8th International Conference on Numerical Simulation of Optoelectronic Devices

Analysis of the Leakage Current of GaInP/AlGaInP High Power Lasers with a self-consistent Simulation Model

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Opto Semiconductors OSRAM

Outline

- Introduction and goals
- Experimental characterisation
- Simulation model
- Analysis of leakage current: sensitivity to model parameters
- Conclusions

High Power Red Lasers

Main applications:

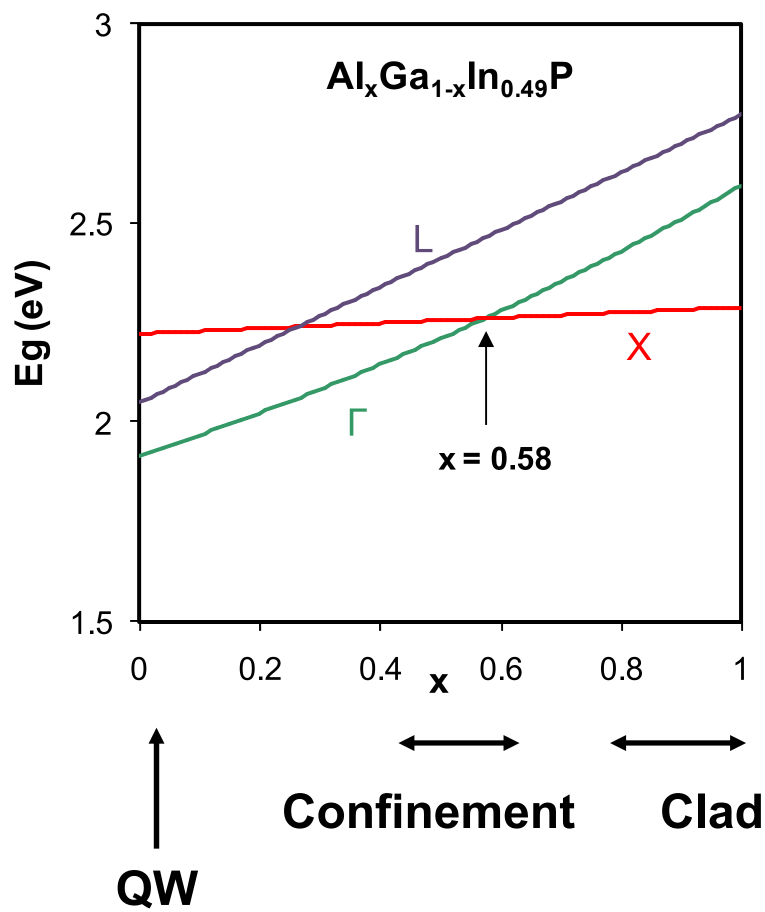
- Photodynamic Therapy
- Fluorescence Imaging of Cancer
- Laser Display Technology
- Pumping of Solid State Lasers

Main problems:

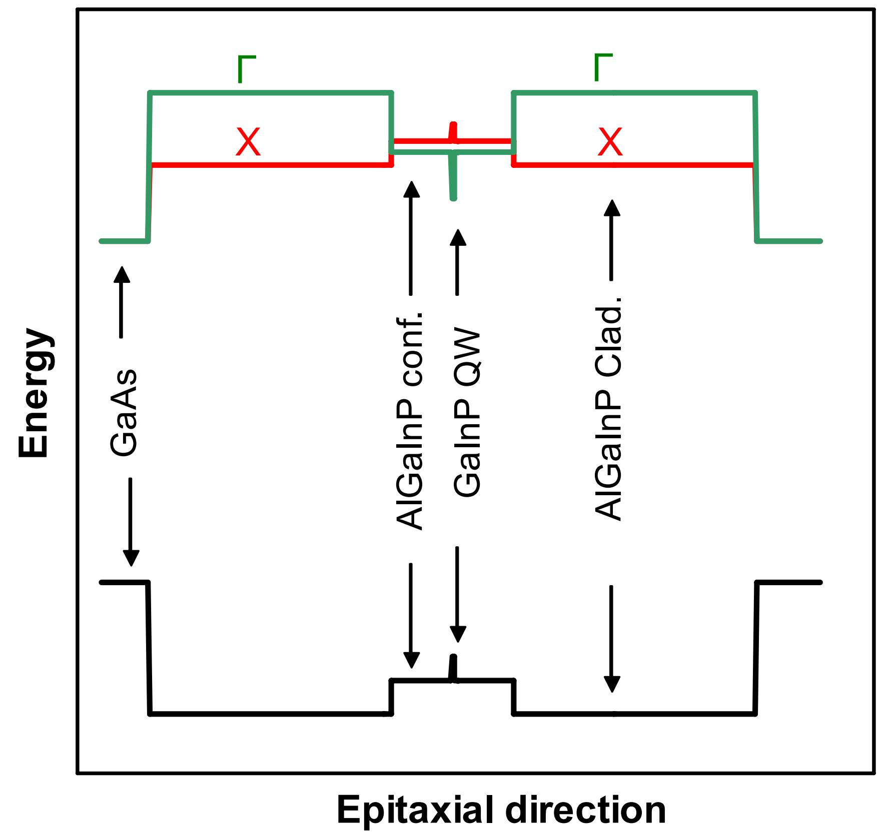
- High dependence of threshold current with temperature
- Decrease of slope efficiency with temperature
- Catastrophical Optical Damage
- Gradual degradation

GaInP/AlGaInP Red Lasers

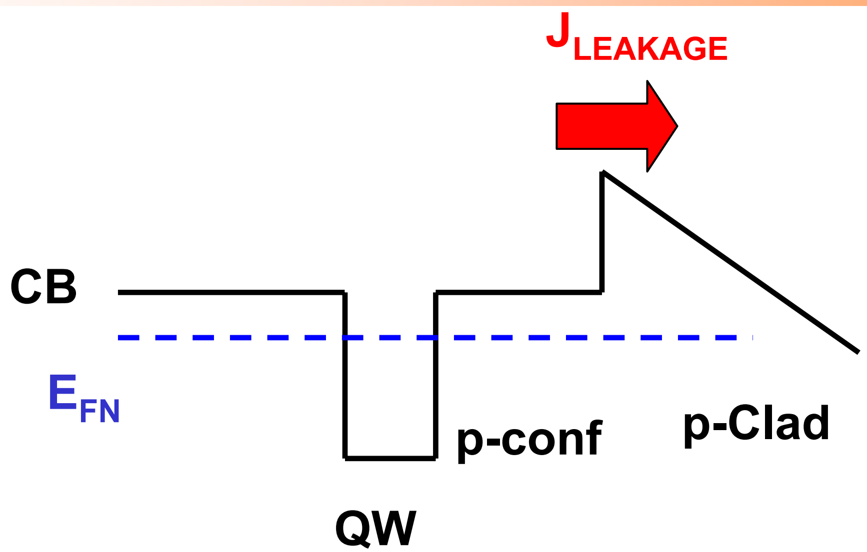
Band-gap vs. composition



Schematic band alignment



Leakage Current in Red Lasers



Analytical Model

$$J_{LEAK} = J_{DRIFT} + J_{DIFFUSION}$$

Leakage current depends on:
band-offset, mobilities, carrier lifetime....

