

Recent Examples of

Numerical Simulation of Semiconductor Optoelectronic Devices (NUSOD!)

By Simon Li





Acknowledgement

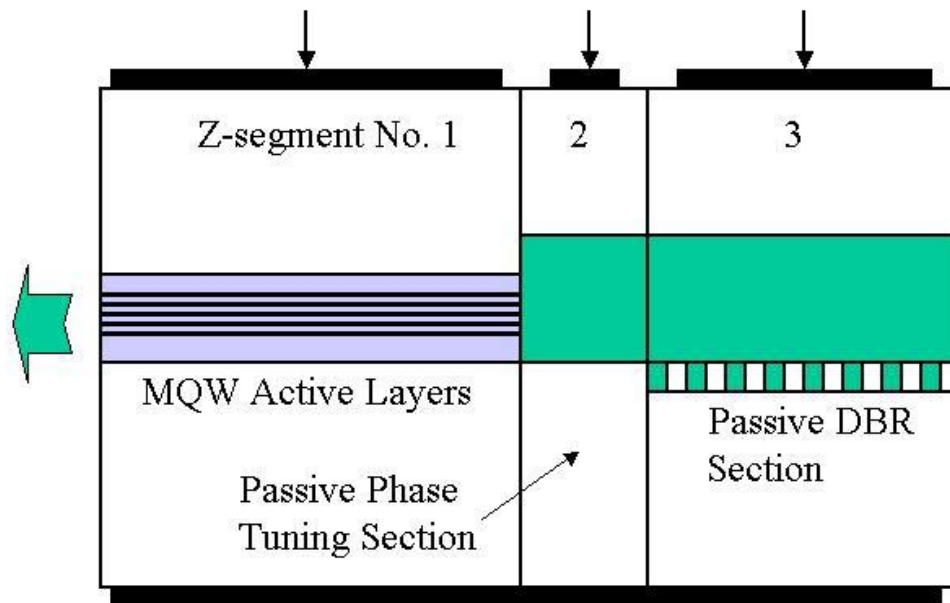
- **Credit goes to all research scientists / engineers in Crosslight.**
- **Especially, Drs. Peter Mensz, Kentaro Uehara, Oleksiy Shmatov, Zhisheng Piao, Zhiqiang Li, ...**
- **Thanks go to all customers who contributed material parameters and proposed interesting device structures.**



Contents

- **Multiple section tunable DFB/DBR laser.**
- **Multiple lateral/longitudinal mode simulation.**
- **Lateral mode competition in VCSEL.**
- **Different k.p theories.**

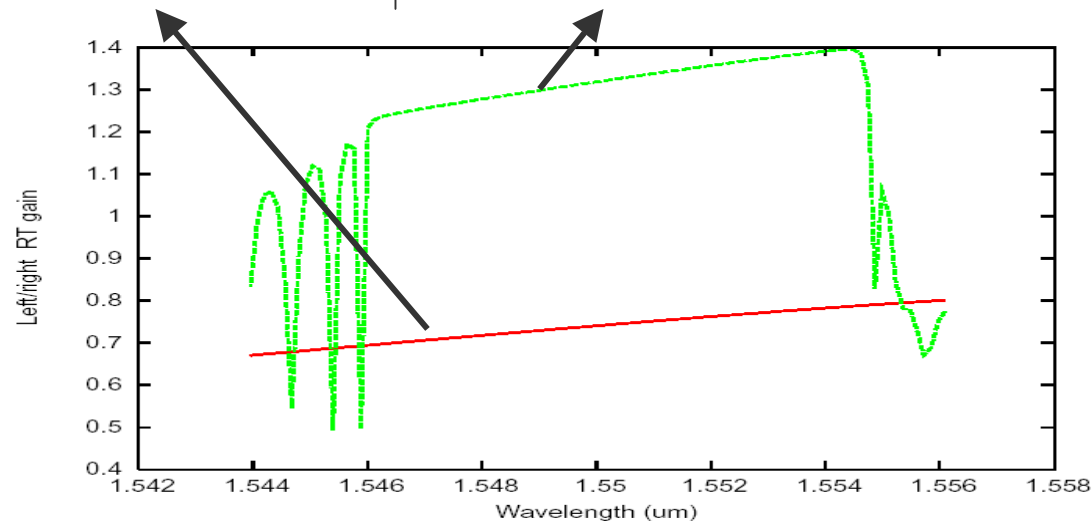
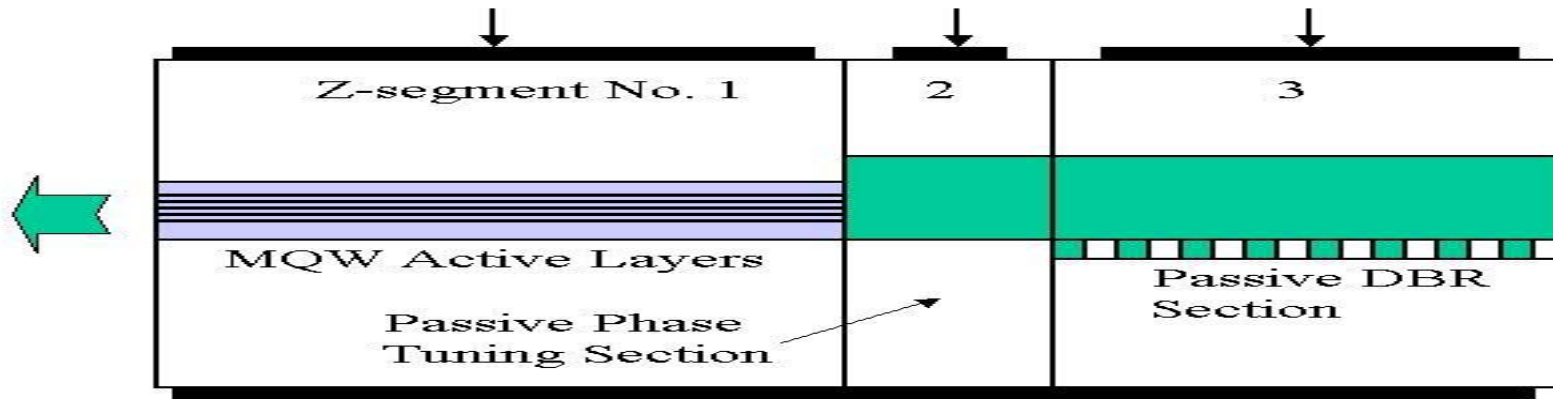
3-section DBR laser



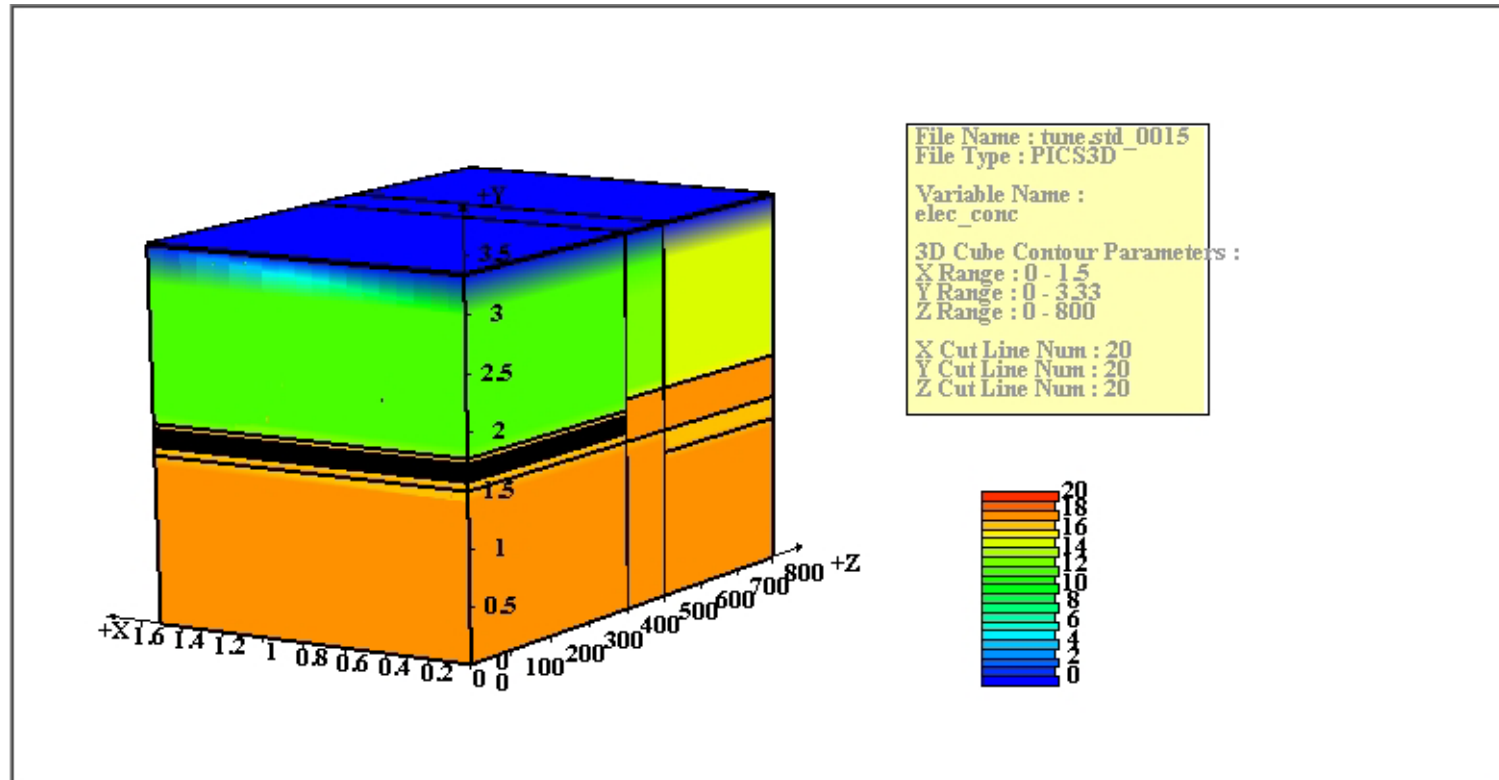
Physical model required:

- Current injection (drift-diffusion model) for all segments.
- MQW gain model in segment 1.
- Index change model in segment 2 & 3.
- DBR grating model in segment 3 (coupled mode theory).
- Lateral optical mode solver for all segments.
- Longitudinal mode model (Green's function theory) for all segments.

