Nano Technology drives LED Advancements

Dr. Norbert Stath
Osram Opto Semiconductors GmbH, Regensburg

Outline

- Progress of LEDs
- Material quality and nano structures
- Thin-Film LEDs
- Phosphor and high flux concepts
- Applications
- Conclusion

Fig. 1

Brightness Evolution of LEDs Since 1970

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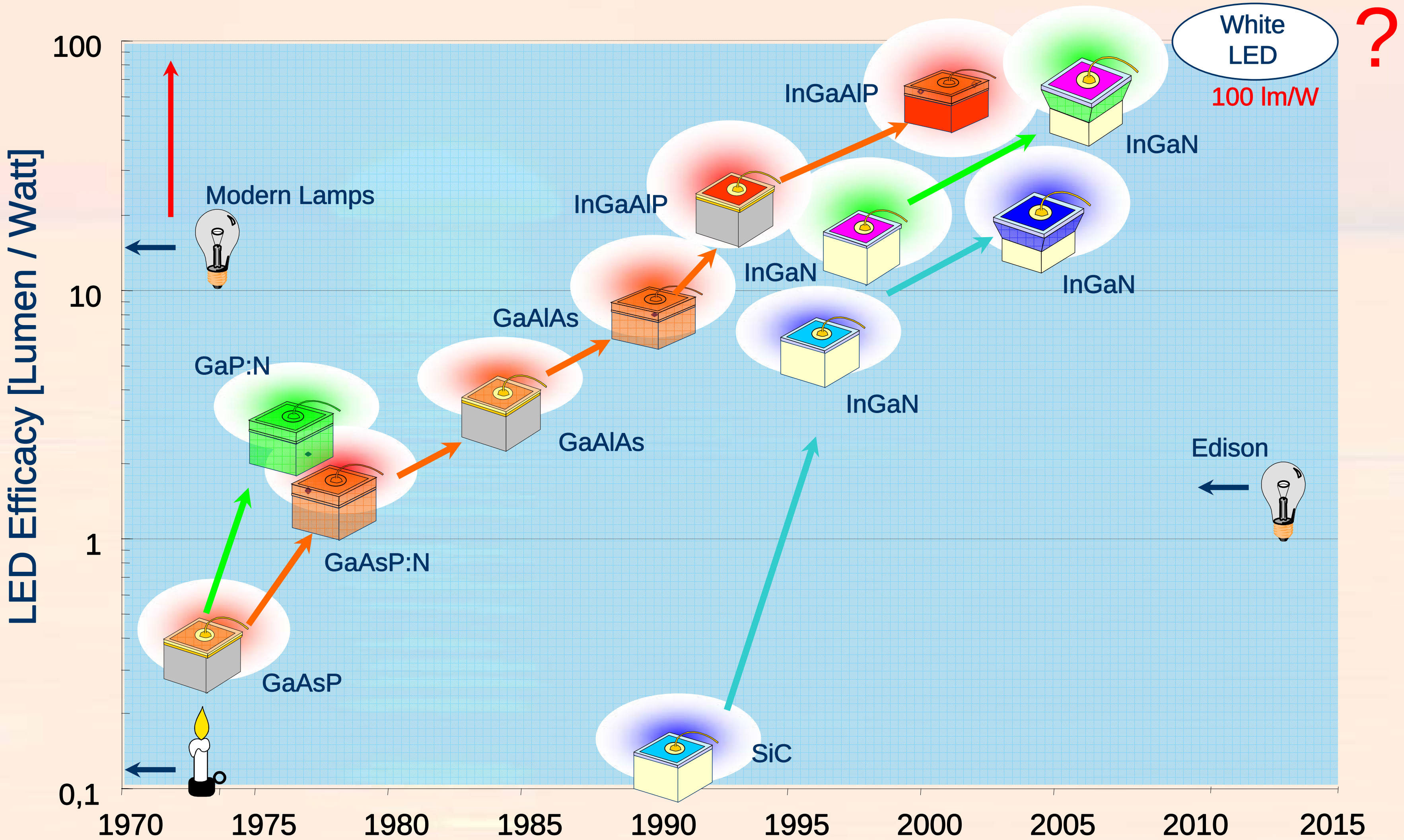

Fig. 2

White LEDs are on a Steep Improvement Curve

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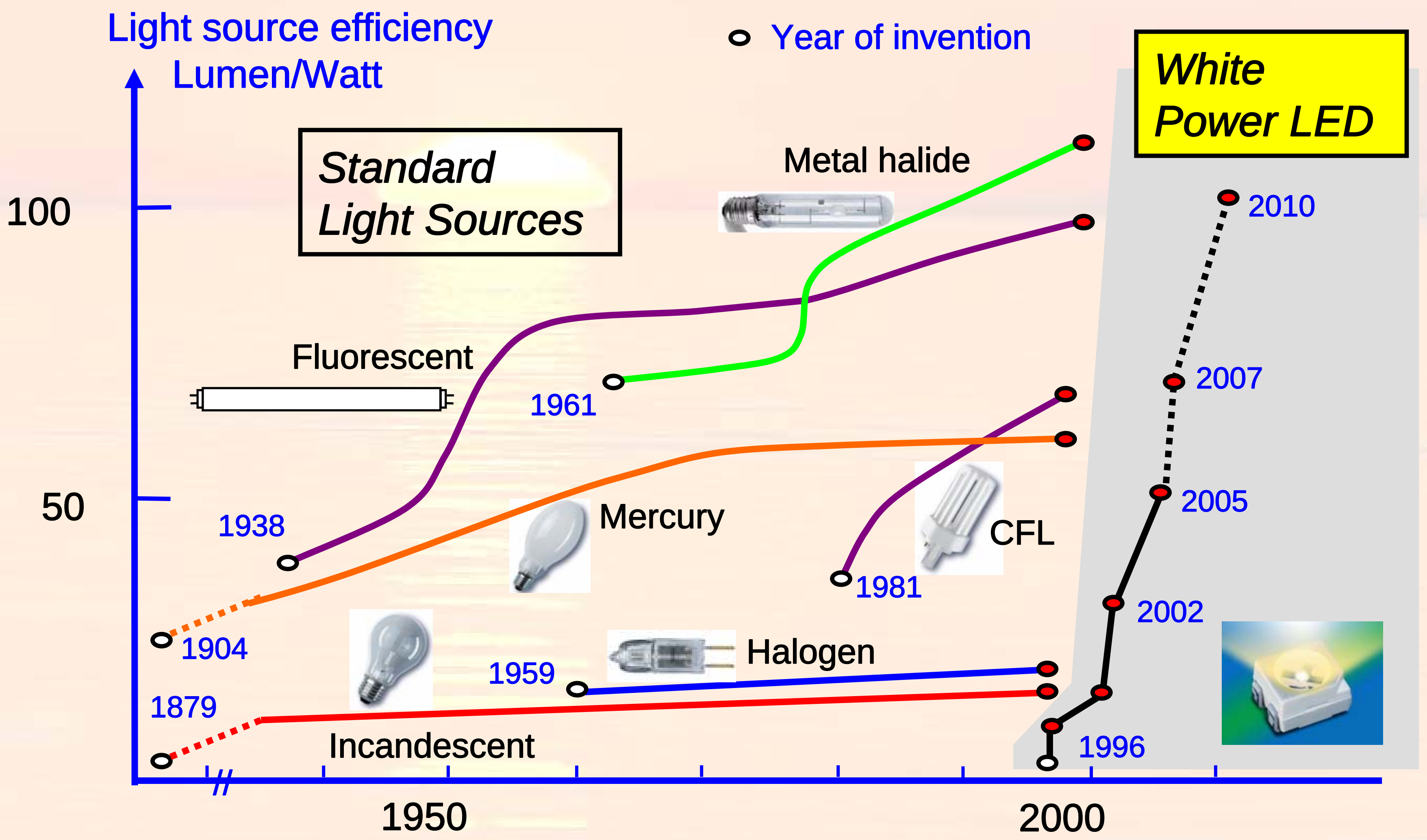

