

Analysis of InGaN/GaN VCSELs

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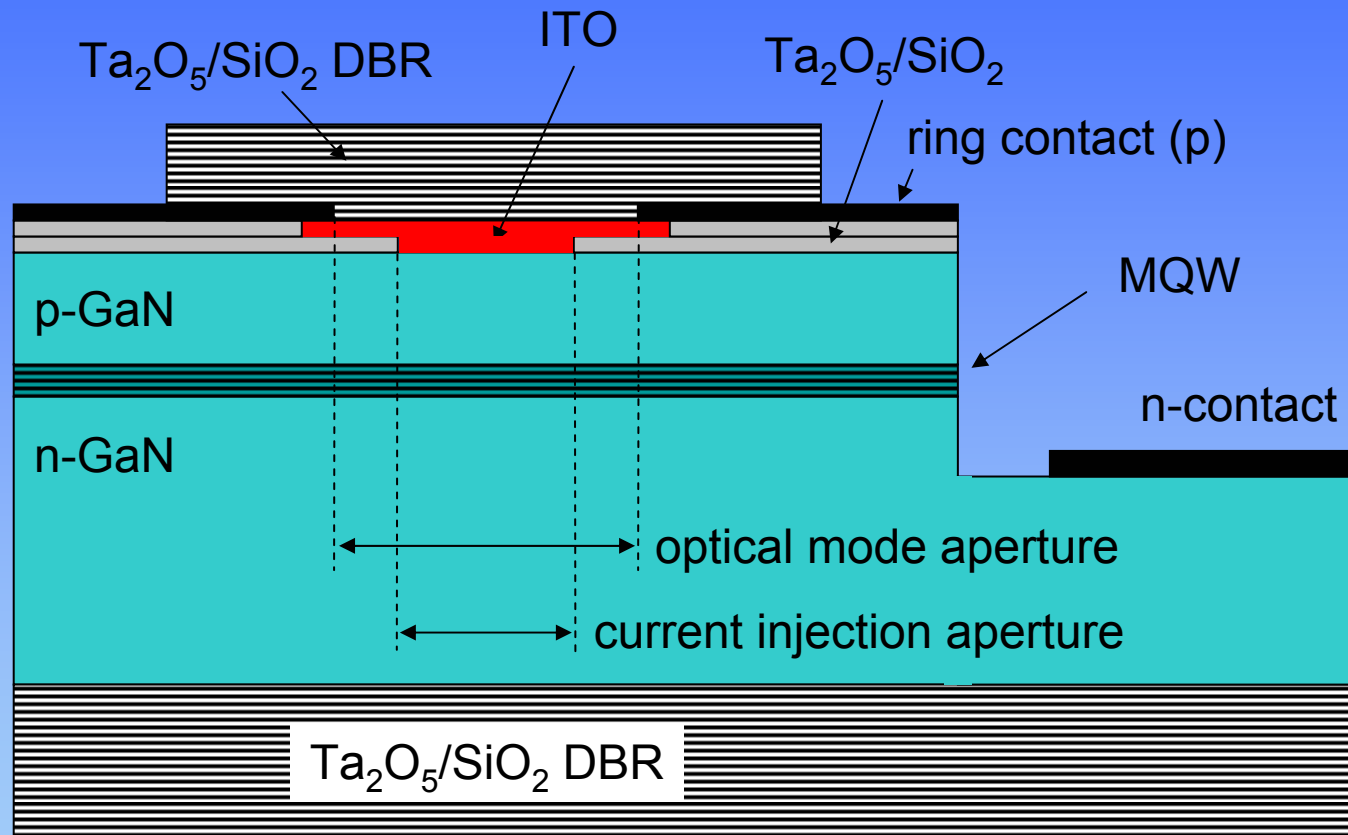
Outline

1. Introduction
2. Device Structure
3. Model and Parameters
4. Simulation Results
 - A. Current Confinement Effects
 - B. Polarization Effects
 - C. Self-Heating Effects
5. Summary

Introduction

- great success of GaAs-based VCSELs
- great success of GaN-based Fabry-Perot lasers
- no injection-type GaN-based VCSEL thus far
- discussed reasons:
 - high optical loss due to insufficient DBR mirrors
 - high electrical resistance due to low p-conductivity
 - problems with forming lateral apertures
 - problems with precise thinning of GaN

