An Advanced Simulator of Vertical Cavity Surface Emitting Lasers (VCSEL)

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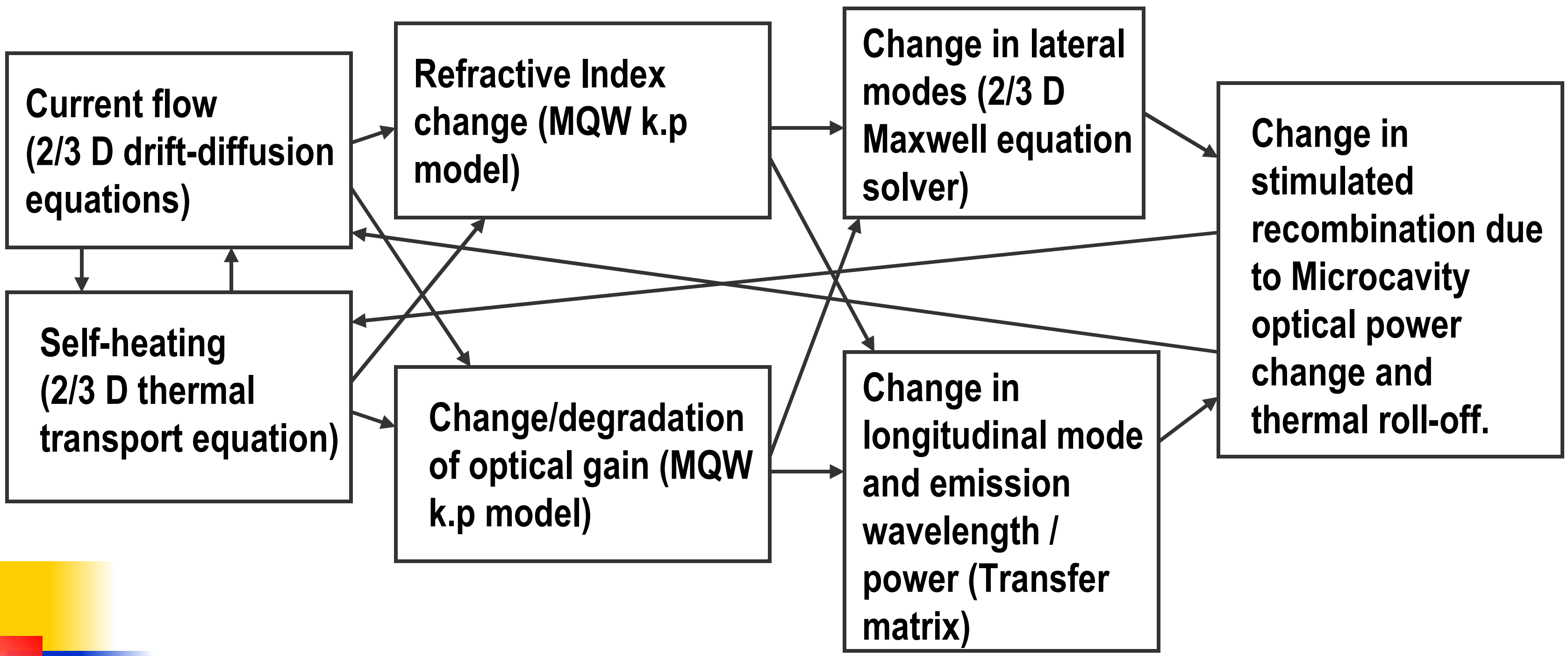
Contents

- Self-consistent models in PICS3D/VCSEL module.
- Basic VCSEL modeling capabilities.
- Advanced features.
- Conclusions.

Crosslight VCSEL Models

- **PICS3D/VCSEL modules include quantum mechanical, electrical, thermal and microcavity optical effects, with stronger interaction than for any other optoelectronic devices.**



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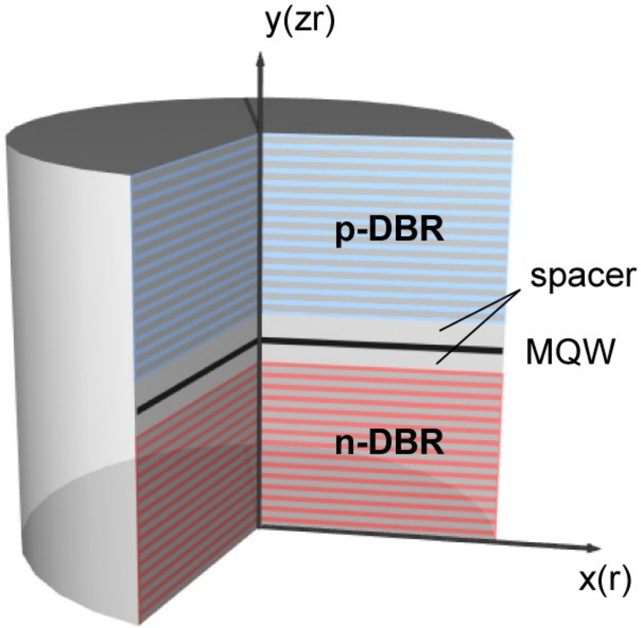
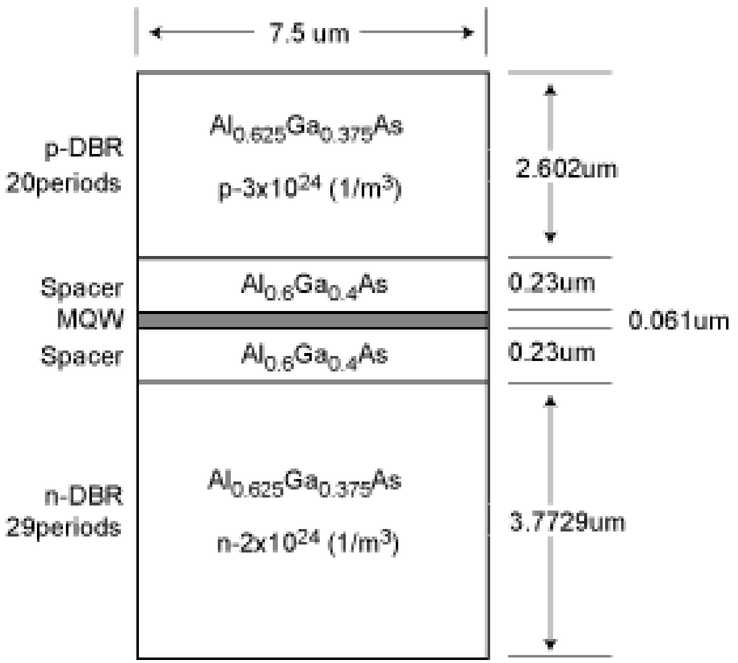
Schematic of Conventional VCSEL Model