Round trip gain (RTG)



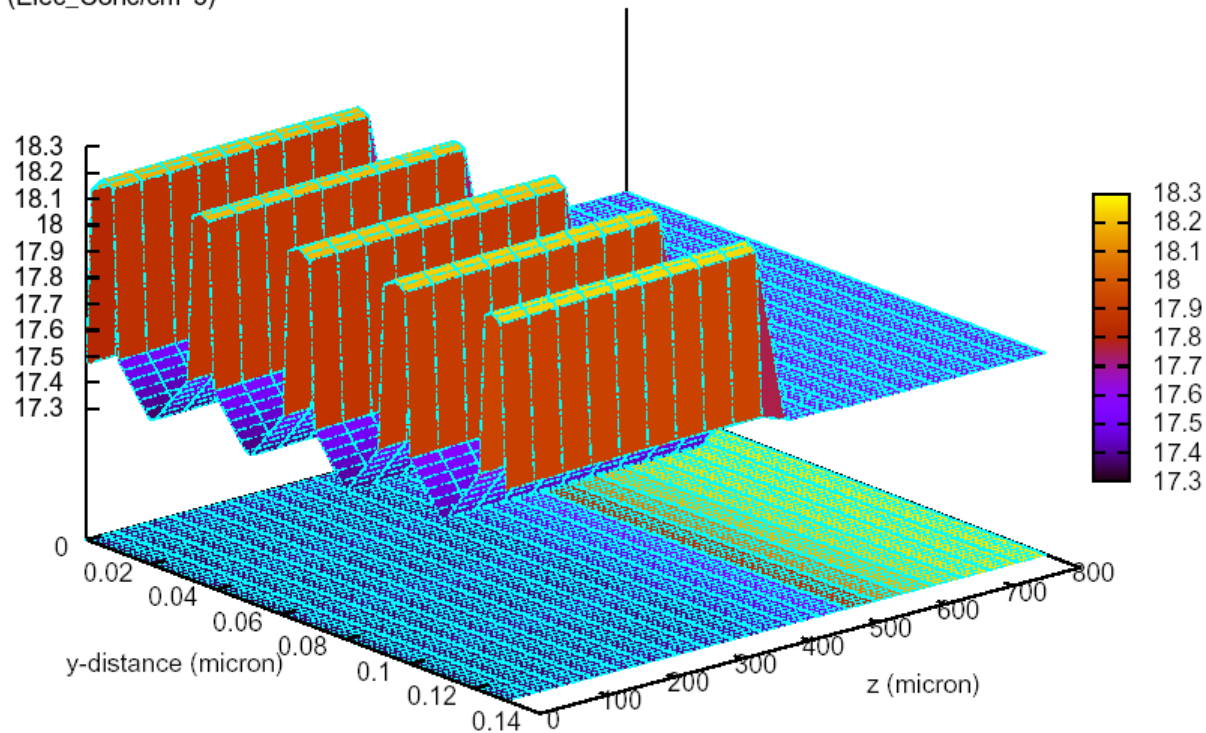
Carrier conc. distribution



- Drift-diffusion equation solver finds 3D distribution of electron/hole carrier concentrations.
- Carrier conc. change → Refractive index distribution → change in lateral/longitudinal modes

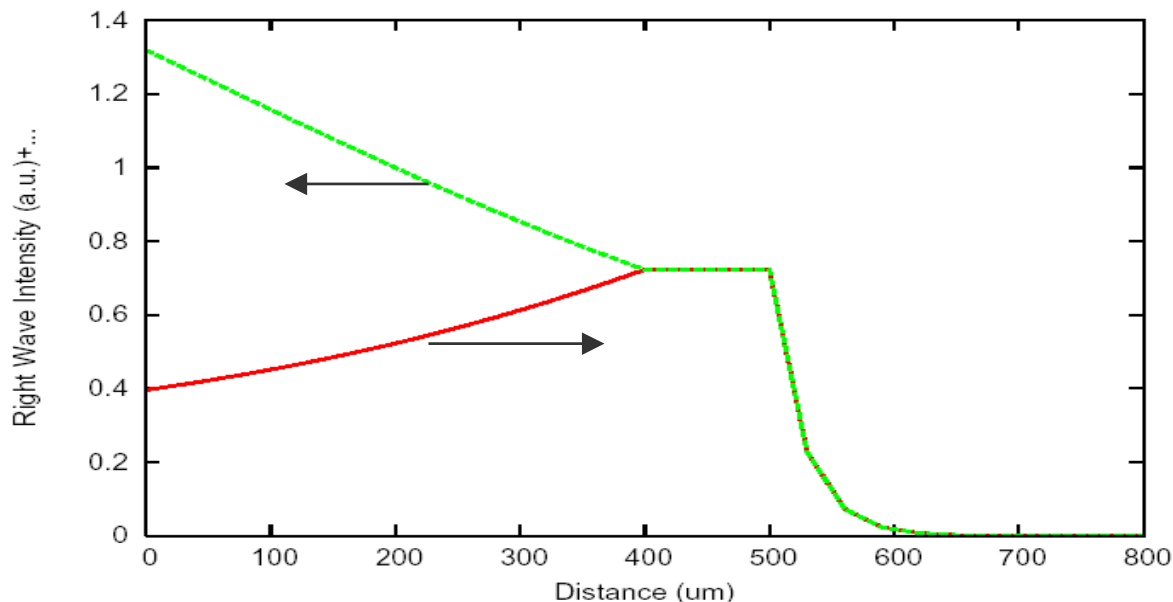
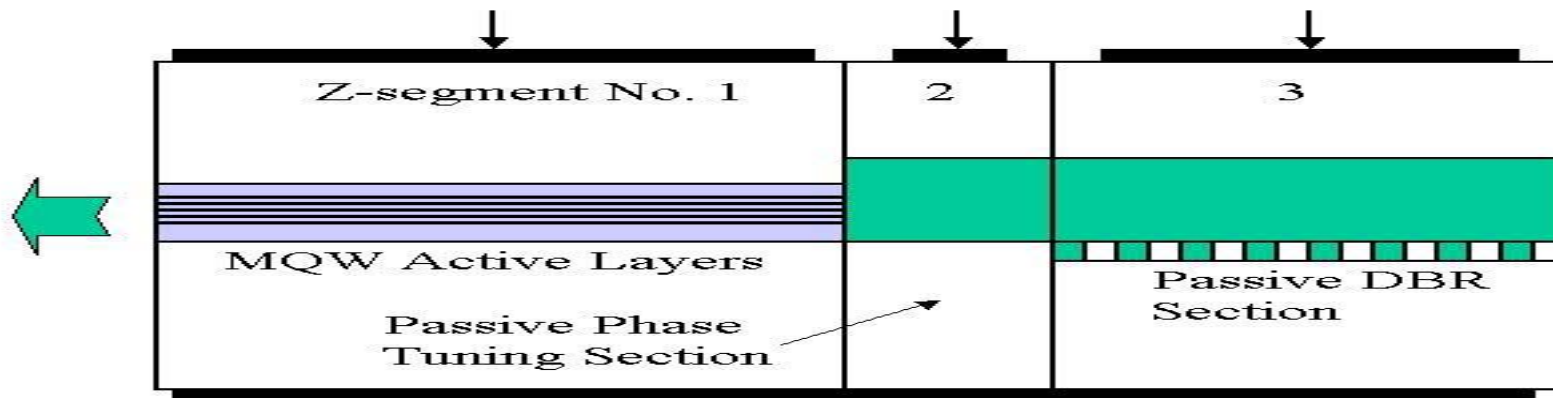
Carrier conc. around MQW

Log (Elec_Conc/cm³)



- Quantum drift-diffusion model finds 3D distribution of electron/hole at MQW regions.
- Optical gain peak of the MQW and DBR spectrum determines lasing wavelength.

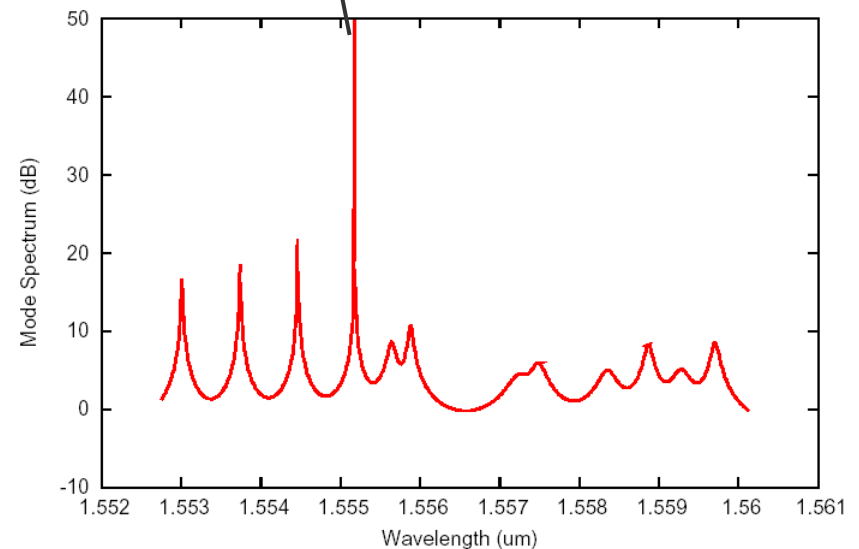
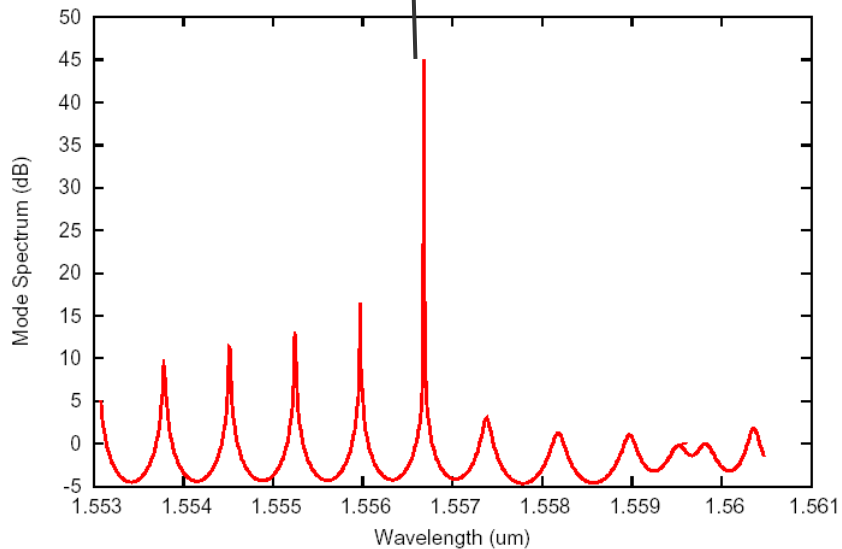
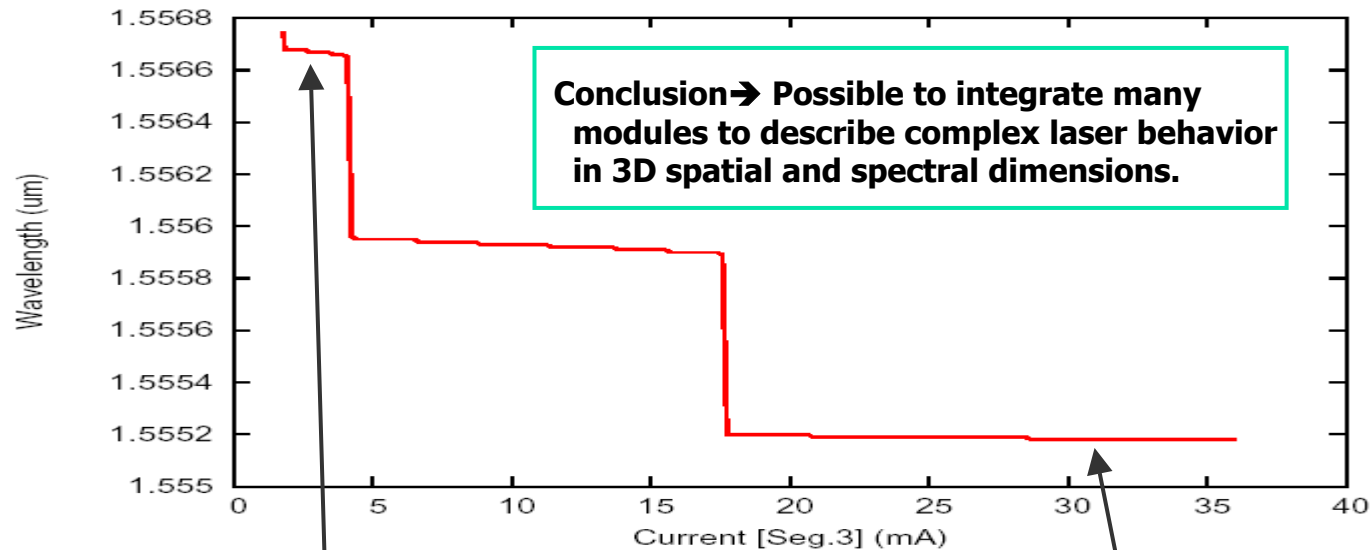
Longitudinal mode distribution



Modeling/Design Issues:

- Segments 2 & 3 should be close to but below bandgap to avoid optical loss but also to provide change of index.
- Both waveguide and DBR grating should vary with injection current.

