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# Closing the green gap

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Osram Opto Semiconductors
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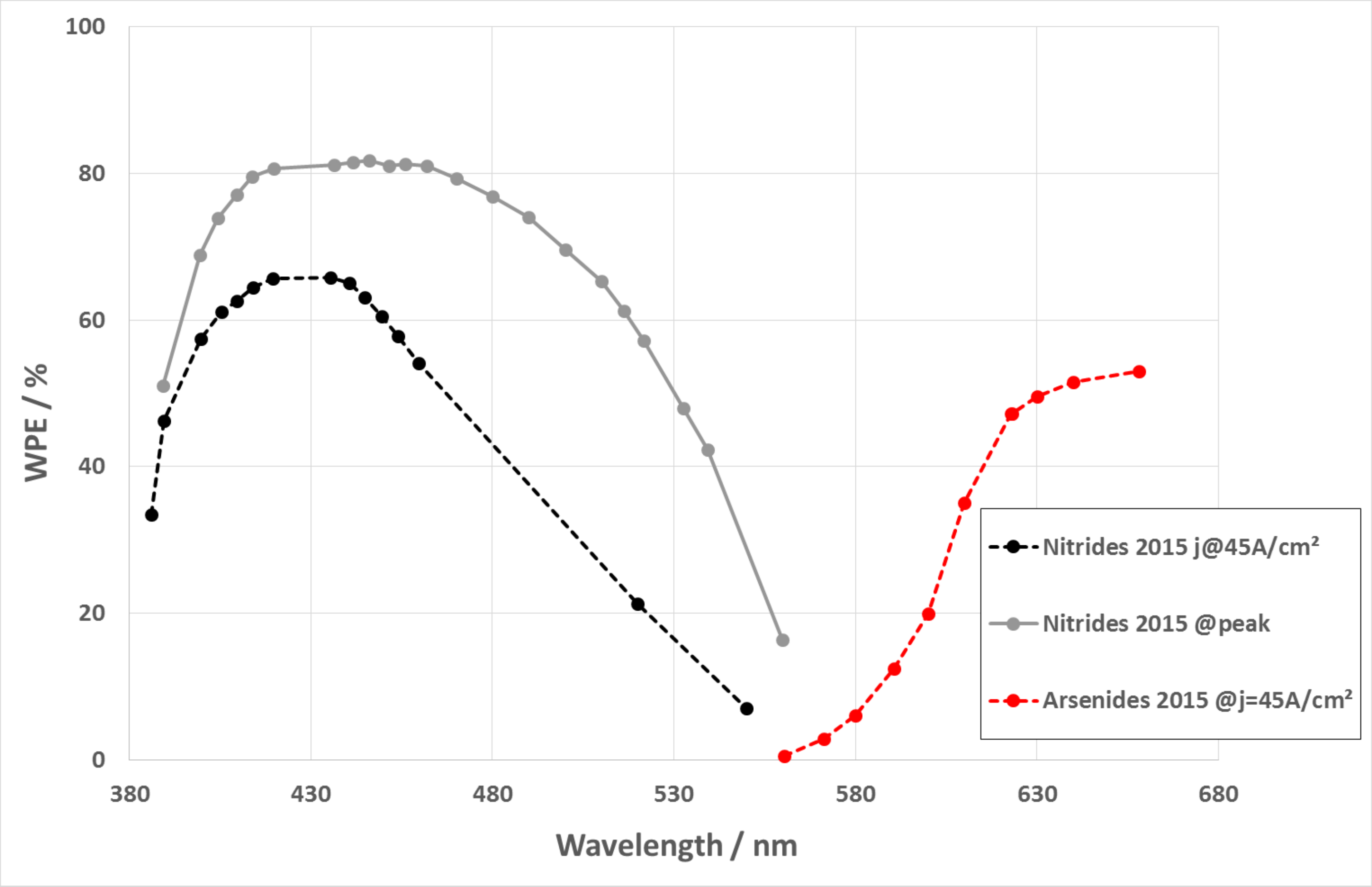
# Wall Plug Efficiency at 350mA/mm²
# Visible spectrum – Status 2015




green gap
- Transport
- Crystal quality (>530nm)