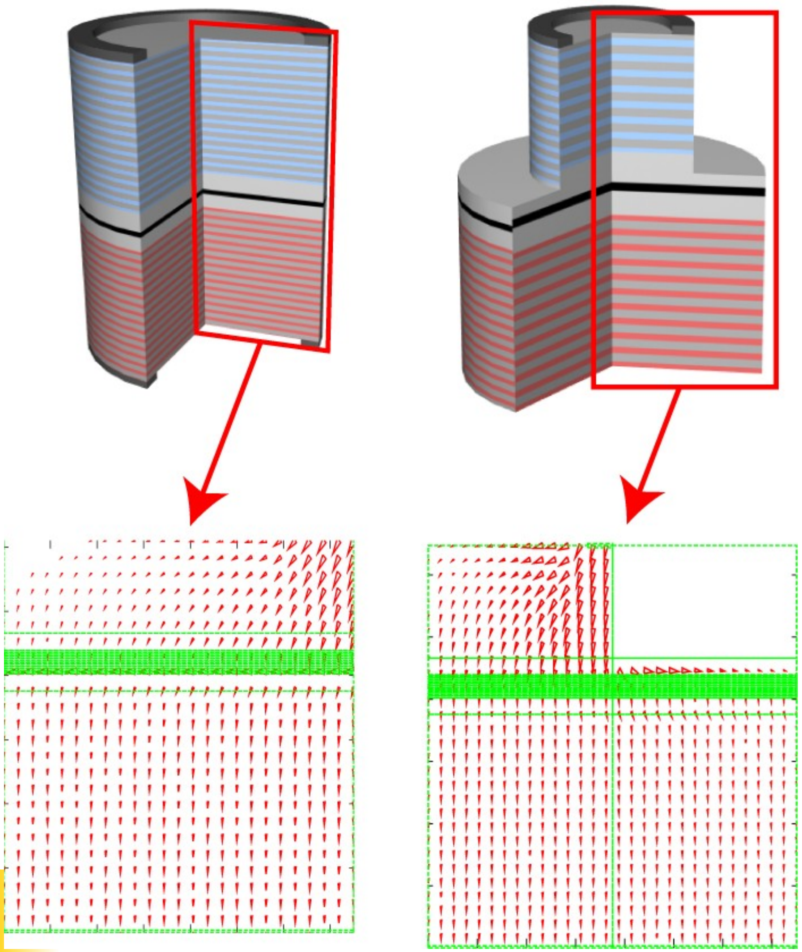


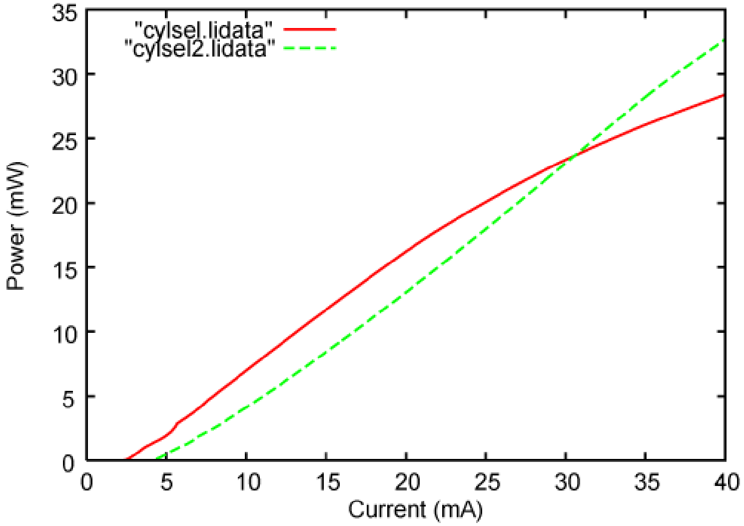
Schematic of simple VCSEL



- 2D-slice and cylindrical coordinates are used to define 3D structure of VCSEL.
- Thickness of spacer layer is adjusted so that the center of MQW and standing wave coincide.

Current Spreading Effect





- Difference in L-I is mainly due to current spreading effect.

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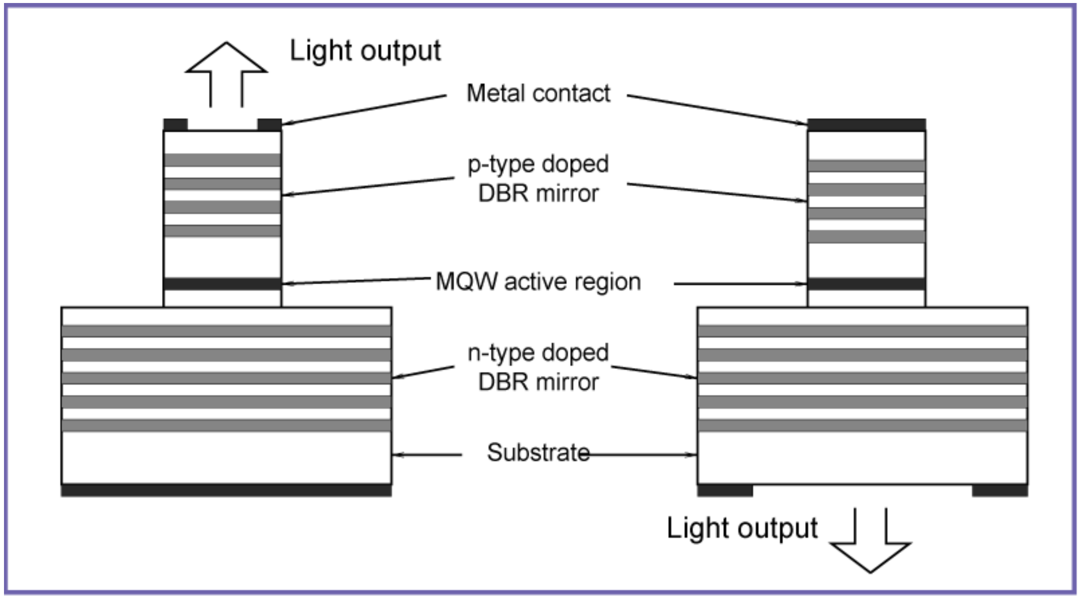
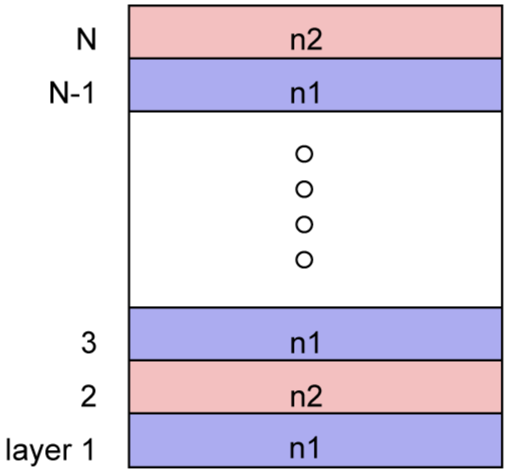
Longitudinal Modes in VCSEL



