

Design Tools for Active and Passive Devices, Circuits, Systems, and Networks

**5th International Conference
Numerical Simulation of Optoelectronic Devices
(NUSOD)**

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Outline

- **Product Overview**
- ***FemSIM***
 - Asymmetric Ridge
 - Multimode Fiber
 - Photonic Crystal Fiber (PCF)
 - Dispersion in PCF's
 - Air Core PCF's
- ***LaserMOD***
 - VCSEL simulation with FEM
 - DFB laser simulation
 - DBR laser simulation
- **Summary**

Product Overview

Passive/Active Device Tools:

*one passive platform
one active platform
(integrated results)*

- *BeamPROP (BPM - PIC's)*
- *FullWAVE (FDTD - Nanostructures)*
- *BandSOLVE (PWE - PBG's)*
- *GratingMOD (CMT - Gratings)*
- *DiffractMOD (RCWA – Metrology)*
- **FemSIM** (FEM - PCF's)
- **LaserMOD** (BIM - FP's, VCSEL's, DFB's)
- *MOST (Genetic, etc... - Design Optimization)*

System Tools:

one platform for all

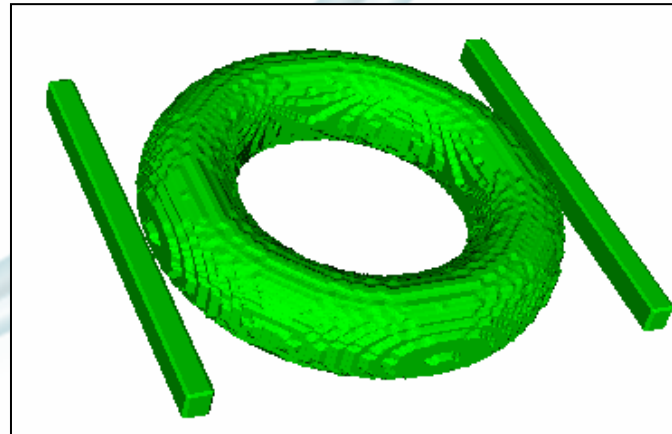
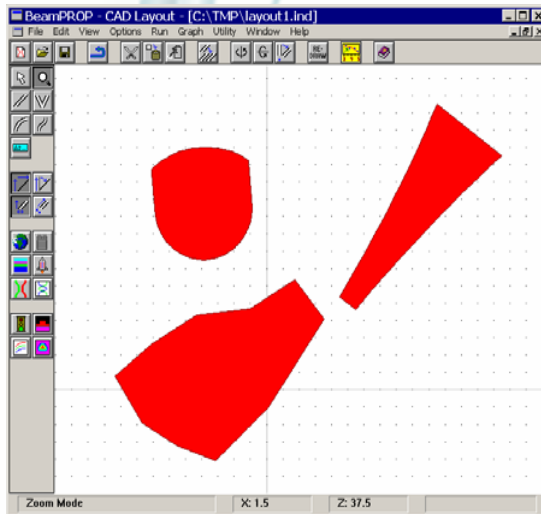
- *OptSim (Time, Frequency - WDM, FTH, CATV)
- Sample Mode Models
- Block Mode Models*
- *LambdaSIM (Wavelength - Channel Crosstalk)*
- *ModeSYS (Spatial - Multimode Systems)*
- *EDFA for Vendors*

Network Tools:

- *Artifex (Petri Nets - Extensive Application Scope)*
- *MetroWAND (Ring & Mesh Networks)*

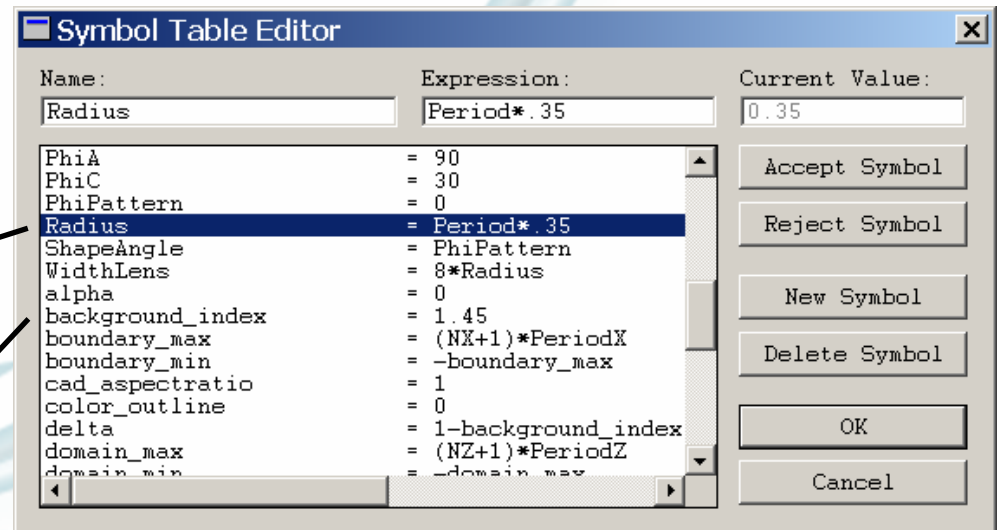
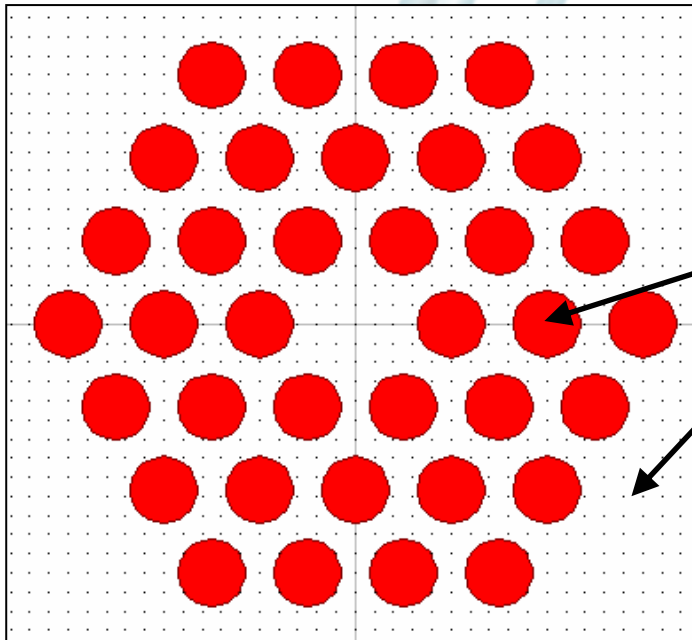
The RSoft CAD Environment:

- The RSoft CAD Environment is a unified design framework shared among all the tools in RSoft component-level design suite, including *BeamPROP* (BPM), *FullWAVE* (FDTD), *BandSOLVE* (PWE+FDTD), *GratingMOD* (CMT), *DiffractMOD* (RCWA), and *FemSIM* (FEM).
- The CAD interface provides powerful layout capabilities for arbitrary structures using both built-in structure types as well as user-defined mathematical expressions and/or functions.



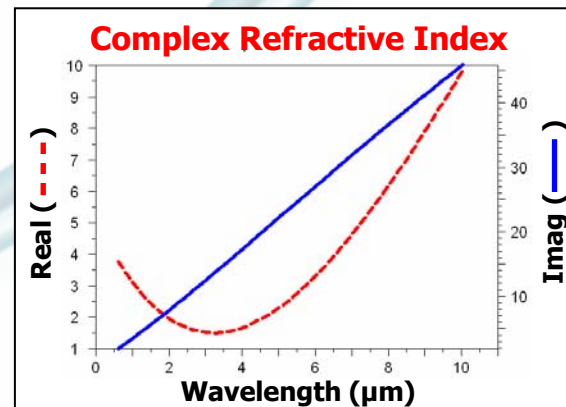
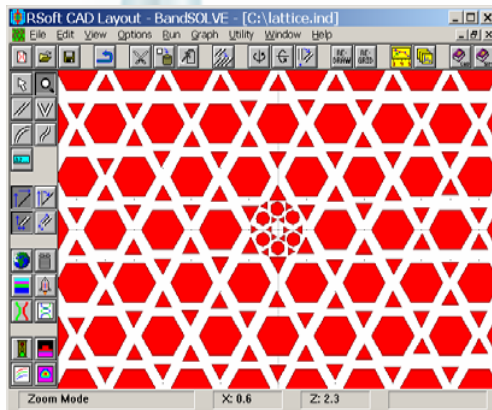
Parametric Design:

- The RSoft CAD Environment allows for the parametric design of arbitrarily complicated structures.
- All geometric and simulation properties can easily be controlled via both built-in and user created variables
- An object-oriented design approach allows each individual element to have its own set of properties and variables



Other CAD Capabilities:

- **Built-in Lattice Library:** Standard 1D, 2D, and 3D periodic structures are easily created with built-in utilities. These layouts can be easily modified to produce custom structures.
- **Hierarchy:** Allows for a pre-existing design file to be imported into another design file as a user-controlled object.
- **Material Systems:** Structures can be a combination of:
 - Standard dielectric materials
 - Inclusion of complex index for metals
 - Inclusion of material dispersion

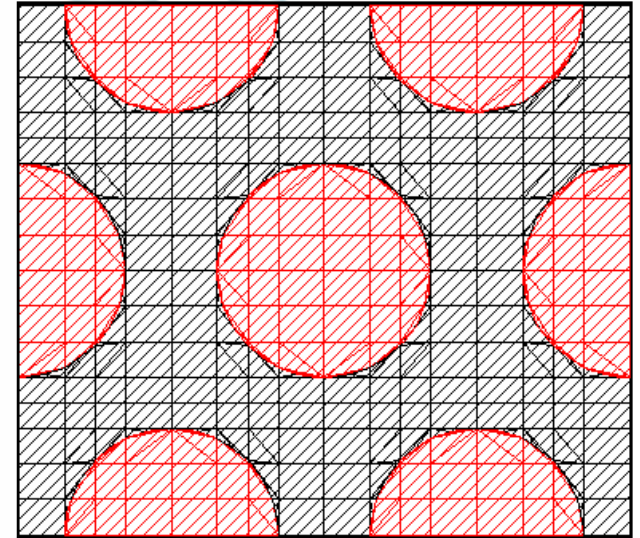


Why FemSIM?

