Advanced Industrial Design Methods for LEDs

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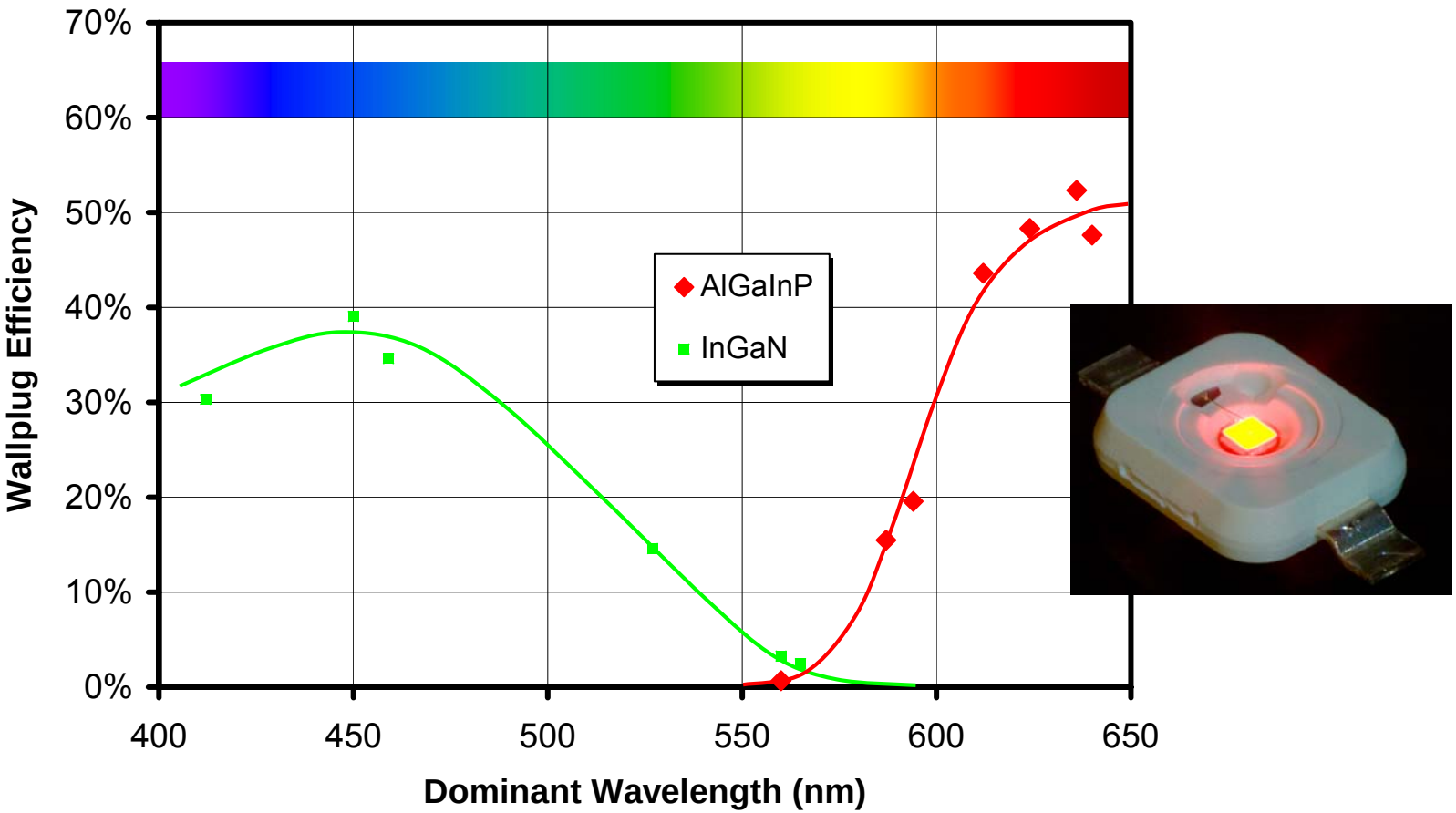
- Status and Trends in LED Technology
- LED Design Criteria
- Aspects of LED Design:
  Layer Structure / Light Extraction / Current Distribution

Maturity of Technology: Device Efficiency



LED Technology Trends: Diversification of Applications

Automotive

General Lighting

Displays

Backlights

LED Technology Trends: Power & Size

TOPLED®

2lm/90mW @20mA
single chip white

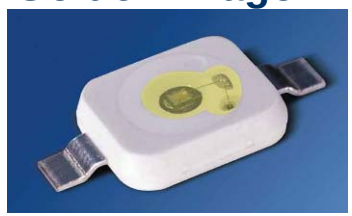
Power TOPLED®

3lm/140mW @30mA
single chip white

Advanced Power TOPLED®

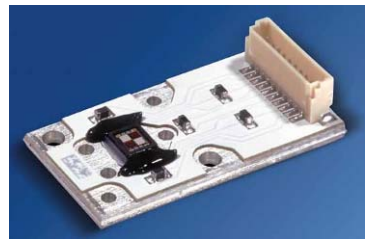
10lm/250mW @200mA
single chip white

Golden Dragon®

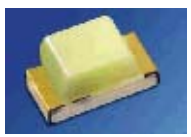


30lm/1,4W @350mA
single chip white

OSTAR®

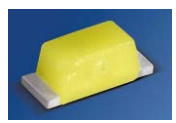


100-1000lm/10 - 50W
multi chip



Chipled
0.8mm

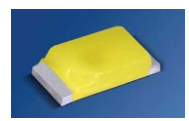
MicroSIDELED®
1.0mm



SmartLED®
0.6mm

MicroSIDELED®
0.6mm

Firefly®
0.5mm

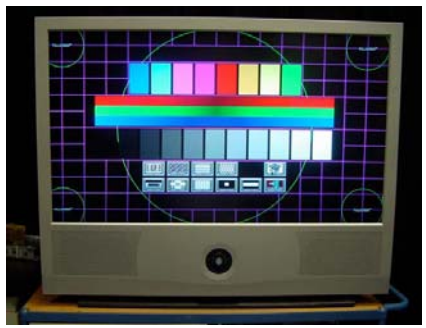


SmartLED®
0.3mm

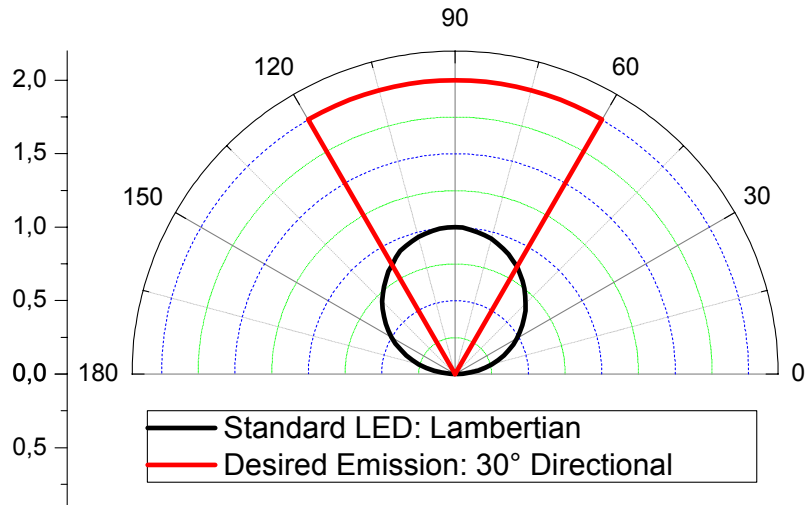
Emerging Technologies?