Schematic of surface emitting lasers of front and back emission.



Schematic of a simple multi-layer optical model for DFB/DBR gratings.

- Material layers form SEL DBR/DFB gratings.
- Compared with edge DFB/DBR LD, VCSEL has fewer number of grating layers: ~50.
- More accurate to use multi-layer optics to describe the longitudinal modes.
- Transfer matrix method is used to calculate optical transmission between layers.

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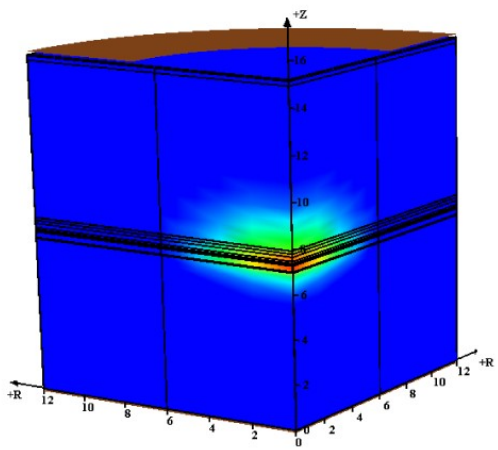
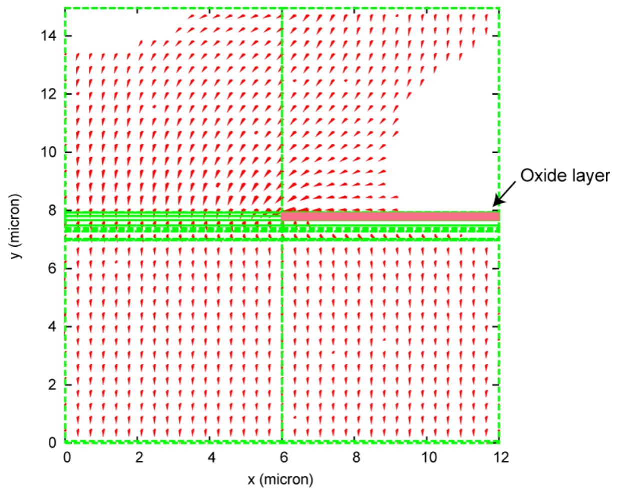
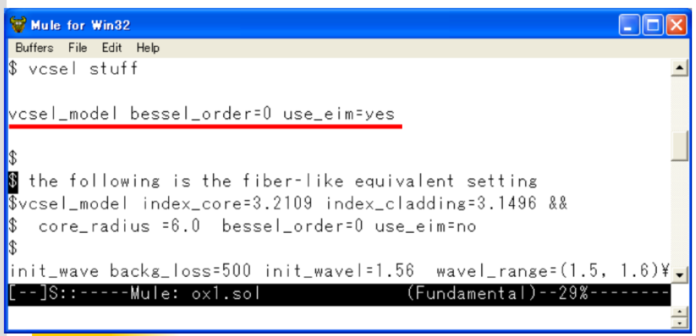
Computation of Lateral Optical Modes of VCSEL by Using EIM



Wave intensity distribution of VCSEL with oxide layer confinement.



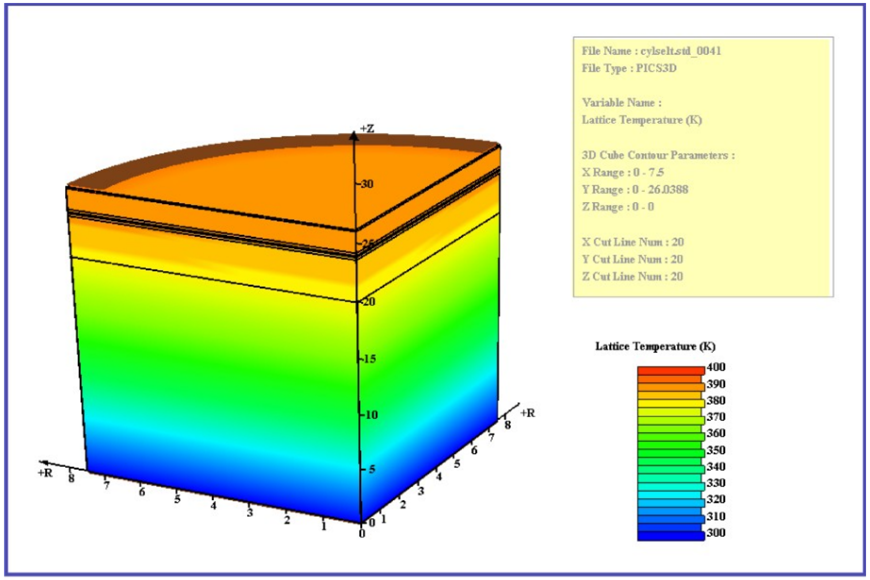
Total current flow of VCSEL with oxide layer confinement.



