Coupled Electro-Thermo-Optical

3D Simulation of Edge-Emitting Lasers

Michael Pfeiffer, Andreas Witzig, Wolfgang Fichtner

Integrated Systems Laboratory
Swiss Federal Institute of Technology, ETH Zurich
Switzerland

Contents

Motivation

- Implement a Versatile Simulation Tool for Laser Simulation
- Physics-Based Laser Models
  → Coupled Opto-Electro-Thermal Simulation
- Focus on Designer Needs
  → Efficiency!

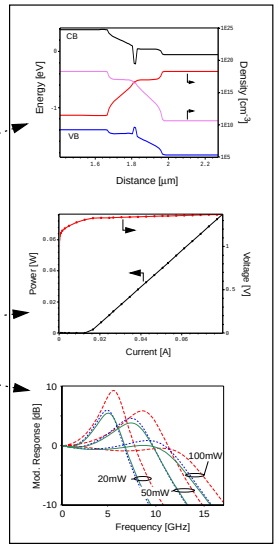
Project Collaboration with End-Users of Laser-Simulator

Embedded in State-of-the-Art TCAD Environment

Provide Design Methodology for effective allocation of resources

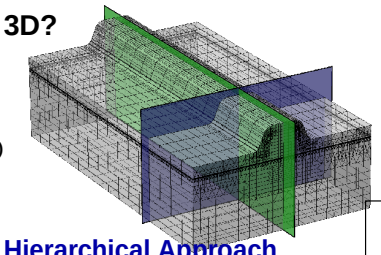
Typical Simulation Results

- Internal Characteristics
  → Band Structure
  → Optical Mode Pattern
  → Current Distribution
- Measurable Characteristics
  → Current-Voltage / Current-Power
  → Modulation Response
  → Gain Curve

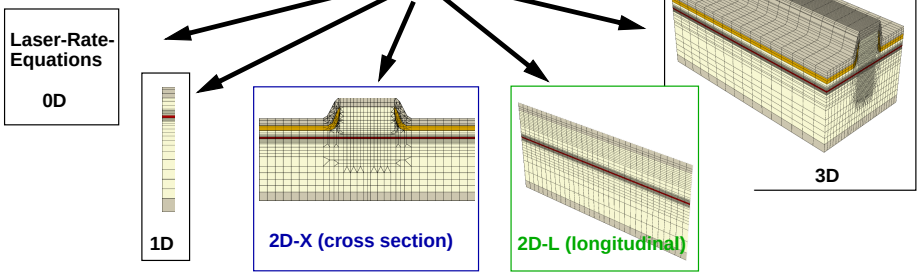


How To Simulate in 3D?

and at the same time
Work Efficiently?!
- ➜ Need a Multi-Dimensional Implementation (OO-Software)
- ➜ Need a Possibility to Handle 3D Structure
- ➜ Need a Design Methodology



Hierarchical Approach



Computational Resources

on a Compaq AlphaServer ES40, 667 MHz

	1D	2D-X	2D-L	3D
	• Mesh Vertices: ~200	• Mesh Vertices: ~2'500	• Mesh Vertices: ~6'000	• Mesh Vertices: ~40'000
	• RAM: ~100 MB • CPU Time: ~minutes	• RAM: ~300 MB • CPU Time: ~hours	• RAM: ~900 MB • CPU Time: ~1 day	• RAM: ~6 GB • CPU Time: 1 week
	• RAM: ~70 MB • CPU Time: ~minutes	• RAM: ~200 MB • CPU Time: ~10 minutes	• RAM: ~600 MB • CPU Time: ~hours	• RAM: ~3 GB • CPU Time: ~ 1 day
Hydrodynamic				
Isothermal				

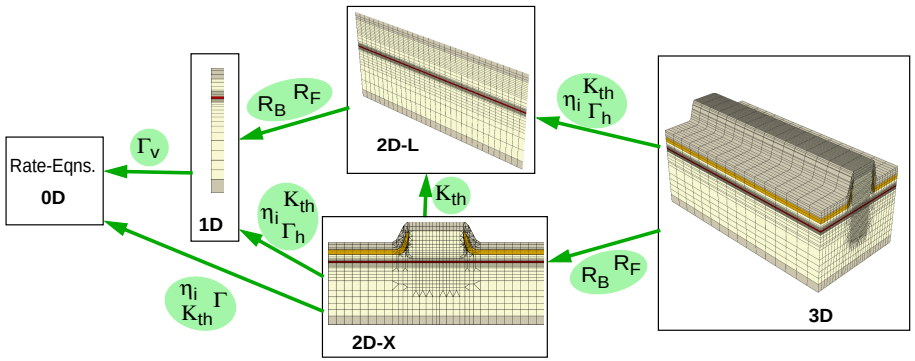
Hierarchical Approach

- Hierarchy of Confinement Factors
- Hierarchy of Approximations

Optical Confinement Factor (Overlap with Active Region & Mirror Losses) Γ_v, Γ_h R_B, R_F

