# Quantitative modeling of resonant PL in InGaN SQW LEDs

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# Outline

- Motivation: Overview and status of LED modeling tasks
- Self-consistent model for InGaN-SQW LED
- Comparison to reverse bias PL-experiment
- What does the model predict?
- Conclusion

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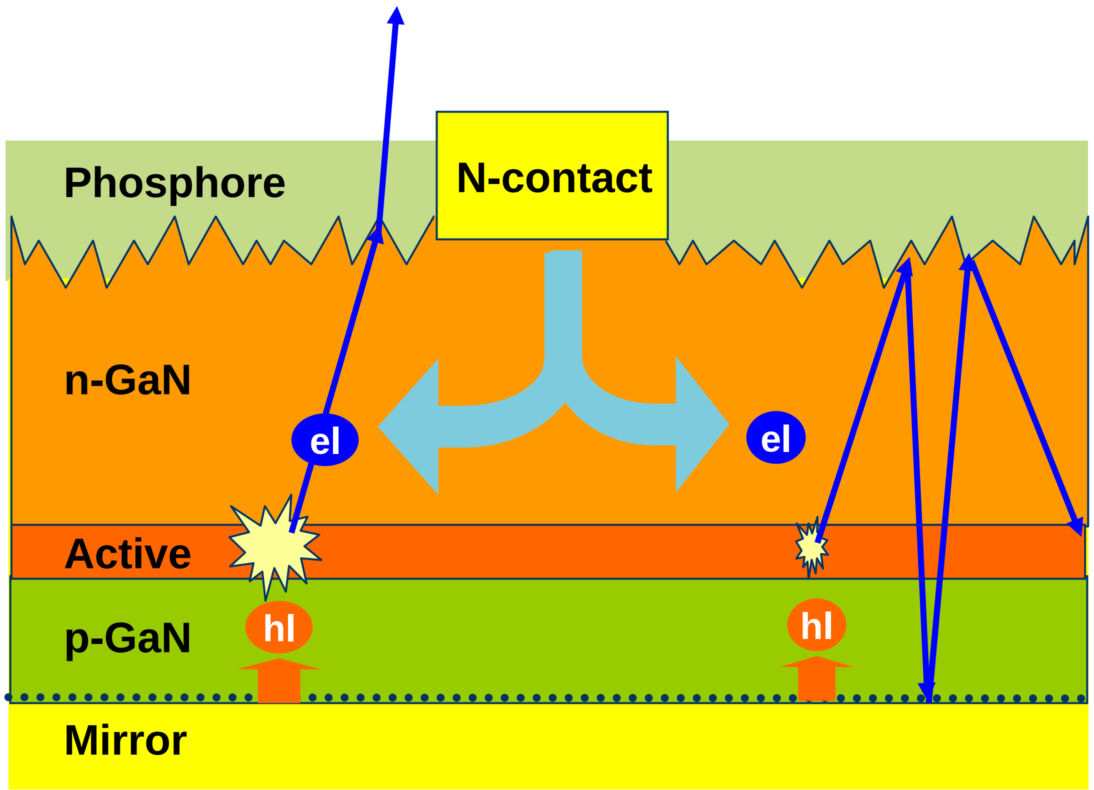
# Our light source: The ThinGaN LED



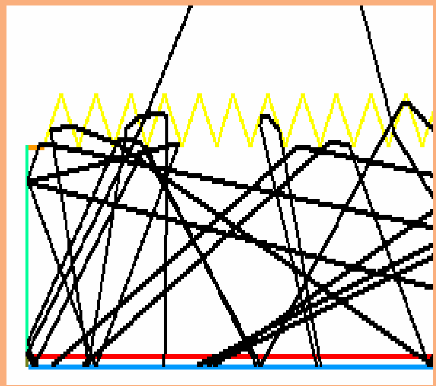

**Main efficiency issues:**

- Series resistance (Rs)
- Light generation (IQE)
- Light extraction (EQE)
- Conversion (Lm/W)
- Thermal resistance (RTh)

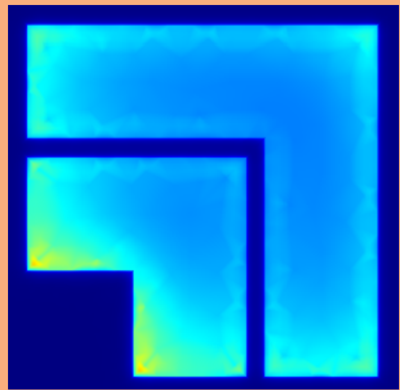
**Goal of modeling: Quantitative description and optimization of entire system**