Tuning behavior

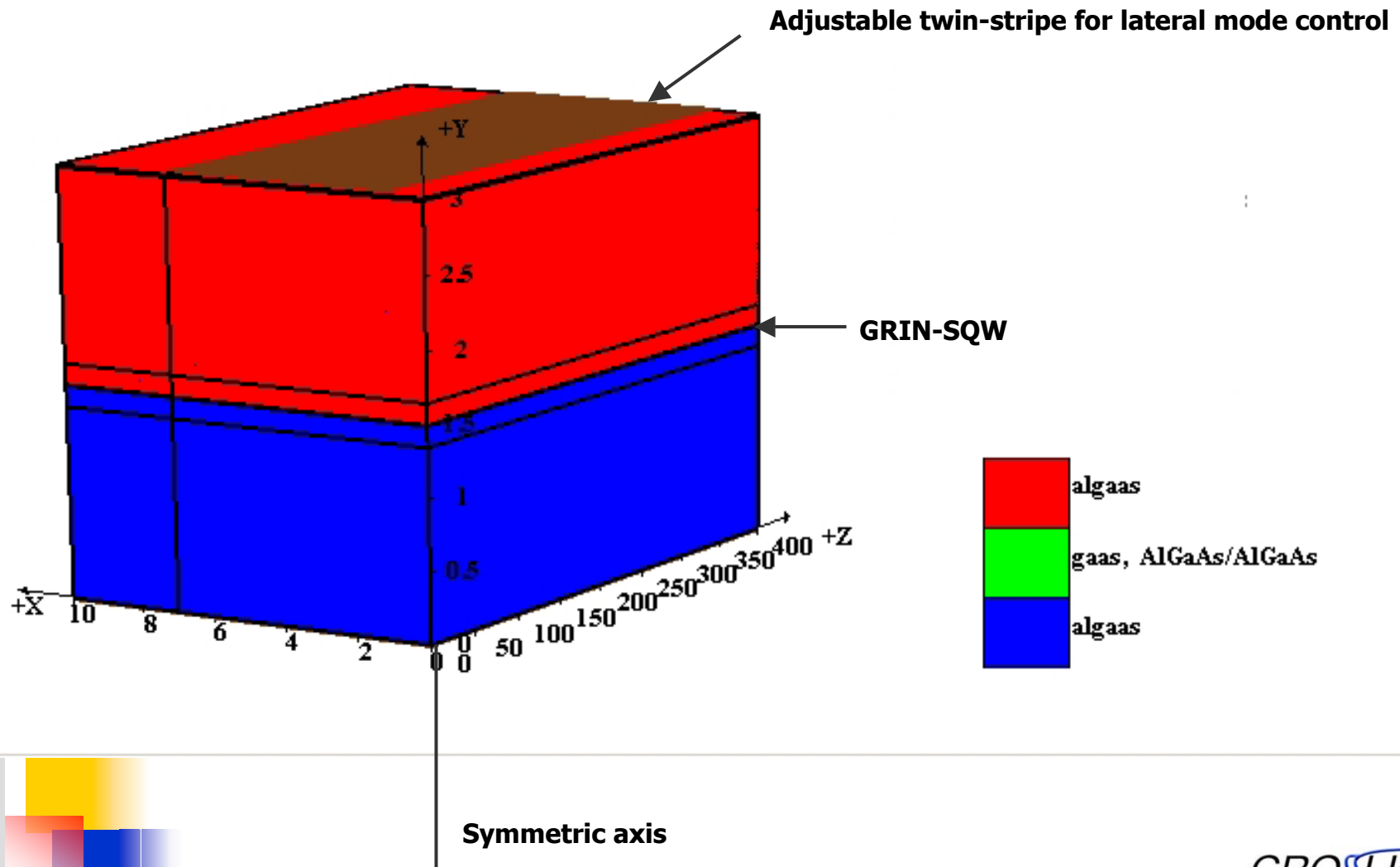




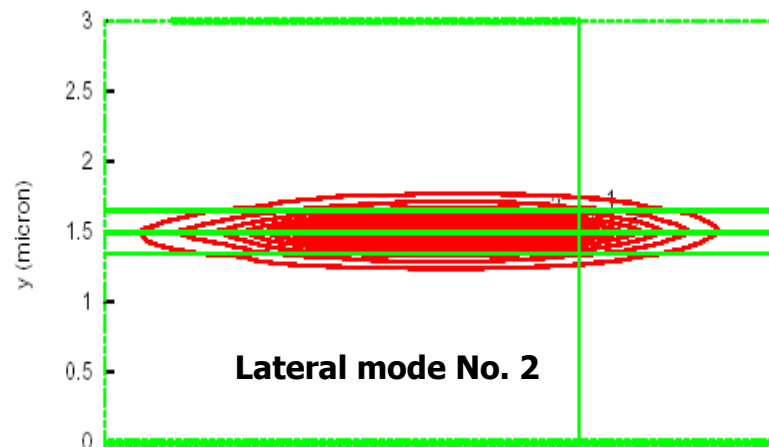
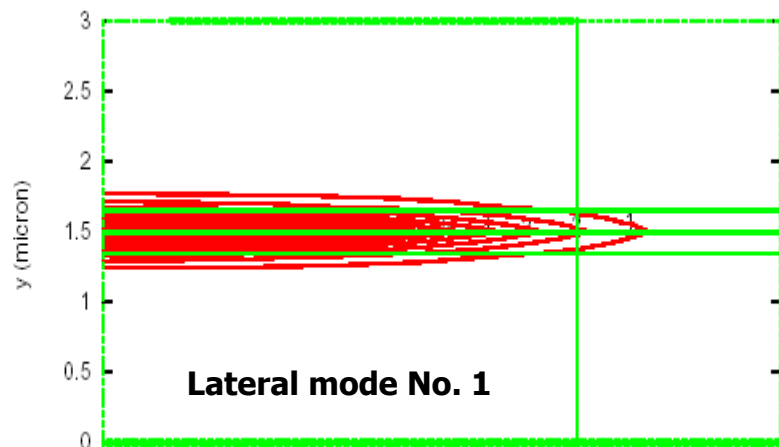
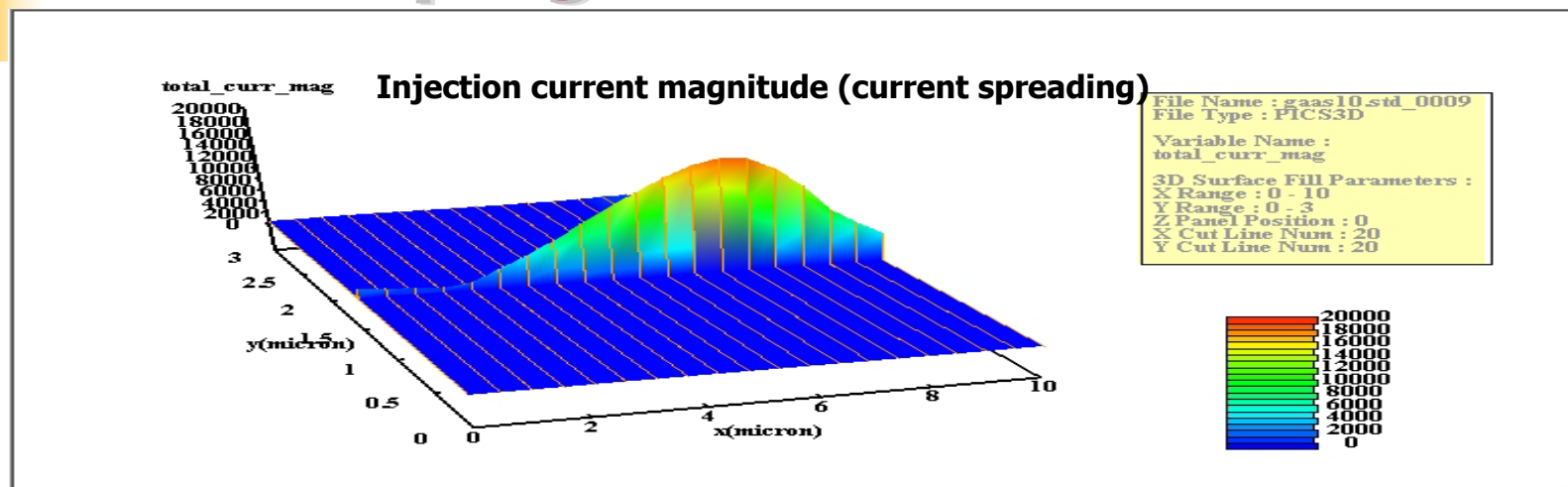
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- Lateral mode competition in VCSEL.
- Different k.p theories.

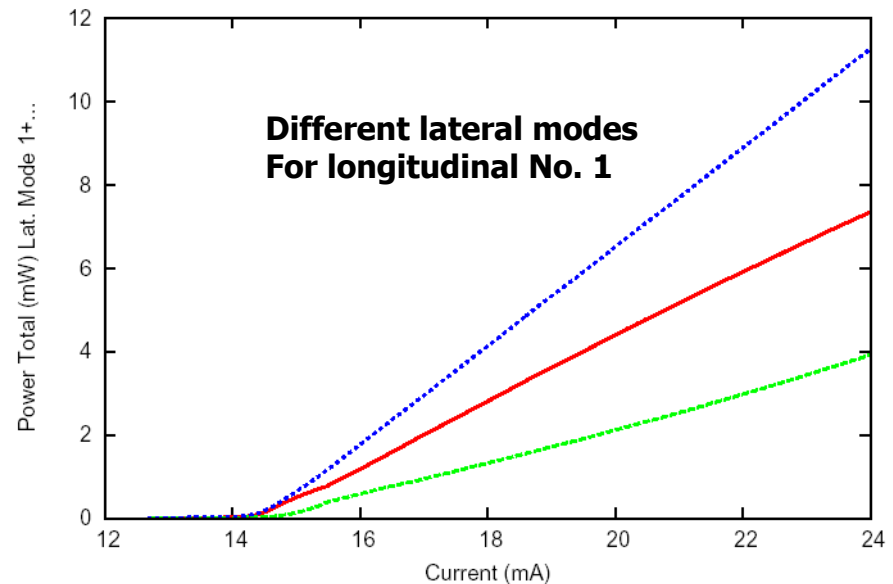
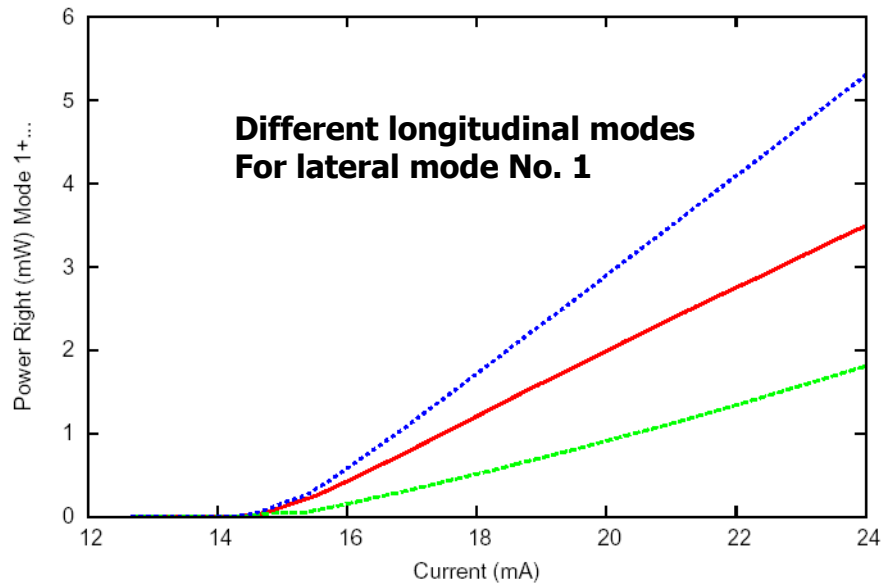
Broad-area laser with adjustable stripe