Fig. 3

High Brightness LEDs: a Multi-billion Dollar Business

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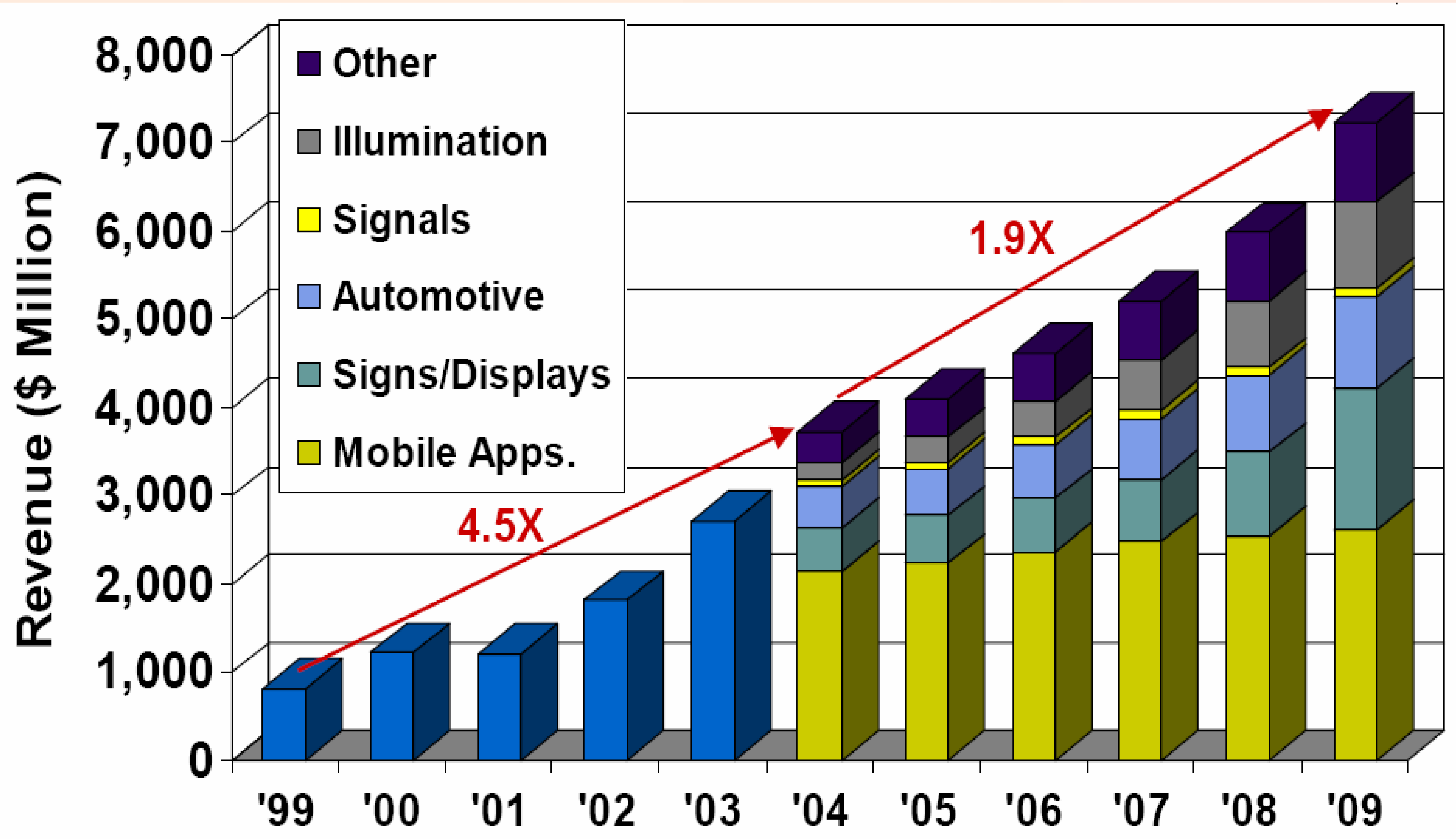

strategies unlimited

Fig. 4

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High Brightness LED Process Chain
Keys for High Wall Plug Efficiency

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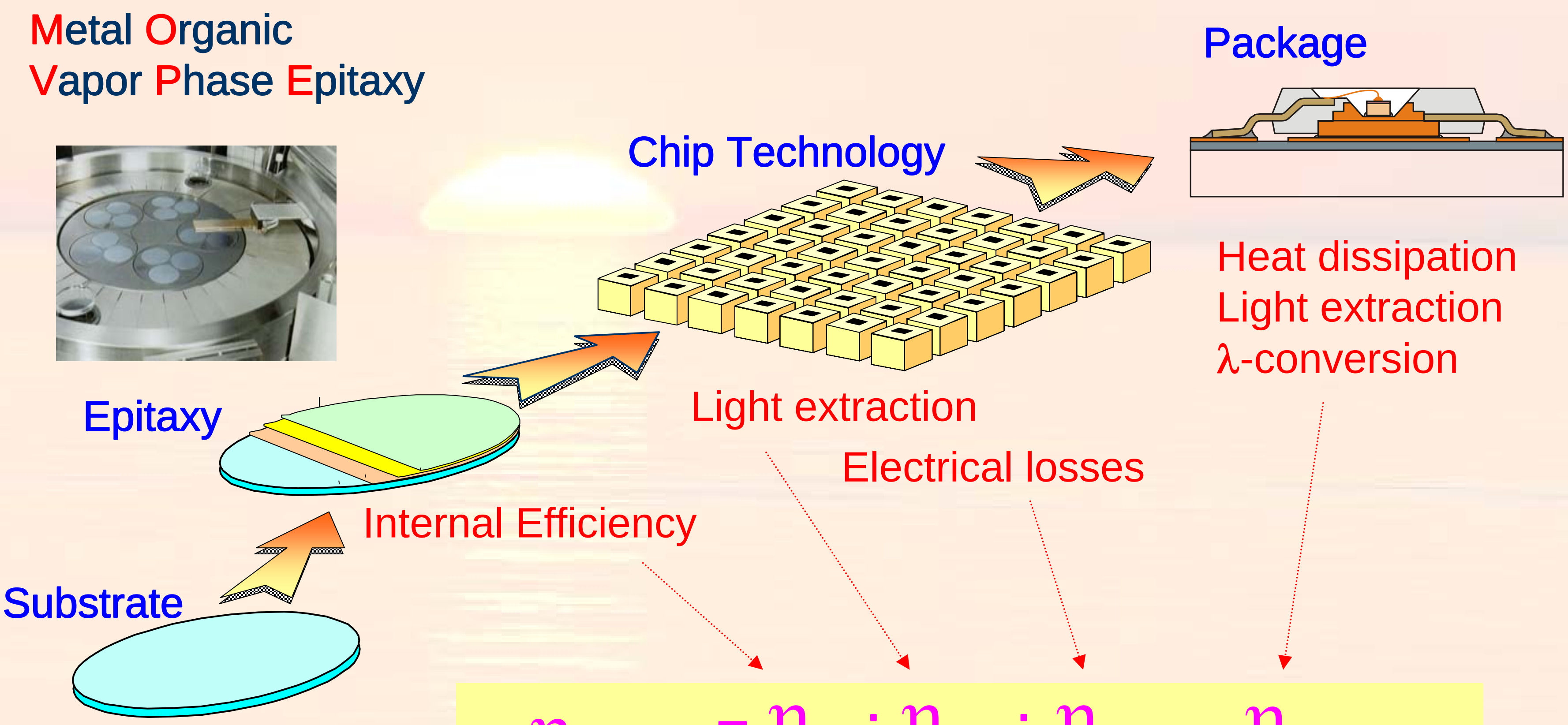

$$\eta_{\text{Wall plug}} = \eta_{\text{int}} \cdot \eta_{\text{extr}} \cdot \eta_{\text{electr}} \cdot \eta_{\text{package}}$$

@ 20 mA								
AlGaInP (red):	40%	=	90%	50%	97%	90%	➡	105 lm/W
GaInN (white):	22%	=	50%	75%	91%	65%	➡	70 lm/W

Fig. 5

Bandgap Engineering for Highly Efficient (AlGa)InP LEDs

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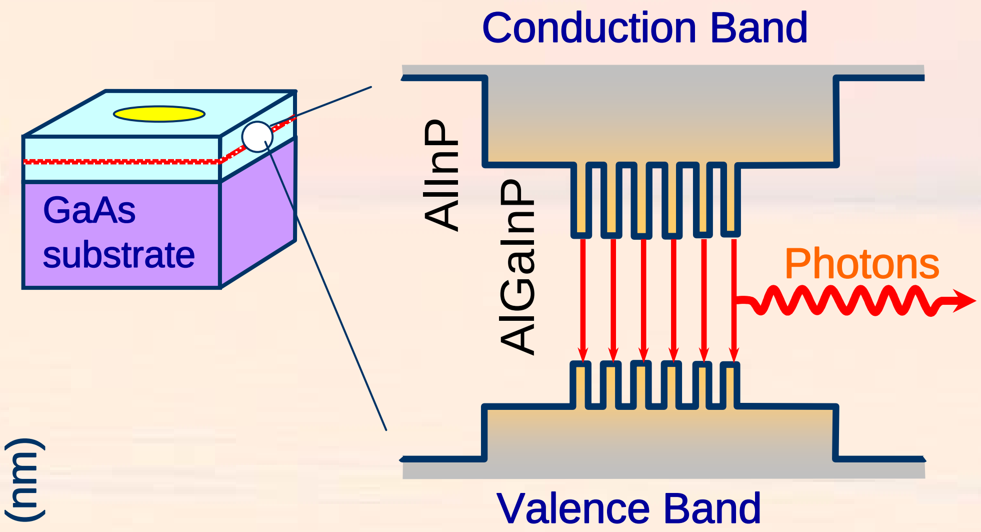
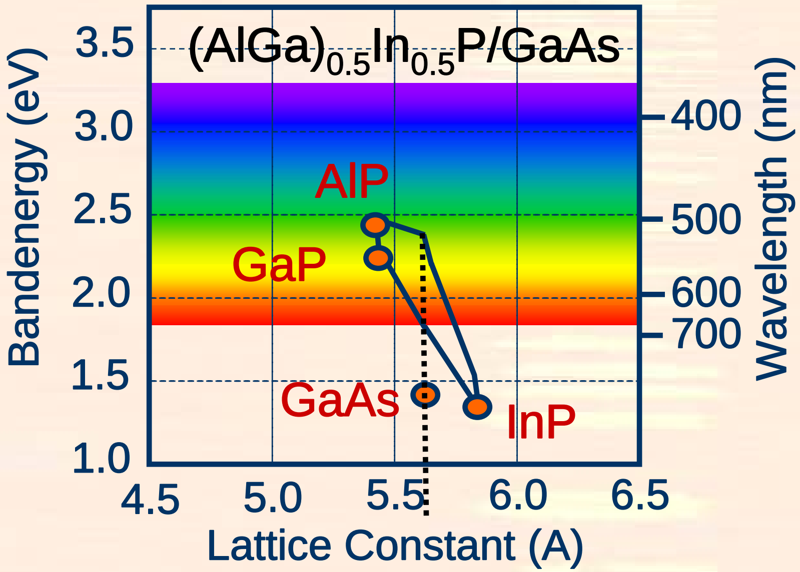
Advancements in MOVPE technology have been enabling Bandgap Engineering on a Nano scale