# Overview modeling tasks for InGaN LEDs: <u>Chip properties</u>

**Light extraction**



**Electrical properties**



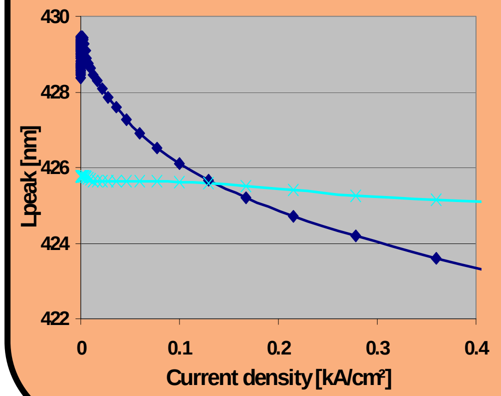
**Thermal properties**

**Integrated model for chip optimization**

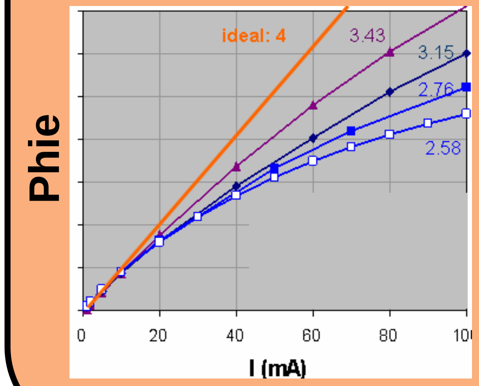
**Status: Quantitative and predictive**

# Overview modeling tasks for InGaN LEDs: Internal properties

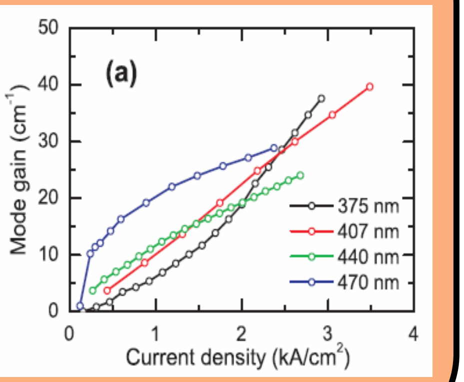
## Wavelength shift




## Efficiency




## Optical gain

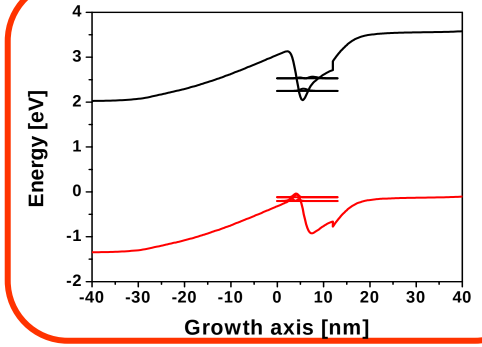



**K. Kojima,** Opt. Express **15**, 7730 (2007)

**Status:** not quantitative, predictive?

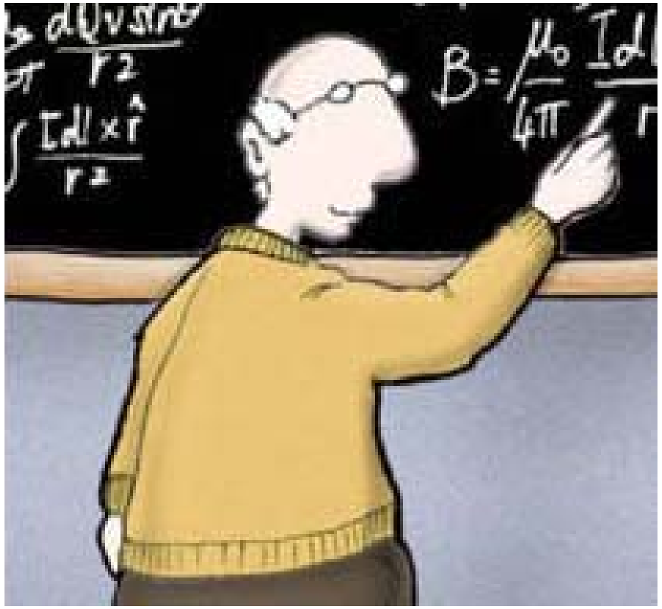
**Goal:** quantitative and predictive!

**Start:** Quantitative description of emission & transport



# Proposed Approach

**Theory**



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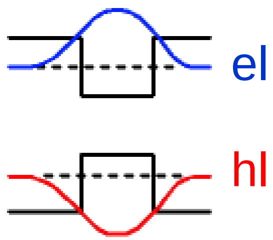
**Experiment**

**Simple but predictive model**

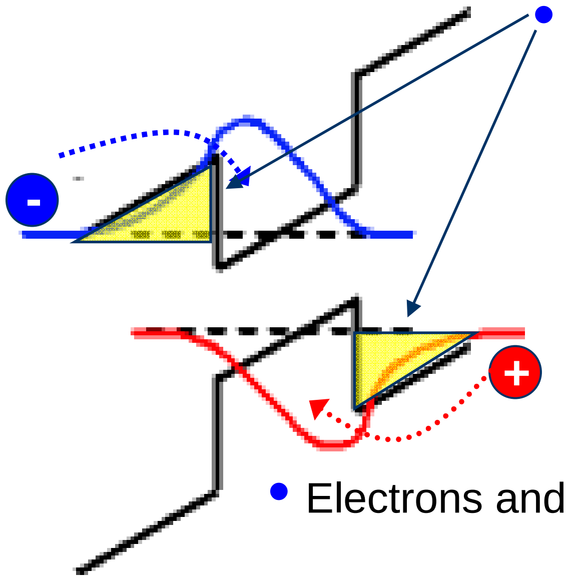
# Introduction: Quantum well in piezoelectric materials

**No piezo-fields:**
(InGaAlP, AlGaAs)




- Good overlap of electrons and holes
- No extra barriers

**With piezo-fields:**
(InGaN, AlGaN along [0001] axis)




- Injection barrier due to Piezoelectric charges
- Electrons and holes **separated**:

**What are the consequences of the piezoelectric fields ?**



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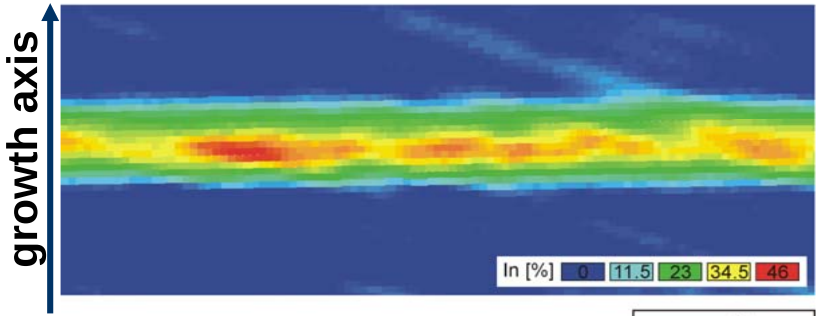
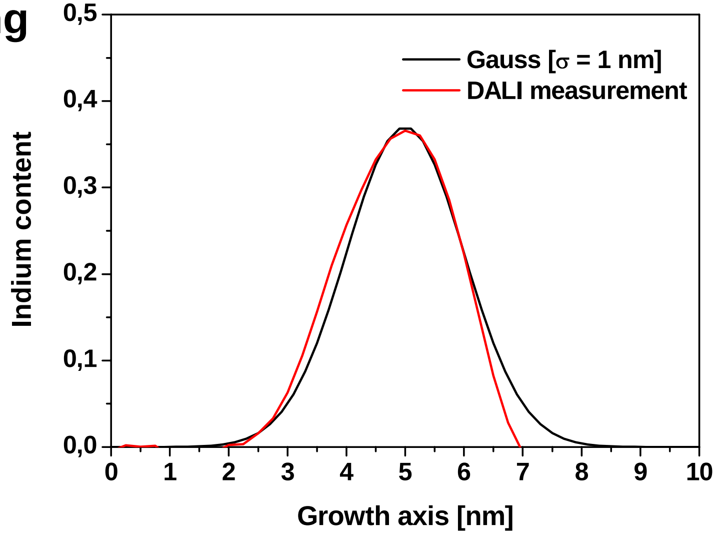
# QW-alloy profile obtained from DALI-measurement




K. Engl, University of Regensburg

Lateral averaging




• **Experiment: Gaussian alloy profile**



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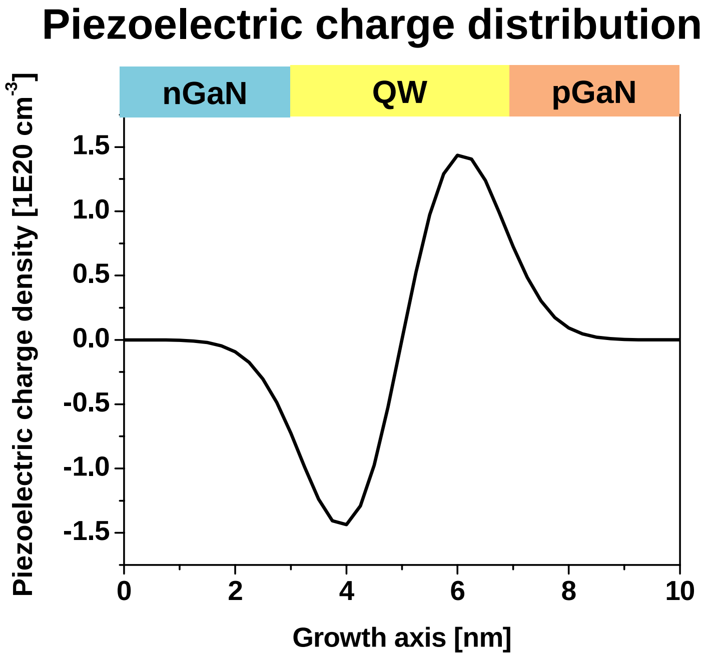
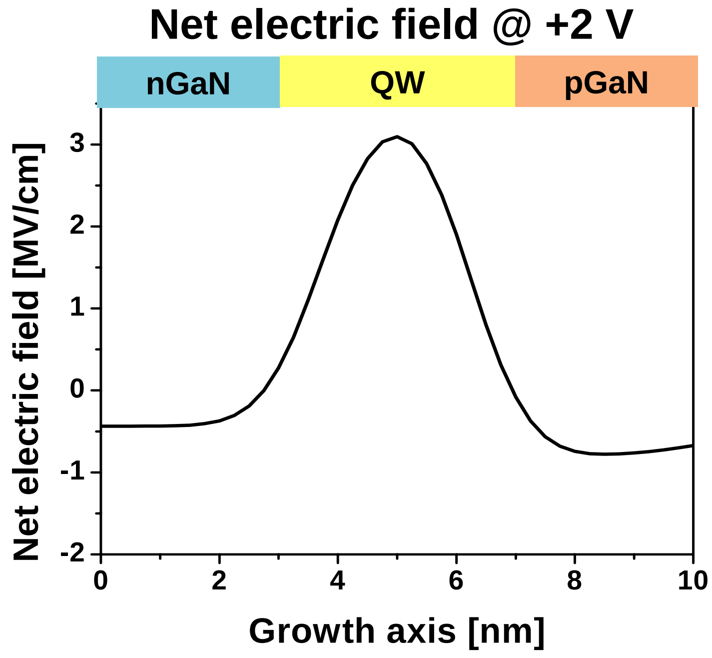
# Piezoelectric charges