Goals

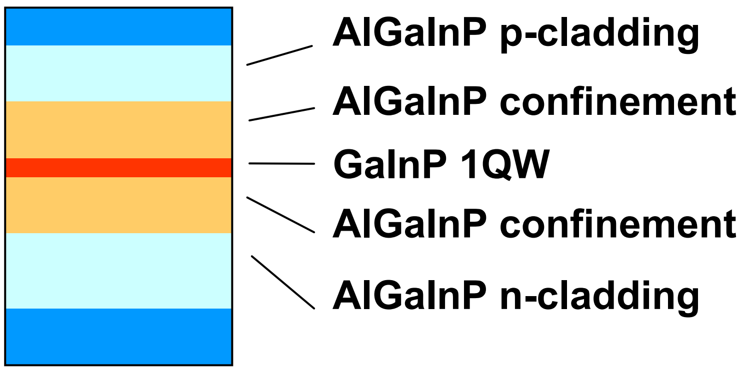
- Analyze leakage current with a self-consistent laser model
- Evaluate the sensitivity of the results to the values of some material parameters
- Evaluate the effect of some design parameters: p-doping

Laser Devices and Experimental characterisation

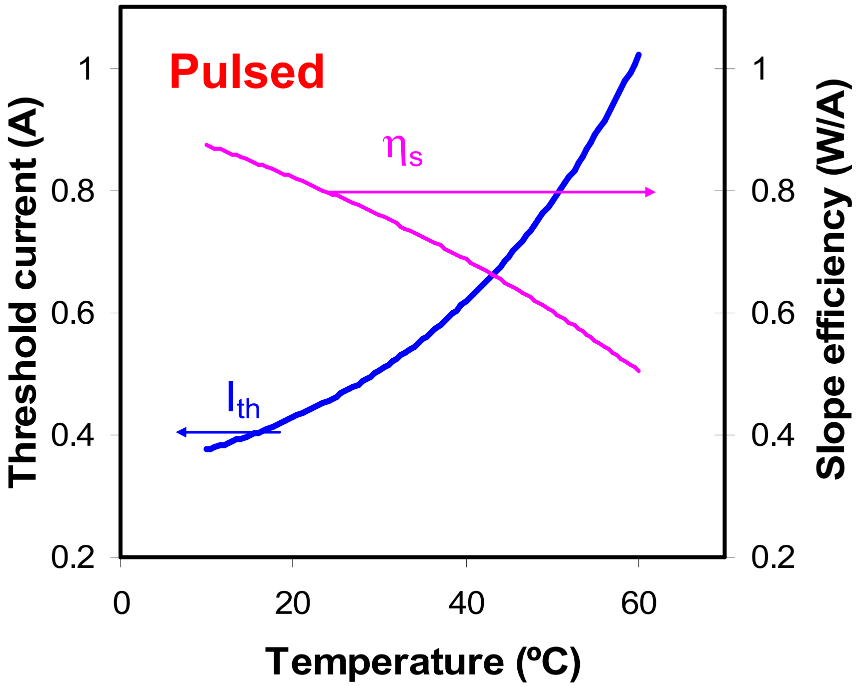
Broad Area Lasers

100 µm x 1.2 mm

Epitaxial design



Wavelength: 635 nm



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Self-consistent laser model

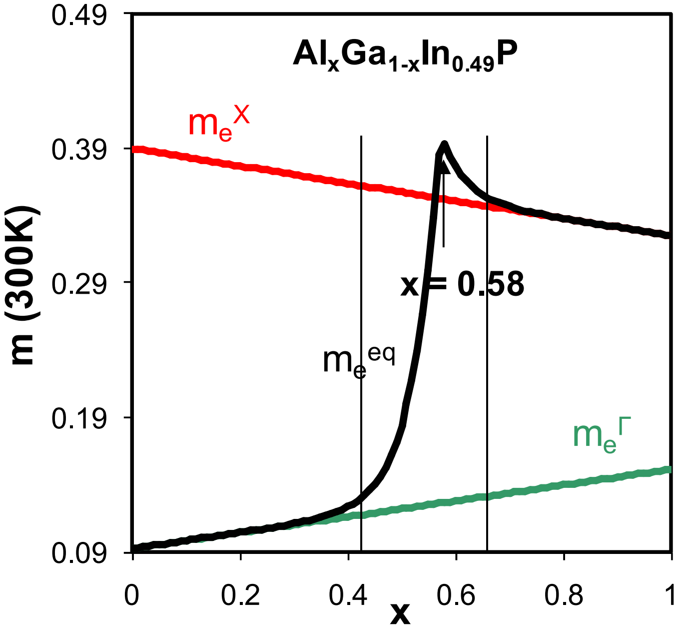
Main features:

- Complete semiconductor equations: Poisson + continuity electrons + continuity holes
- QW carrier capture/escape processes
- Gain calculations using parabolic fitting of VB structure (calculated by **k.p** band mixing model)
- Γ and X valleys in the CB

Model for multiple valleys in CB

- Assumption: thermal equilibrium between electrons in different valleys
- Single CB minimum with equivalent effective mass and mobility
- m_e^{eq} and μ_e^{eq} are calculated analytically

$$m_e^{eq} = f_m(m_e^X, m_e^\Gamma, E_C^X - E_C^\Gamma, T)$$
$$\mu_n^{eq} = f_\mu(\mu_n^X, \mu_n^\Gamma, E_C^X - E_C^\Gamma, T)$$

