Analysis of Substrate Modes in a (Al,In)GaN/SiC Semiconductor Laser using Finite Element Approach

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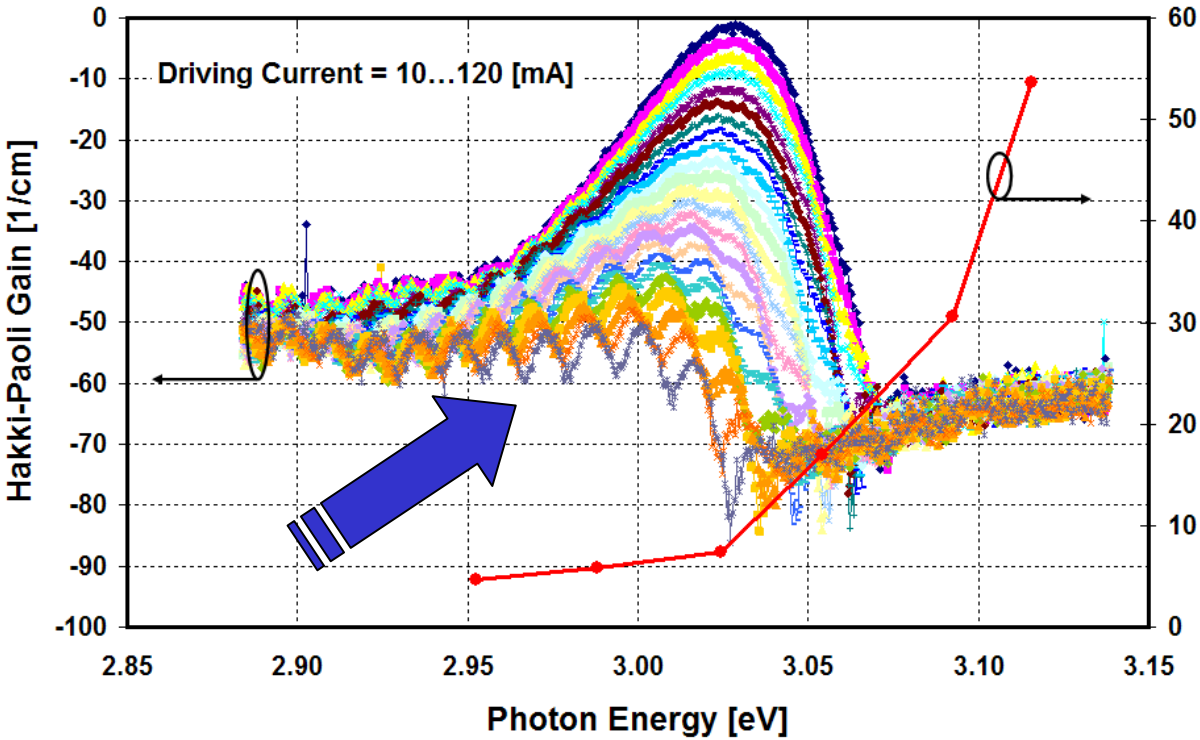
Outline

- Motivation
- Problem definition
- Solution of the Helmholtz eq.
- Substrate modes explanation
- Design variations
- Conclusion and outlook