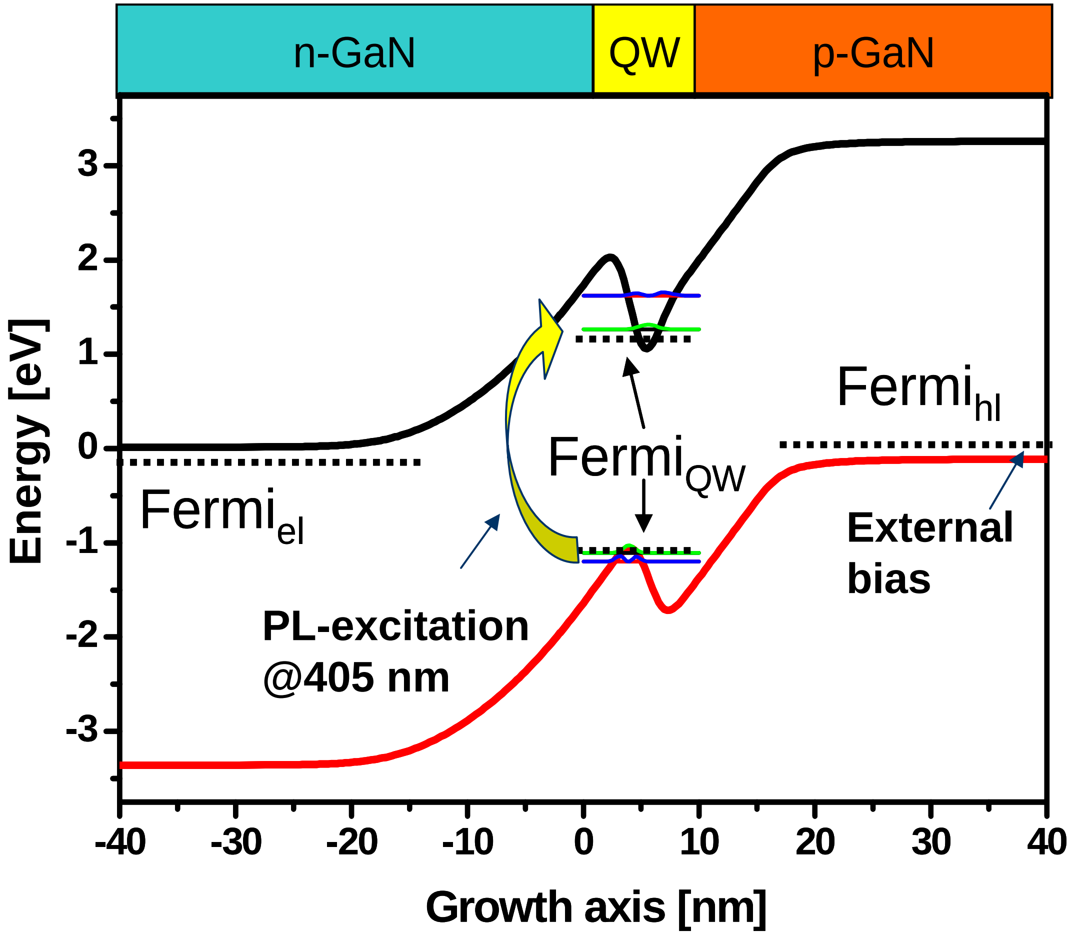




- **Gaussian alloy profile → continous distribution of the piezoelectric charges**
- **Maximum electric field inside QW ~ 3 [MV/cm]**

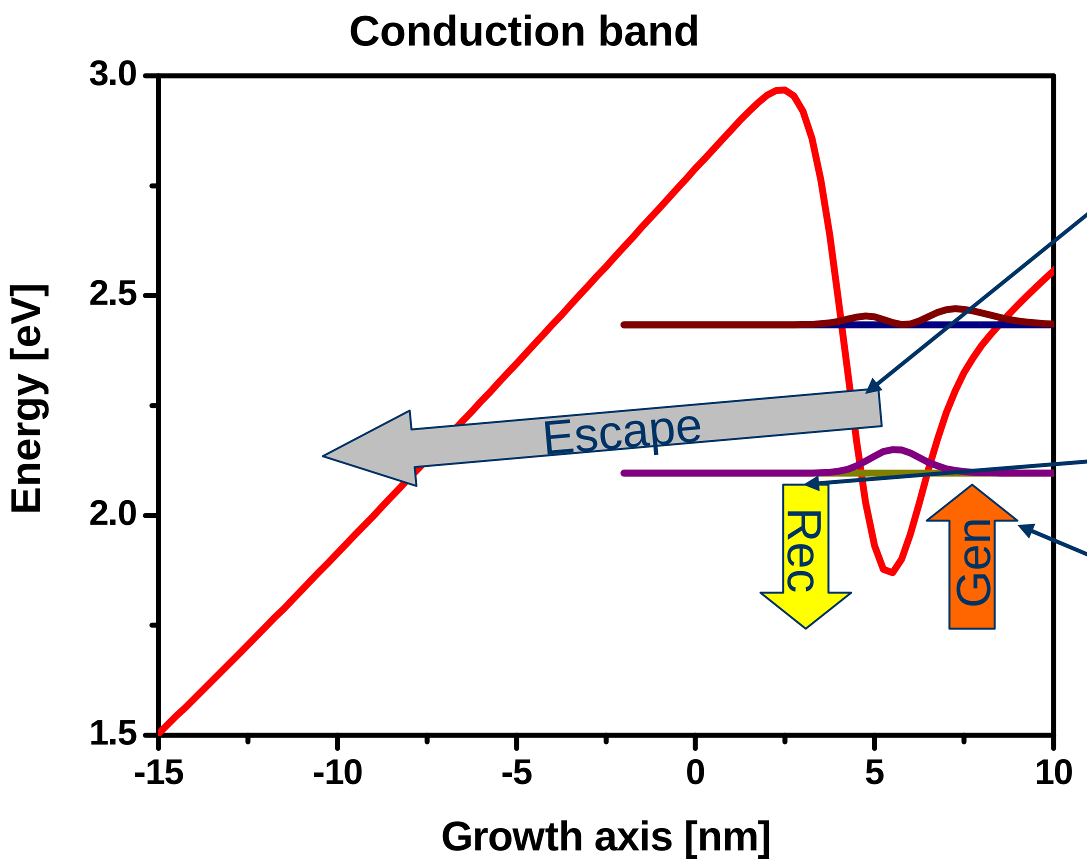
# Schematic picture of bandstructure in PL