- BPM-based mode solving techniques are very accurate for low-contrast structures, but are harder to use when solving for modes of high-index and lossy structures, as well as structures with small feature sizes.
- These structures include highly hybrid structures, photonic crystal air-core fibers, and omniguide fibers.
- *FemSIM* is a generalized mode solver for arbitrary structures that handles these cases, as well as many other general cases, with ease.

Simulation Domain, Boundary, and Mesh:

- Choice of coordinate system, element shape, and element order
- Convenient control over domain, PML thickness, and other boundary condition properties
- Both PML and symmetry boundary conditions available
- User selectable non-uniform mesh properties
- Pre-simulation mesh and index profile viewing
- First and second order hybrid edge-node elements used to avoid spurious solutions



Simulation Capabilities:

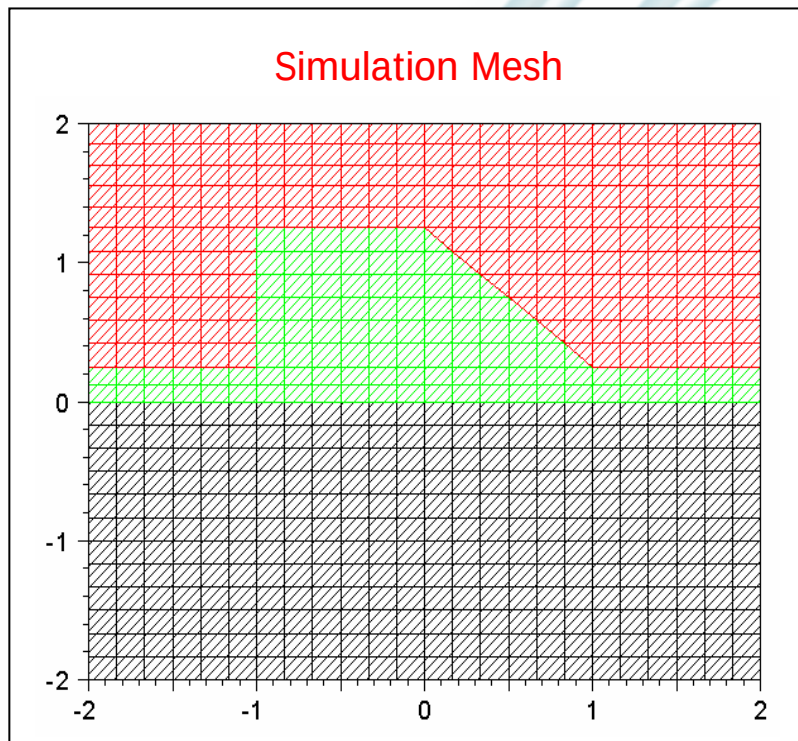
- Full-vectorial analysis for both Cartesian and cylindrical (azimuthally symmetric) structures
- Determination of guided, leaky, and cavity modes
- Accommodates complex index for lossy materials, and high index profiles
- Intelligent reordering of mesh elements for efficient computation
- Simple setup of numerical solver control parameters

Analysis Features:

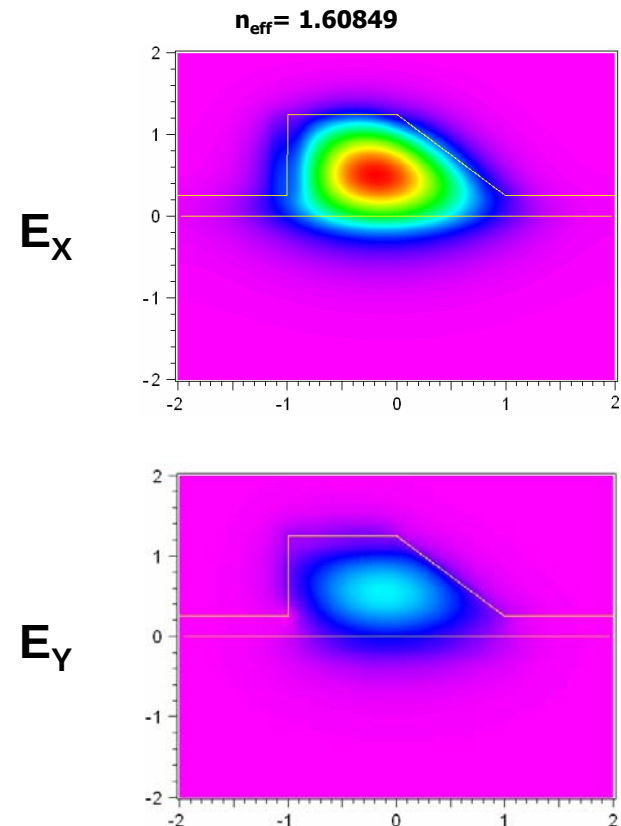
- Independent selection of output for each field component.
- Choice of number of modes to output
- Simulation progress window
- Display of complex effective index for each mode
- Output of all complex effective indices vs. wavelength
- Choice of ordering for index output
- Include full-functional scientific plotting tool: *WinPLOT*
- Viewing of all modes and mesh in slideshow format via: *RSdataBROWSER*

Example 1: Asymmetric Ridge Waveguide

- *FemSIM* solves the Full-Vector form of Maxwell's equations, so it can handle high-index structures that have a hybrid modes.

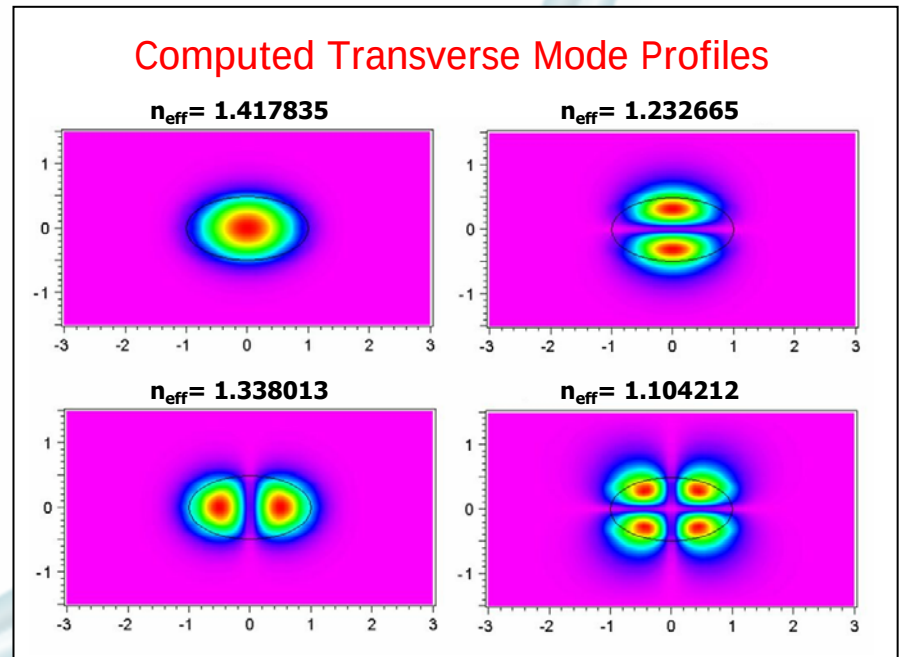
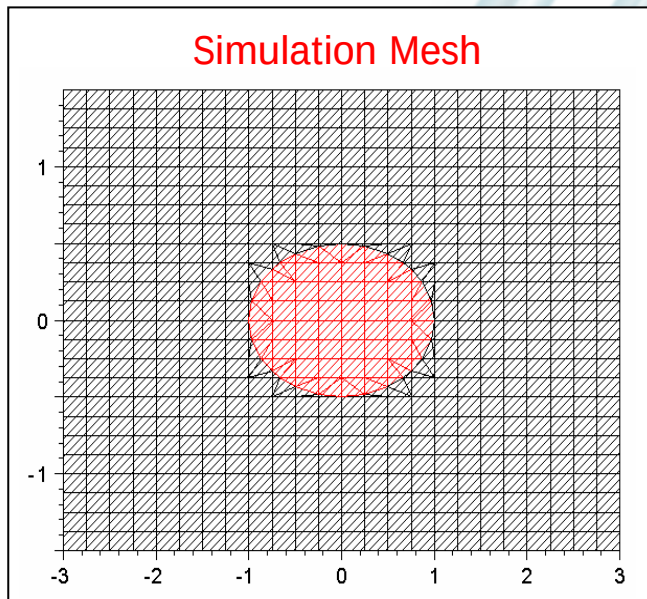


