LED: Critical Research Issues

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SMART LIGHTING

Rensselaer
why not change the world?

DOE Solid State Lighting
R&D Workshop
Long Beach, CA

January 30, 2013

NSF

NYSTAR®

This work is supported by a United States of America DOE/NETL Solid-State Lighting Contract of Directed Research under DE-EE0000627. This work is also supported by the NSF under cooperative agreement EEC-0812056 and by New York State under NYSTAR contract C090145.

Materials Development Needs

- Droop Reduction

  => Higher Efficiency

  => Higher Lumen

  => Less Cooling

- Integration LED + Phosphor

  => Direct Spectrum LED

- Integration LED + Driver + Sensor + Controls

  => AC LED System

New Ideas on How to Avoid Droop

APPLIED PHYSICS LETTERS **102**, 031120 (2013)

Suppression of Auger-stimulated efficiency droop in nitride-based light emitting diodes

AIP Applied Physics Letters

R. Vaxenburg,[1] E. Lifshitz,[1] and Al. L. Efros[2]
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[2]*Naval Research Laboratory, Washington, District of Columbia 20375, USA*

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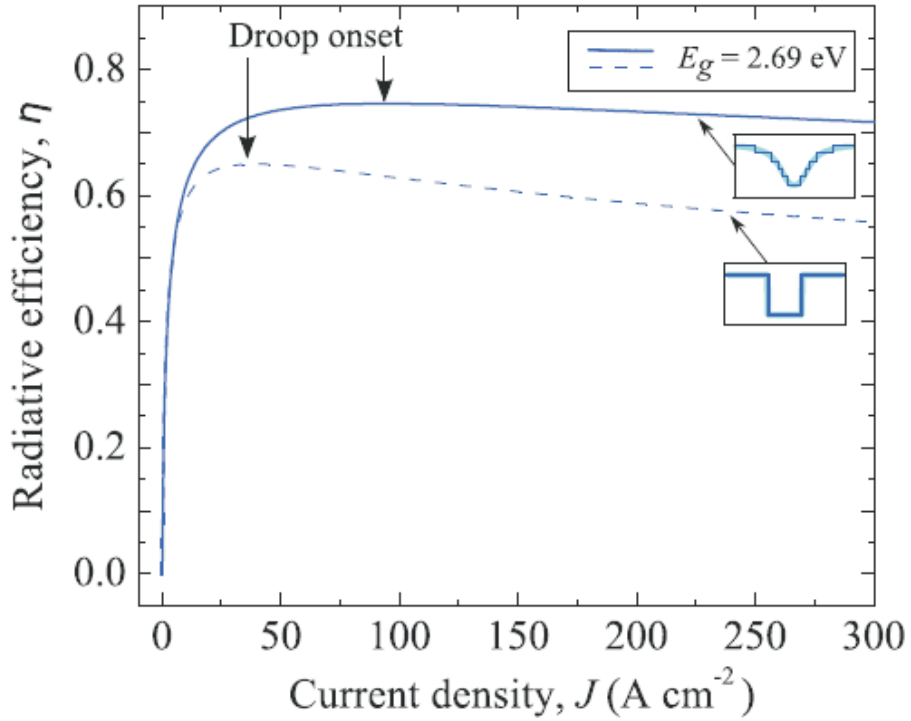
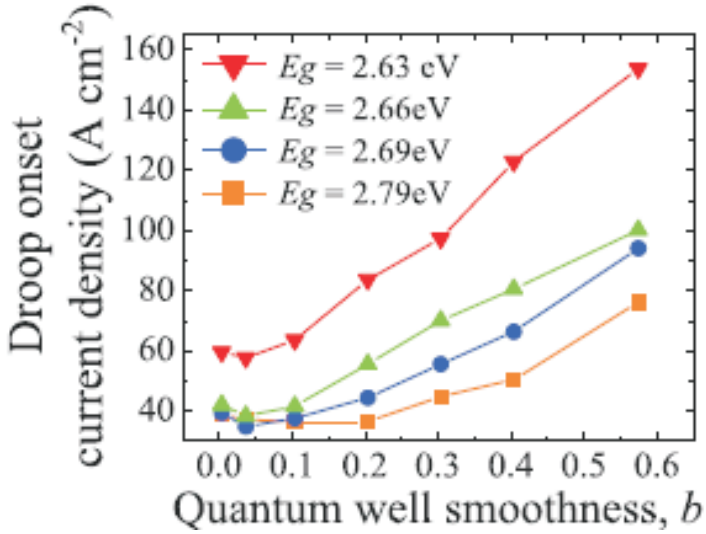


