An Iterative Model of Current Distribution in Oxide Vertical-Cavity Surface-Emitting Lasers (VCSELS)

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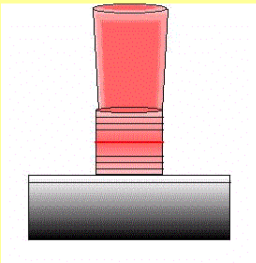
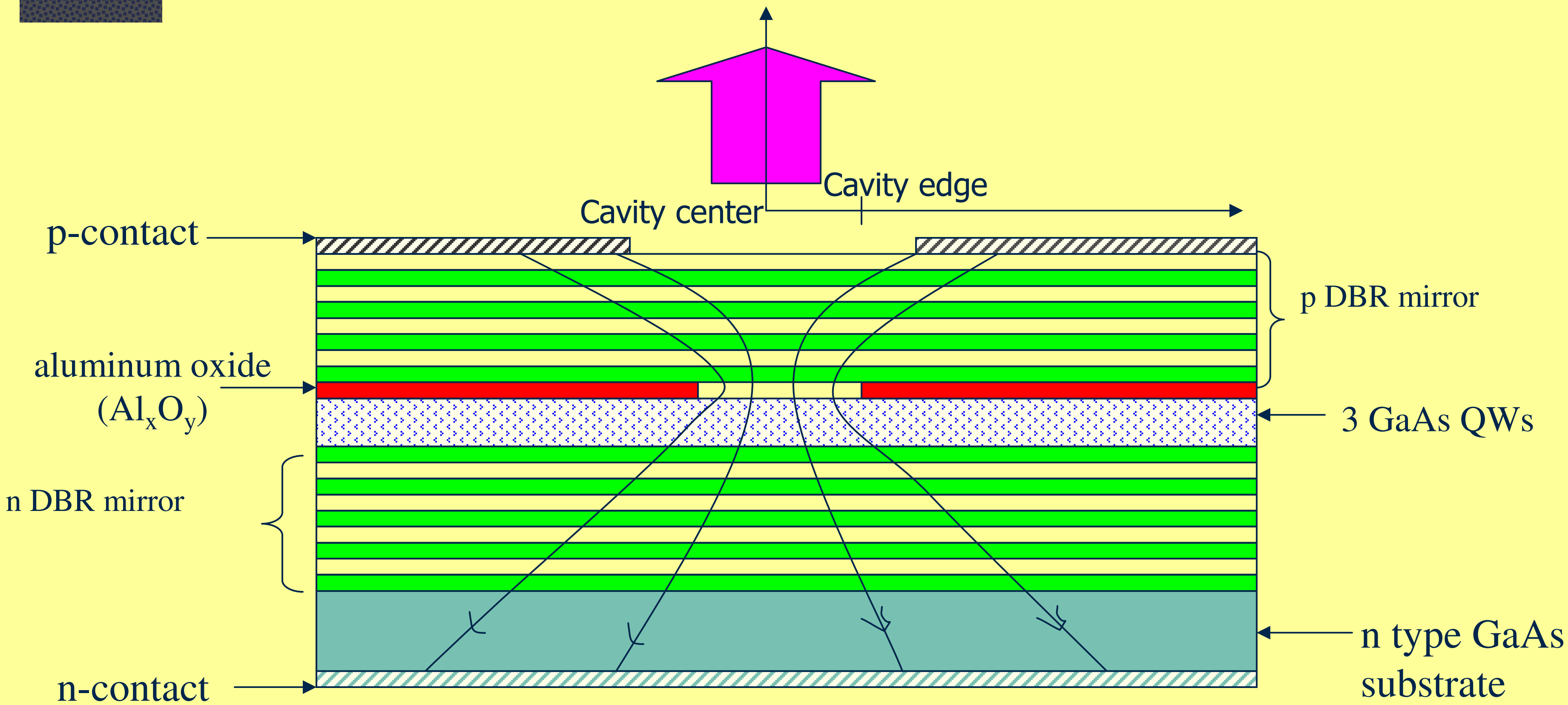
The VCSELS