Pumping of different modes

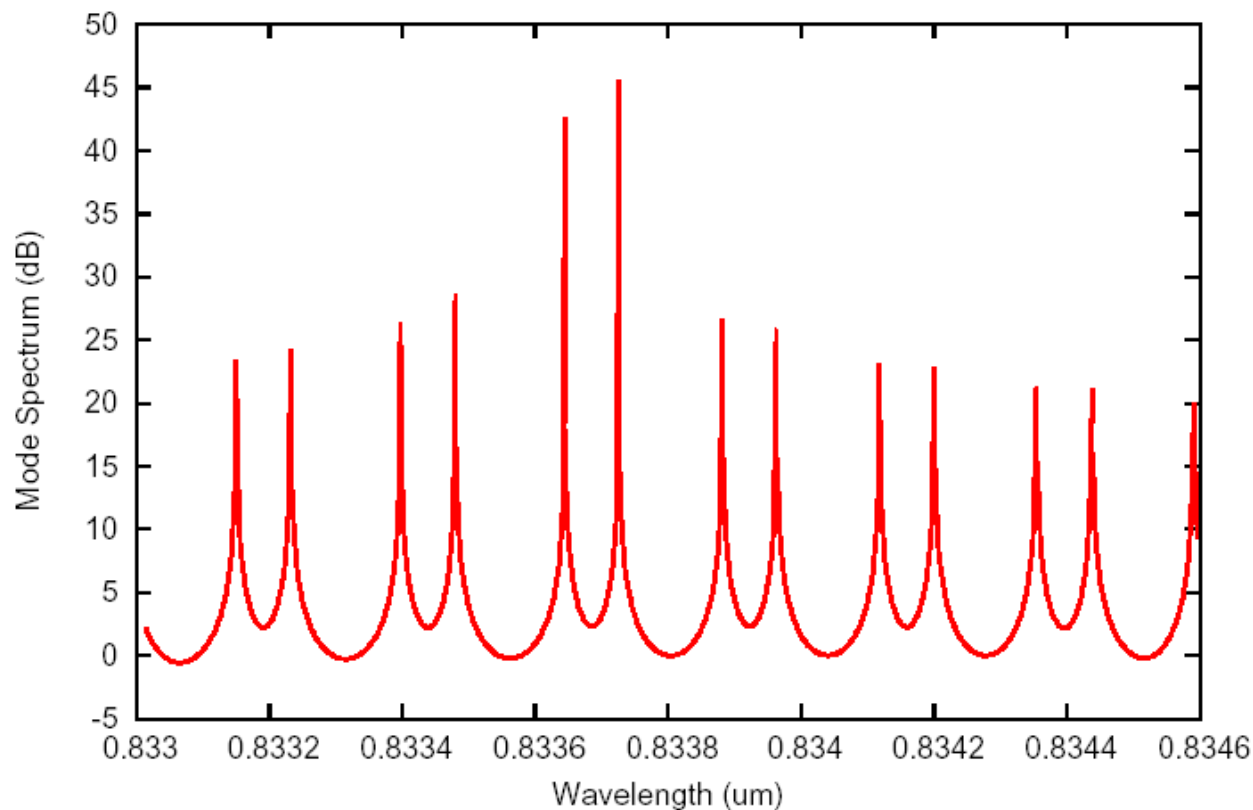


Multi-mode considerations



- **Must solve a whole different set of longitudinal modes using modal indices of different lateral modes.**
- **Each longitudinal mode is always associated with a particular lateral mode.**
- **Must consider longitudinal and lateral spatial hole burning effects for different lateral/longitudinal modes.**

Multi-lateral mode spectrum



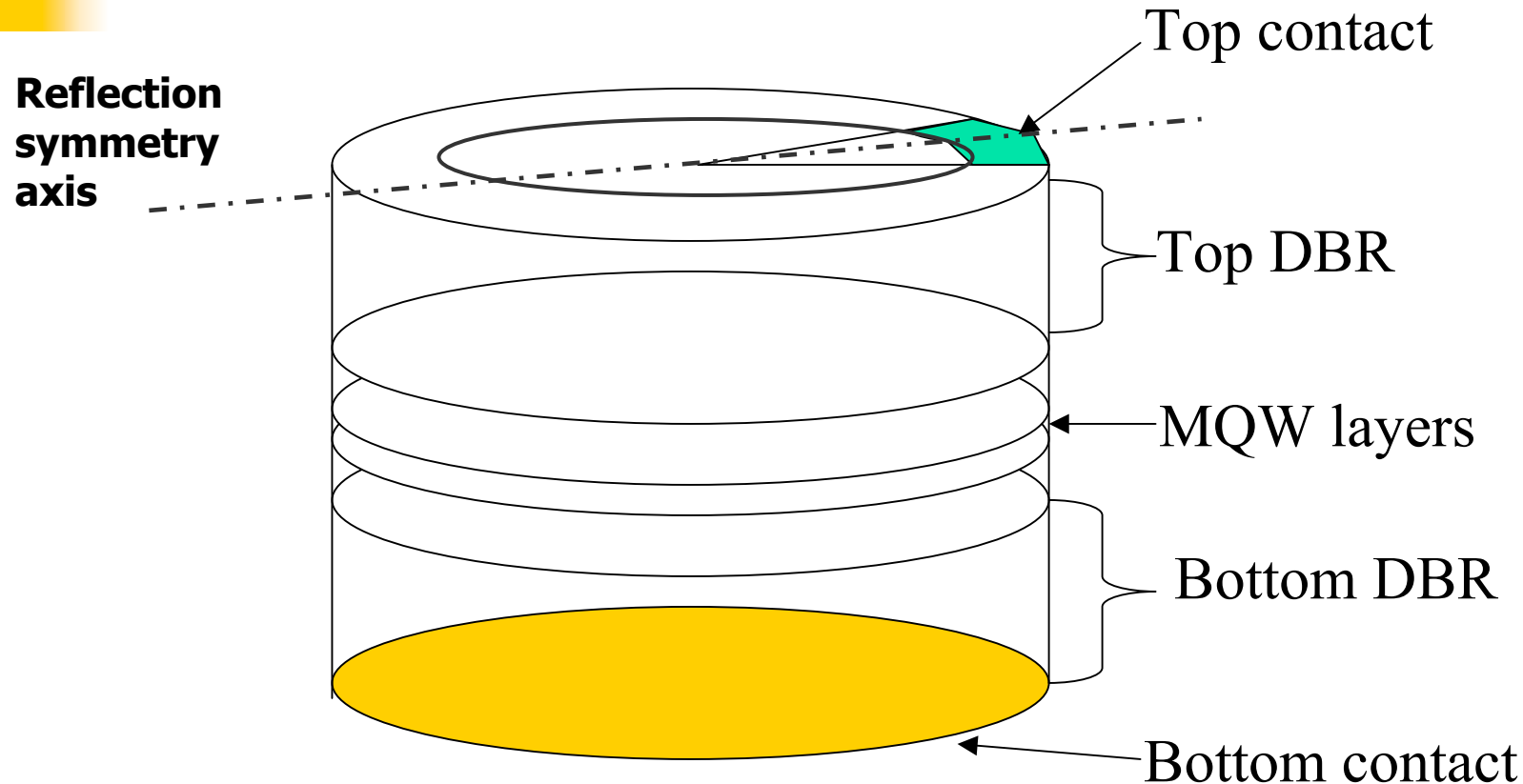
- Different peaks for different lateral modes.
- May be used to monitor suppression of lateral modes.



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Symmetric v. asymmetric VCSEL



Models required:

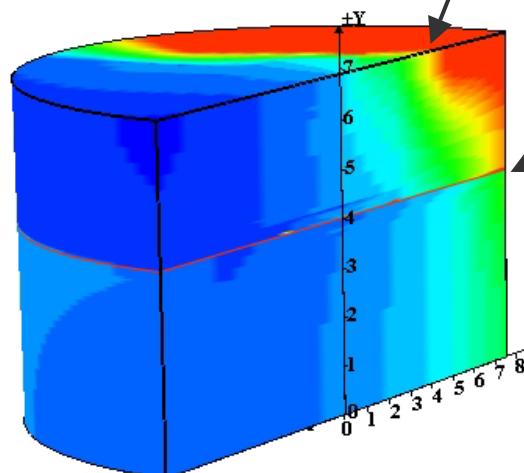
- Full 3D drift-diffusion model: cylindrical symmetry no longer available.
- Lateral mode model with both ϕ and θ dependence.
- MQW gain model as usual.
- Transfer matrix model for longitudinal modes as usual.

