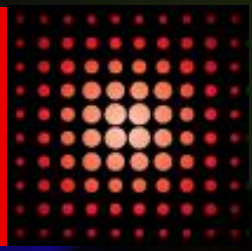
New developments in LED components for SSL



Nicolas Grandjean

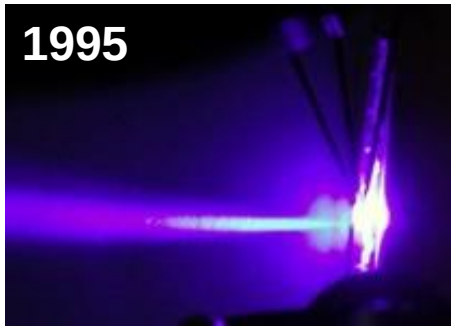
Institute of Condensed Matter Physics
Ecole Polytechnique Fédérale de Lausanne, Switzerland

III-nitride semiconductors

And the “blue” came in the early 90’s

with III-V nitrides (Al,Ga,In)N

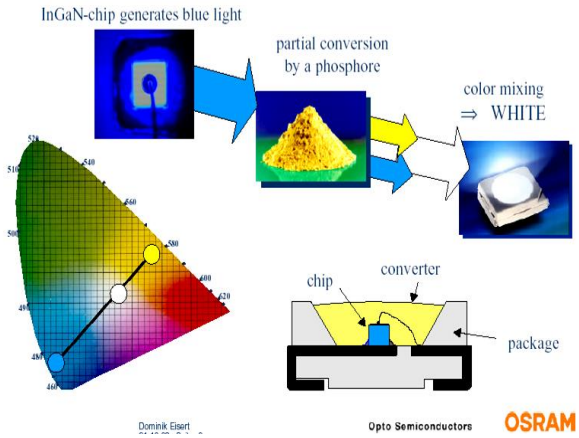
S. Nakamura



S. Nakamura

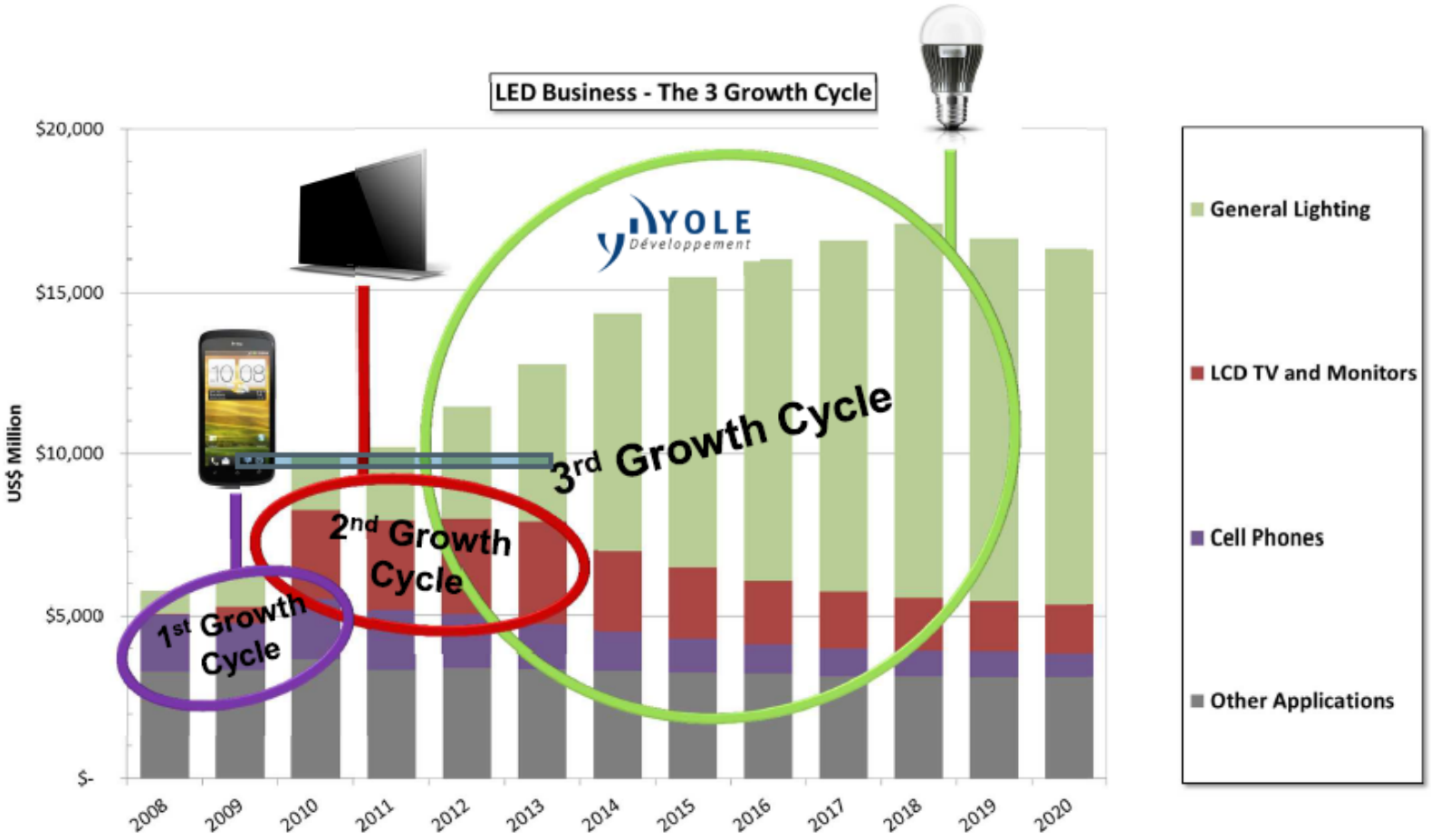
UV, blue, and green LEDs **Color displays, High density DVD**