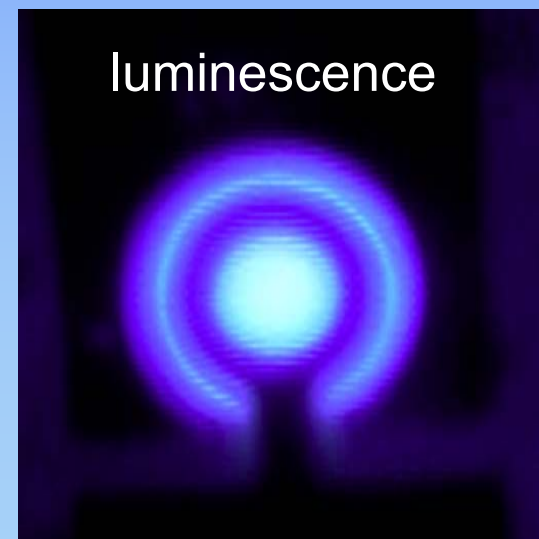
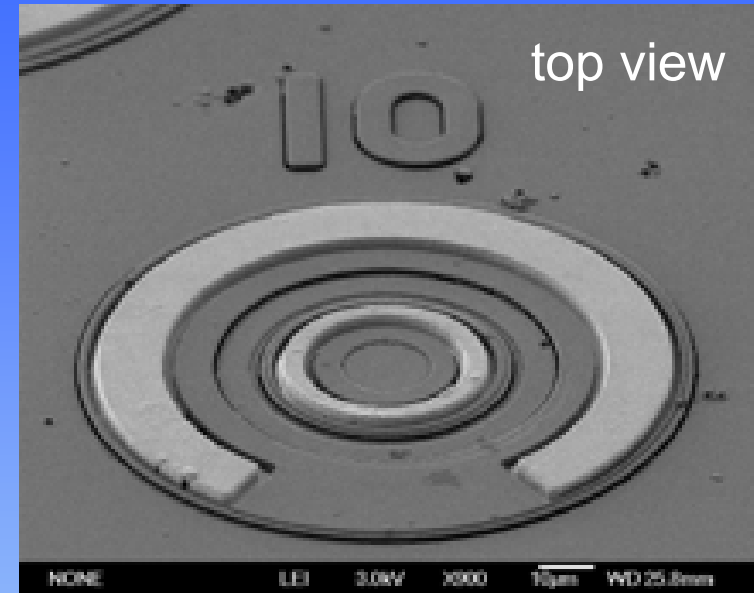
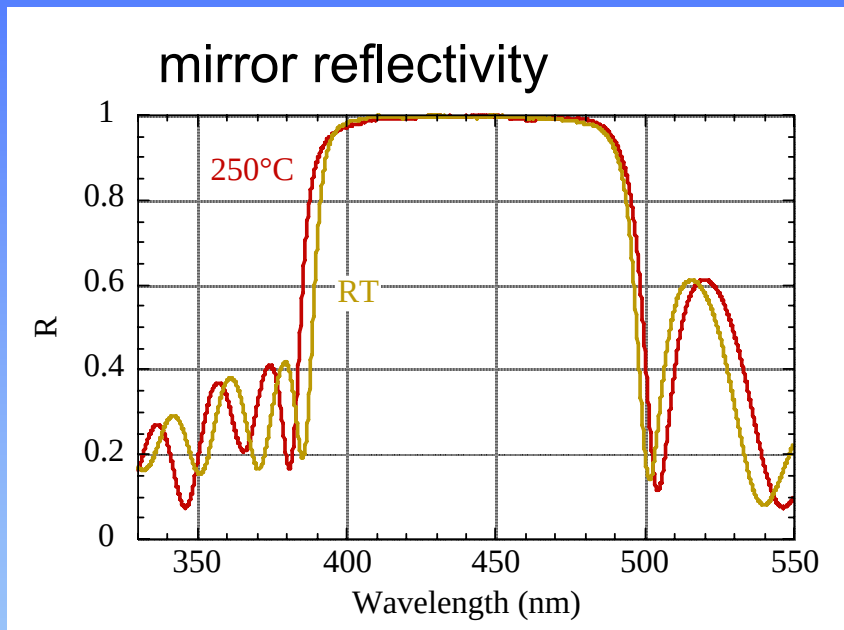
VCSEL Device Structure



[Tal Margalith, Ph.D. Thesis, UCSB 2002]