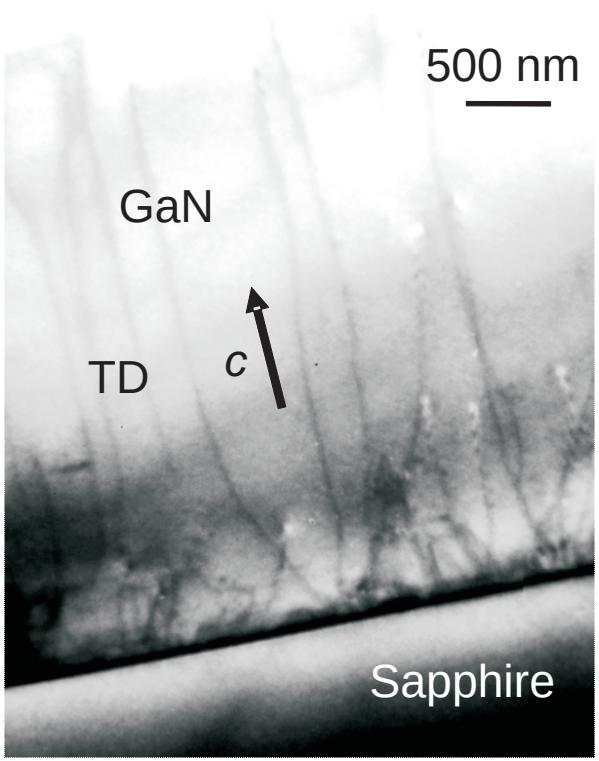


New ideas — need to be tested

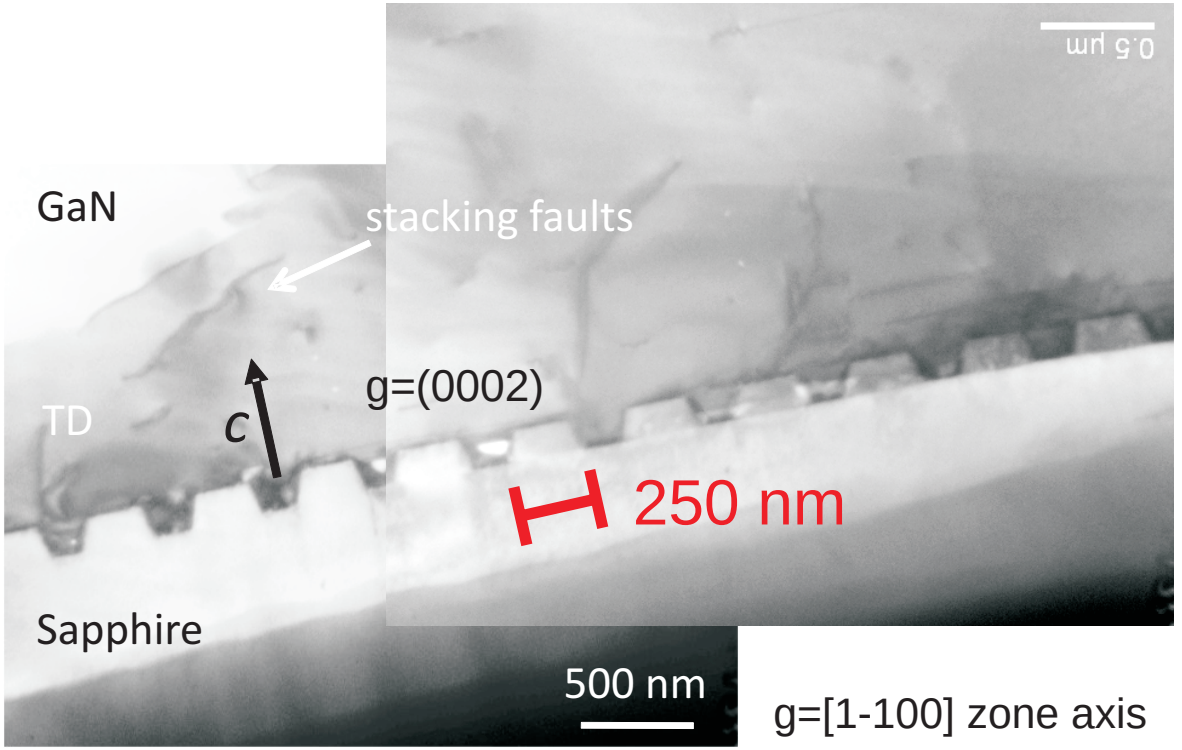
GaN on Nano-Patterned Sapphire

profound change in defect structure

reference LED



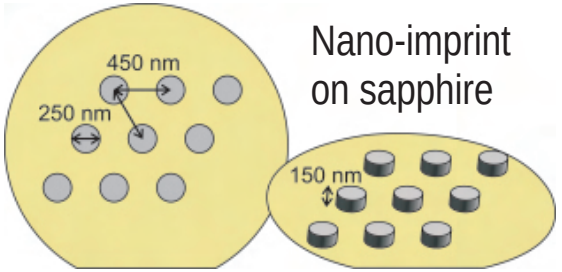
LED on nanopatterned substrate



g=[1-100] zone axis

TD density (plan view TEM):

6.4×10^{8} cm^{-2} << 3.6×10^{8} cm^{-2} -44%



Nano-imprint on sapphire

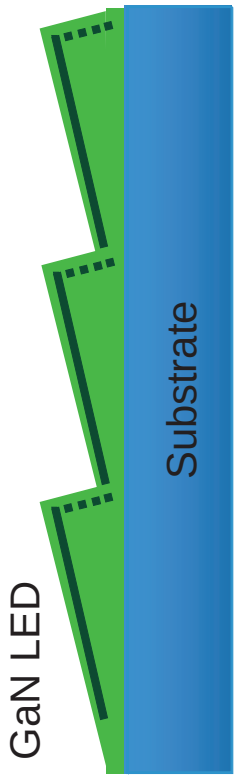
AIP Applied Physics Letters

Yufeng Li, *et al*. Appl. Phys. Lett, **98**(15), 151102 (2011). doi:10.1063/1.3579255

Epitaxy on Large Surface Miscut – Built-In Patterning

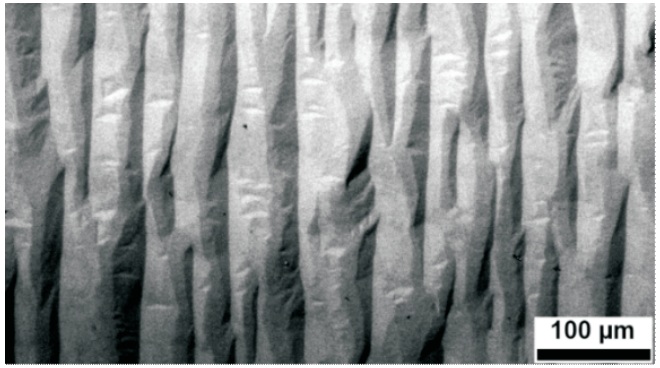
the art of light extraction

Entire LEDs in fish scale pattern

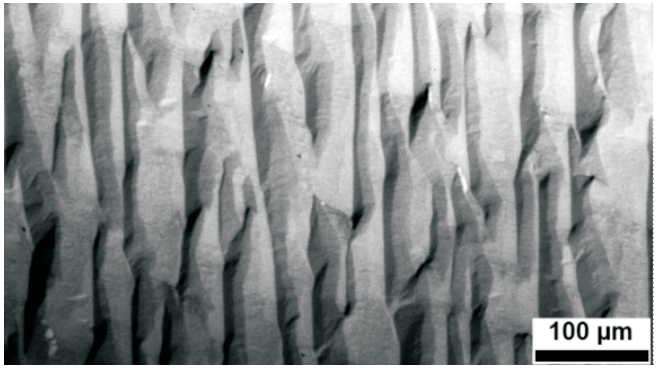


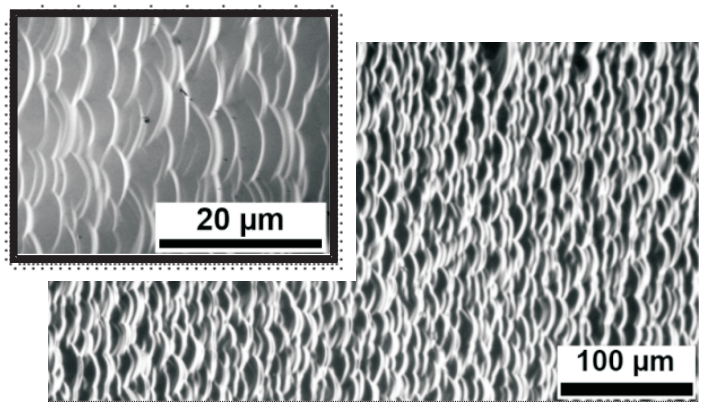
GaN substrate miscut (deg)