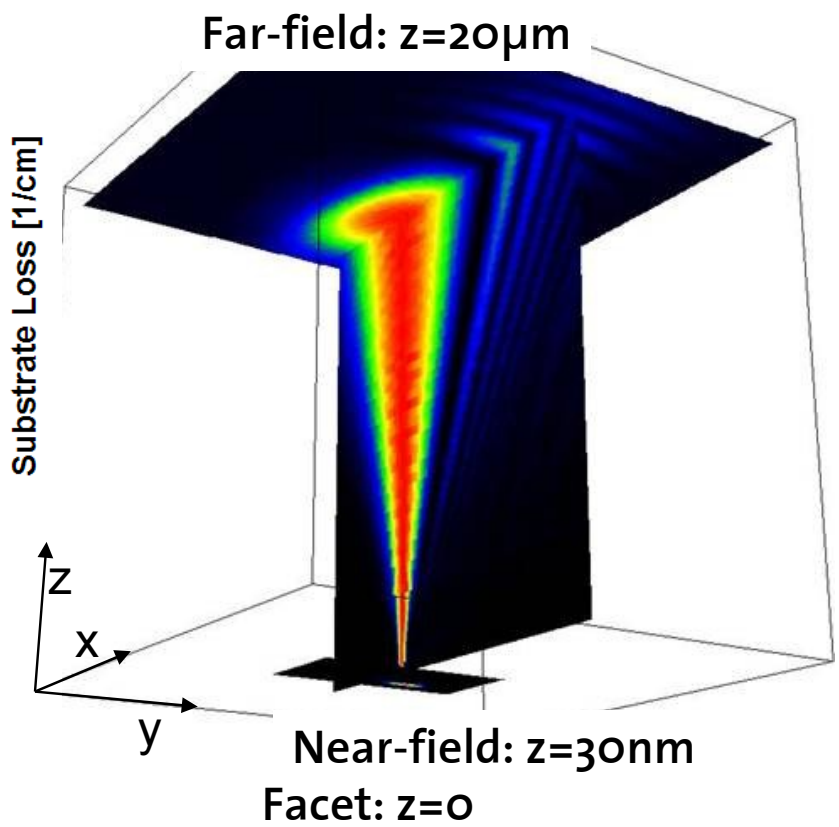
Motivation

Oscillations in Hakki-Paoli Gain Measurements



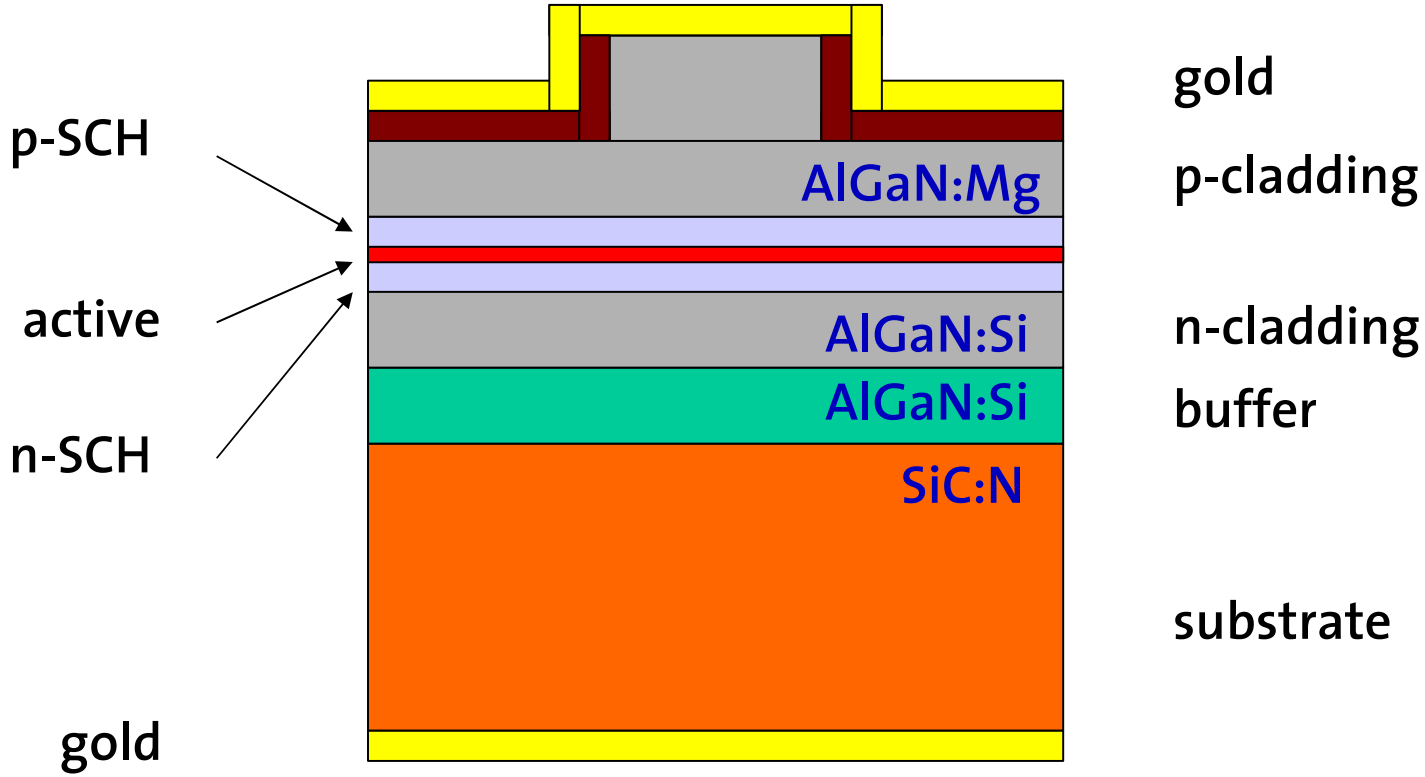
- (Al,In)GaN on SiC
- no oscill. on Sapphire

Secondary Lobes in Far Field



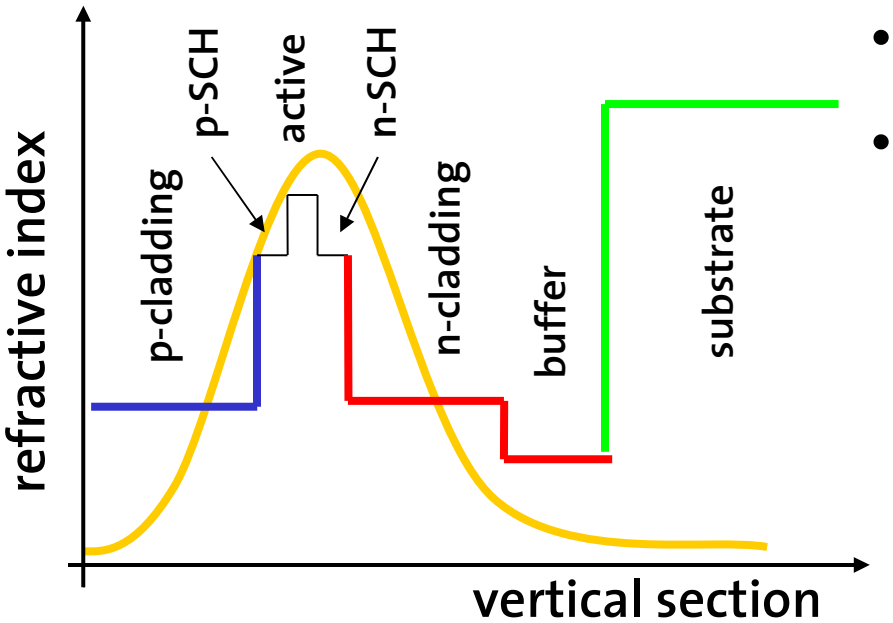
Device Description I

(In/Al)GaN edge emitting blue laser (OSRAM)



for details: U. T. Schwarz et all, *Excitonic signature in gain and carrier induced change of refractive index spectra of (In,Al)GaN quantum well lasers*, Applied Physics Letters, volume 85, number 9, 2004

Device Description II



- p-dopant induces optical loss
- optical mode extends into substrate (1D TMM)

	opt. loss [1/cm]
Gold	5.8×10^5
p-doped GaN	100
n-doped GaN	12
SiC	4.5

for details:

APL 85, N. 9, 2004
APL 68, N. 5, 1996
APL 68, N.22, 1996
APL 80, N.1, 2002
JJAP 33, pp. 2479, 1994

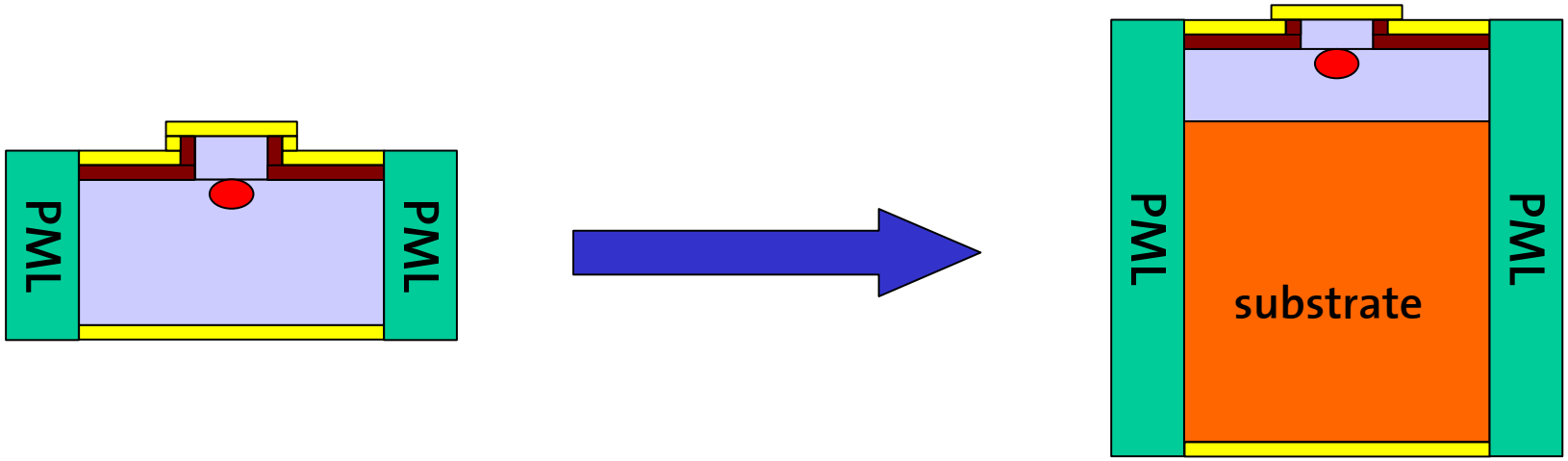
Hypothesis:

substrate induces periodic variations in modal loss

$$G = \Gamma \cdot g - \alpha_{cavity} - \alpha_{mirror} - \alpha_{substrate}$$

Solution of Helmholtz Equation

- finite element 2-D
- vectorial formulation to describe interfaces properly
- complex notation for refractive index (gain/loss)
- boundary conditions: Dirichlet + PMLs
- two steps: first guess for model including substrate



Solution of Helmholtz Equation

eigenvalue:

real and imaginary part of effective cavity index

eigenvector:

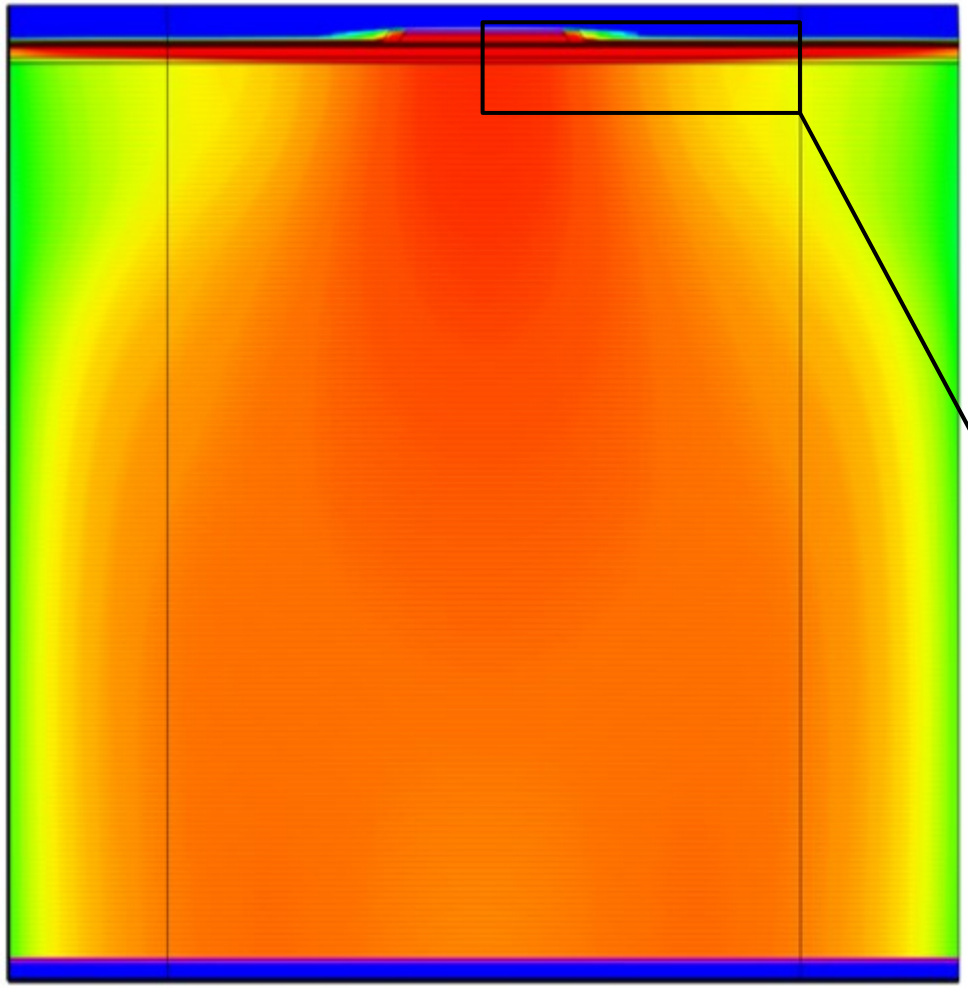
spatial distribution of electric field intensity

plot imaginary part of eigenvalue vs. photon energy

Available Data

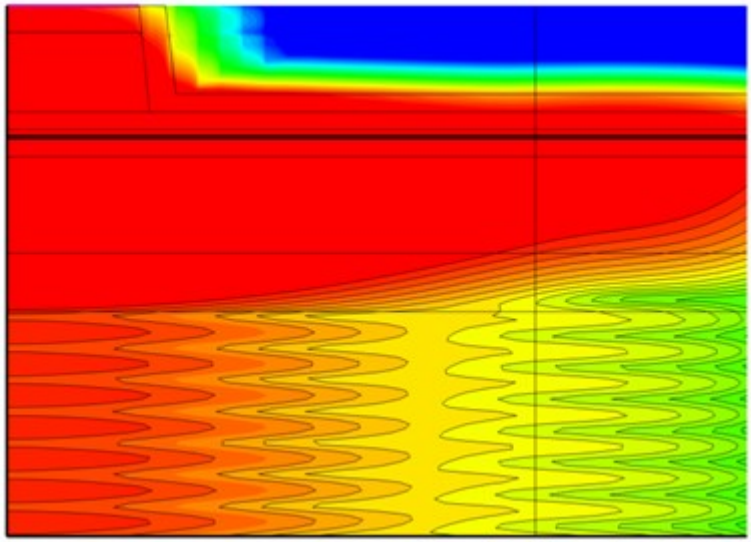
- spectral optical gain (Hakki-Paoli)
- SiC optical loss vs. energy
- Epitaxial structure
- SEM picture (cross section)