Beam-Shaping in LEDs

Pocket Beamer



Rear-Projection TV



➢ Photonic Crystal LEDs?

see Paper ThB3

LEDs with Polarized Emission

LED Backlights for LCD-TV

LED Design is set between…

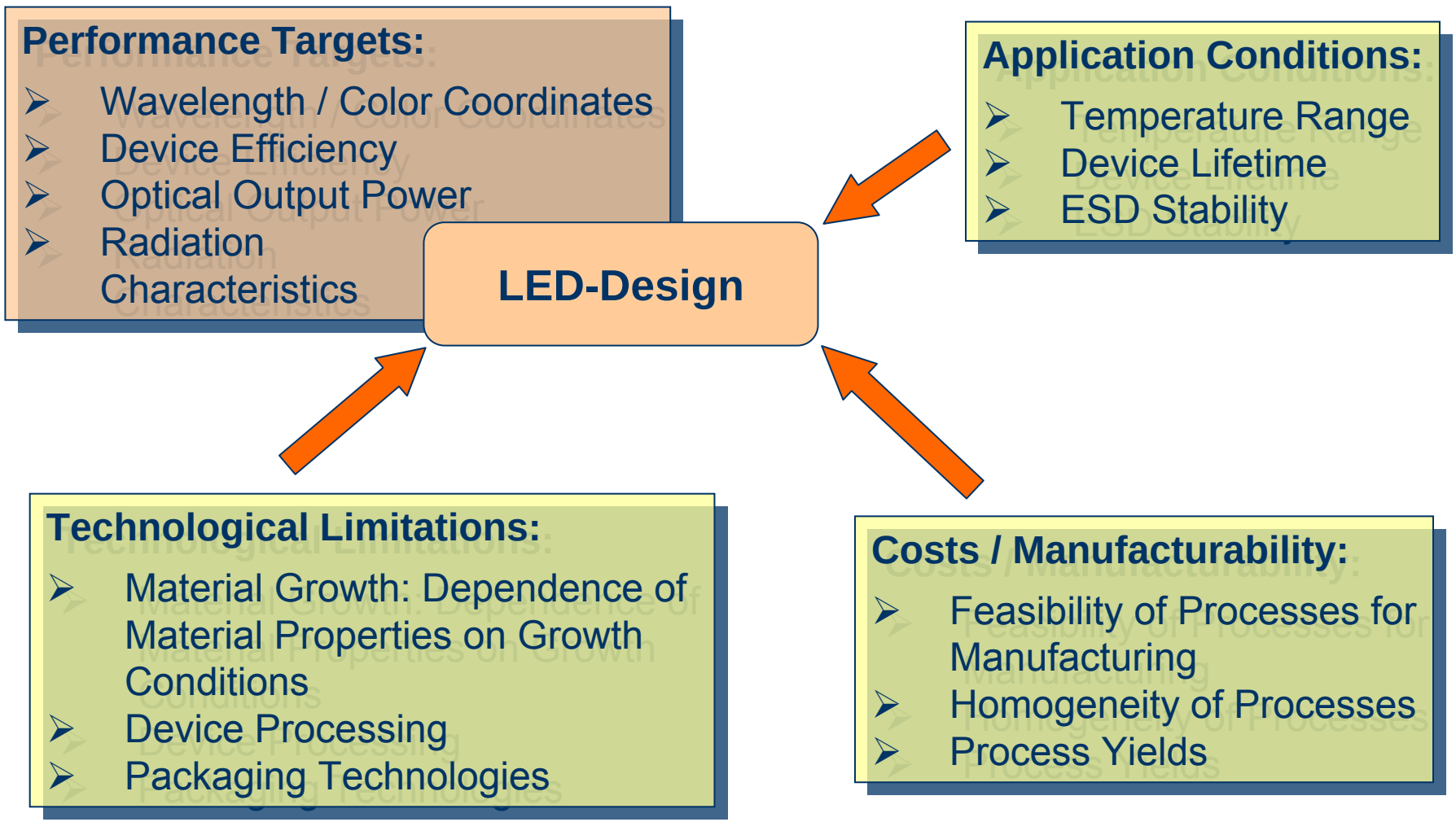
Engineering

- Improvement of devices based on existing technologies
- Quantitative prediction and analysis of device performance

Science

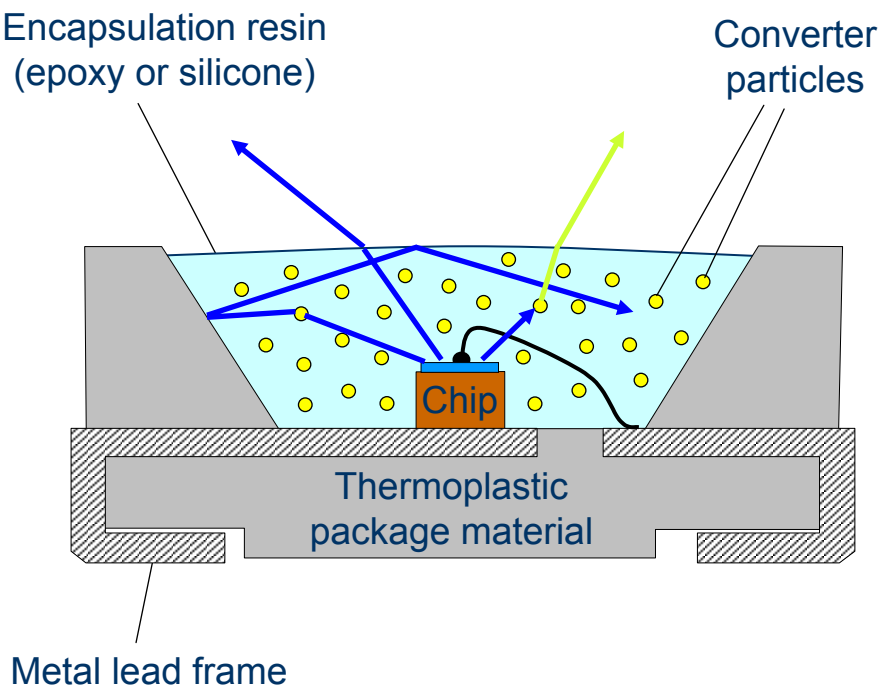
- Find concepts for new functionalities
- Identification and test of (possible) design principles

LED Design Criteria



LED Design: Components

White LED



Functional Components

LED Chip:

- Epitaxial structure
- Chip structuring
- …

Package:

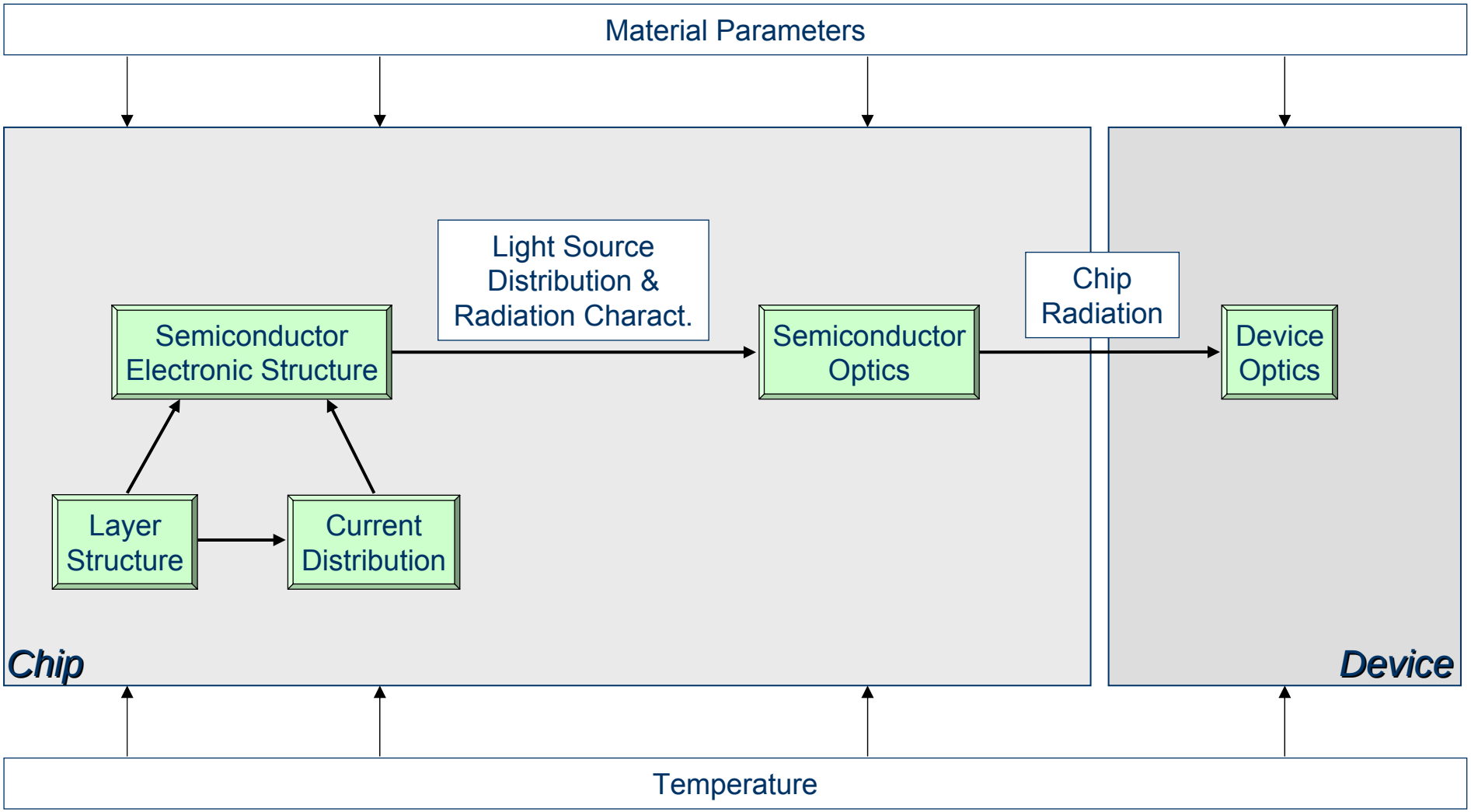
- Reflector (Reflectivity, geometry)
- Resin (Refractive index, geometry)
- …