Computed Transverse Mode Profile



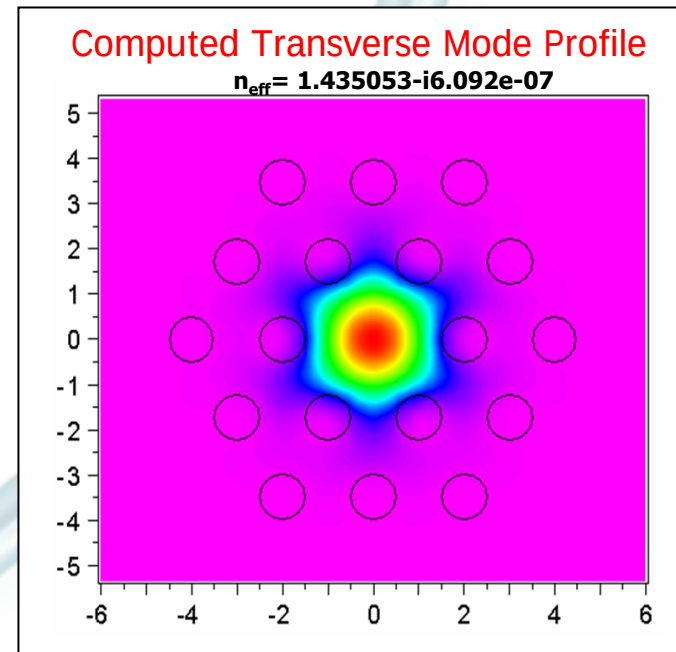
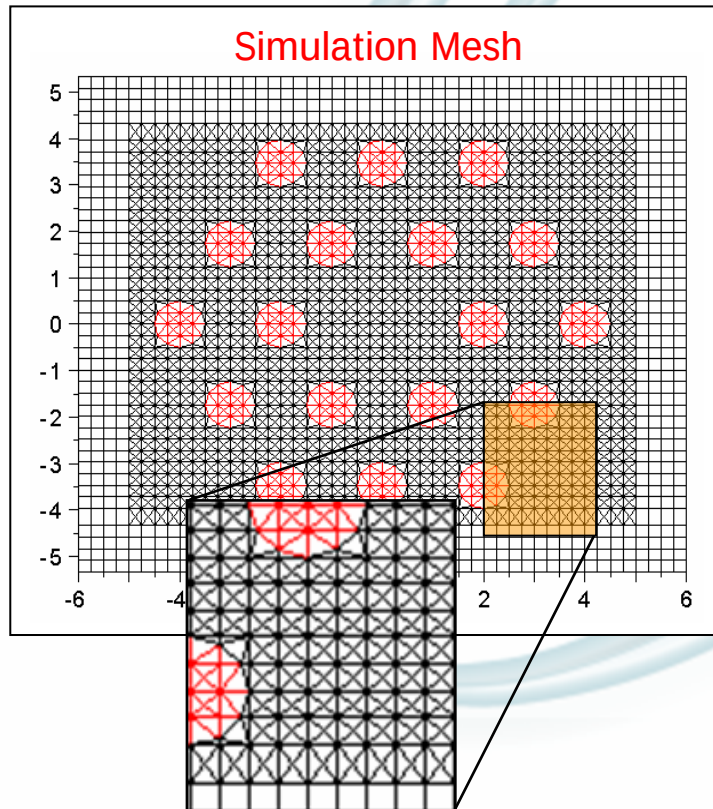
Example 2: Multimode Elliptical Fiber

- An advantage of *FemSIM* is that any number of modes can be requested, all of which will be solved simultaneously. Furthermore, the user can specify where, in the spectrum, to begin searching for the modes.



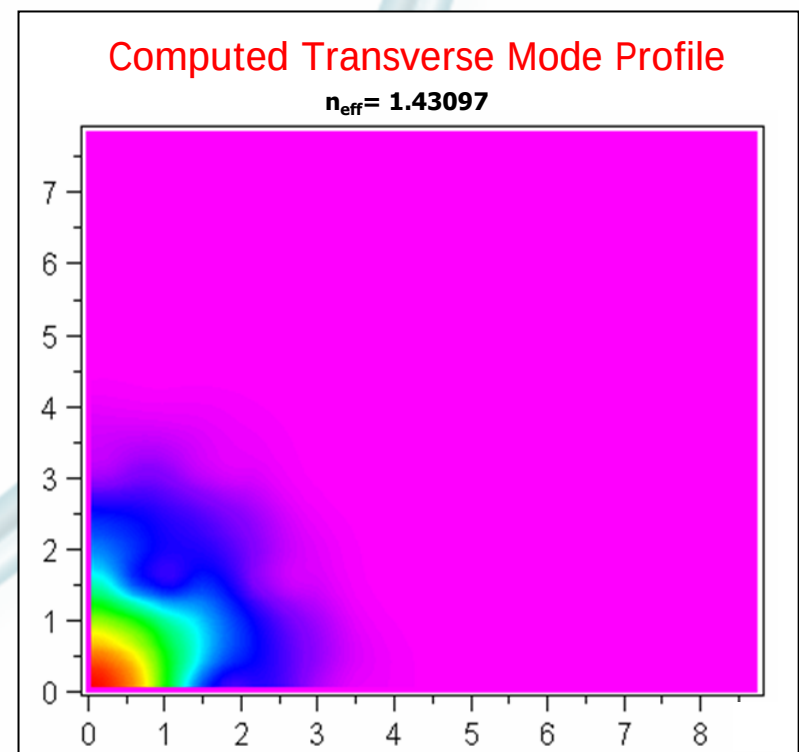
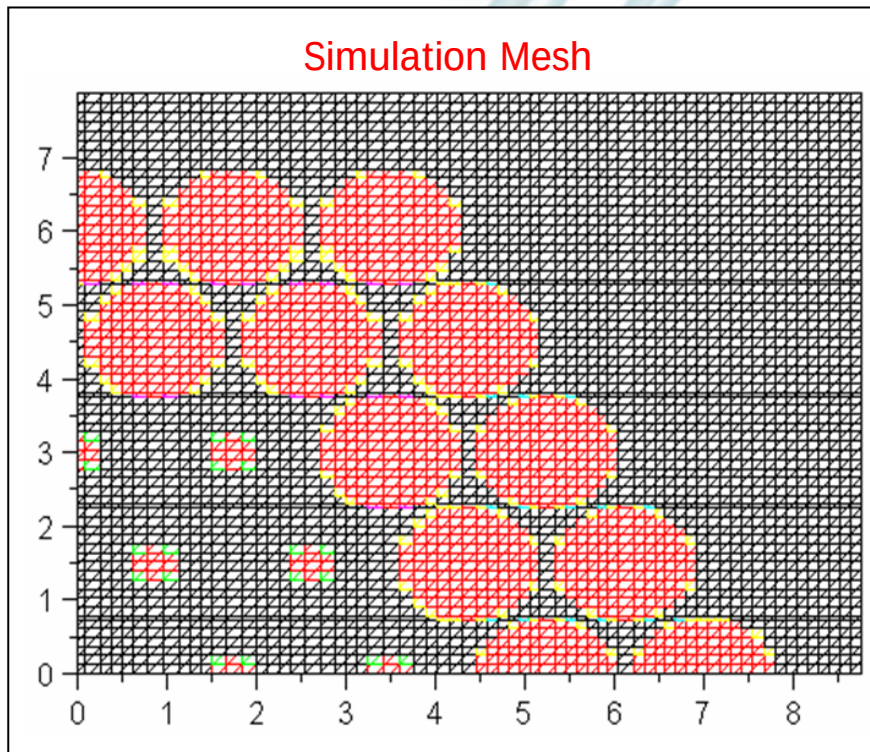
Example 3: Photonic Crystal Fiber (PCF)

- An inherent advantage of the Finite Element method is the ability to efficiently resolve complex geometries with appropriate combinations of mesh elements. It can also determine hybrid modes and their losses.



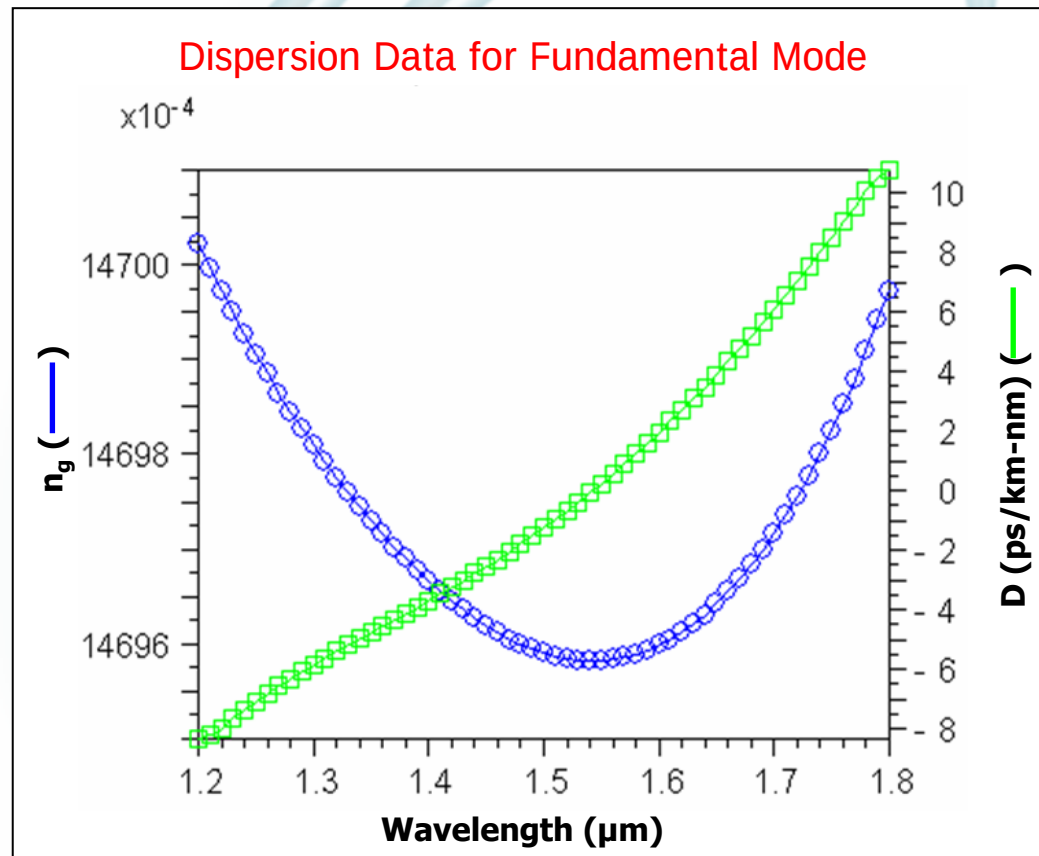
Example 4: Dispersion in PCF

- The mesh and mode profile for quadrant 1 of the simulation domain (symmetry about X and Y axis) is shown. To calculate dispersive properties, the wavelength can be scanned and the mode recalculated automatically.



