"What is LED Lighting: Technology Overview and Introduction"

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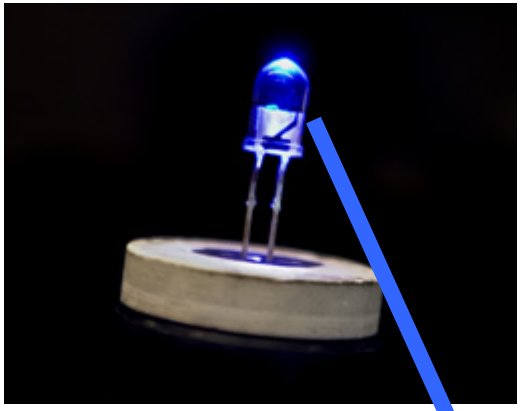
Outline

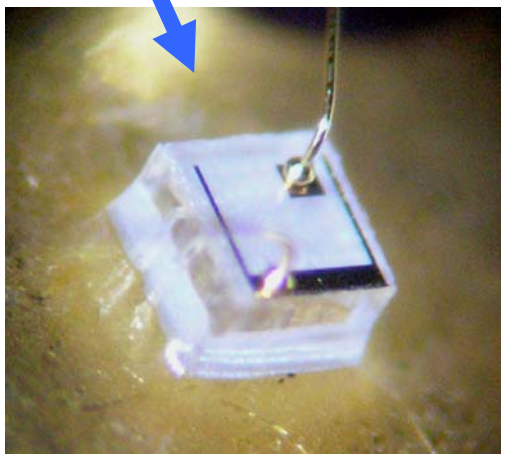
- **LED Basics**
  - **P-n junctions**
- **Materials Selection (GaN, AlGaInP)**
- **Electrical and Luminous Efficiencies**
  - **Electrical to Light Conversion**
  - **Luminous Efficincy**
- **Special Considerations**
  - **Heat**
  - **Efficiency Droop**
  - **System Efficacy**

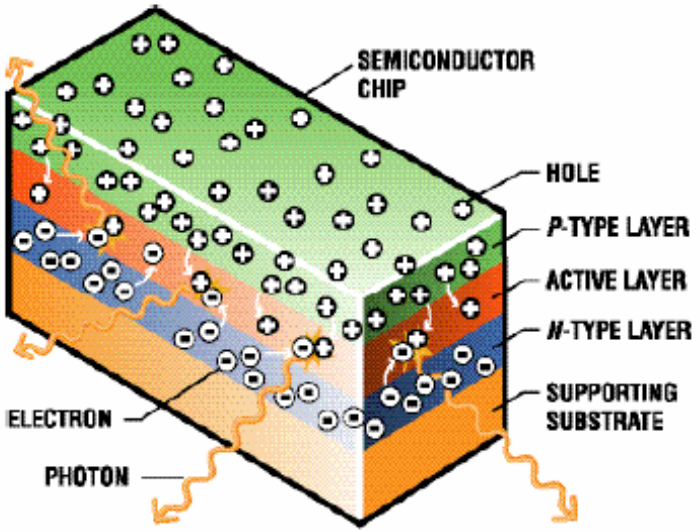
What is an LED?
(a p-n doped semiconductor)

L.E.D.= Light Emitting Diode (GaN Runs on 3.2V DC Power)



Blue LED





LED produces light by combining Positive and negative charges inside Indium-Gallium-Nitride (InGaN)crystal

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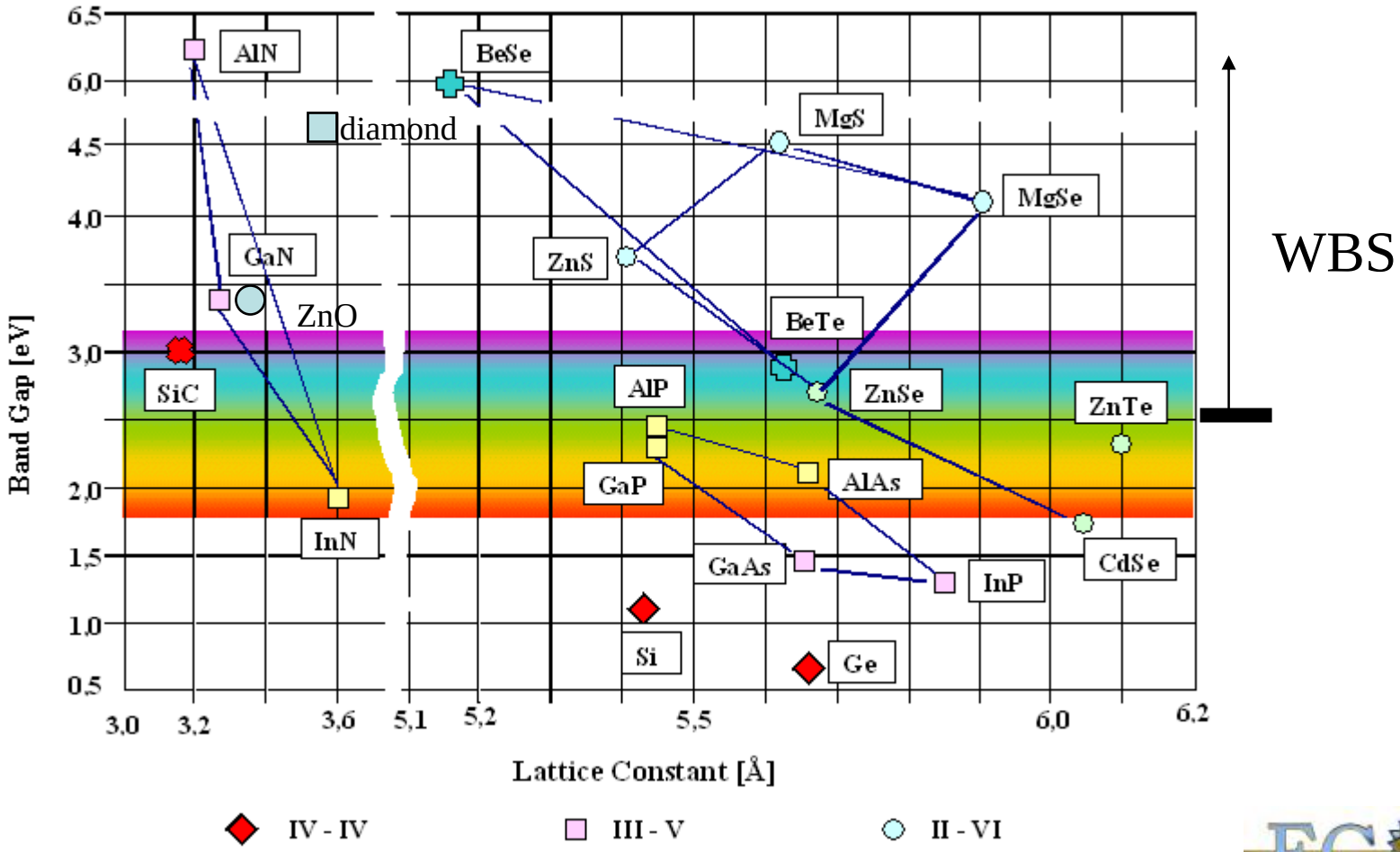
Bandgap Energy of LED Semiconductors