Phosphor:

- Material
- Particle sizes / shapes
- …

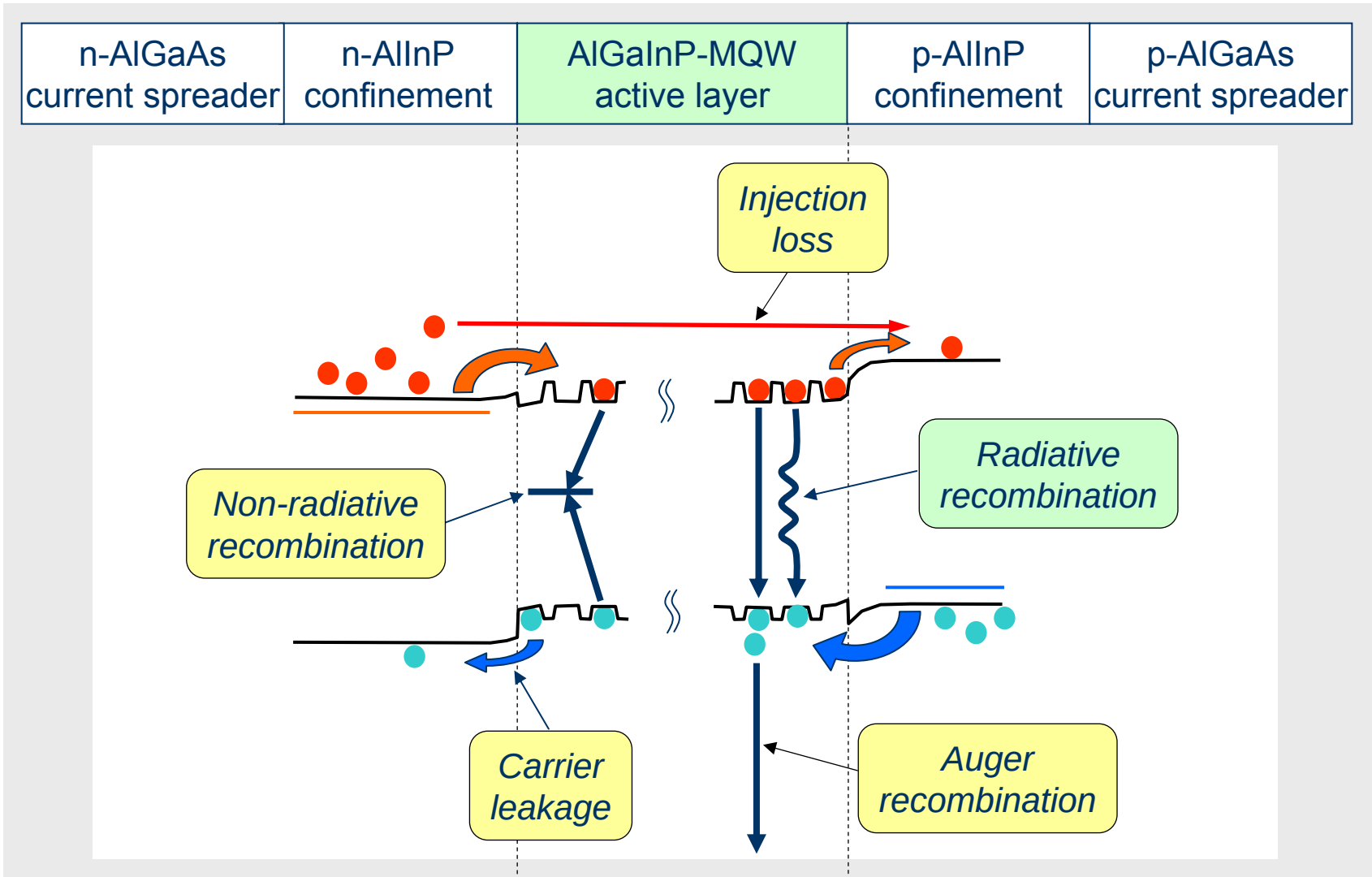
- LED Design requires consideration of chip, package, phosophor (and secondary optics)

CAD Model for LED Design



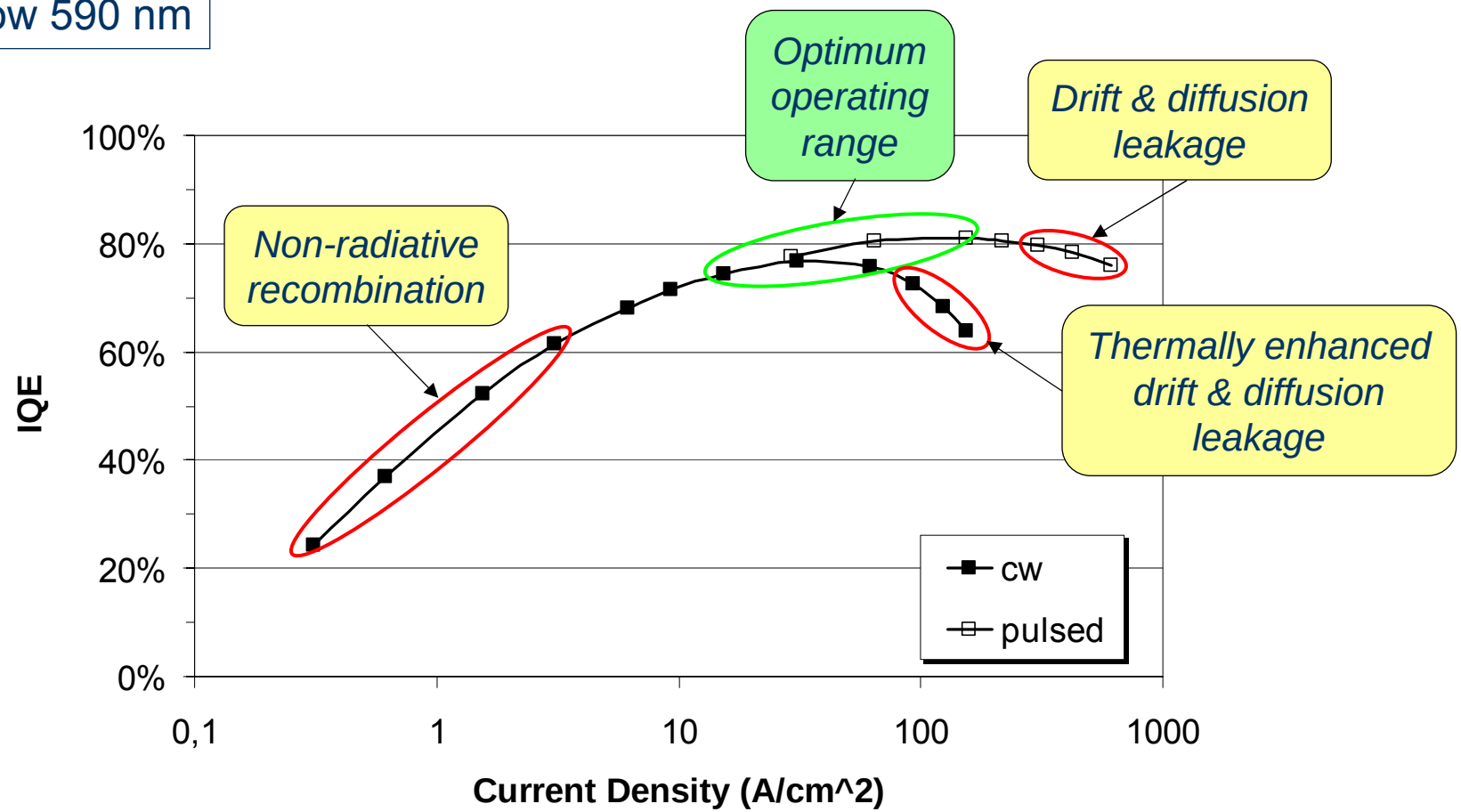
Semiconductor Layer Structure Design & Internal Efficiency

Internal Quantum Efficiency (IQE): Recombination & Loss Mechanisms



IQE: Current Dependence & Dominant Loss Mechanisms

AlGaInP-LED
yellow 590 nm



Semiconductor Layer Structure: Device Simulation

Semiconductor Device Simulators based on

- Poisson‘s equation + carrier continuity
- Drift-diffusion transport equations
- Carrier statistics

+ optional refined models, e.g.