White LEDs



GaN is the building block of Solid State Lighting

White LED market



White LEDs: cost issue

Incandescent
< $1

Fluorescent
~ $3-$5

LED
~ $10 - $30[1]

$$\text{COST} = \frac{\$}{\text{LUMEN}}$$

Manufacturing Efficiency

- Higher equipment throughput and yields
- Dedicated equipment
- Economy of scale

x3

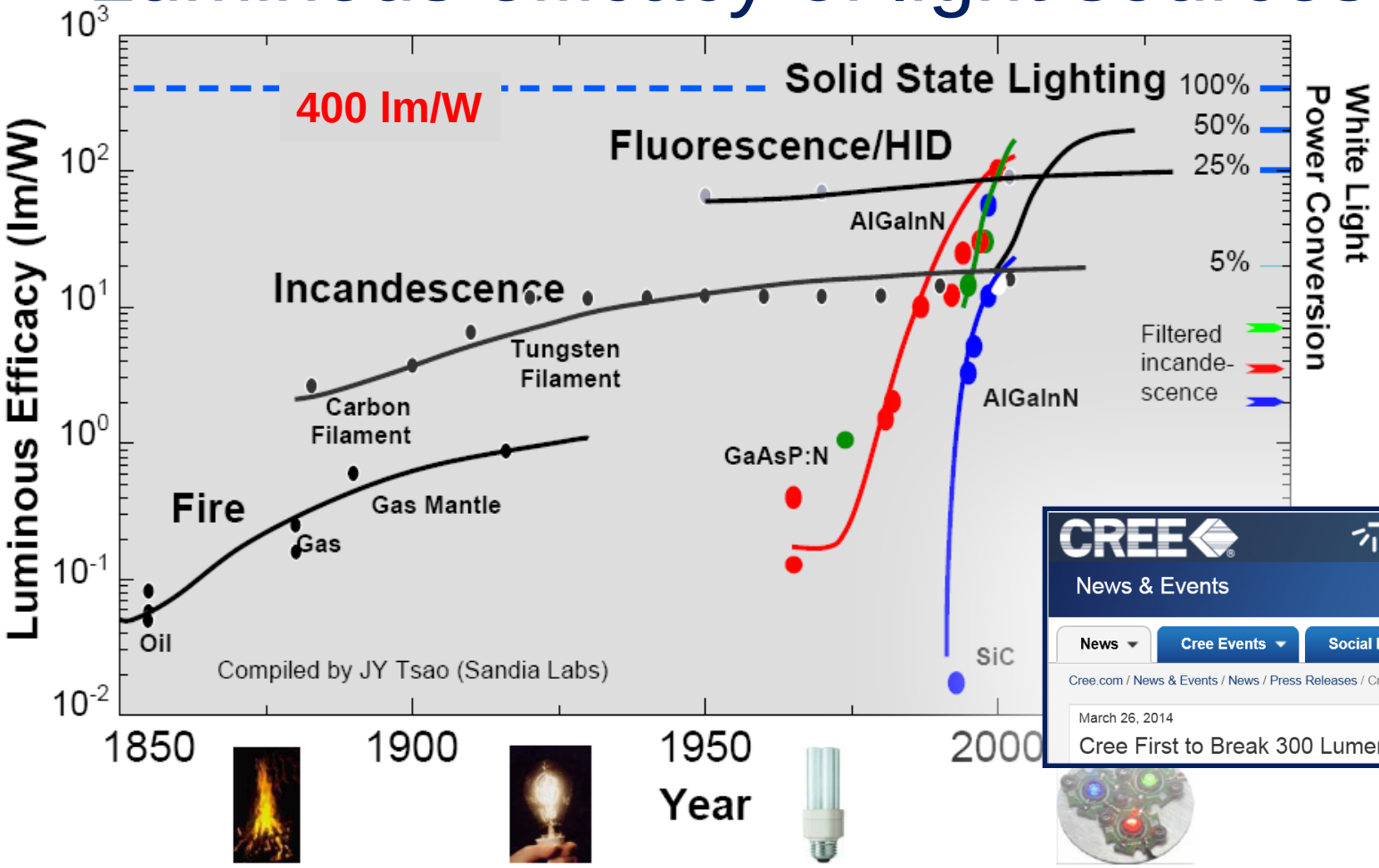
LED Performance

- Higher efficiency (lumen/W)
- More light per chip (driving current)