Visible range 1.7V to 3.2Volts



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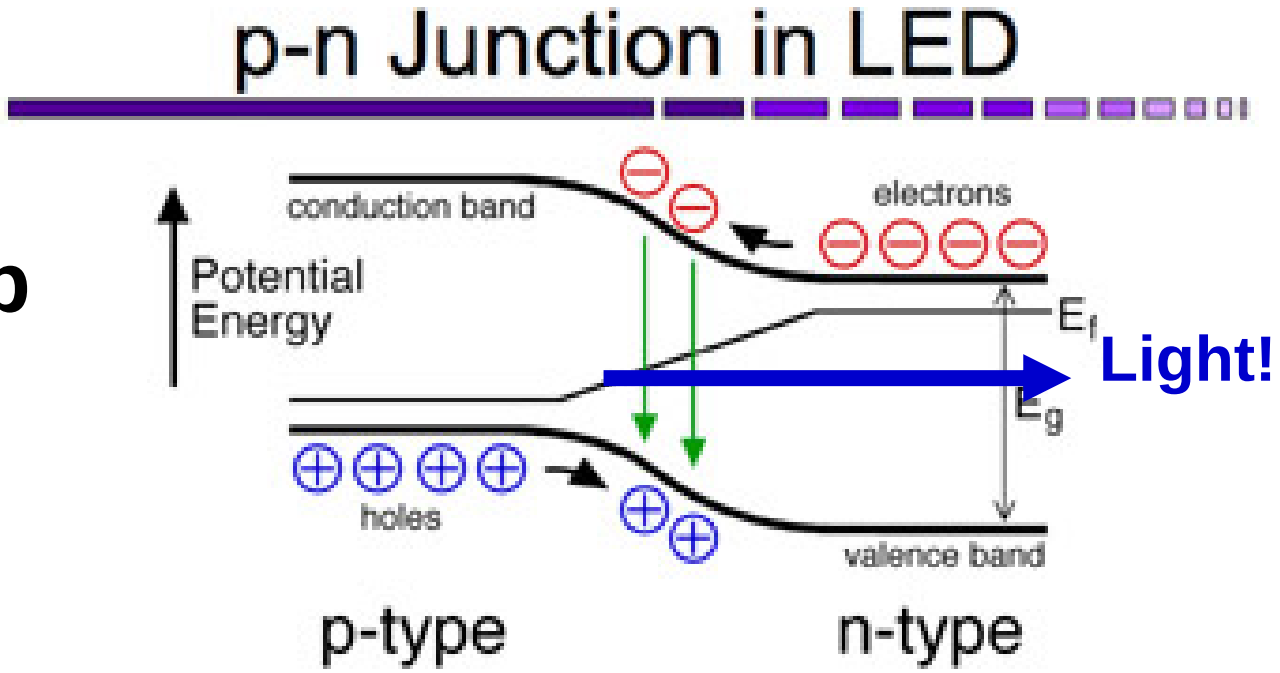
Semiconductor p-n junction

BandGap
3.0V



- Positive charges(holes) combine with negative charges(electrons) to produce light (photons)
- The opposite flow of a Solar Cell!

Reference: http://mrsec.wisc.edu/Edetc

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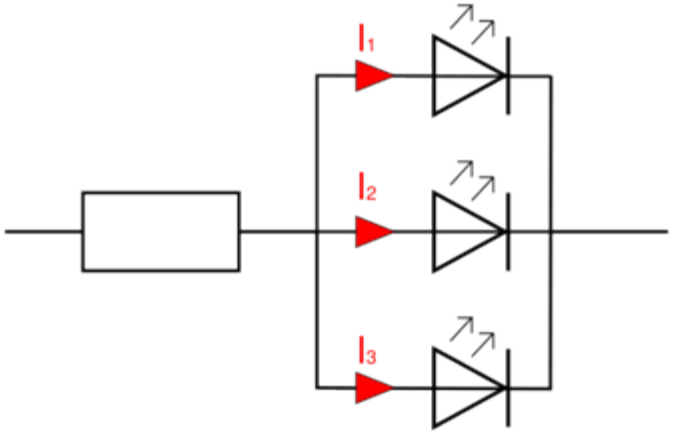
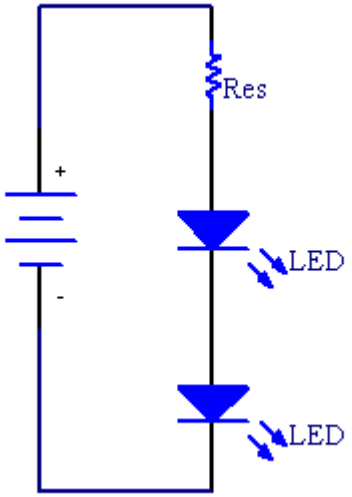
LED Circuits

- LEDs 3.0V forward Voltage, Can be combined in Series or Parallel



>3.0V Drive required

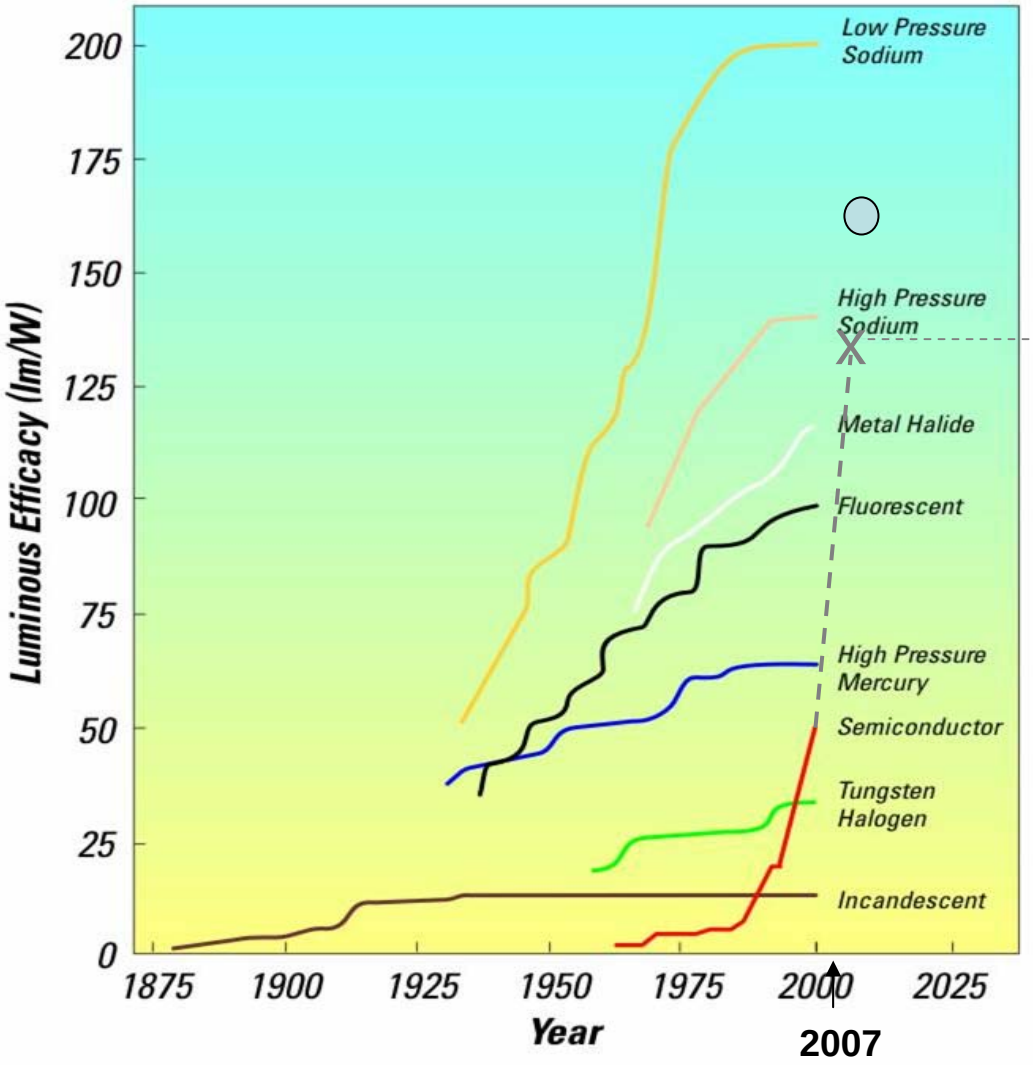


>6.0V Drive Required

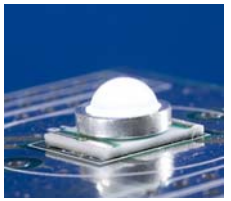
Image Source: www.wikipedia.com, http://www.overclockers.com.au