Lattice matched active BG structure



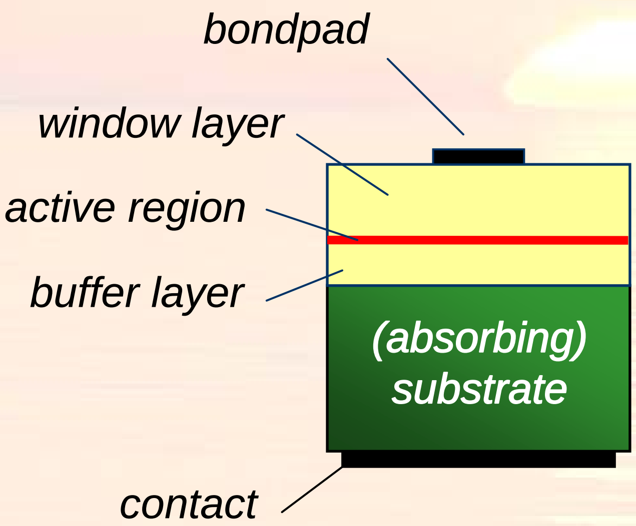


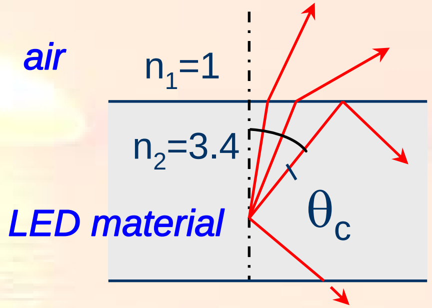
- Q-wells and barriers 5-10 nm thick
- Wavelength tuned by Al/Ga-ratio
- 90% int. Q.E. for red emission (high band offsets, low thermal carrier overflow)

Fig. 6

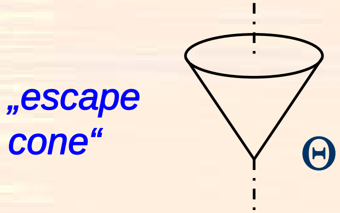
Thin-Film Technology for LEDs to Free the Photons

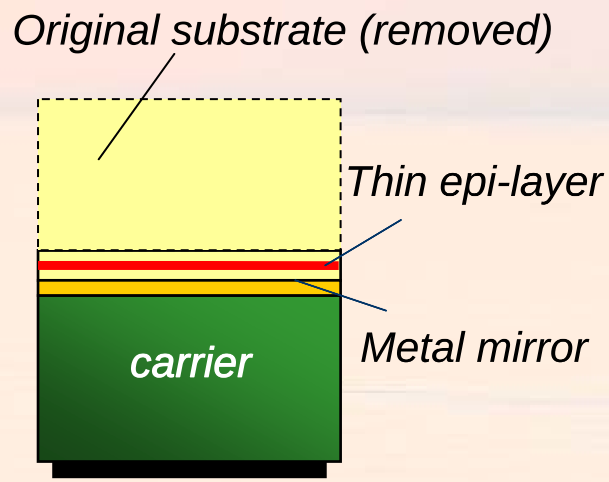
Conventional LED → Thin-Film LED





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





GaAs – air: $\Theta_c = 17°$ ⇨ $\eta_{ex} = 2.2\%$

- Thin-Film Technology pioneered by Osram OS
- World-record performance AlGaInP LEDs (amber, red)

Fig. 7

Thin-Film (TF) LED: Principle of Operation and Realization

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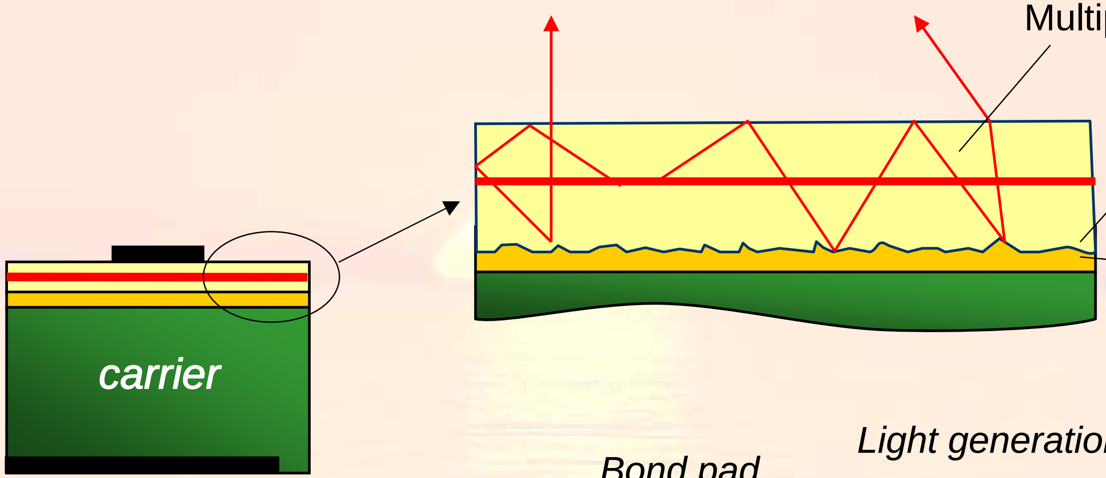
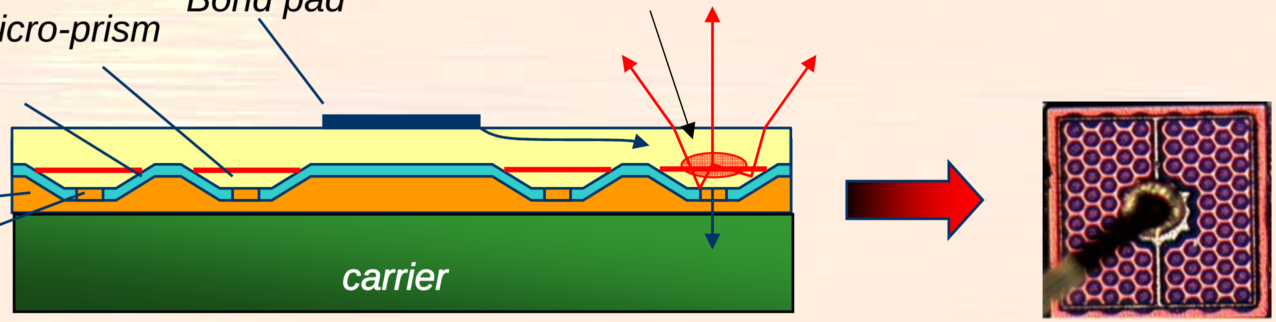


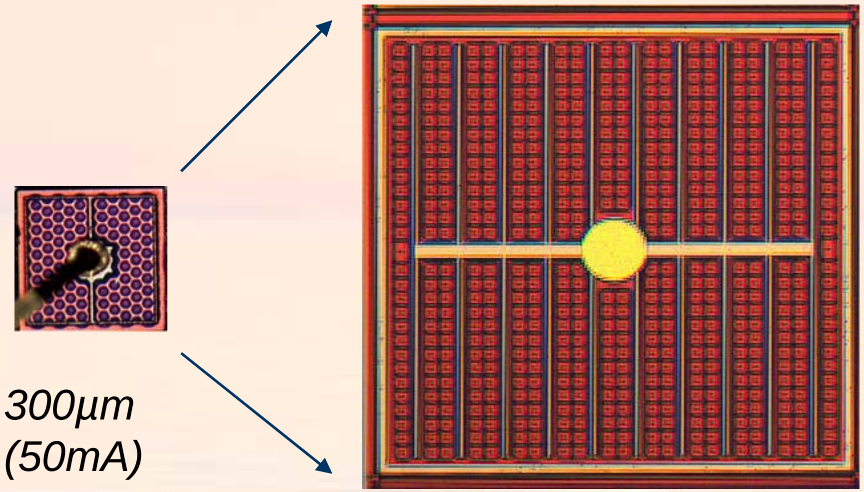


- Local current injection and generation of light
- Micro-prism reflectors
- High reflective dielectric/metal mirror

High extraction efficiency

Fig. 8

Scalability of TF to High Flux w/o Efficiency Loss



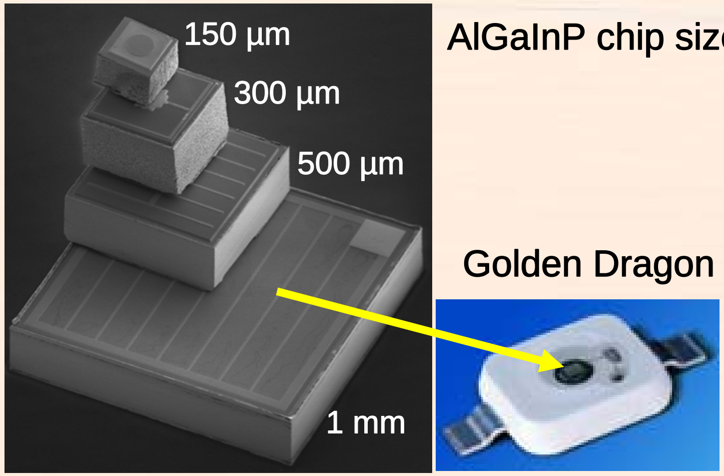
300µm (50mA)

1mm (1 A)

Large chip area for high operation currents

Comparable current density at operation current for small and large chips

Requires an optimized power package to dissipate the heat -> Golden Dragon



- Light is extracted only through the top surface
- LED efficiency is independent of device area

Fig. 9

Evolution of Red AlGaInP-LED Brightness by Applying Nanotechnology

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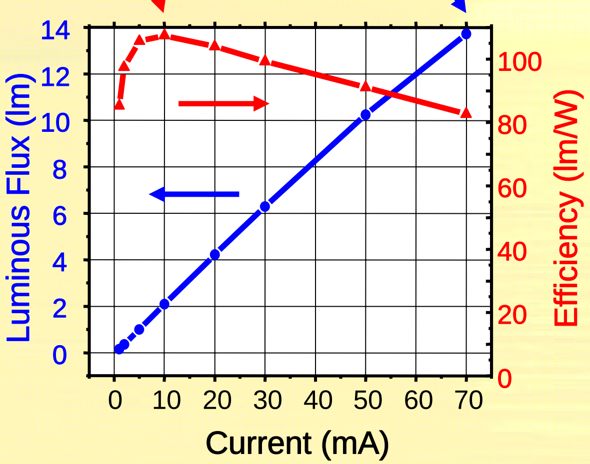
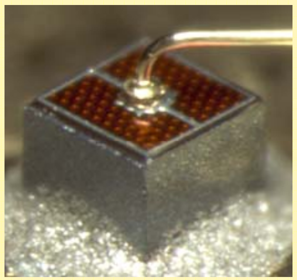
Red LED efficiency record !





