3D Modeling of Superluminescent Light-Emitting Diodes

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Outline

- Introduction
- Theoretical models based on Green's function theory
- Results and comparison with experiments
- Summary

Introduction

- SLED is a light source with properties between those of LED and LD, high power, broad band and good directionality
- Used in communication, sensing, and medical instruments.
- SLED spectrum is sensitive to carrier distribution inside MQWs.
- Accurate modeling tool is useful for the design

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- LED: spontaneous emission, broad band, low power
- LD: stimulated emission, narrow band, high power, high directionality
- SLED: amplified spontaneous emission, broad band, high power, high directionality

Theoretical Models

- So far, two types of model in literatures
  - 1-D wave equation along ***z*** (propagation) direction. Neglects the carrier transport on transverse plane and lateral optical confinement.
  - 2-D carrier transport model, assumes uniform carrier distribution in ***z***, and neglects spatial hole burning (SHB).
- Our approach combines 3-D carrier transport, 2-D transverse optical profile and 1-D optics along ***z***

System of equations

3D drift-diffusion equation:

$$\nabla \cdot \epsilon \nabla \phi + q(n - p - N_D^+ + N_A^-) = 0$$

$$\nabla \cdot J_n = U + q\frac{\partial n}{\partial t}$$

$$-\nabla \cdot J_p = U + q\frac{\partial p}{\partial t}$$

Separating 3D optical field:

$$E_\omega(x,y,z) = \sum_n E(z)_\omega \psi_n(x,y)$$

Transverse Helmholtz equation:

$$\Delta_T \psi_n(x,y) + \frac{\omega^2}{c^2}\varepsilon \psi_n(x,y) = k_n^2 \psi_n(x,y)$$

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Green's function theory

1-D inhomogeneous Helmholtz equation

Spontaneous noise

$$\left[\frac{\partial^2}{\partial z^2} + k_n^2(z)\right] E_\omega(z) = f_\omega(z)$$

Green's function is a solution of

$$\left[\frac{\partial^2}{\partial z^2} + k_n^2(z)\right] g(z, z_s) = \delta(z - z_s)$$

Contribution of point source at z_s to the field at z

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Solution

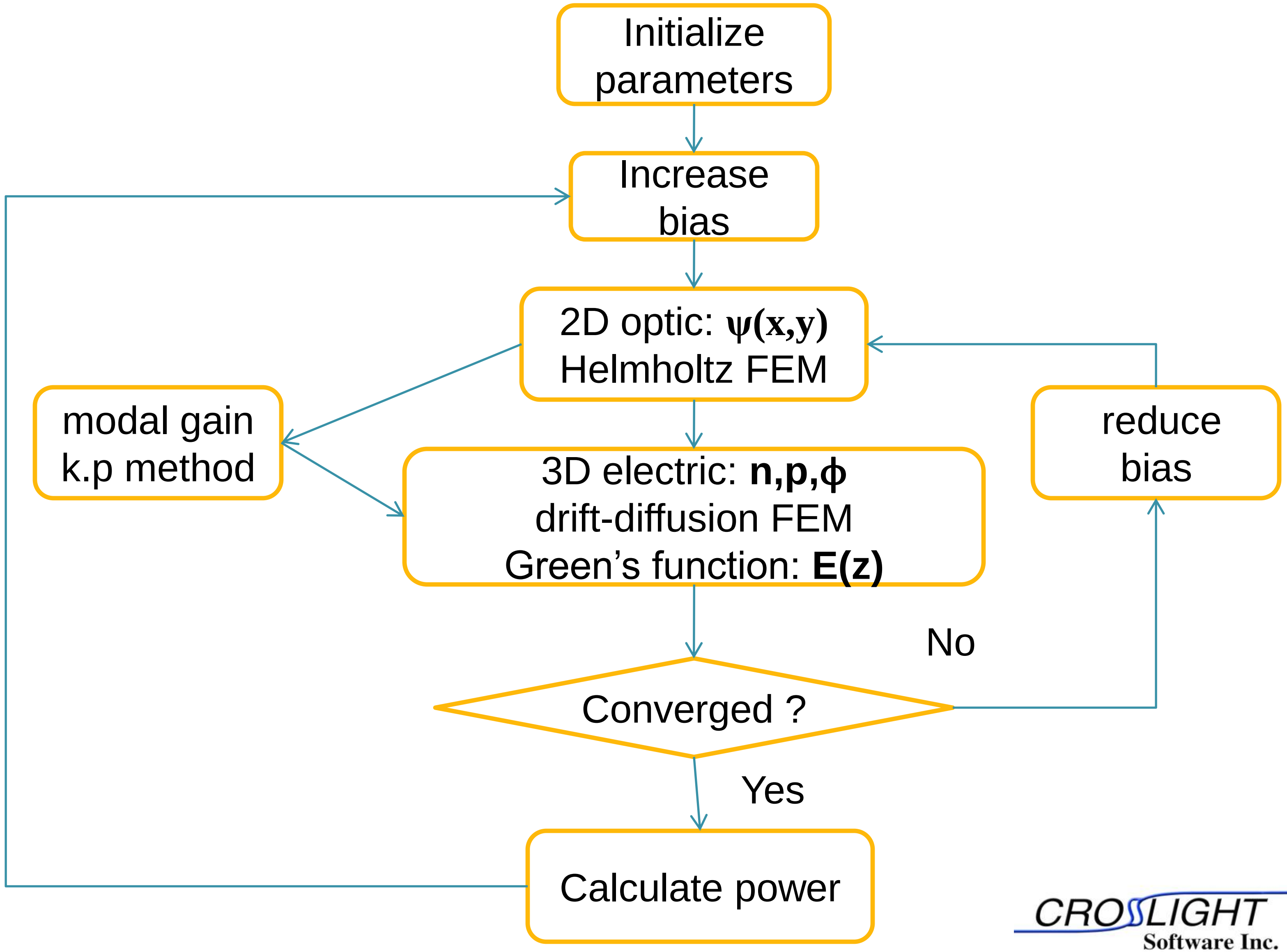
$$E_\omega(z) = \int_0^L g(z, z_s) f_\omega(z_s) dz_s$$