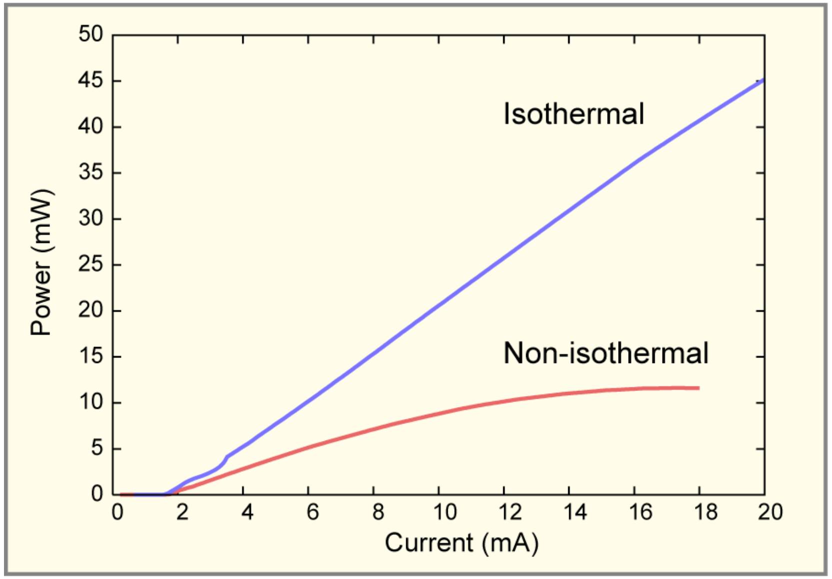
- A convenient traditional fiber-like EIM implemented.
- Optionally sophisticated EIM mode solver may be activated for accuracy.
- EIM is especially useful, when a VCSEL has an oxide confinement aperture.

G. R. Hadley et. Al., "*Comprehensive numerical modeling of vertical-cavity surface-emitting lasers*", IEEE J. Quantum Electron., Vol. 32, pp607-616, 1996.

Self-heating effect in VCSEL simulation



Thermal VCSEL simulation: temperature distribution



L-I characteristic: Iso- vs. Non-isothermal simulation

- Large substrate with bottom contact attached to external heat sink@300K.
- Self-heating effect causes degradation of slope efficiency.

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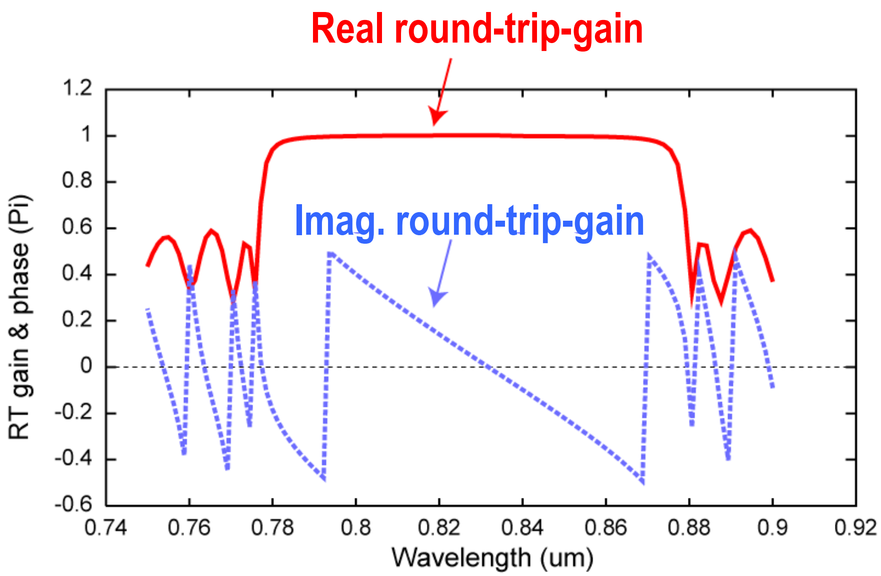
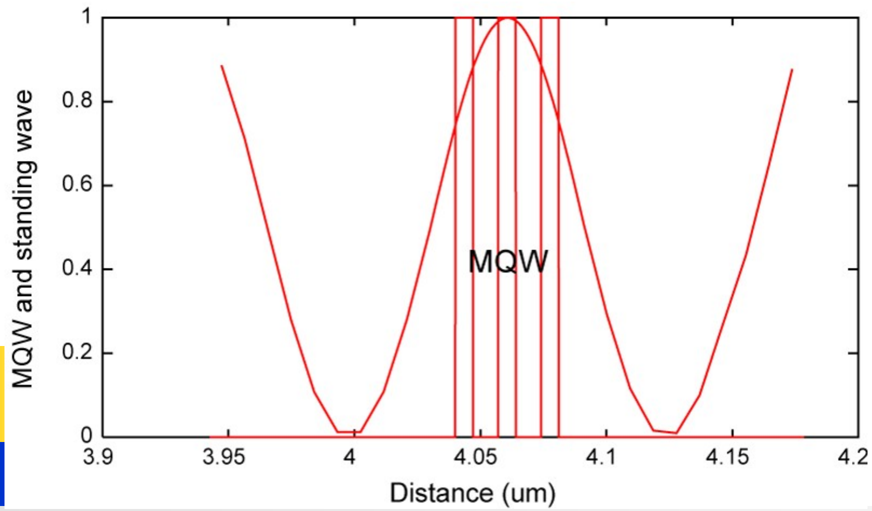
Automatic VCSEL Cavity Design Module





- Tune_vcsel utility can adjust VCSEL structure so that emission wavelength tunes with material gain peak.
- Also, position of MQW is automatically adjusted so that the center of standing wave and MQW coincide.