Experimental Results

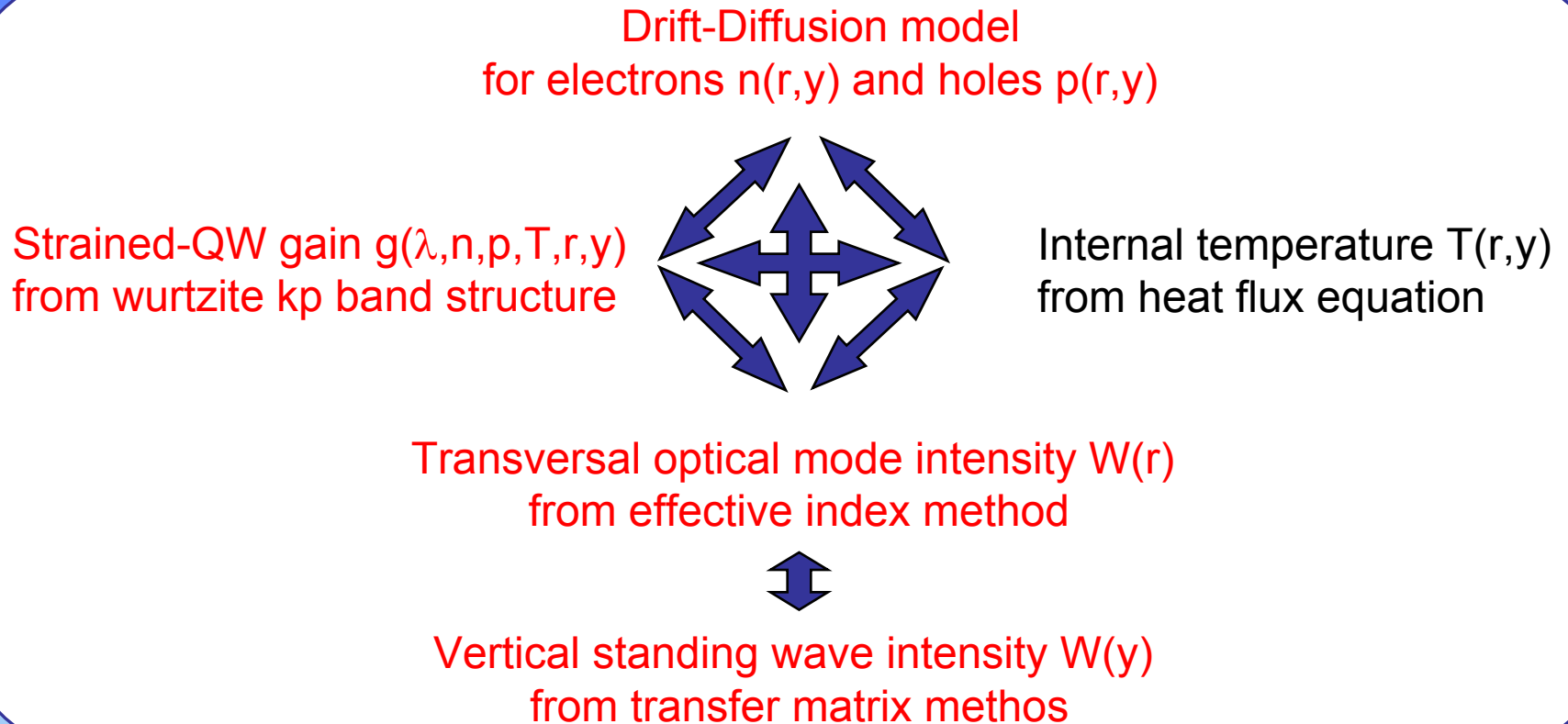
[Tal Margalith, Ph.D. Thesis, UCSB 2002]



no lasing – why ?

PICS3D Software

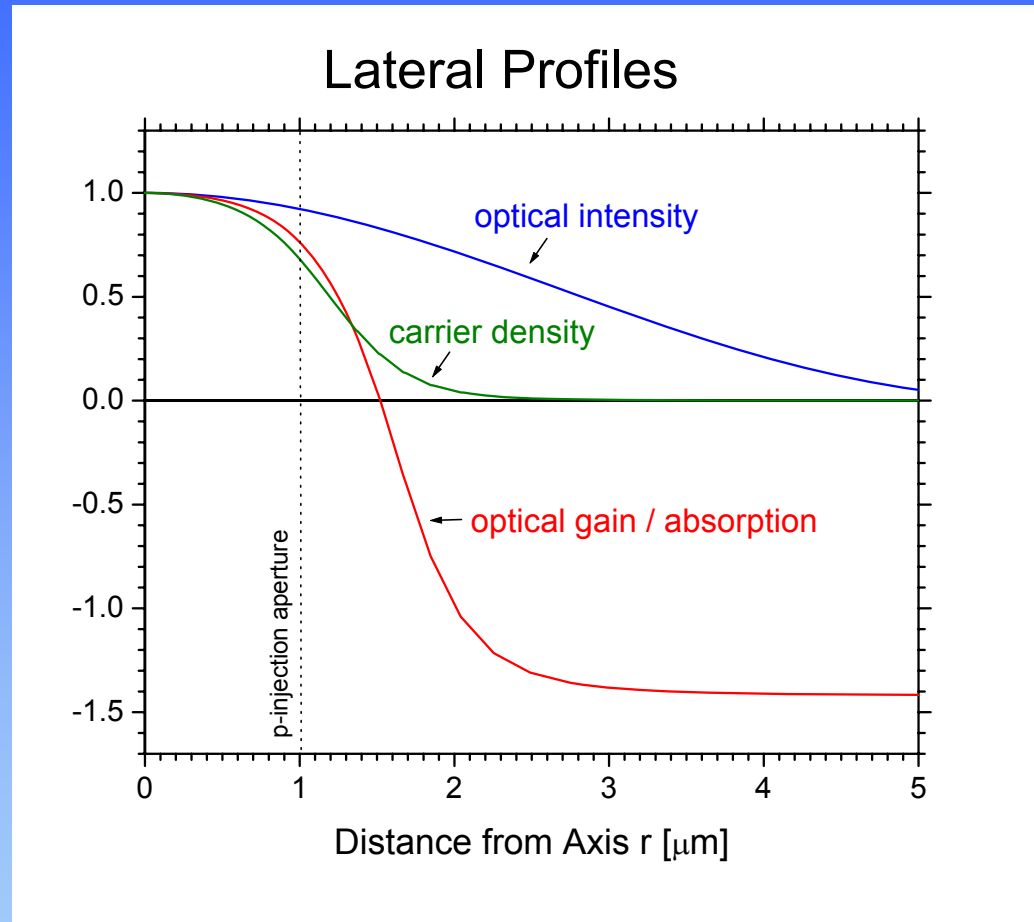
two-dimensional (r,y) physics-based model