Spontaneous noise power

$$< S_\omega(z) >= \int_{-\infty}^{\infty} < E_\omega(z) E^*_{\omega'}(z) > d\omega'$$

Z.Q. Li and Simon Li, IEEE JQE, vol.46, p.454, 2010
R. Loudon et al., J. Lightw. Tech., vol.23, 2491,2005

Flow-chart



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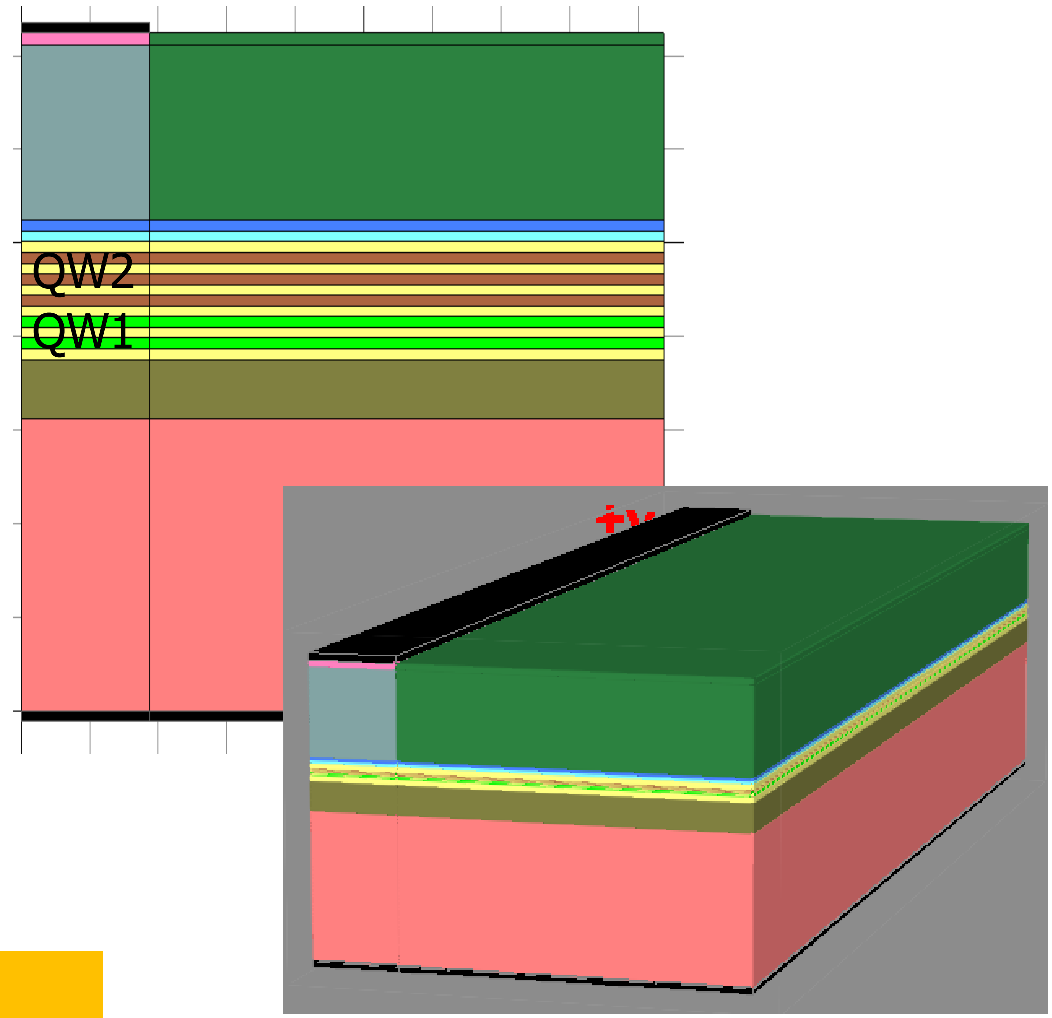
Test device structure