Asymmetric VCSEL injection

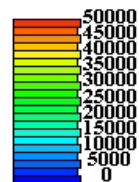
Current magnitude

Contact

QW's

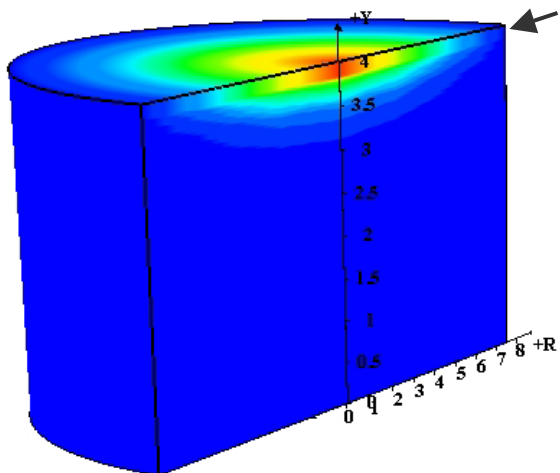


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File Type : PICS3D
Variable Name :
total_curr_mag
3D Cube Contour Parameters :
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Y Range : 0 - 6.8959
Z Range : 0 - 180
X Cut Line Num : 20
Y Cut Line Num : 20
Z Cut Line Num : 20



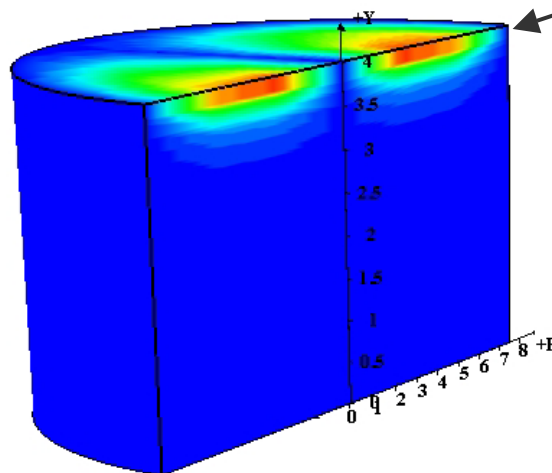
Fundamental mode

QW's



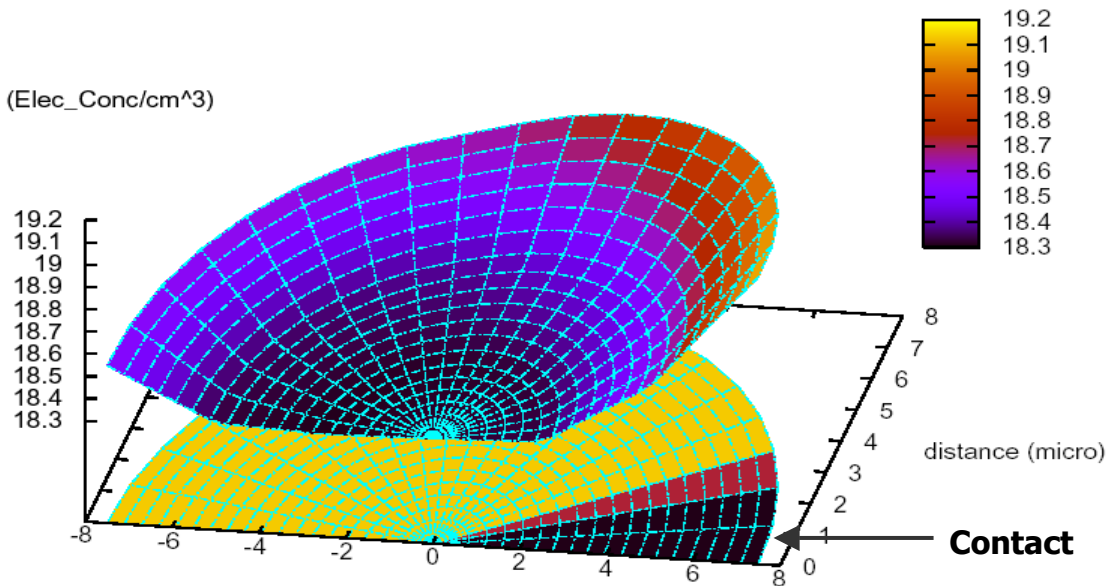
2nd order mode

QW's

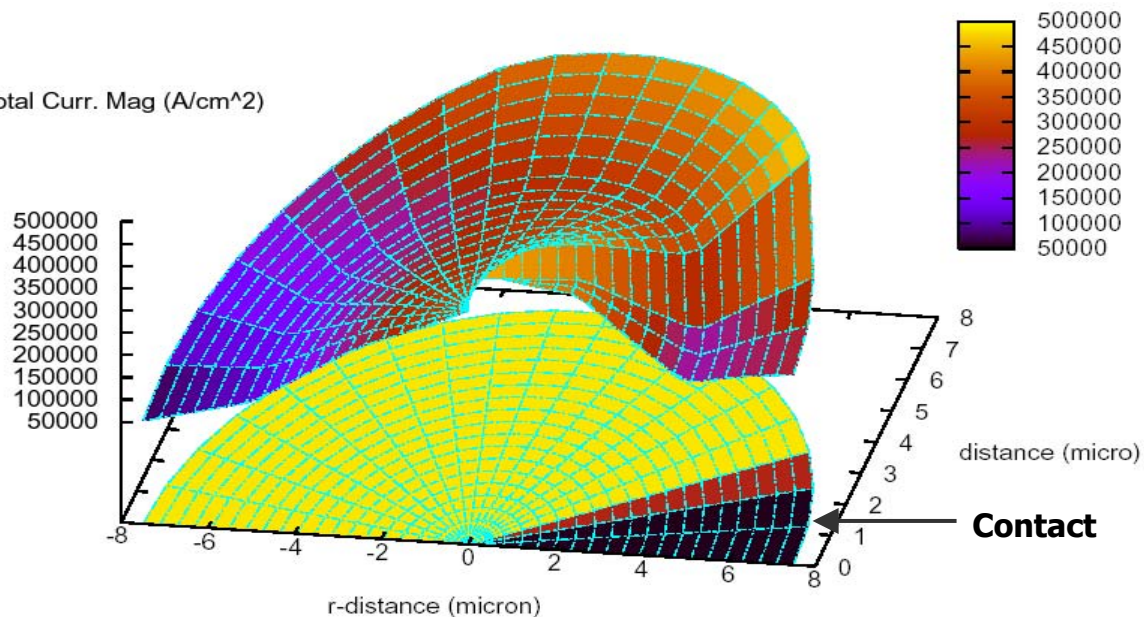


Within the quantum well

Log (Elec_Conc/cm³)



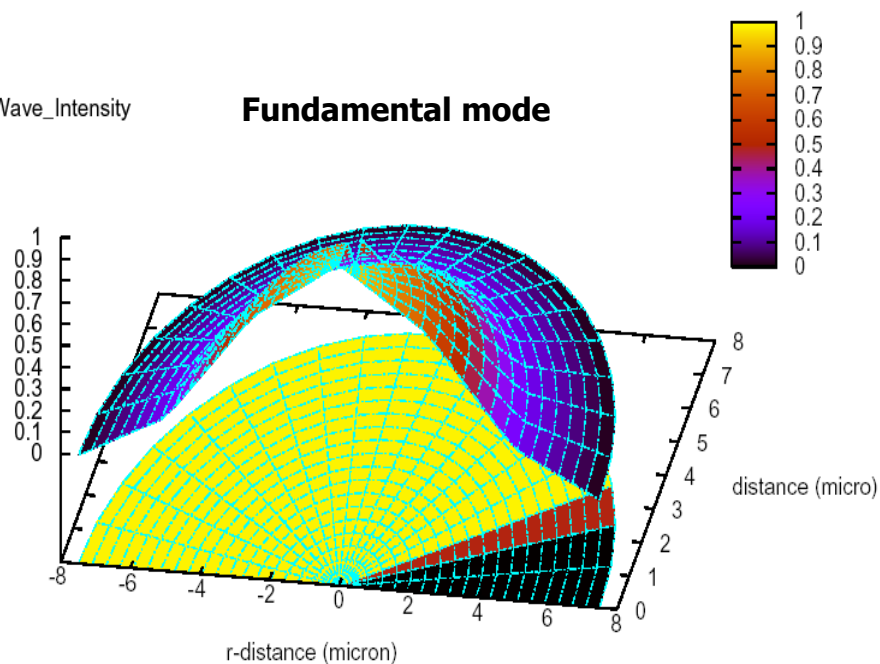
Total Curr. Mag (A/cm²)