Simulation Results



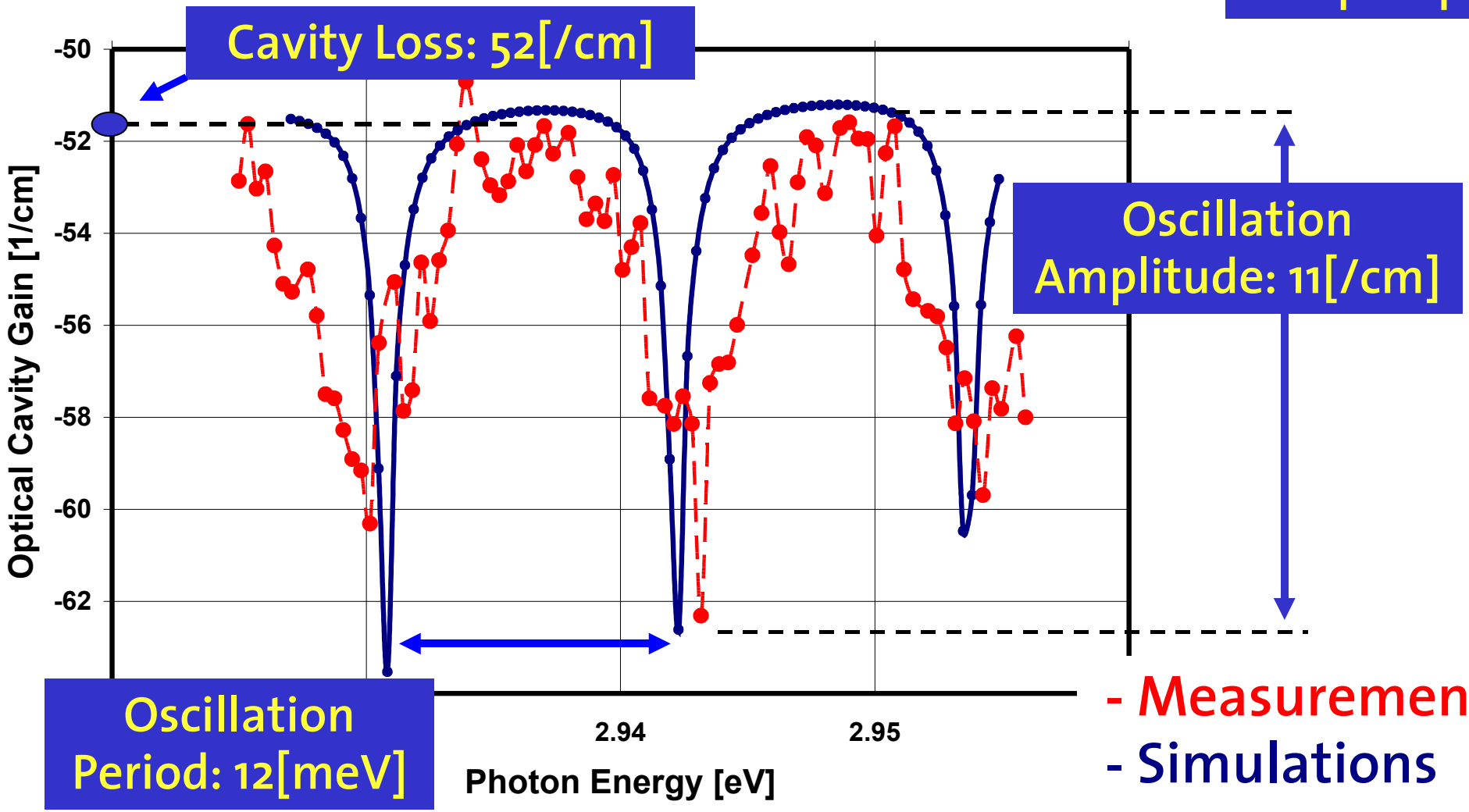
- evanescent wave excites propagating wave in substrate
- bottom gold reflects
- standing wave in substrate

