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

- Current flow (2/3 D drift-diffusion equations)
- Self-heating (2/3 D thermal transport equation)
- Refractive Index change (MQW k.p model)
- Change/degradation of optical gain (MQW k.p model)
- Change in lateral modes (2/3 D Maxwell equation solver)
- Change in longitudinal mode and emission wavelength / power (Transfer matrix)
- Change in stimulated recombination due to Microcavity optical power change and thermal roll-off.
Self-consistent models in PICS3D/VCSEL module.

Basic VCSEL modeling capabilities.

Advanced features.

Conclusions.
- 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.
Longitudinal Modes in VCSEL

- 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.
Computation of Lateral Optical Modes of VCSEL by Using EIM

- 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.

Self-heating effect in VCSEL 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.
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.
VCSEL has similar lateral mode competition behavior as edge lasers.

Perfect rotation symmetry assumed here for VCSEL structure.
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.
Different lateral modes produce different propagation constants which causes multiple peaks in simulated emission spectrum as a result of the self-consistent calculation.
Non-symmetric VCSEL in Cylindrical Coordinate

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.

Half-slice of non-symmetric 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
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.