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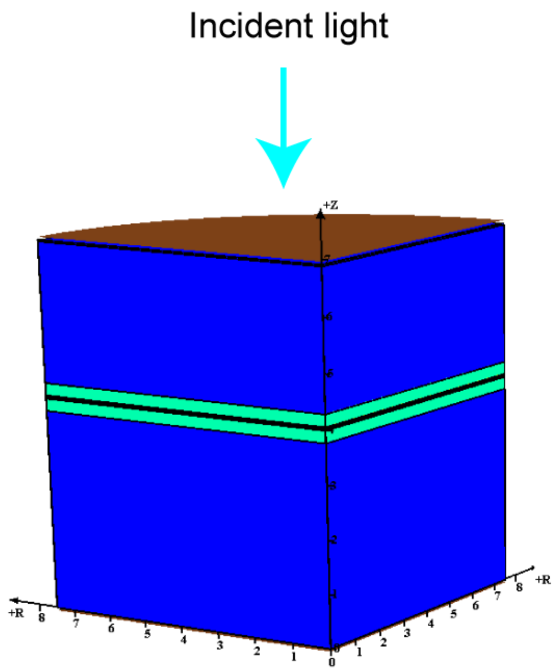
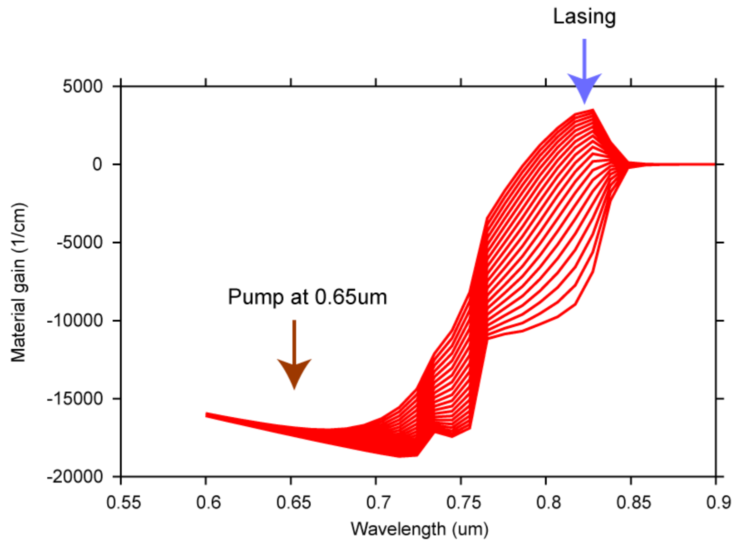
Optically Pumped VCSEL





Gain spectrum of optically pumped laser.

- Incident light at shorter wavelength (well above bandgap wavelength) is absorbed and generates carriers.
- Photo-carriers causes population inversion and lasing action at near the bandgap energy.

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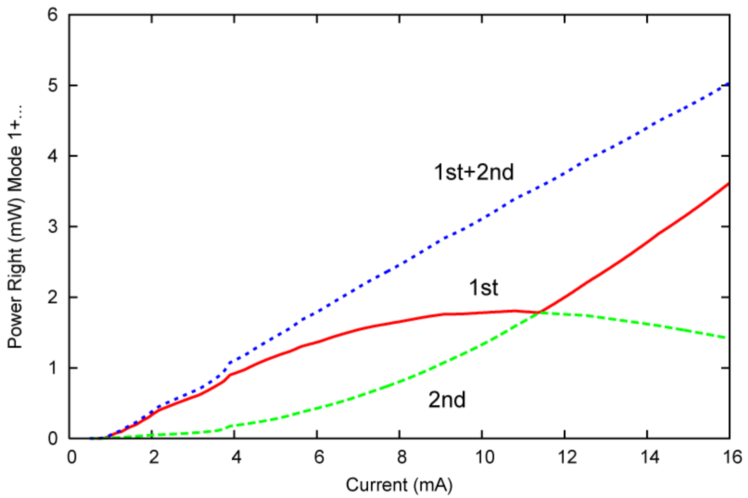
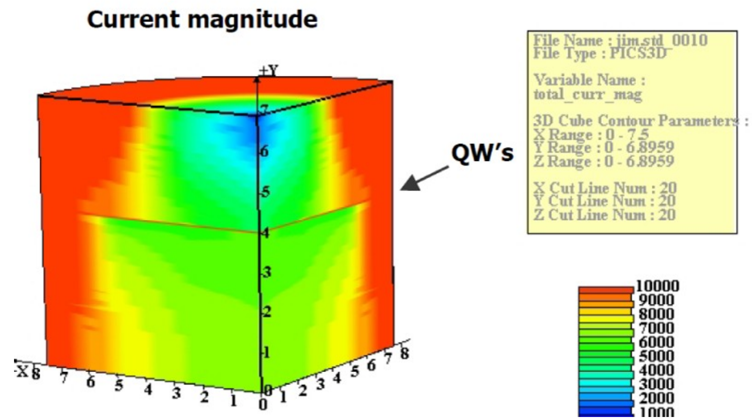
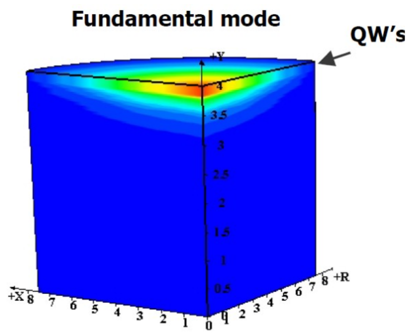
Multi-lateral Modes Calculation of VCSEL

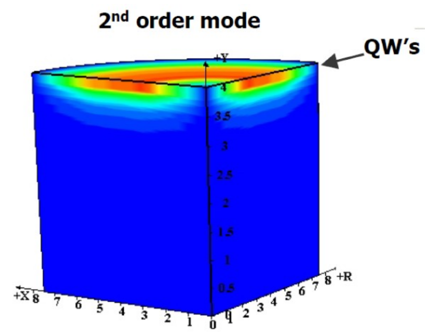


L-I curve from multimode calculation.



- VCSEL has similar lateral mode competition behavior as edge lasers.
- Perfect rotation symmetry assumed here for VCSEL structure.