0.06° GaN

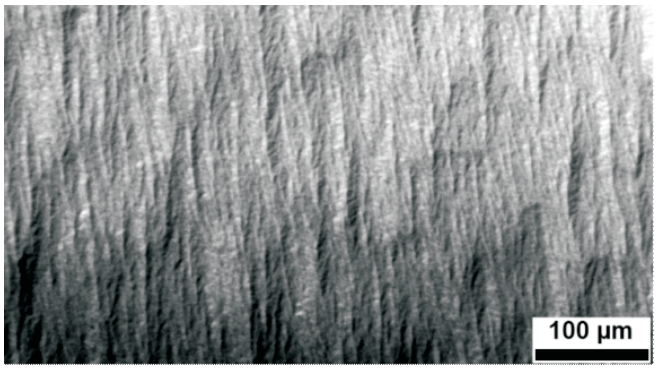


0.70° GaN





2.24° GaN



0.25° Sapphire

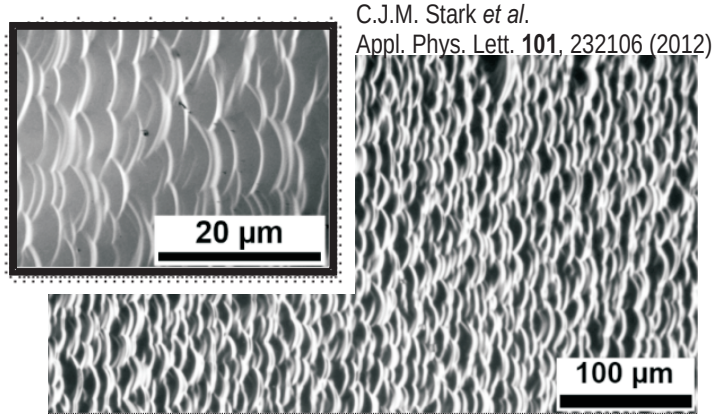
LED surface image

AIP Applied Physics Letters

C.J.M. Stark *et al*. Appl. Phys. Lett. **101**, 232106 (2012), dx.doi.org/10.1063/1.4769442

Droop Reduction

- Bulk GaN
  - homoepitaxy
- New QWs
  - new profile
  - new alloy
- Semipolar
  - substrate
  - epitaxy
- Nano-patterned
  - Si substrate
  - new substrates



C.J.M. Stark *et al.*
Appl. Phys. Lett. **101**, 232106 (2012)

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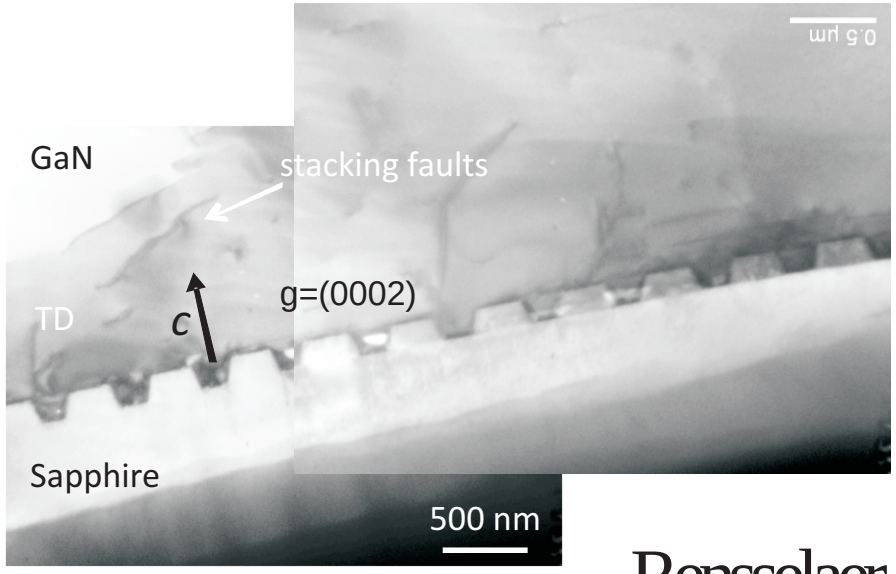
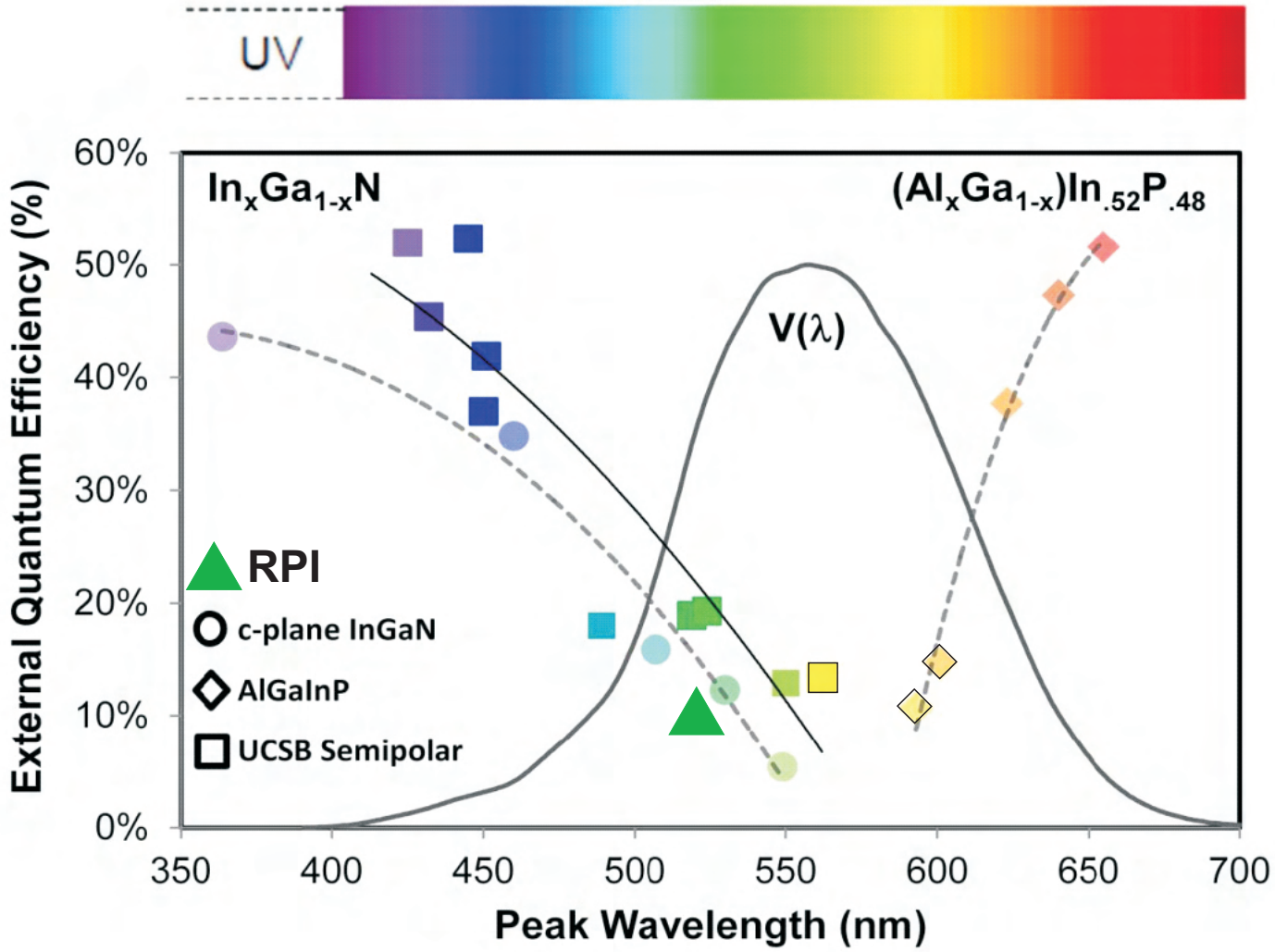