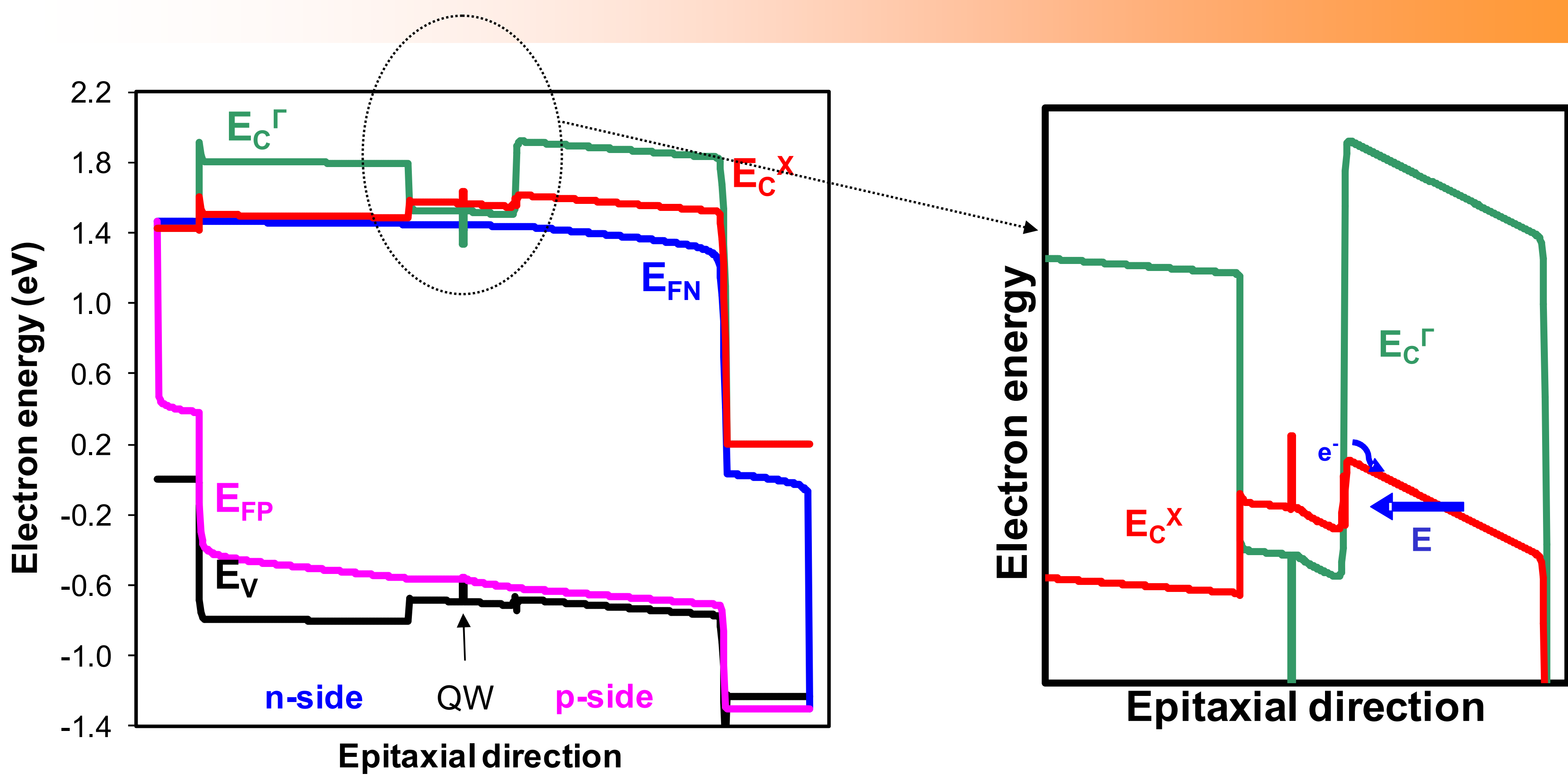


Equivalent effective electron mass

Main model parameters affecting leakage

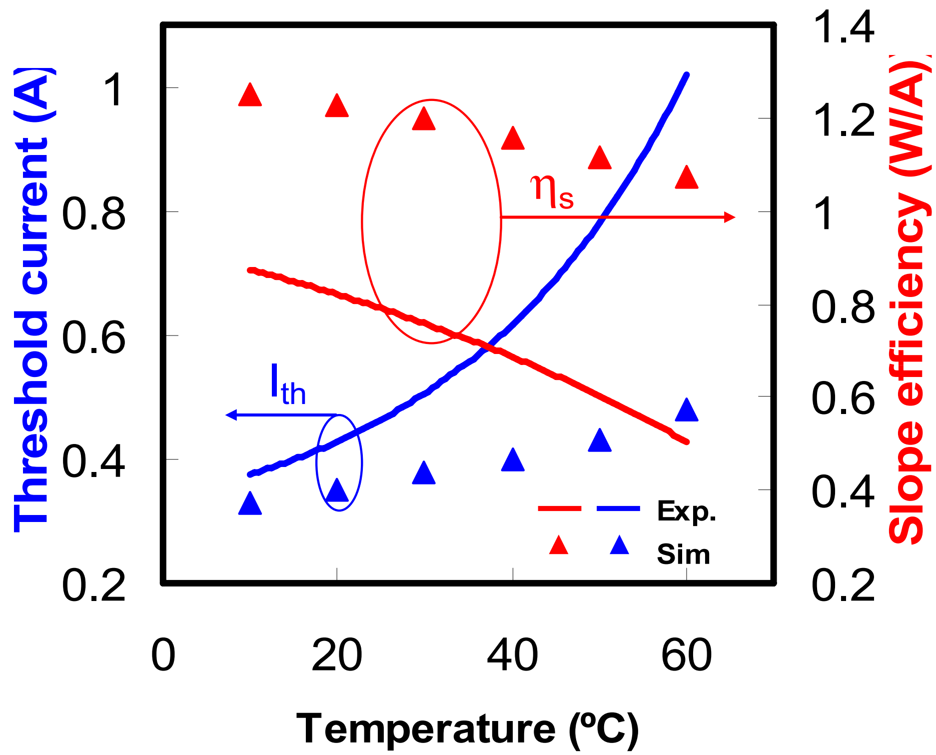
- **Electron/ hole mobilities**
- **Electron/ hole capture times**
- Band line-ups
- Γ and X valleys effective masses
- **SRH recombination parameters**: trap density, trap energy, trap carrier capture section