Luminous Efficacy of Various Light Sources

280lm/W Goal



LED



Current number for
GaN white LED at UCSB
Is 152 lm/W @20mA

Nichia (169 lm/W)@20mA
Cree (100lm/W) @ 350mA

Graph taken from www.lampteck.co.uk

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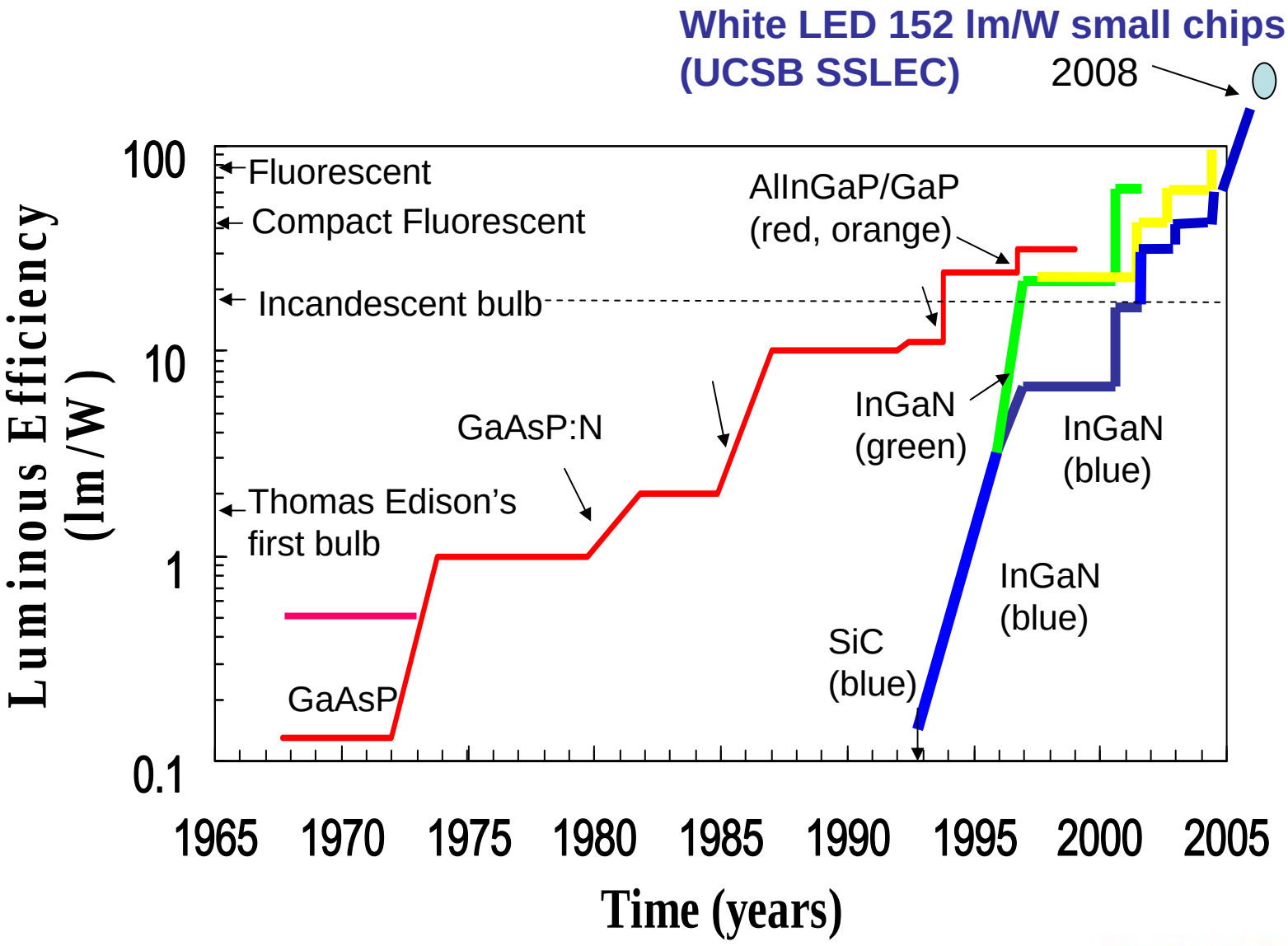
GaN LED Historical Development



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LED Efficiencies

- Luminous Eff. (lm/Watt) $= K_* \eta_{elec} * \eta_{IQE} * \eta_{extrac} * \eta_{conv}$

	GOAL	CURRENT
• Electrical Efficiency	95%	80%
• Internal Quantum Efficiency	100%	80%
• Extraction Efficiency	90%	70%
• White Conversion Efficiency	100%	60%

- K=luminous efficacy of 6500K white at 100%QE (340lm/watt)

Wall-Plug Efficiency = $\eta_{elec} * \eta_{IQE} * \eta_{extrac}$

External Quantum Efficiency = $\eta_{IQE} * \eta_{extrac}$

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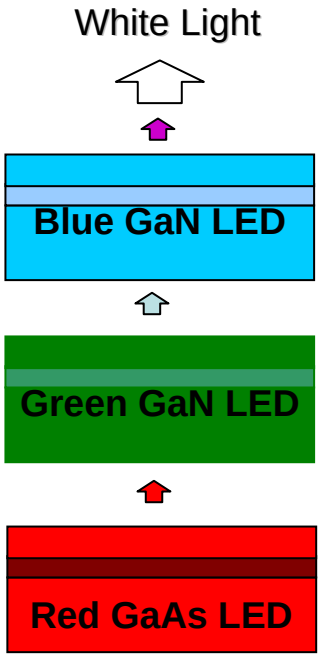
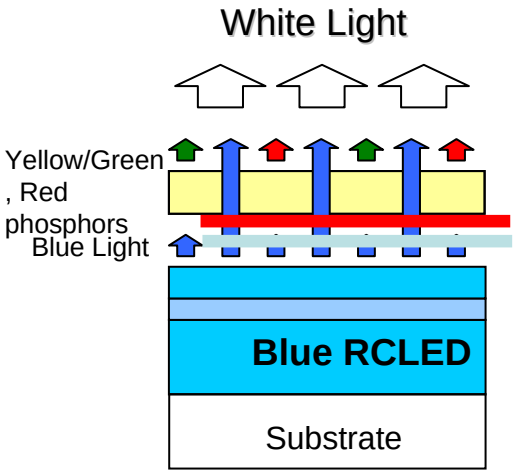
White LEDs

2 Methods of Generating White LEDs





Multi-Chip, RGB
-best efficiency(theoretically)
-Tunable
-Green LED low Efficiency now 80lm/W
-highest cost
(5% market)

Blue+ Phosphors
-lowest cost
-Currently Highest Efficiency
160lm/W(cool white)
(95%market share)