Yufeng Li, *et al*. Appl. Phys. Lett, **98**(15), 151102 (2011)

The Green Gap

window of opportunity



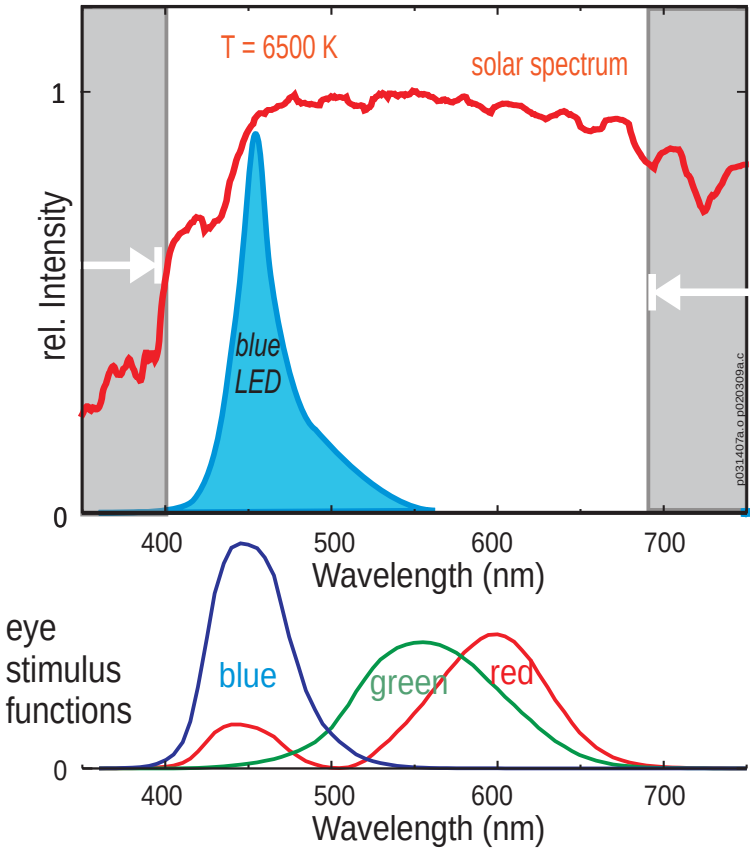
after: S. DenBaars, LS-13 Intern. Symp. Science Technology Lighting, June 2012, Troy NY