x2

Light source efficacy

Luminous efficacy of light sources



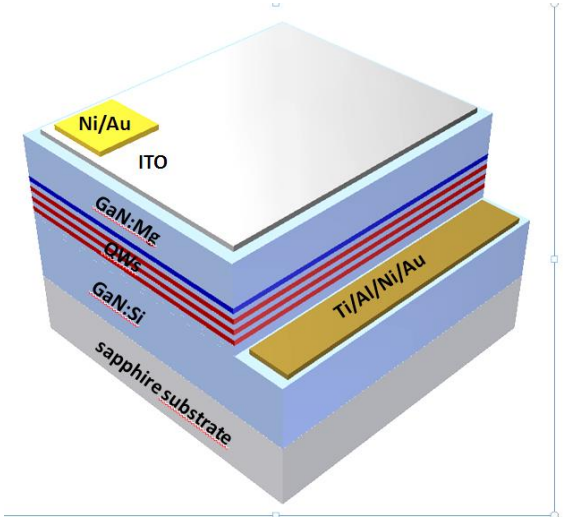
Incandescent lamp: 15 lm/W

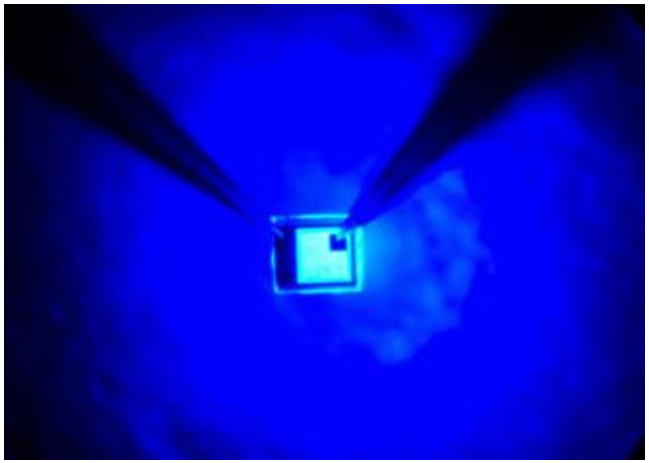
Fluorescent lamp: 50-100 lm/W

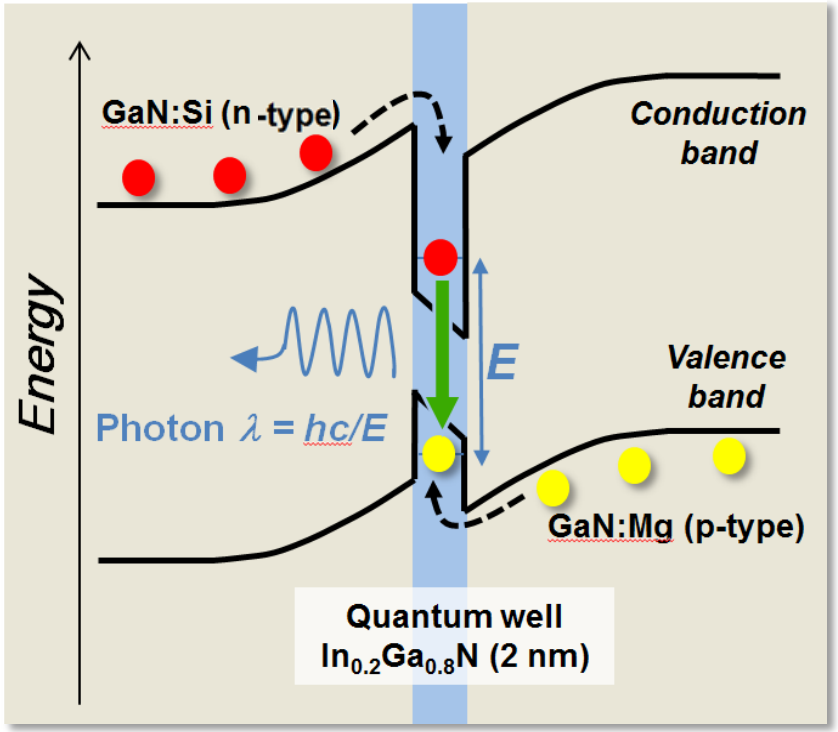
LED lamp: 100 lm/W

Solid state lighting with GaN

How can we make such high efficiency LEDs ?
and how do they work ?



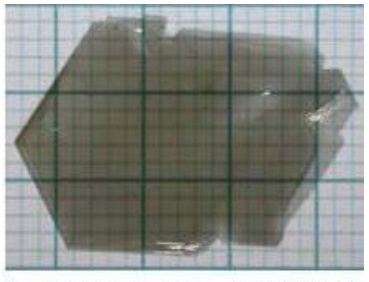




Growth of III-V nitrides

Lack of GaN bulk substrates

produced only at Unipress (PL) - 1 cm²



GaN technology has been developed on foreign substrates

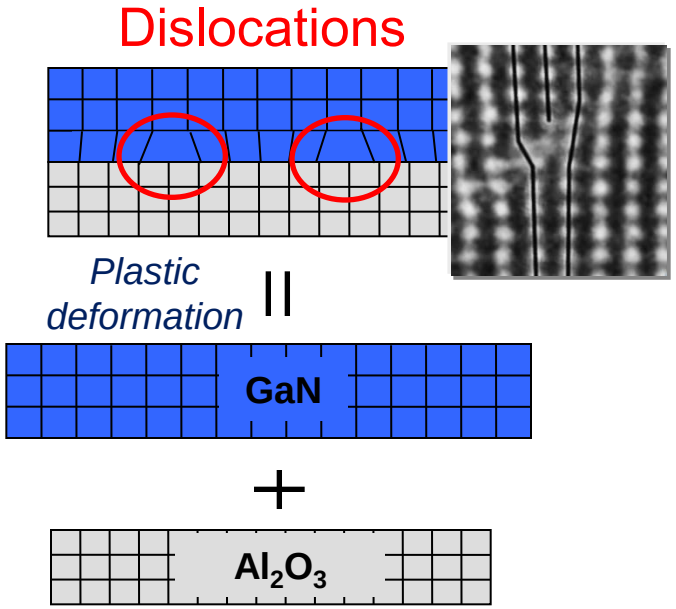
⇨ **Large Lattice mismatch**

Al_2O_3 (0001): +16 %

6H-SiC (0001): -3,5 %

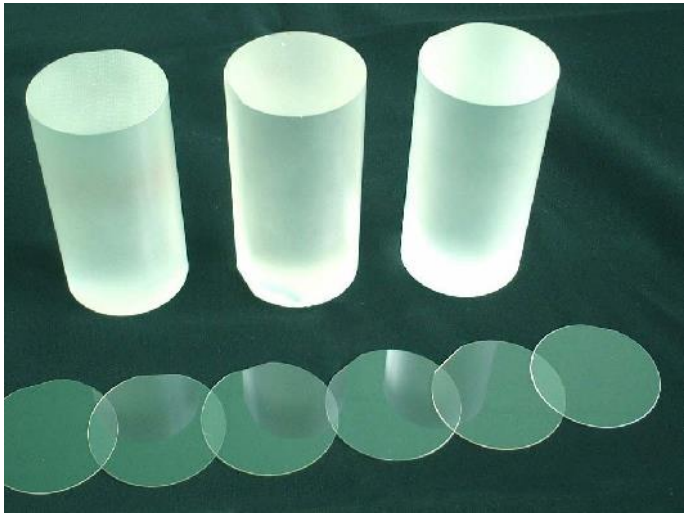
Si (111): -17 %

(GaAs/Si: +4 %)