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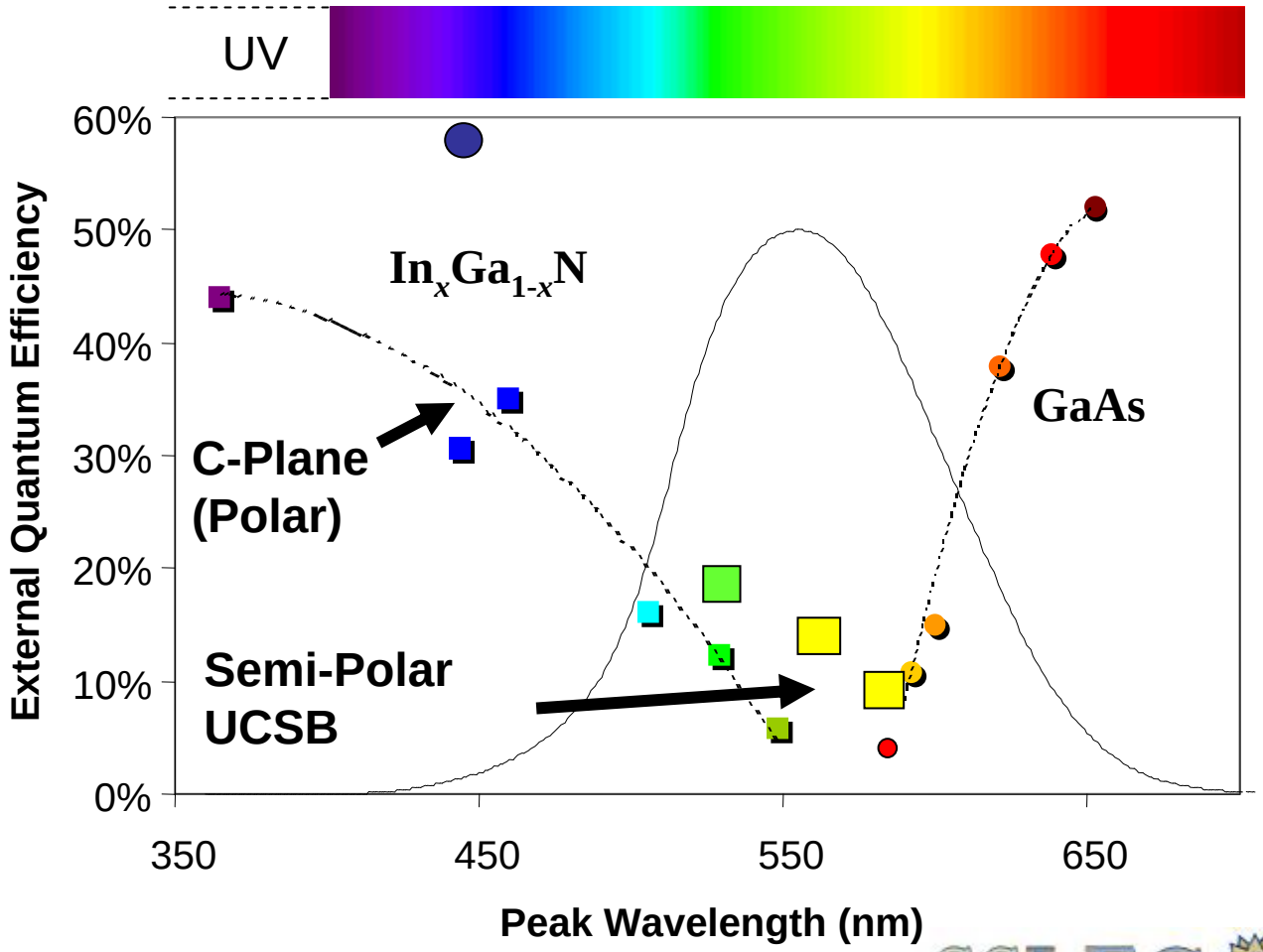
Polar/SemiPolar GaN: LED Efficiency vs. Wavelength

- Better Energy Efficiency in **green,yellow eventually white**



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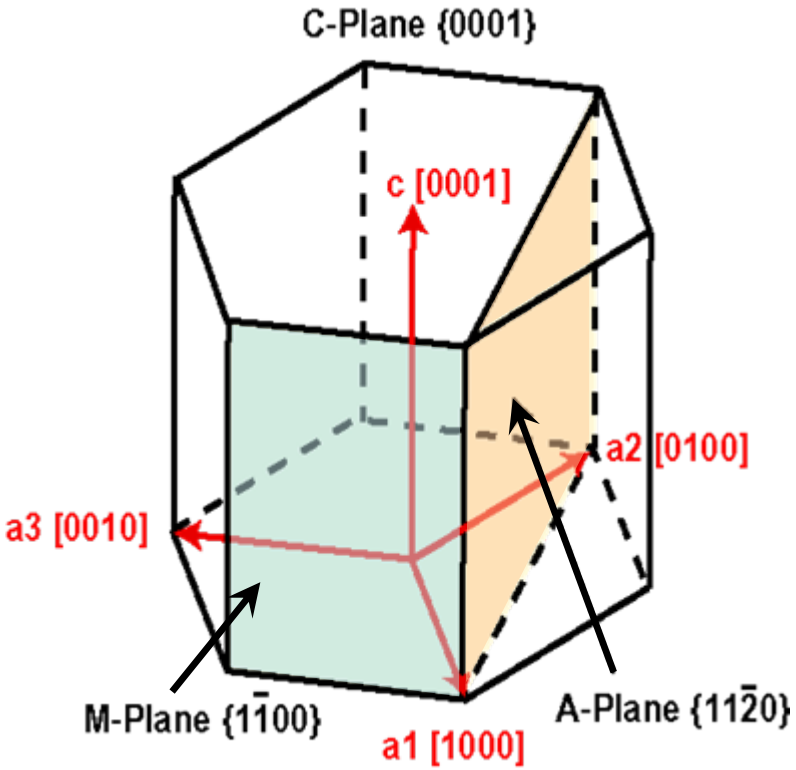
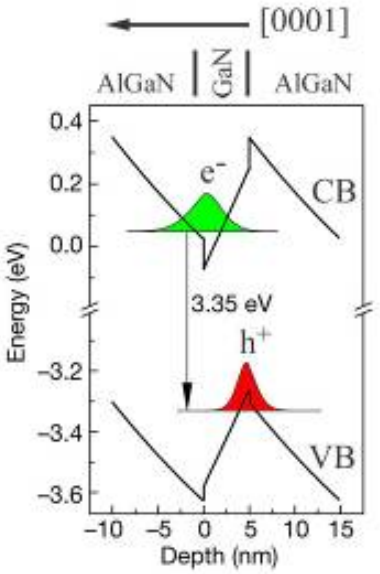
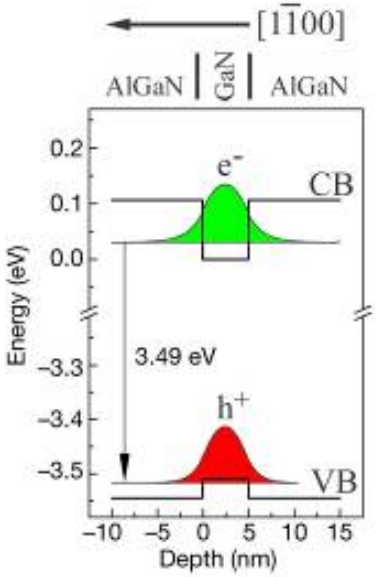
GaN LED Crystal Structure





Polar
(C-plane)



Non-Polar
(A,M-Plane)

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Yellow GaN LED on Semipolar GaN

Chip A

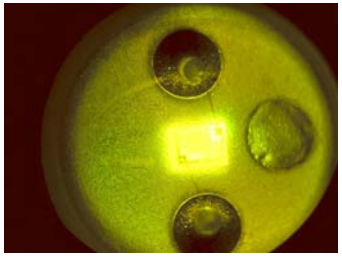
20mA@DC :

4.2 mW, 9.5%EQE

20mA@pulsed:

5.9 mW, 13.4%EQW

(564 nm)



Chip B

20mA@DC :

3.1 mW, 7.1%EQE

20mA@pulsed:

3.5 mW, 8.2%EQW

(575.7 nm)