**Self-consistency**
**→Solve:**

**- Schrödinger**
**- Poisson**
**- Current**



# Relevant transport processes for resonant PL



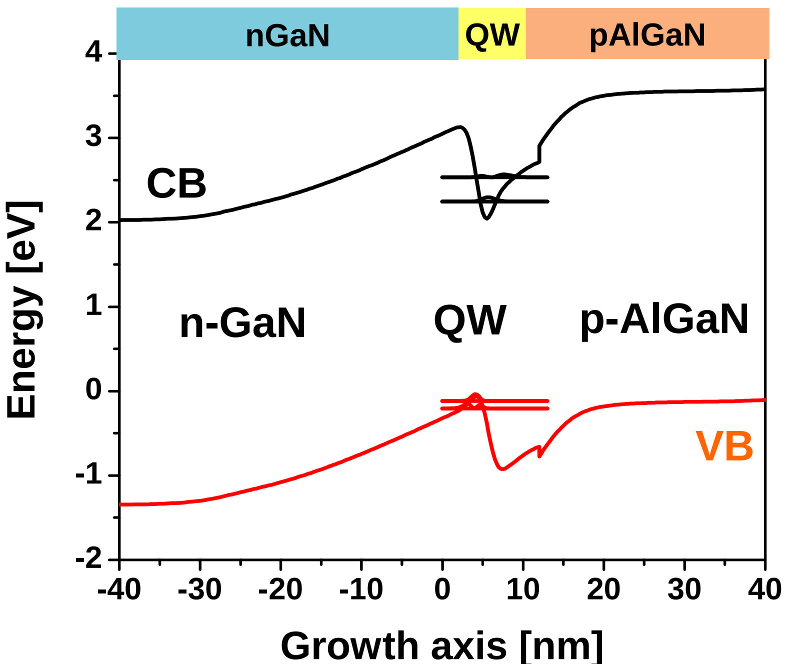

**Escape:**
Carrier escape via thermionic tunneling

**Recombination:**
Radiative recombination $\propto$ electron-hole overlap

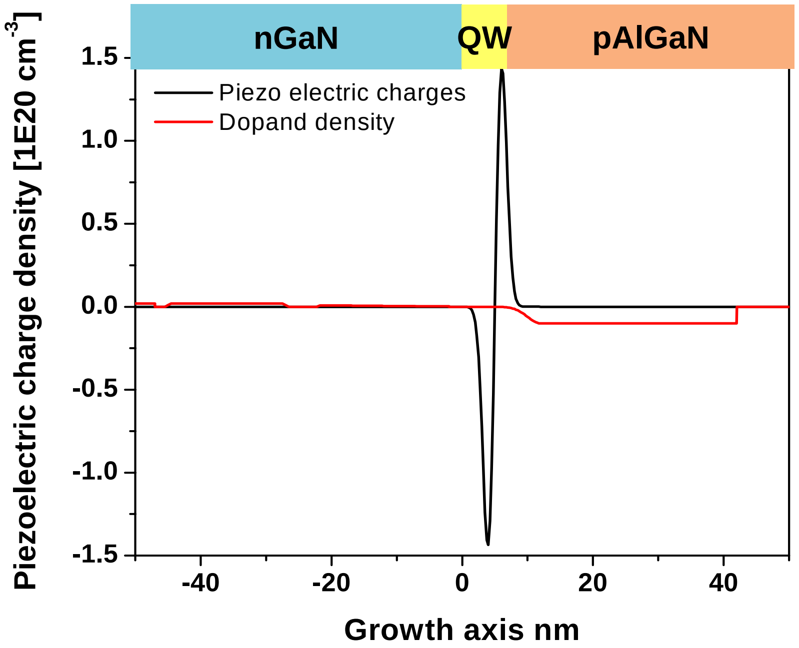
**Generation:**
Relaxation time < 100fs
→ Thermal distribution

# Application to real LED-structure

**Band structure**

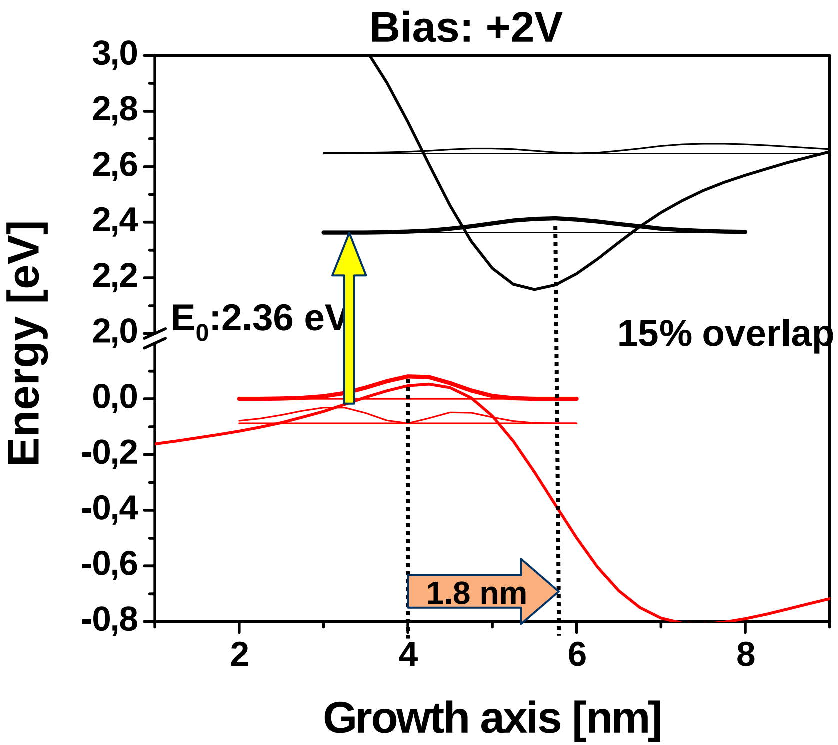


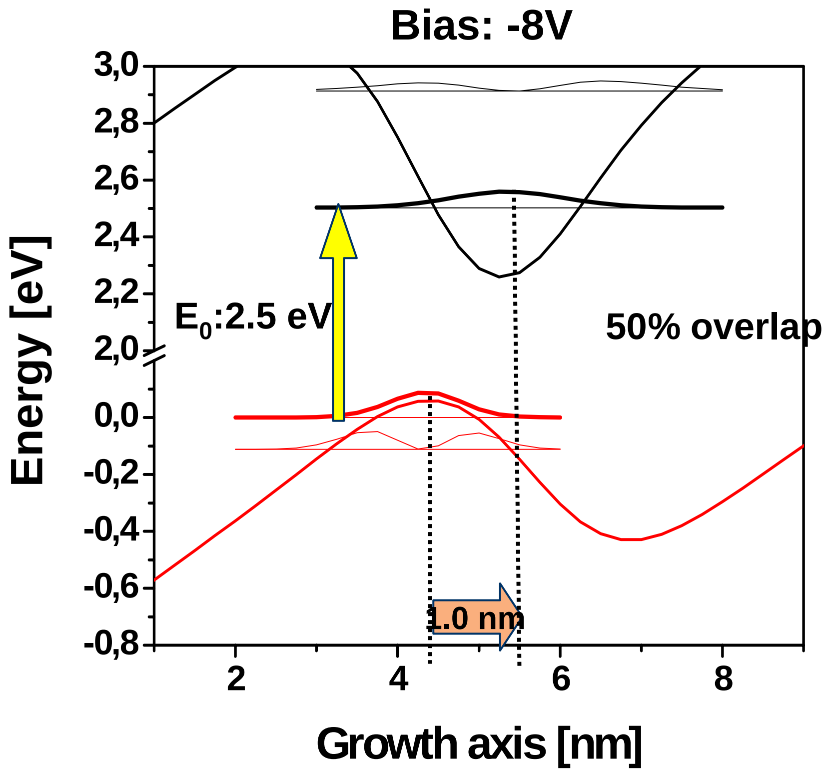

**Doping vs. piezoelectric charges**




- **Green LED: Piezoelectric charges dominant**
  **→ Complete screening of piezoelectric charges via doping not realistic.**