VCSEL Results A

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Problem with Small Current Aperture

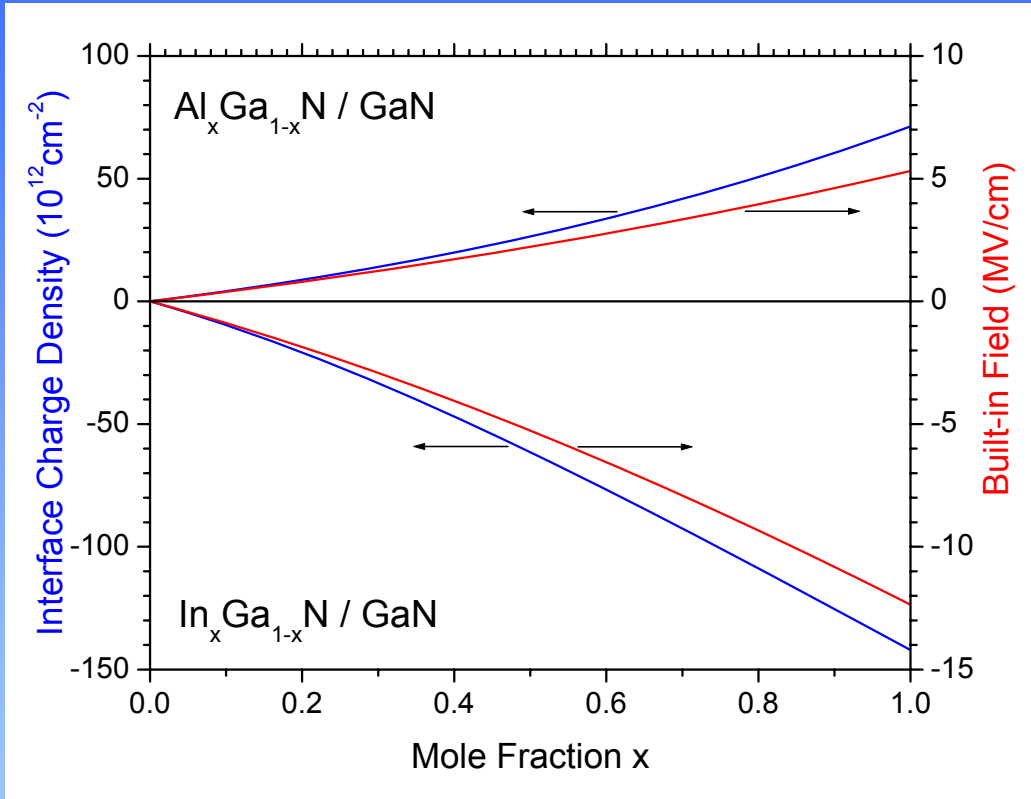


no lasing with current aperture $\ll$ optical aperture

VCSEL Results B

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Polarization Field



$$P_{sp} + 2 \frac{a_s - a_0}{a_0} \left(e_{31} - \frac{C_{13}}{C_{33}} e_{33} \right)$$

In_{0.1}Ga_{0.9}N well:

built-in field = 1.8 MV/cm

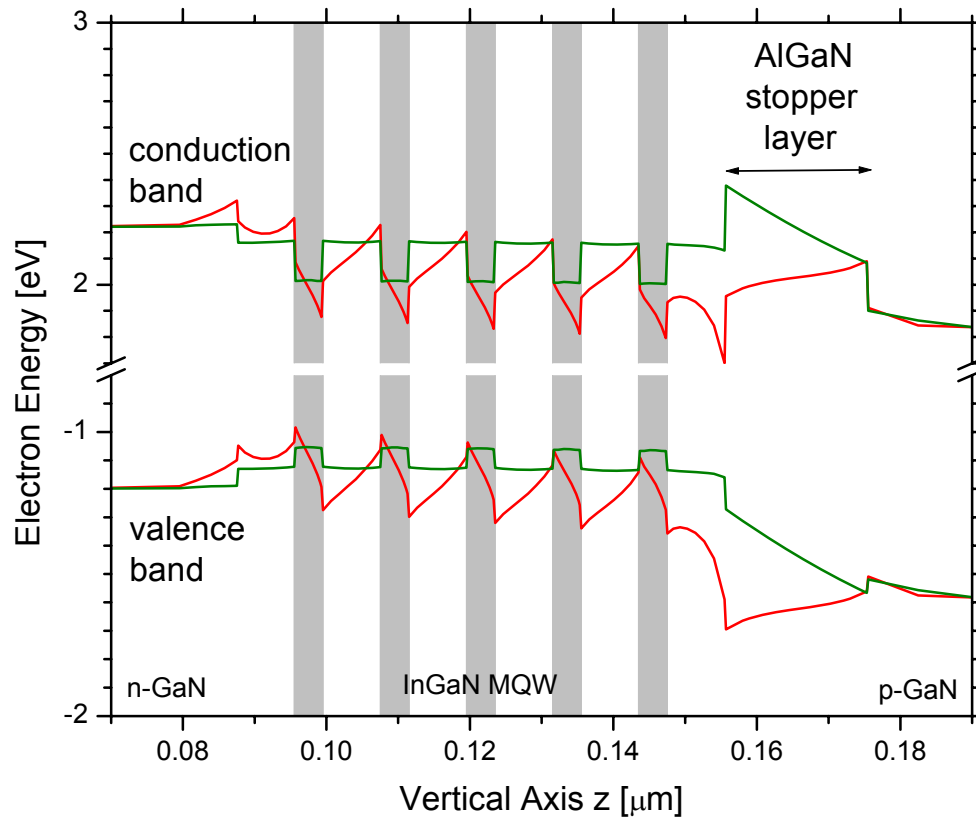
charges = $9.6 \cdot 10^{12} \text{ cm}^{-2}$

over 4nm: $2.4 \cdot 10^{19} \text{ cm}^{-3}$

Parameter	Symbol	Unit	InN	GaN	AlN
Spontaneous polarization	P_{sp}	Cm^{-2}	-0.042	-0.034	-0.09
piezoelectric constant (z)	e_{33}	Cm^{-2}	0.810	0.670	1.50
piezoelectric constant (x,y)	e_{31}	Cm^{-2}	-0.410	-0.340	-0.53

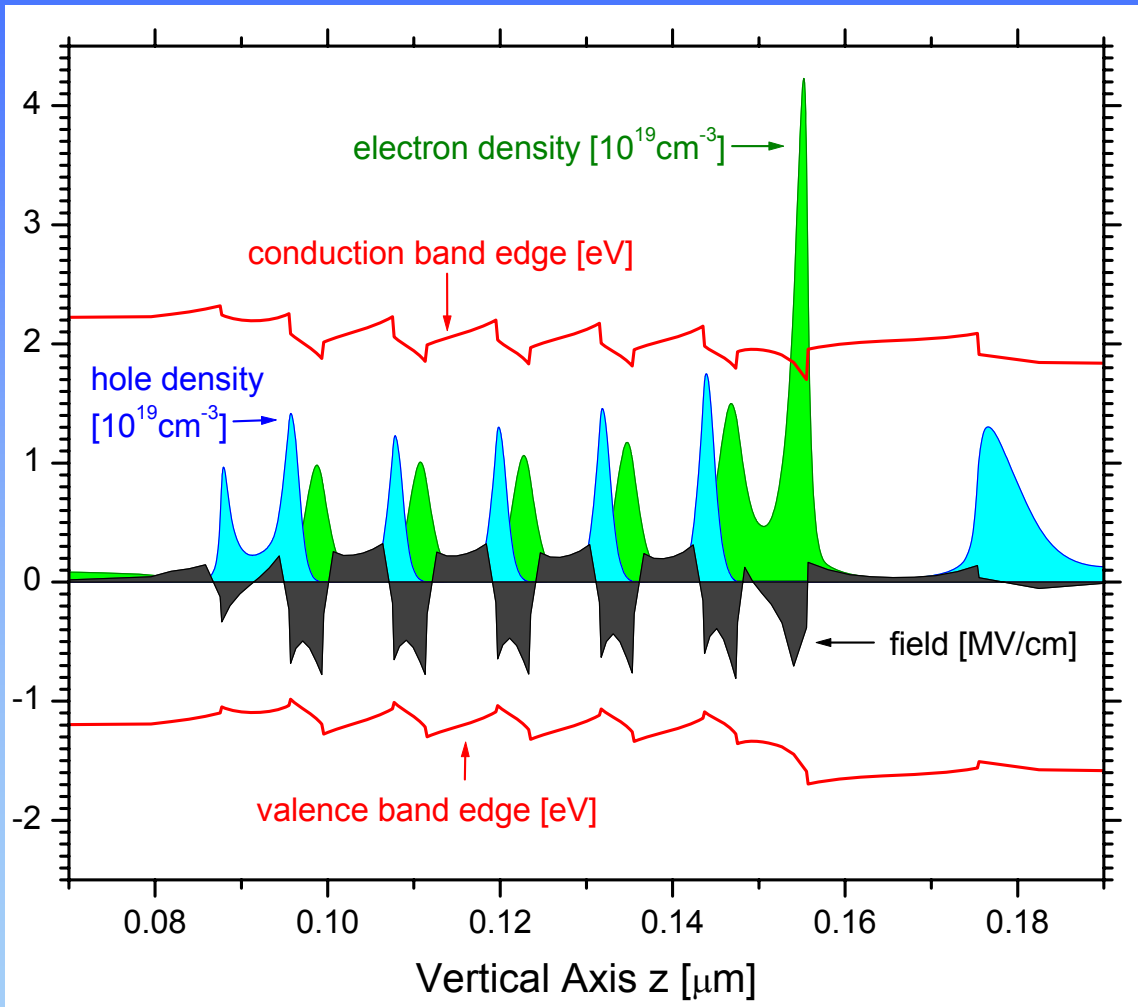
[Fiorentini et al., APL 80, 1204 (2002)]