Chip size 300 x 300 µm²

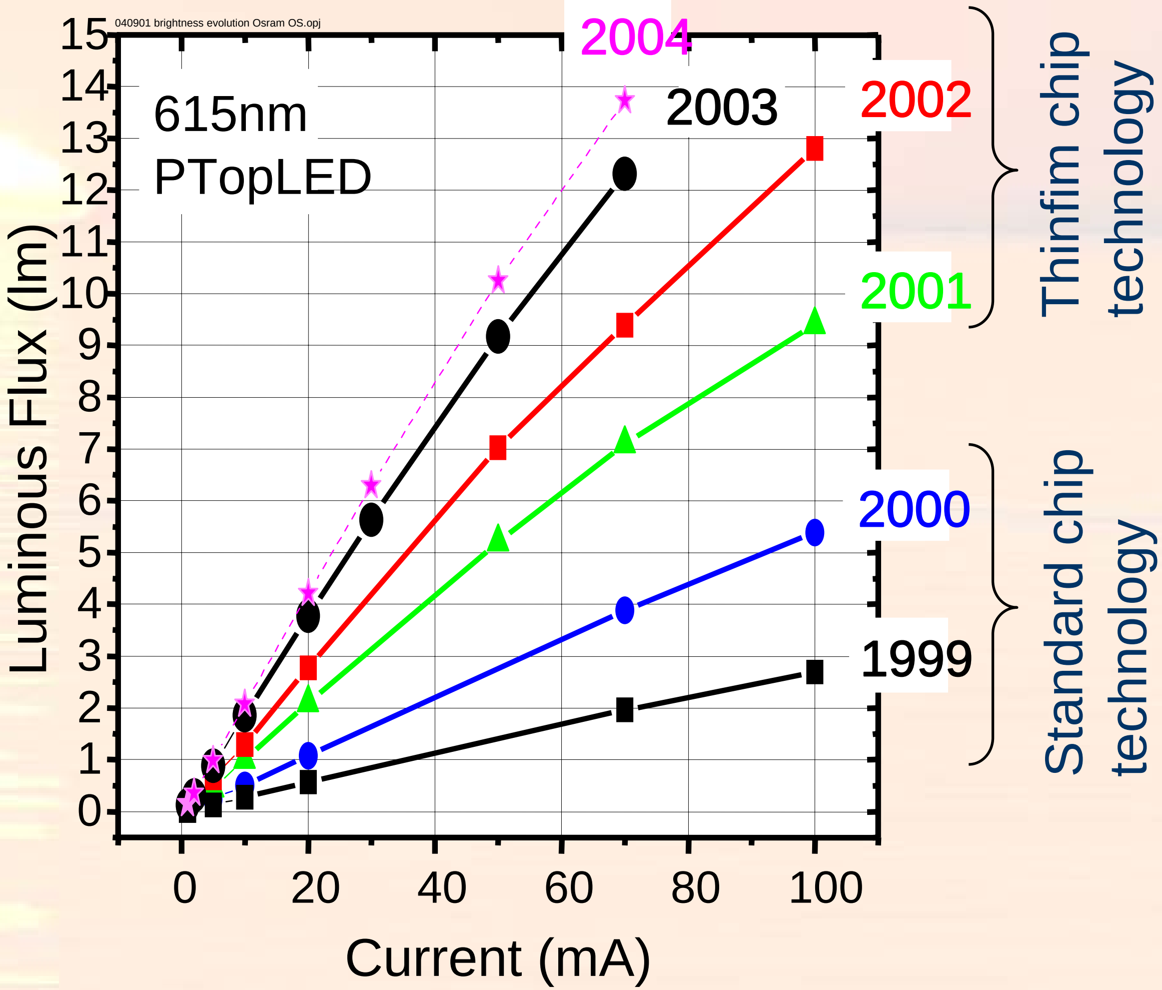


Fig. 10

InGaN LEDs are „Applied Nano Technology“

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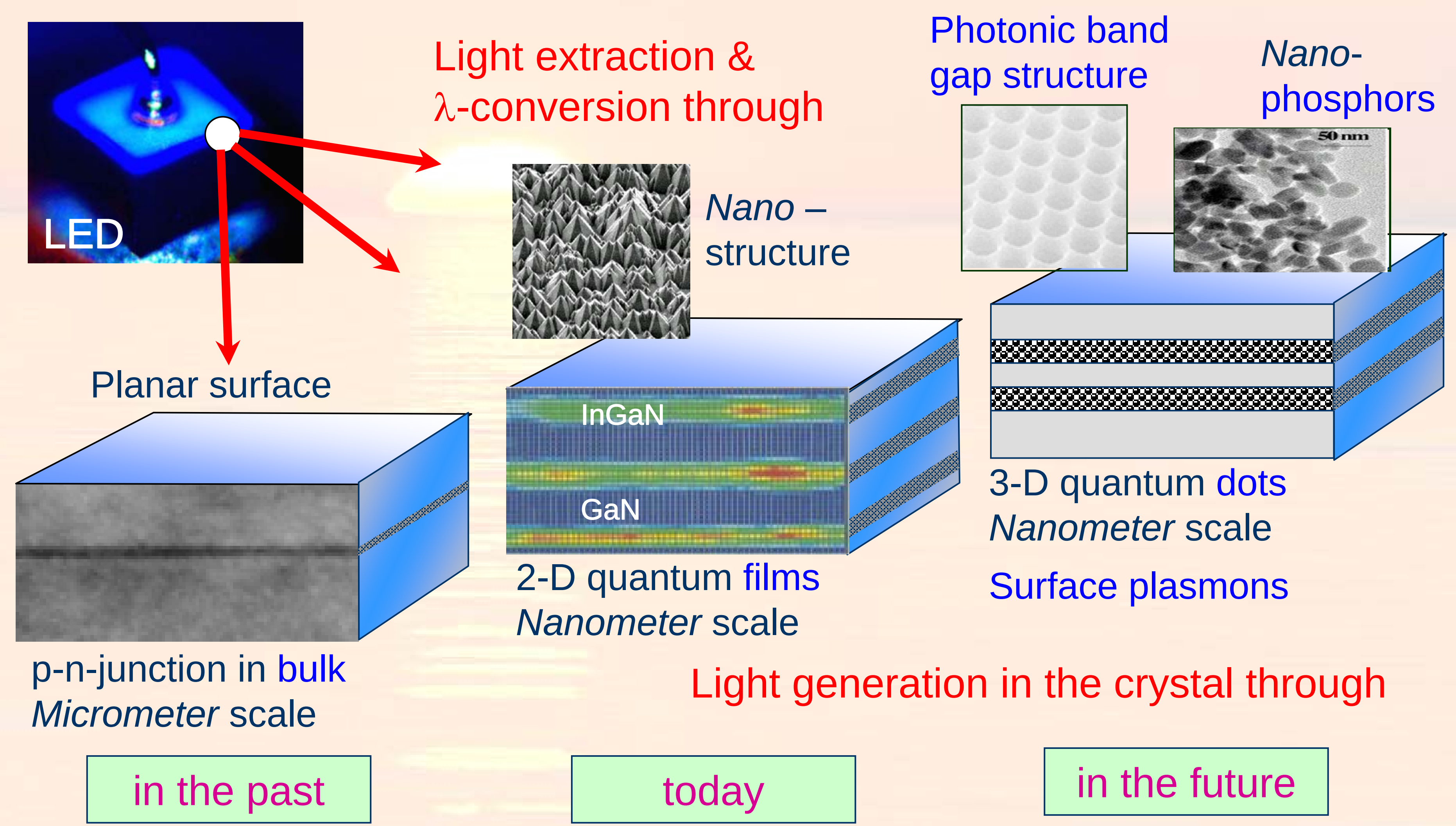