- Applications:
  - Optical fiber networks, optical storage, printing, optical sensing and display systems.
- Advantages:
  - Optical: Fiber coupling, single longitudinal mode and ultra low threshold current
  - Electrical: 10G modulation and compatible with CMOS driver
  - Manufacture: On wafer testing, small planar area and reliability
- Challenges:
  - Higher power
  - Long wavelength and higher order mode
  - Thermal control



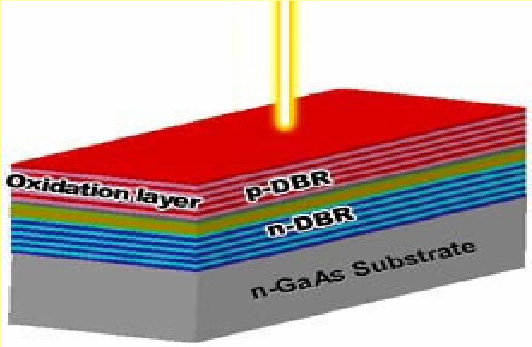
Oxide VCSELS



Schematic diagram of an index-guided VCSEL
at 850nm lasing wavelength

The Iterative Model

- A model for current distribution in VCSELS
  - Design engineers : better performance
  - Process engineers : improve process
- Iterative model solution
  - Circuit concept: p-mirror for resistance and active region for the diodes
  - Optical property: above threshold operation with two optical mode consideration
  - Iterative algorithm: changing the voltage parameters to match the desired stimulated/measured total current

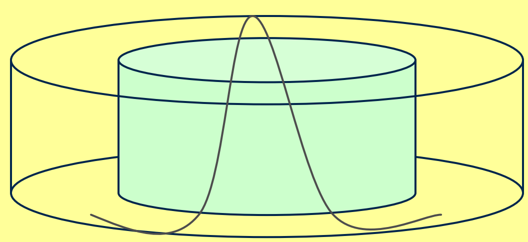


Schematics of the Iterative Model

- 46 nodes of diodes are for the active region
- N-mirror is assumed to be equal potential
- The resistances accounts for the p-mirror

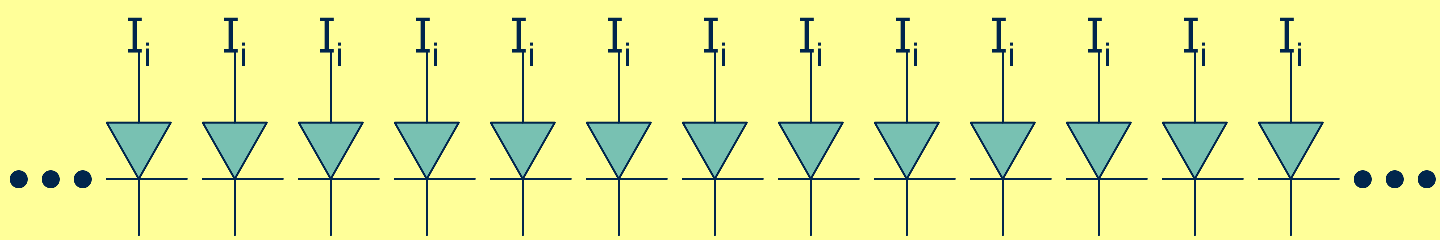
Resistance and Optical Parameters

- Resistance
  - Known/measurable parameters
  - Adjustment: V/H and T/B anisotropy
  - Results: conductance
- Optical parameters
  - Mode profile: solution to Maxwell equation in a dielectric cylindrical wave guide
  - Two modes consideration



Current Parameters

- Perimeter current (I_p)
  - Only present in the edge node because of high trap density
- Lateral diffusion current (I_{late})
  - Carrier density gradients between diodes
- Spontaneous current (I_{spon})
  - Radiative recombination
  - Consideration of degeneracy for conduction or/and valence band
- Stimulate current (I_{stim})
  - Stimulated current for different optical modes