Different modes

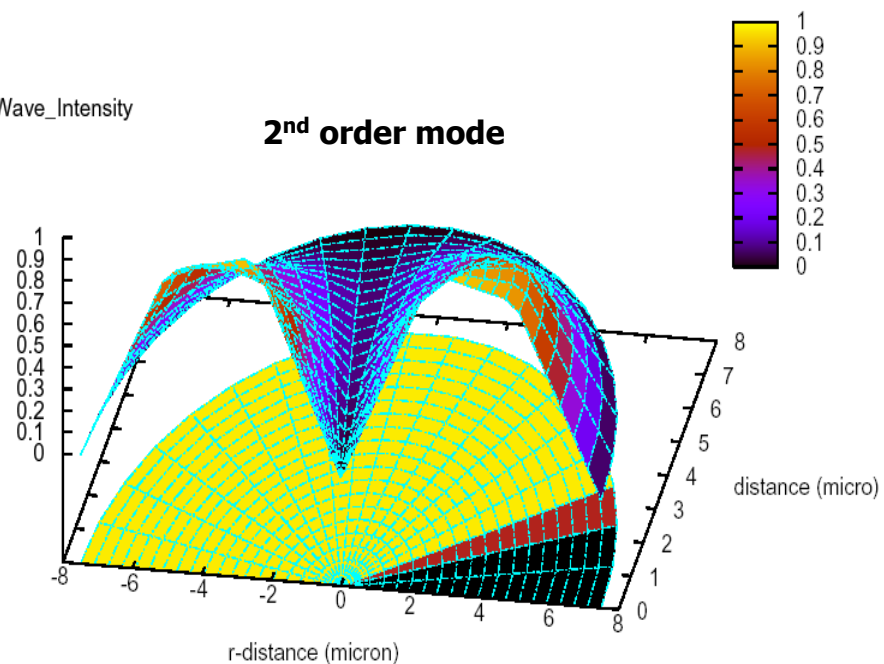
Wave_Intensity

Fundamental mode



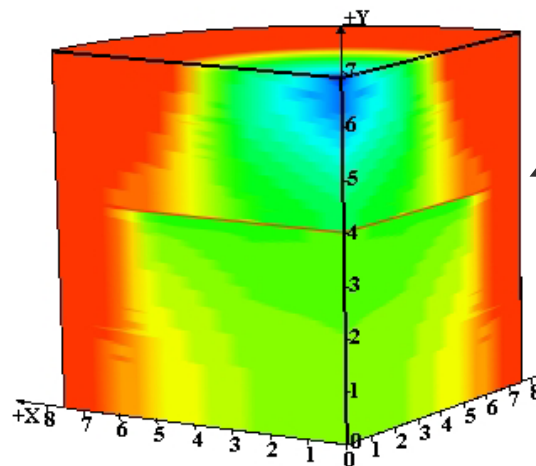
Wave_Intensity

2nd order mode

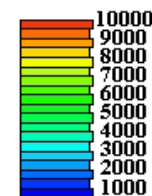


Symmetric VCSEL injection

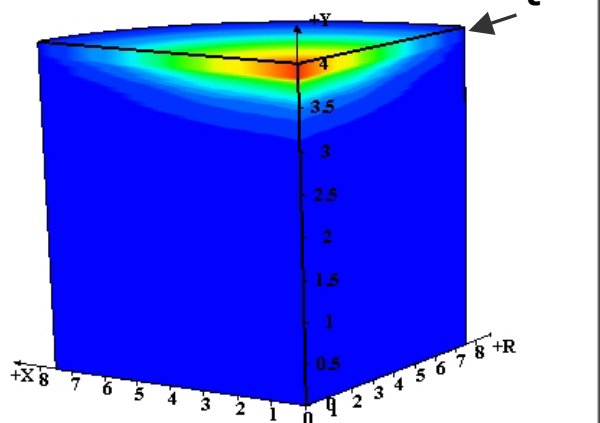
Current magnitude



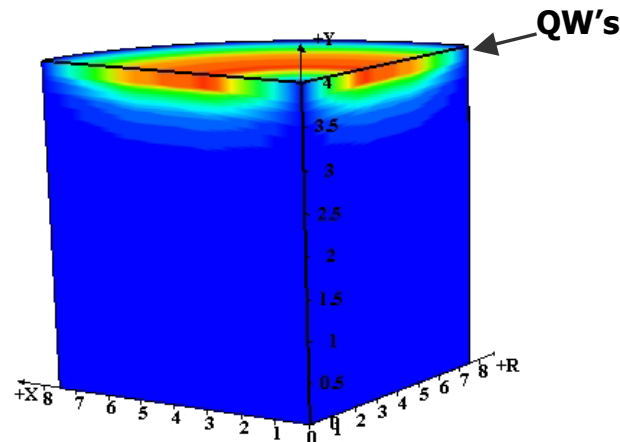
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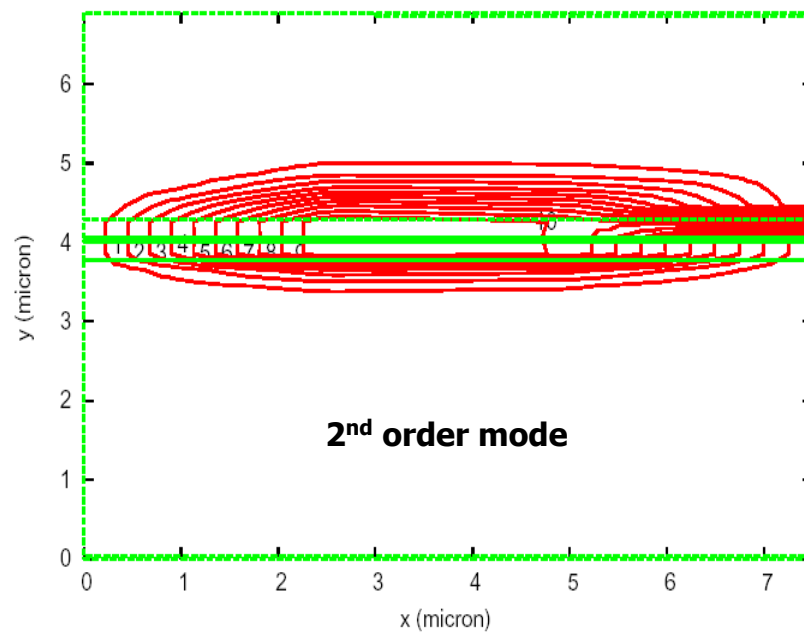
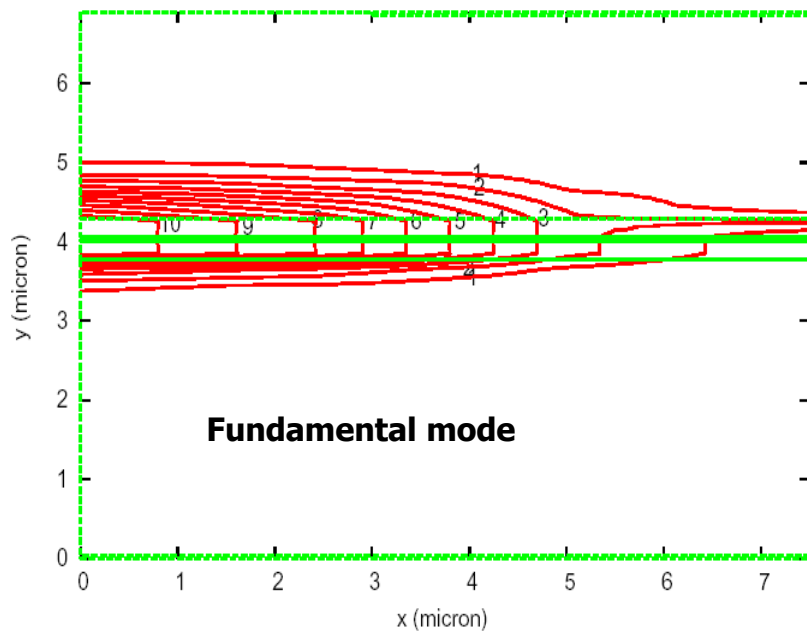
Fundamental mode



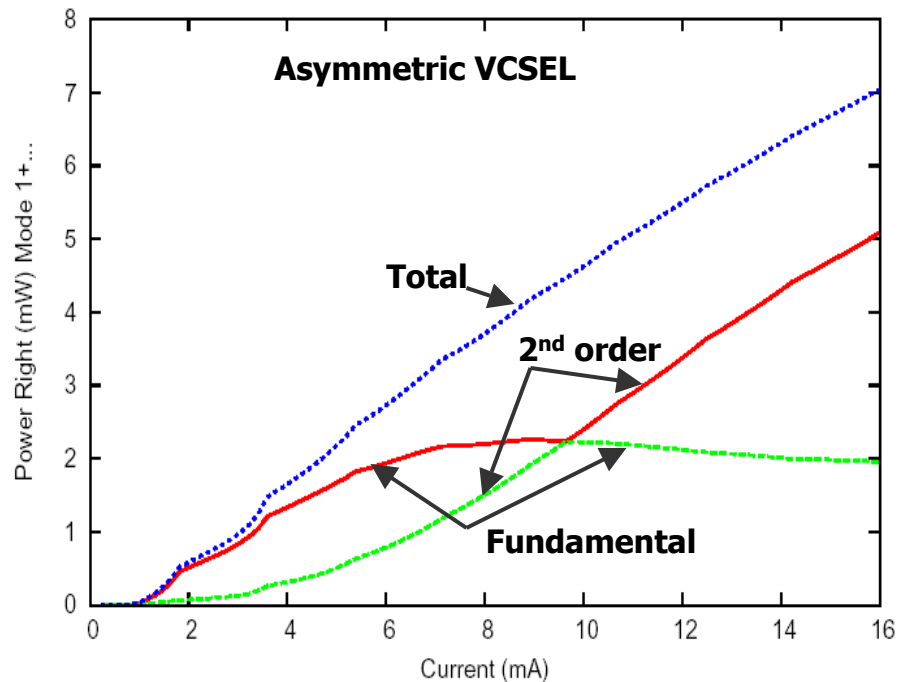
2nd order mode



Different symmetric modes

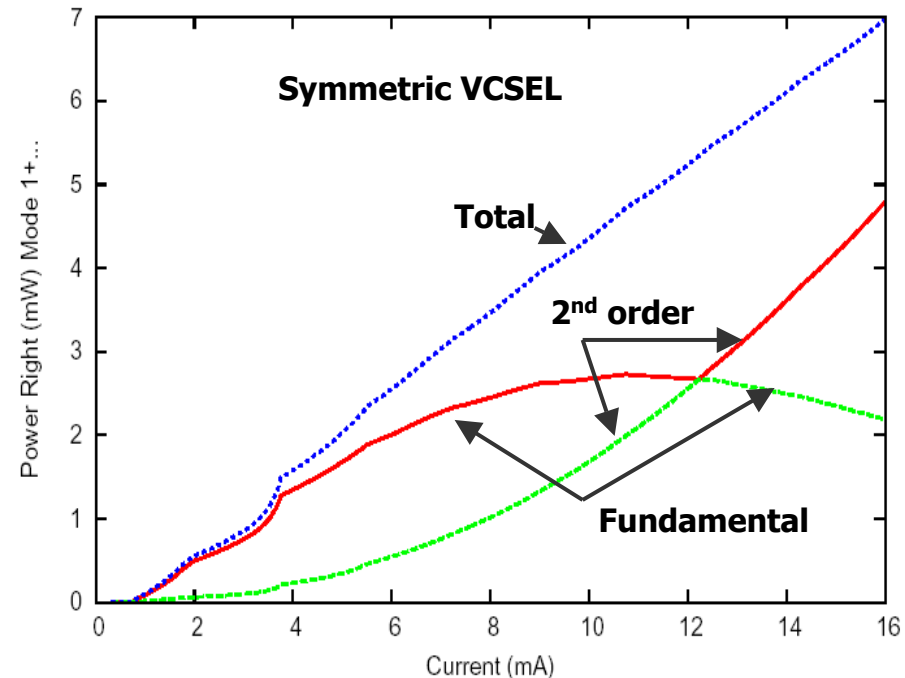


Mode competition behavior



Conclusions

- a) VCSEL has similar lateral mode competition behavior as edge laser;
- b) Asymmetric VCSEL mode is necessary to simulate multi-lateral mode behavior.