Fig. 11

Material Quality: The Key to Improve Internal Q.E. of InGaN-based LEDs

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InGaN - Nano Structures

TEM-Analysis:
Prof. Dr. J. Zweck,
Uni Regensburg

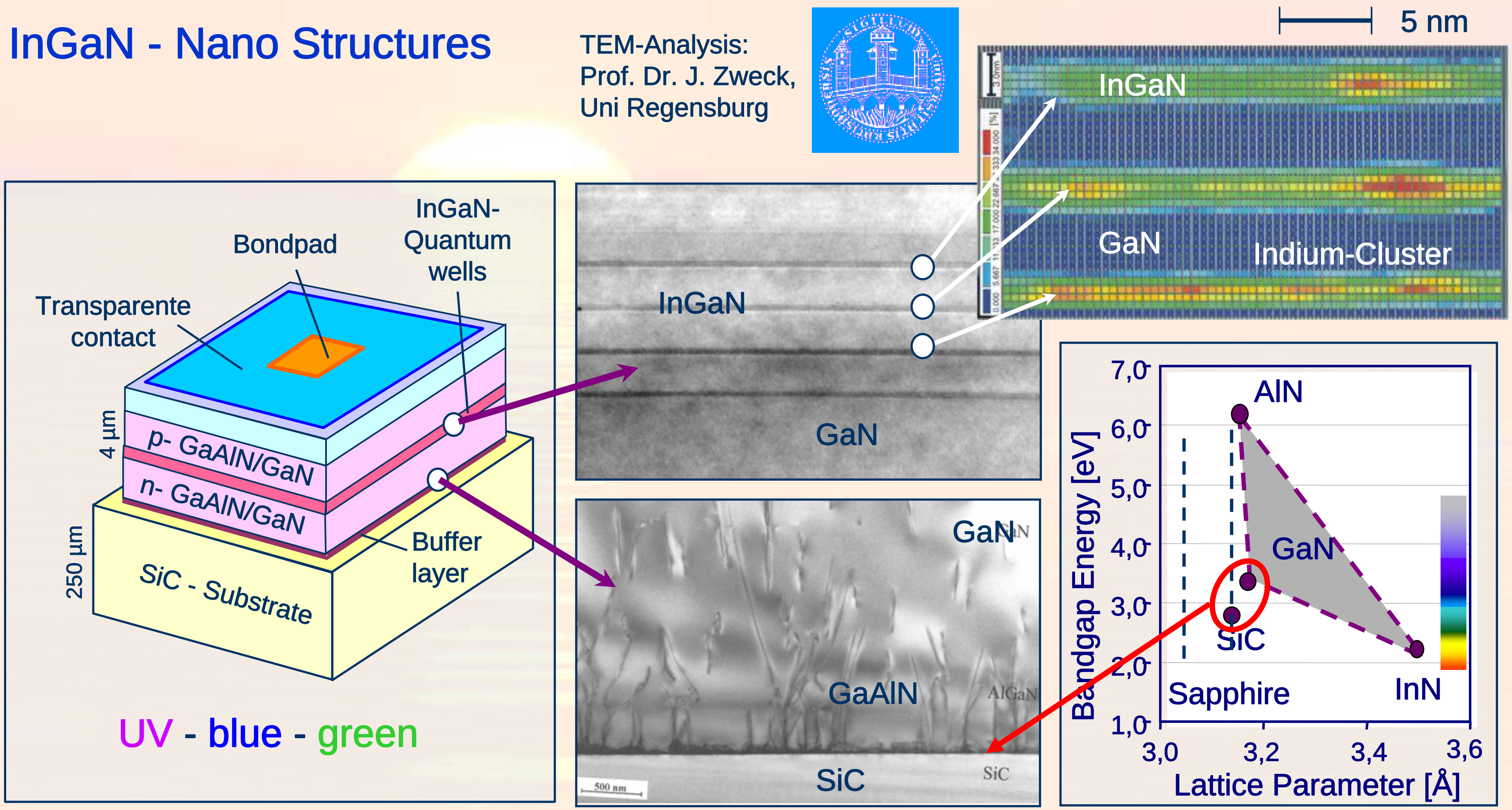

Fig. 12

Learning from Violette-Blue InGaN Laser: Frontier of Material Technology

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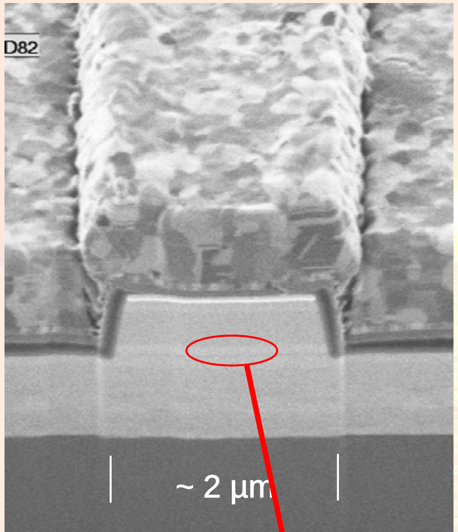
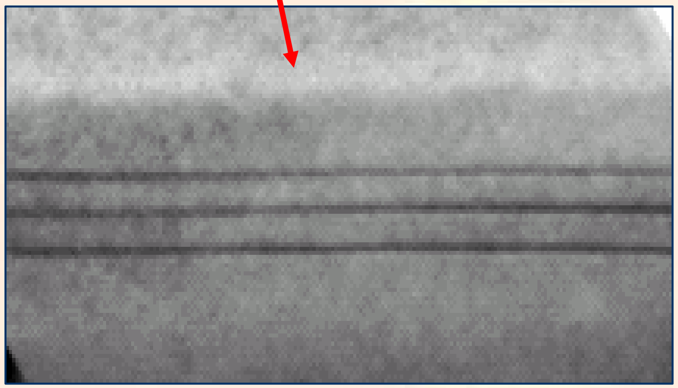


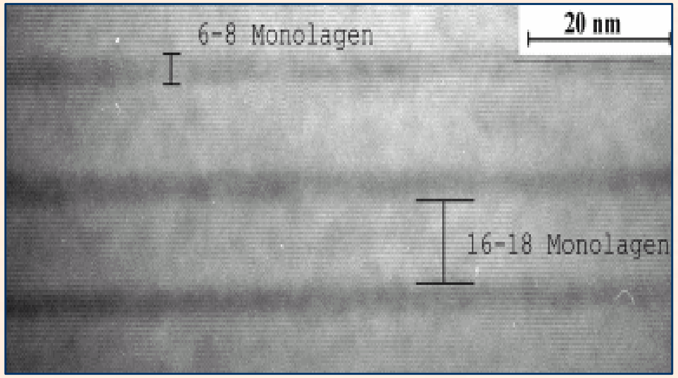
405 nm InGaN ridge waveguide laser

The success factors:

- controlled monolayer deposition
- well defined abrupt interfaces
- very low defect levels

Quantum well structure





TEM-Analysis @ university of Regensburg

Fig. 13

Impact of Defect Density on Laser Performance

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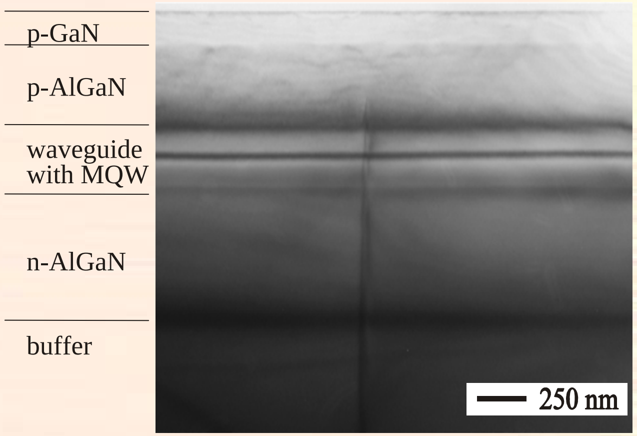
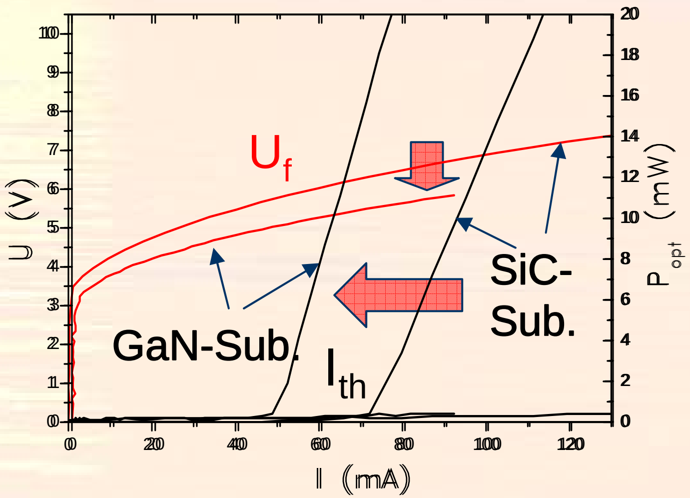
Laser structure grown on GaN

Defect den..: $5x10^6$ cm^{-2}

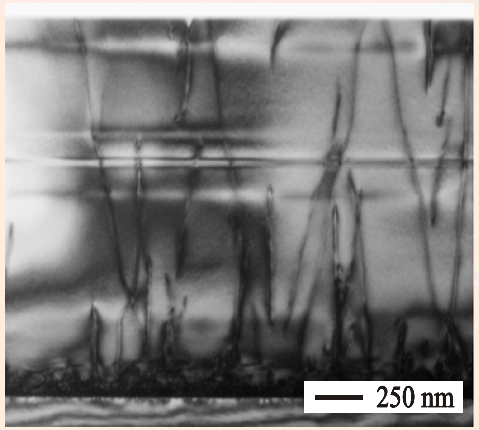


InGaN Laser characteristics with GaN-Sub. vs. SiC-Sub.