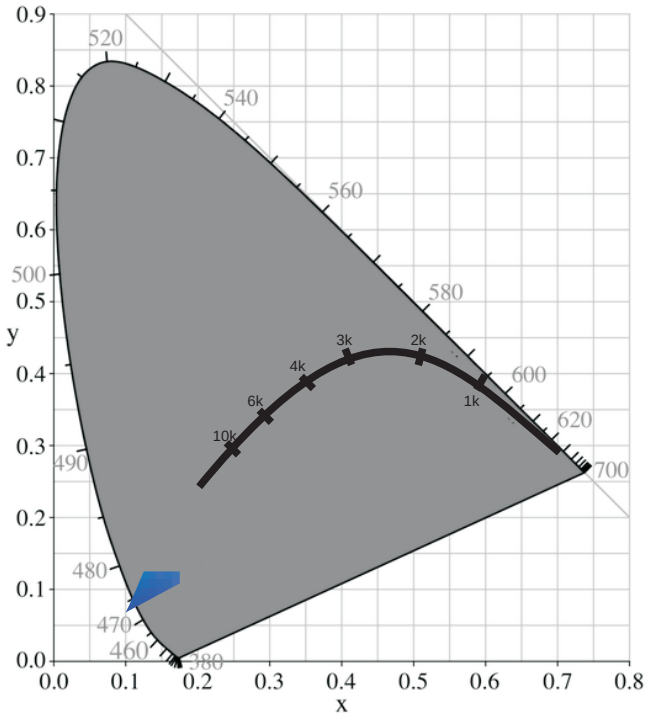
AIP Applied Physics Letters

Y. Li *et al* Appl. Phys. Lett. **98**, 151102 (2011)

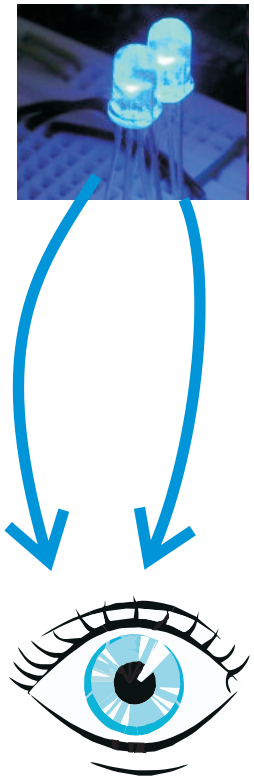
Composite White Light Emitting Diode

blue plus phosphor





1931 Chromaticity Diagram



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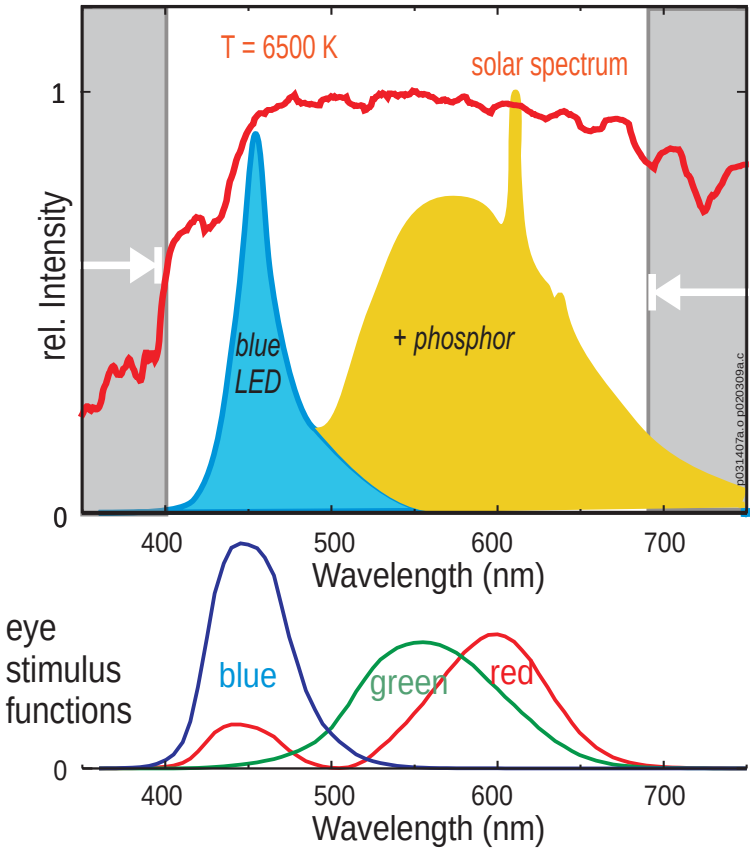
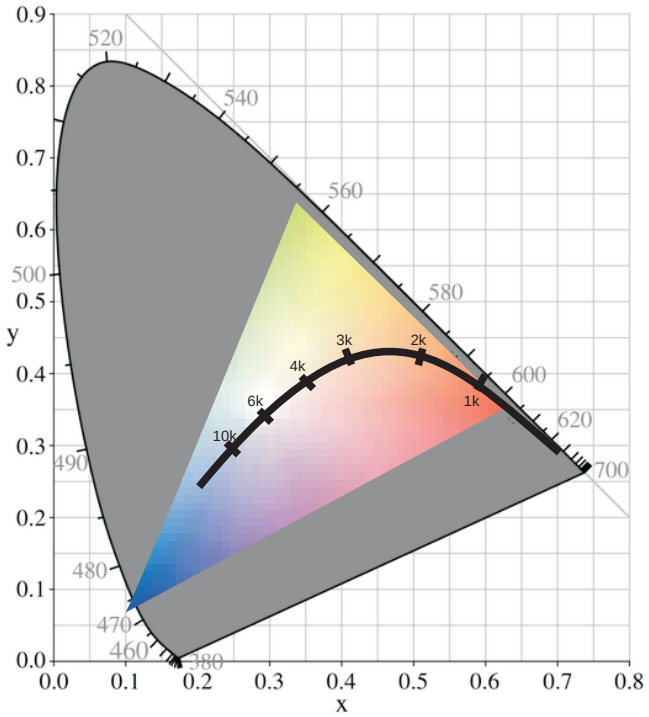
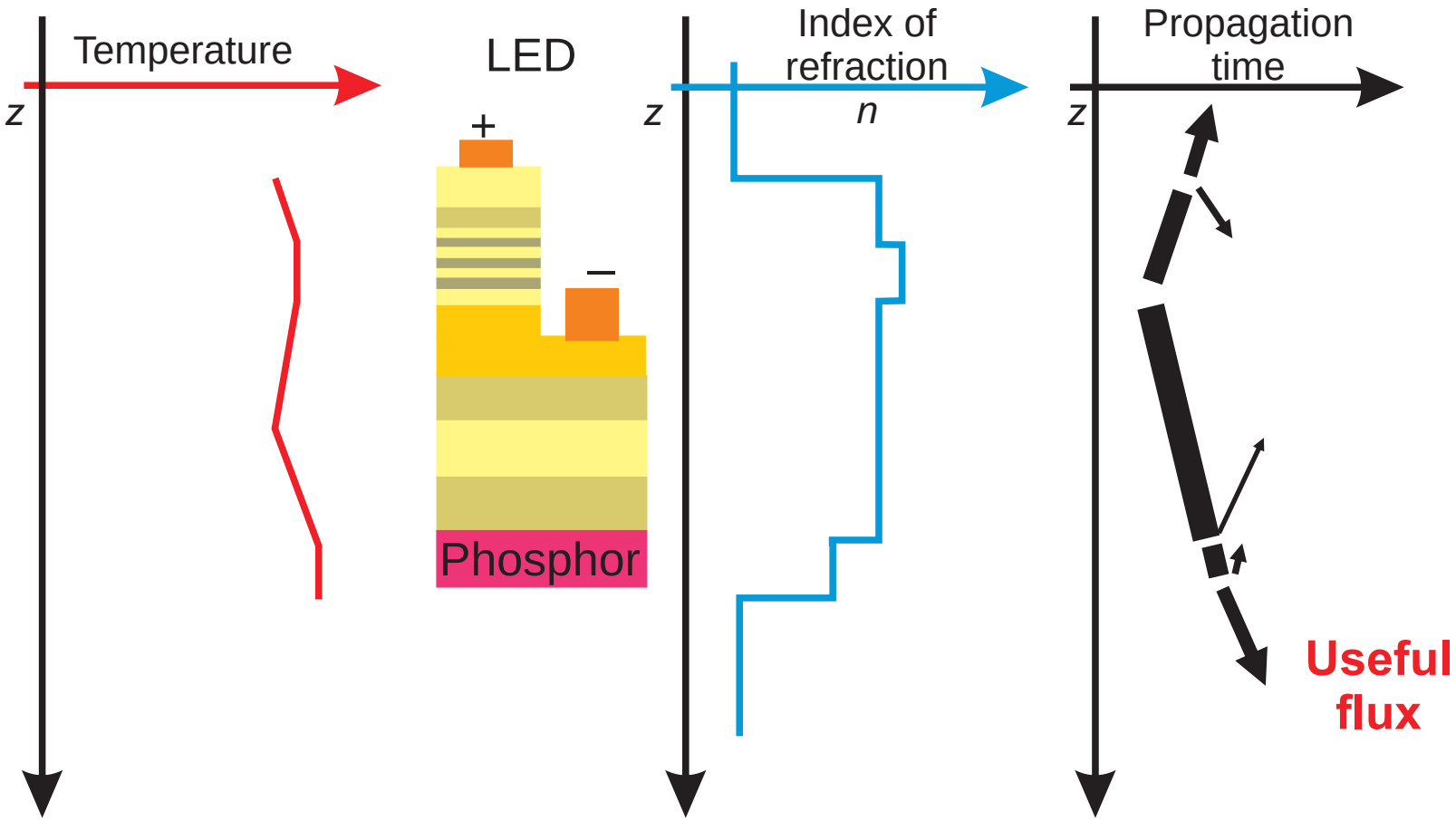