- Thermionic emission
- Tunneling
- Quantum states
- …

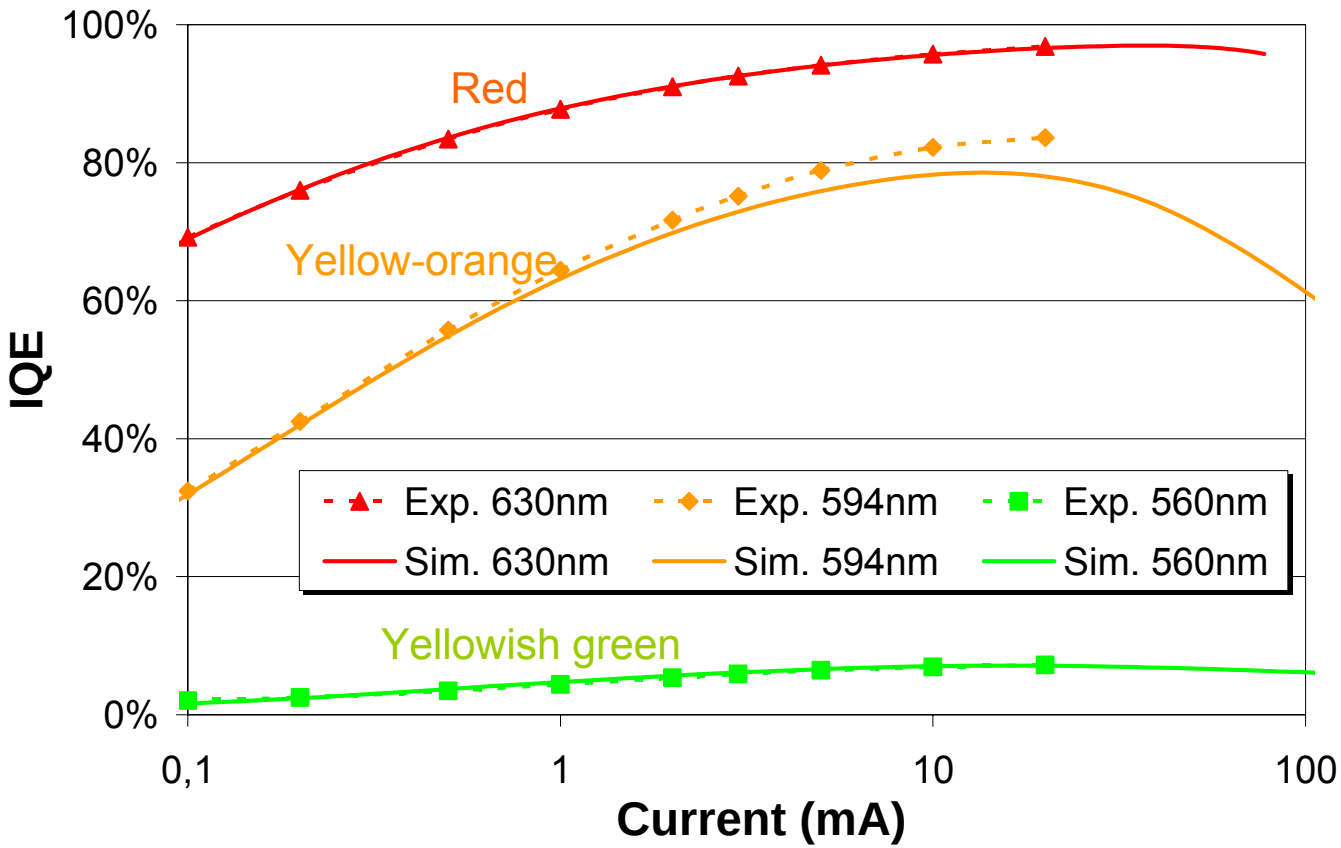
Essential: Generation-recombination terms

Spontaneous Emission (Rad. rec.): $R_{rad} = B(np - n_i^2)$

Non-radiative recombination: $R_{non-rad} = \frac{np - n_i^2}{\tau_p (n + n_T) + \tau_n (p + p_T)}$

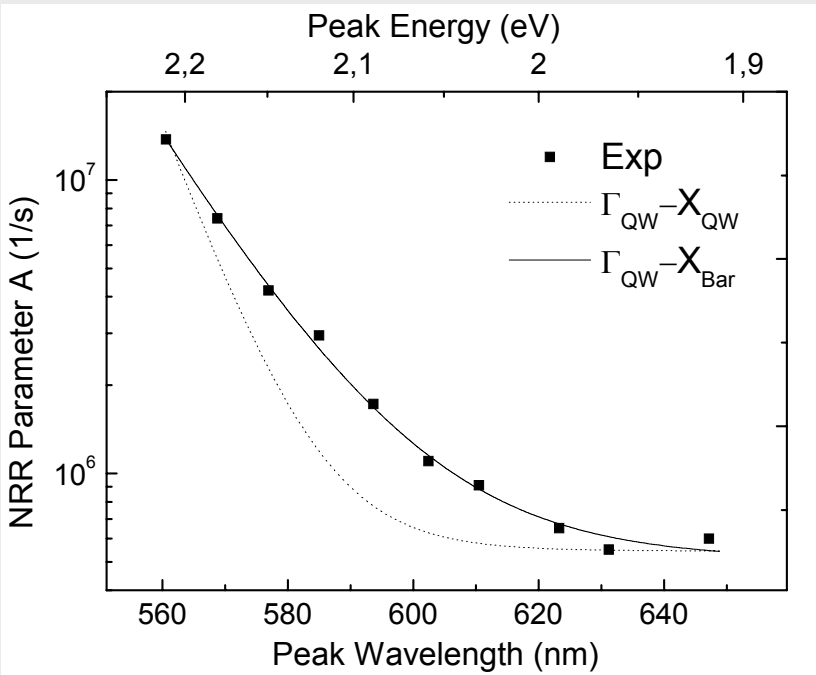
IQE: AlGaInP-LEDs of Various Colors

Experimental and simulated IQE characteristics of AlGaInP-LED test structures at 630 nm, 594 nm, and 560 nm



IQE: Parameter Dependence of Models

- Precise parameter calibration is essential for reliable structure analysis / design
- Some parameters (e.g., the non-radiative coeff.) depend critically on material properties, i.e. the epitaxial growth conditions, doping profiles, processing parameters, …

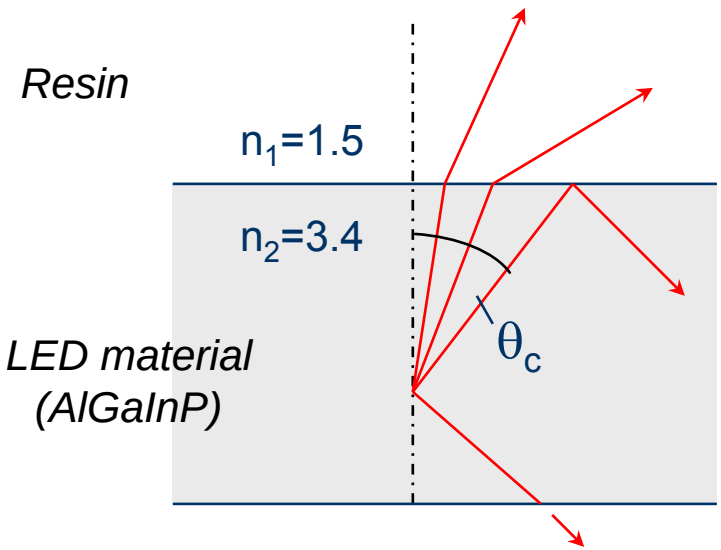


Non-radiative recombination rate of $(Al_xGa_{1-x})_{0.5}In_{0.5}P$ as a function of the Al content