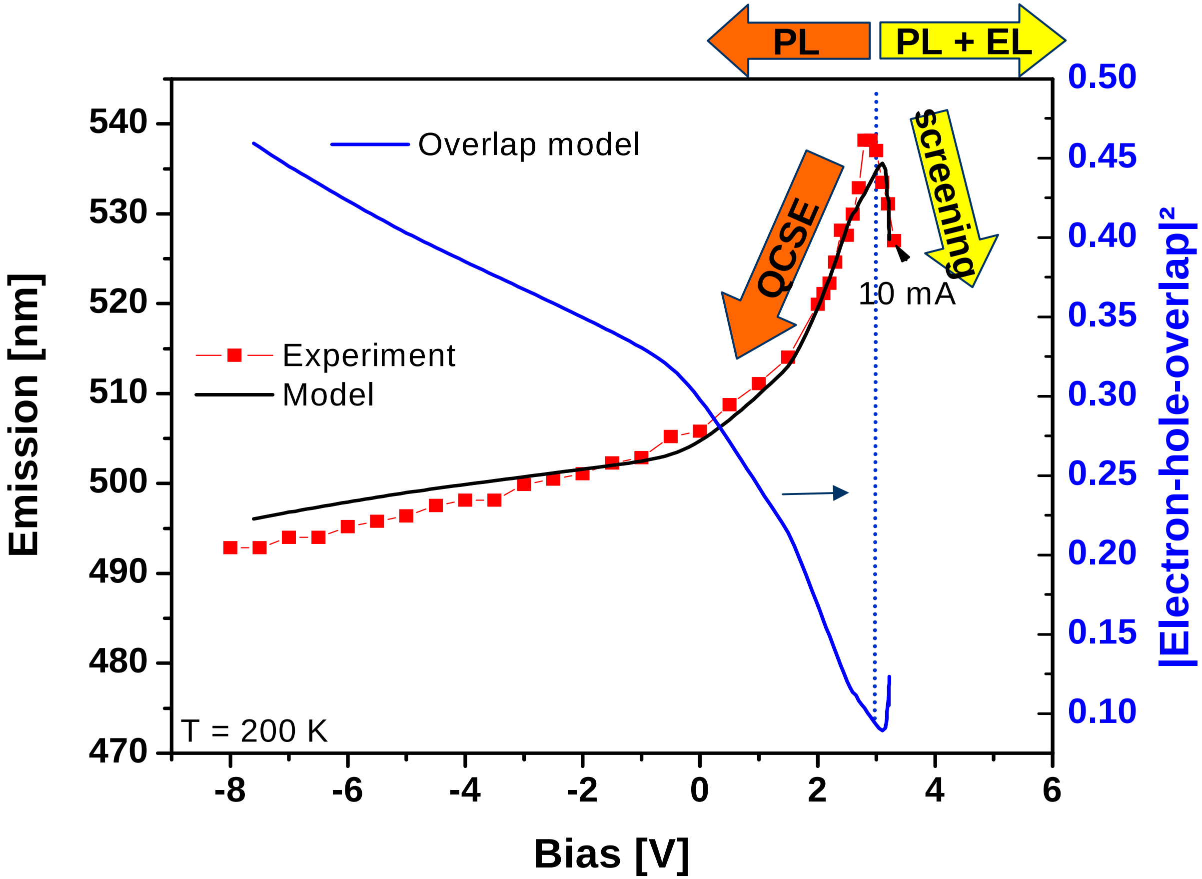
# Physics: Quantum confined Stark effect (QCSE)



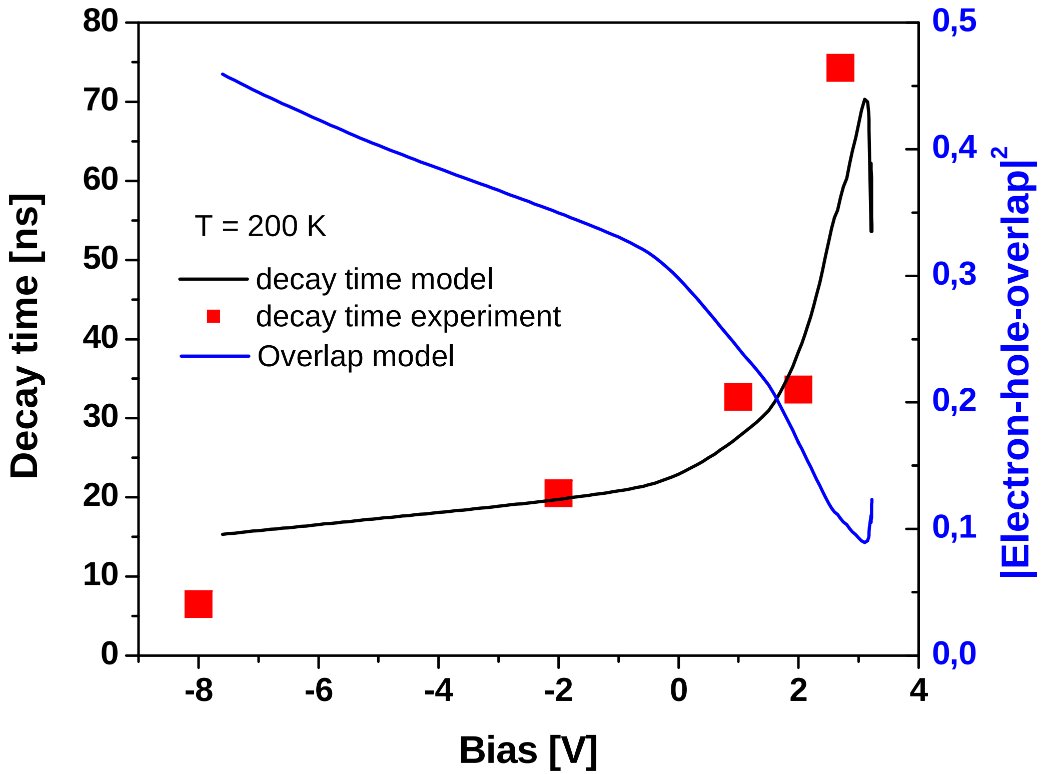

- Peak shift follows change in overlap (QCSE)