1931 Chromaticity Diagram

Proper Placement of Phosphor Layer

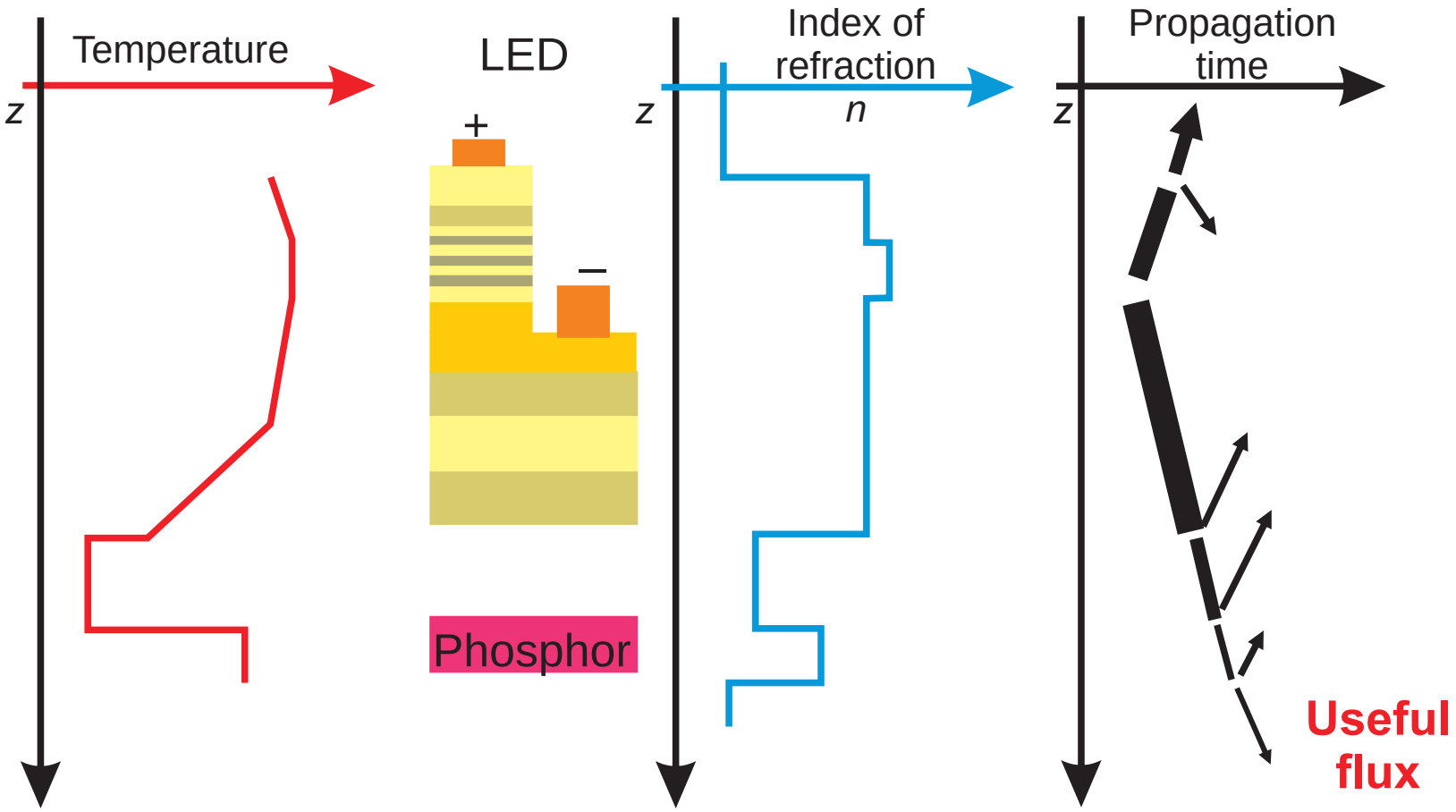
index and thermal matching



sandwiched phosphor — too hot of for standard phosphor

Proper Placement of Phosphor Layer

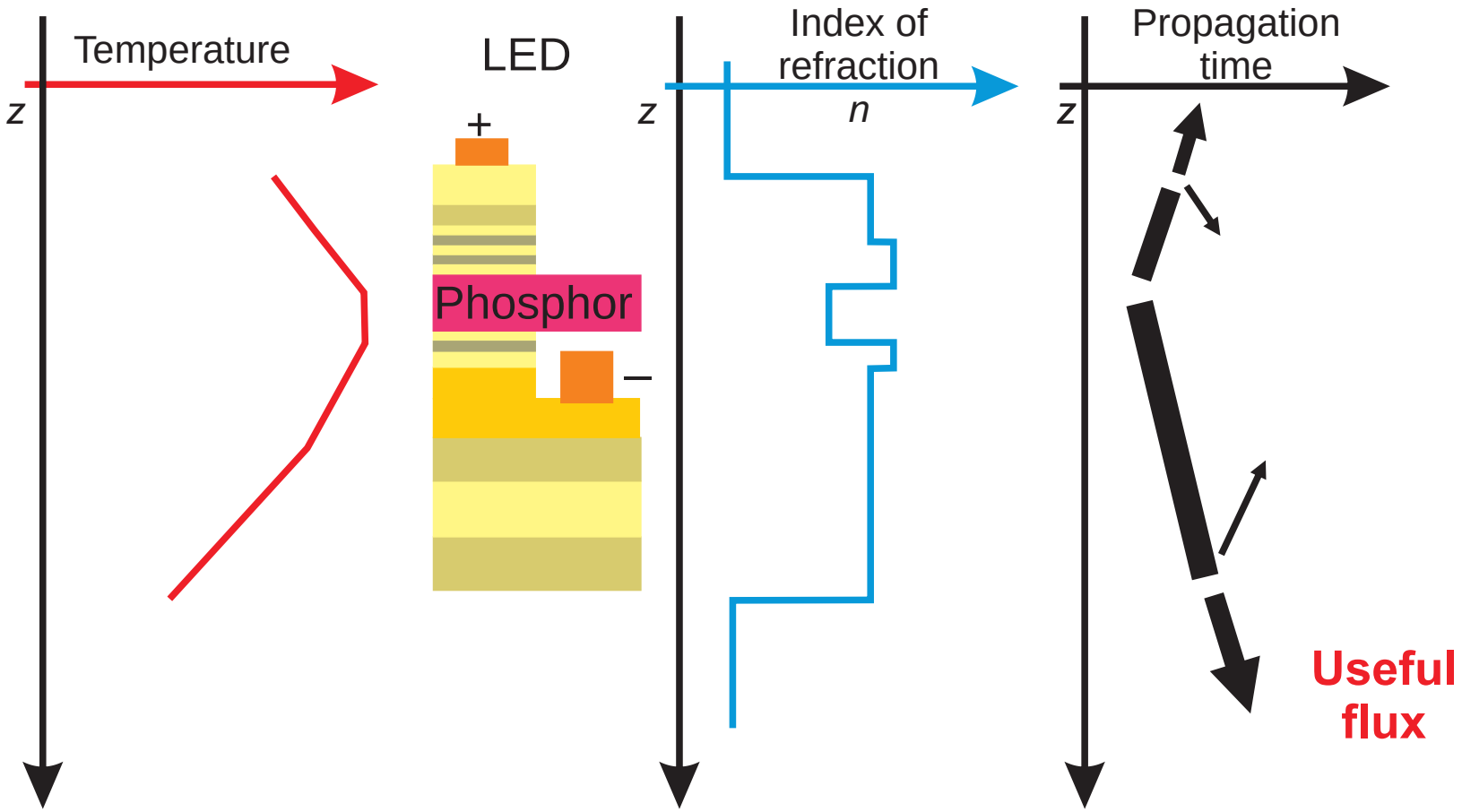
index and thermal matching



remote phosphor — high light coupling losses

Proper Placement of Phosphor Layer

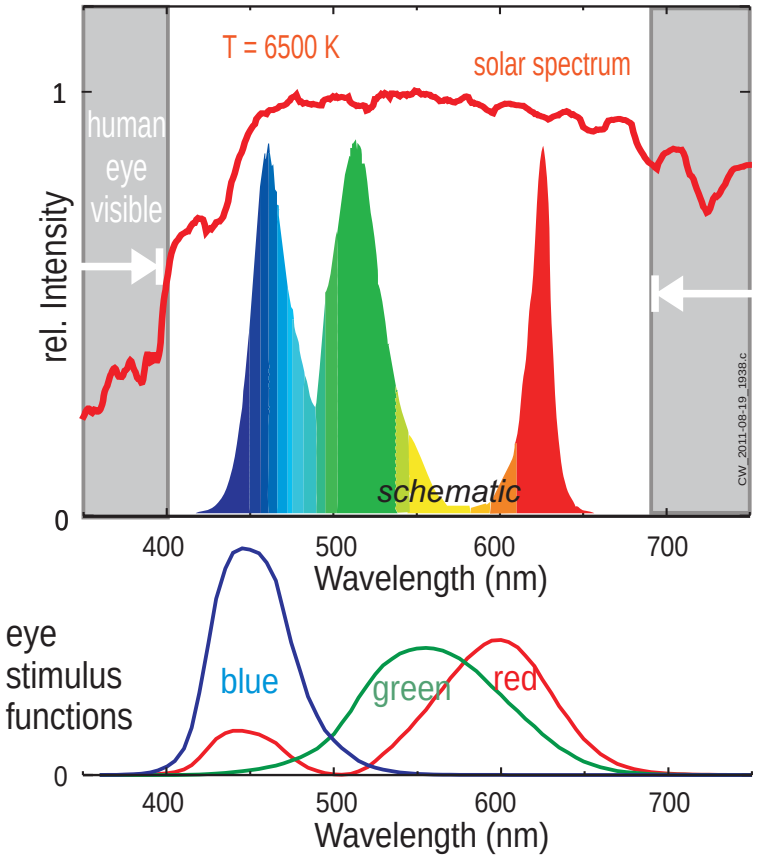