# Closing the green gap

## currently pursued approaches at OS

### 1) direct green LEDs (prior art)

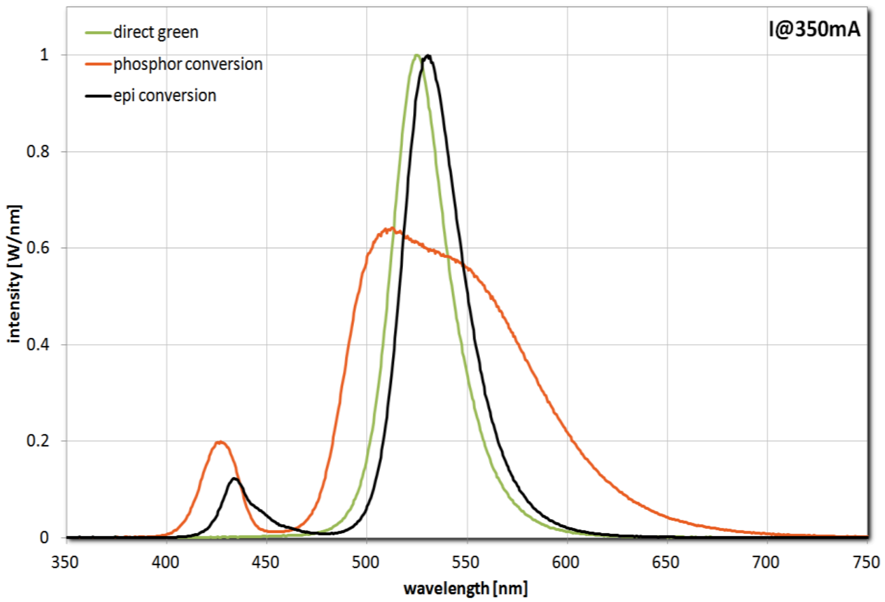
\+ small spectral FWHM – inferior efficiency
\+ single component technology, minimized complexity

### 2) phosphor converted blue LEDs

\+ currently superior efficiency – increased spectral FWHM
– two component technology, higher complexity

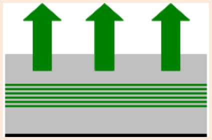
### 3) Hi-Q-LED / epi conversion (2015)

\+ FWHM comparable to direct emitting LEDs
o efficacies outperform direct green LEDs in some applications
– two component technology, higher complexity




### 4) new generation of direct green LEDs (2018)

\+ small spectral FWHM + superior efficiency
\+ single component technology, minimized complexity