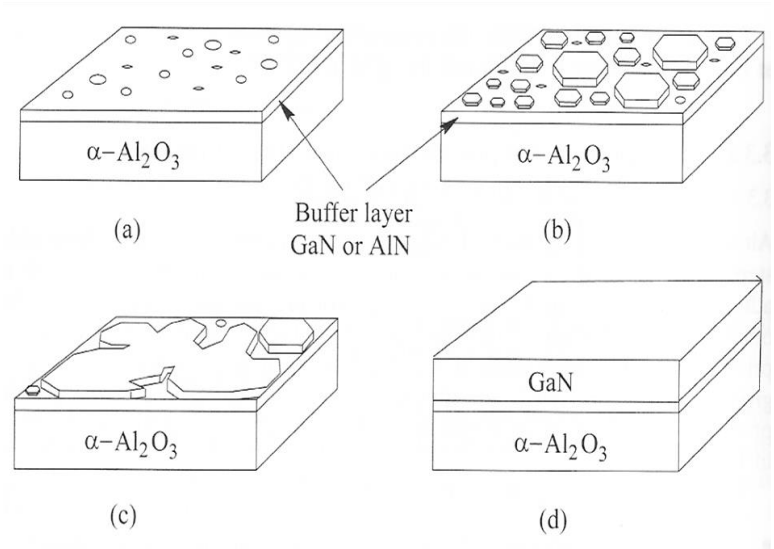


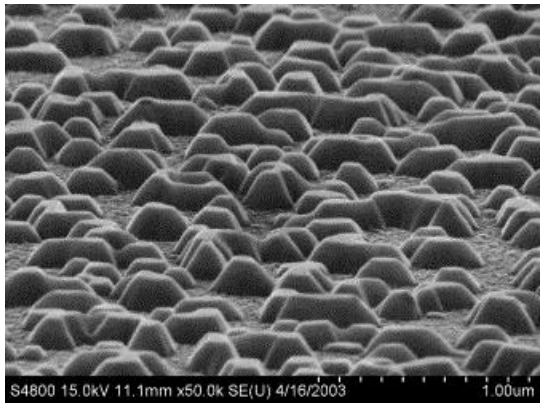
Hetero-Epitaxial Growth ⇨ Dislocations

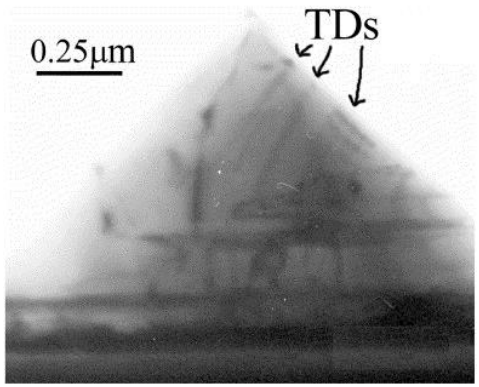
Epitaxial growth of III-V nitrides



Most commonly used substrate: sapphire (0001)







Two-step growth procedure

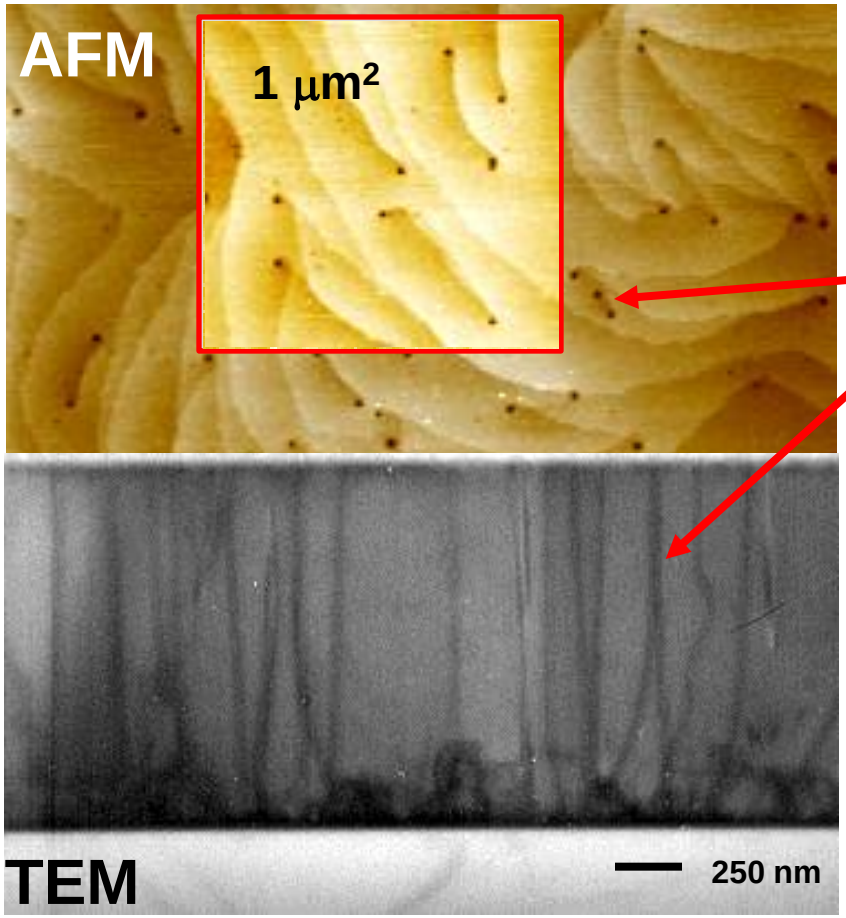
1) a thin buffer layer (25 nm) deposited at low-temperature (500°C) and further annealed

2) growth at high-temperature (1050-1100°C)

H. Amano *et al.* , Appl. Phys. Lett. 48, 353 (1986)

Epitaxial growth of III-V nitrides

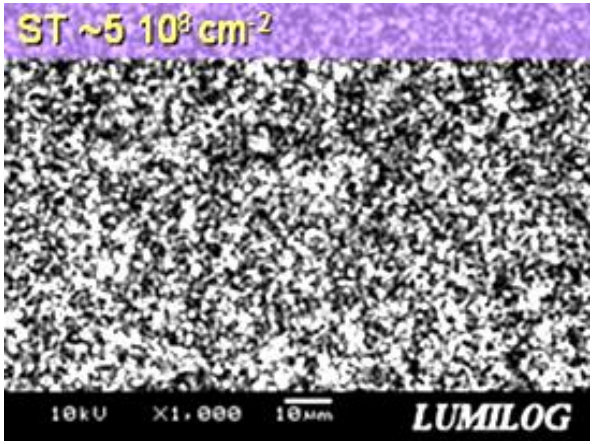
High dislocation density: 1-10x10^{8} cm^{-2}