MQW Energy Band Diagram



no polarization
vs.
100% polarization

MQW Field & Carriers



QW built-in field
of 1.8 MV/cm
is only partly screened
at $j = 10 \text{ kA/cm}^2$!

strong effect on electron
stopper layer
(depends on doping)

VCSEL Threshold Current

partial compensation
of built-in polarization
by interface charges

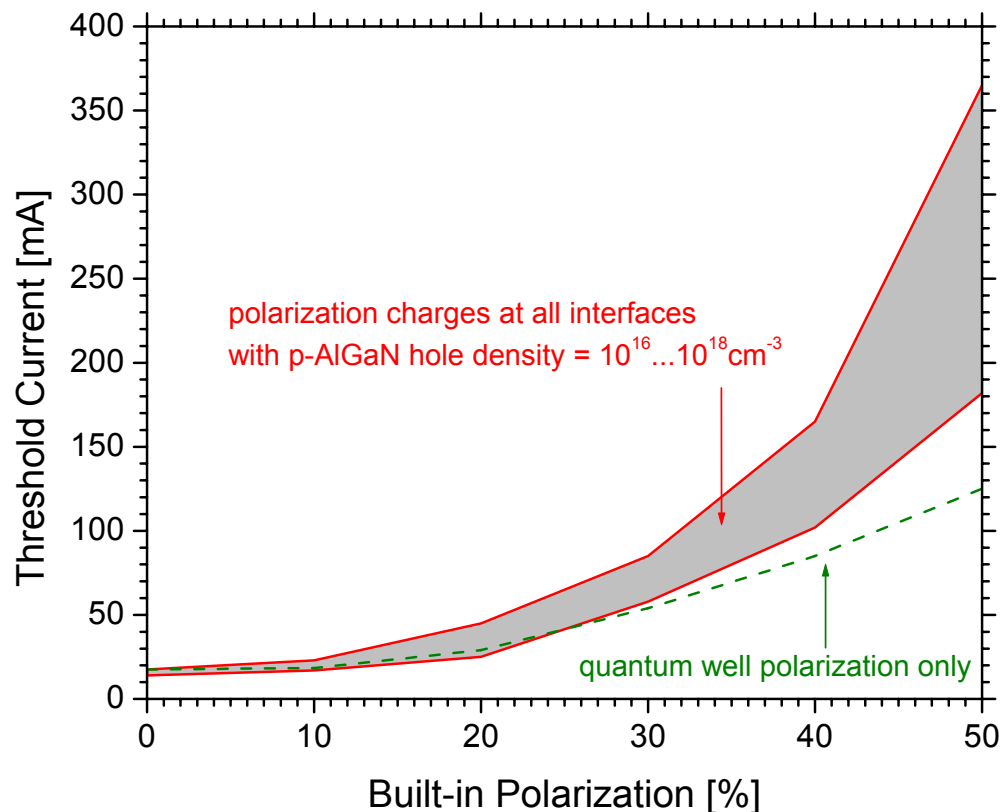
Threshold rises due to
1. n-p separation in QW
2. electron leakage