Band profiles under bias



T = 20 ºC; I = 2 A

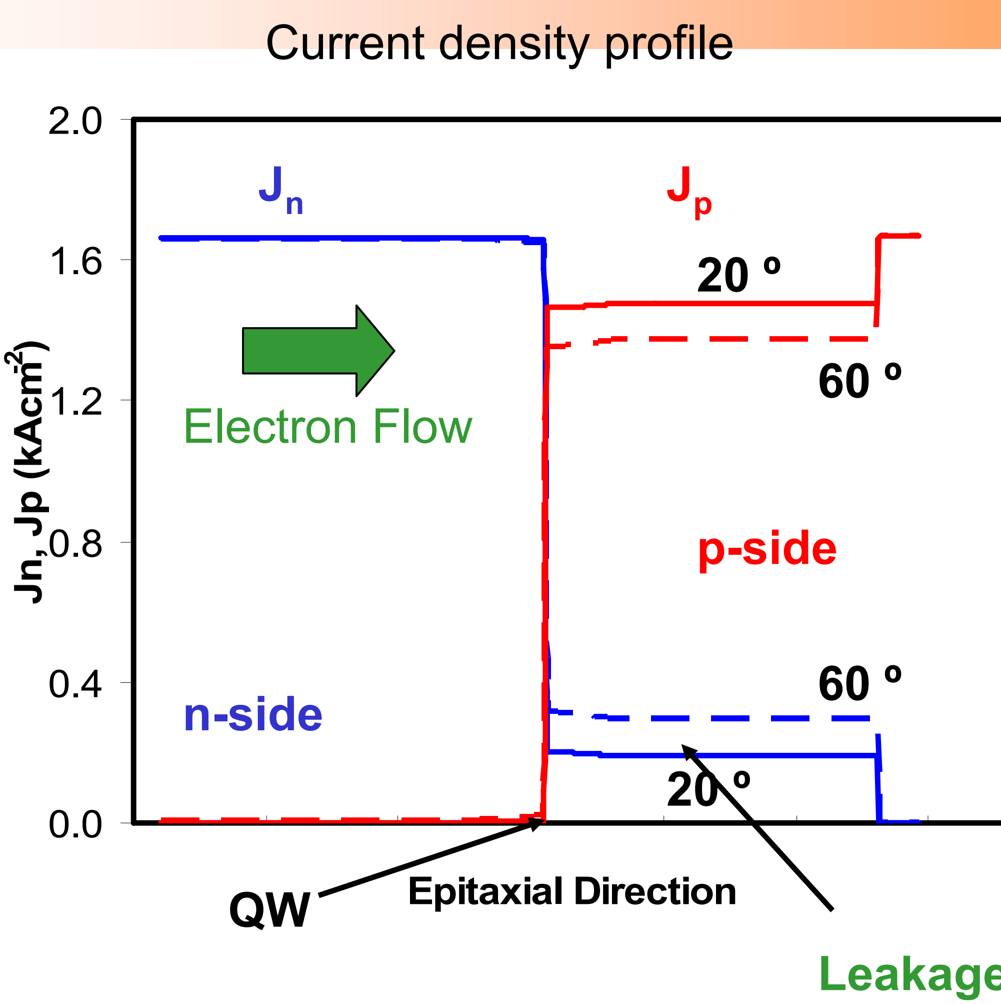
No SRH recombination



✓ Low I_{th}; weak temperature dependence

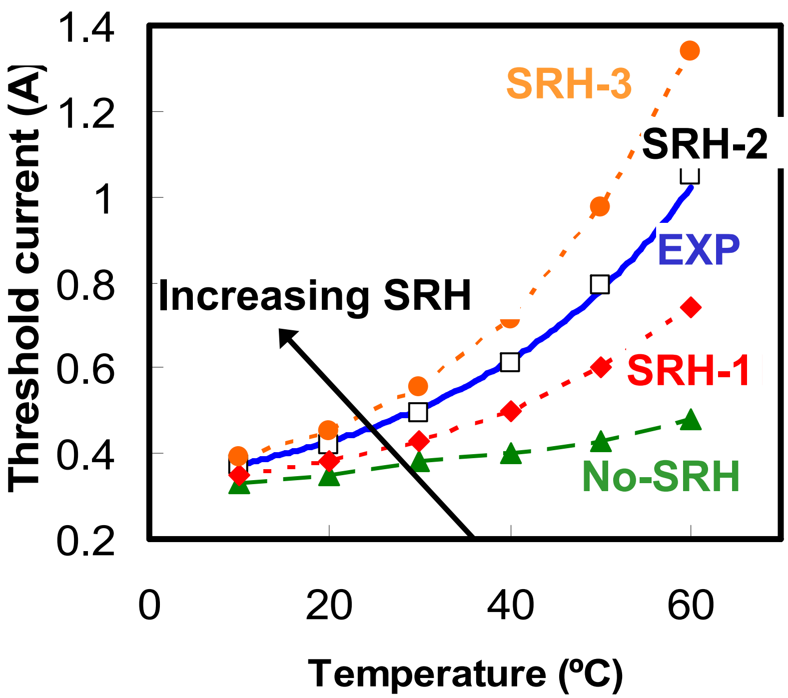
✓ High η_S; weak temperature dependence

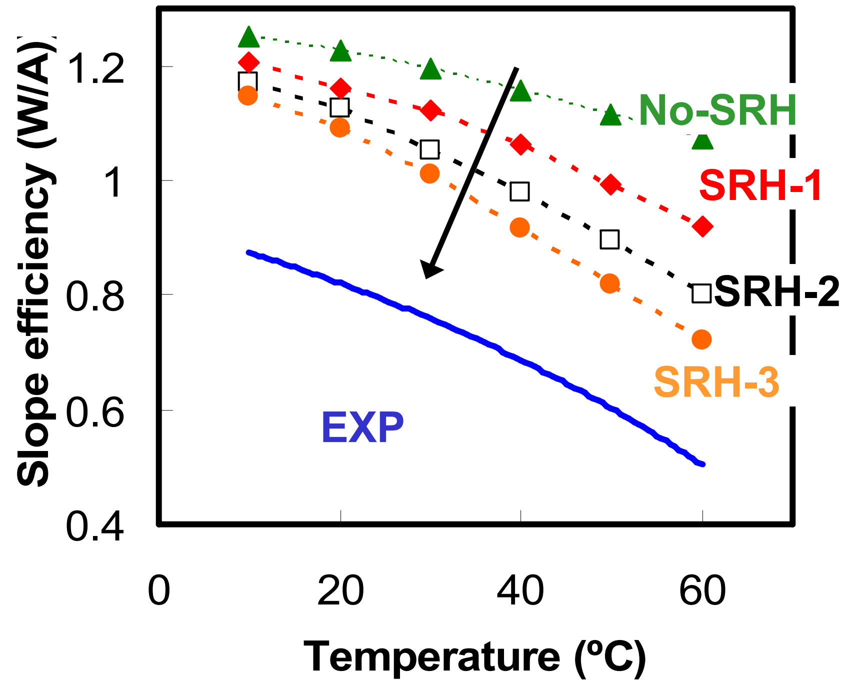
No SRH recombination



I = 2 A

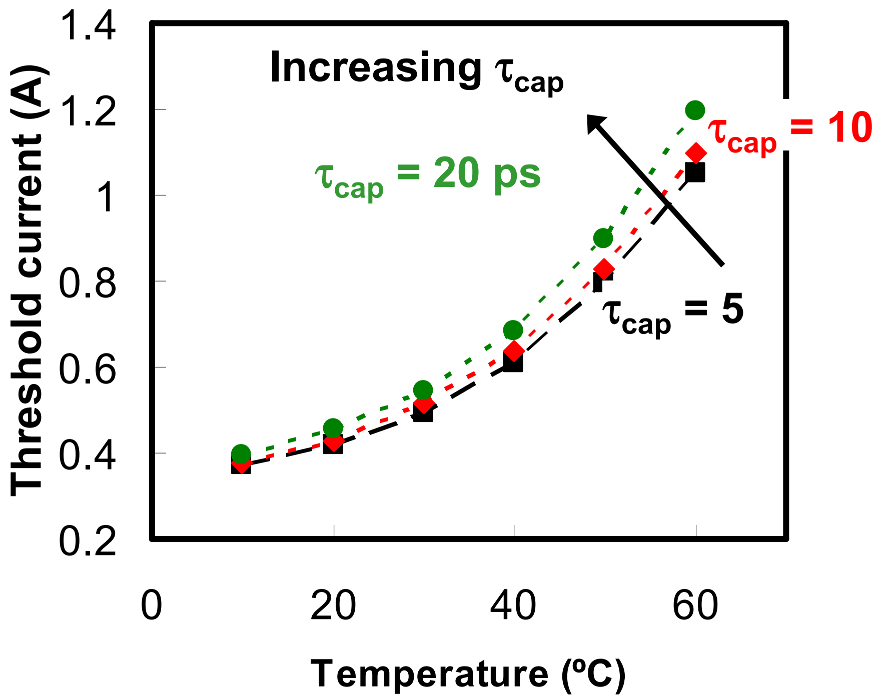
Role of SRH recombination

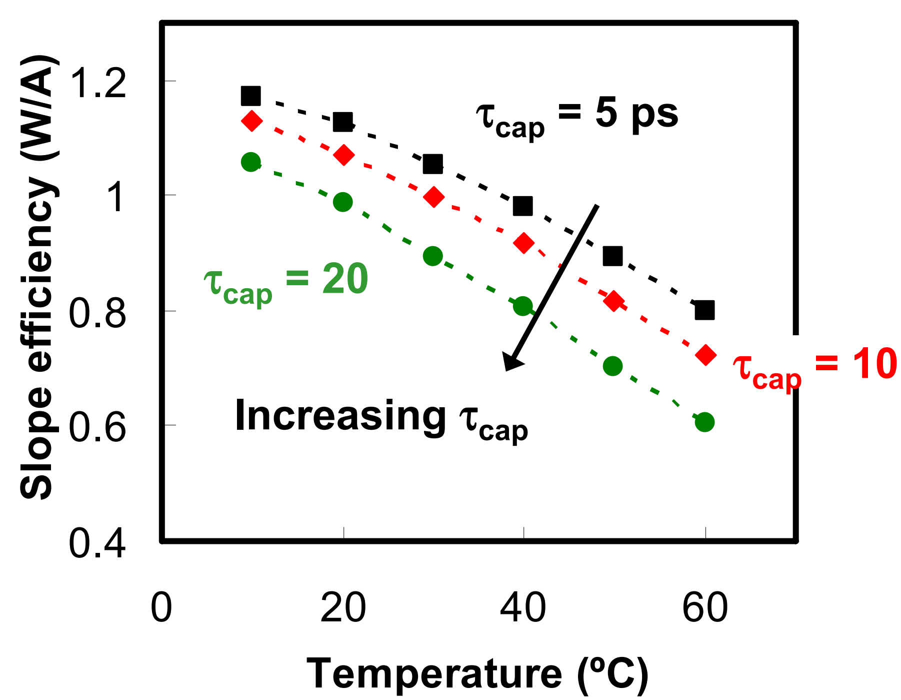




	Traps in p-conf	Traps in p-clad
SRH-1	$1 \cdot 10^{17}$ cm^{-3}	$0.5 \cdot 10^{16}$ cm^{-3}
SRH-2	$3 \cdot 10^{17}$ cm^{-3}	$1 \cdot 10^{16}$ cm^{-3}
SRH-3	$5 \cdot 10^{17}$ cm^{-3}	$1.5 \cdot 10^{16}$ cm^{-3}

Role of electron capture time





$\tau_{cap} \uparrow \Longrightarrow I_{leakage} \uparrow$

(Increasing electron density in confinement layers)