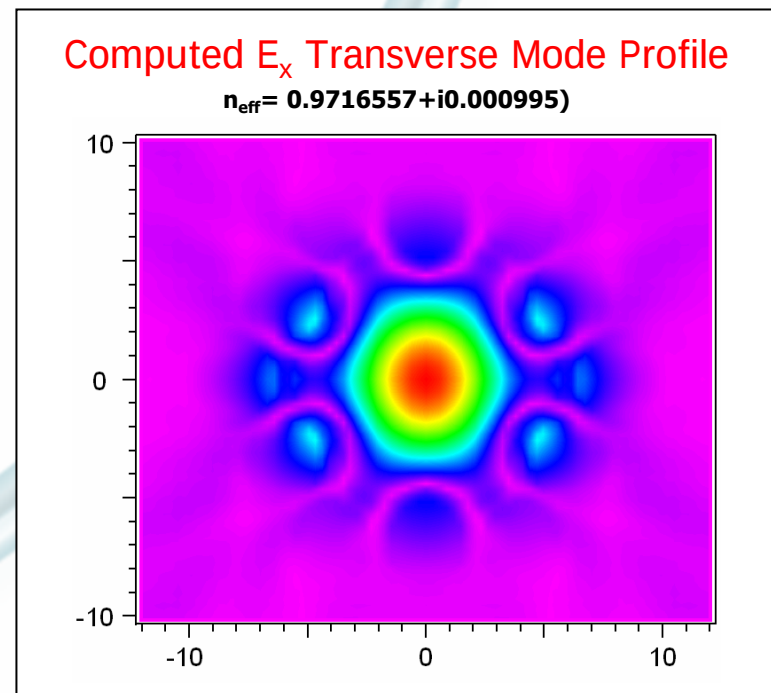
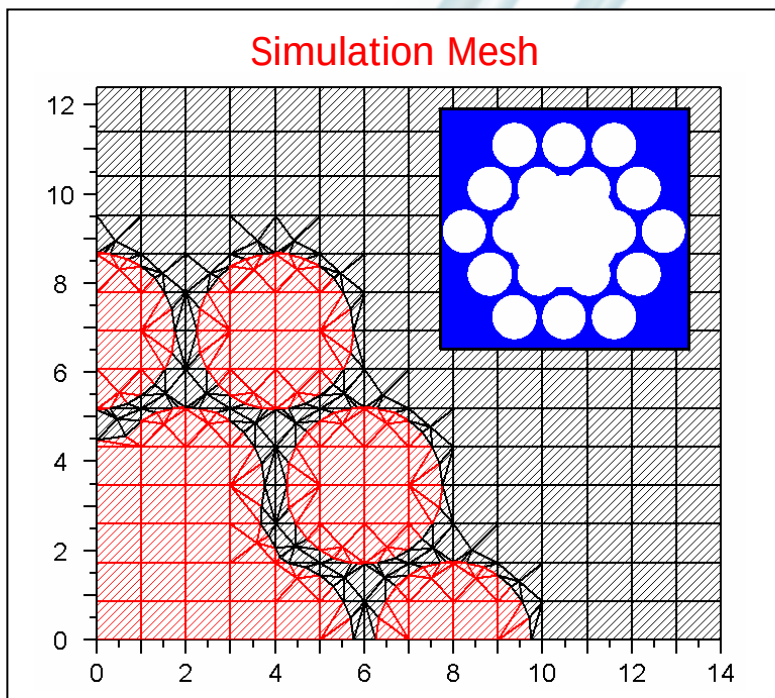
Example 4: Dispersion in PCF - cont'd

- Dispersion results for a PCF formed by air holes with two different sizes



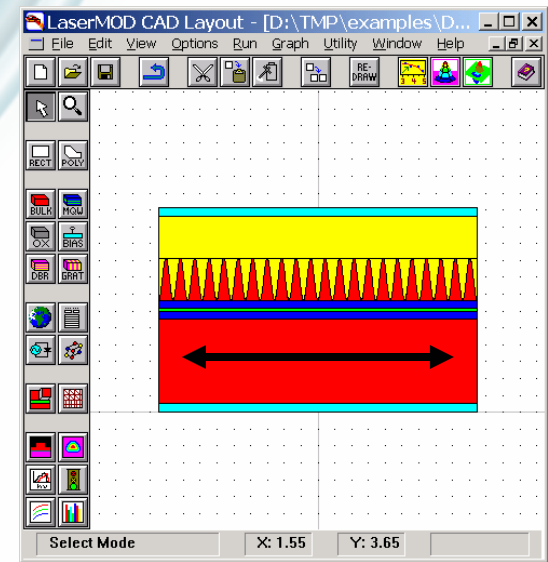
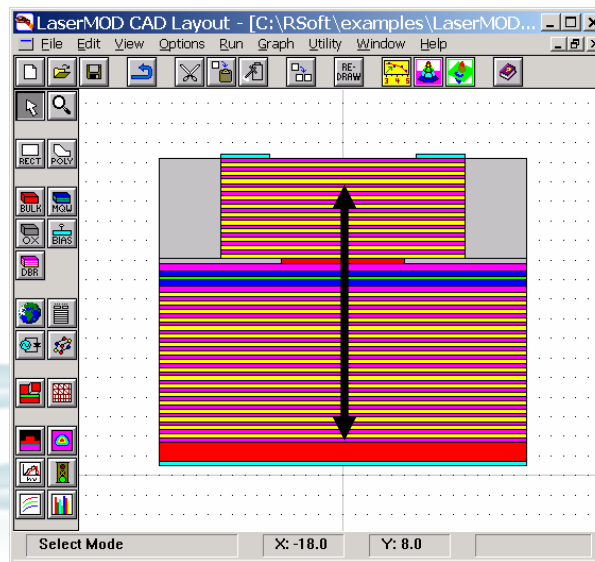
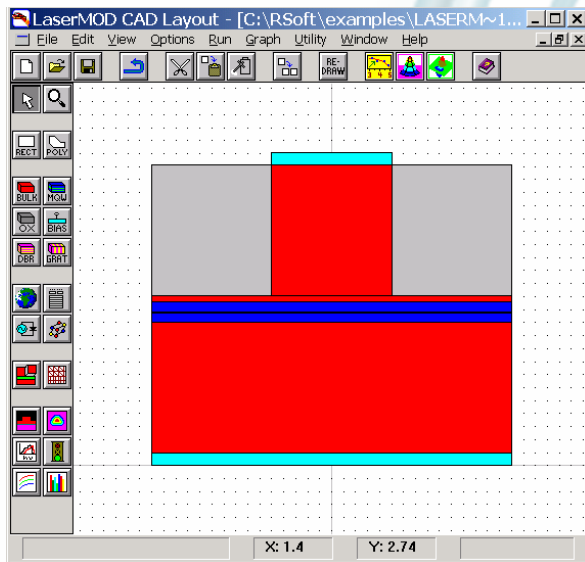
Example 5: Air-Core Fiber

- FEM mesh, with fiber profile shown in inset, for an air-core fiber. These types of structures present difficulties to other mode solving methods because of their inherent leaky nature. FEM-based methods have no such difficulty.