strong AlGaIn doping effect

$$\alpha_i = 20/\text{cm}$$

$$\tau_{\text{qw}} = 0.5\text{ns}$$

$$T = 300\text{K}$$

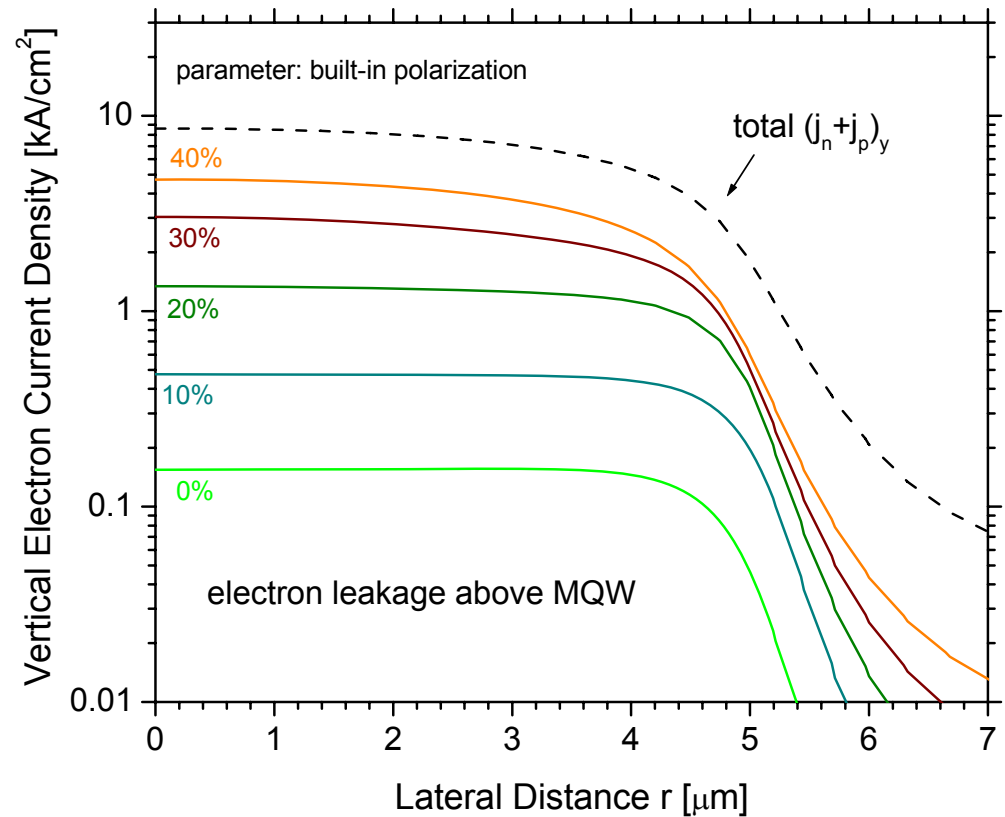


100% = Fiorentini model

Electron Leakage

current density profile
for constant current
at different
built-in polarization

worst case:
 $p=10^{16}\text{cm}^{-3}$ in AlGaIn

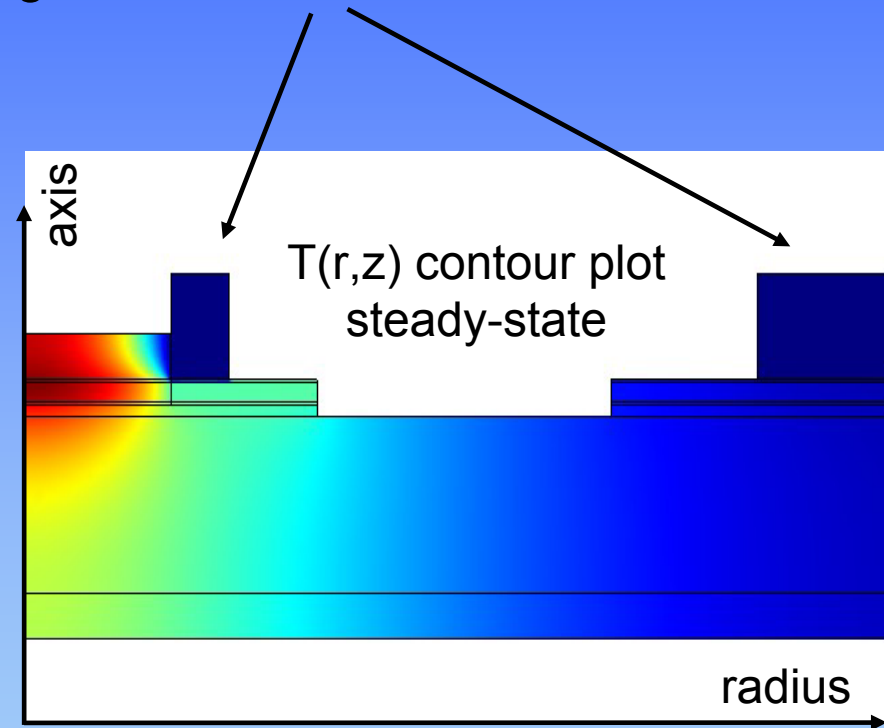
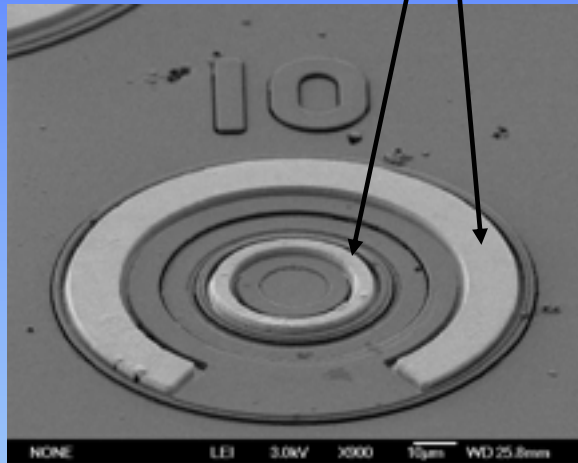


VCSEL Results C

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Thermal Simulation using FEMLAB