# Compare to experiment: Peak shift



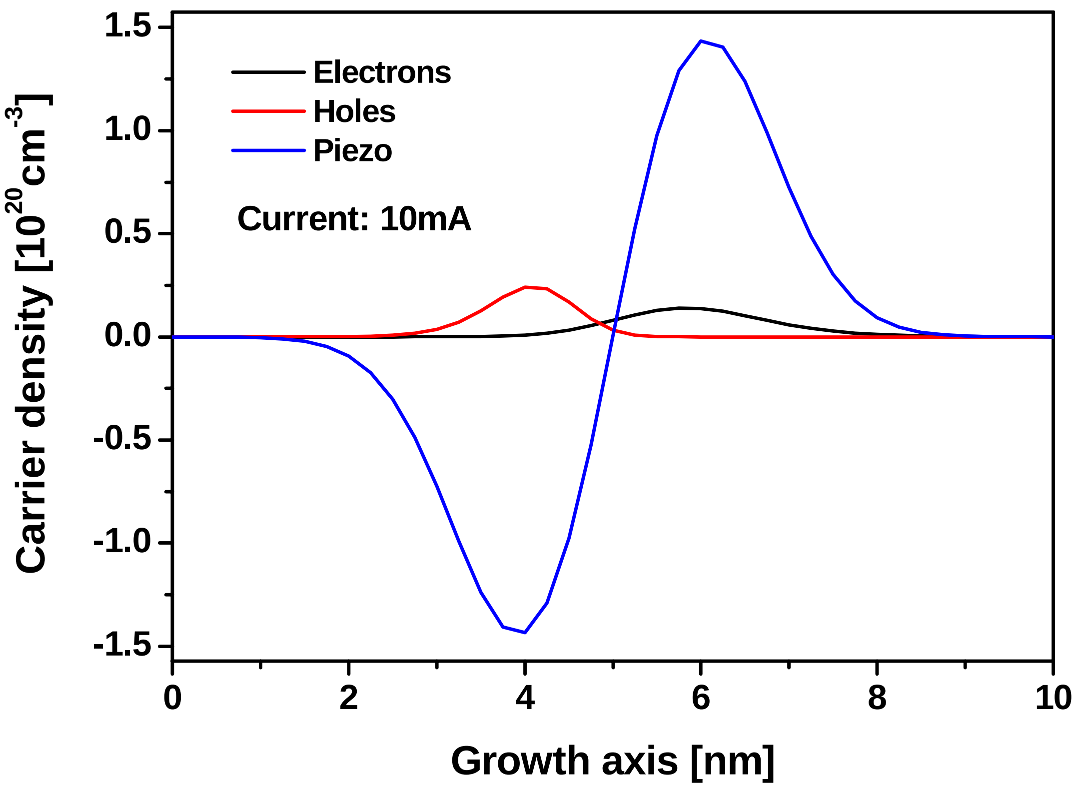

- Reverse bias (PL) → Realistic piezoelectric fields and doping-profile
- Forward bias (PL+EL) → Screening sufficient to predict blue-shift.

# Compare to experiment: Decay time




- Decay rate $\propto$ electron-hole overlap
- Strong influence of piezoelectric field

# Screening @ forward bias (10mA)




- High carrier densities (>2E19) due to slow decay rates.
- Only partial screening of piezoelectric charges



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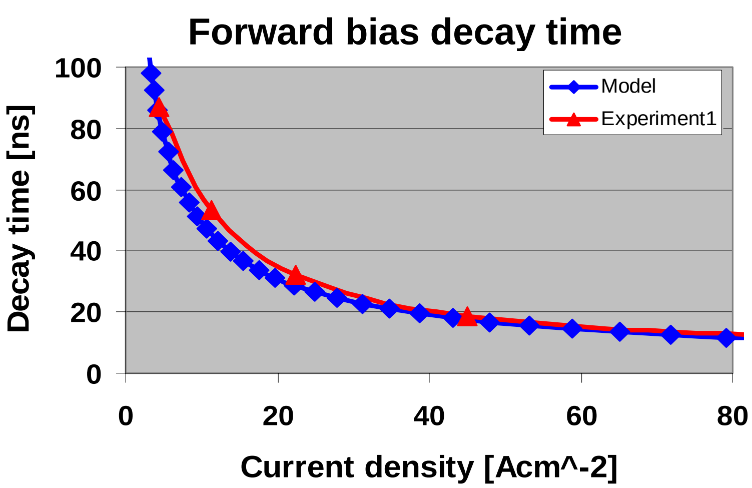
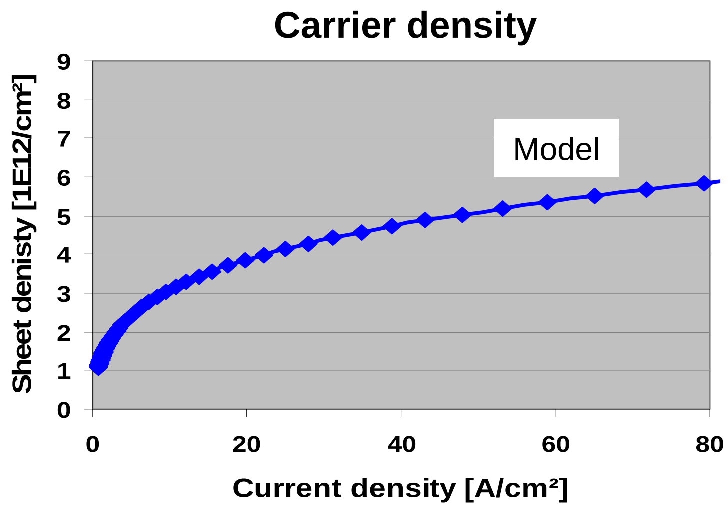
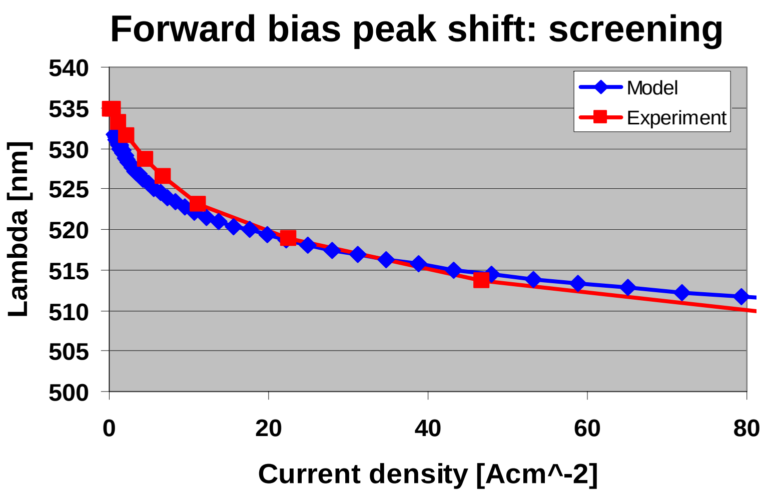
# Forward bias: Screening of piezoelectric fields