Role of carrier mobility in p-clad

μ_p (majority) ↑ ⟶ $I_{leakage}$ (drift) ↓

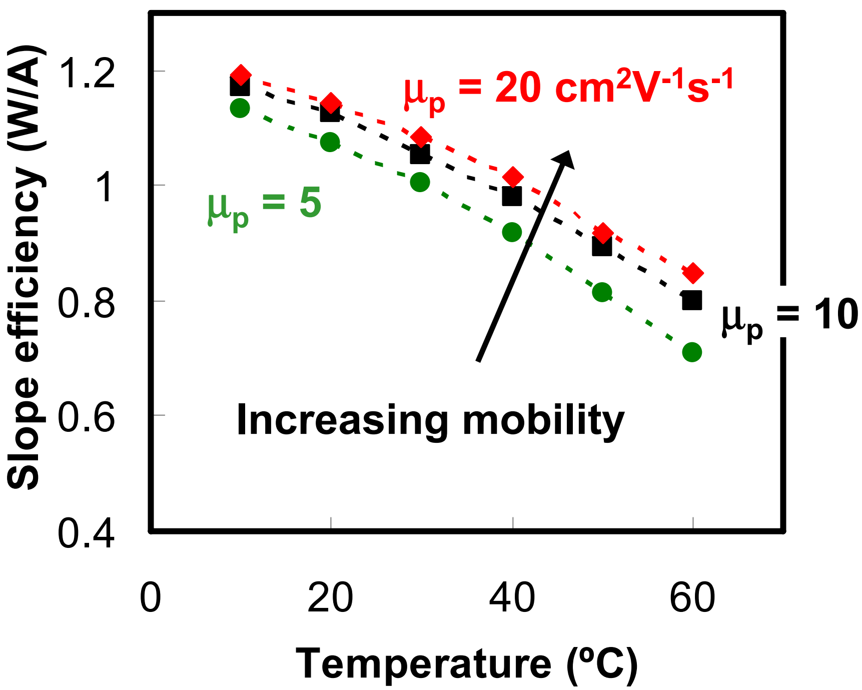
Lower Electric field ($J_p = qp\mu_p E$)

μ_n (minority) ↑ ⟶ $I_{leakage}$ (diffusion) ↑

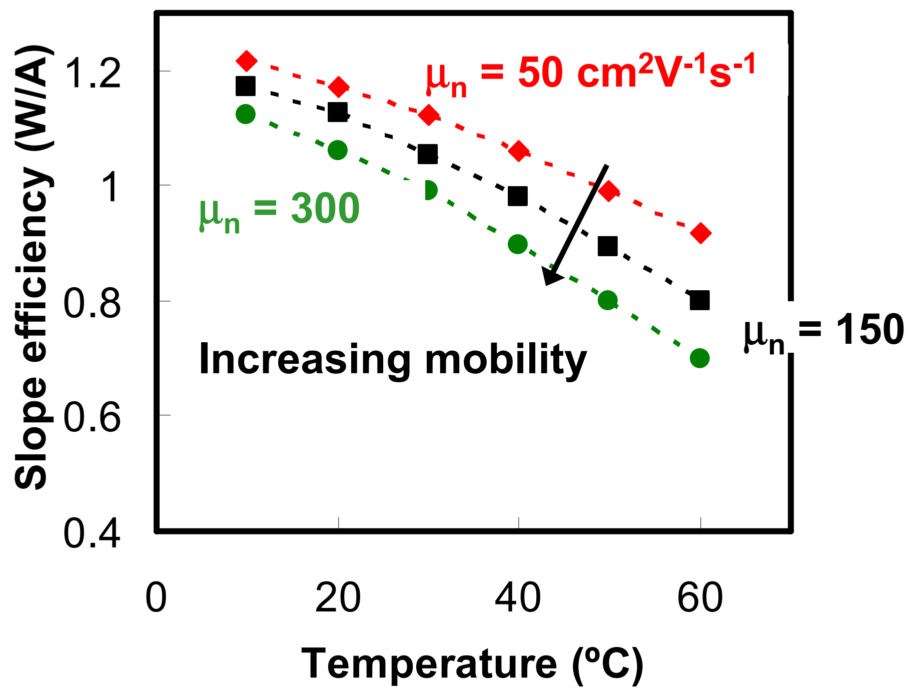
Higher diffusion coefficient ($J_{n\ (dif)} = \mu_n kT dn/dx$)

Role of carrier mobility in p-clad

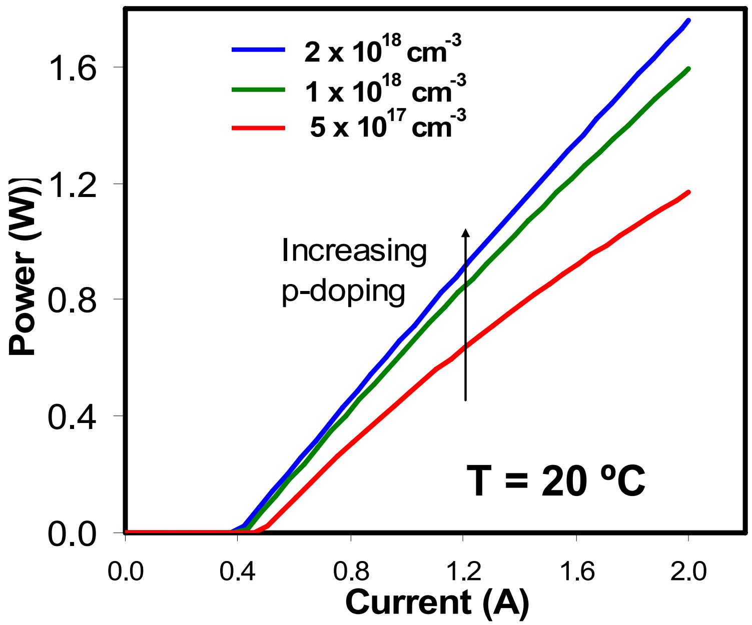
μ_p (majority)

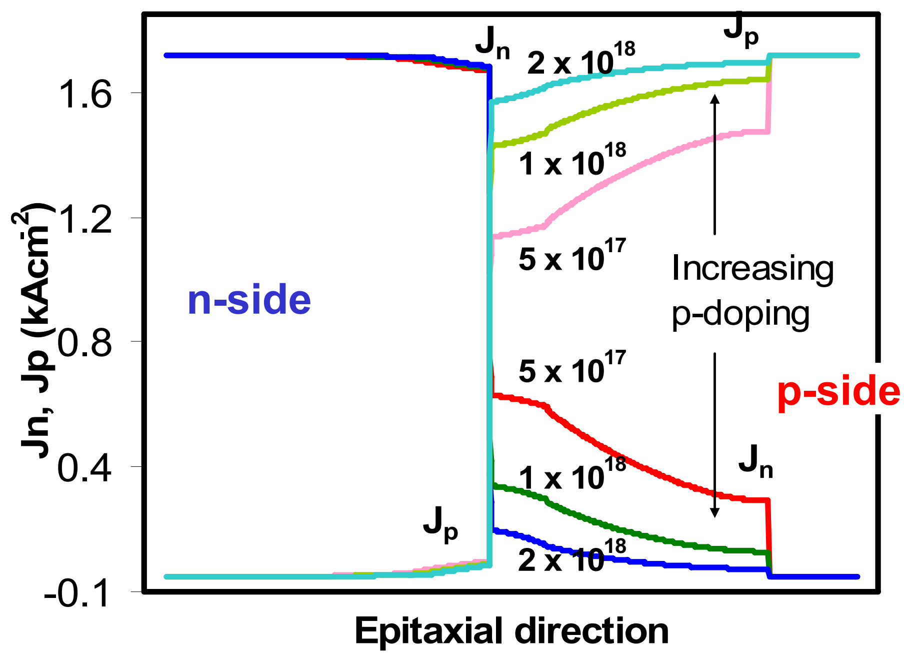


μ_n (minority)