Laser structure grown on SiC

Defect den..: $2x10^9$ cm^{-2}



Improvements of InGaN-Laser on GaN

- significant lower threshold currents
- lower forward voltages
- much higher lifetimes

Fig. 14

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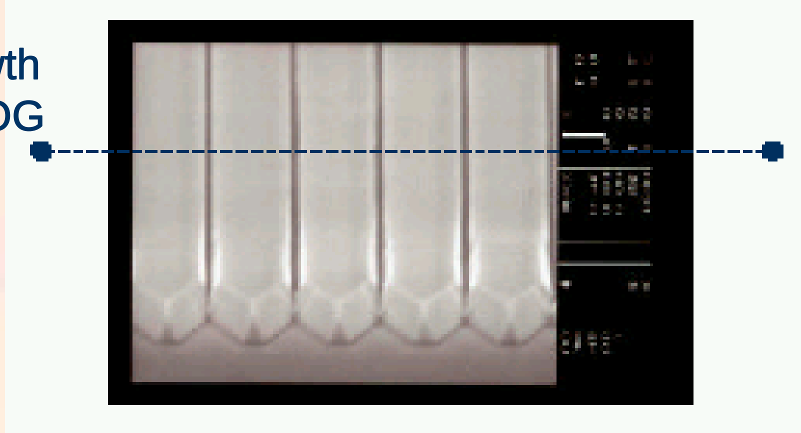
„Epitaxial Lateral Overgrowth (ELOG)“ a Method to Reduce Epi-Defects

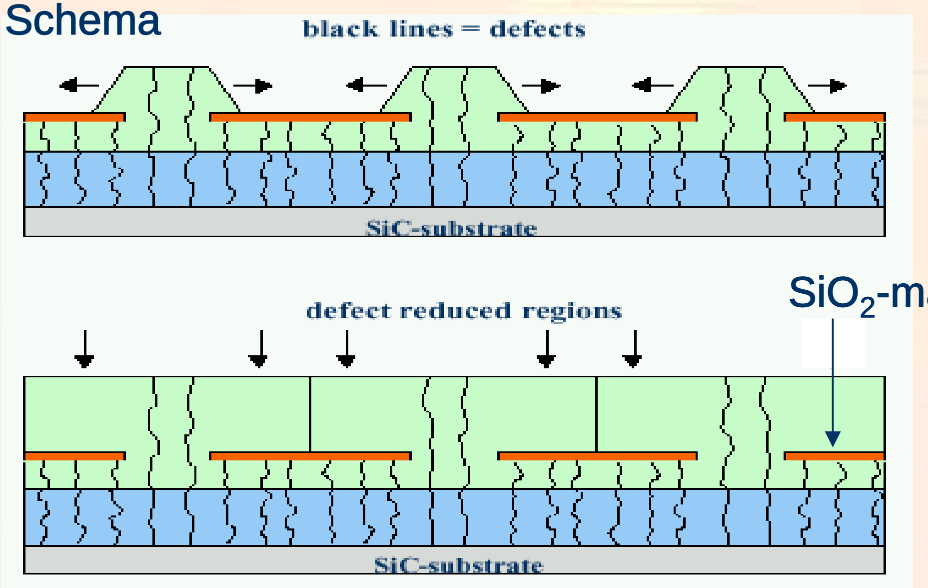
Epi growth with ELOG



TEM-Analysis on ELOG-grown GaN-Structures

TEM-Analysis:
Prof. Dr. J. Zweck,
Uni Regensburg

Schema



SiO_2-mask

„Bending of dislocations“

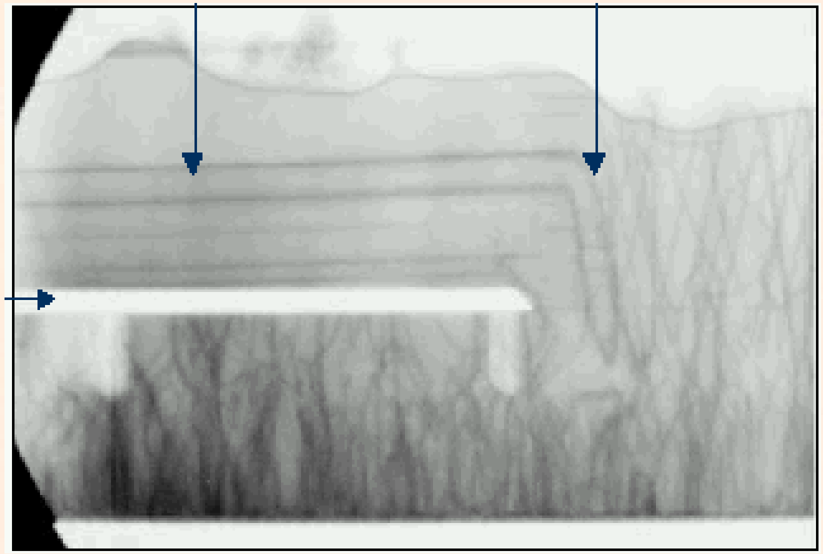


Fig. 15

In-situ SiN_x-Masking and Overgrowth to Reduce Defect Density in InGaN Epi

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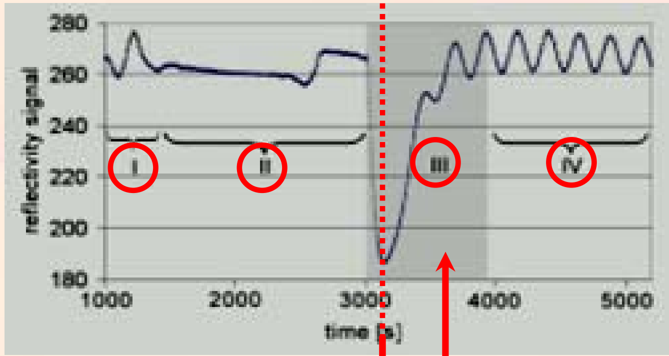
Epi process steps

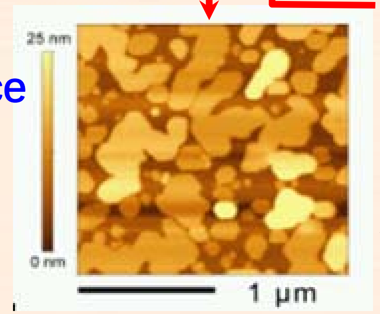
I. GaN growth
II. SiN_x masking
III. GaN cluster growth
(reduced reflection signal)
IV. Coalescence of GaN clusters
(interferring reflection signal)

In-situ reflection signal



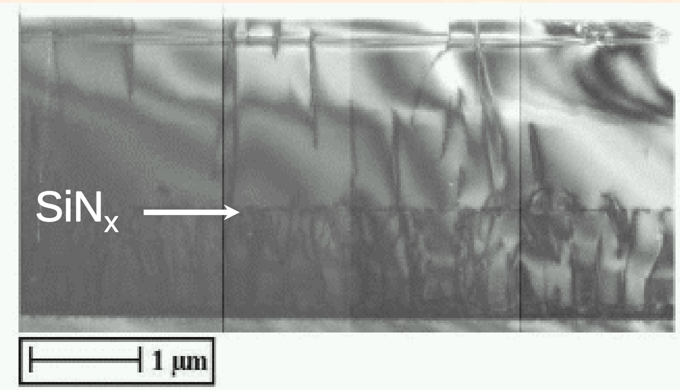
Flatness reached with 180nm growth (start of interferrence)

Atomic Force Microscopy (AFM):



Δ - cluster hight: 10 - 20nm

TEM - Analysis



- Method allows a reduction of dislocation density by factor of 10 (down to $5x10^7$ cm^{-2})

Fig. 16

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New Chip Designs for Blue InGaN LED Brightness Advancements

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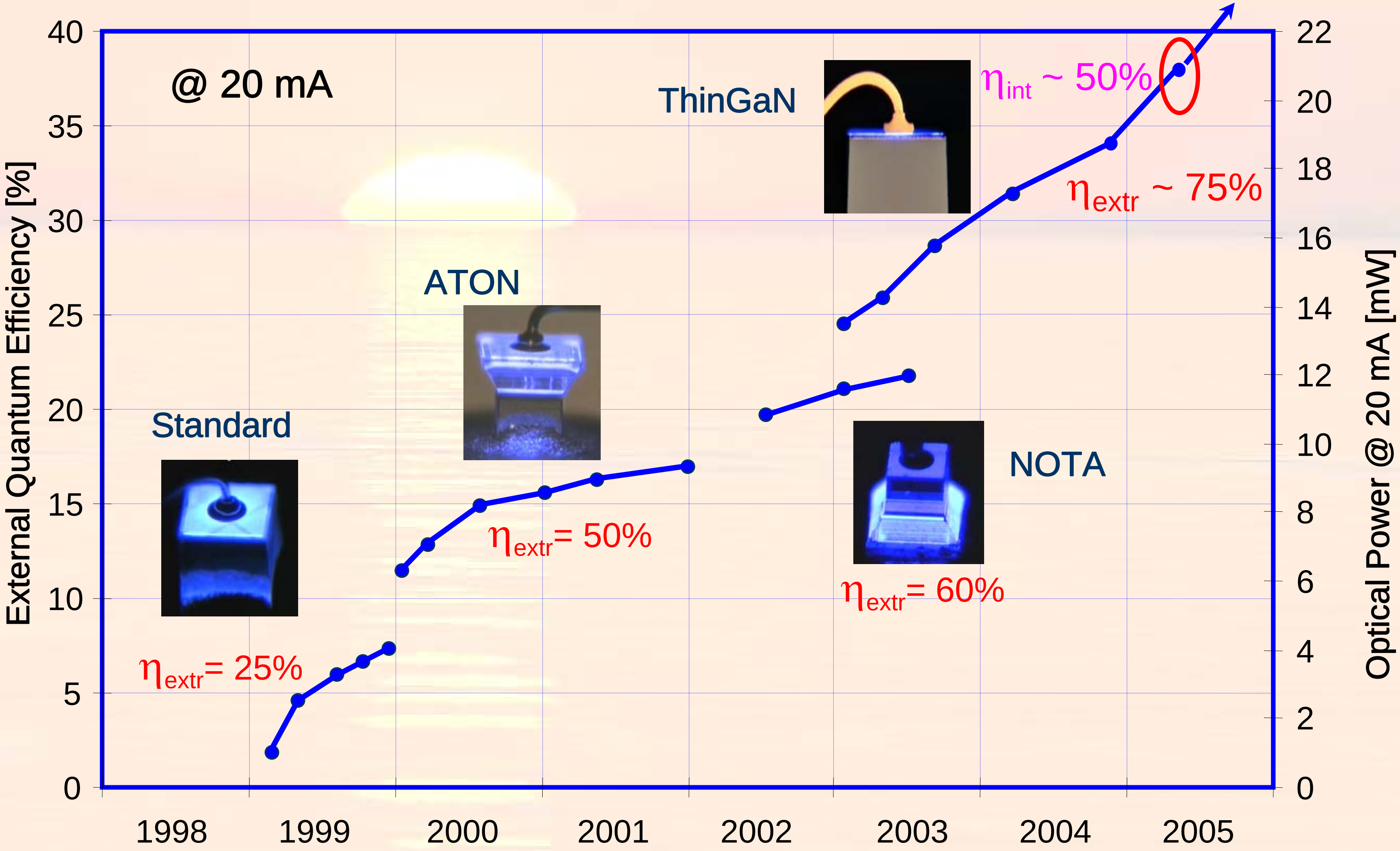