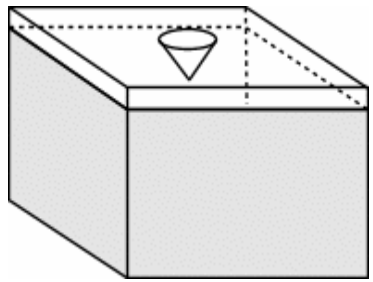
- Quantitative model-based epitaxial design is impossible in many cases

Semiconductor Optical Design & External Efficiency

Light Extraction: Total Internal Reflection



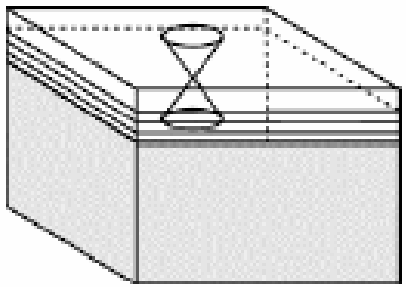
Critical angle: $\Theta_c = \sin^{-1}(n_1 / n_2)$



Top Escape-Cone (AlGaInP in Epoxy):
$\eta_{ex} \approx 4\%$

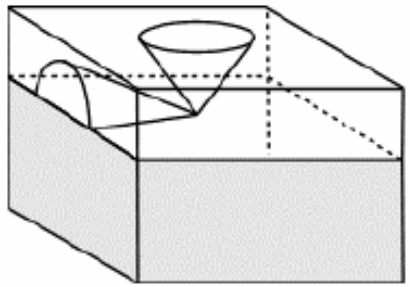
Light Extraction: Classical solutions

More escape cones …



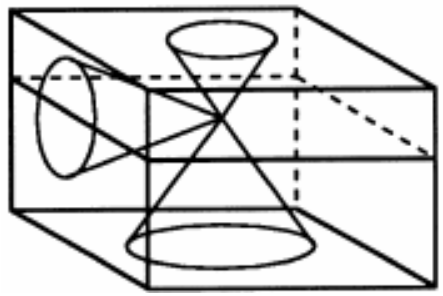
η_{ex} ~ 8 %

- DBR mirror



~ 12 %

- thick window layer

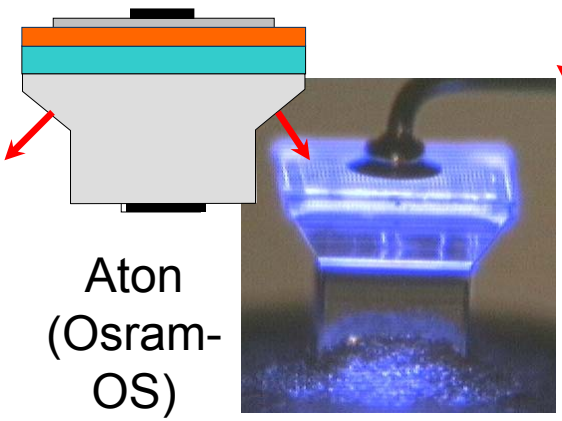


~ 24 %

- transparent substrate
- thick window layer

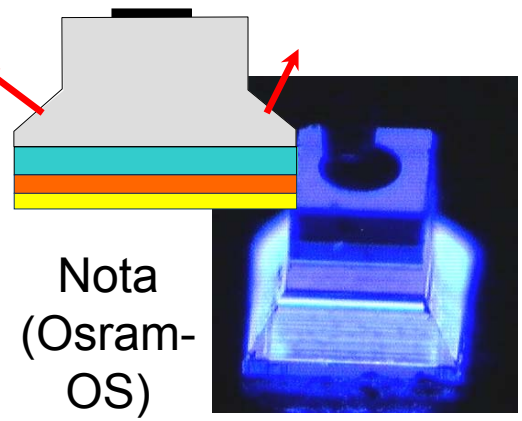
and chip shaping

TIPLED (Lumileds)



Aton (Osram-OS)

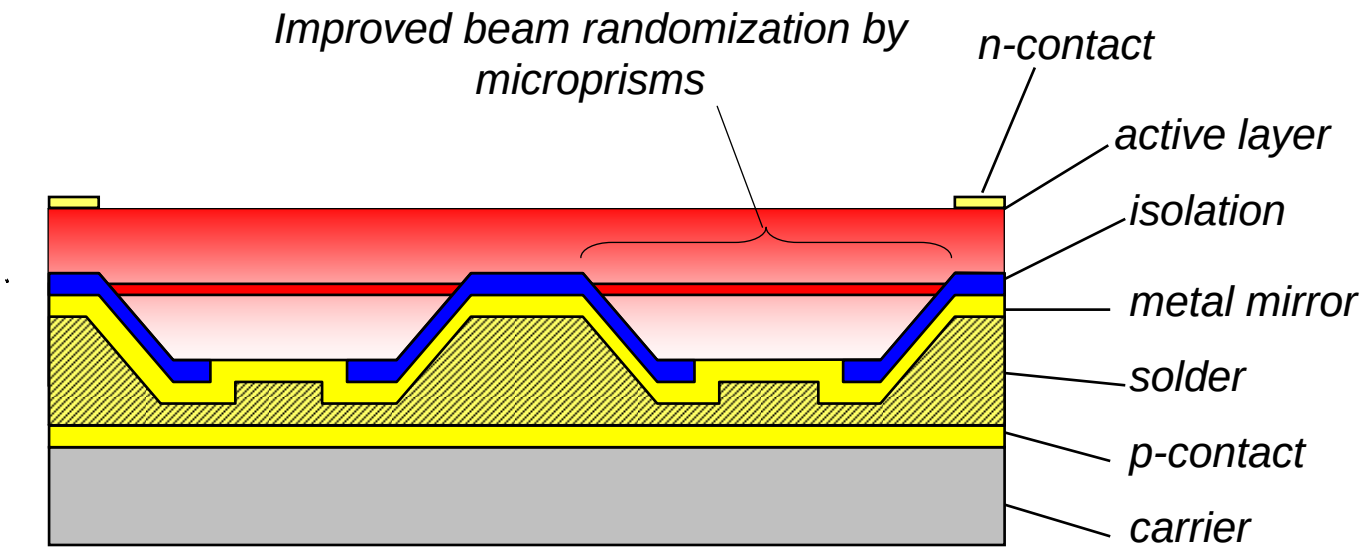
52%



Nota (Osram-OS)

