary weight: 1
 - improve stability, make fit passive
 - Test: number of test points: 6
 - test points table:

	x	y
1	-15	10
2	-15	-10
3	-15	0
4	20	10
5	20	-10
6	20	0
- Mesh settings Tab (Bottom Right):**
 - mesh type: auto non-uniform
 - Mesh accuracy: mesh accuracy: 3
 - Time step: dt stability factor: 0.99, dt (fs): 0.0718482
 - Mesh refinement: mesh refinement: conformal variant 0
 - Minimum mesh step settings: min mesh step (μm): 1e-05

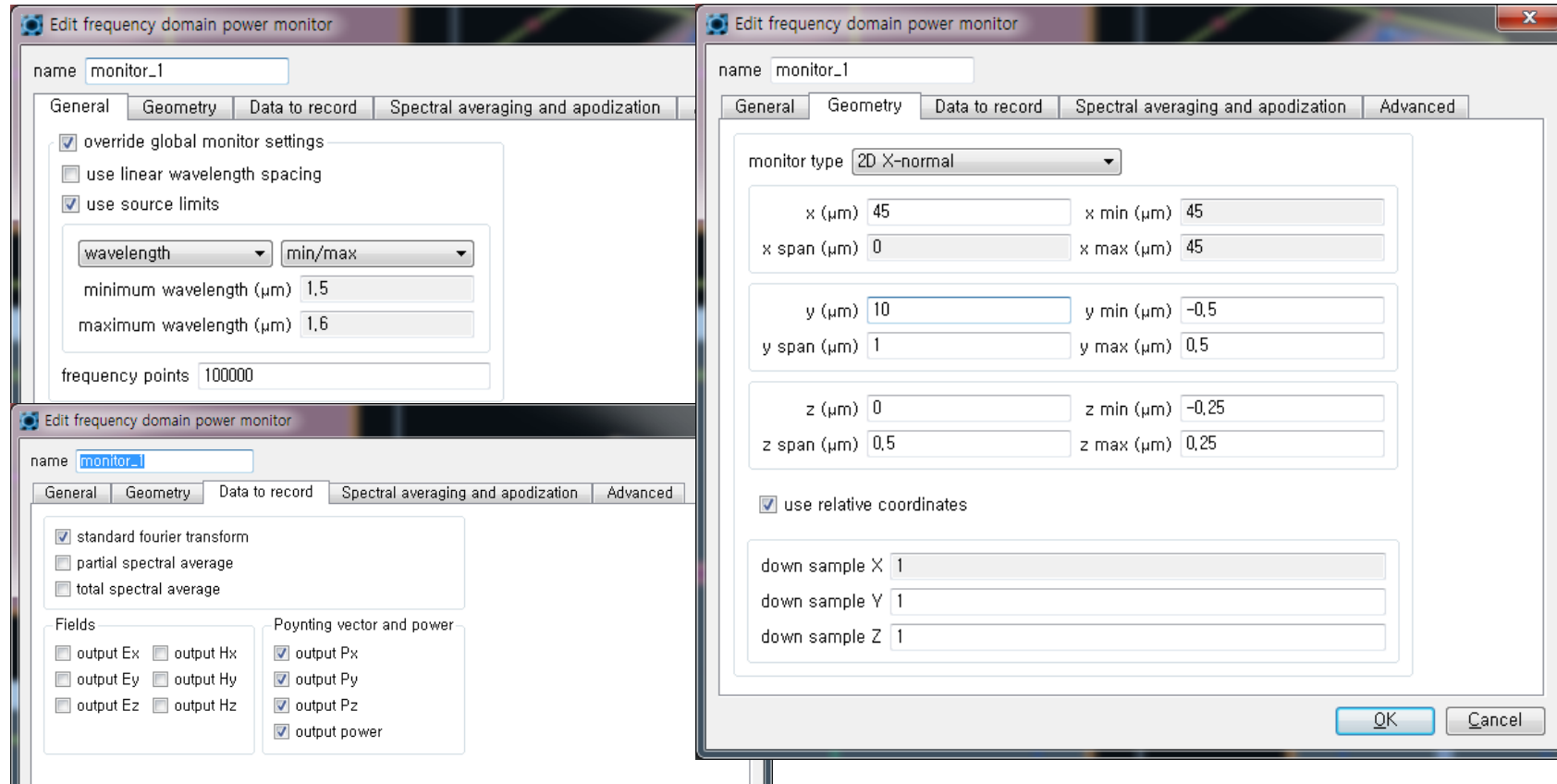
Simulation Setup

- Source Setting (MODE source)