Internal Quantum Efficiency (Due to Current Spreading) η_i

Thermal Confinement Factor (Due to Lateral Heat Flux) K_{th}



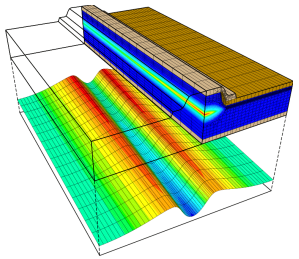
Electronics ⟵ Self-Consistent Solution ⟶ **Optics**

Poisson Equation: ψ

Continuity Equations: n, p

Energy Balance Equations: T_e, T_h, T_l

Quantum Carrier Model: n, p



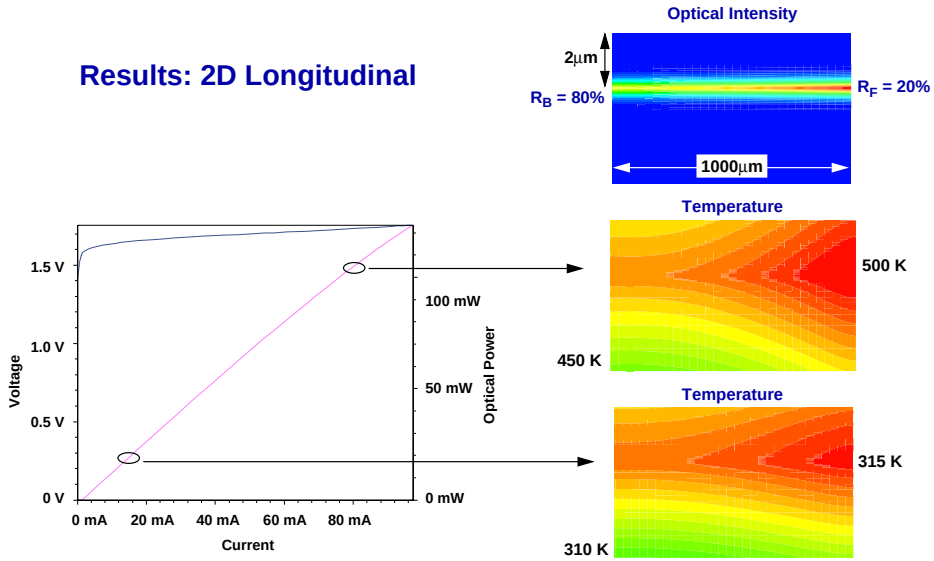
Complex Wave Equation: ϕ, f

Photon Rate Equations: S

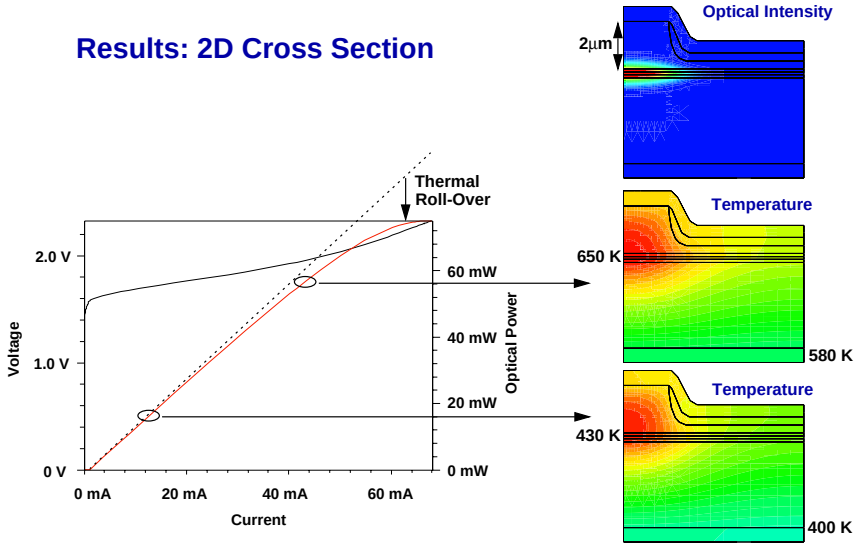
Gain Model: G

ψ: Electrostatic Potential
n/p: Electron/Hole Density
$T_{e/h/l}$: Carrier/Lattice Temperature
ϕ: Optical Wave Amplitude
f: Cavity Resonance Frequency
S: Photon Number
G: Optical Gain