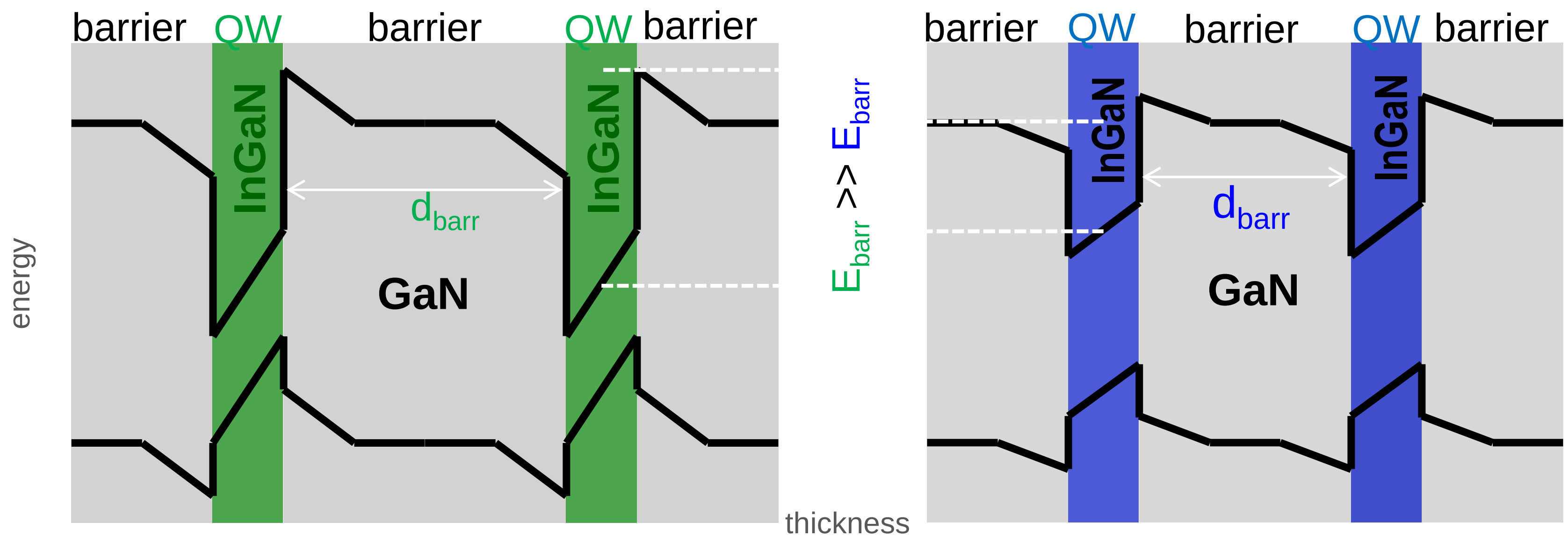


+40% efficacy

# closing the green gap

## disruptive approach

### what is primary efficacy limitation of green InGaN LEDs?




green LEDs have
- higher barriers
- thicker barriers

→ higher forward voltage

available options:
- lower barriers
- thinner barriers

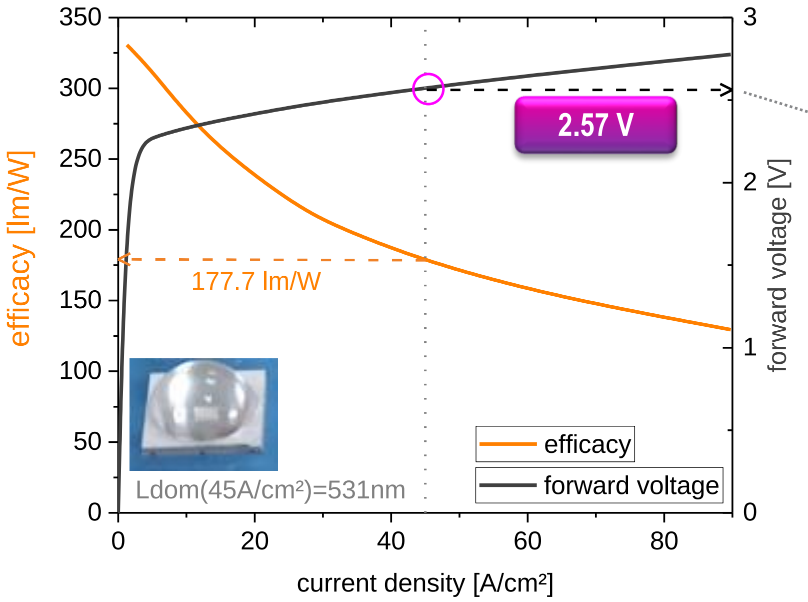
→ epitaxial quality too low for high In content QW

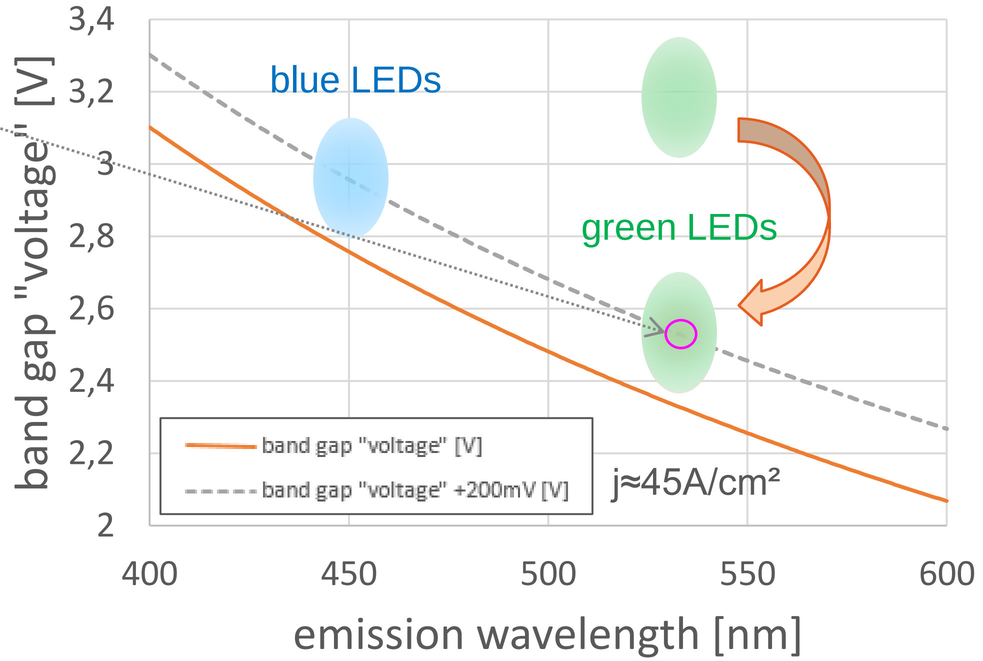
disruptive approach:

→ „bypass" barriers

# 40% efficacy boost for InGaN based green products

accompanying press release: http://www.osram-group.com/en/media/press-releases/pr-2018/08-05-2018
→ *Longer battery life for fitness trackers: Osram increases the efficiency of green LEDs by 40 percent*




- only approx. +200mV offset to theoretical voltage limit now available up to 545nm