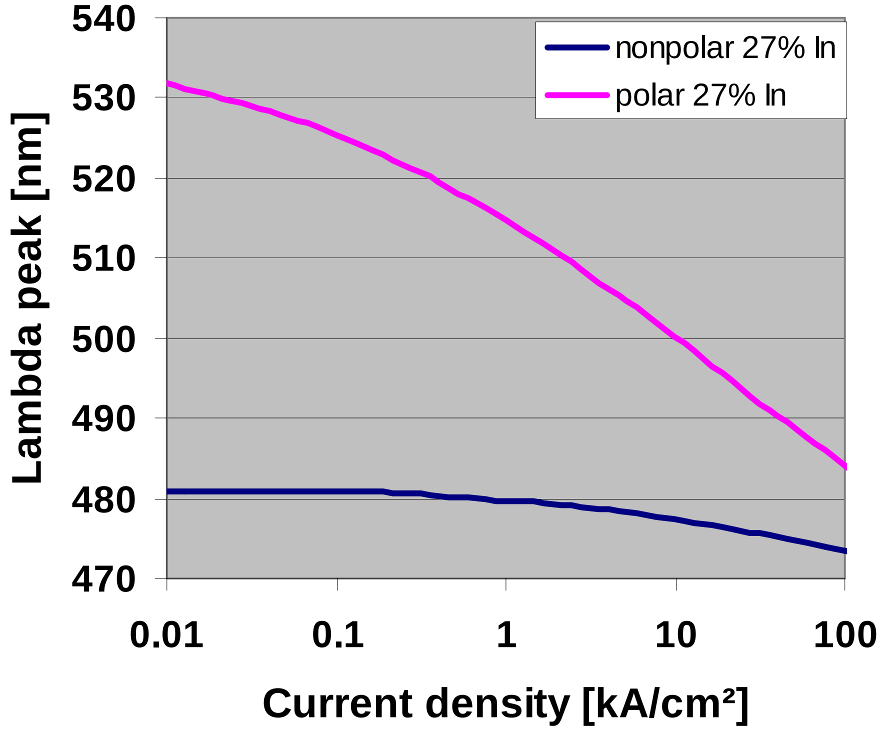




**Realistic**
- **Carrier density**
- **Confinement**

**→ Peakshift without piezofield ?**

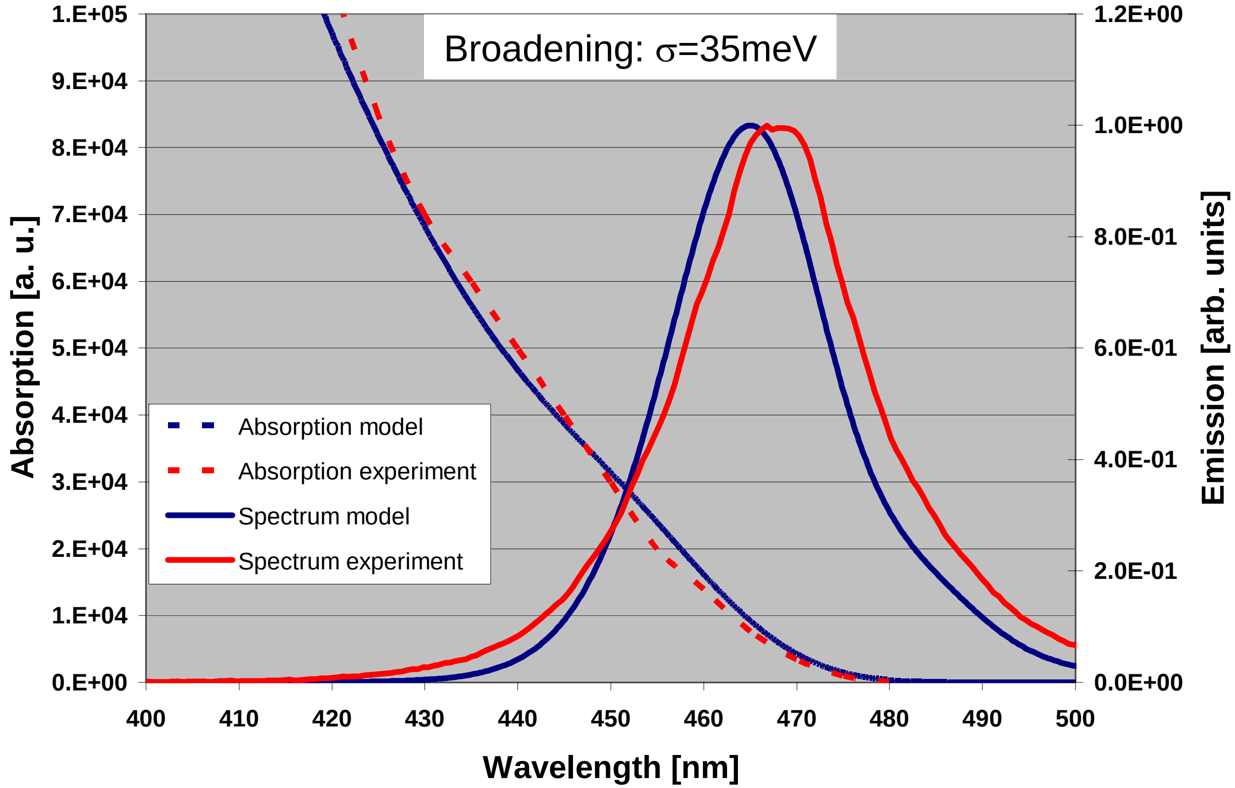
# Prediction: Compare polar – nonpolar peakshift




- **Low currents: 50nm shorter peak wavelength without piezoelectric fields**
- **High currents: Peaks approach each other due to screening piezoelectric fields**

**→ Can the model predict the absorption and emission?**

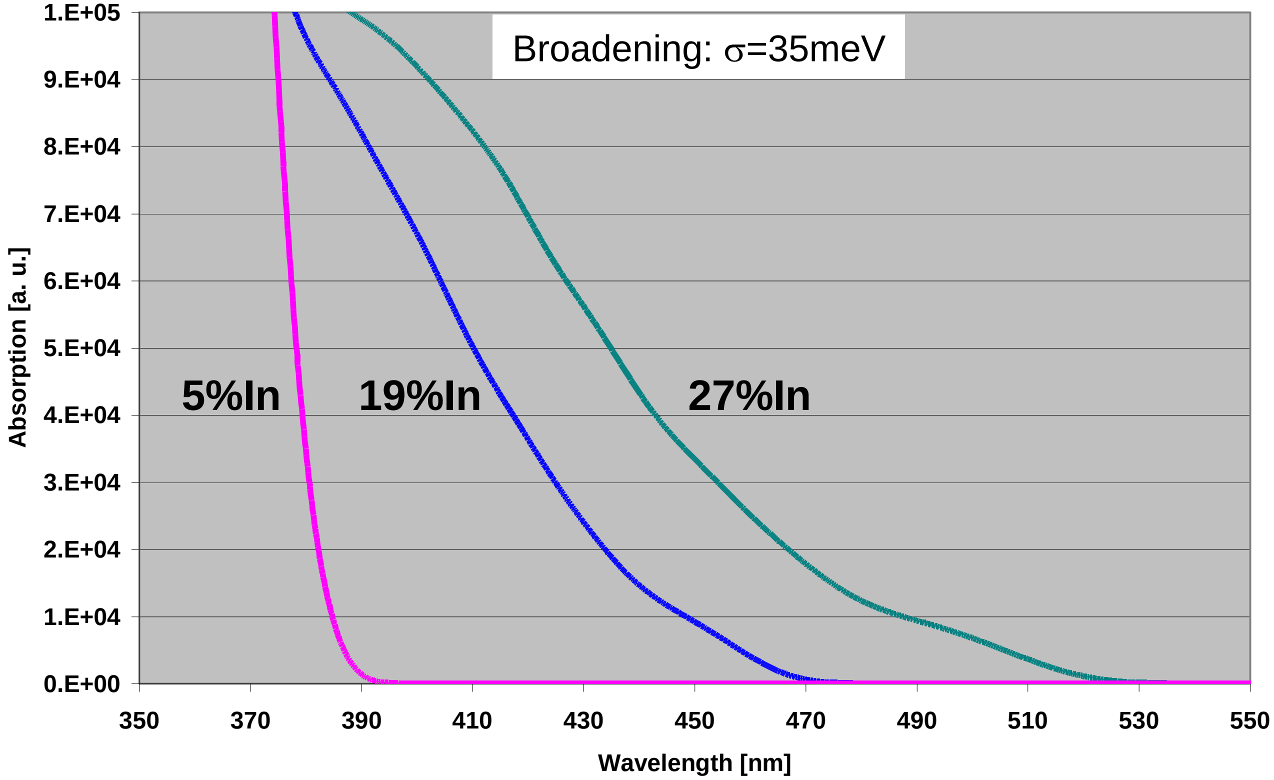
# Compare to experiment: emission and absorption