Active Device Layout

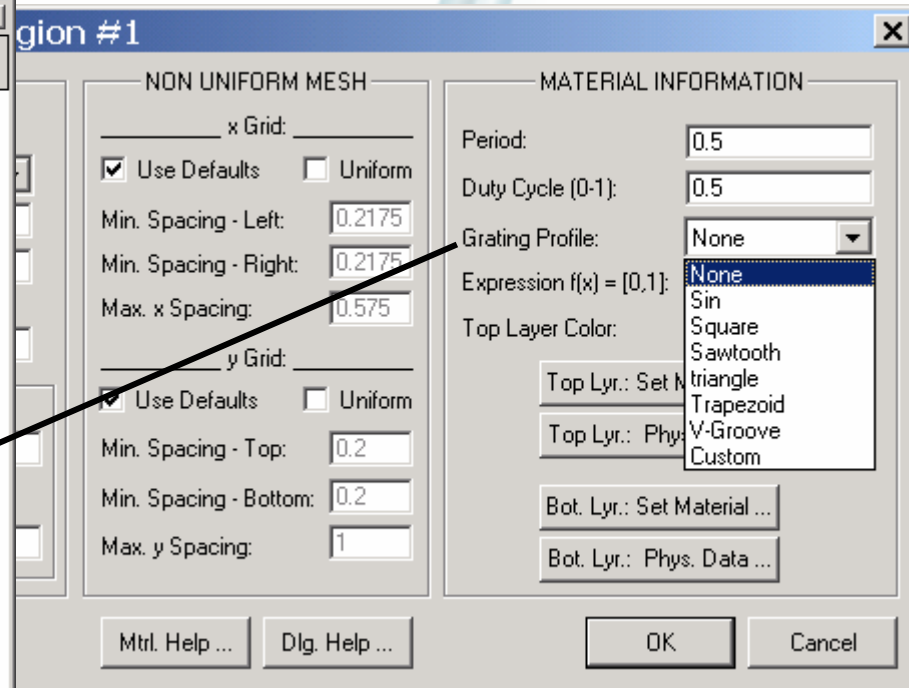
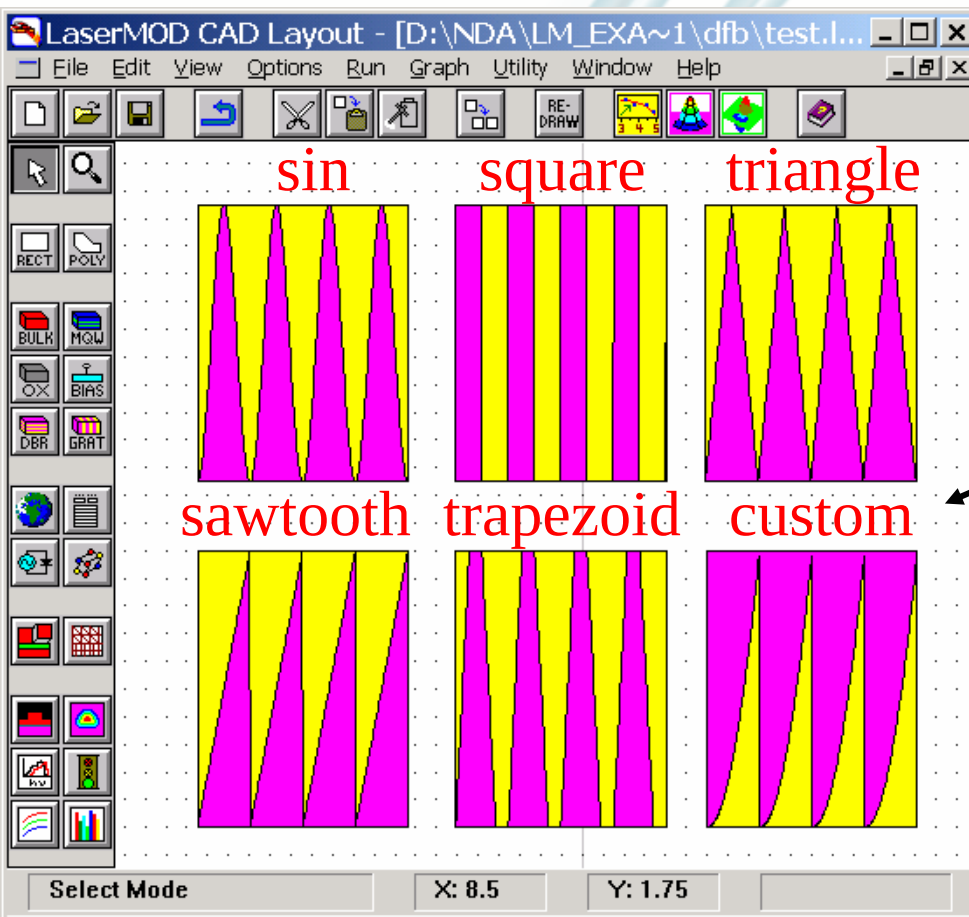
- Fabrey-Perot (FP) lasers are described by their waveguide cross-section geometry
- Vertical Cavity Surface Emitting lasers (VCSEL) are described by the diametric cross-section of their cylindrical geometry
- Distributed Feedback (DFB) lasers are described by their longitudinal cross-section geometry



LaserMOD

DFB Layout

- The DFB layout is similar to other laser structures, except for the presence of a new region type, the grating region. By controlling the width of this region and the period, the phase of the grating at the right facet is determined.

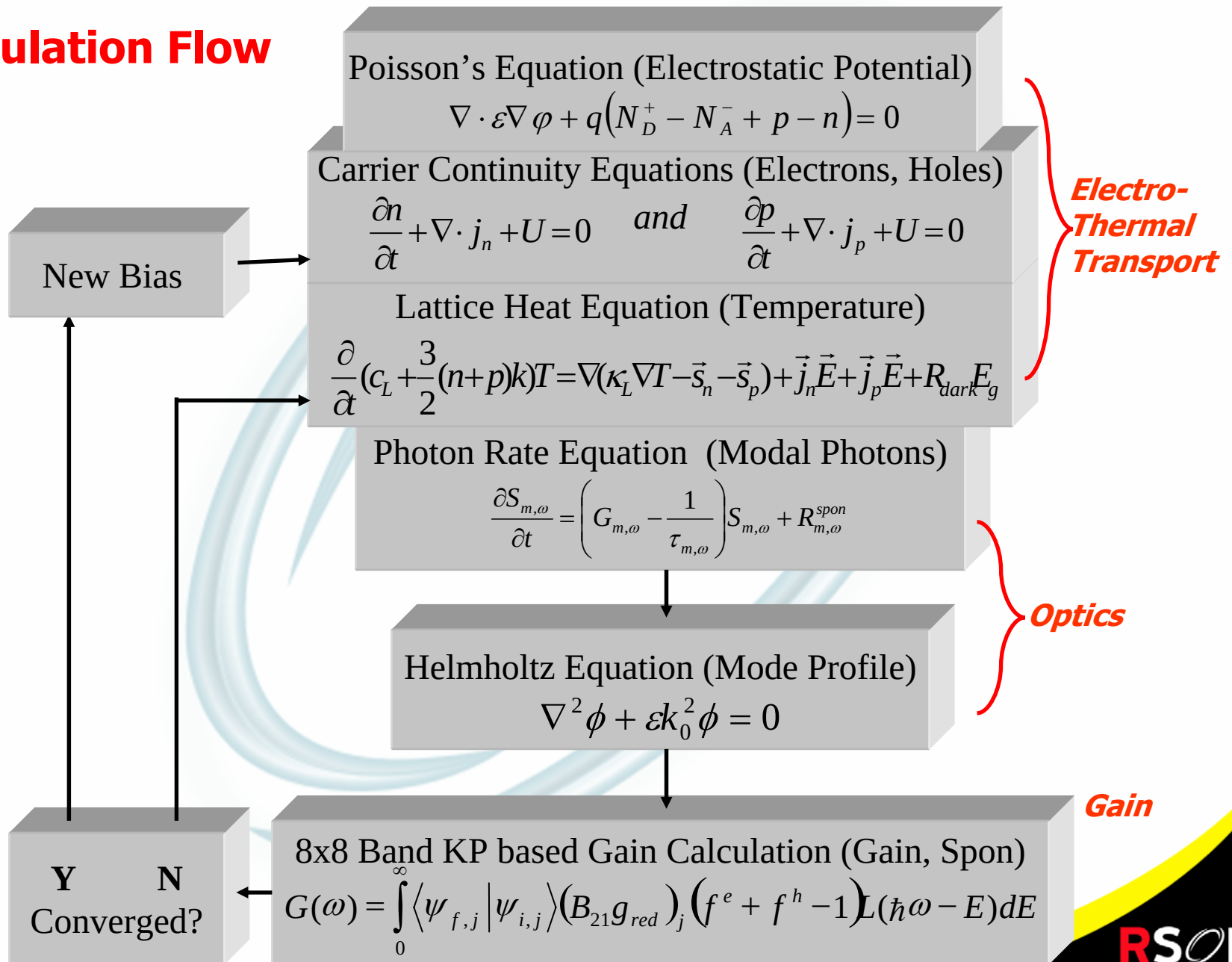


CAD features

- Same parametric description of geometry and materials as passive device platform (global and local variables)
- Bulk semiconductors, insulators, multiple quantum wells, contacts
- Arbitrary profiles for doping and alloy composition
- Modular for efficient design: meshing, profiling, gain, optics, simulation, plot generation & visualization all from one interface
- Integration with passive device tools: *BeamPROP*, *FullWAVE*, *FemSIM*
- Integration with system tools: *Optsim*, *ModeSYS*

LaserMOD

Simulation Flow



Simulation features

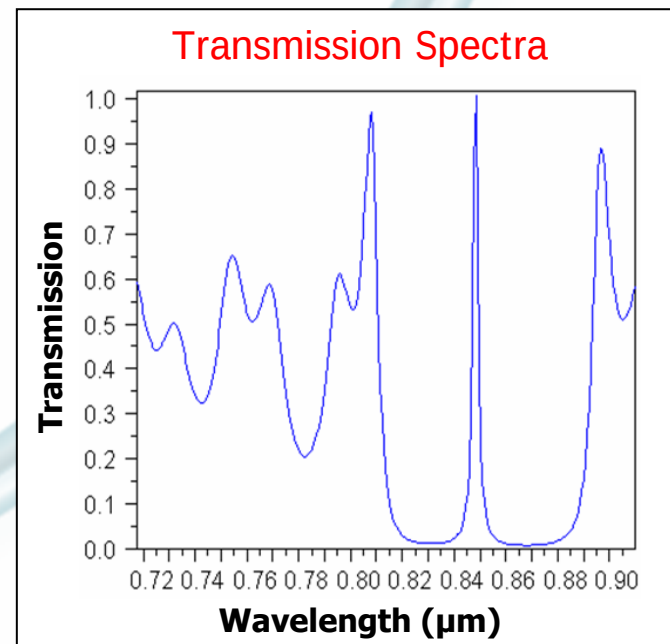
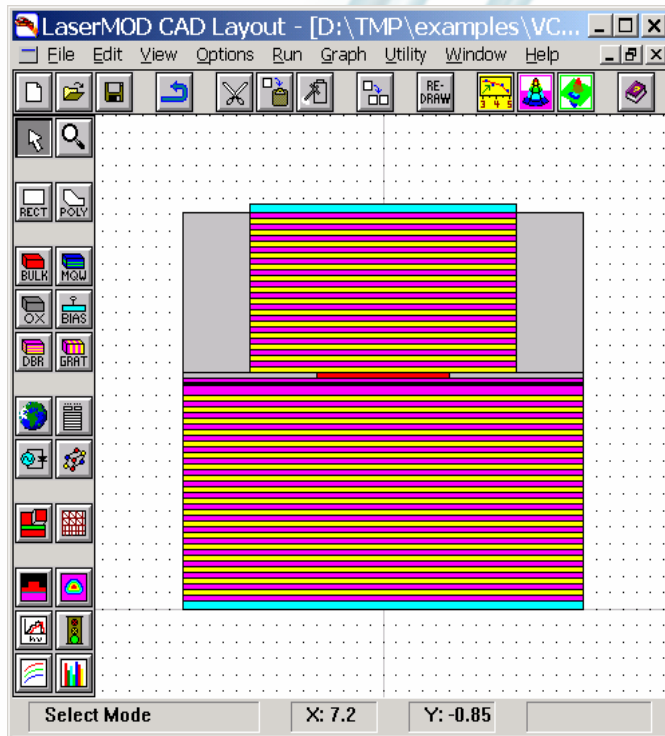
- LaserMOD solves electro-thermal transport and carrier-photon interactions using a fully coupled numerical scheme, along with optical wave propagation and gain in a self-consistent manner, all on a spatial discretization of the device geometry.
- Optical mode solvers: Ritz-iteration, BPM, FDTD, FEM, TMM
- Gain models: 8x8 KP, Look-Up Tables, Parabolic. All accounting for Bandgap renormalization
- Electro-thermal transport models include: Joule, Thomson, Peltier, and recombination sources, Incomplete carrier capture into bound states, Temp/Carrier dep. Mobility, Auger & SRH, Thermionic Emission, Interface Tunneling & Recombination, Quantum corrections at interfaces, and Free-carrier absorption
- These account for numerous effects such as Mode Competition, Spatial Hole Burning, and Self-Heating