Fig. 17

ThinGaN Provides True Surface Emitting Chips, Scalability to Hi-flux, Low Electrical Losses

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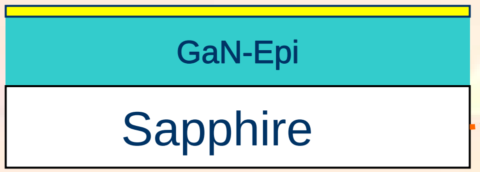
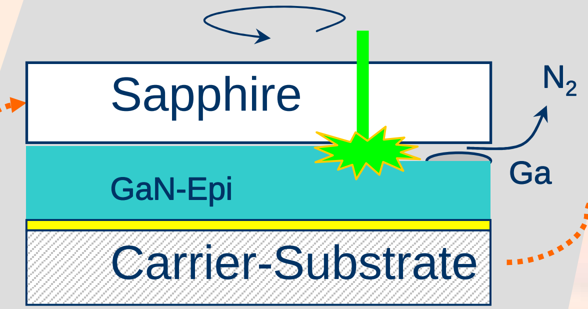
Process Flow ThinGaN:

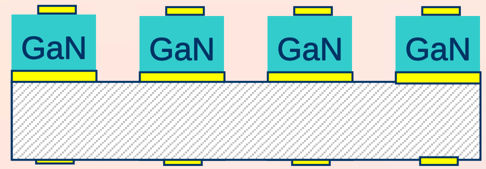


- Epitaxy on Sapphire
- Mirror metallization

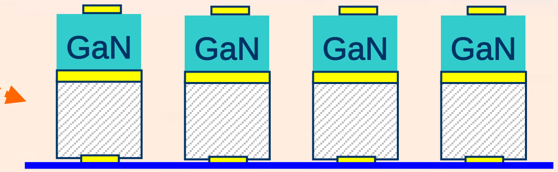


- Soldering on carrier
- Epi Laser-lift off

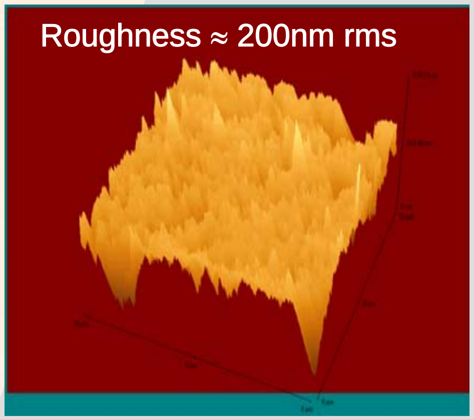
(M. Stutzmann, WSI München OSRAM Patent)



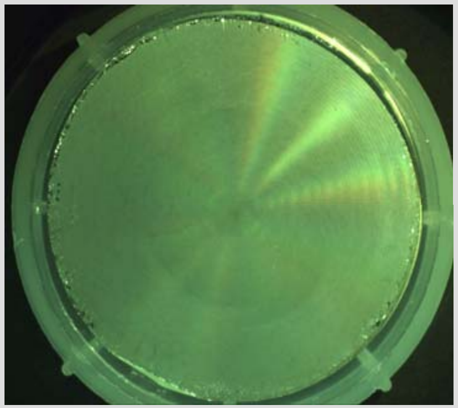
- Chip-Processing



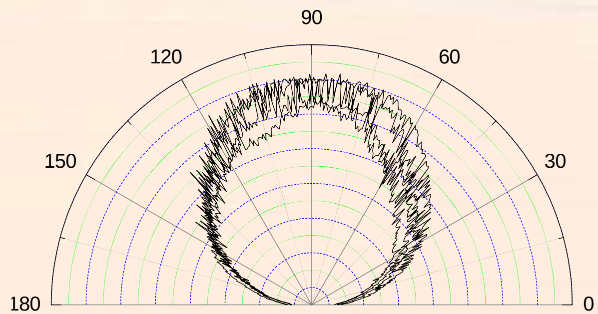
- Chip dicing on foil

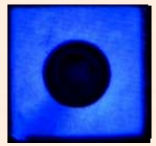


- AFM (Surface text.)



- 4 µm Epi on carrier





- True surface emitter

Fig. 18

ThinGaN: Why is Surface Structuring so Important?

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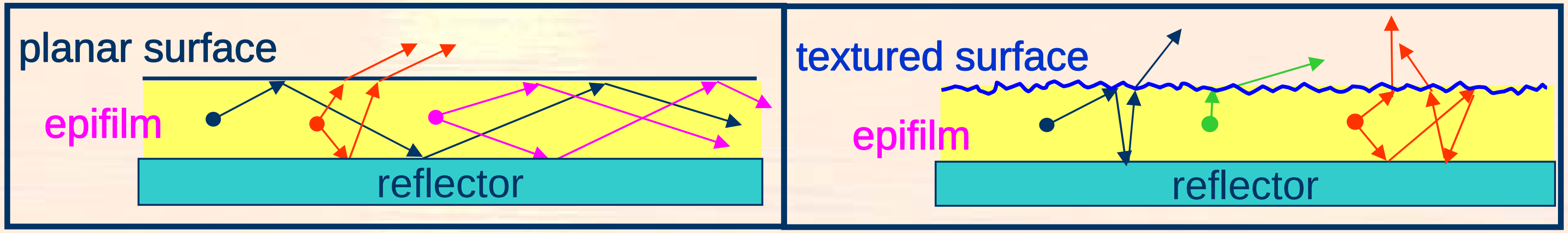
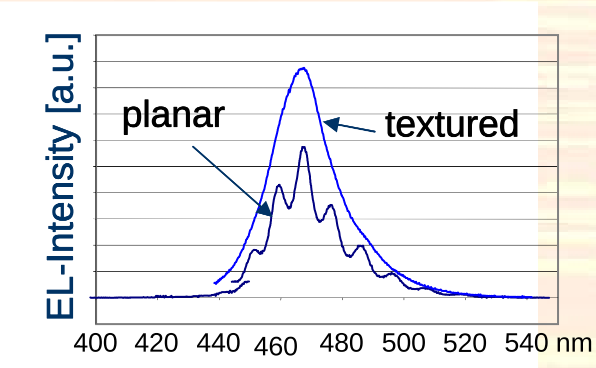
ThinGaN concept:

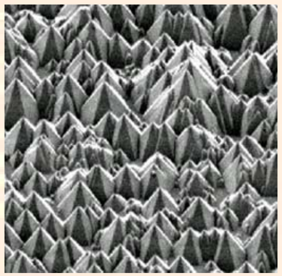
- reduced internal absorption ⇒ thin layers
- no losses on the backside ⇒ highly reflective mirror
- prevent waveguiding ⇒ surface texturing

Texturing: „Give photons multiple chances to find an escape cone“



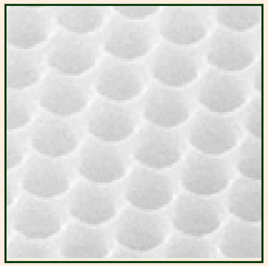


Emission spectra



Nano texturing

future

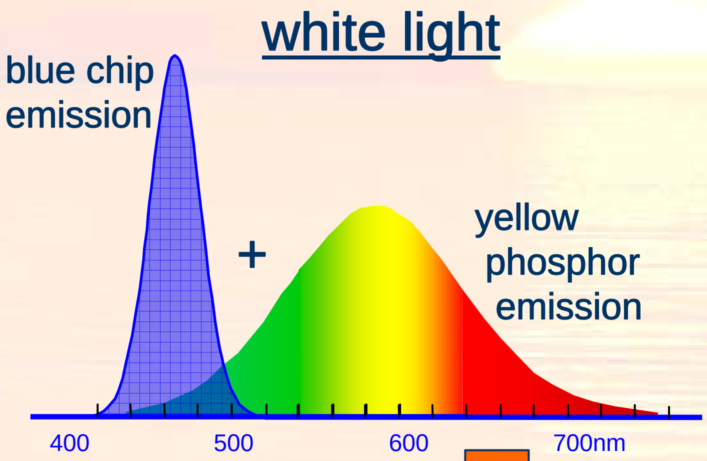


Phot. bandgap structures

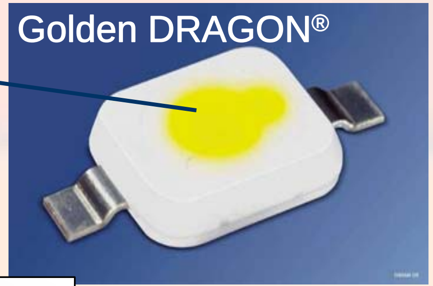
Enabling resonant cavities and directed light extraction