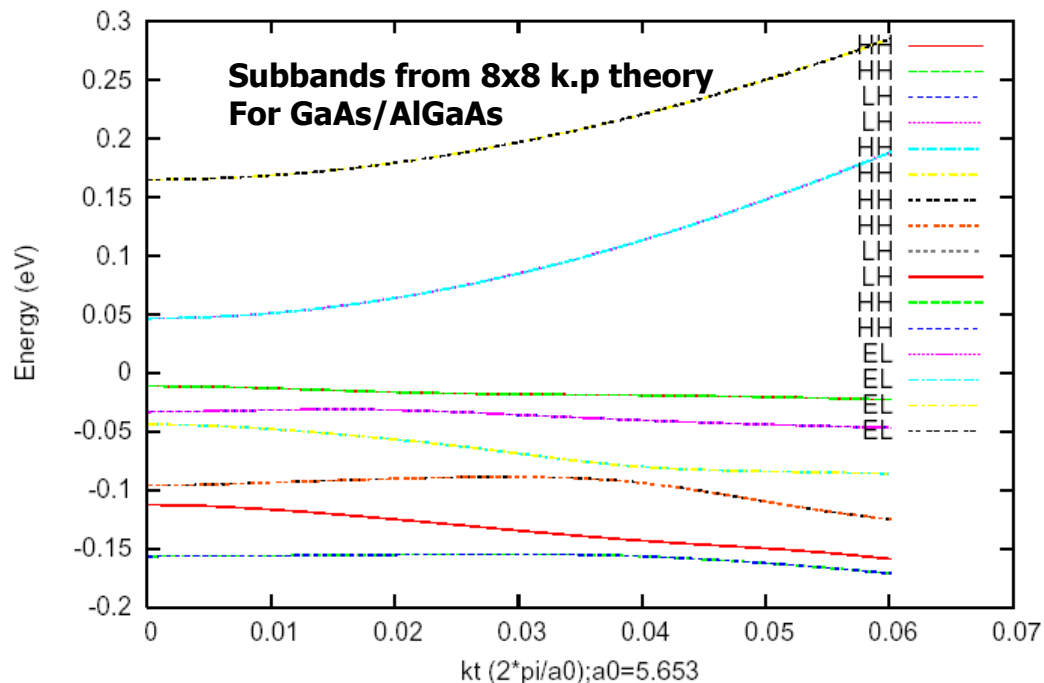




Contents

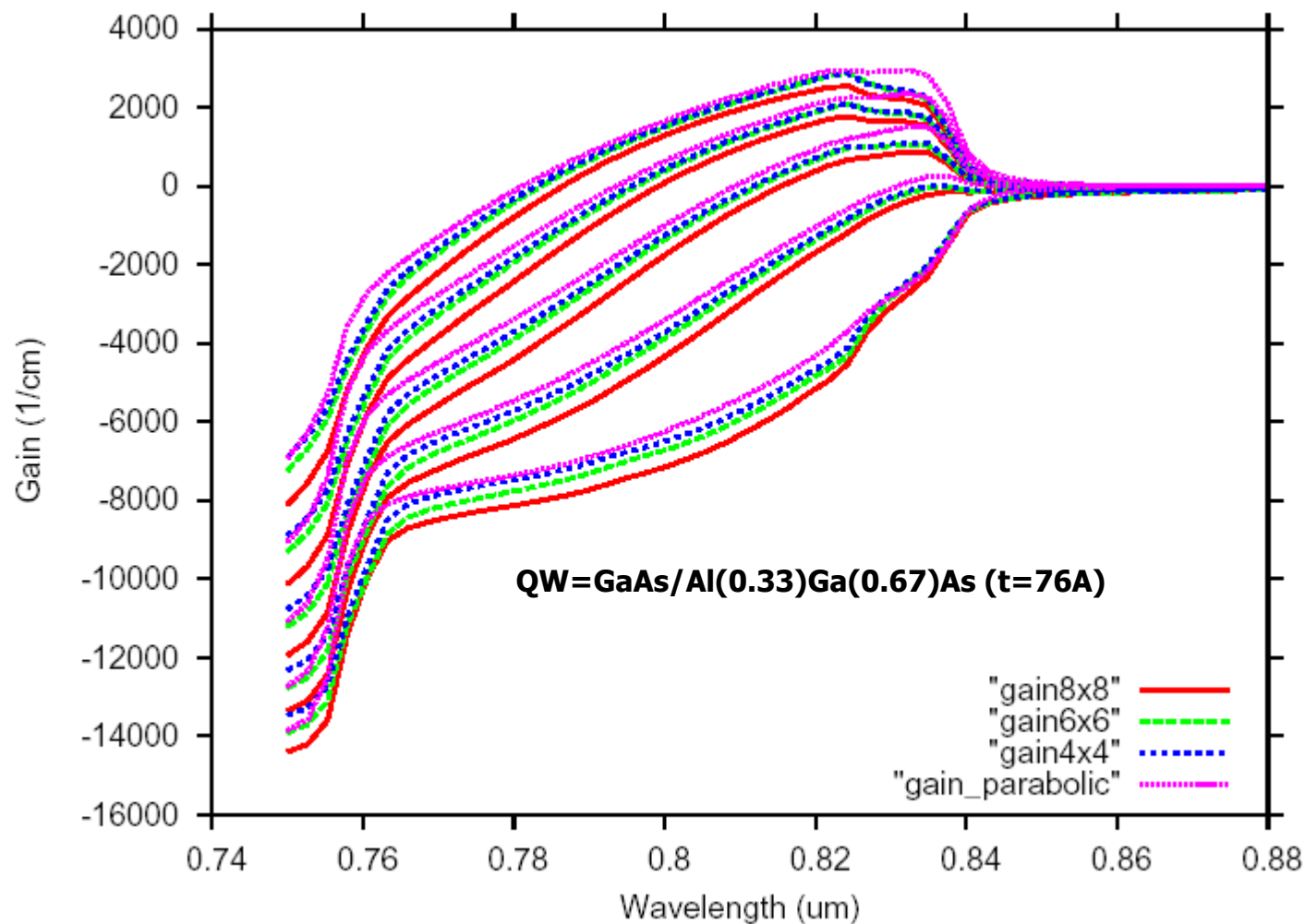
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Subbands from 8x8 k.p theory For GaAs/AlGaAs

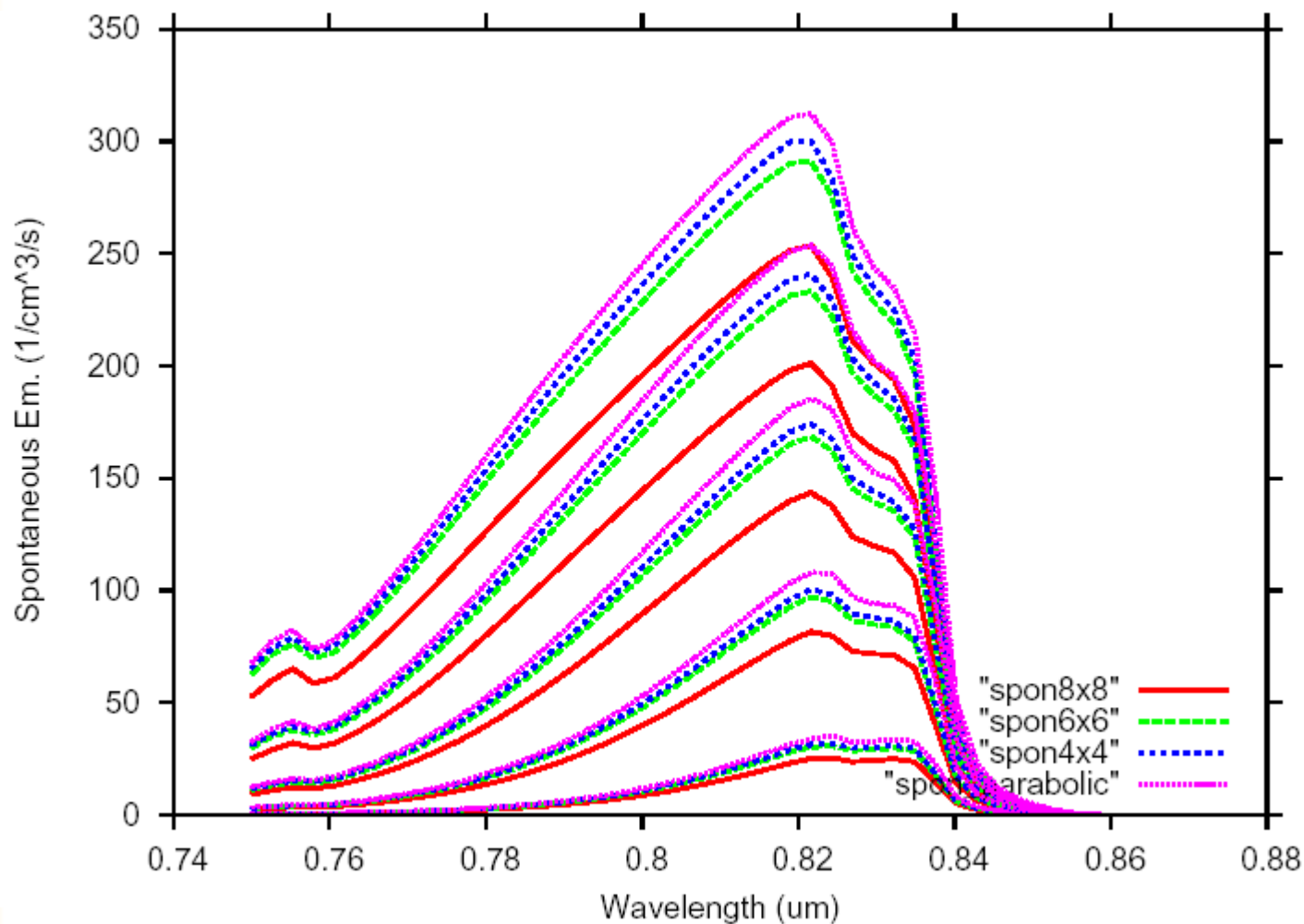


- When conventional parabolic gain model does not fit experiment, we need to try something else.
- Need to determine whether it is worth the trouble to go to higher order k.p theories.