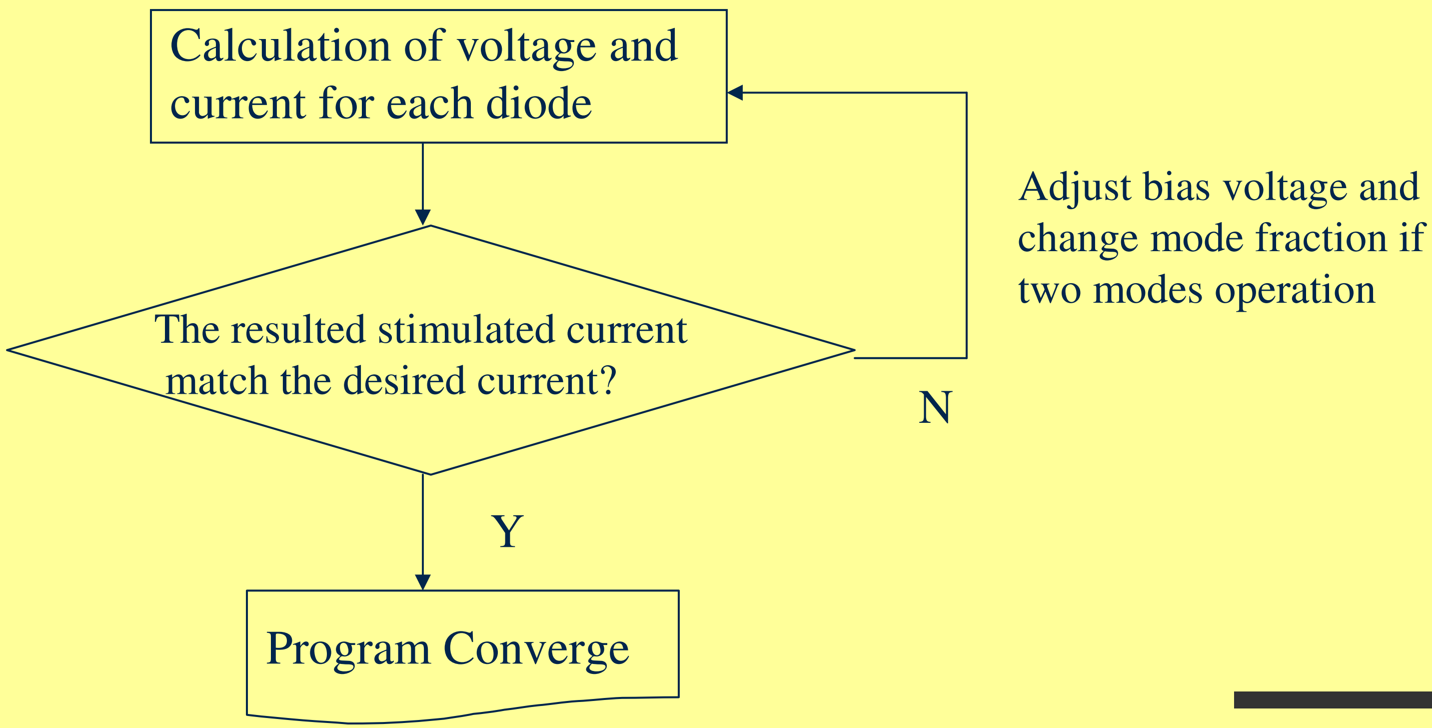
$I_i = f(I_{late}, I_{spon}, I_{stim})$

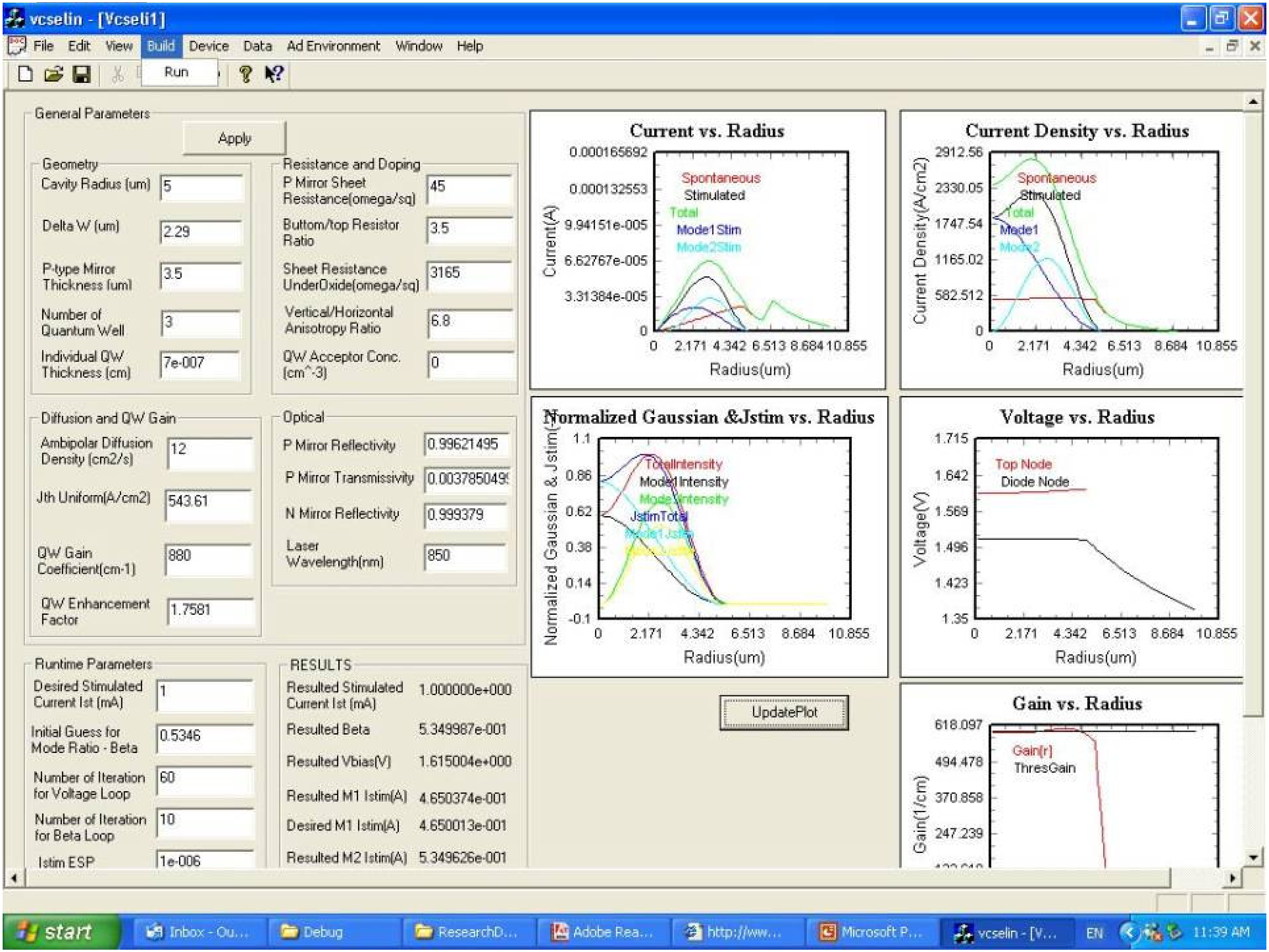
Voltage Parameters

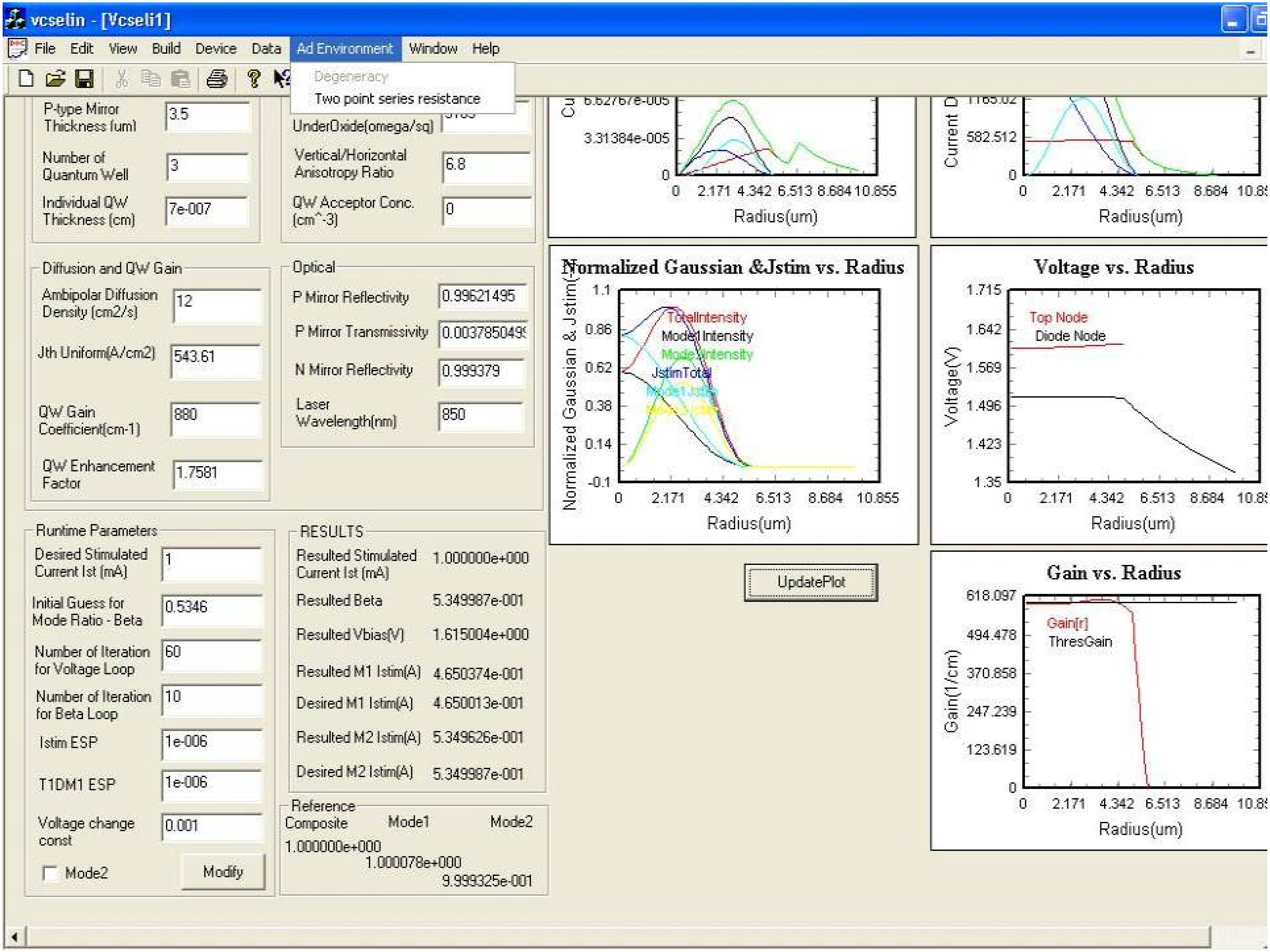
- Applied bias voltage
  - Voltage at anode node=applied bias voltage
- Resulted bias voltage
  - Bias voltage distributed in the cavity area nodes
  - For each node: V_{bias}=f(neighbor V_{bias}, neighbor top conductance, vertical conductance, bottom voltage)
- Bottom voltage calculations
  - The resistance under oxide (for some nodes)
  - f(neighbor V_{bot}, V_{bias}, vertical conductance neighbor bottom conductance ,current parameters)