➢ analysis of cavity loss



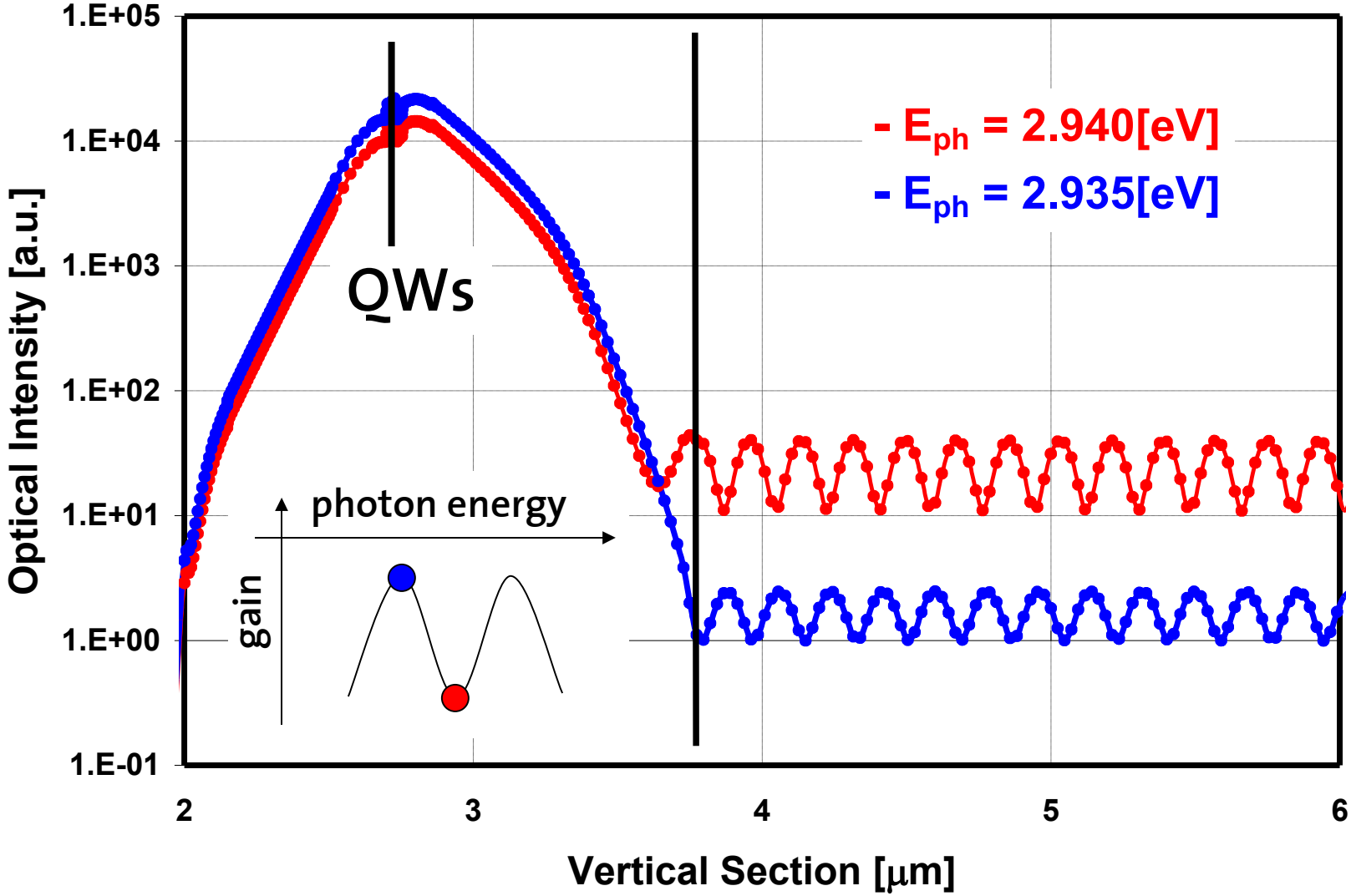
Simulation Results

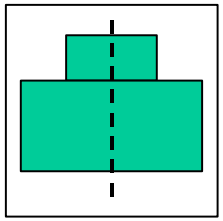
active region not pumped



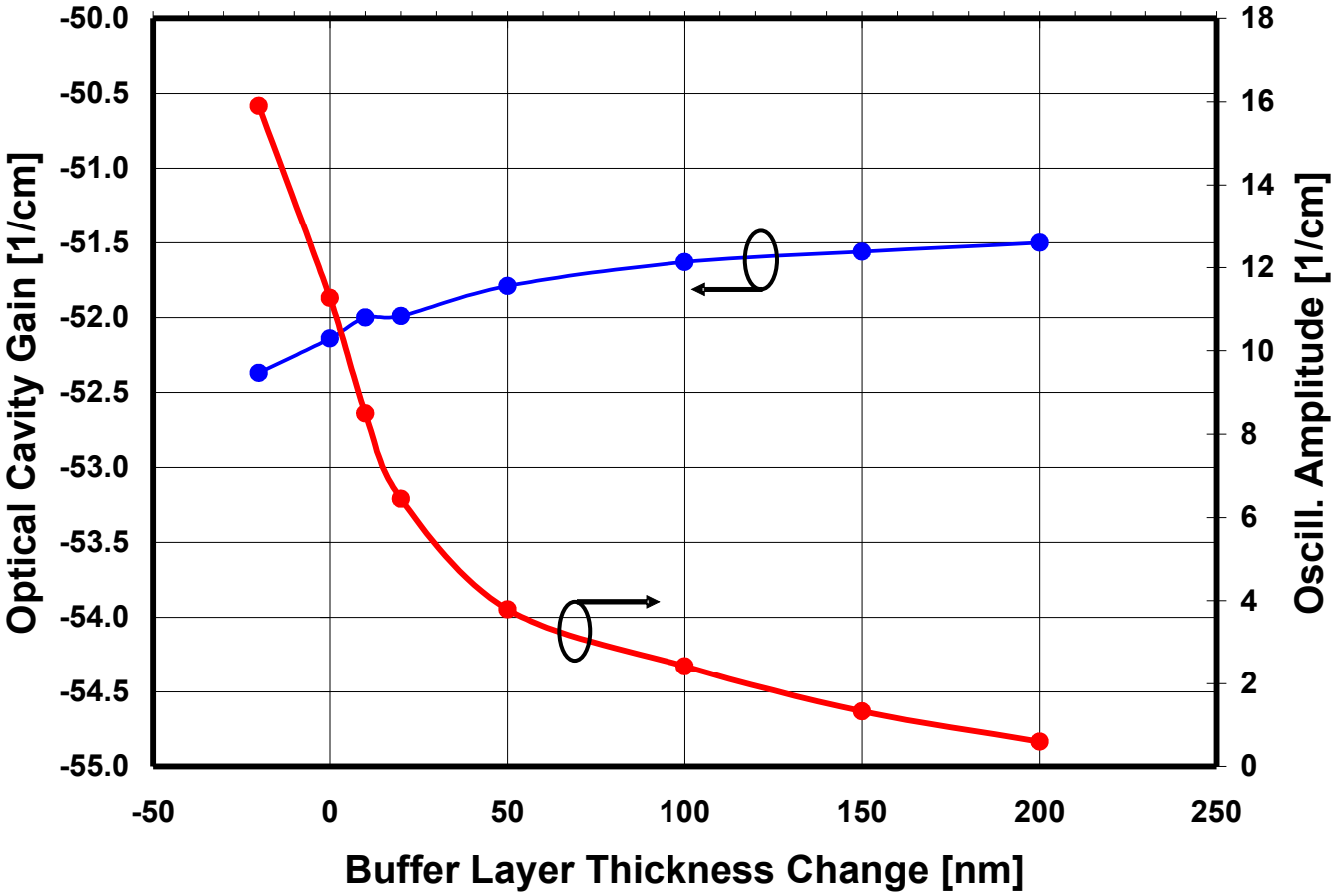
- Measurements
- Simulations

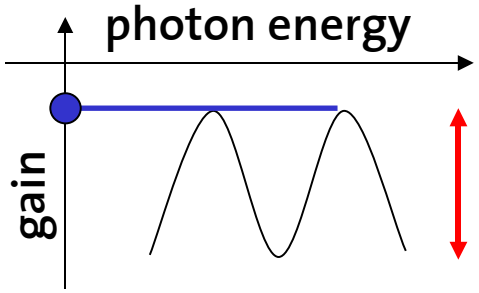
Origin of Oscillations in Spectral Gain

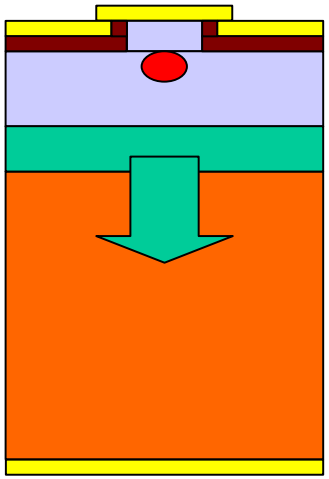




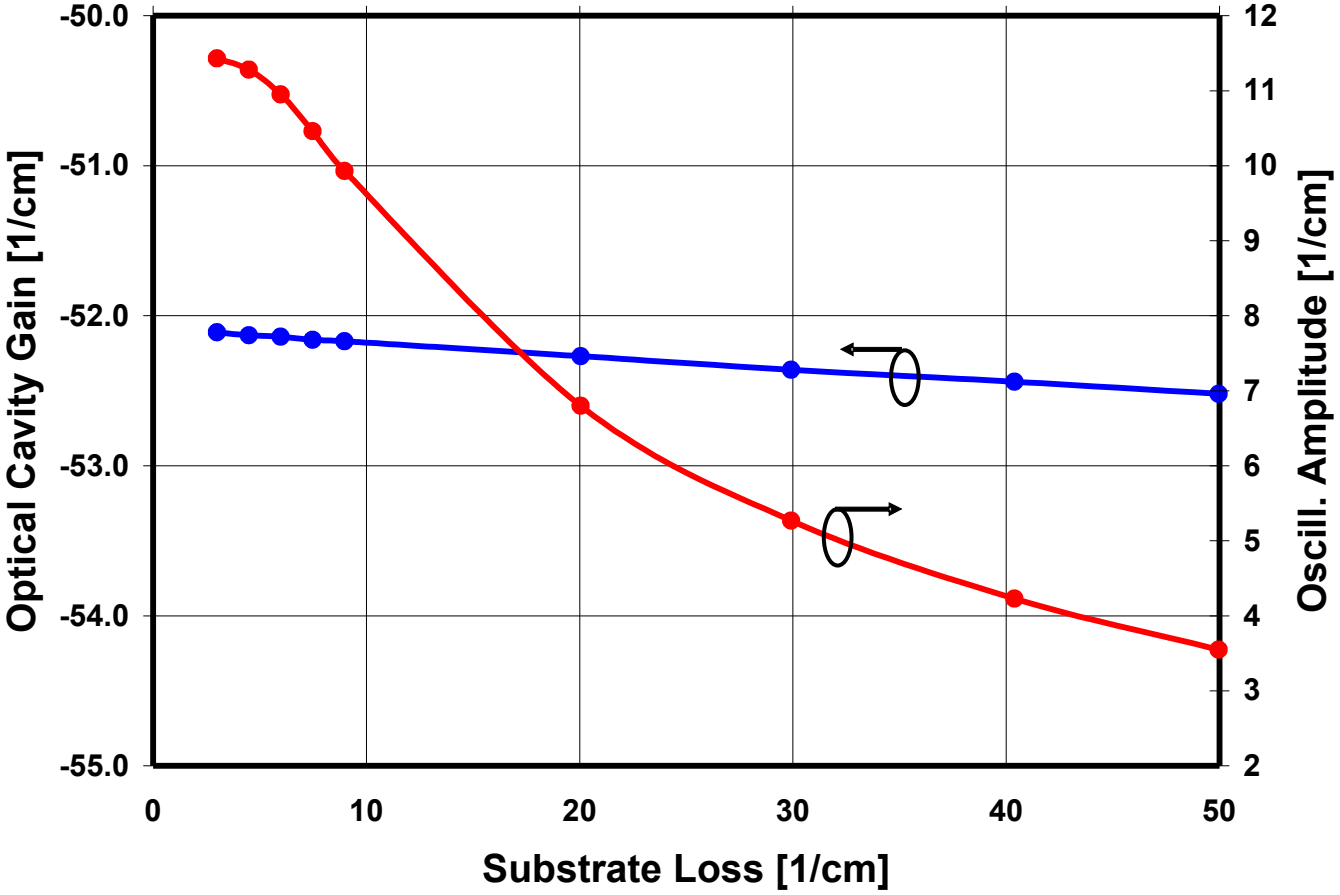