Data Courtesy UCSB SSLEC

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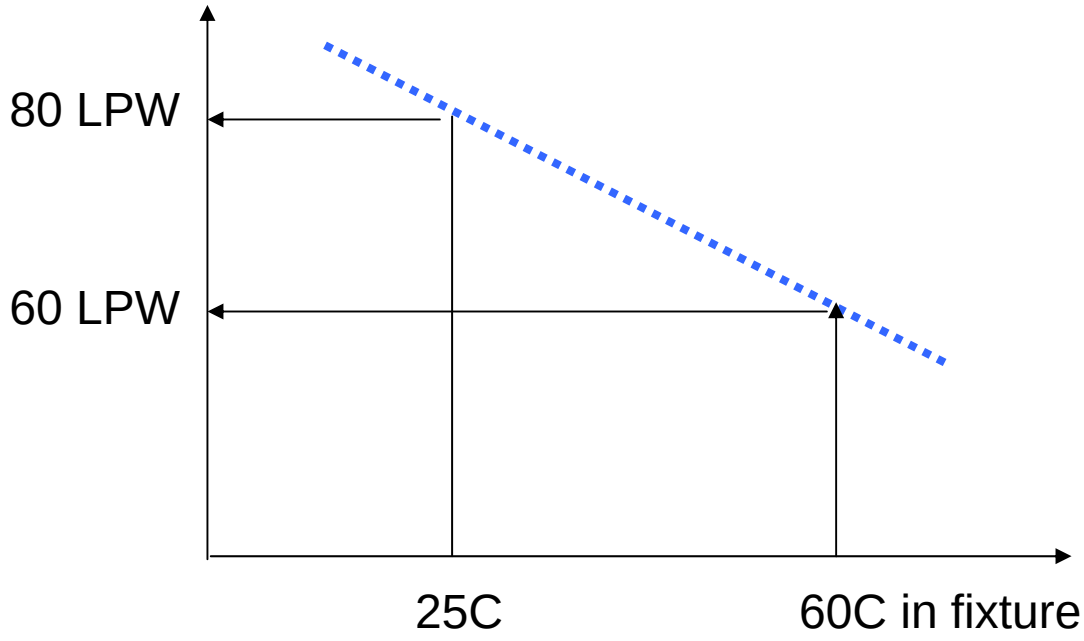
The Reality

- Commercial White LED “Bulb” 50-80 LPW
- Fixture Efficiency all over the map 30-80%
- Luminaire System Efficacy 15- 64 LPW
- HEAT is a BIG Problem



Lamp Casing Temperature

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LED “Lamp” Eff. vs. System Eff.

Company Claims LED		Temp/Fixture Eff.	System Efficacy
– **LED A**	**80 LPW**	**80%**	**64LPW**
– **LED B**	**45LPW**	**50%**	**22.5LPW**
– **LED C**	**50LPW**	**30%**	**15LPW**
– **CFL**	**60LPW**	**60%**	**36LPW**

– Energy Star Ratings Needed

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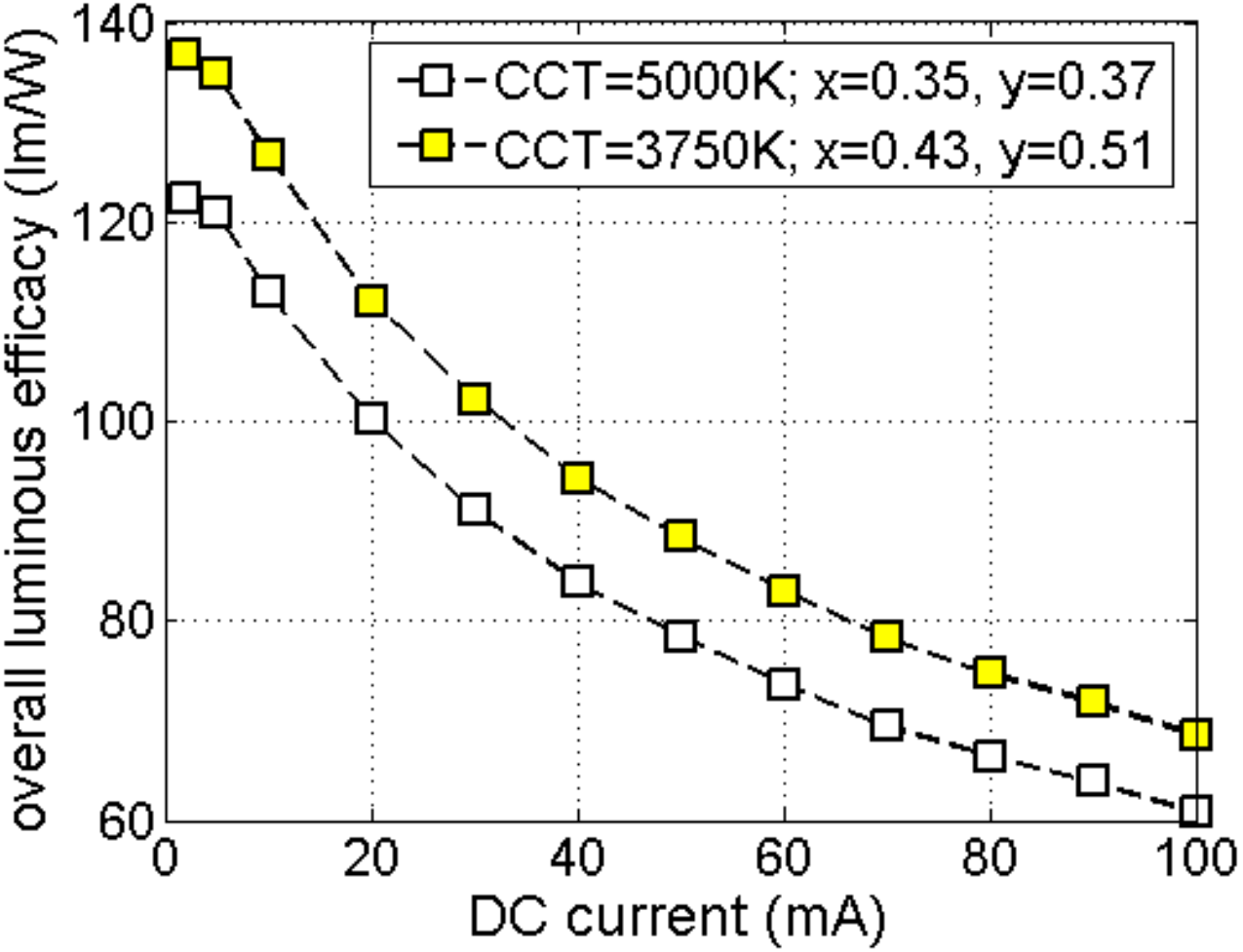