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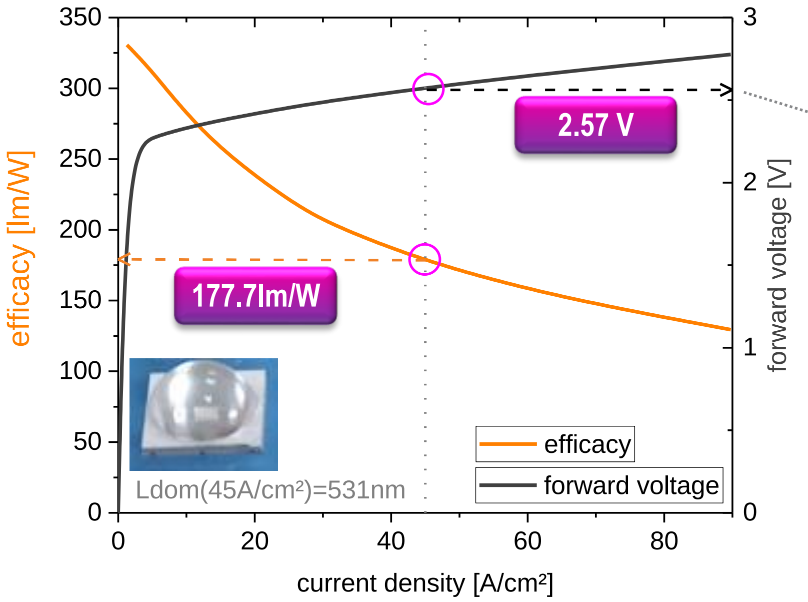


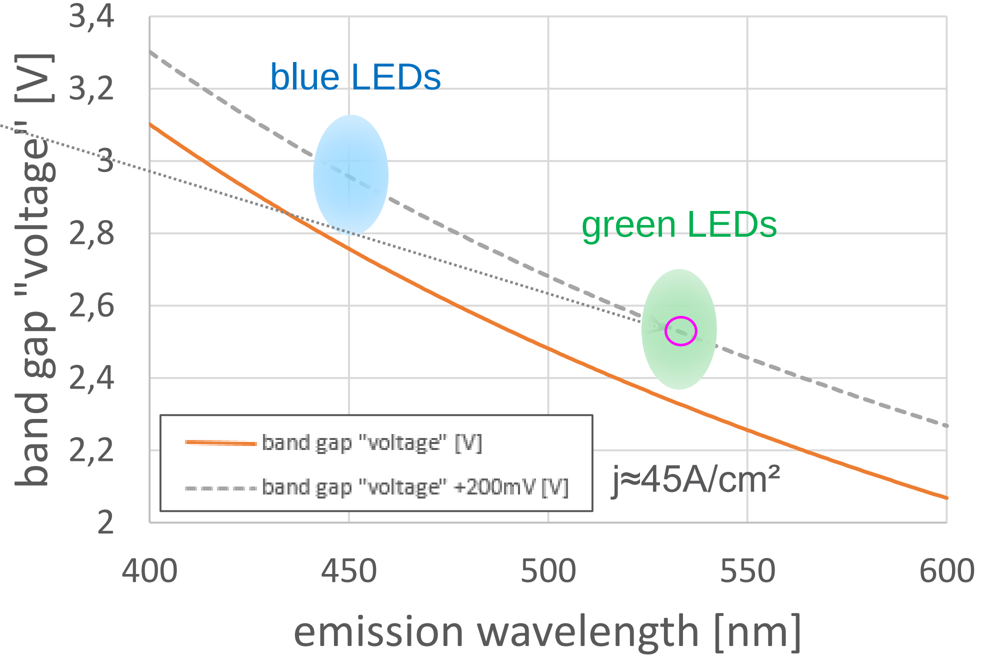


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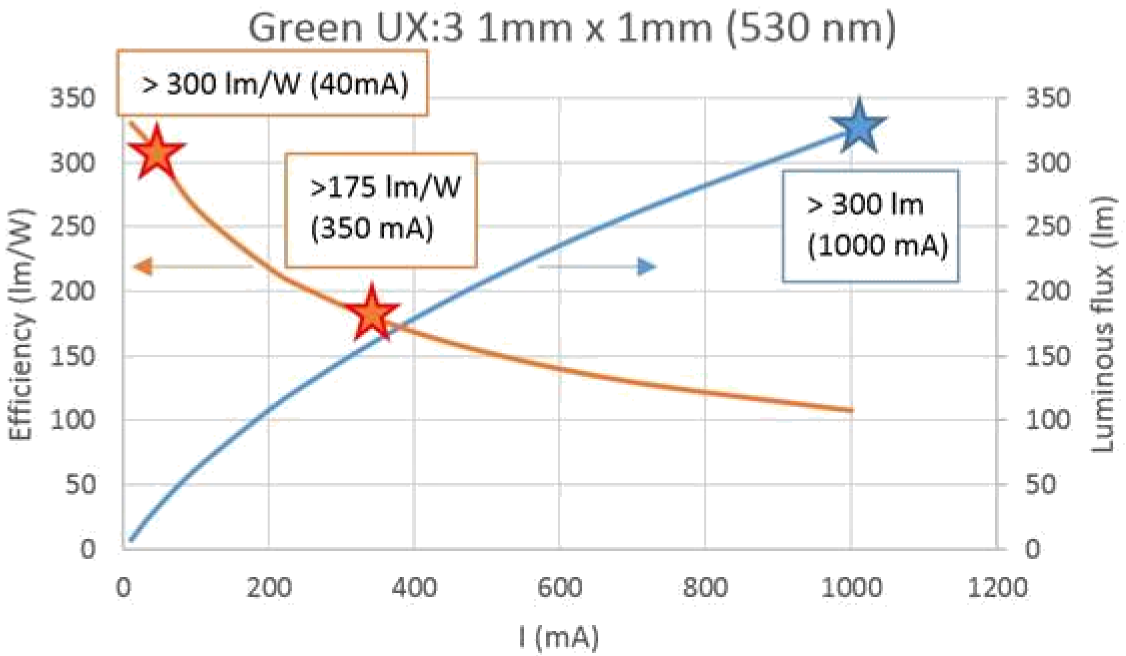