Variation of Buffer Thickness

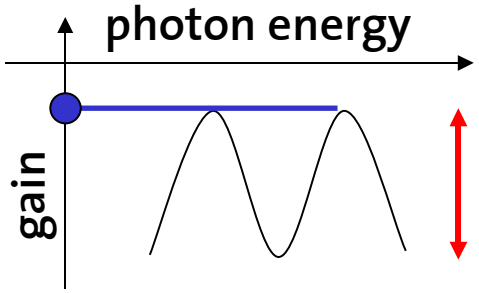


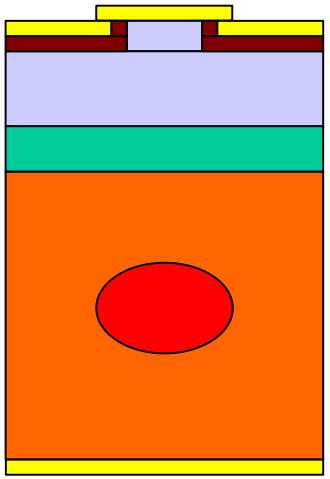




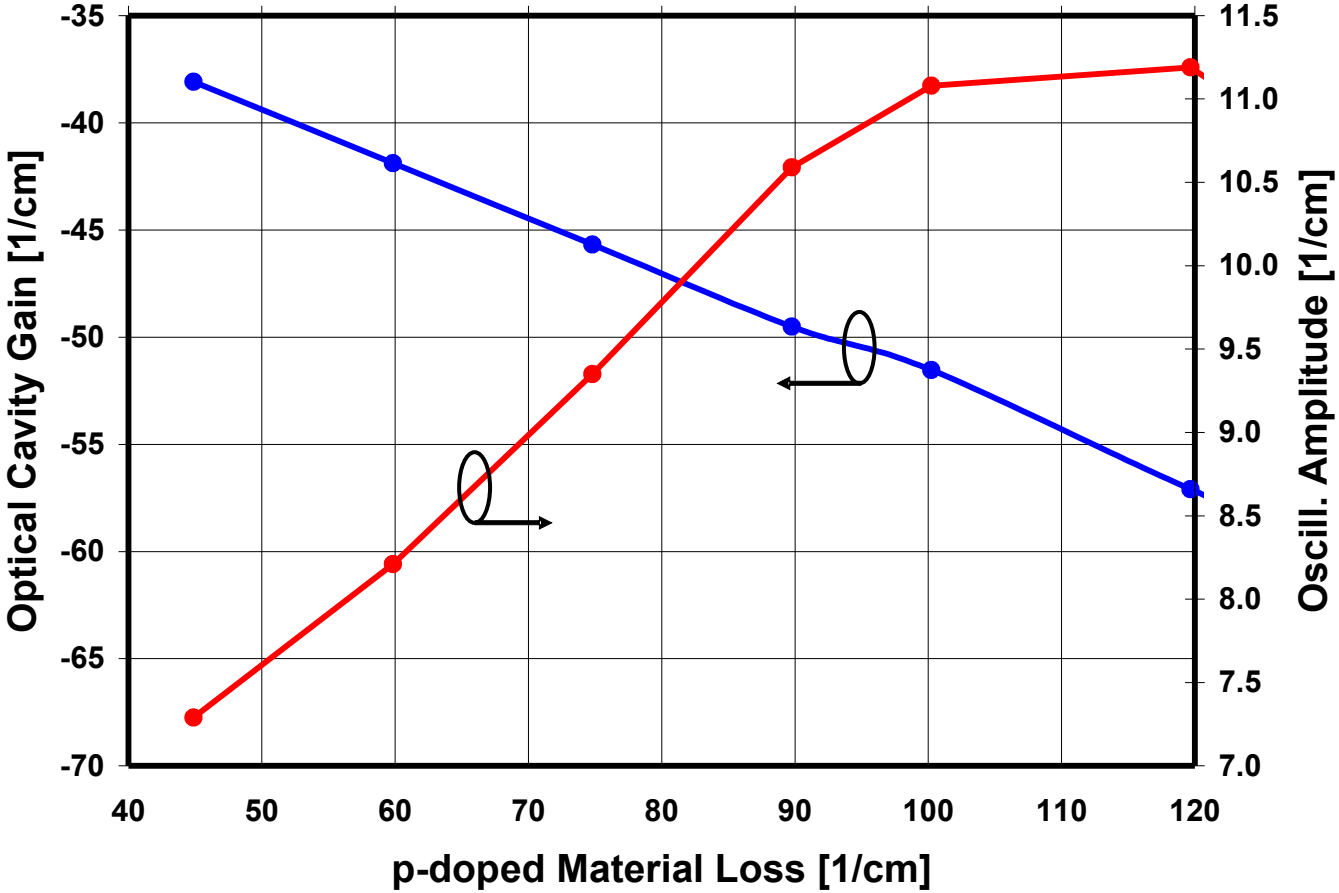
Variation of Substrate Loss

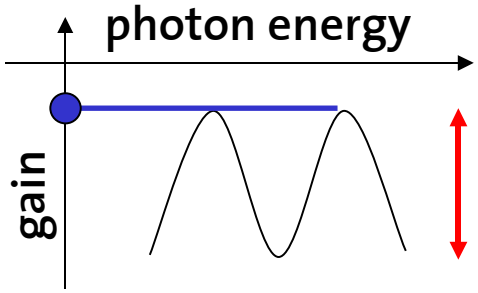


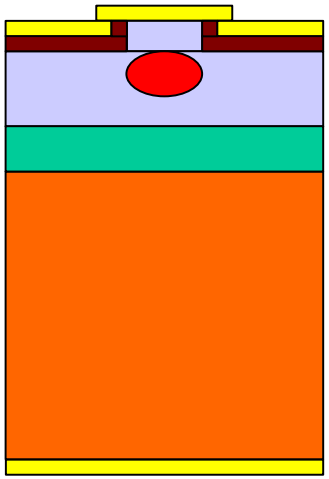




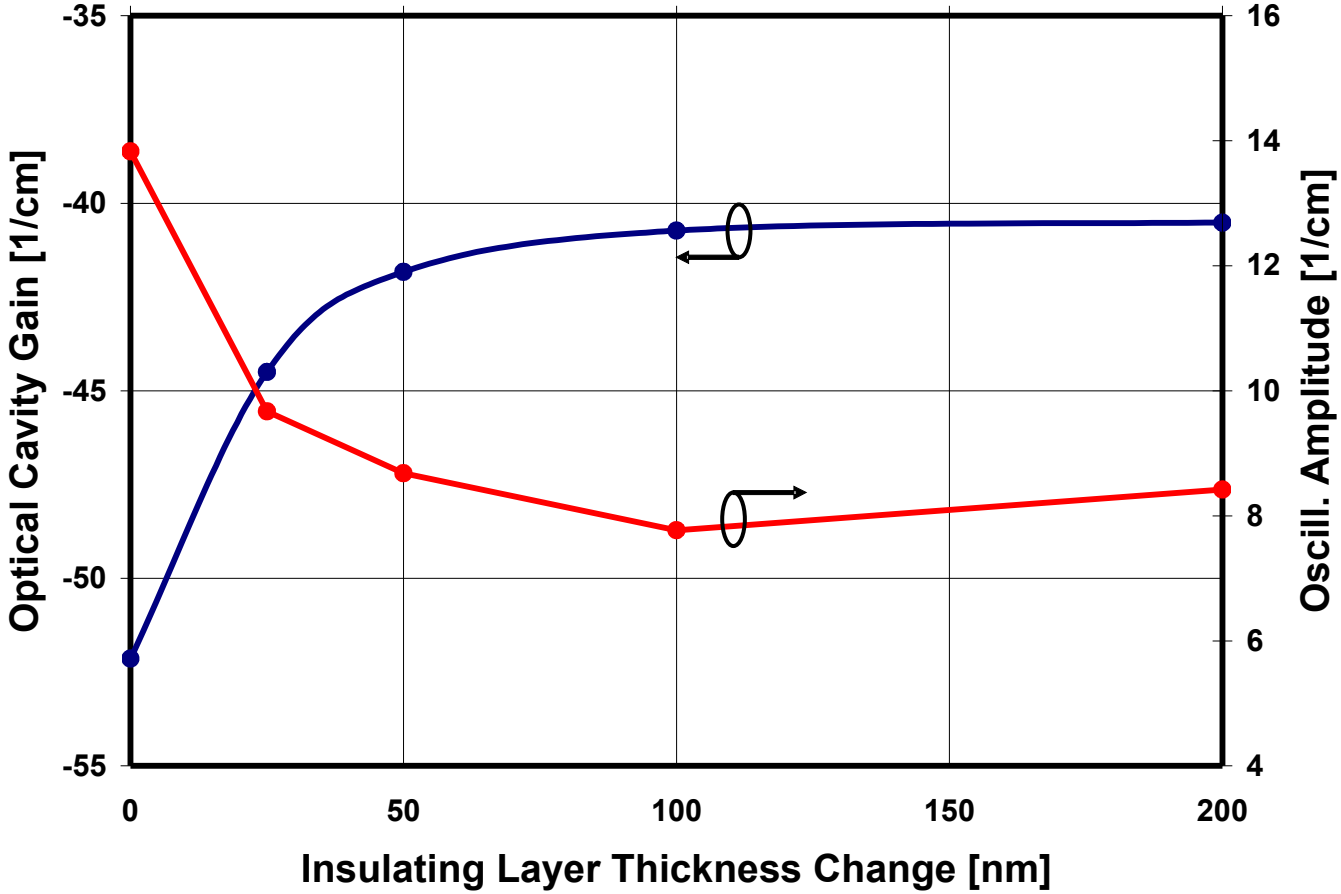
Variation of the p-doped Regions Loss

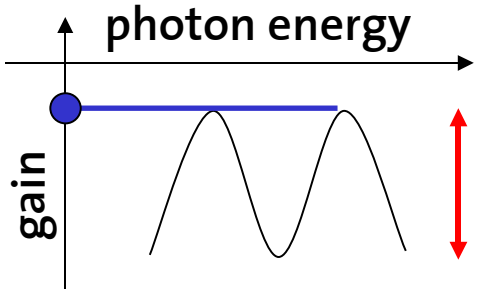