index and thermal matching

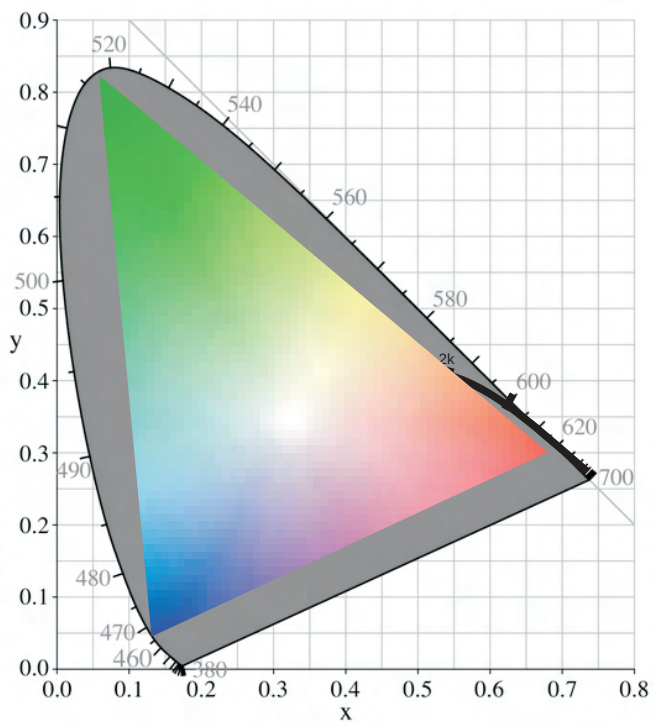


phosphor in source — highest possible flux
need epi compatible

Composite White Light Emitting Diode

RGB LED





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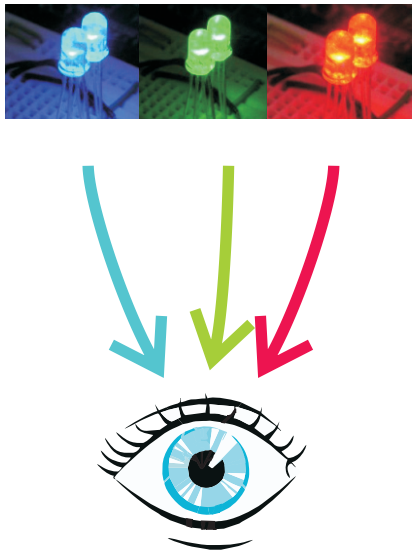
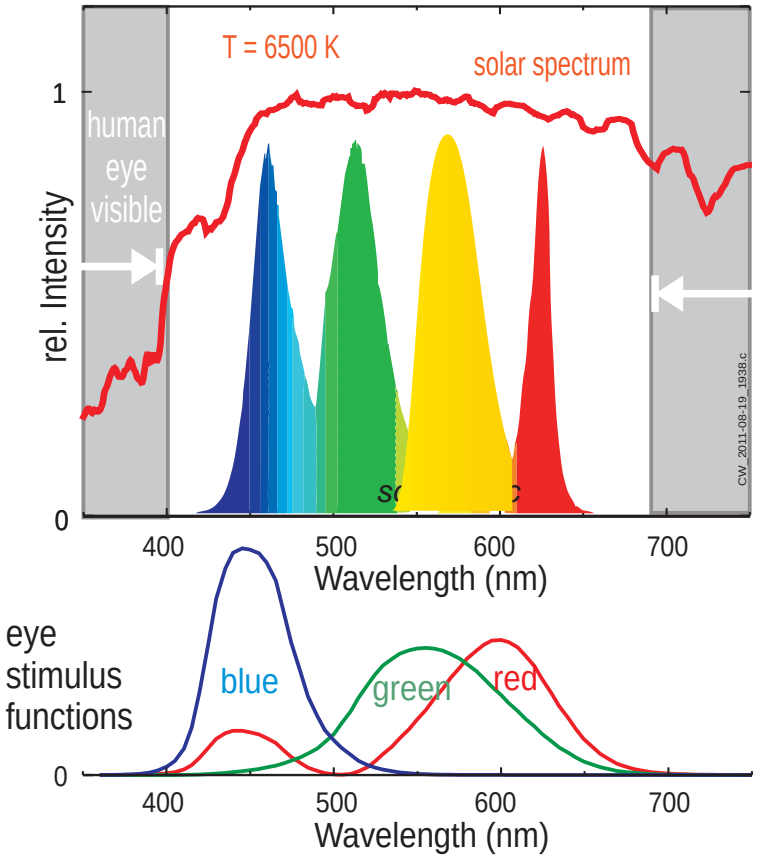
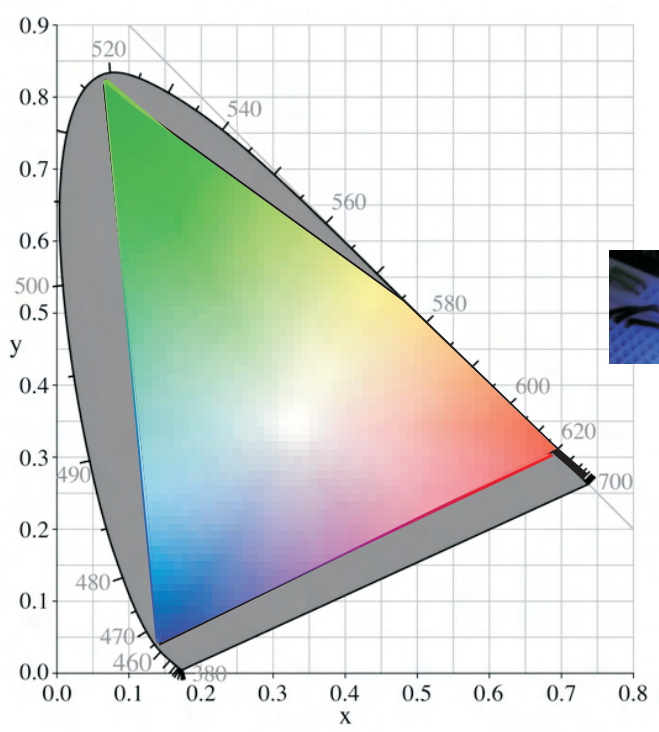


Composite White Light Emitting Diode

RGBY LED