QW1: 15nm
$In_{53}Ga_{47}As$

QW2: 6nm
$In_{67}Ga_{33}As_{72}P_{28}$

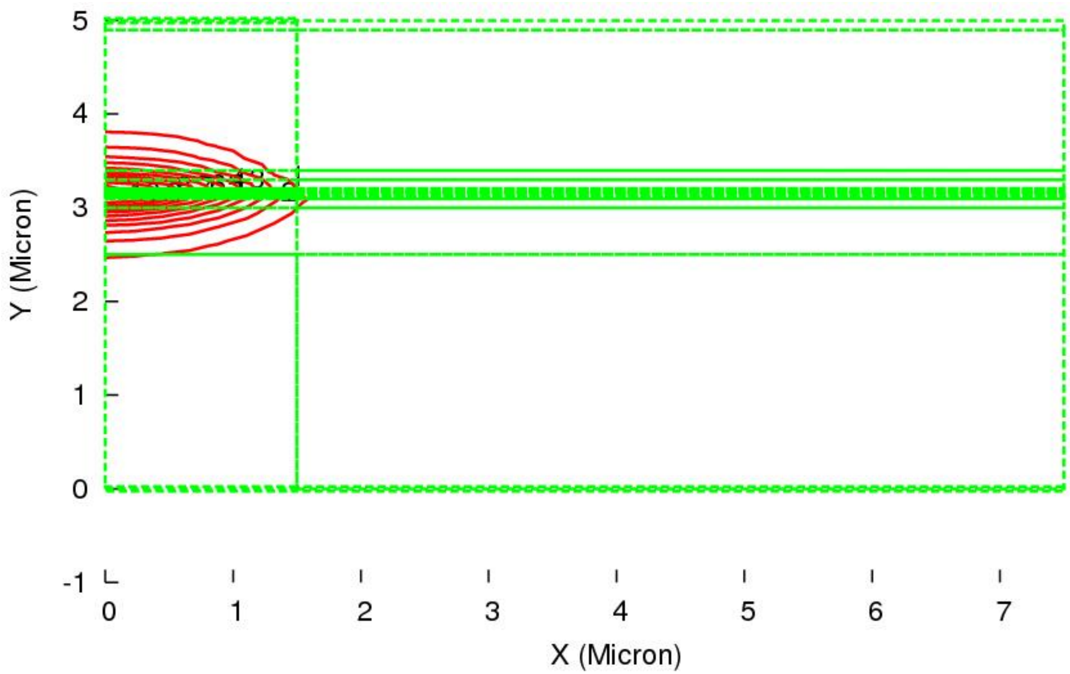
Barrier: 15nm
$In_{86}Ga_{14}As_{30}P_{70}$