- only approx. +200mV offset to theoretical voltage limit now available up to 545nm
- 177lm/W is highest reported efficacy value for direct green InGaN LEDs at standard *j*
- even >300lm/W at application significant current densities (e.g. 40mA in 1mm² die)
- chip processing remains unchanged

  → **proven quality of UX:3 technology still utilized**


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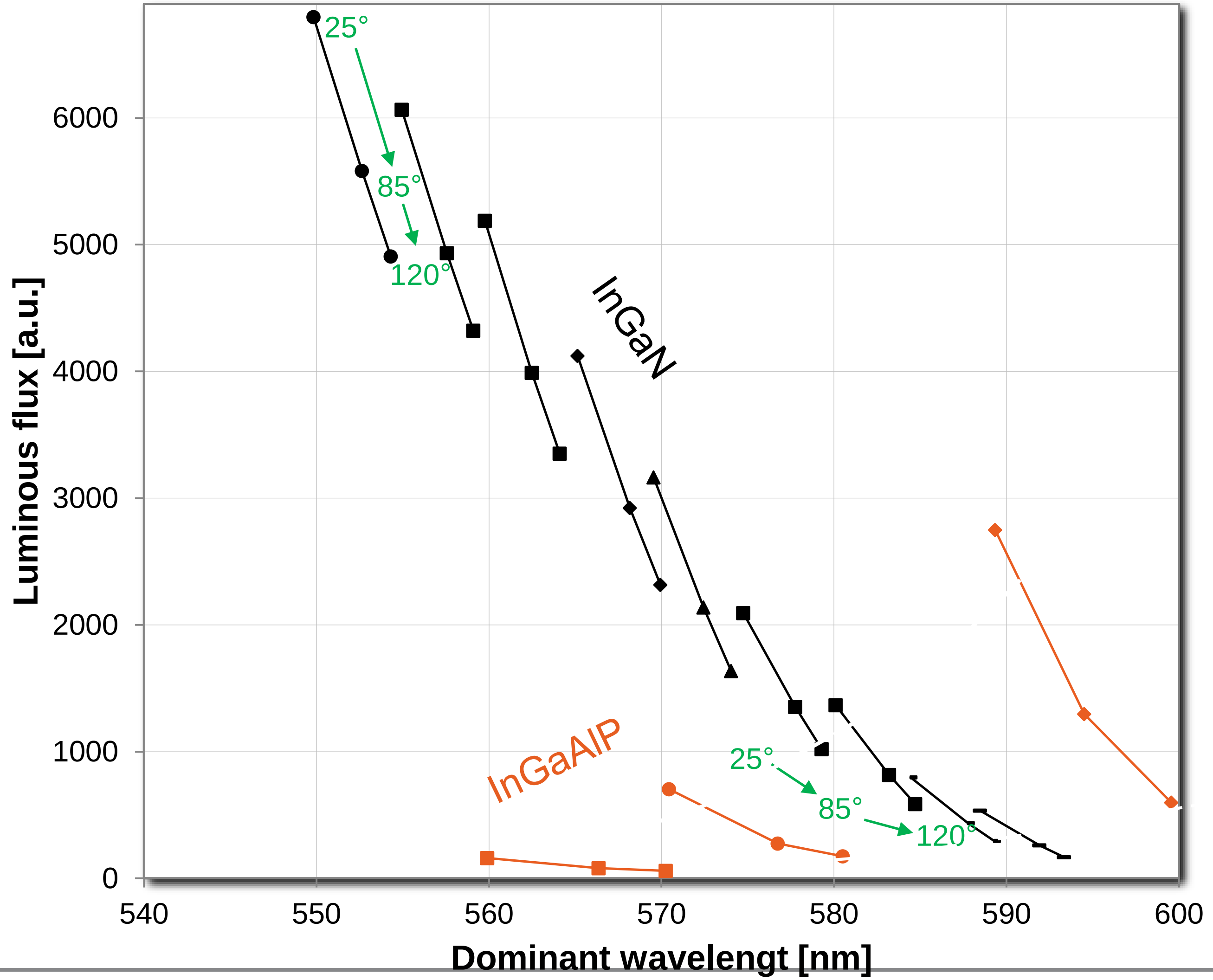
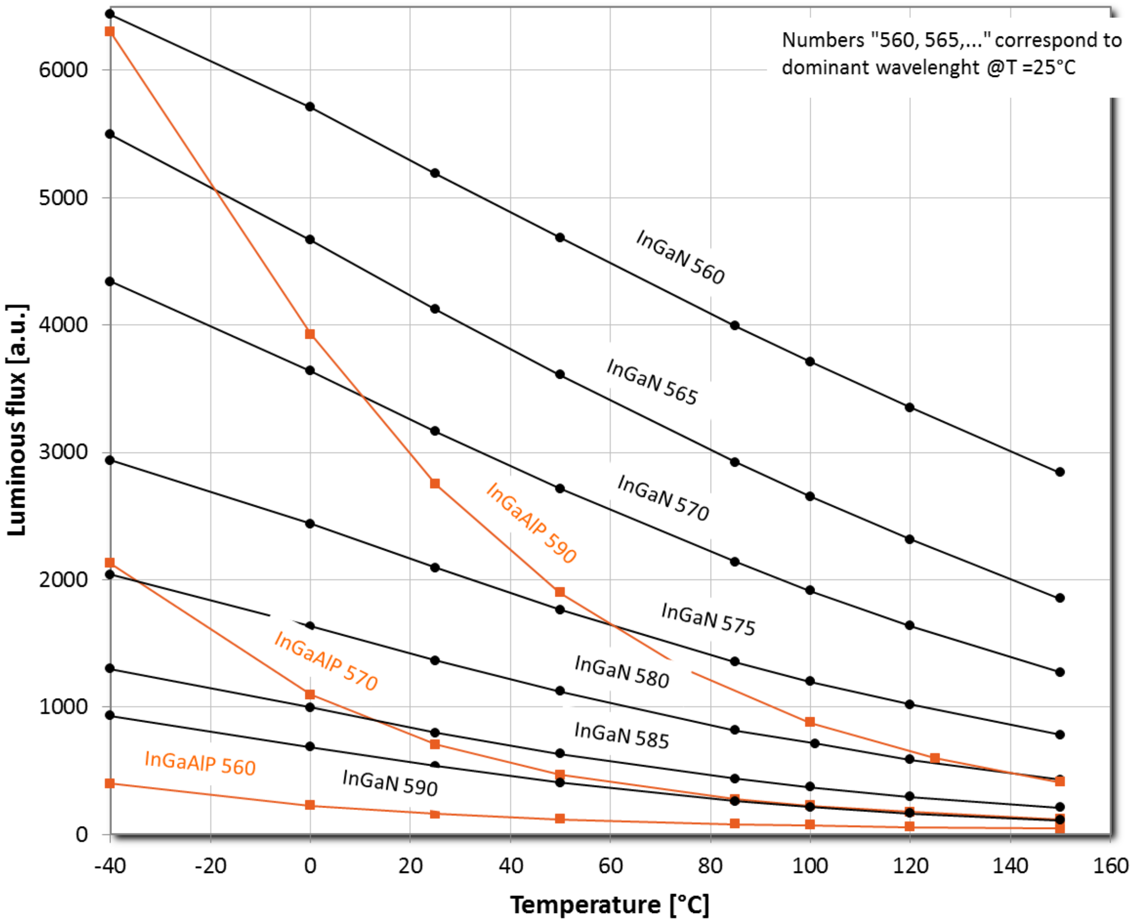
# phi_v 20 mA




**Much higher light output for InGaN at 560 nm (x30) and 570 nm (x4)**

@ 25°C: **crossing of Phi_v at about 578 nm Ldom.**
@ 120°C: **crossing at about 588 mm Ldom.**