Analysis features

- *LaserMOD* provides a complete set of post-processing and visualization capabilities.
- Standard plots include I-V & L-I curves, Transient and Frequency responses, Wavefunctions, Bandstructure, DOS, Modal and Material Gain, Optical Spectra, Near/Far fields, Energy bands, carrier profiles, Mesh and Index profiles
- Custom plots can be generated from nearly all internal parameters, and fall into 3 basic groups: spatial data, spectral data, and per-bias data
- Analytic Post-Processing of data is also available

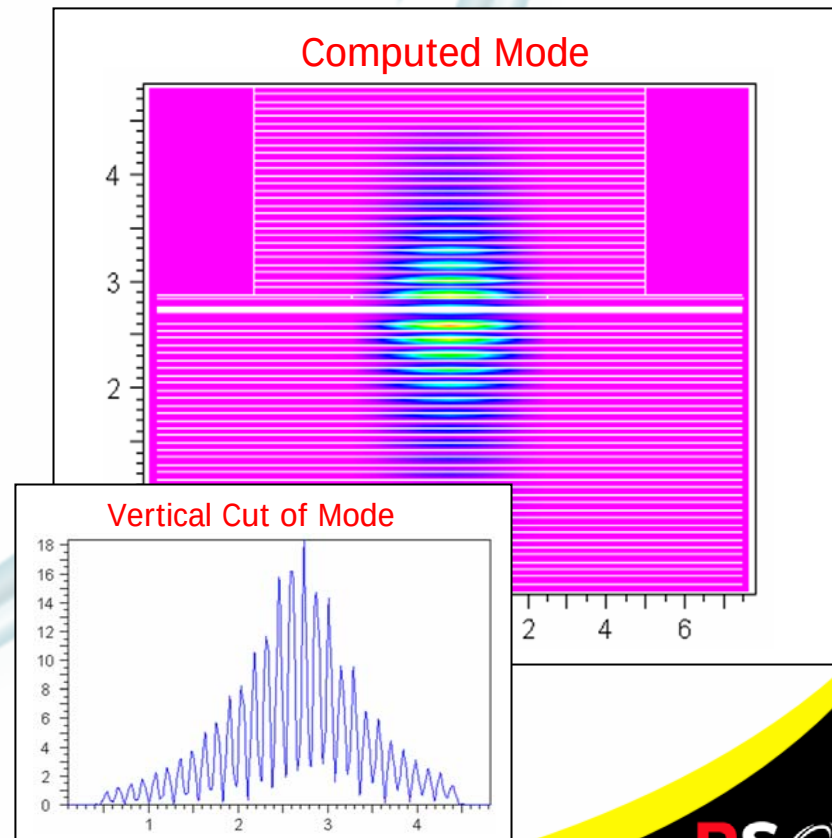
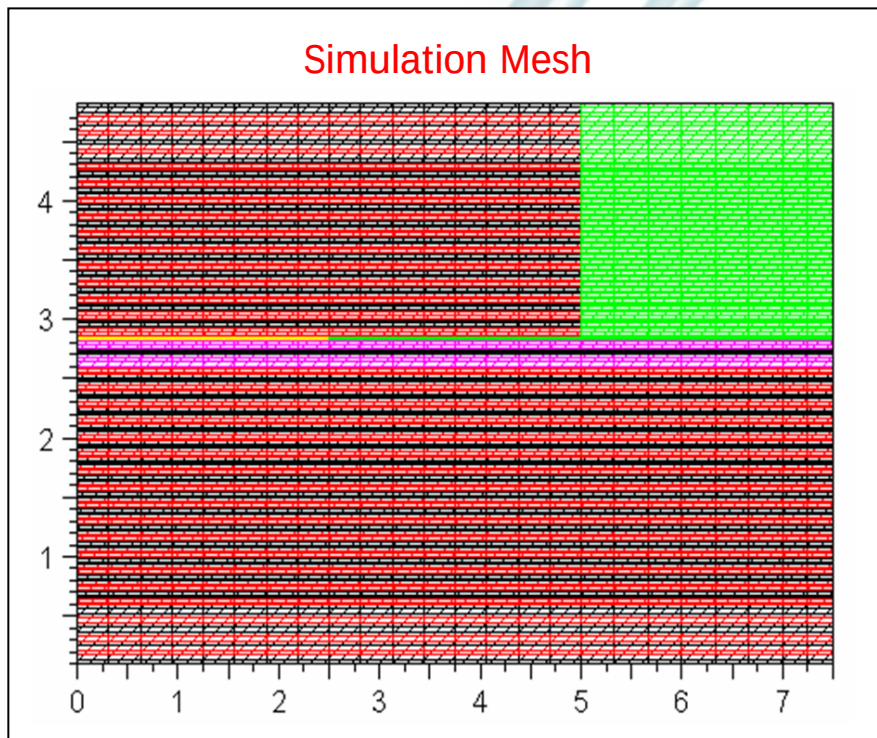
Example 1: Cylindrical VCSEL with FEM

- Layout (left) and plane wave transmission spectrum (right) of an oxide aperture VCSEL cavity. Peaks in the spectrum provide a useful initial guess for *FemSIM* for the cavity mode calculation. In this case, the index profile used by *FemSIM* was taken directly from the semiconductor laser design tool, *LaserMOD*.



Example 3: Cylindrical VCSEL with FEM - cont'd

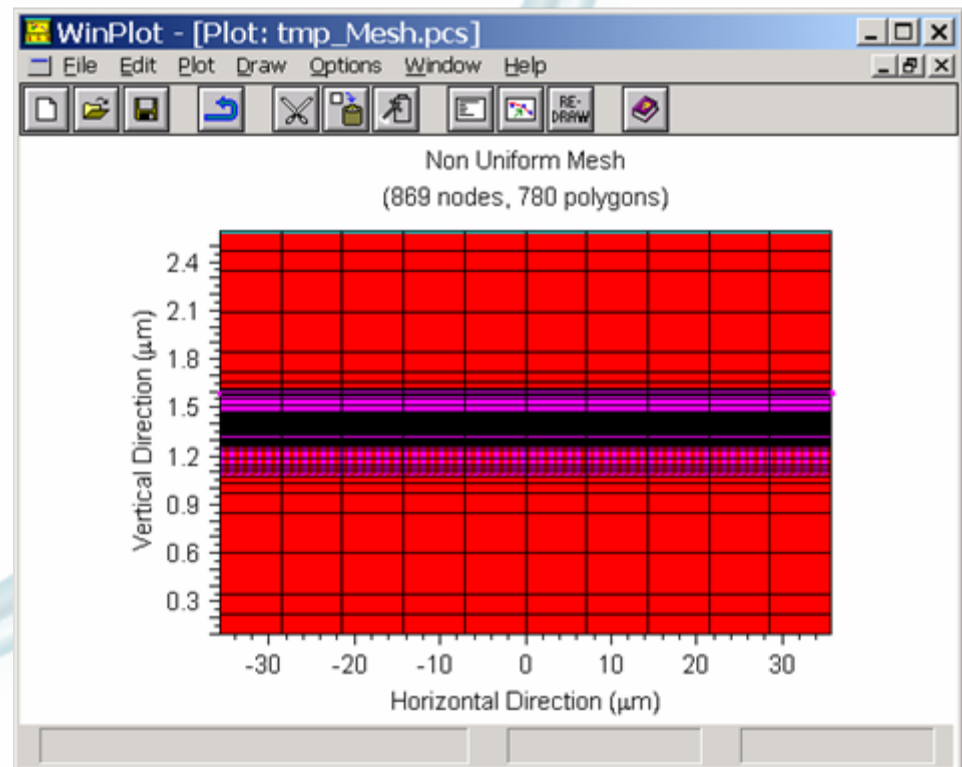
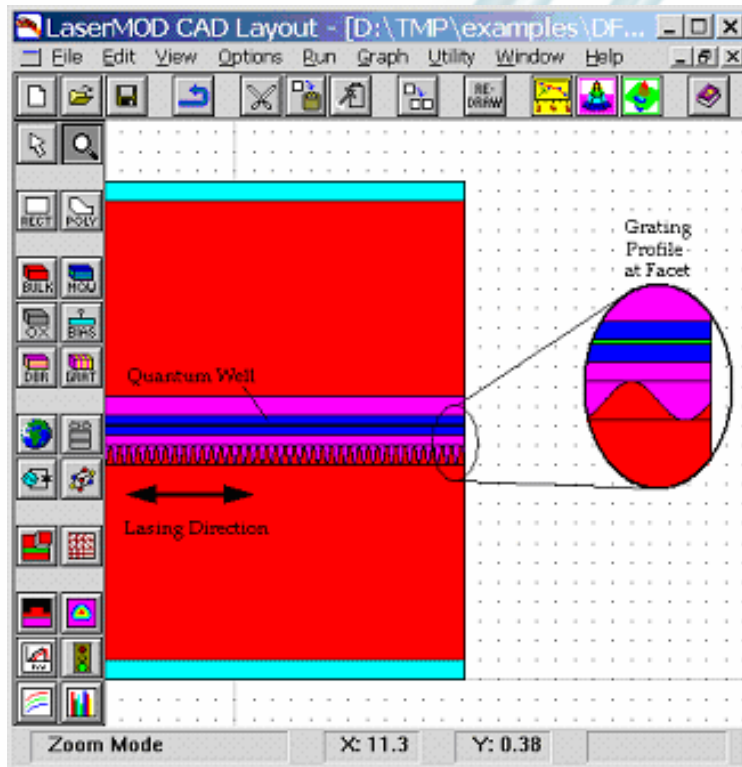
- FEM mesh (left) and fundamental mode profile (right) for the oxide aperture VCSEL. The inset (lower right) shows the intensity along the y-axis of the device. Resonance wavelength and cavity loss are also determined by *FemSIM*.