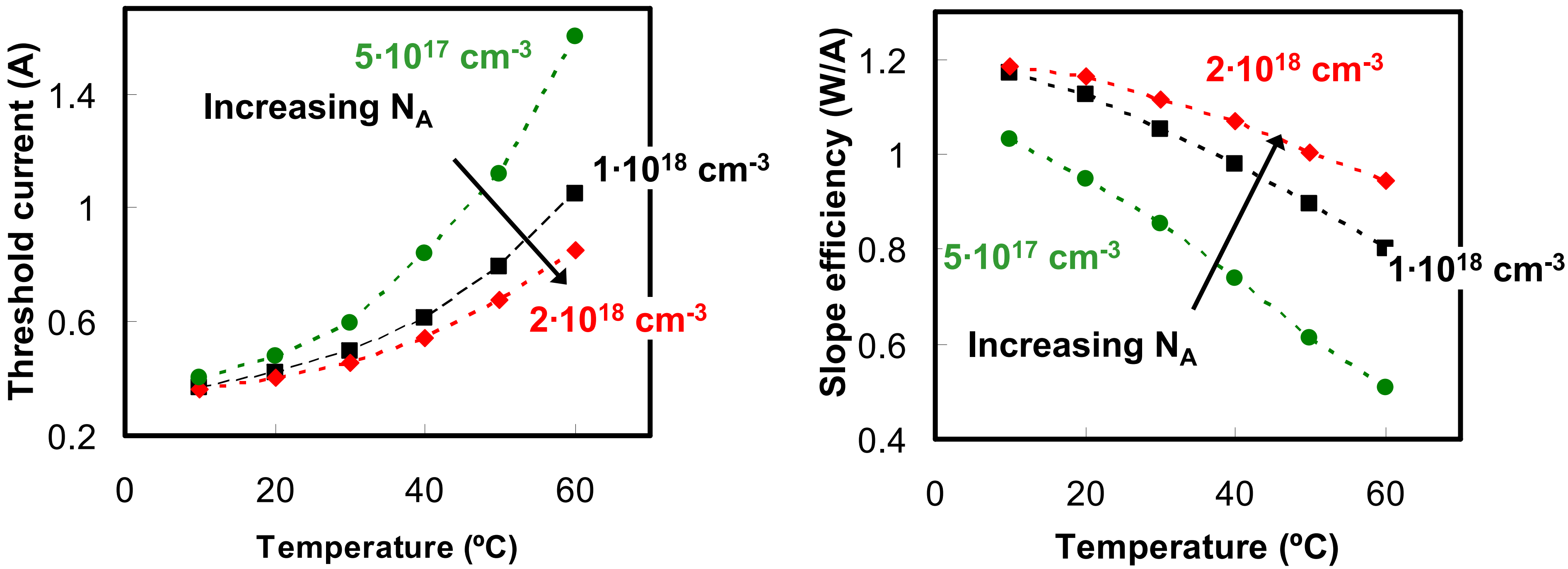
Role of doping in p-cladding





T = 20 ºC; I = 2 A

Role of doping in p-cladding

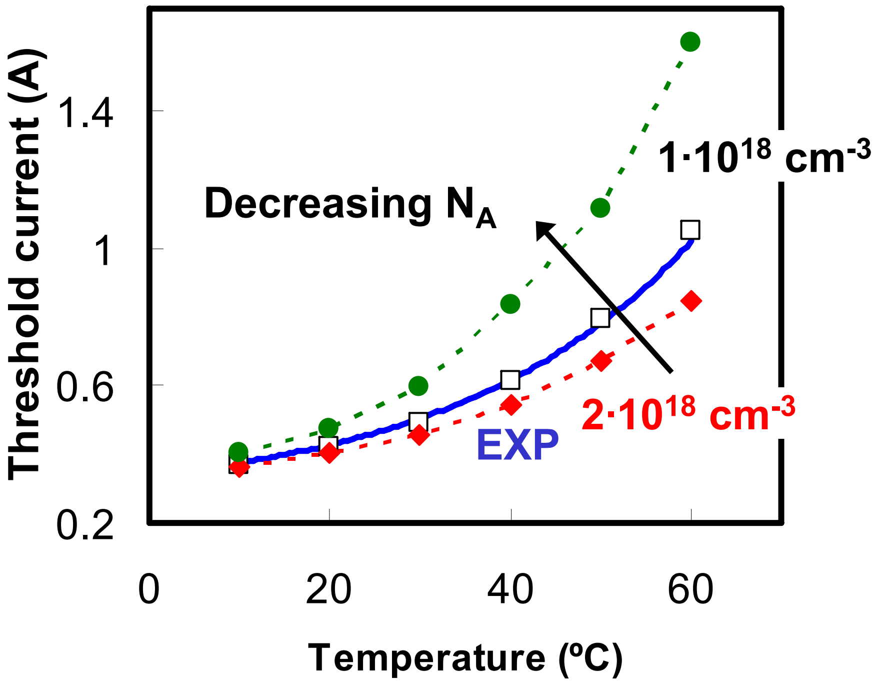


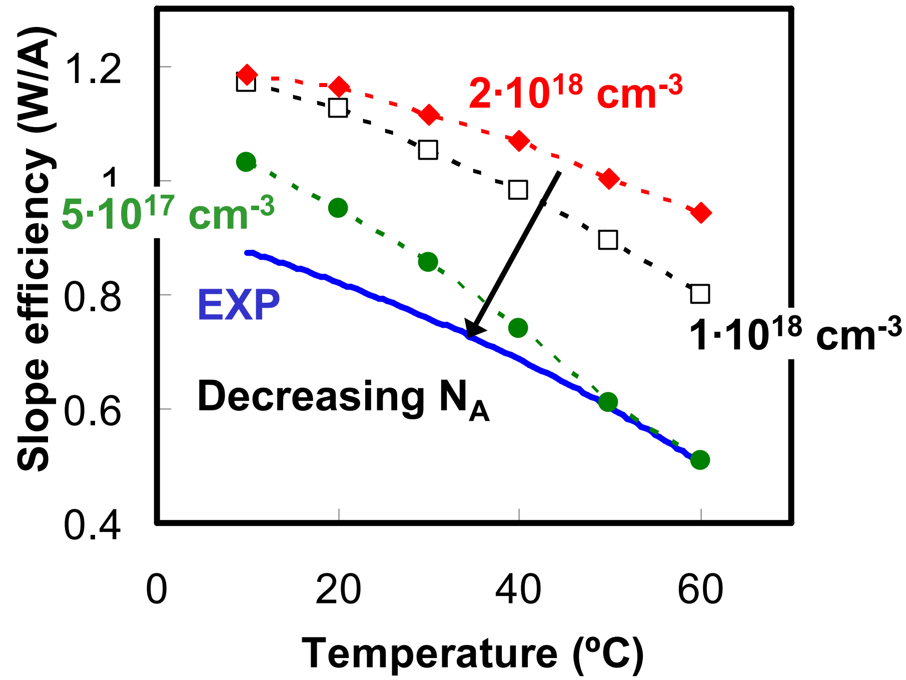
✓ Increasing p-doping reduces drift leakage