**Simple single particle model with artificial broadening shows good agreement**

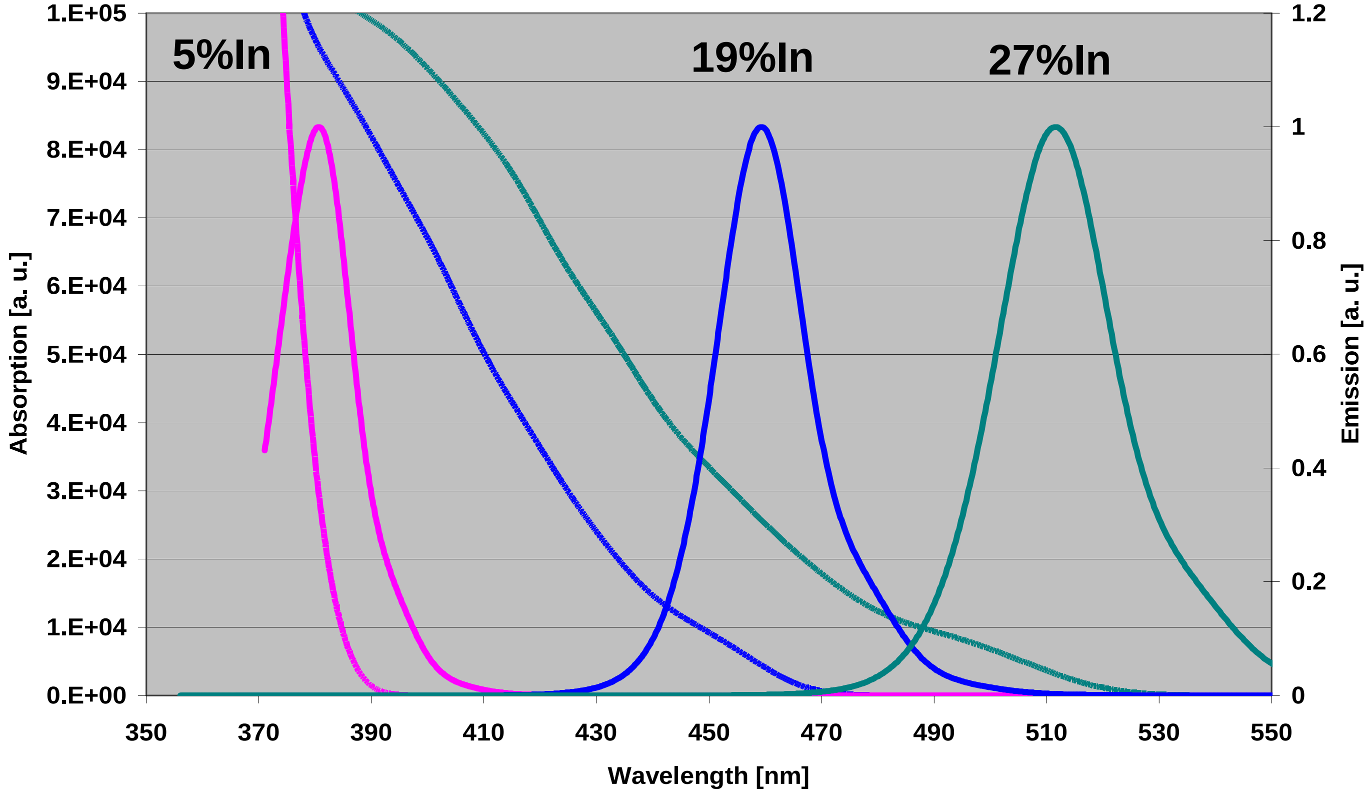
**→ How does Indium content influence absorption and Stokes-shift?**

# Prediction: absorption tail vs. Indium content




**Absorption tail strongly increases with increasing indium content**

# Prediction: Stokes-shift vs. Indium content

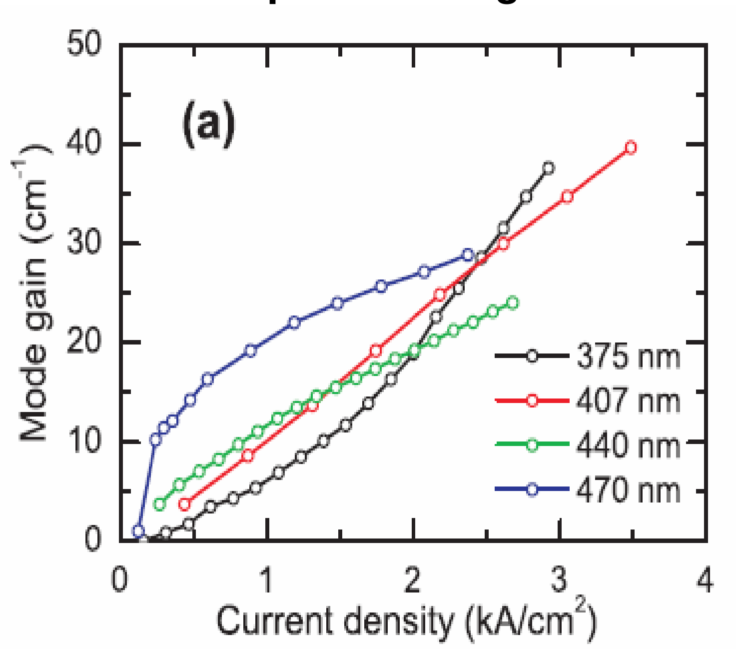



**Stokes shift strongly increases with increasing indium content**

**→ How does the Indium content influence the gain?**

# Compare to experiment: Peak gain vs. current

**Experimental gain**

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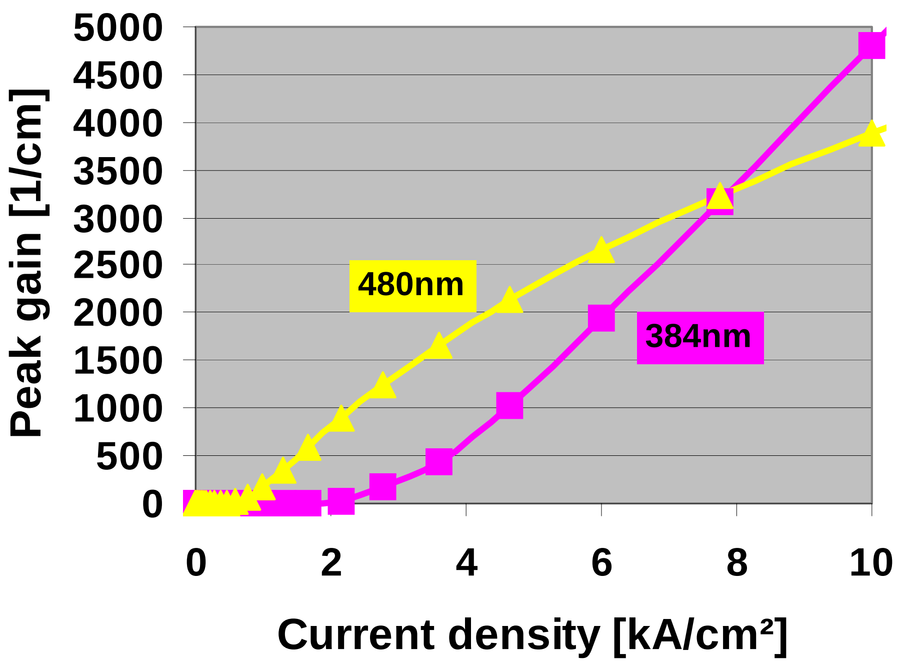
**Calculated gain**




- **Different gain evolution as function of current for different Indium contents**
- **Qualitative agreement with model**

# Conclusion

**Successful collaboration between theory and experiment**

**<u>Quantitative</u> prediction of:**

- **peak-shift (EL and reverse bias PL)**
- **electron-hole overlap**
- **carrier densities**
- **absorption and Stokes shift**

**<u>Qualitative</u> prediction of:**

- **gain**

**Quantitative modeling of InGaN structures is possible with ‘simple’ model**