Length: 300μm



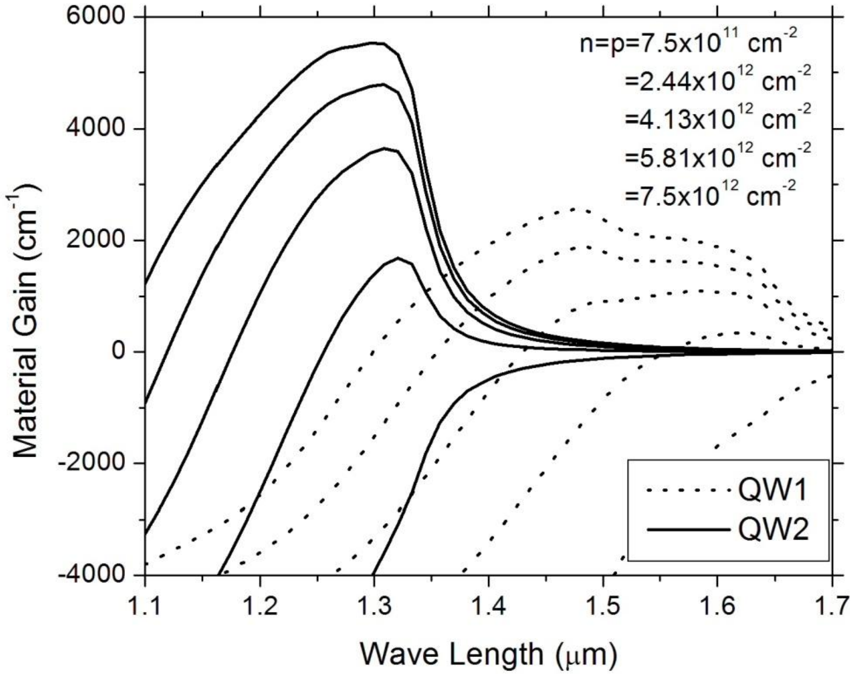
C.F. Lin, et al. IEEE Photon. Tech. Lett. Vol16, p1441,2004