Iterative Algorithm

- By changing the mode fraction for the stimulated current, we can find the voltages and current for each diode.
- We can see the optical mode migrate from the fundamental mode to a higher order mode




vcselin - [Vcseli1]
File Edit View Build Device Data Ad Environment Window Help
Run
General Parameters
Apply
Geometry
Cavity Radius (um) 5
Delta W (um) 2.29
P-type Mirror Thickness (um) 3.5
Number of Quantum Well 3
Individual QW Thickness (cm) 7e-007
Resistance and Doping
P Mirror Sheet Resistance(omega/sq) 45
Buttom/top Resistor Ratio 3.5
Sheet Resistance UnderOxide(omega/sq) 3165
Vertical/Horizontal Anisotropy Ratio 6.8
QW Acceptor Conc. (cm^-3) 0
Diffusion and QW Gain
Ambipolar Diffusion Density (cm2/s) 12
Jth Uniform(A/cm2) 543.61
QW Gain Coefficient(cm-1) 880
QW Enhancement Factor 1.7581
Optical
P Mirror Reflectivity 0.99621495
P Mirror Transmissivity 0.003785049
N Mirror Reflectivity 0.999379
Laser Wavelength(nm) 850
Runtime Parameters
Desired Stimulated Current Ist (mA) 1
Initial Guess for Mode Ratio - Beta 0.5346
Number of Iteration for Voltage Loop 60
Number of Iteration for Beta Loop 10
Istim ESP 1e-006
RESULTS
Resulted Stimulated Current Ist (mA) 1.000000e+000
Resulted Beta 5.349987e-001
Resulted Vbias(V) 1.615004e+000
Resulted M1 Istim(A) 4.650374e-001
Desired M1 Istim(A) 4.650013e-001
Resulted M2 Istim(A) 5.349626e-001
Current vs. Radius
Current(A)
Radius(um)
Spontaneous
Stimulated
Total
Mode1Stim
Mode2Stim
Current Density vs. Radius
Current Density(A/cm2)
Radius(um)
Spontaneous
Stimulated
Total
Mode1
Mode2
Normalized Gaussian &Jstim vs. Radius
Normalized Gaussian & Jstim
Radius(um)
TotalIntensity
Mode1Intensity
Mode2Intensity
JstimTotal
Mode1Jstim
Voltage vs. Radius
Voltage(V)
Radius(um)
Top Node
Diode Node
UpdatePlot
Gain vs. Radius
Gain(1/cm)
Gain[r]
ThresGain
start
11:39 AM



vcselin - [Vcseli1]
File Edit View Build Device Data Ad Environment Window Help
Degeneracy
Two point series resistance
P-type Mirror Thickness (um)
3.5
Number of Quantum Well
3
Individual QW Thickness (cm)
7e-007
UnderOxide(omega/sq)
Vertical/Horizontal Anisotropy Ratio
6.8
QW Acceptor Conc. (cm^-3)
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Diffusion and QW Gain
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0.5346
Number of Iteration for Voltage Loop
60
Number of Iteration for Beta Loop
10
Istim ESP
1e-006
T1DM1 ESP
1e-006
Voltage change const
0.001
Mode2
Modify
RESULTS
Resulted Stimulated Current Ist (mA)
1.000000e+000
Resulted Beta
5.349987e-001
Resulted Vbias(V)
1.615004e+000
Resulted M1 Istim(A)
4.650374e-001
Desired M1 Istim(A)
4.650013e-001
Resulted M2 Istim(A)
5.349626e-001
Desired M2 Istim(A)
5.349987e-001
Reference
Composite
Mode1
Mode2
1.000000e+000
1.000078e+000
9.999325e-001
3.31384e-005
Radius(um)
582.512
Current D
Normalized Gaussian &Jstim vs. Radius
TotalIntensity
Mode1 Intensity
Mode2 Intensity
JstimTotal
Mode1Jstim
Normalized Gaussian & Jstim
Radius(um)
Voltage vs. Radius
Top Node
Diode Node
Voltage(V)
Radius(um)
UpdatePlot
Gain vs. Radius
Gain[r]
ThresGain
Gain(1/cm)
Radius(um)

Conclusions & Future Improvements

- Conclusions:
  - Higher current excites the higher order mode
  - A physical model for understanding of the current distribution in VCSEL
- Current works:
  - Add proton VCSEL
  - Doped quantum well and gain coefficient calculation
  - Optical properties with DBR
- Future Improvement:
  - Apply to edge emitting laser