Simulation Setup

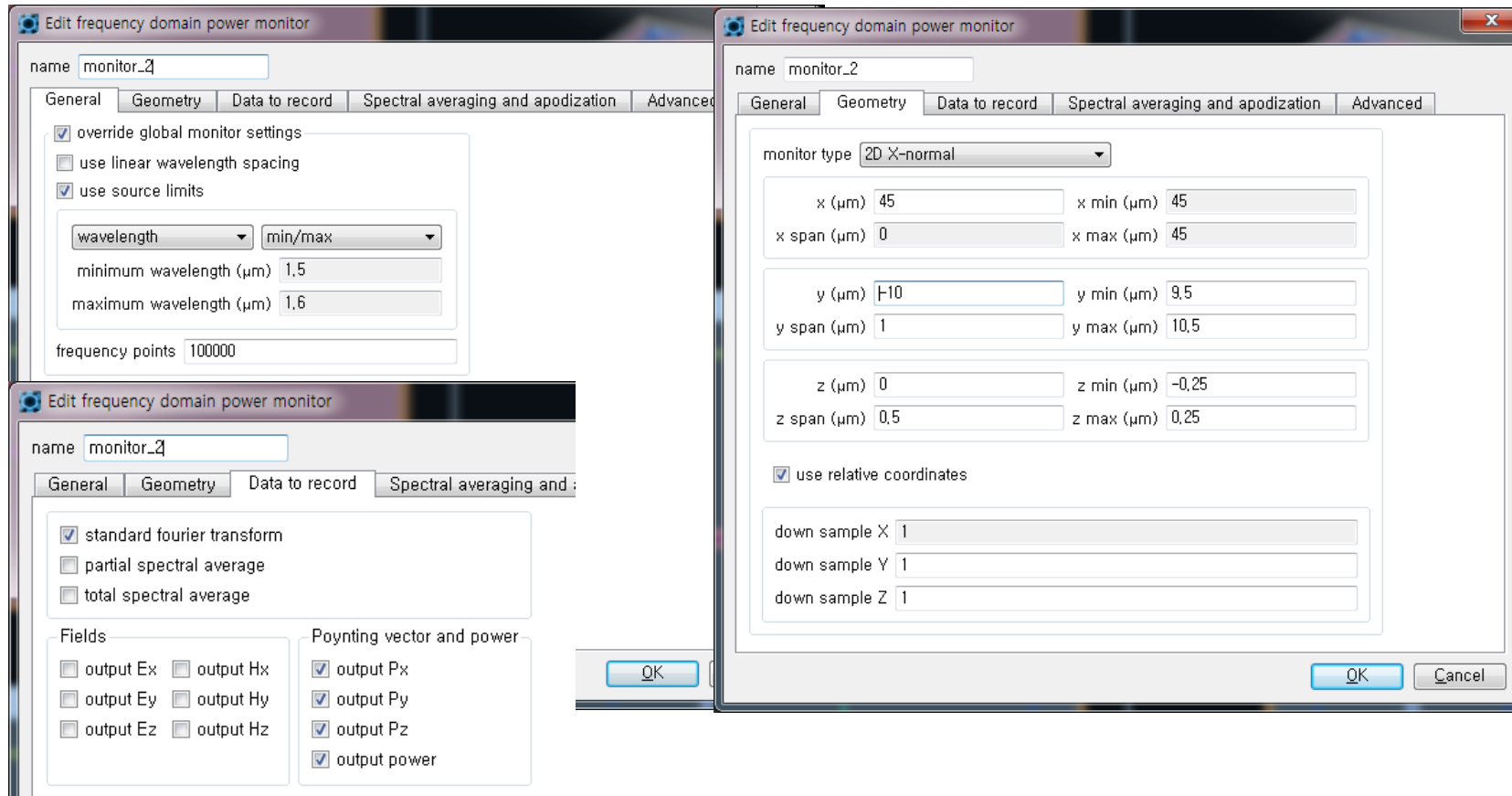
- **Monitor 1 Setting (Frequency domain field and power)**