Lateral mode profile

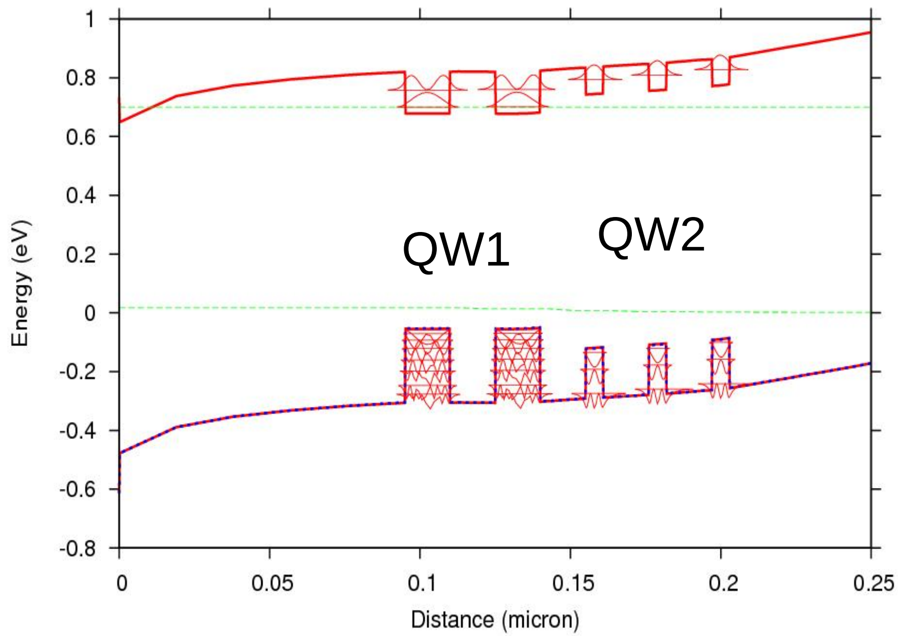


Multiple lateral modes can be included

Material gains of QW



Band diagram at 0.7V



QW1: two transitions
QW2:one transition
Broad band 1.3-1.6um

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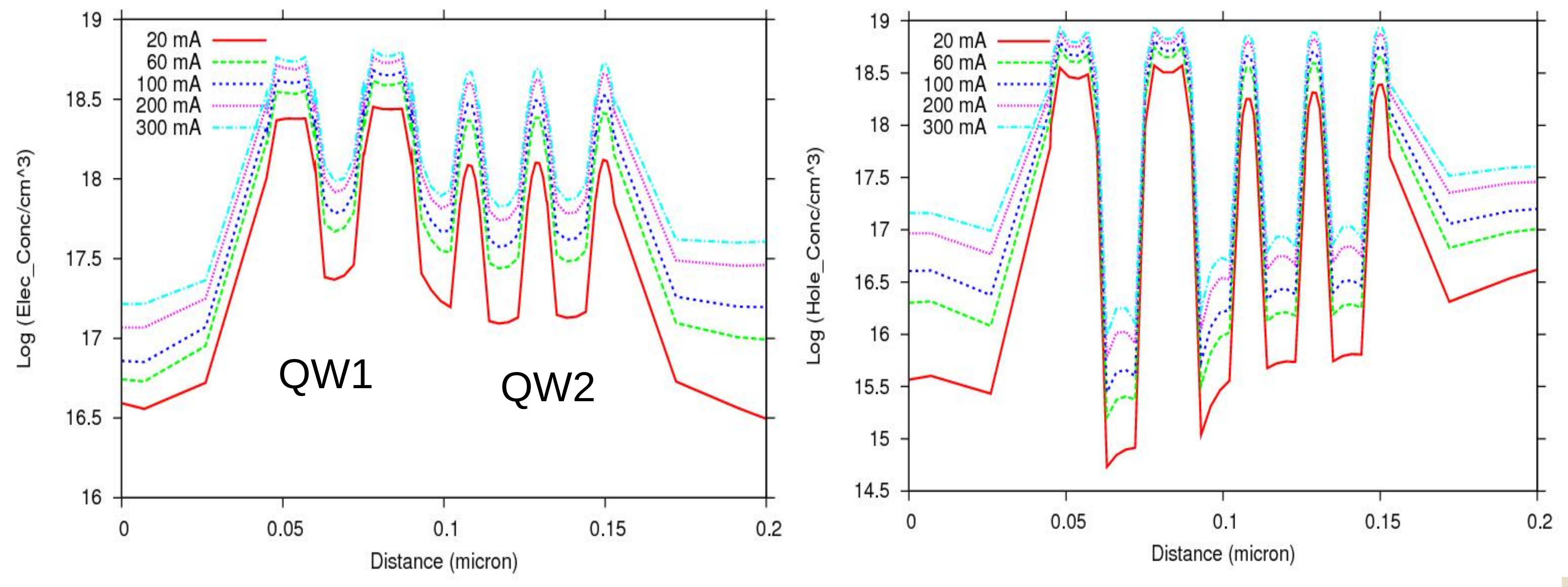
Carrier distribution at different injections



Carrier first captured in QW1, and in QW2 at high injection

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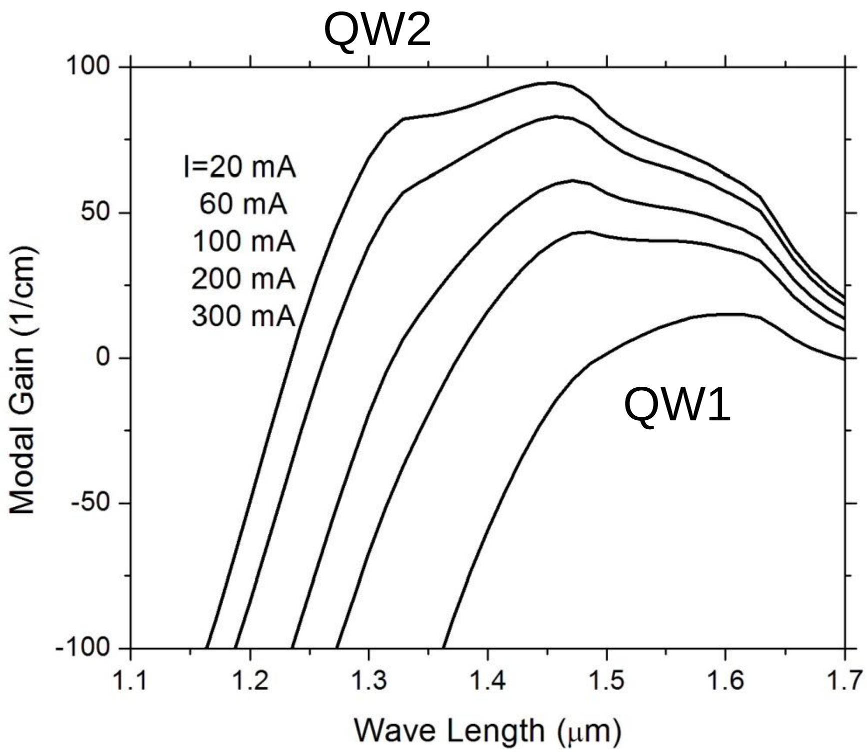
Modal gain at different injections