- top-down mounting
- heat flow to heat sink through metal contacts



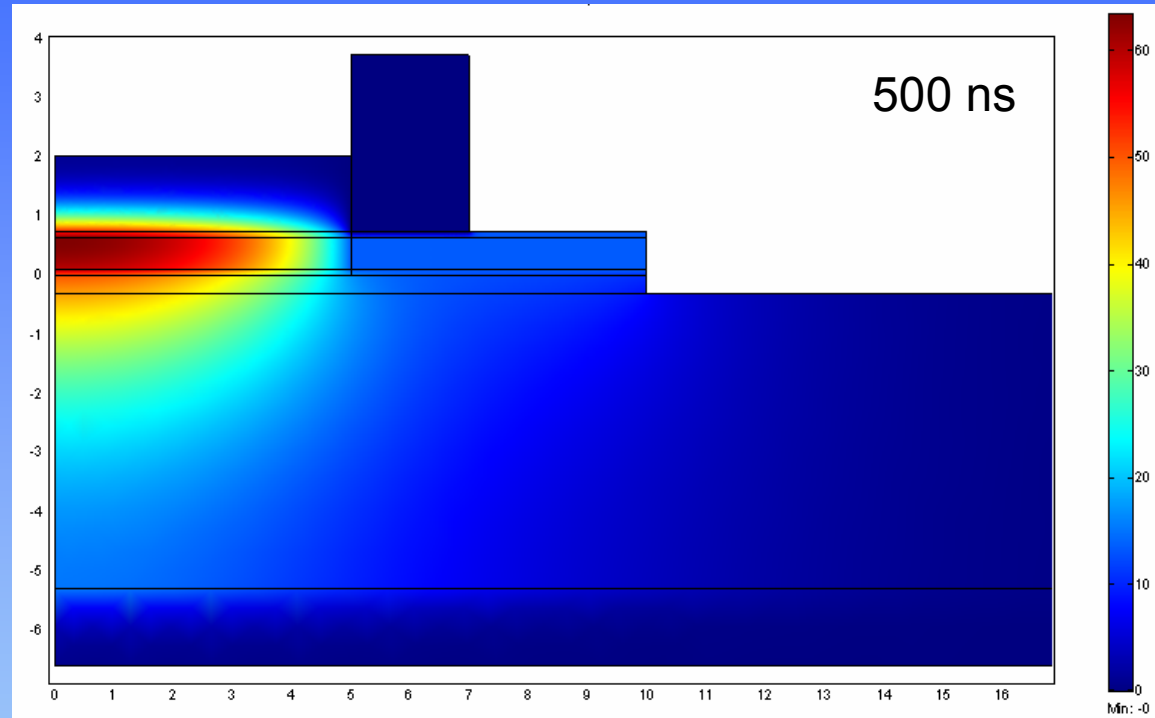
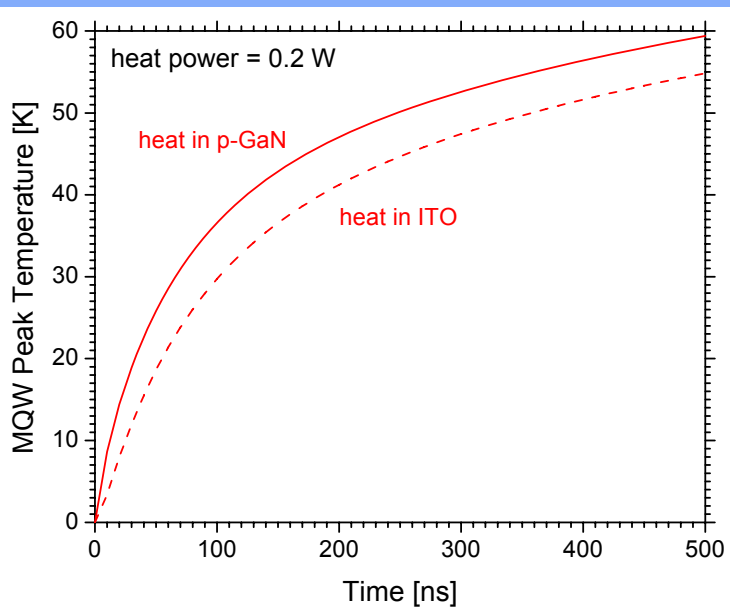
$I=10\text{mA}$, $V=20\text{V}$, $R_{\text{th}}= 550 \text{ K/W}$, $\Delta T=110\text{K}$

in-plane GaN-laser: $I=10\text{mA}$, $V=3\text{V}$, $R_{\text{th}}= 75 \text{ K/W}$, $\Delta T=2\text{K}$

Time-Dependent Temperature Rise

500 ns pulse
200 mW

$$\Delta T_{\max} = 63 \text{ K}$$
$$\Delta T_{\text{mqw}} = 59 \text{ K}$$



60% of steady-state temperature
reached after 500 ns pulse !

Summary

identified internal physical processes that prevent our GaN-VCSELs from lasing:

1. current confinement narrower than optical mode
2. strong electron leakage due to built-in polarization
3. strong self-heating due to low p-conductivity