Conclusions

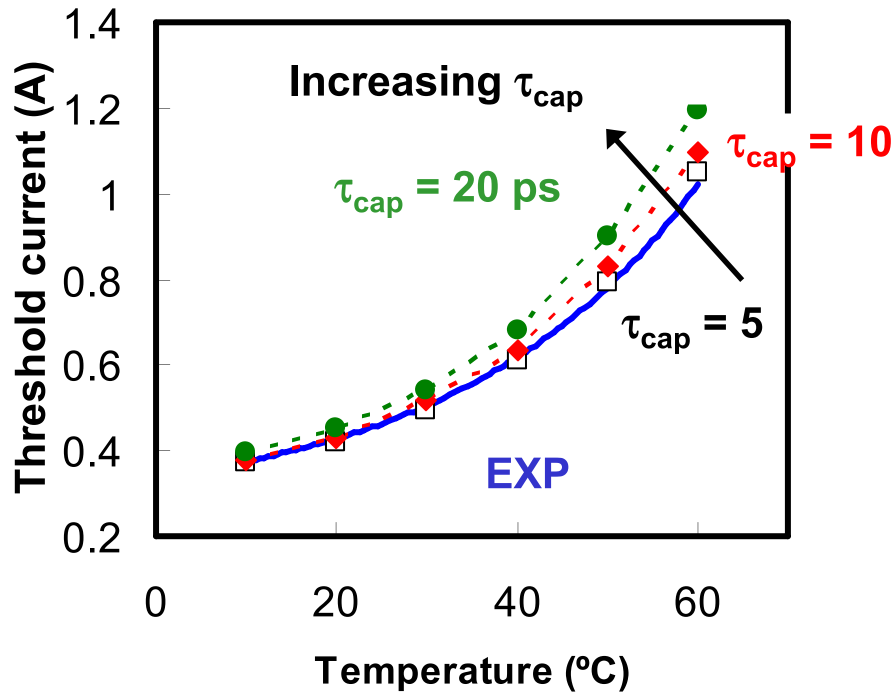
- ✓ Self-consistent model predicts leakage current over p-cladding
- ✓ Leakage current is very sensitive to model parameters
- ✓ Need to determine basic material parameters to optimize red lasers
- ✓ Simulation emphasizes the Important role of increasing p-doping level.