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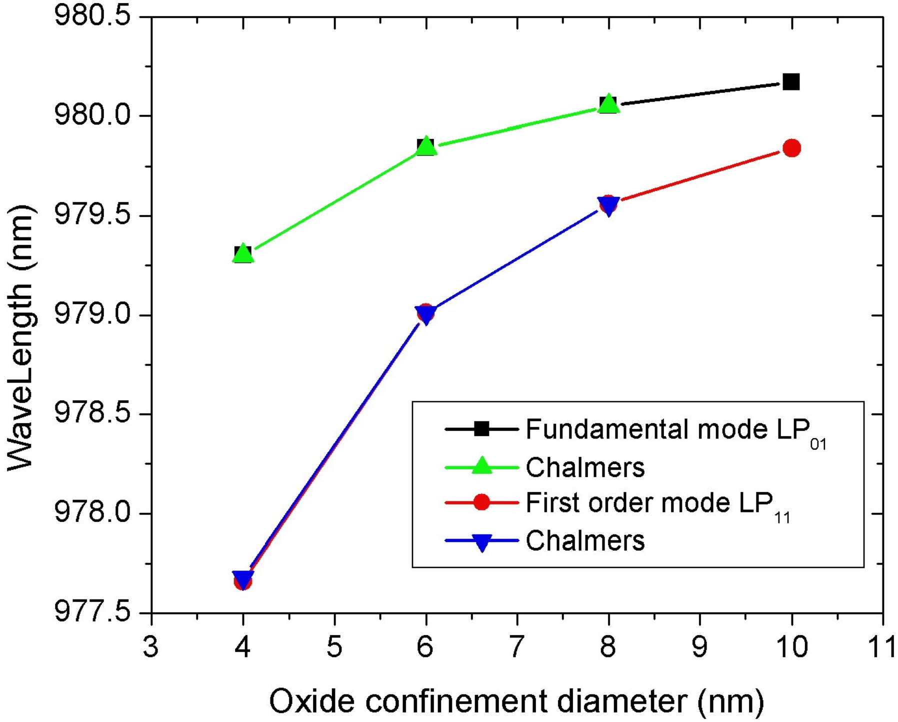
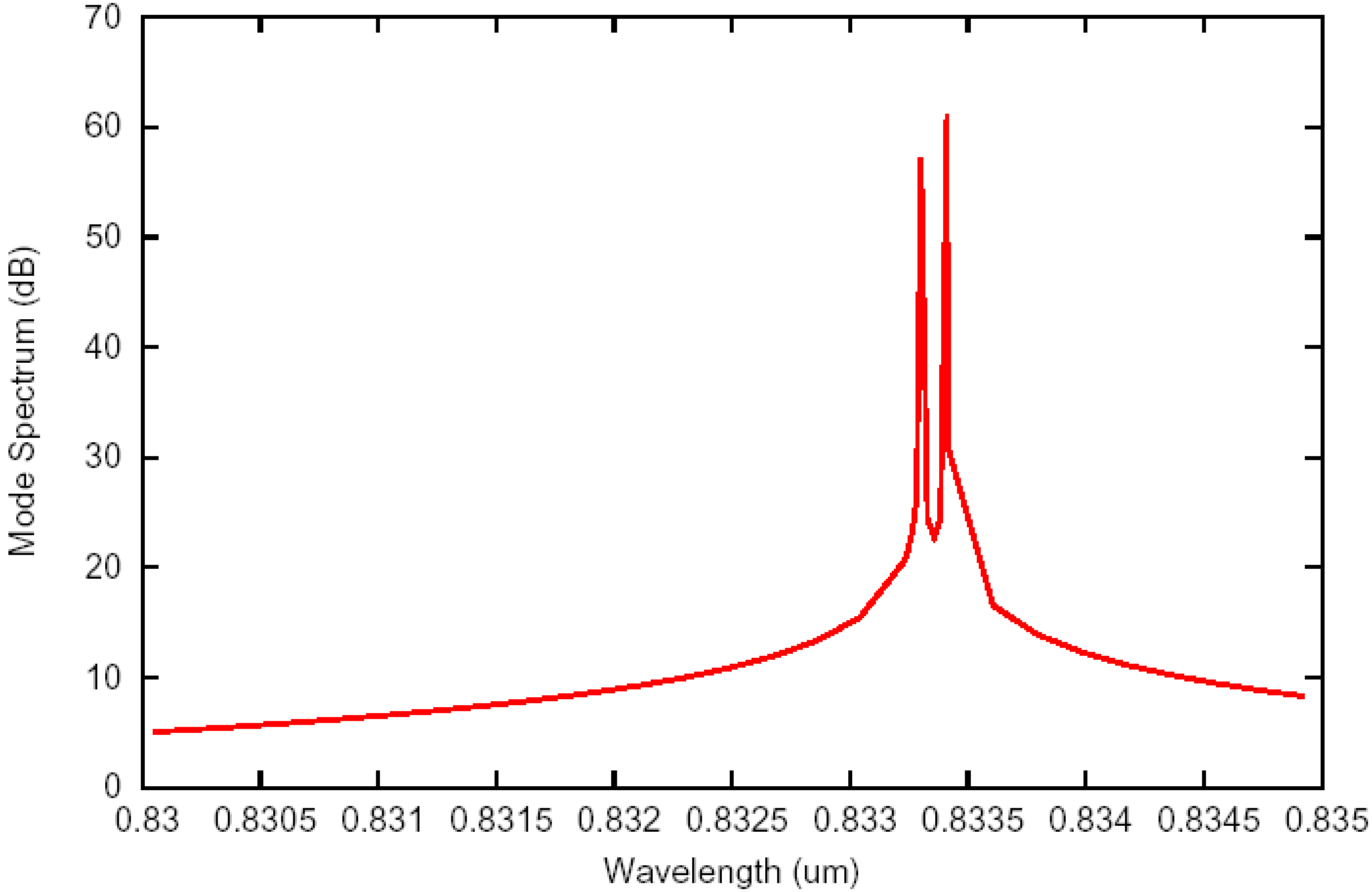
Resonating Wavelength of multimode VCSEL using EIM

Using effective index method(EIM), the resonating wavelength of oxide-confined VCSELs with different apperture diameters have been calculated and compared with others. The benchmark structure is taken from

IEEE J. Quan. Elec., vol. 37, p1618, 2001.



Spectrum of multi-lateral mode of VCSEL



Different lateral modes produce different propagation constants which causes multiple peaks in simulated emission spectrum as a result of the self-consistent calculation.