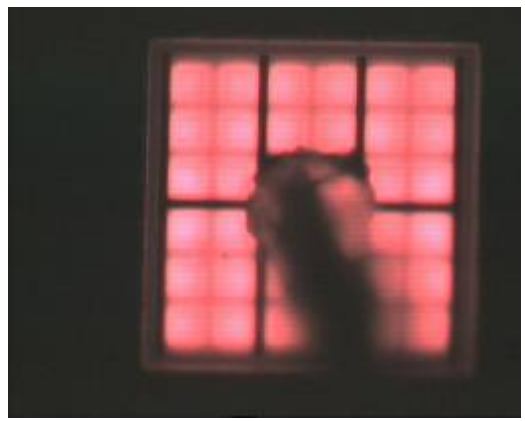
60%

Optimized High-Efficiency Design

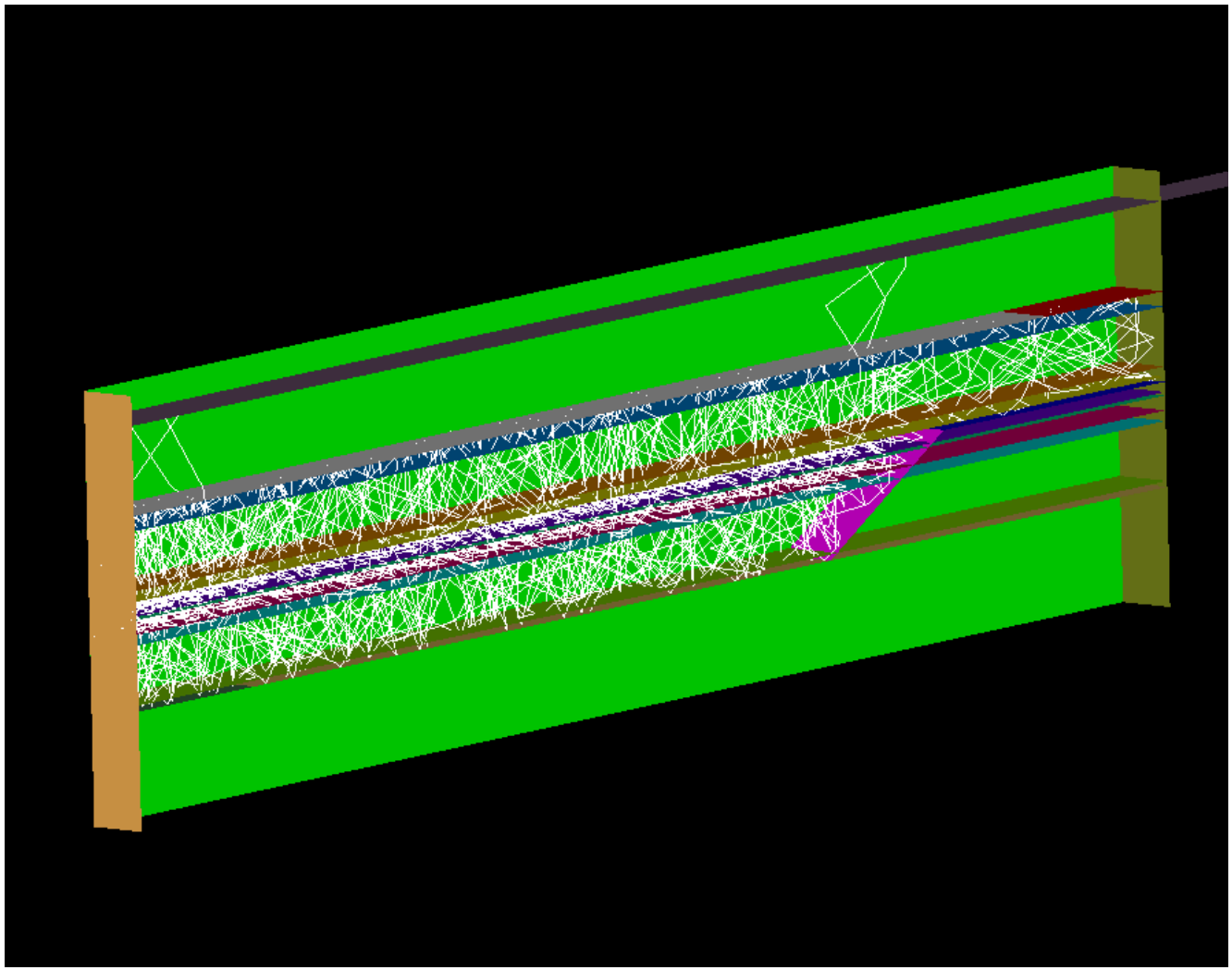


Design elements:

- Microprism geometry
- Mirror design (reflectivity)
- Epi-layer thickness

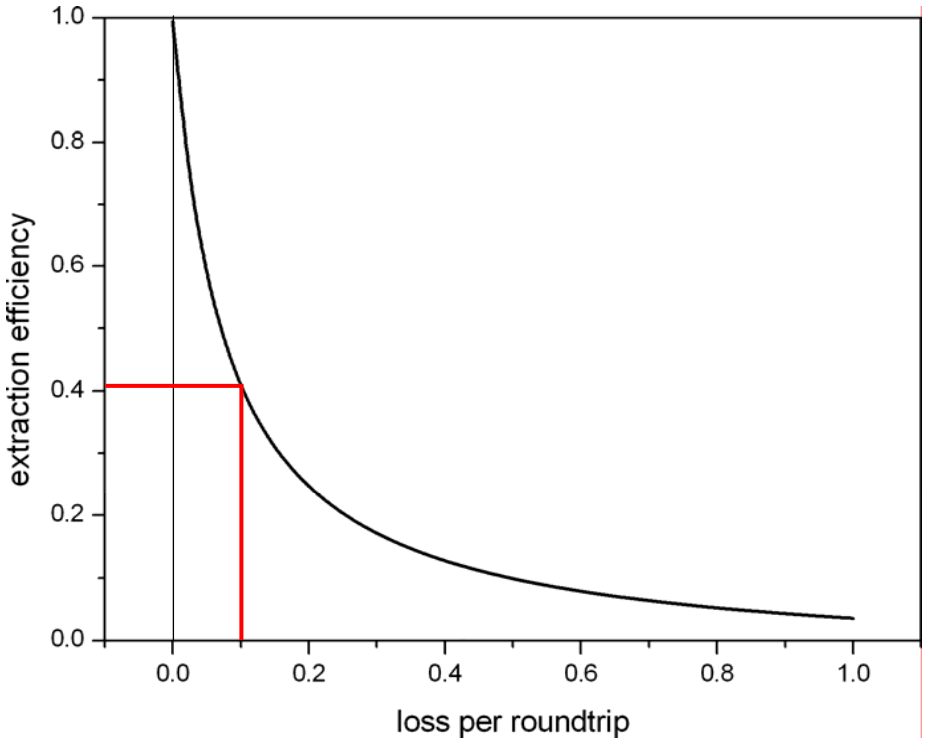


Raytracing Model of Thin Film LED



ThinFilm Light Extraction: Influence of Losses

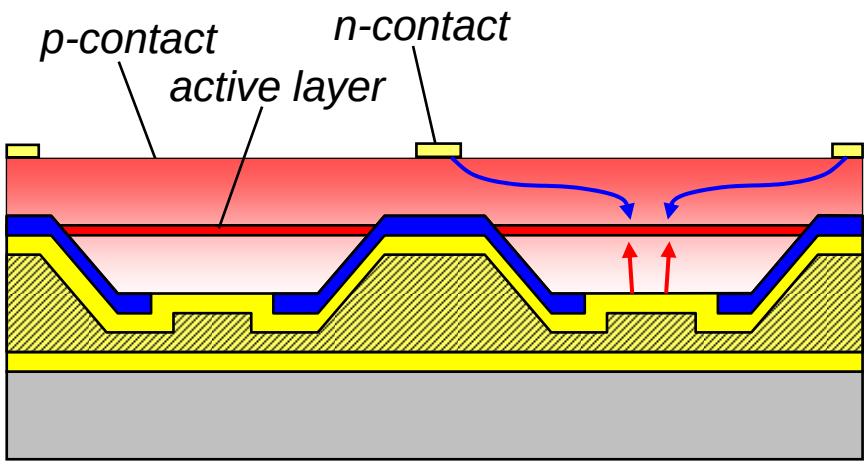
- Extraction efficiency of ThinFilm LED depends critically on round-trip losses:



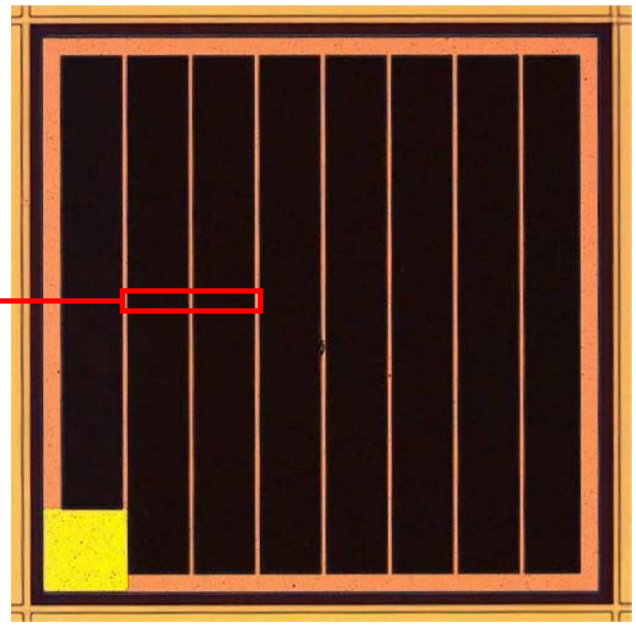
- Accurate modelling requires precise knowledge of optical material parameters: reflectivities, absorption coefficients, scattering functions, …