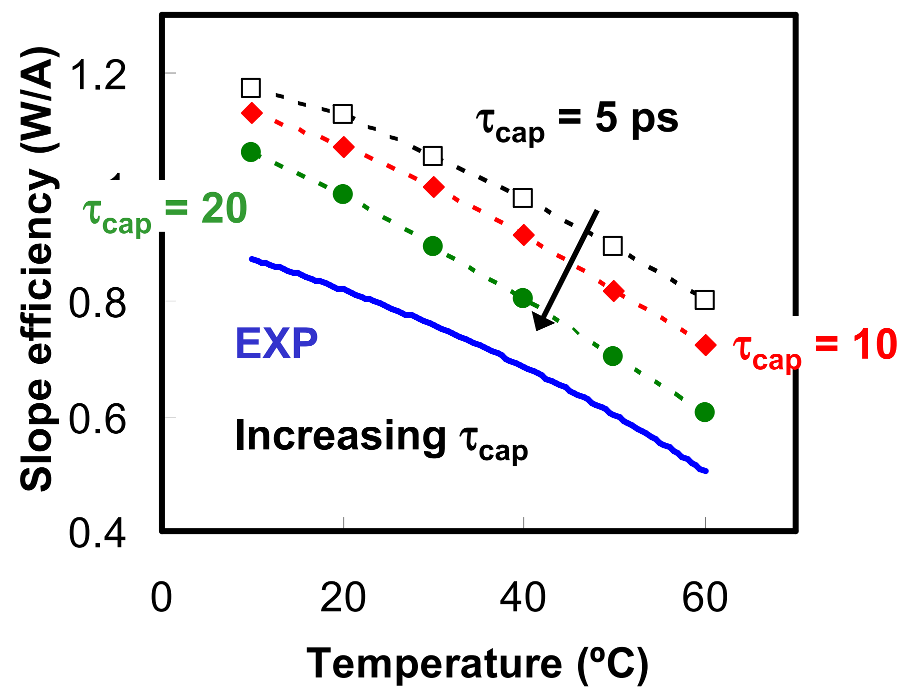
Role of doping in p-cladding



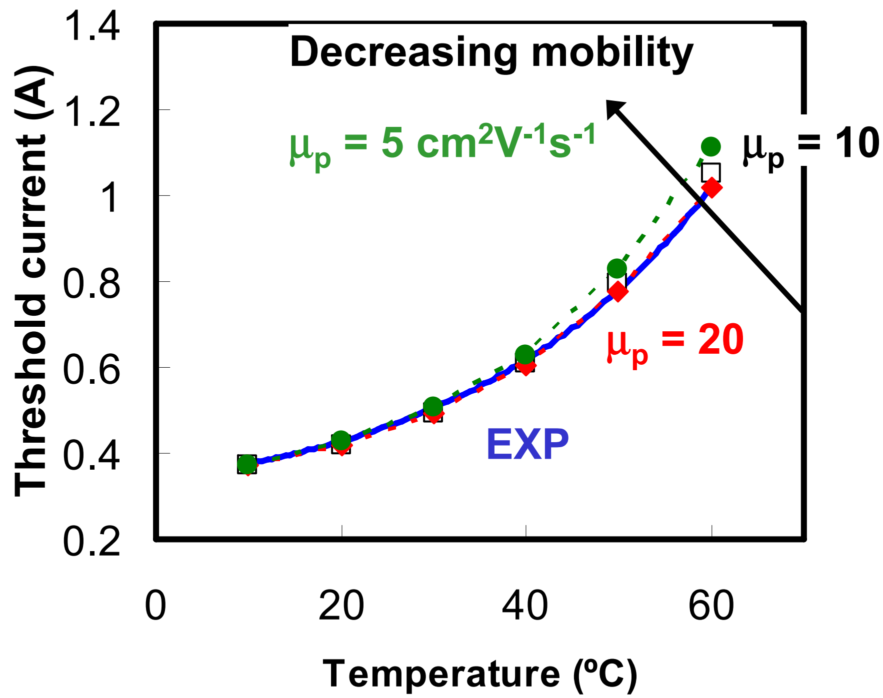


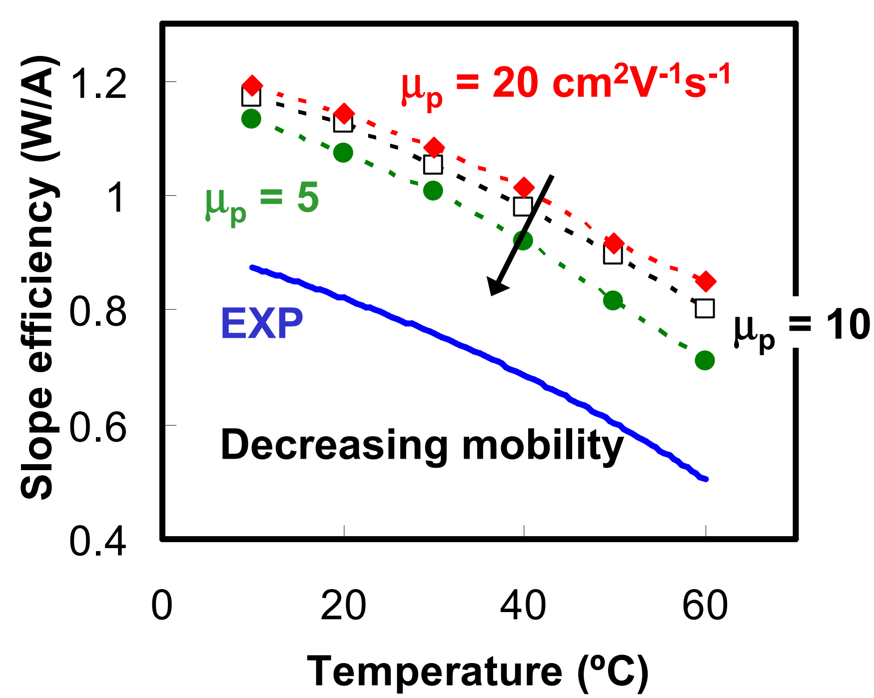
Role of electron capture time



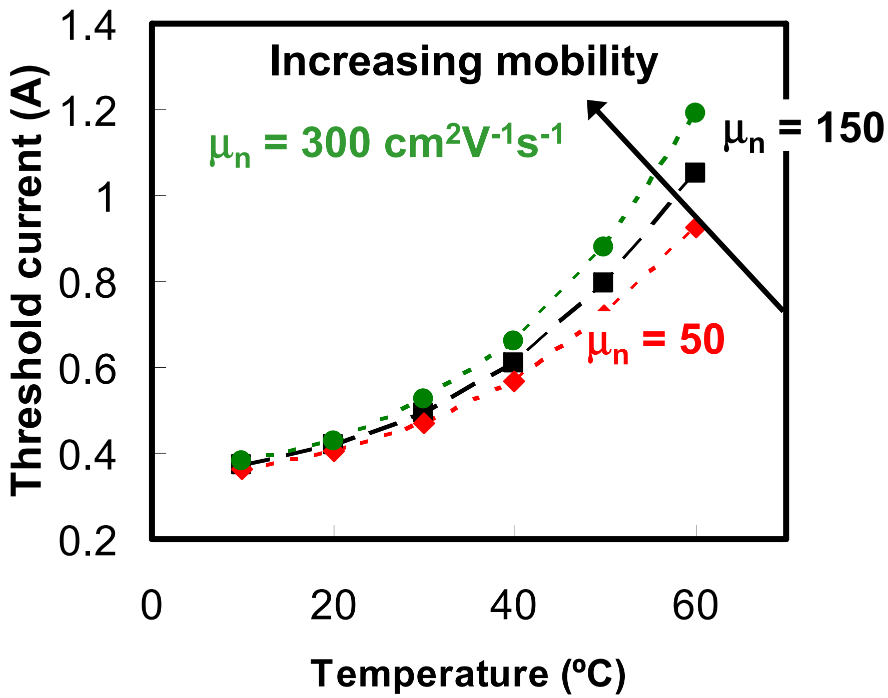


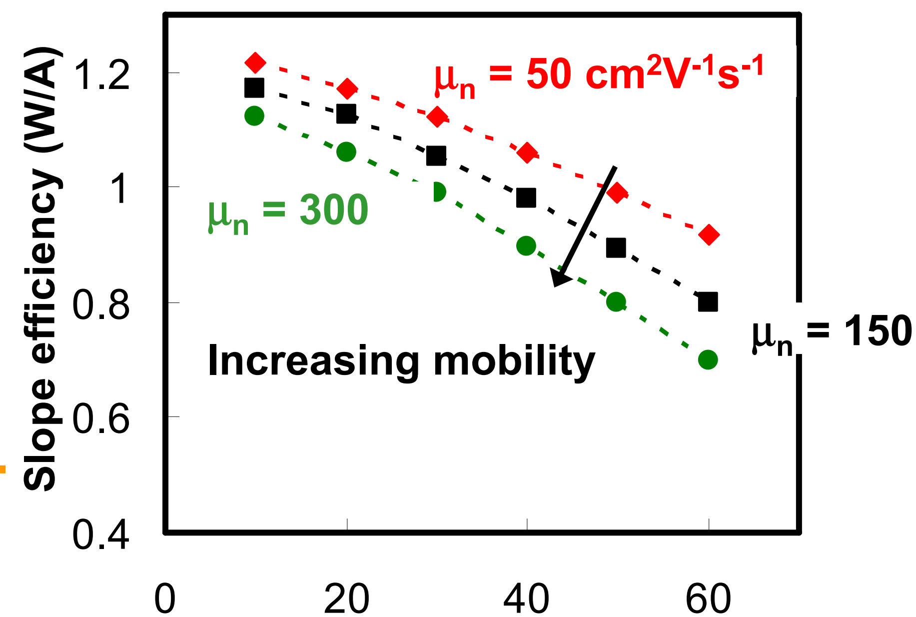
Role of hole mobility in p-clad



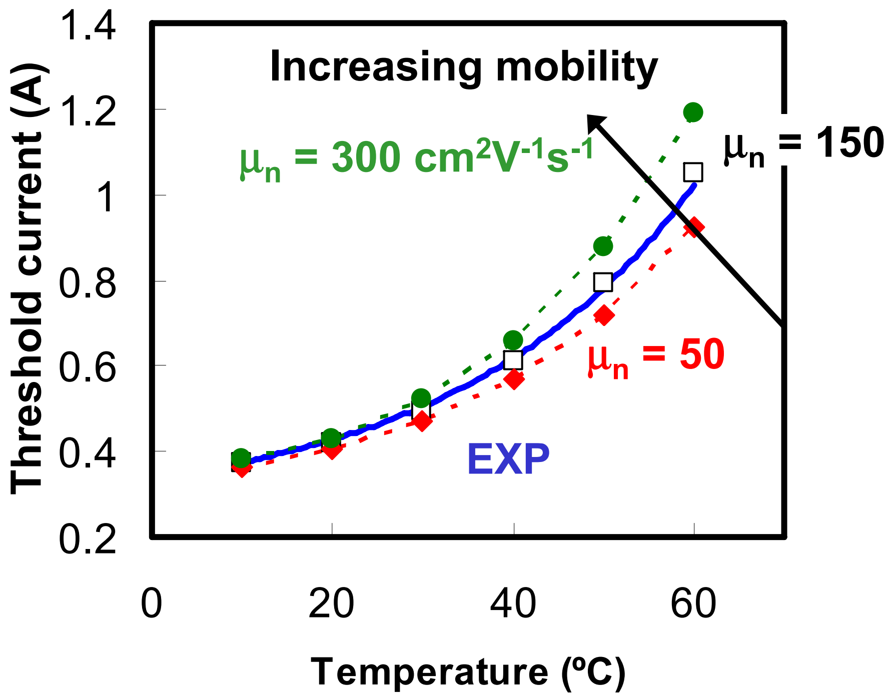


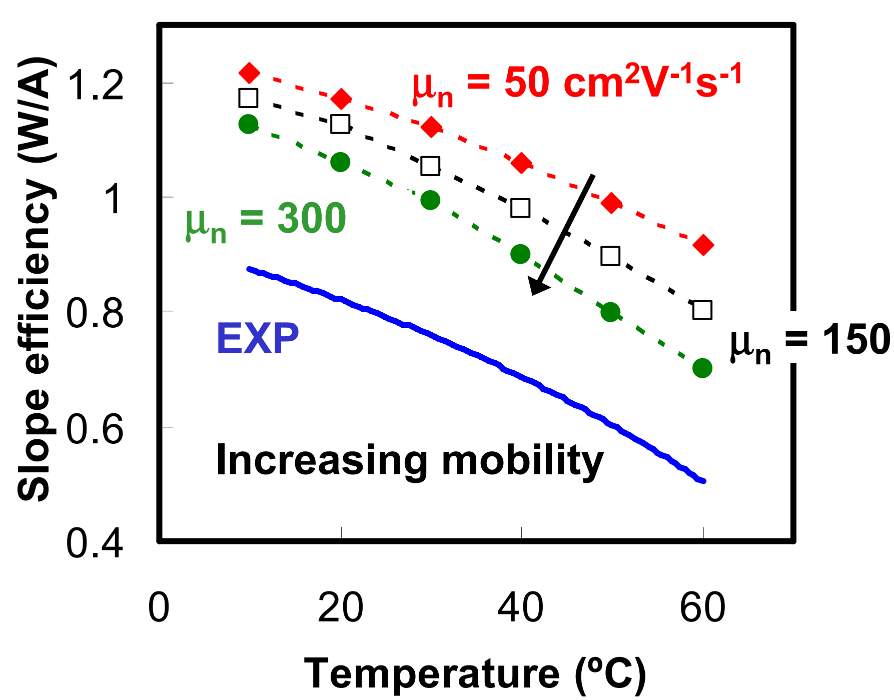
Role of electron mobility in p-clad





Role of electron mobility in p-clad





Role of hole mobility in p-clad