η_{lum} ≈ 135lm/W at 3750K and 5mA DC
η_{lum} ≈ 112lm/W at 3750K and 20mA DC

η_{lum} ≈ 121lm/W at 5000K and 5mA DC
η_{lum} ≈ 100lm/W at 5000K and 20mA DC

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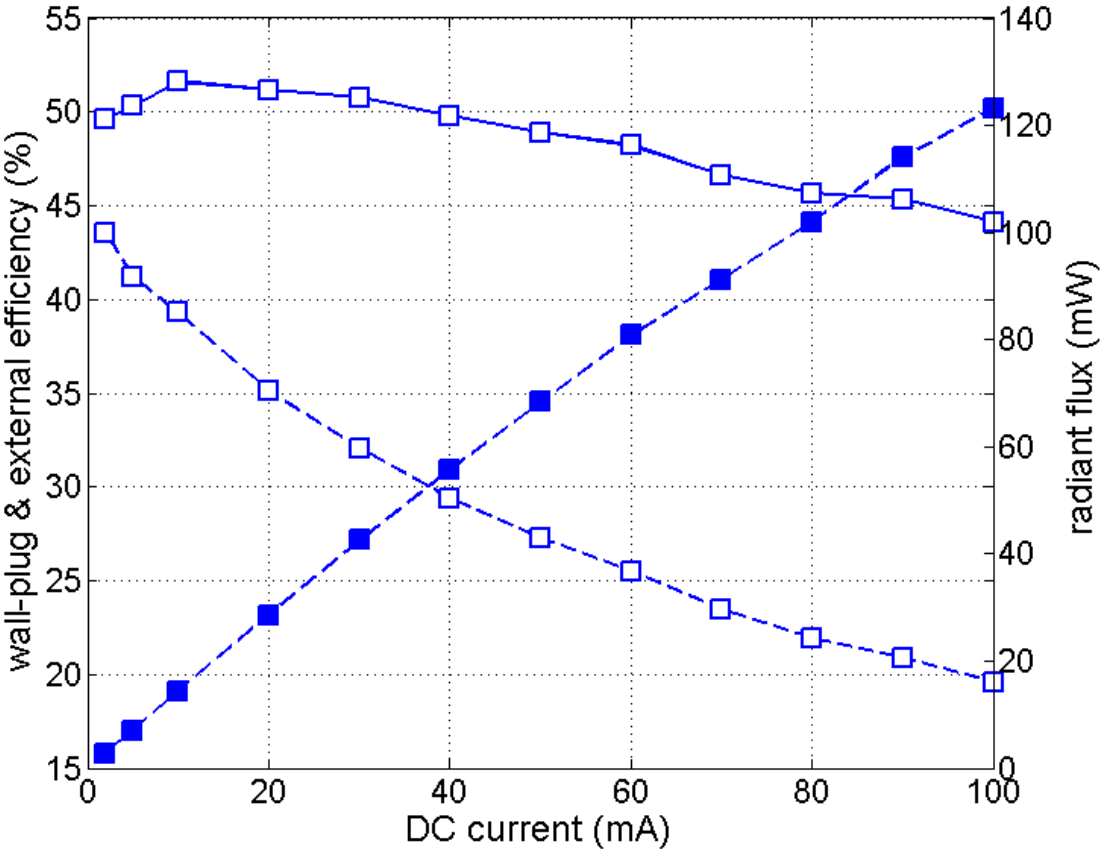
Efficiency Roll-off “Droop”



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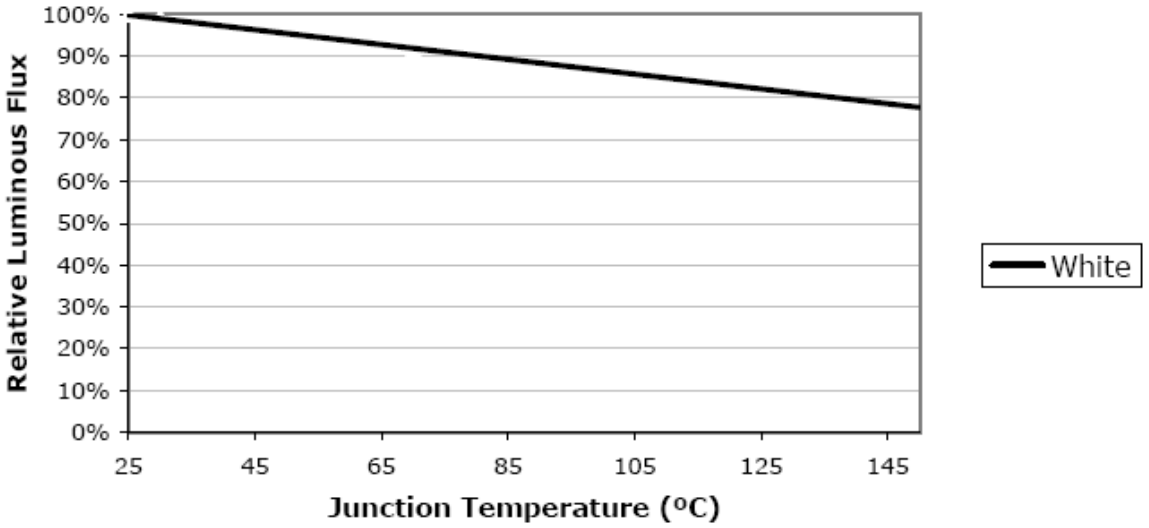
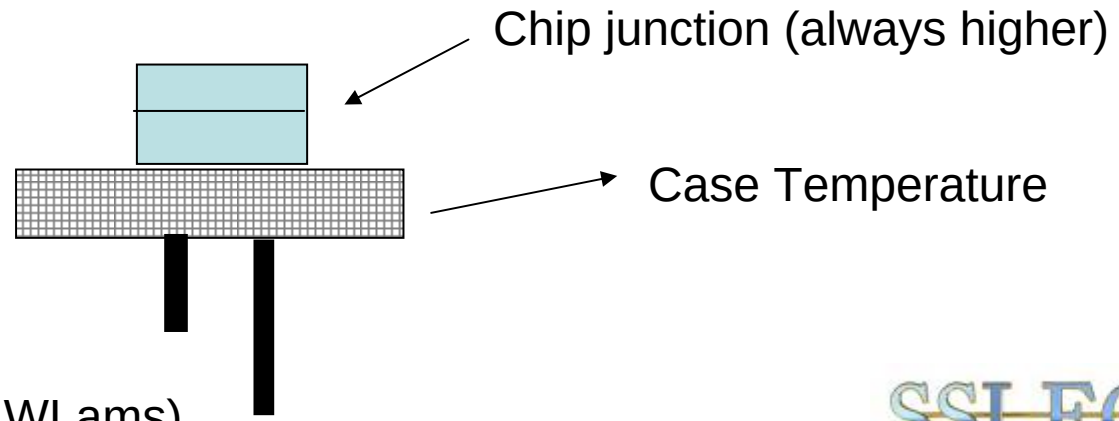
Effect of Temperature on LEDs

Relative Flux vs Junction Temperature (I_F = 350 mA)

The following graph represents typical performance of XLamp MC-E LEDs with all four LEDs driven in series at 350 mA.





Source: Cree Inc (Power WLams)

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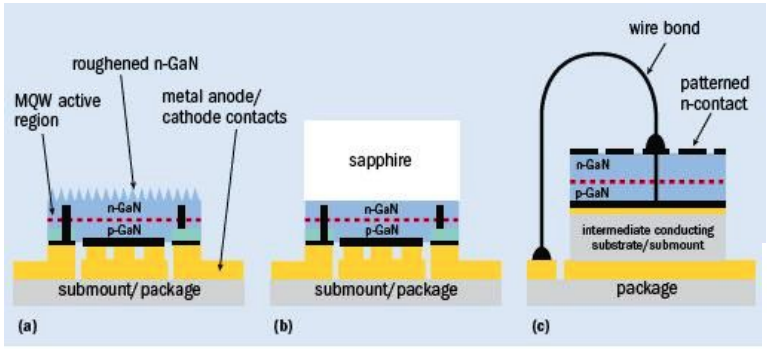
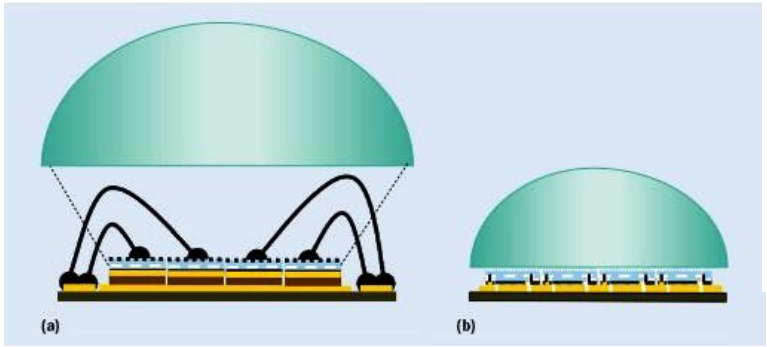
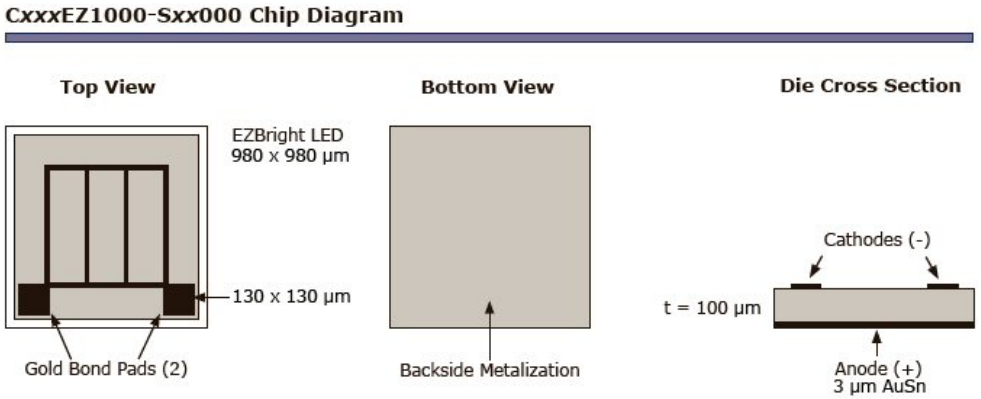
Chip Designs