Comparison for GaAs/AlGaAs QW

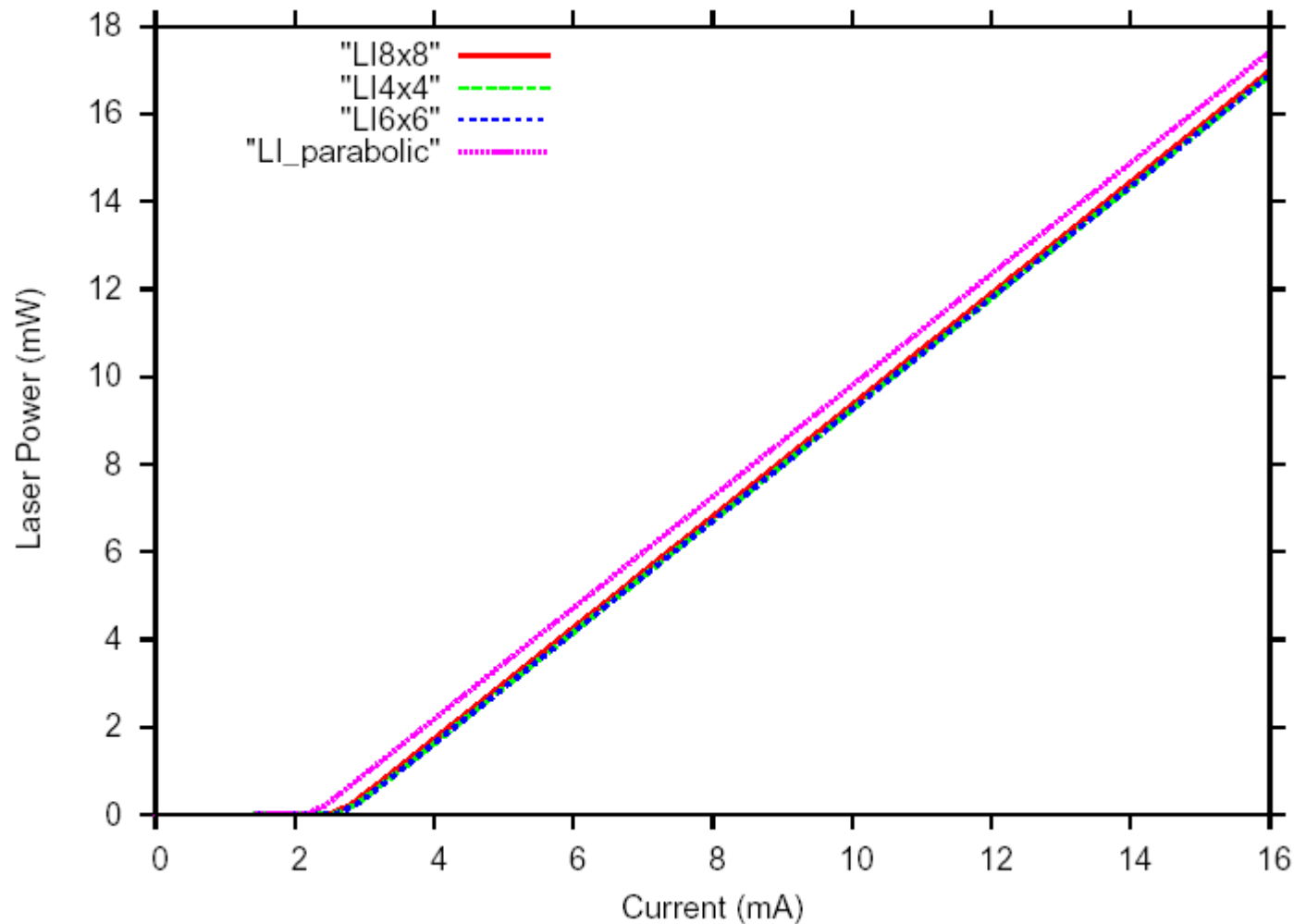


Spontaneous em. spectrum



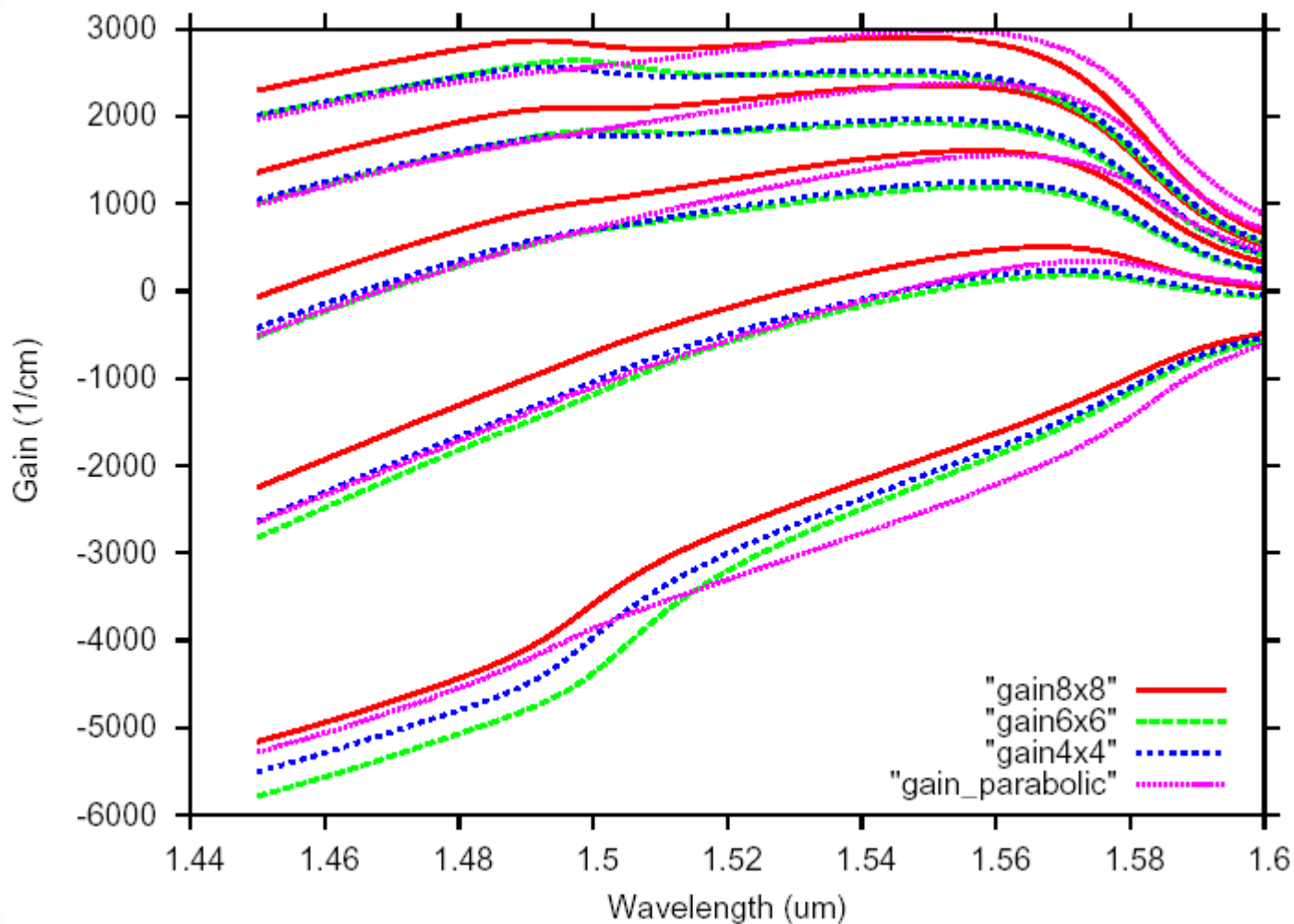
QW=GaAs/Al(0.33)Ga(0.67)As (t=76Å)

Light v. current



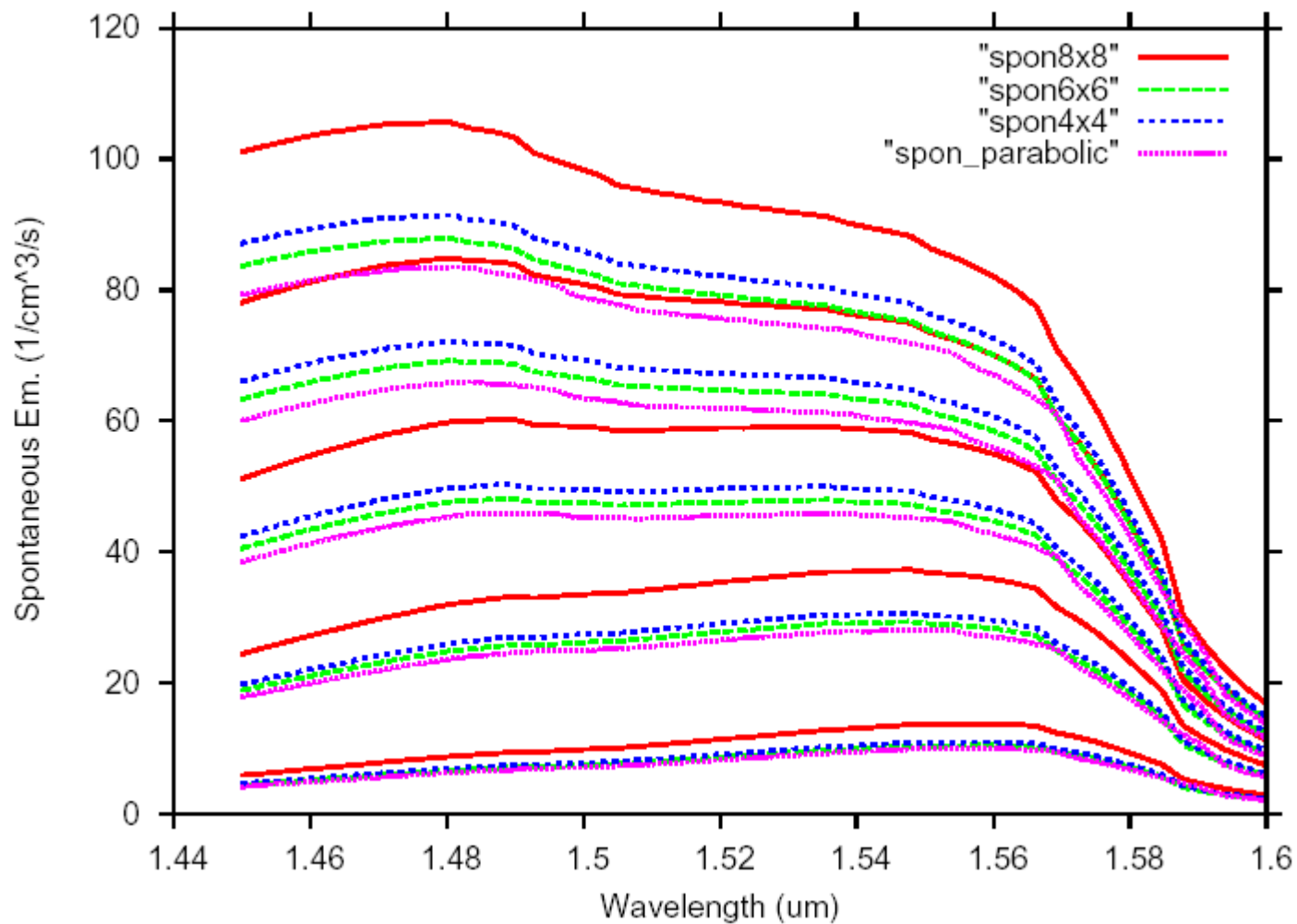
QW=GaAs/Al(0.33)Ga(0.67)As (t=76Å)

Comparison for InGaAsP QW



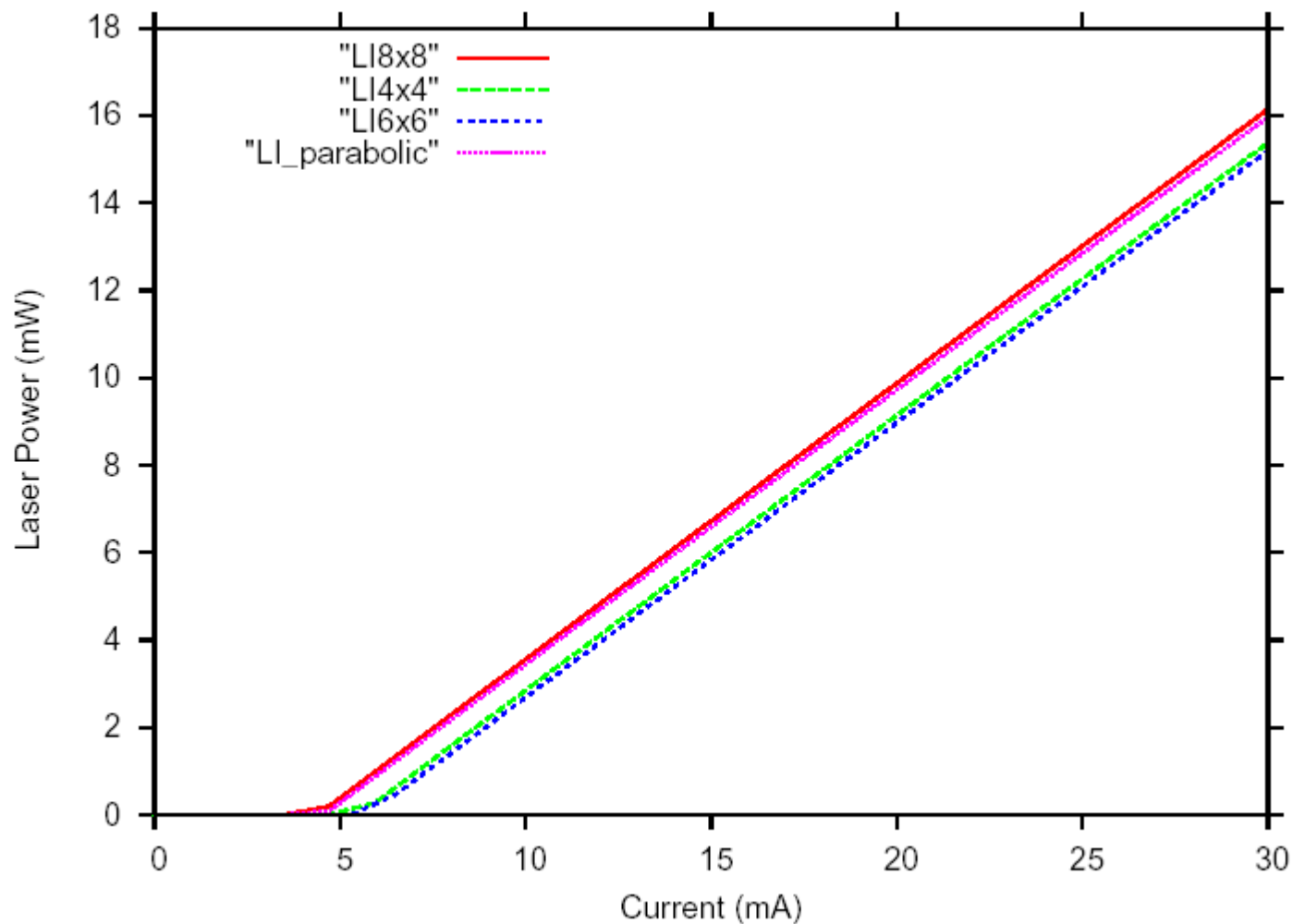
QW=InGa(.47)As/In(.74)Ga(.26)As(.57)P(.43) t=60A

InGaAsP QW PL



QW=InGa(.47)As/In(.74)Ga(.26)As(.57)P(.43) t=60A

InGaAsP QW L-I curve



QW=InGa(.47)As/In(.74)Ga(.26)As(.57)P(.43) t=60Å

Conclusions on k.p models

- **For wide bandgap system such as GaAs, no need to go to 8x8.**
- **For smaller bandgap system such as InGaAsP at 1.55 μm , 8x8 may improve accuracy.**
- **8x8 does not make fundamental difference to PL/gain spectrum shape.**
- **JDOS and/or manybody effects more likely to results in better fit to experiments.**