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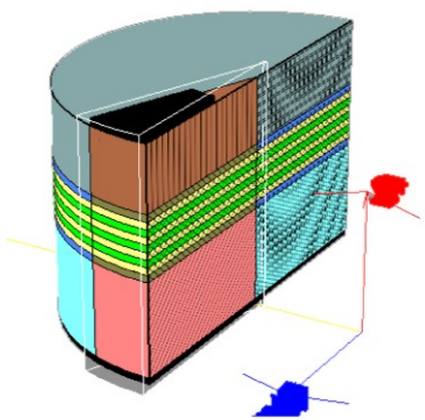
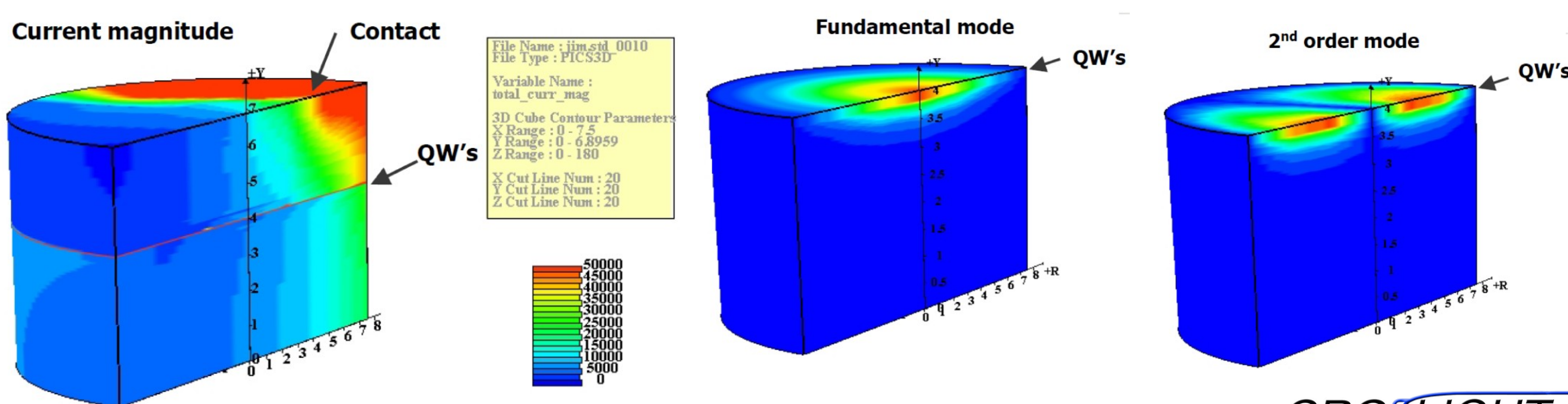
Non-symmetric VCSEL in Cylindrical Coordinate



Half-slice of non-symmetric VCSEL.

Model required:

- Full 3D drift-diffusion model.
- Lateral mode with both radian and angular dependence.
- Full 3D interaction of electrical and optical behaviors.
- Typical application: VCSEL with top or side contact in a non-symmetric position.



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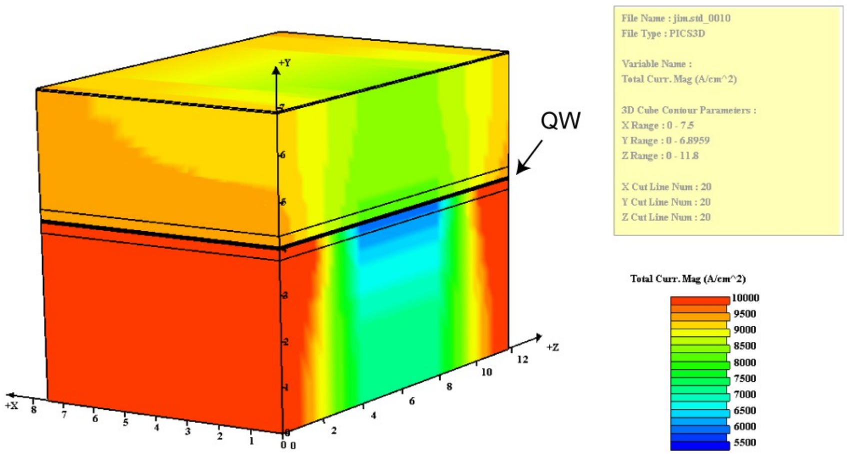
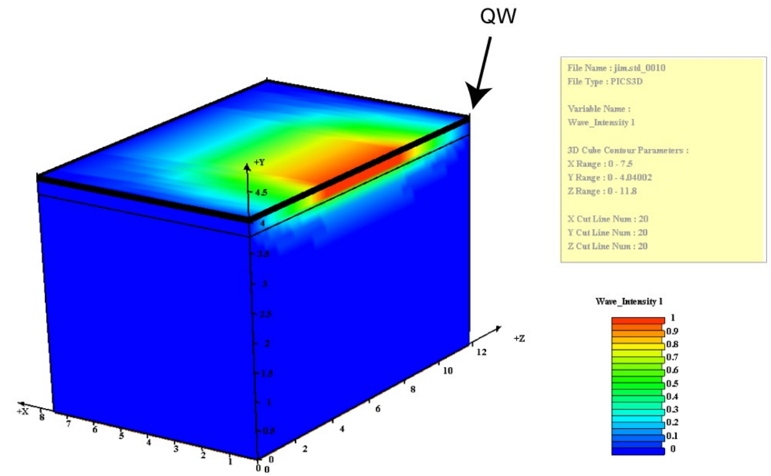
Rectangular Shape VCSEL



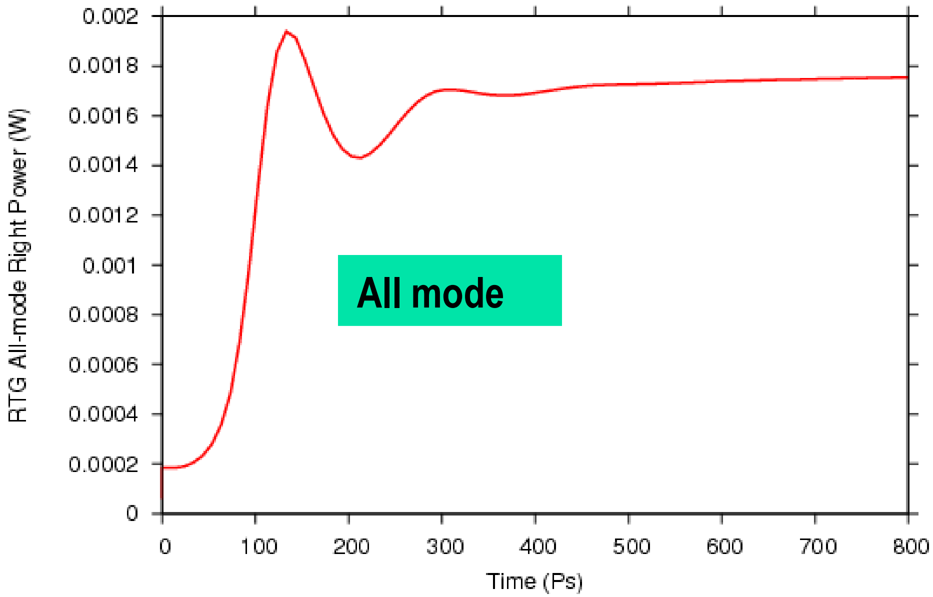
3D distribution of total current magnitude