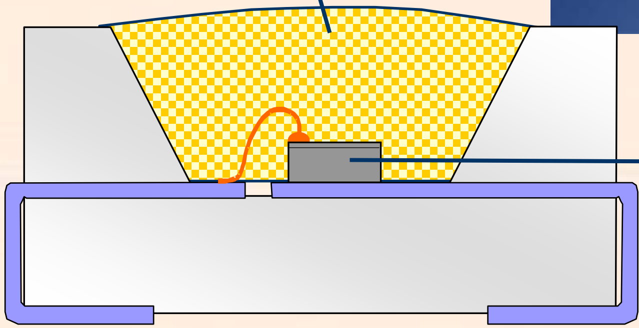
Fig. 19

Standard light conversion by volume casting

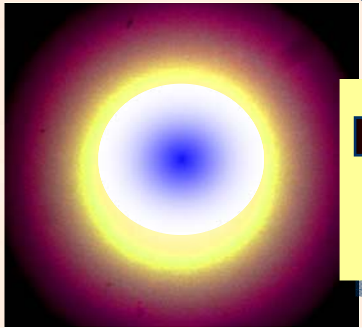


phosphor homogenously dispersed in silicone casting material





semiconductor chip ($1mm^2$ ThinGaN)

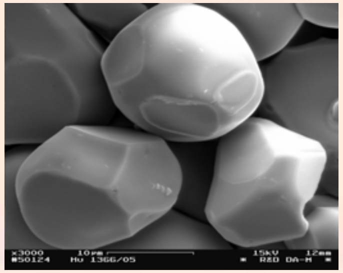


→ insufficient color homogeneity and luminance

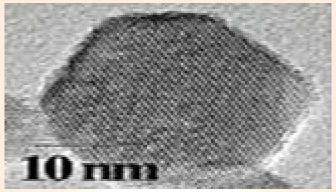
→ conversion on chip level needed

Fig. 20

Chip Level Conversion (CLC) for White and Color on Demand LEDs



Today: µm sized YAG:Ce phosphor particles

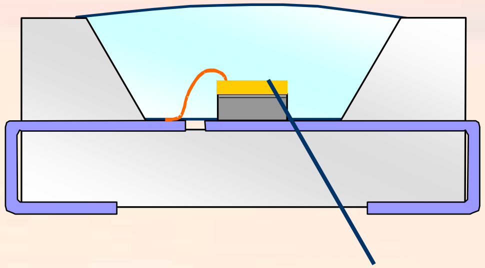


In the future: Nanophosphors ?

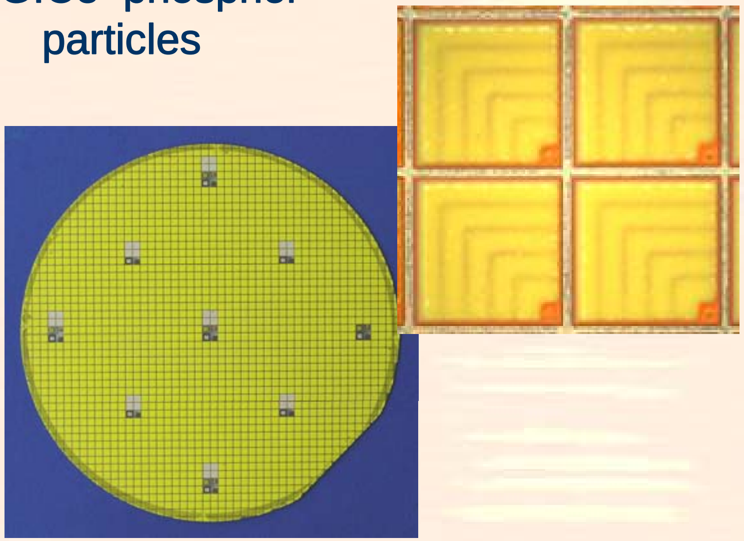
> 50 lm @ 350 mA

> 60 lm w. lens

clear silicone casting



CLC layer (phosphor + silicone) on surface emitter (1mm² ThinGaN chip)



1mm² ThinGaN wafer with 20 µm CLC layer

- ⇨ excellent color homogeneity
- ⇨ high luminance
- ⇨ perfectly suitable for optical systems

Fig. 21

OSTAR®-Platform for High Flux Applications

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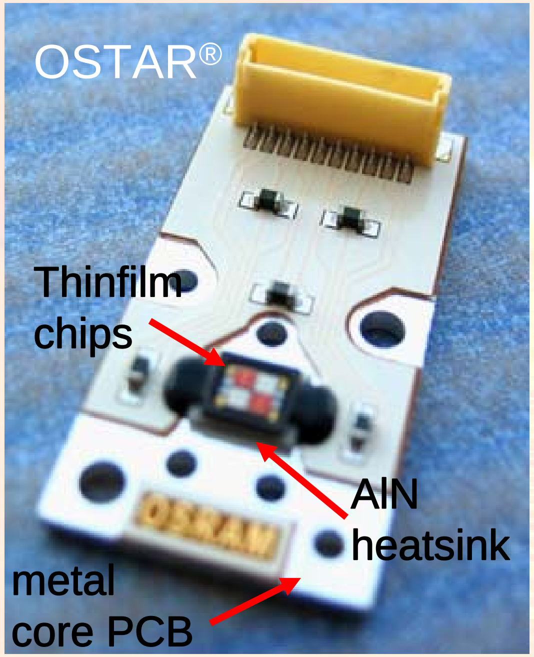


Special features for different applications

- very compact RGGB design
- low thermal resistance
- high luminance
- lambertian emitter
- flexible optics close to chip

Projection

Head up Display

Headlamp

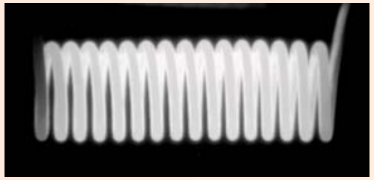
Solid State Lighting

Luminous flux (4 chips monochrome):

red:	220 lm	(750mA per chip)
green:	170 lm	(500mA per chip)
blue:	44 lm	(500mA per chip)

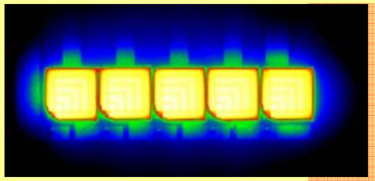
Fig. 22

OSTAR® for Automotive Forward Lighting



conventional tungsten coil in halogen lamp

OSTAR® Headlamp



- five 1mm² CLC ThinGaN chips

- assembled on OSTAR module
- > 250 lm @ 700 mA

Automotive Forward Lighting

Source: Hella

- primary optics
- beam shaping
- second. optics for projection

- beam pattern on street

Fig. 23

DRAGON® for LCD – TV Display (32" – 46")
LED Backlighting Application

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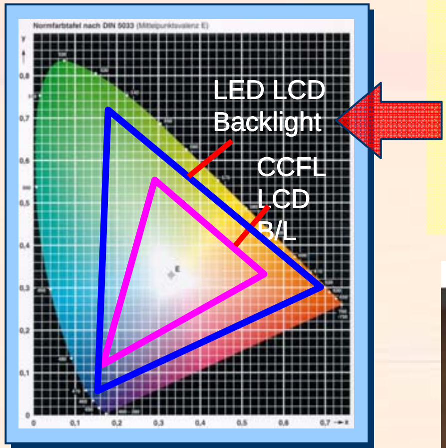
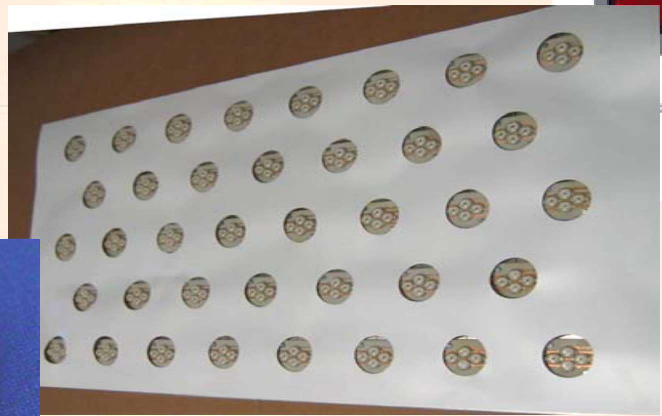
LED – B/L Benefits

- brilliant colors
- high contrast
- no blurring
- wide color gamut (> 100% NTSC)



32" – 46" LCD-TV screen



Arrangement of RGGB pixels on metal plate with reflector

R-G-B Power Dragons

Performance of direct B/L concept for 40" Display

- 250 Power Dragon
- 180 W electrical power
- 450 cd/m^2 on screen
- 40 mm unit thickness

Fig. 24

Conclusion

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- LEDs are on a steep improvement curve starting now to outperform conventional light sources
- Internal quantum efficiency is continously improved by increased material quality and “bandgap engineering” on a nano scale
- Nano structured AlGaInP and InGaN Thin-Film LEDs enabling highest light extraction and scalability to hi-flux
- Hi-flux package and new phosphor concepts drive LED performance due to thermal and color management
- There are many applications out there, waiting for further LED advancements

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Fig. 25