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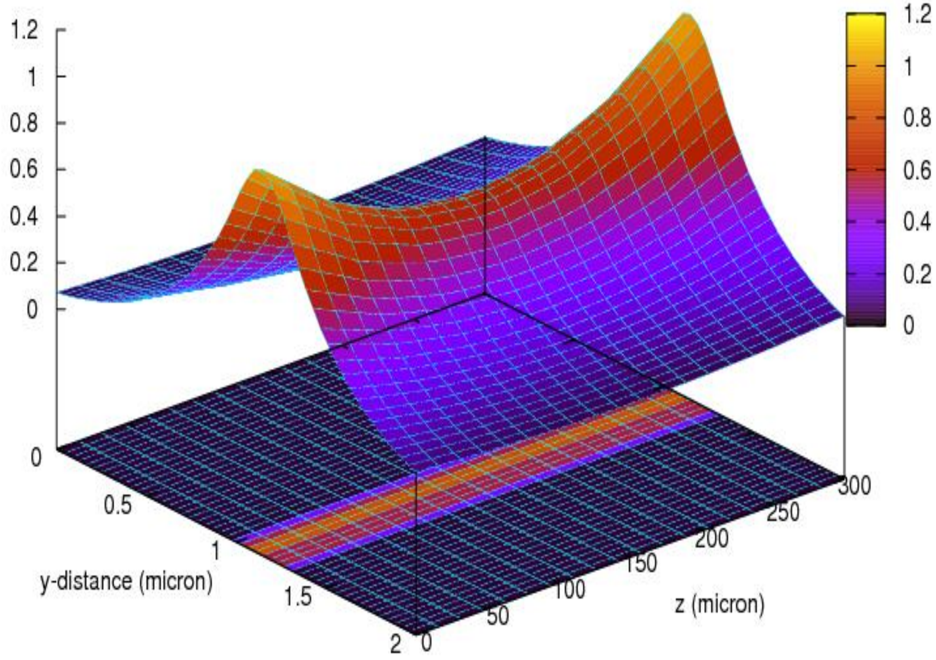
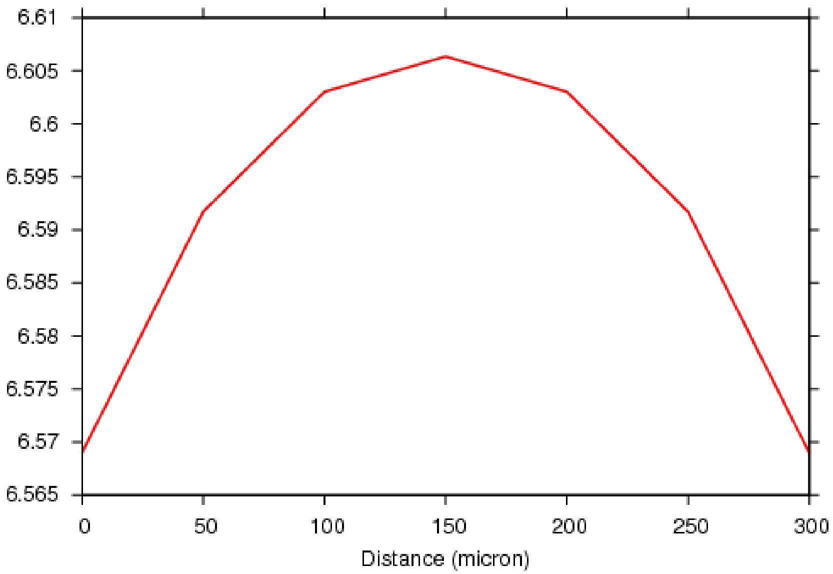
3D wave, SHB