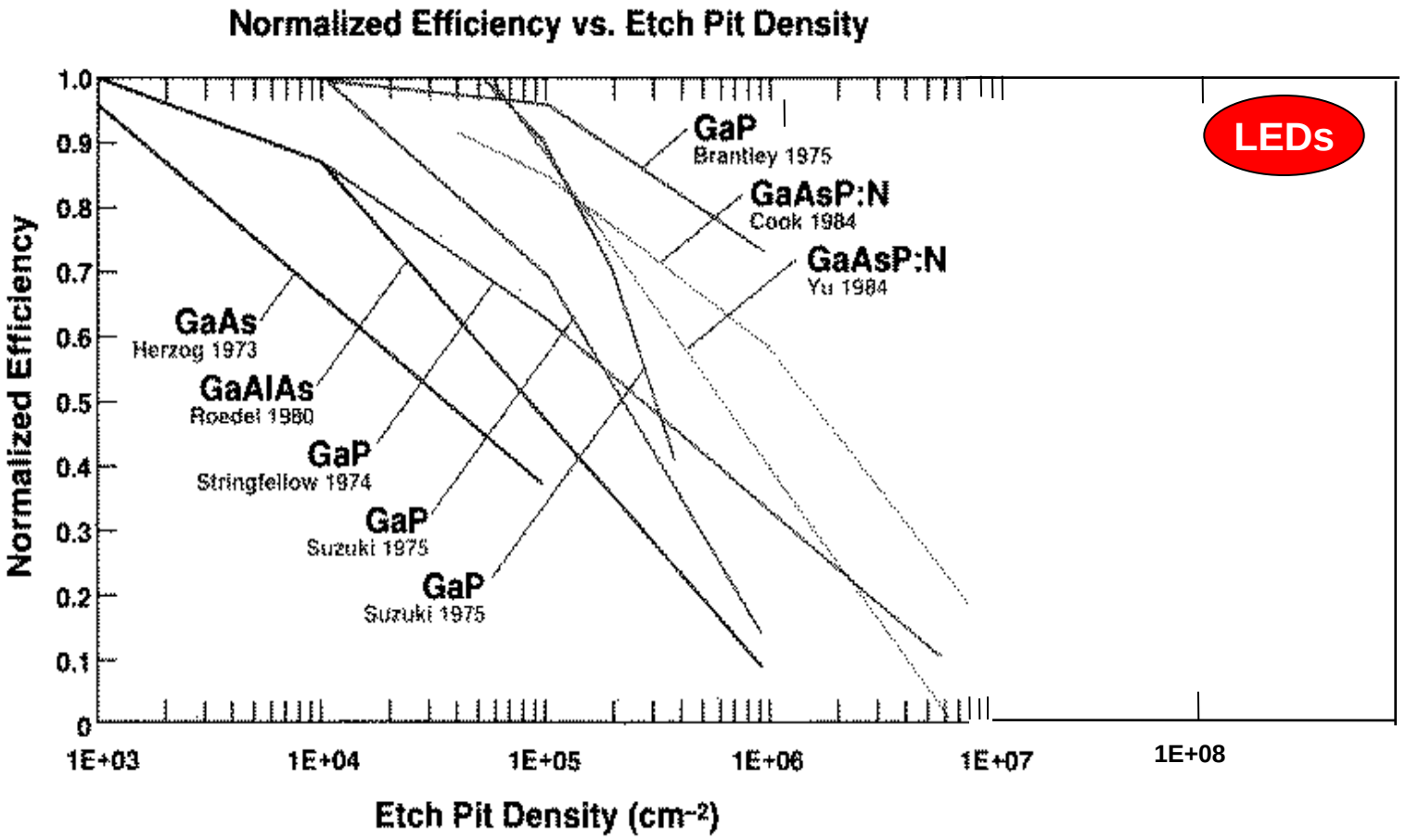
Surface

Cross-section

Dislocations



LED efficiency

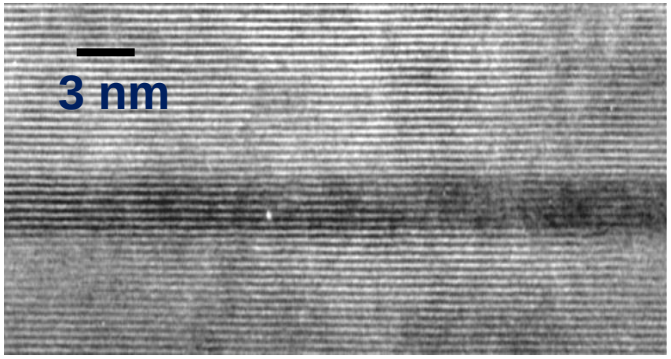


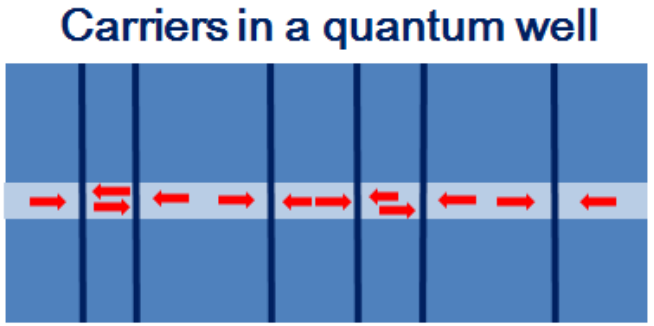
1 – LEDs: high efficiency (IQE>90%) despite high density of defects

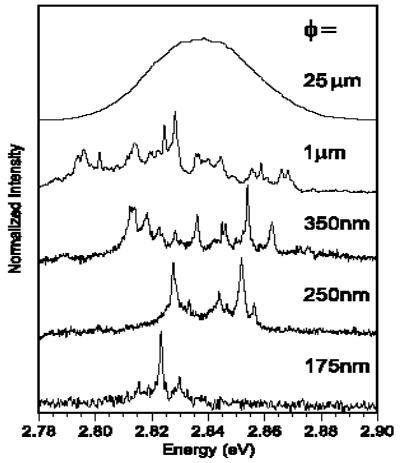
2 - LEDs are less sensitive than LDs to the presence of dislocations

LED efficiency

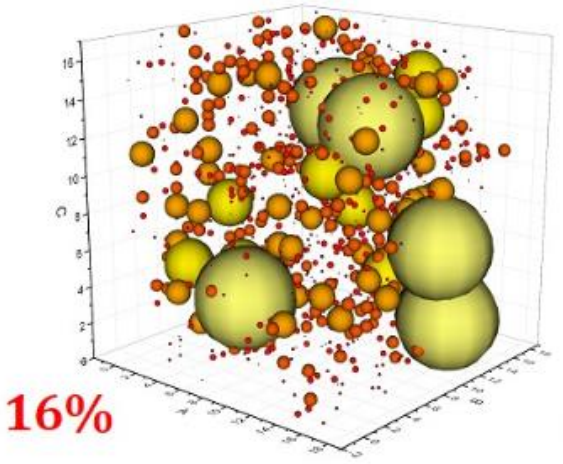
Efficiency of a defective medium

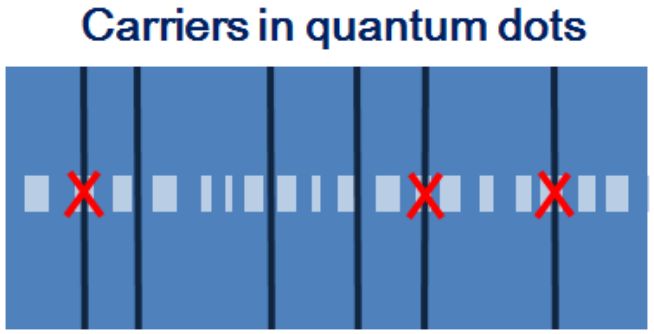






Schömig *et al*, PRL (2004)