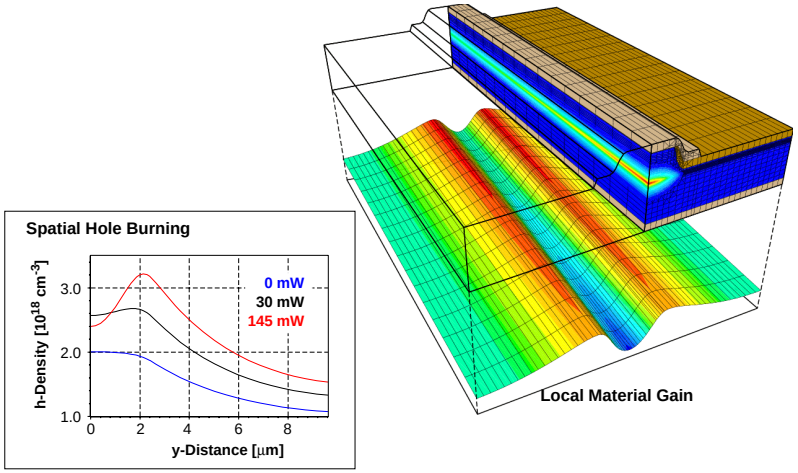
Results: 2D Longitudinal



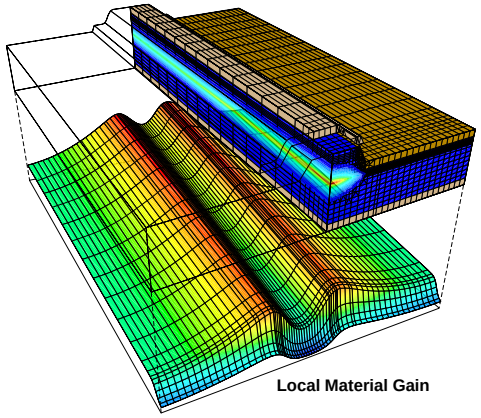
Results: 2D Cross Section



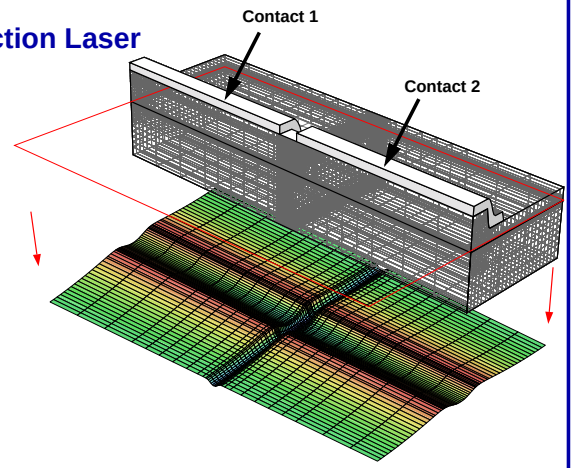
Results: 3D Isothermal Simulation



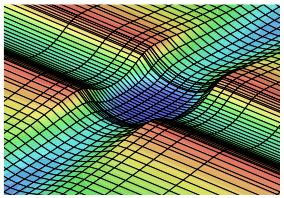
3D Results: Truncated Contacts



3D Results: Multi-Section Laser



Zoom:



Local Material Gain

Conclusion

- 3D Electro-Opto-Thermal Simulation is (Very) Expensive
- Good Simulation Procedure is based on Hierarchical Modeling
- Thermal Gradients Very Small for Typical Fabry-Perrot Lasers

Outlook

- 3D Electro-Opto-Thermal Simulation Required for Multi-Section Lasers and Semiconductor Optical Amplifiers