Hole density along z

Spatial hole burning is not negligible

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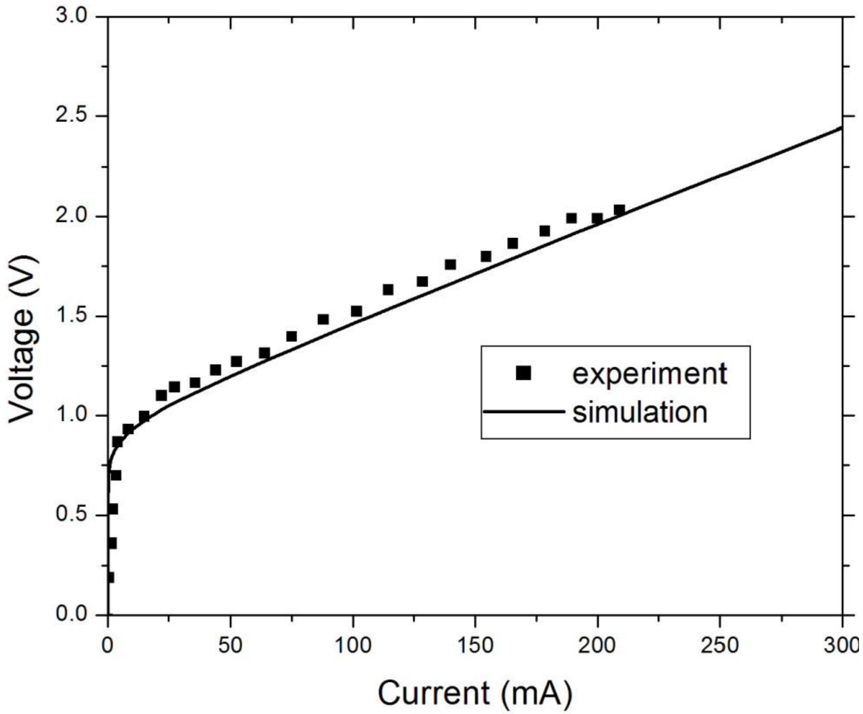
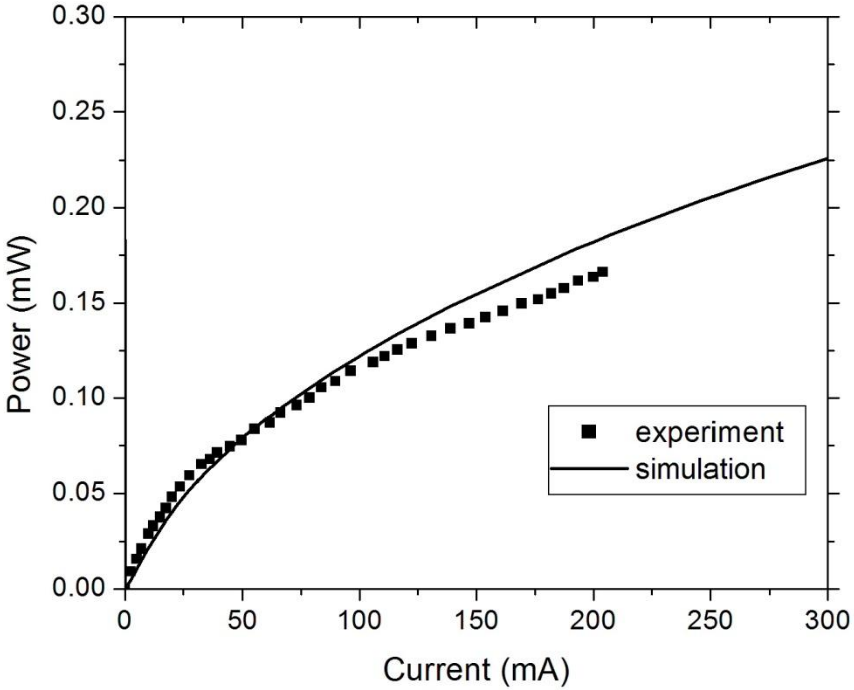
I-V and L-I curves





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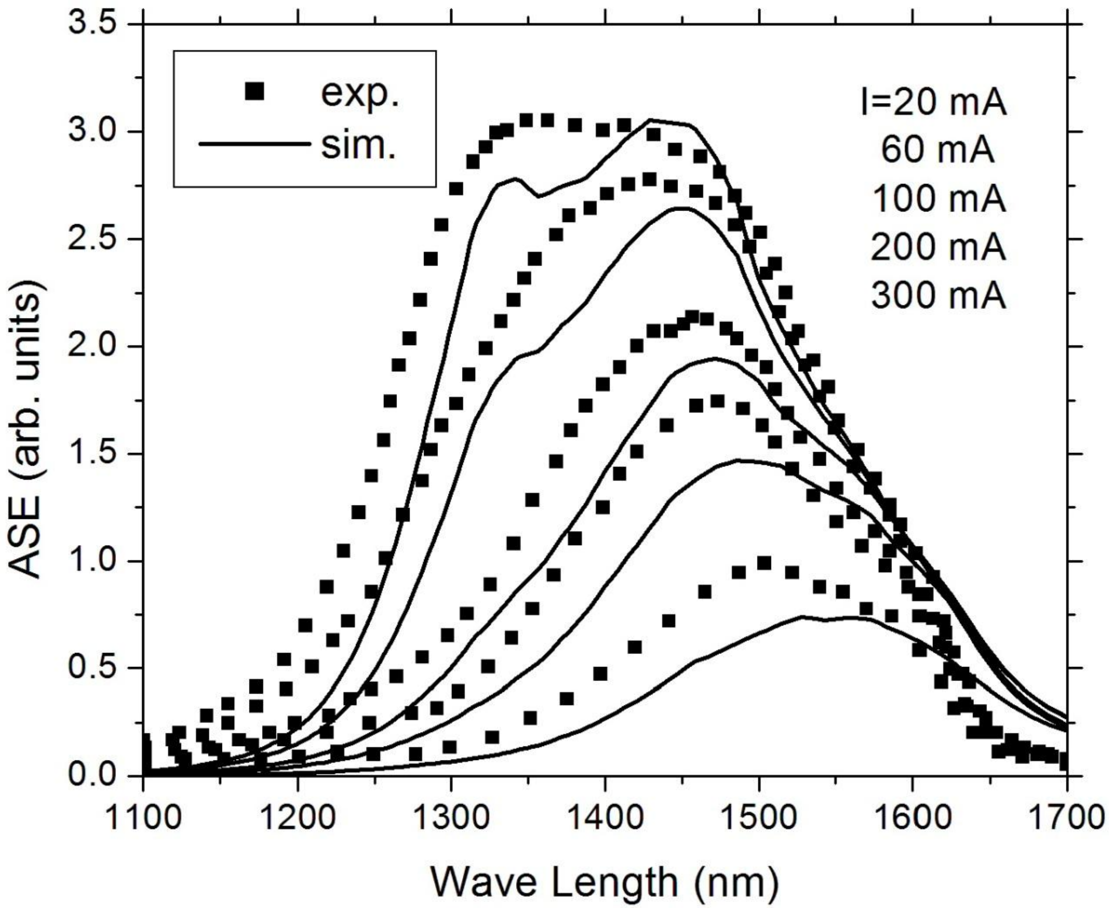
Amplifier spontaneous emission