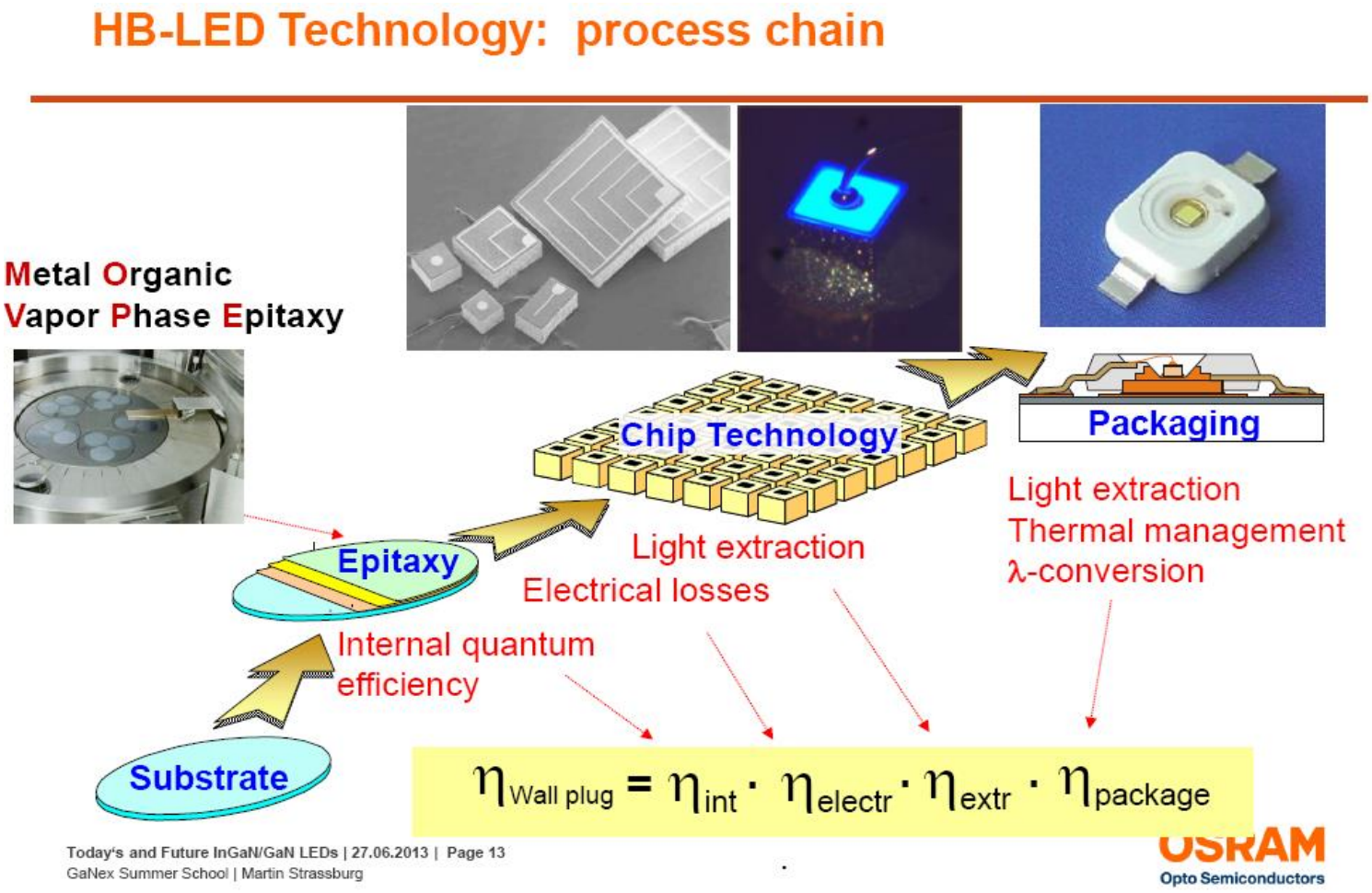


Gérard and Weisbuch (patent 1990)

Carrier localization prevents radiative efficiency collapse

IQE > 95%

Current technology – LEDs



Blue LEDs: IQE > 90% Ext. Eff.> 85% EQE = 80%

Wall plug efficiency (WPE)> 60%

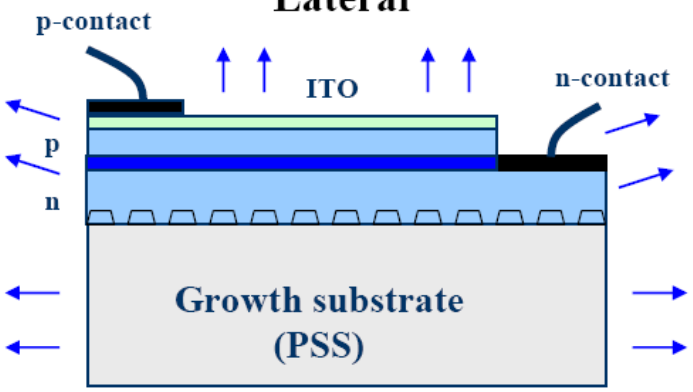
LED efficiency: light extraction

Pre-dominant Nitride chip designs

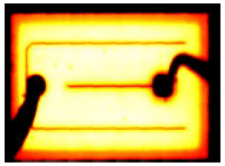
OSRAM
Opto Semiconductors

Lateral and Verticle chip designs prevail in selected applications

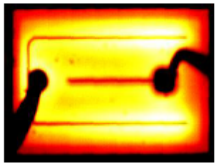
Lateral



Low current

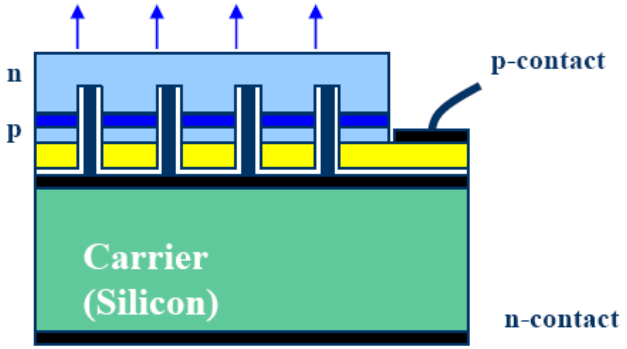


High current

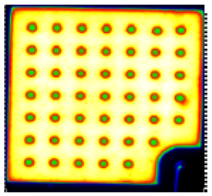


Limited current distribution

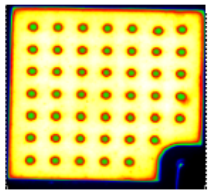
Vertical (eg. UX:3)