LaserMOD

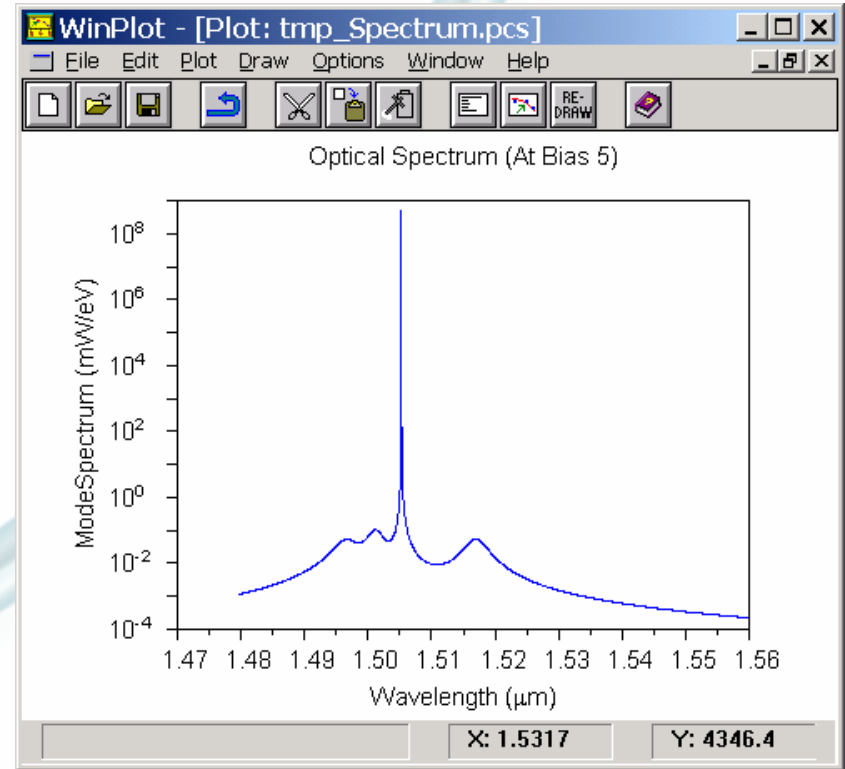
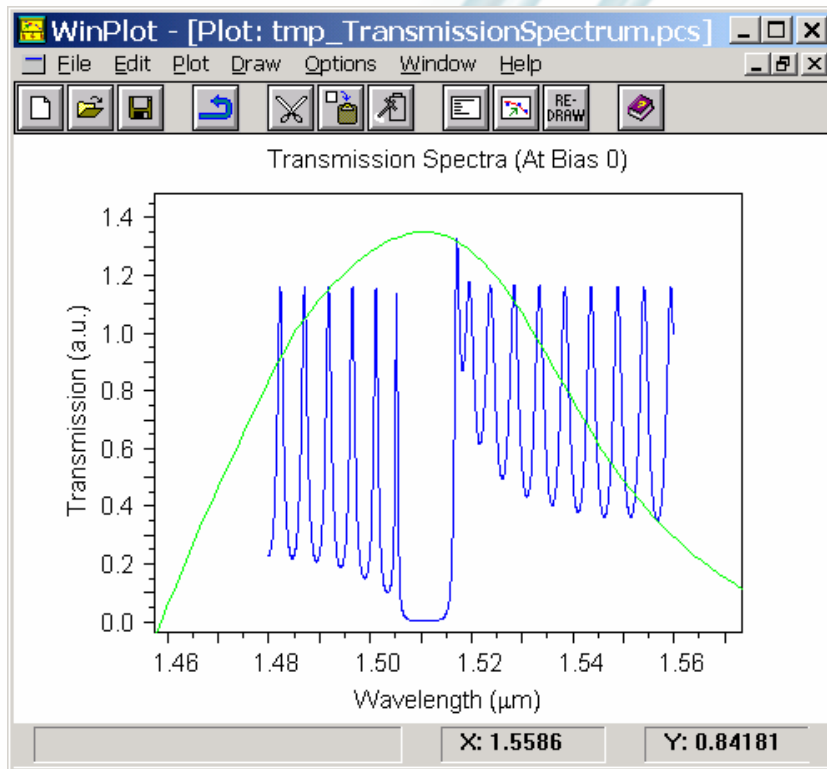
Example 2: Single section DFB

- The DFB layout is shown left, with the non-zero facet phase shown inset.
- The mesh for electro-thermal transport is shown right (optical mesh is much denser)



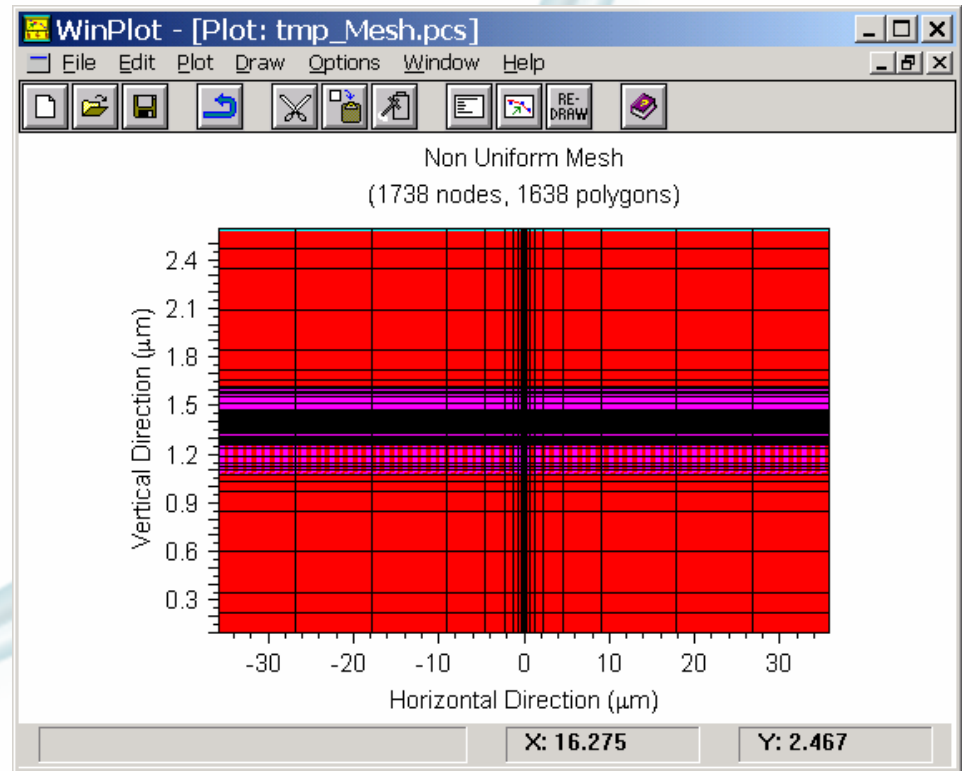
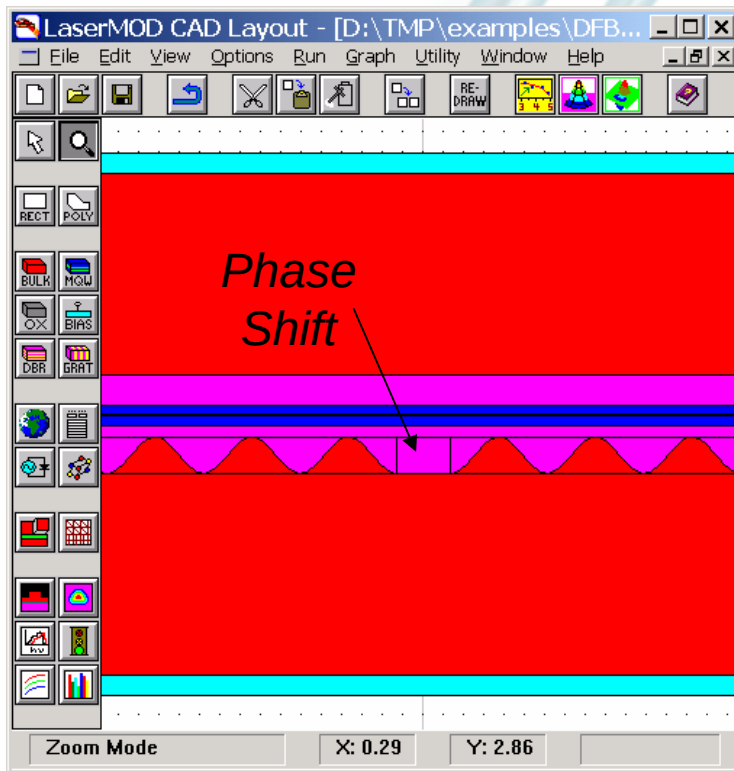
Example 2: Single section DFB - cont'd

- The DFB cold cavity spectrum is shown with material gain overlay.
- Above-threshold lasing spectrum is shown, right. Four modes have been tracked for this simulation, but there is no limit.