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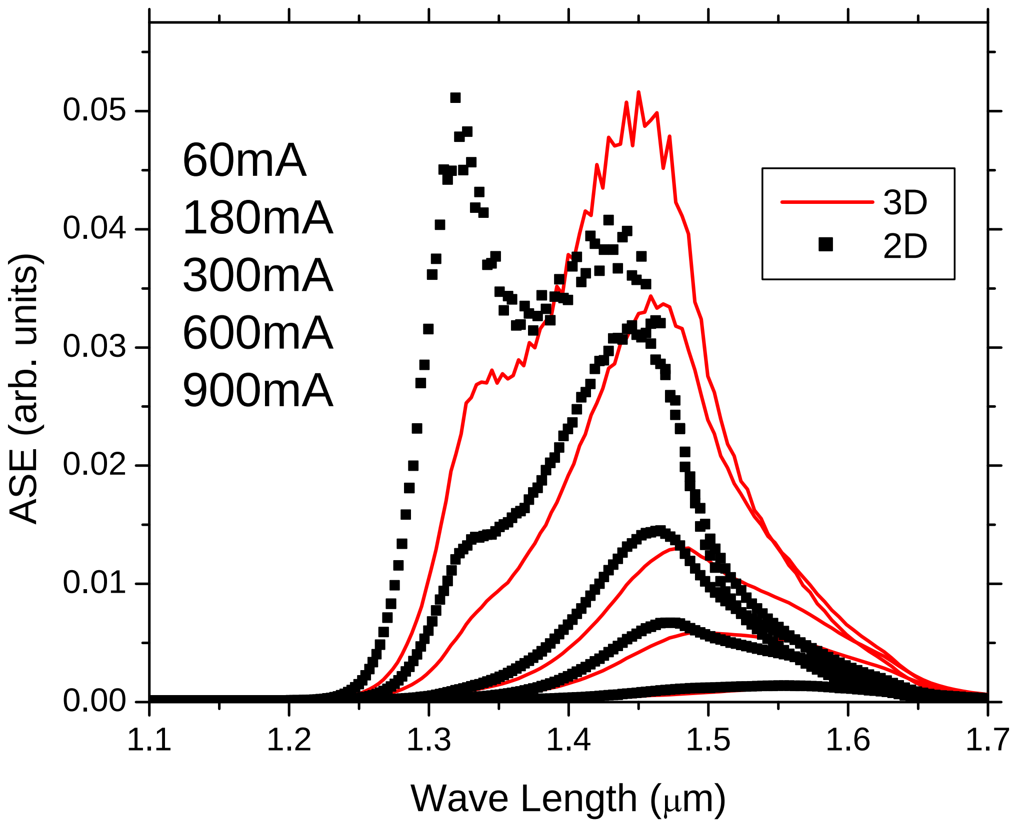
3D effect on ASE



Cavity length: 900 μm
3D effect shown at higher injections

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Summary

- Comprehensive model for SLED simulation is presented. 3D carrier dynamics and longitudinal SHP are included.
- Carrier distribution is important for broad-band SLED.
- SHB is not negligible at high injections
- Full 3D simulation is necessary