Low current

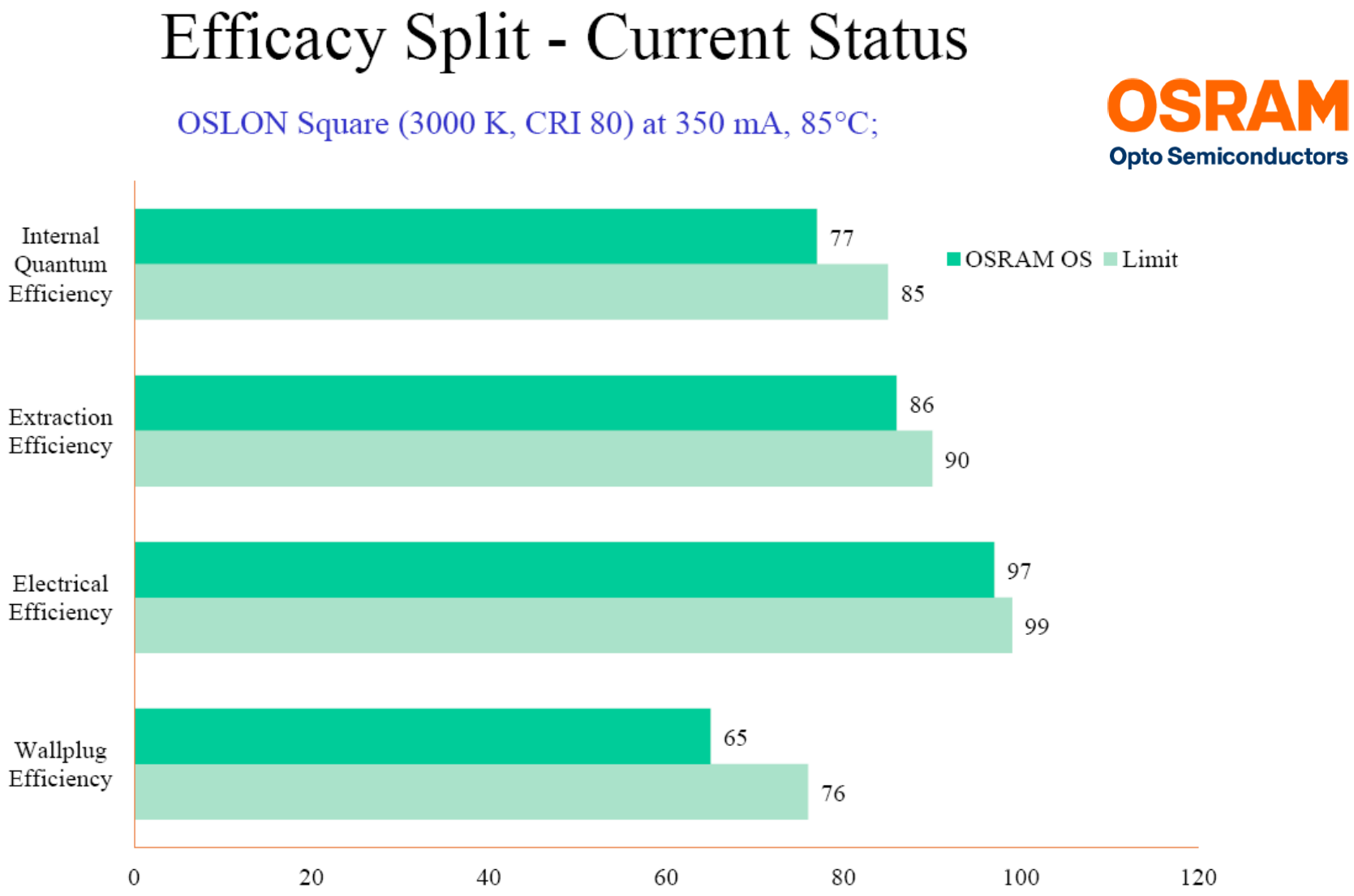


High current



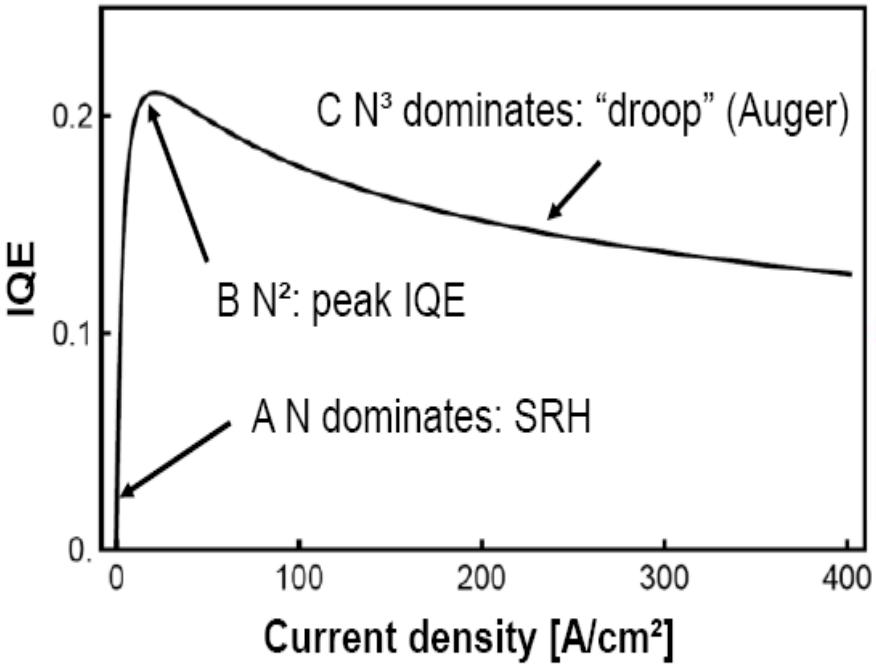
Maximum lumen output per chip area

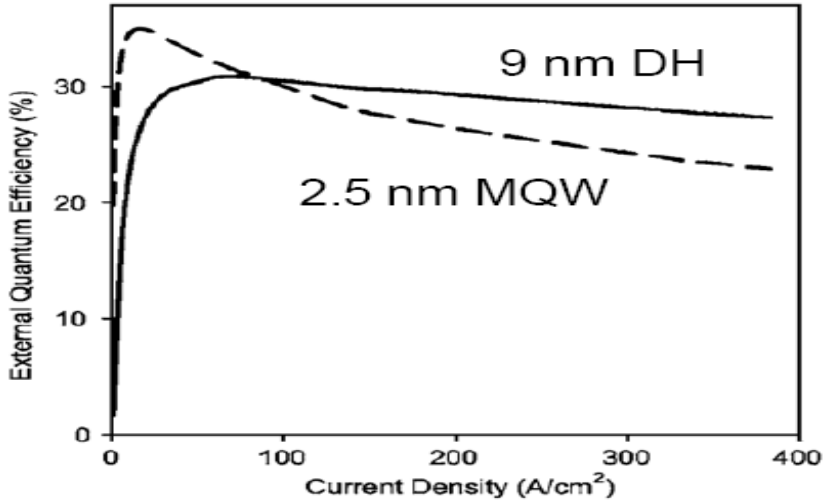
LED efficiency



LEDs – Challenges and perspectives

IQE – droop – green gap





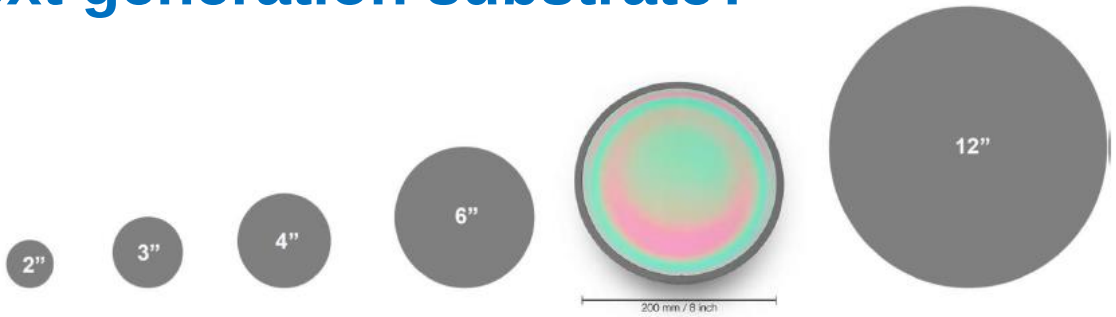
Gardner, et al., Appl. Phys. Lett. **91**, 243506 (2007)

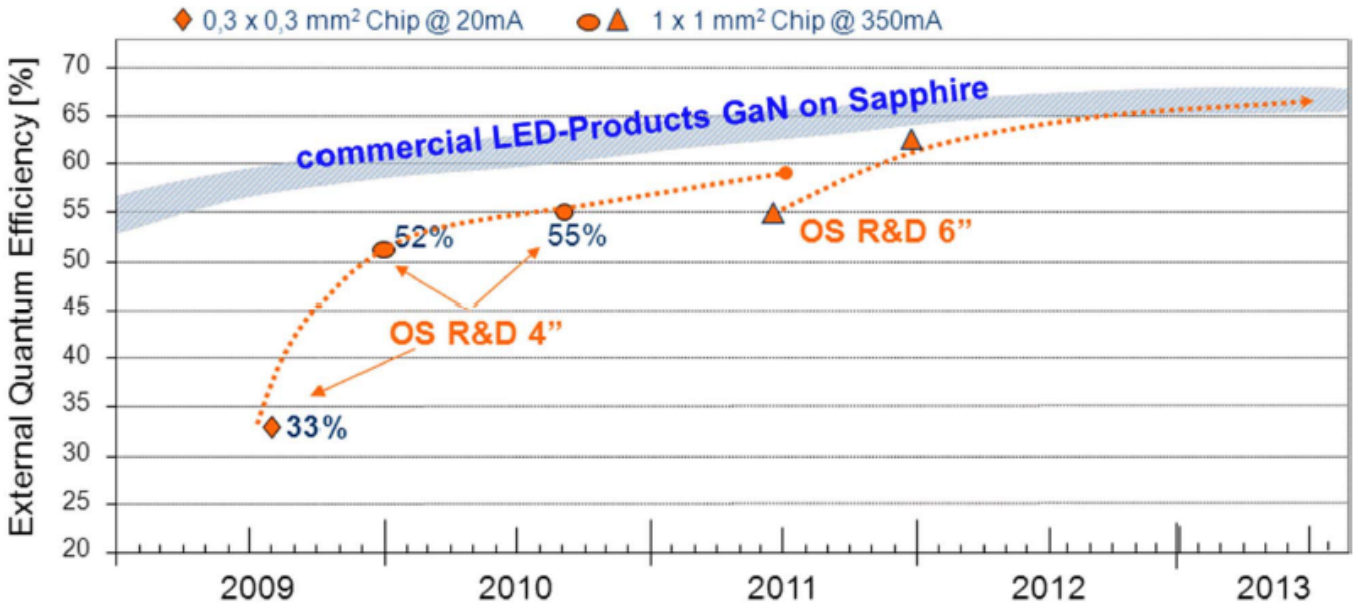
Droop curve: $$IQE = \frac{R_{rad}}{R_{rad} + R_{nr}} = \frac{B_{rad} N^2}{A_{SRH} N + B_{rad} N^2 + C_{Auger} N^3}$$

R: recombination rates *N*: carrier density in quantum well

LEDs – Challenges and perspectives

Silicon as next generation substrate?





P. Stauss, SPIE Photonics West 2012

OSRAM
Opto Semiconductors

Conclusion – Challenges and perspectives

Higher efficiency (limiting the efficiency droop)

Longer wavelengths

Cheaper fabrication process (NWRs, Si, new materials)

Better Light (CRI): UV LEDs + phosphors?