-Frequency point should be large enough

Simulation Setup

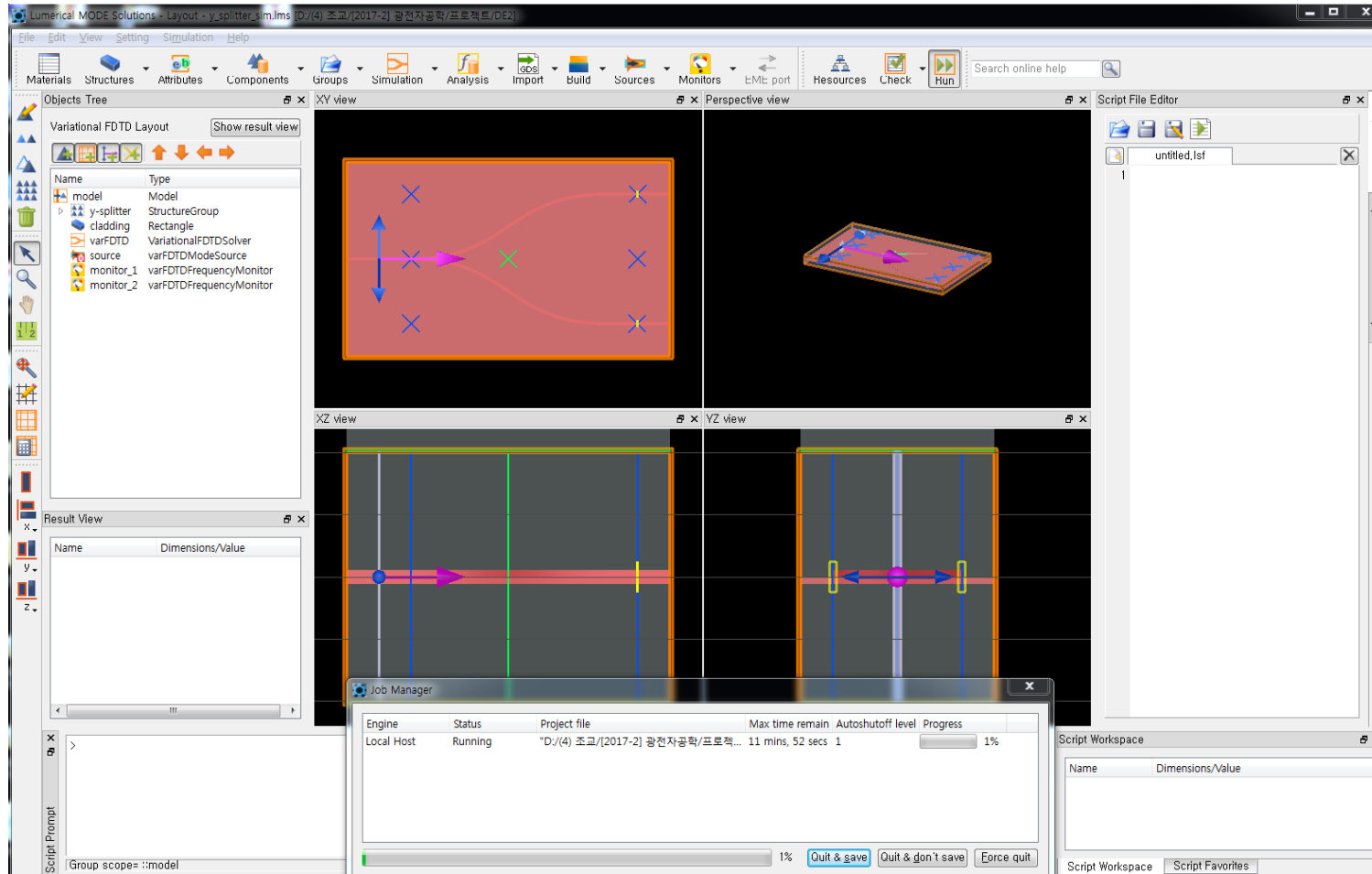
- Monitor 2 Setting (Frequency domain field and power)