# InGaN potentials beyond 550nm




- new approach paves the way to efficient yellow/red direct InGaN emitters

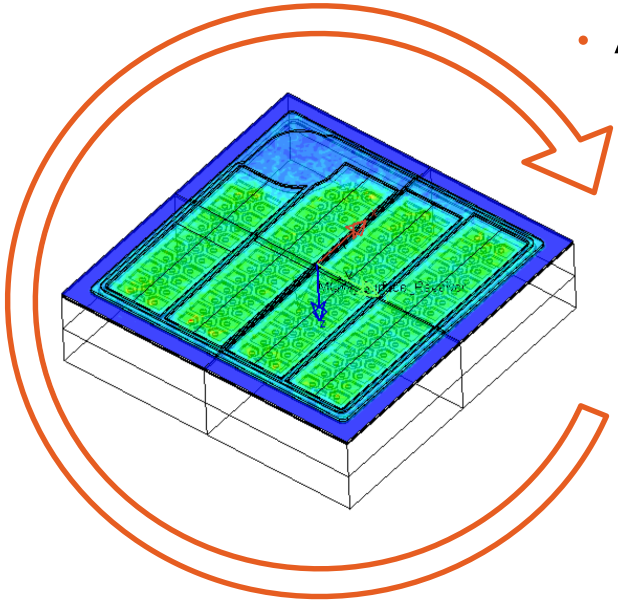
# Device Complexity & Challenges

## Example of a typical InGaAlP LED

### Thermal aspects
- Self-heating of the device
- Package-Design

### Optical Characteristics
- Material absorption / Optical constants
- Contact- & Mirror-Reflectivities
- Active-Region Spectral Power Density

### Electric Properties
- Current-spreading
- Conductivities & Contact-Resistances



Interplay of all aspects

### Geometry
- “Guiding” light inside a device
- Current-Spreading Control

### Transport aspects
- Carrier-Injection / Leakage
- Internal Quantum Efficiency
- Microscopic Bandstructure Engineering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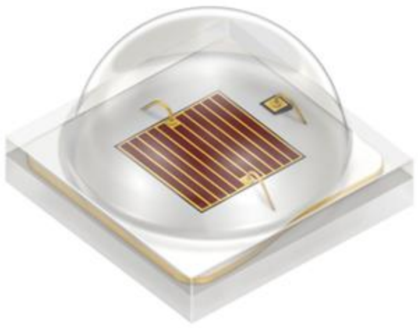
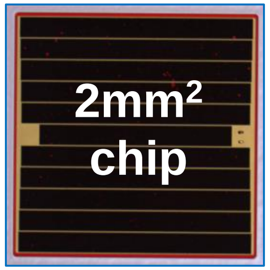
# Horticulture package, chip design & improvements

Confidential

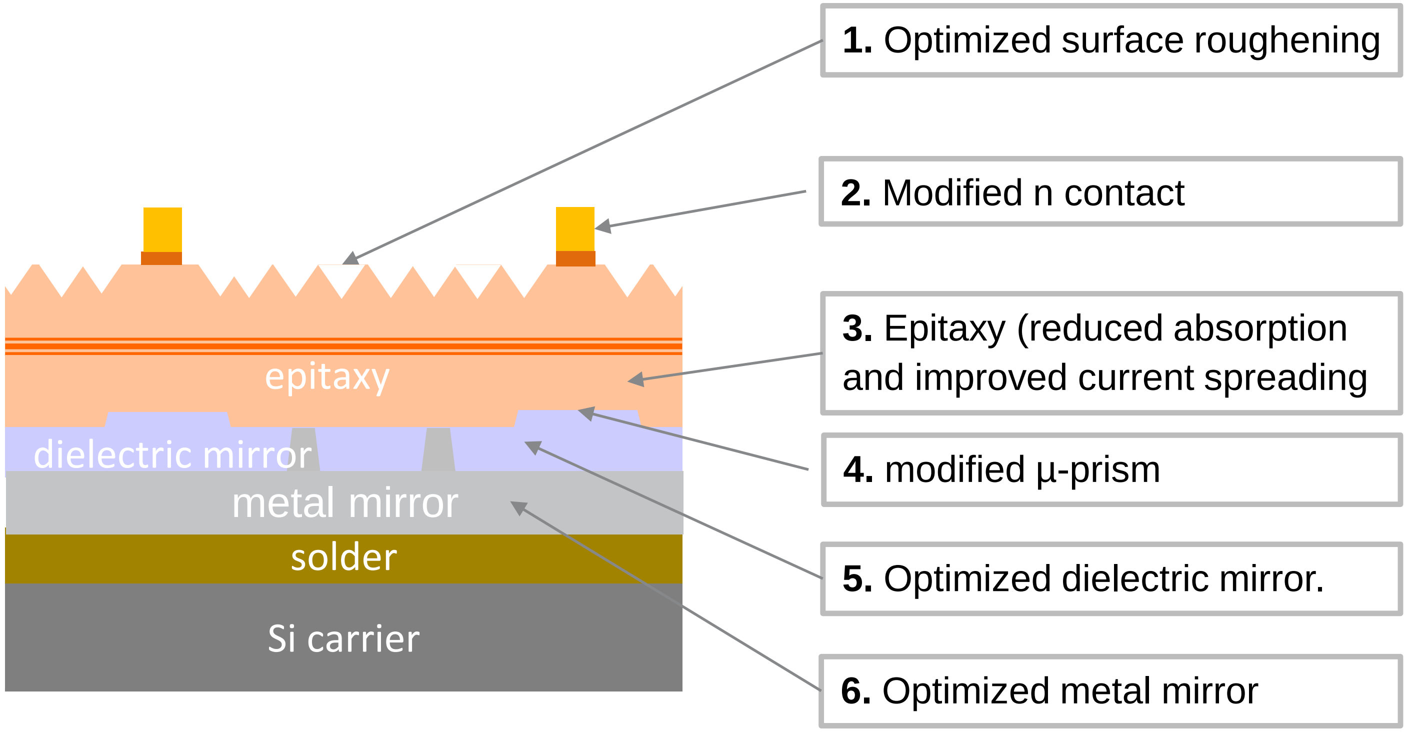
## Oslon Giant package:



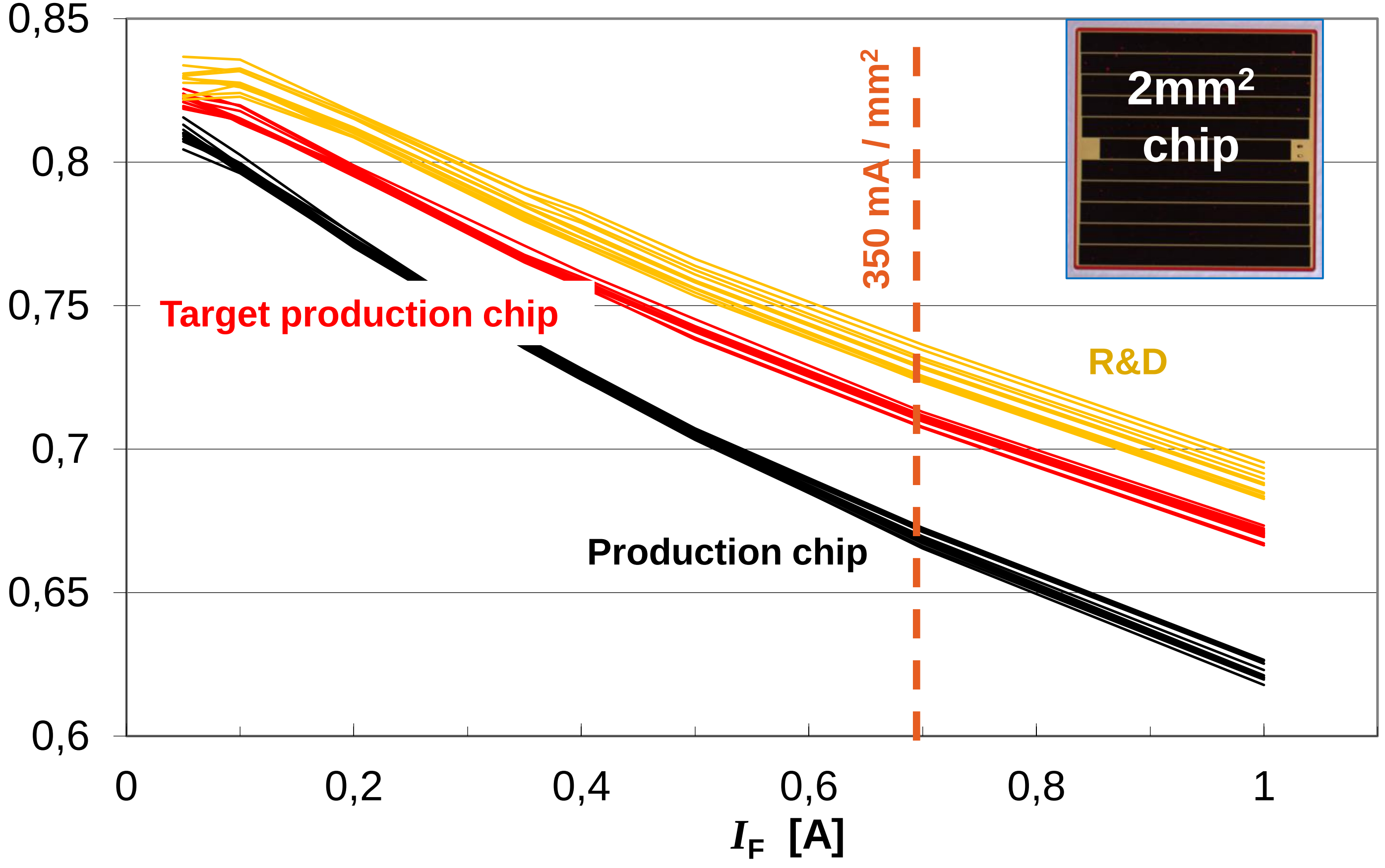
## 2mm Horticulture chip:




## Chip cross section & improvement areas:



# InGaAlP – 660nm – Horticulture WPE performance




**Horticulture WPE in OSLON Giant @ 350mA / 1mm²:**

- **R&D:** ≈73%
- **Target production chip:** ≈70%
- **Production chip:** ≈65%

# Wall Plug Efficiency at 350mA/mm²
# Visible spectrum – Progress 2015→2018