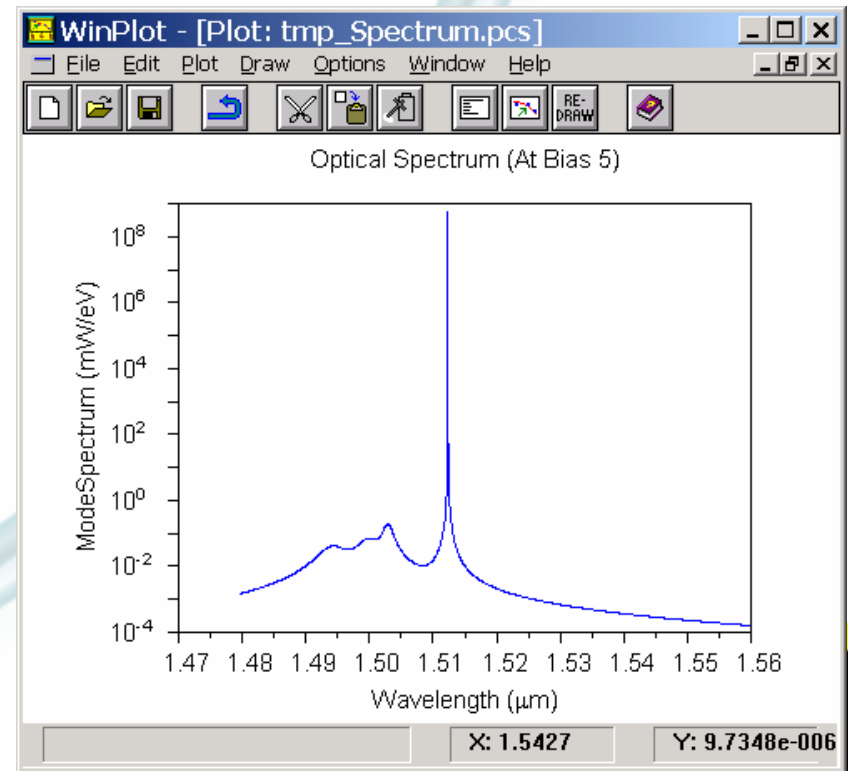
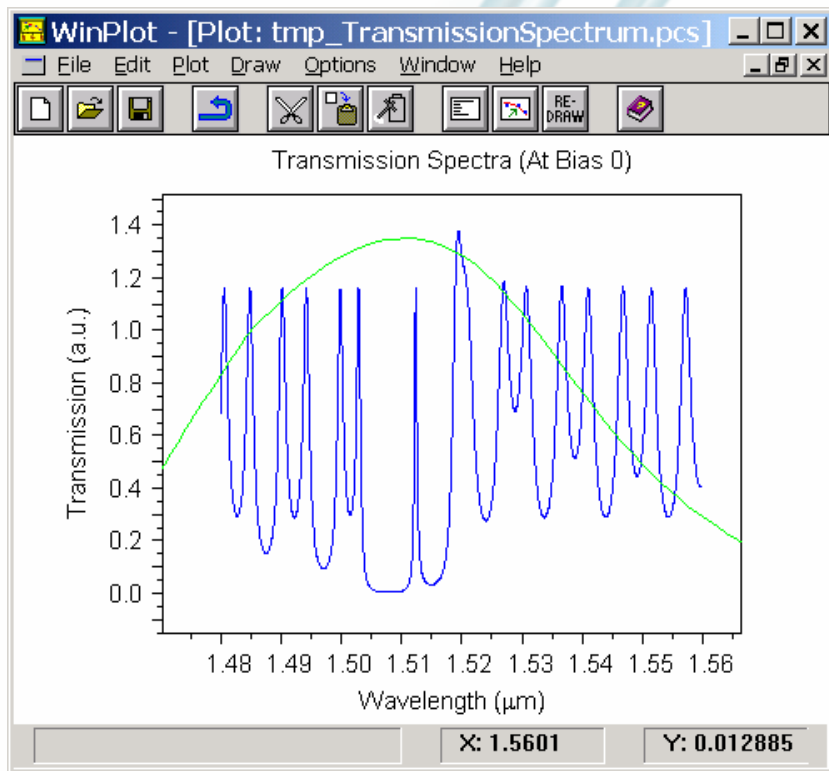
Example 3: DFB with phase shift (DBR)

- This DFB has 2 grating sections separated by a small region without any grating. This introduces a $\pi/2$ phase shift which creates an extra mode in the middle of the stop-band.
- Corresponding electro-thermal mesh is shown, right.



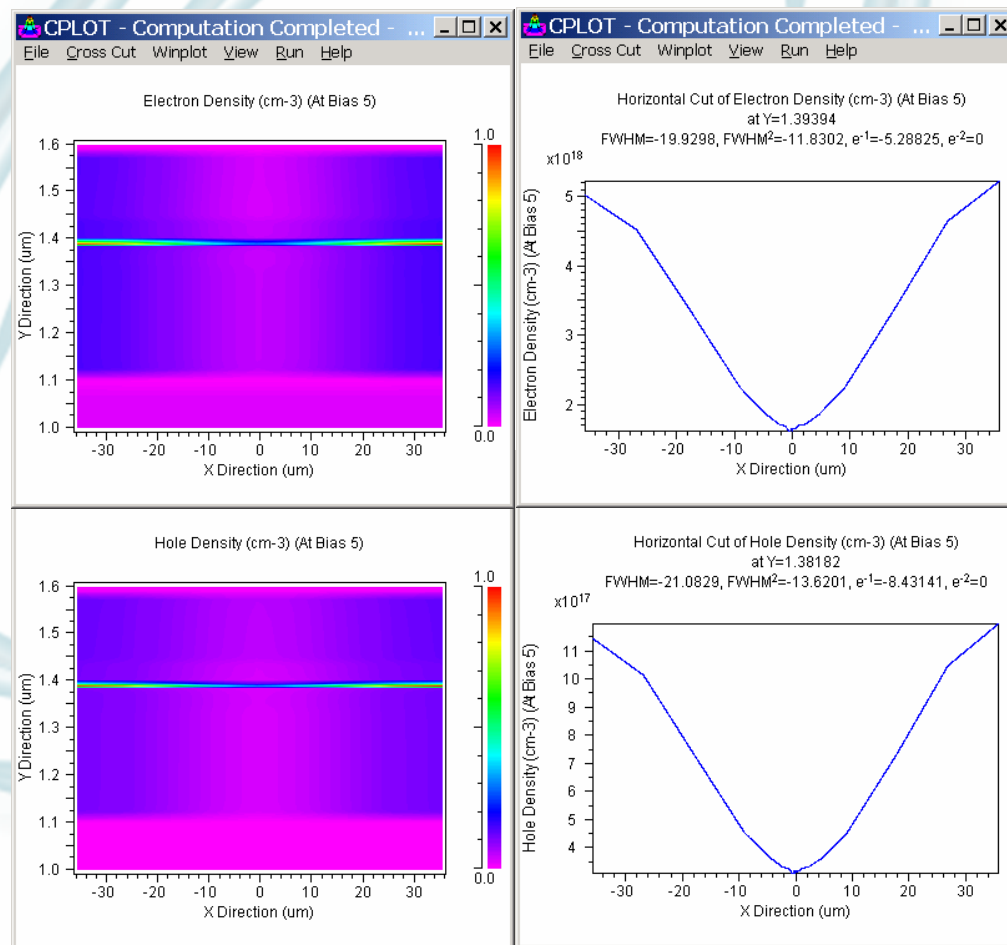
Example 3: DFB with phase shift (DBR) - cont'd

- The extra mode in the middle of the stop-band can be seen in the cold cavity spectrum, one again shown with material gain overlay.
- Above-threshold lasing spectrum shown right - only four modes have been tracked here.



Example 3: DFB with phase shift (DBR) - cont'd

- The longitudinal spatial hole burning can be seen for electrons (top) and holes (bottom). Contour plots are shown (left), as are cross-cuts (right) along the length of the waveguide (taken at the quantum well).



Summary

FemSIM is an advanced mode solving tool based on a state-of-the-art Finite Element Method.

- First and second order hybrid edge-node elements are used to avoid spurious solutions. PML and symmetry boundary conditions can be selected.
- Full vector solutions of complex, high-contrast index profiles.
- Determination of propagating, leaky, and cavity modes.
- Cartesian and cylindrical geometries.
- Automatic non-uniform mesh generation.
- Display of all modes and their field components.
- Integrated with RSoft CAD Environment and other tools.

LaserMOD is an active device platform for simulating semiconductor opto-electronic devices.

- Fully coupled electro-thermal transport with gain and optical propagation solved self-consistently.
- Integrated layout and simulation environment
- FP, VCSEL, DFB, Modulators applications
- Integrated with passive device & system platforms