-Frequency point should be large enough

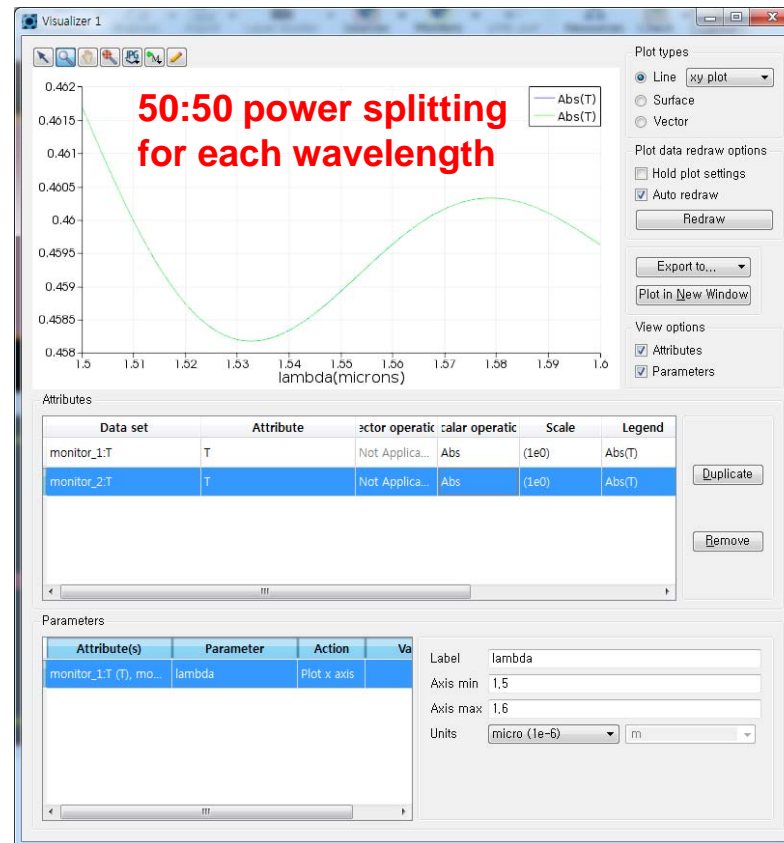
Run Simulation

- After setup, run simulation



Result

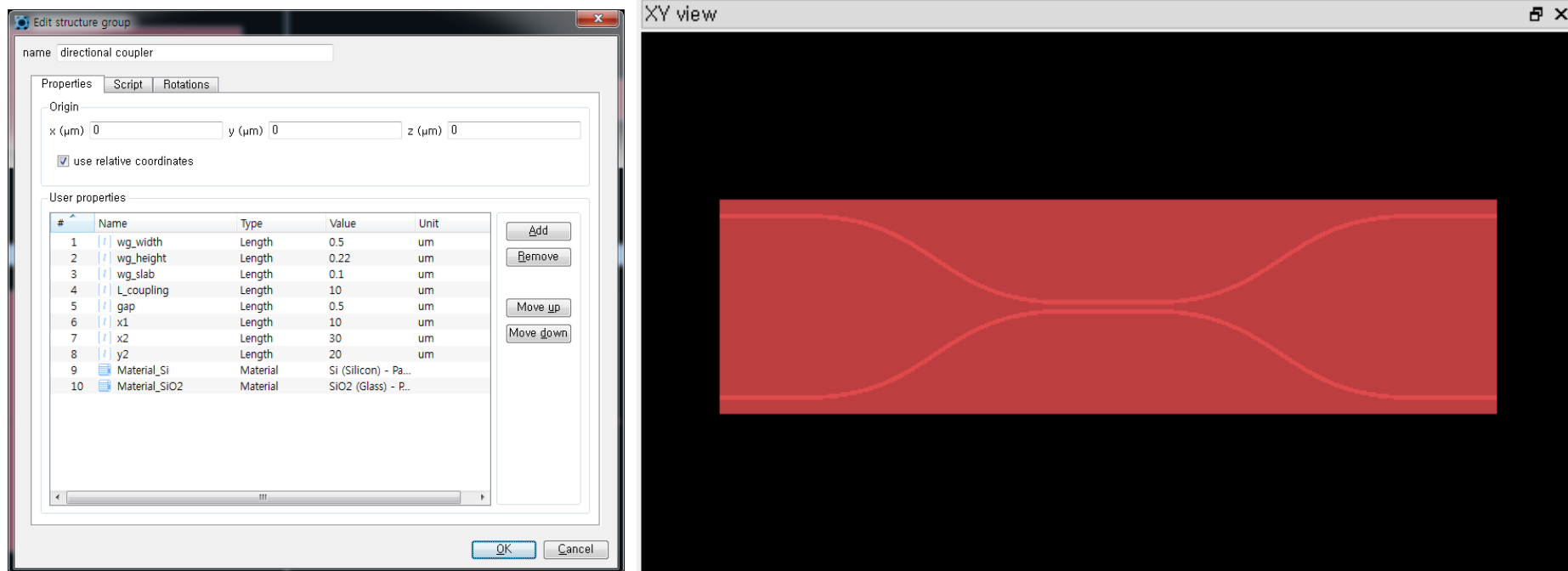
- Monitor 1 (Right click) → Visualize → T
- Monitor 2 (Right click) → add to visualizer 1 → T



Design Exercise 2-2

Design rib waveguide type Directional Coupler. Use waveguide width from the result of Design Exercise 2-1.

-220nm thick & 100nm slab at 1550nm



Due: 27 Nov. in class