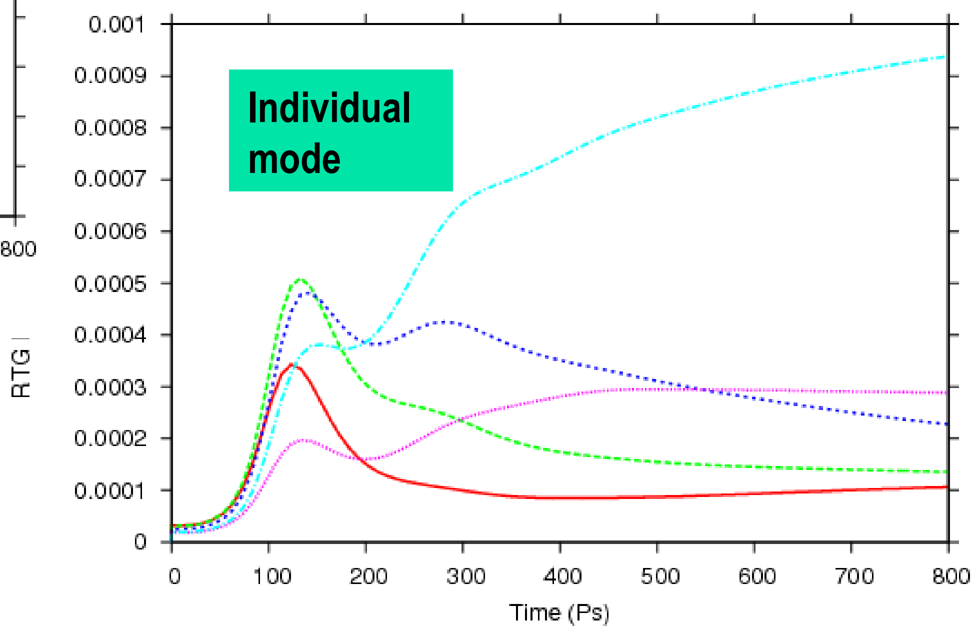


Wave intensity distribution of rectangular shape VCSEL

- In this example, only a half of the device is simulated to save computational cost.
- Full 3D current flow model is used.

Multimode transient (large signal) simulation





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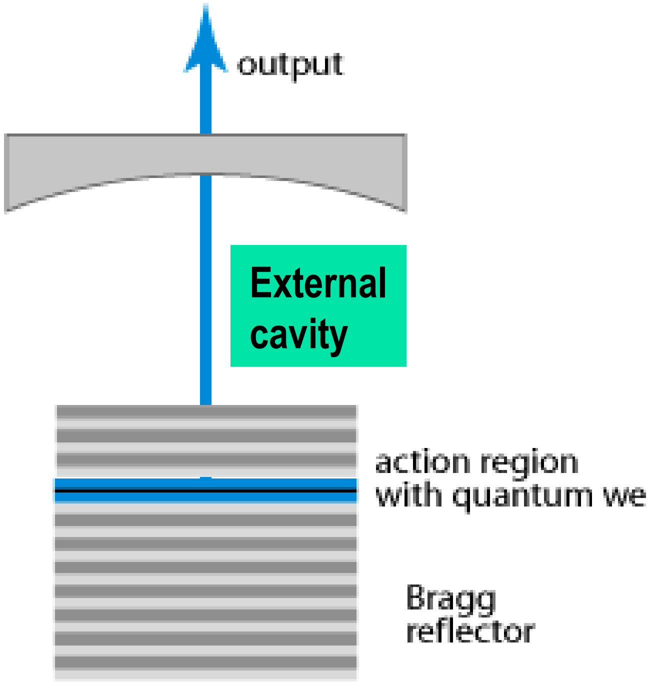
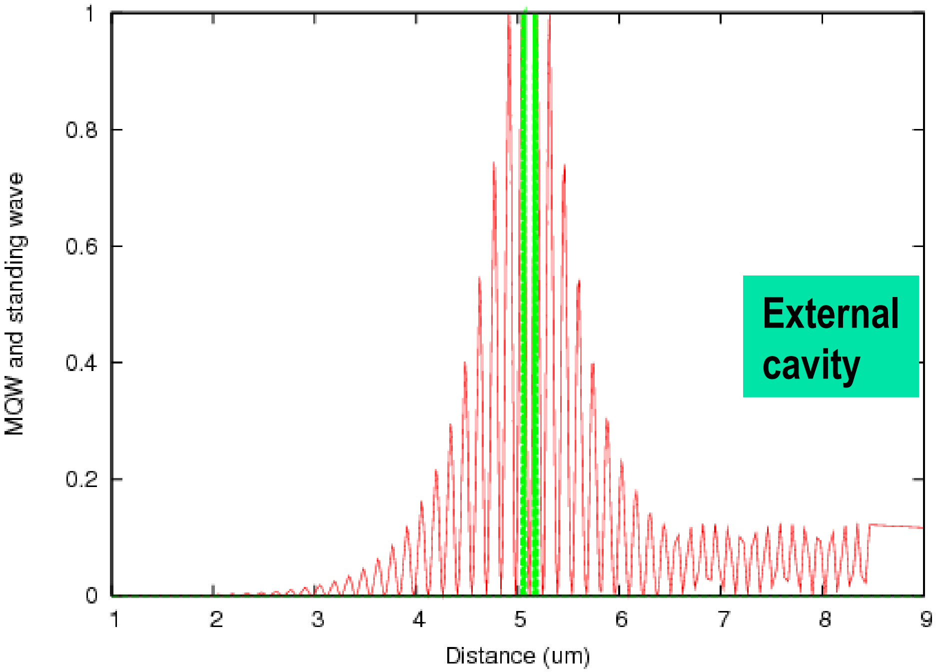
Vertical external cavity surface emitting laser (VECSEL)





Conclusions

- A rather comprehensive set of self-consistent physical models for VCSEL simulation implemented in PICS3D.
- Utilities such as round-trip gain calculator and VCSEL structure tuner makes it convenient for initial set-up.
- The final simulation run integrates all the important model elements for a VCSEL.