TFFC Philips-Lumileds

Cree XLamp

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Light Extraction Efficiency

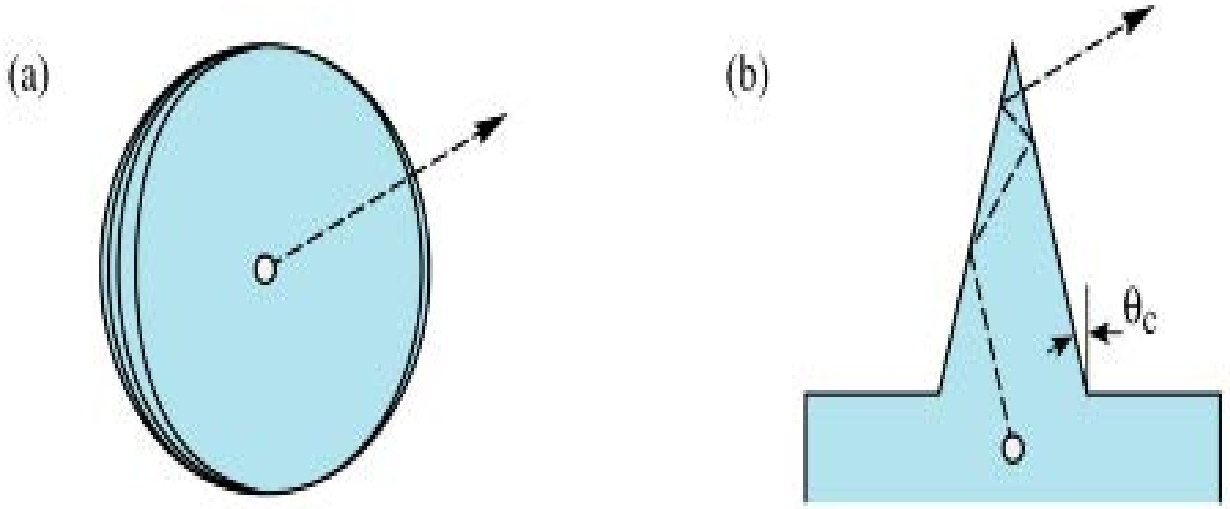
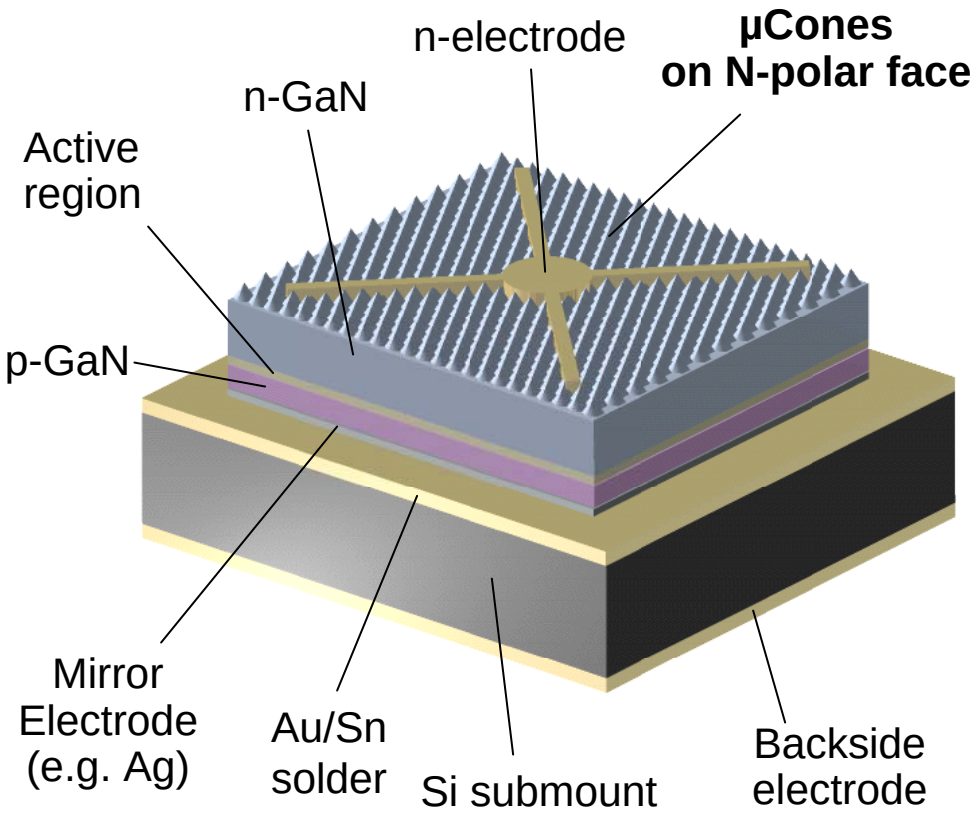


Fig. 6.4. Schematic illustration of different geometric shapes for LEDs with perfect extraction efficiency. (a) Spherical LED with point-like light-emitting region in the center of the sphere. (b) Cone-shaped LED.