Lateral Current Distribution

Current Spreading



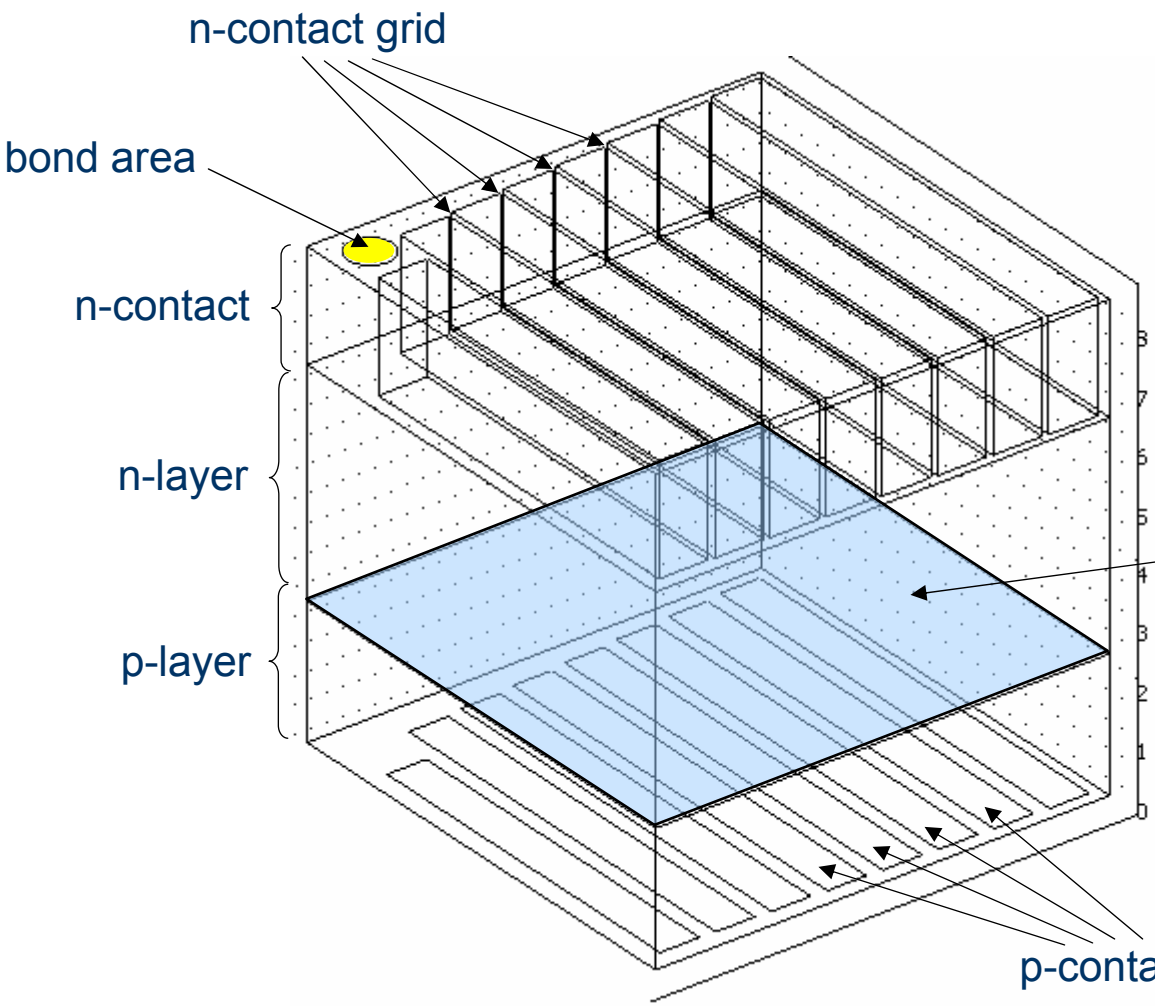
Top view of AlGaInP power chip



Design Targets:

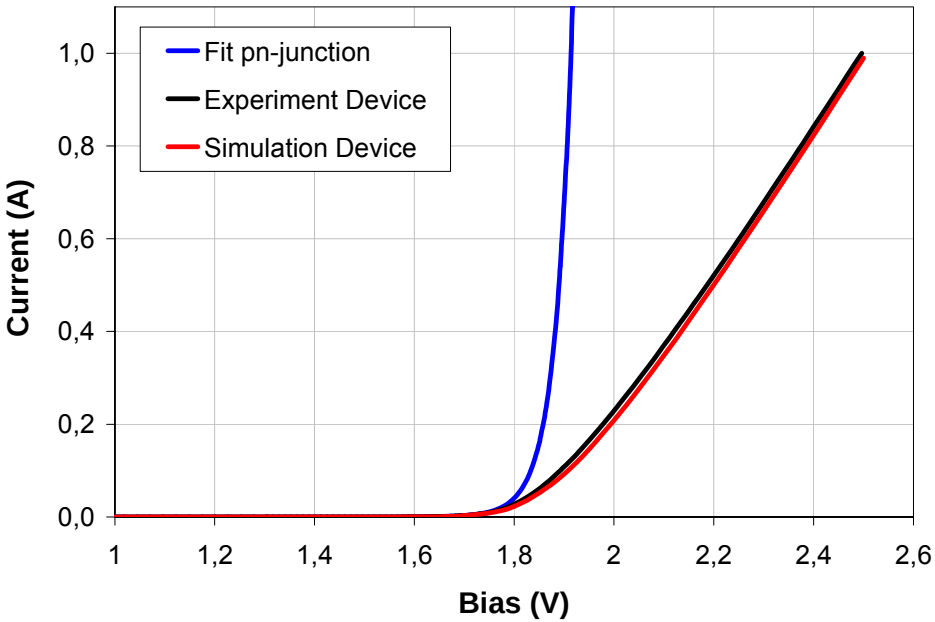
- Homogeneous current distribution
- Minimized contact area
- Minimized contact and layer resistances