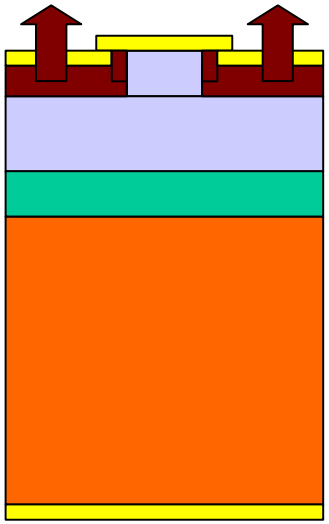




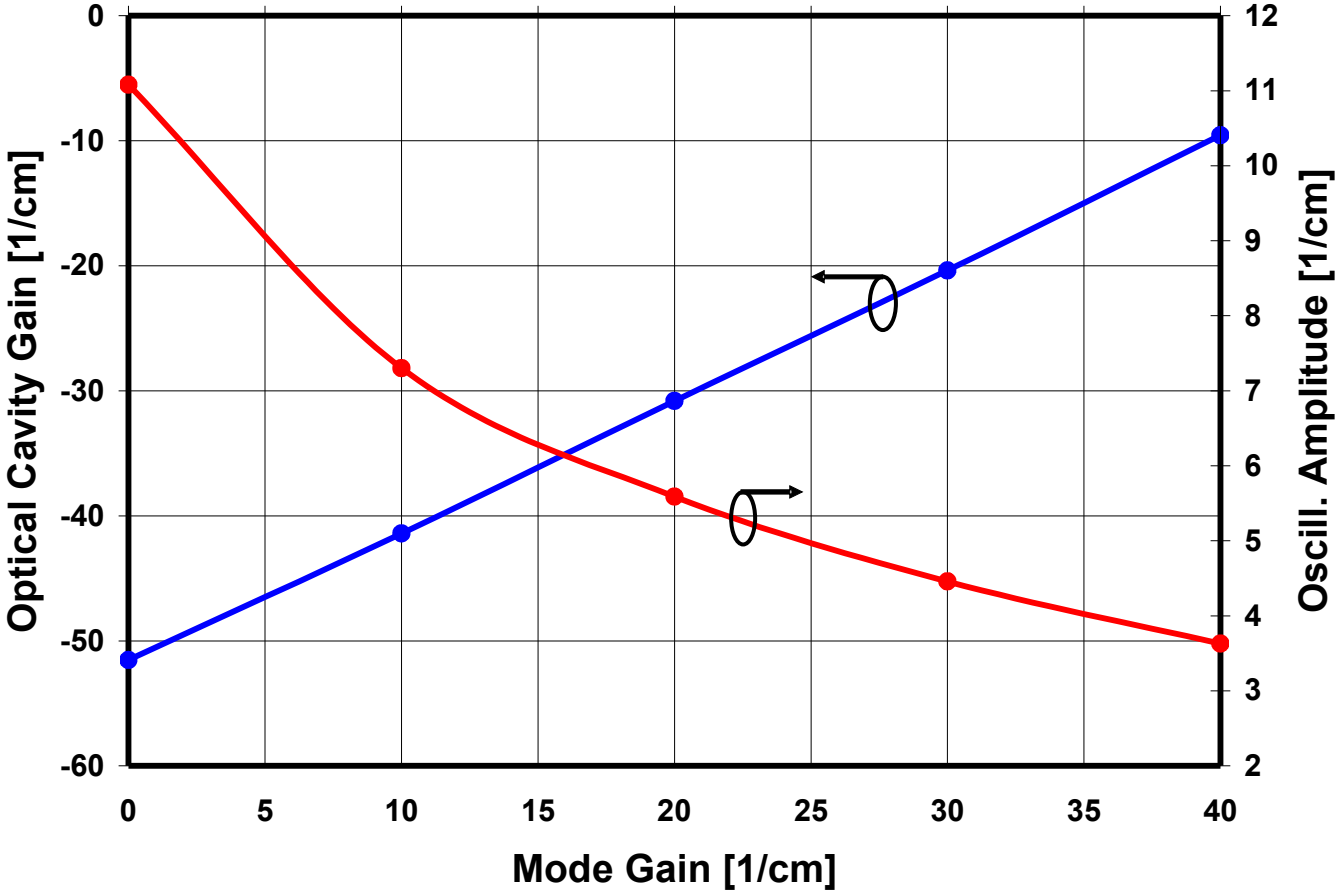
Variation of Insulating Layer Thickness

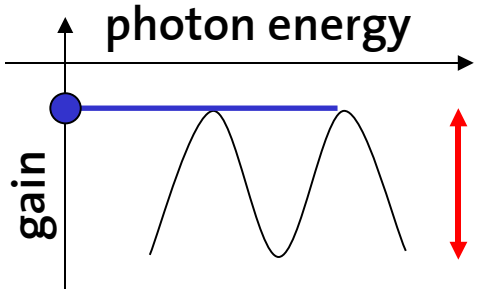


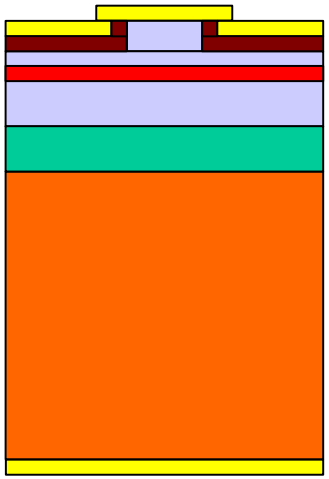




Variation of Material Gain







Conclusions

1. Oscillations in gain spectra:
   - source is substrate mode
   - strong loss contribution by bottom gold at resonance

2. TCAD analysis of cavity loss:
   - main loss sources are p-cladding & top gold

Design Recommendations

1. To decrease oscillation amplitude:
   - increase buffer layer thickness
   - increase substrate loss

2. To decrease total cavity loss:
   - decrease p-dopant loss
   - increase insulating layer thickness

Thank You!

Acknowledgments:

OSRAM

SYNOPSYS

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