μCone LEDs: Light Extraction by Roughening



- **No semitransparent electrode**
- **Reflective backside mirror**

  → **Increase in light extraction**

- **Lower thermal resistance than than sapphire substrates**

  → **High operating current**

- **Vertical current flow**

  → **Easy to scale up**

- **Cone-shaped surface features**

  → **Good for light extraction**

T. Fujii, Y. Gao, R. Sharma, E.L. Hu, S. P. DenBaars and S. Nakamura
Appl. Phys. Lett. 84 (2004) 855

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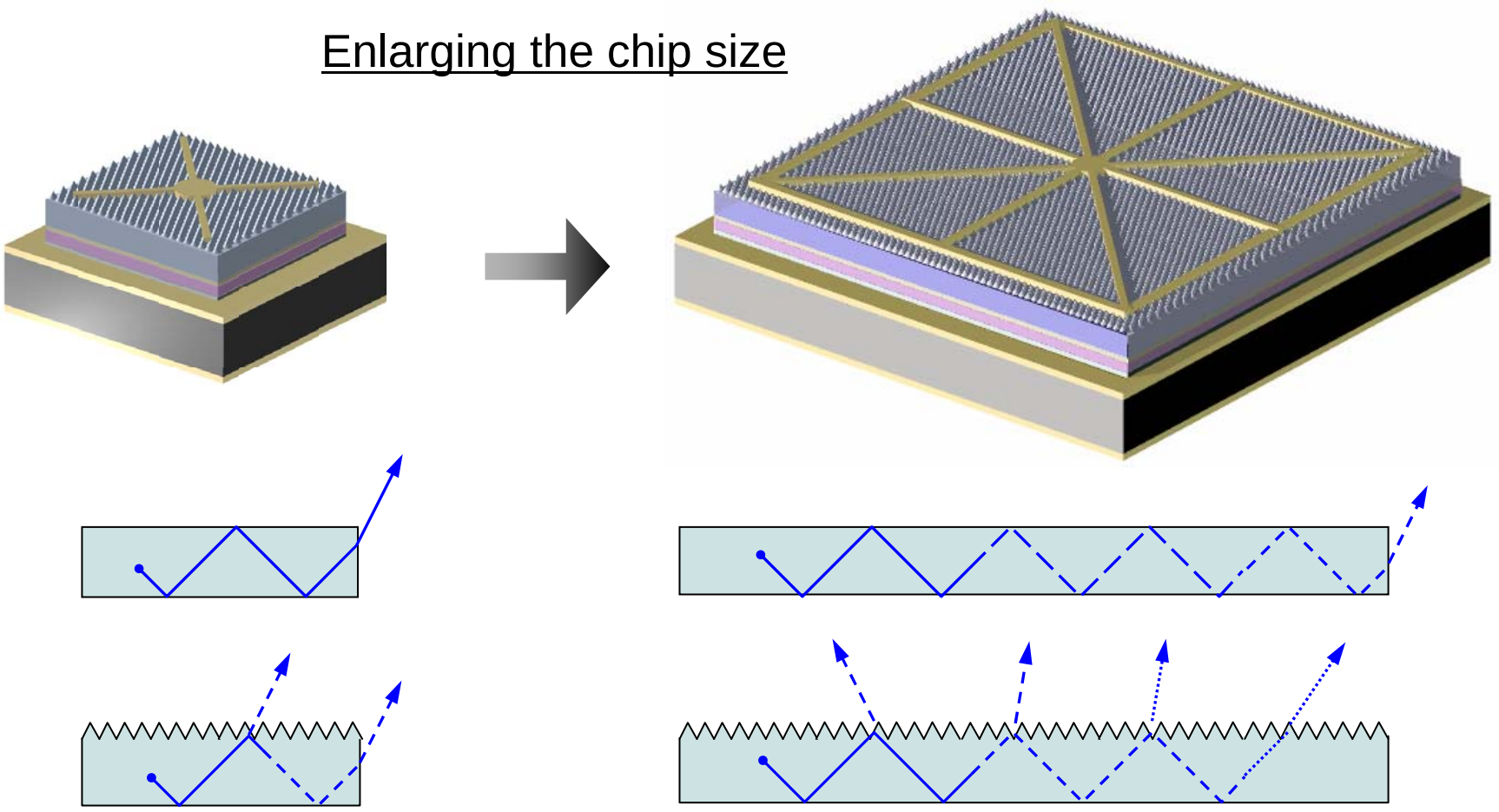
μCone LED Scalability

Enlarging the chip size



Lateral size of the μCone LED does not affect extraction

Lighting System Efficacy

Luminaire Type		Lumens Per Watt	Fixture Efficiency	Usable Lumens Per Watt
Halogen Incandescent		17	45%	8
Compact Fluorescent		45	33%	15
150 W Cobra Head Type II Streetlight (HPS)		91	50%	46
400W HID w/Glass Housing (MH)		70	54%	38
XLamp LED Lighting Fixture		71	***90%***	***64***
T8 Fluorescent Tube		80	77%	62

Courtesy Cree Inc

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LED Lighting System

UCSB Streetlights (June 08)
Beta LED

LLF (Cree) 650 lumens (12watts)

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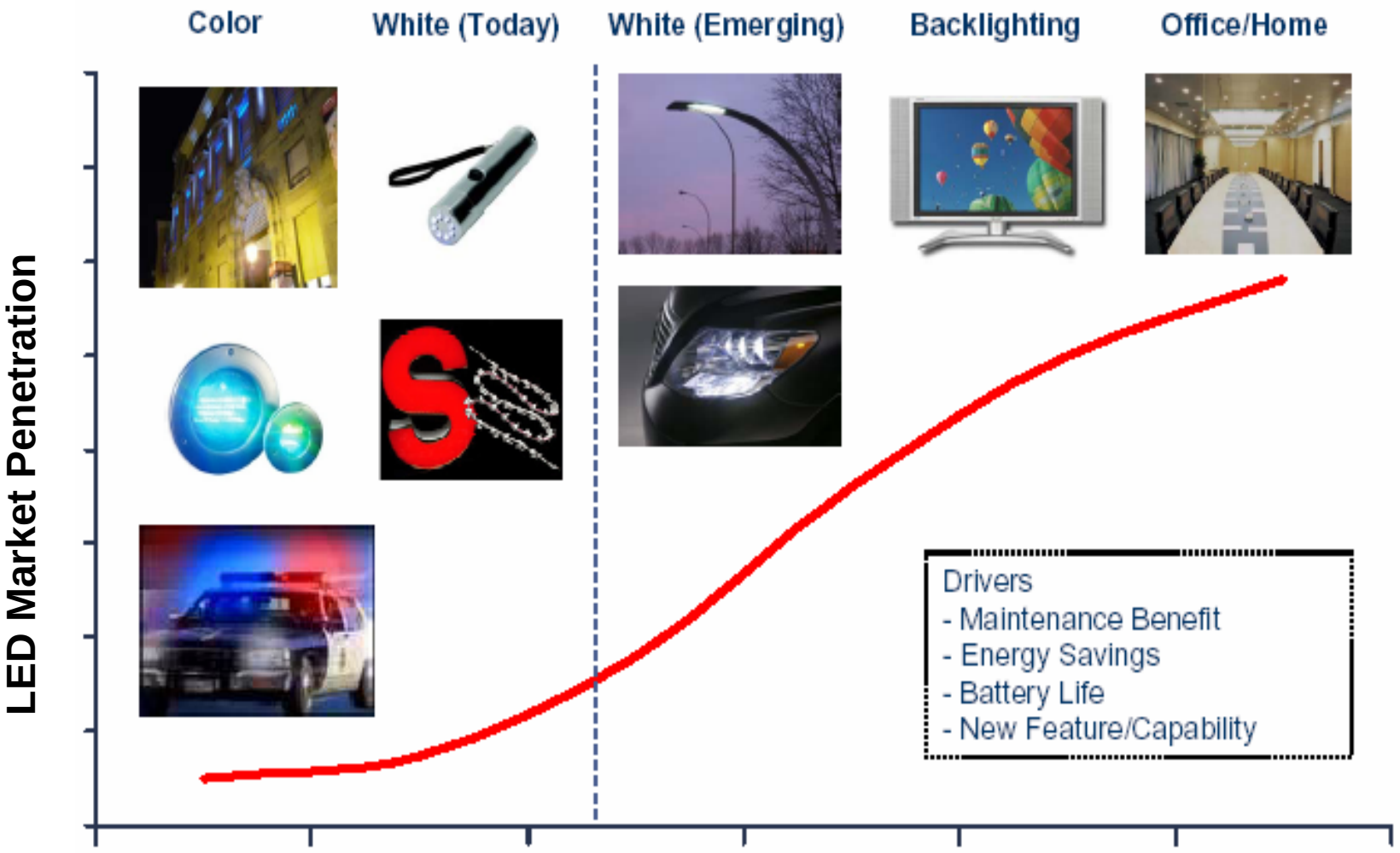
LED Market Penetration



Courtesy Cree Inc

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Solar(Photovoltaics) + LED (Off-grid)

www.lutw.org

Light Up The World Foundation

- Kerosene lighting and firewood are used by 1/3 of the world; they cause countless fires and are very inefficient **(0.03 lm/watt).**
- The average villager spends 10-25% of their annual income on kerosene.
- LED Lighting costs much less on an annual basis and payback period is just 6 months.
- LED Lighting /Solar Cell Off-Grid

www.lutw.org

"In the few months we have had the White LED lamps the improvement in the children's academic performance has been absolutely remarkable"

Headmaster, Mubarak Village, Pakistan June 2004

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CONCLUSION

- **R&D Level LED Single lamp efficacy (169lm/W) in lab settings(pusled), However:**

- **Commercial based LED Lamp Fixtures are much lower 64LPW due to several factors that need further research and development in**
  - **Efficiency roll-off “Droop”**
  - **Fixture Efficiency**
  - **Heat Sinking**
  - **Scale up to Mass production**

- **LED Chip, Lamp, and Lighting Fixture Mfgs have to work together to help implement the Solid-State Lighting Revolution…**

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