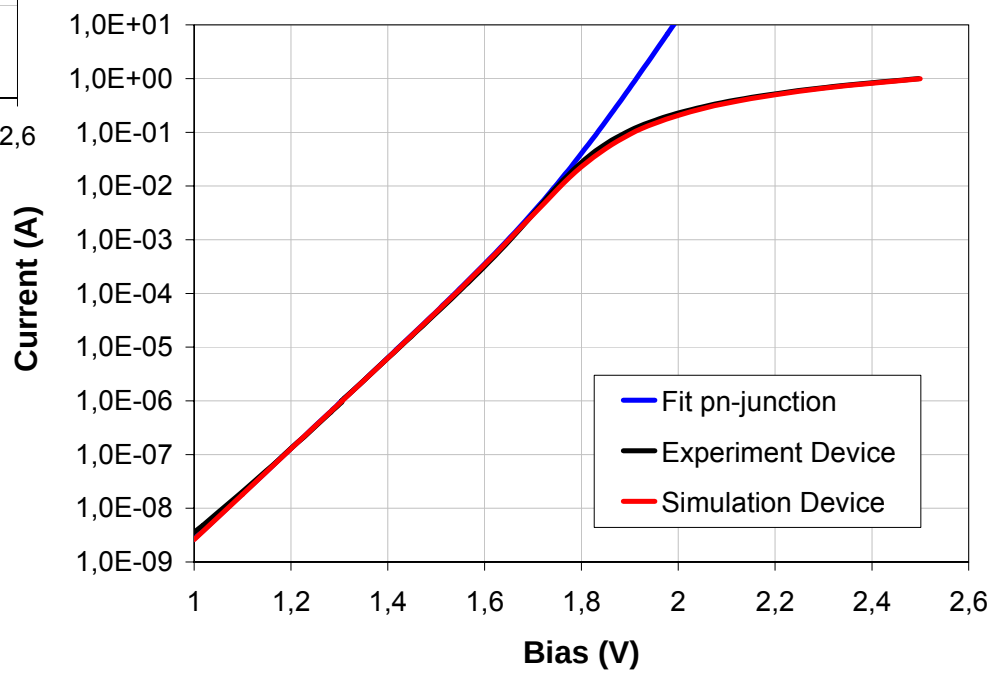
Current Spreading: 3D FEM Model



$$j(\Delta V) = \sum_i j_{0i} e^{\frac{\Delta V}{n_i kT}}$$

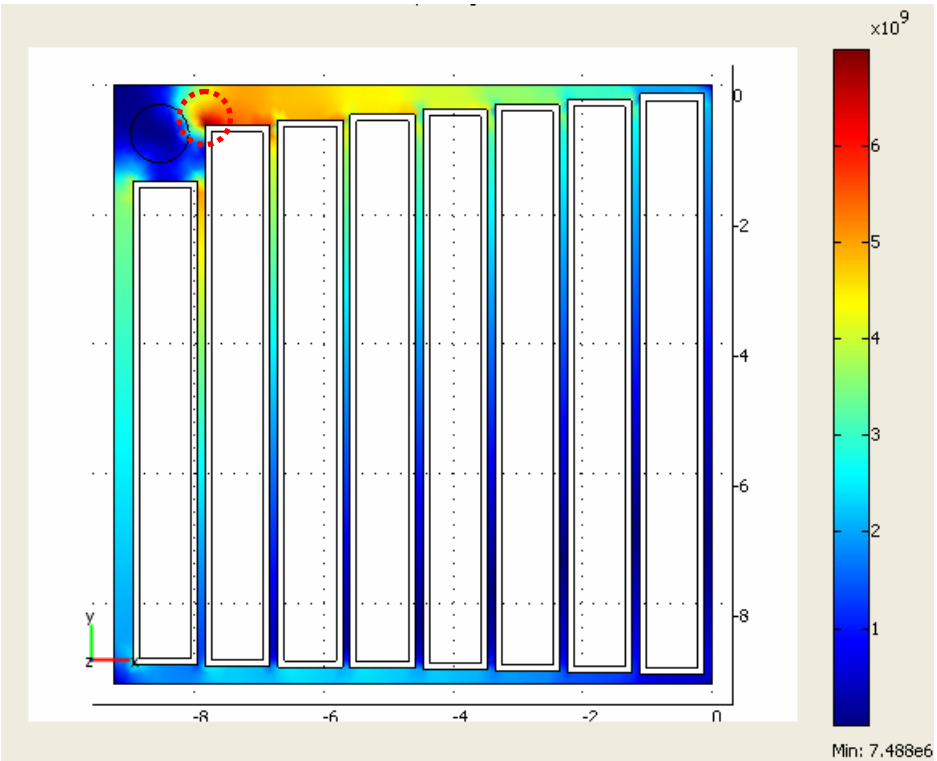
Current Spreading: Calibration of I-V Characteristics



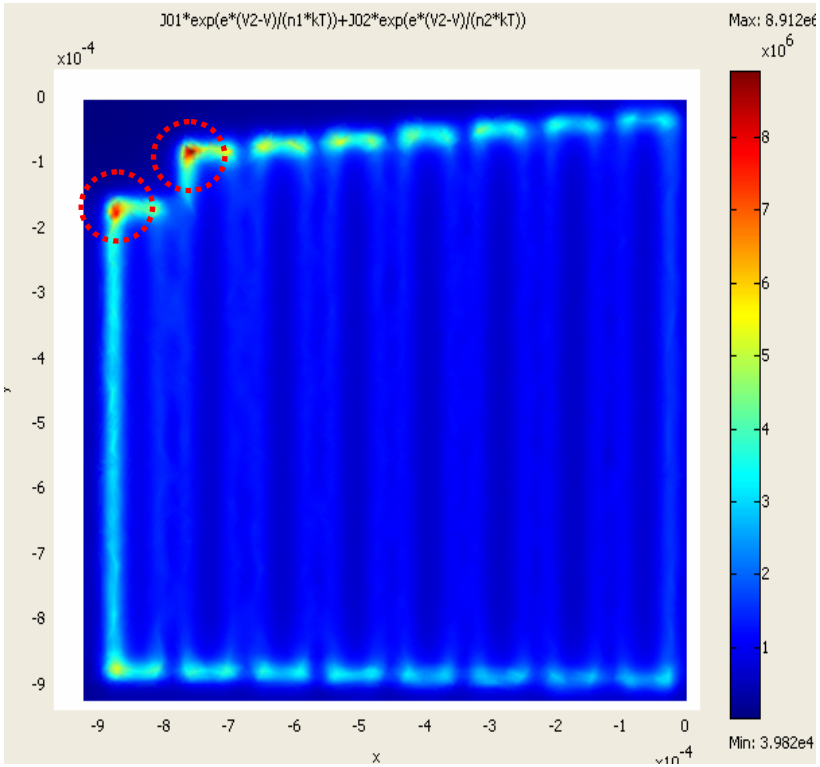


Simulated Current Distributions

Current Density in n-Contact



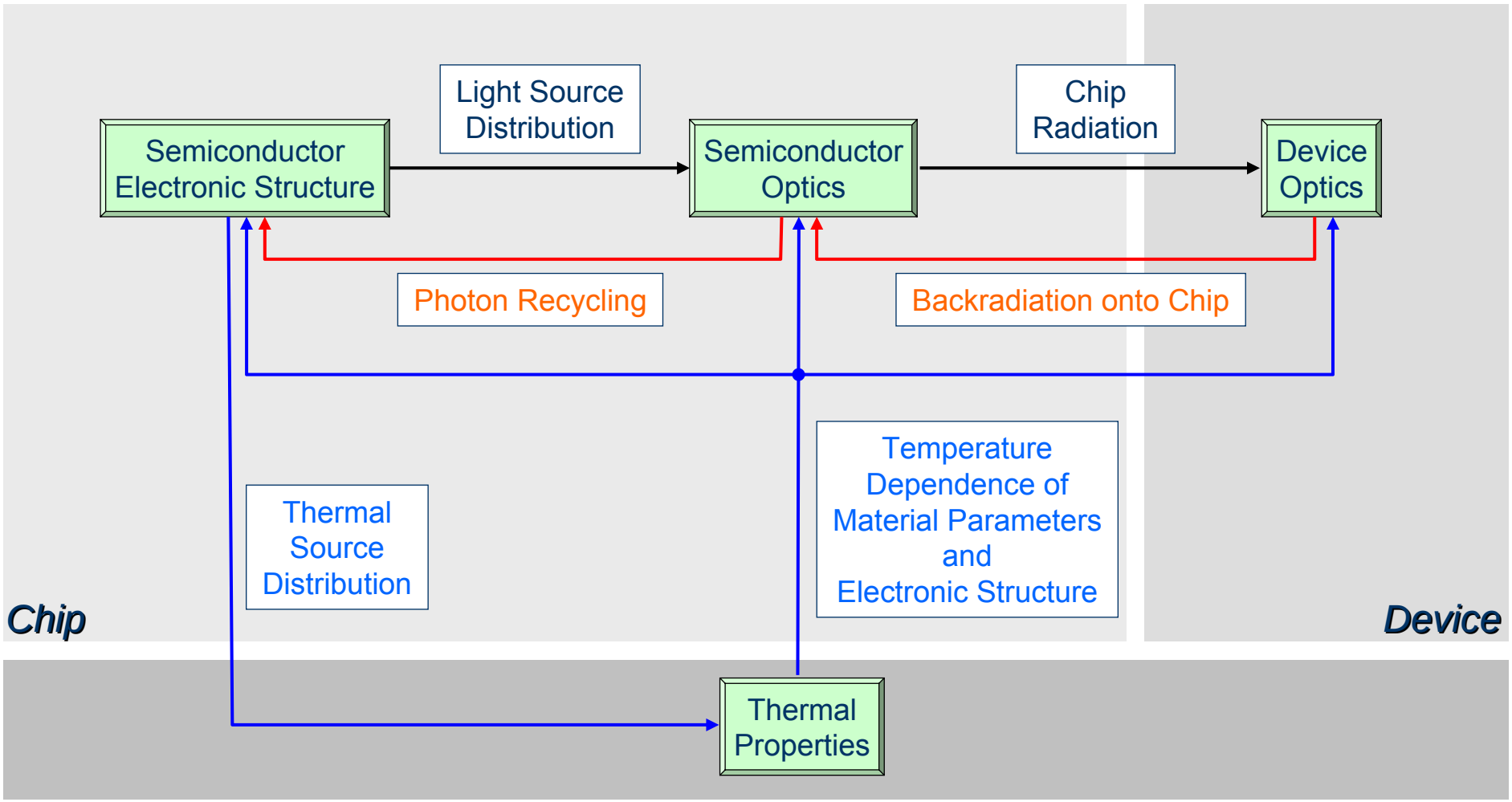
Current Density in pn-Junction



Critical features

Coupled Effects…

Coupling of Model Components



Summary

- Computer-aided design methods are valuable for the LED design process
- Precise parameter calibration is necessary for quantitative design
- Computer design of complete devices requires advanced computational methods