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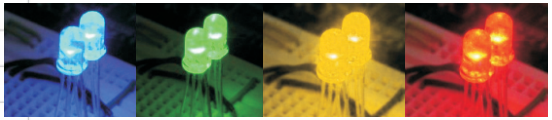
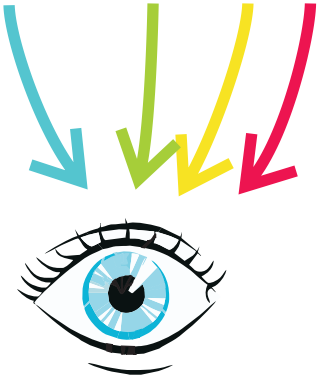




Direct Spectrum LED

keep it semiconductor

Green, Yellow Red

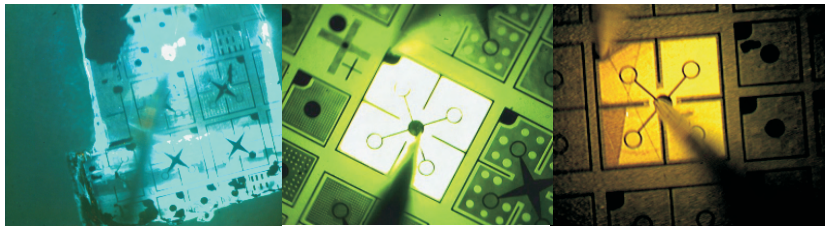
- rare earth free
- phosphor free
- index matched
- InGaN or some new alloy

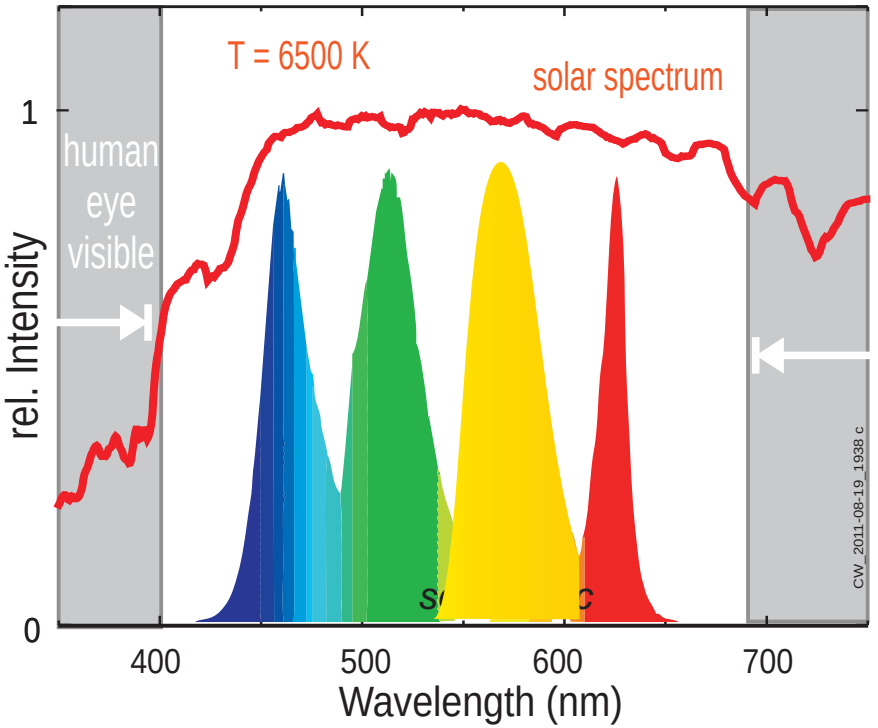
Individual RGBY

- semipolar
- bulk GaN-based

Multicolored RGBY

- microstructured
- nanostructured

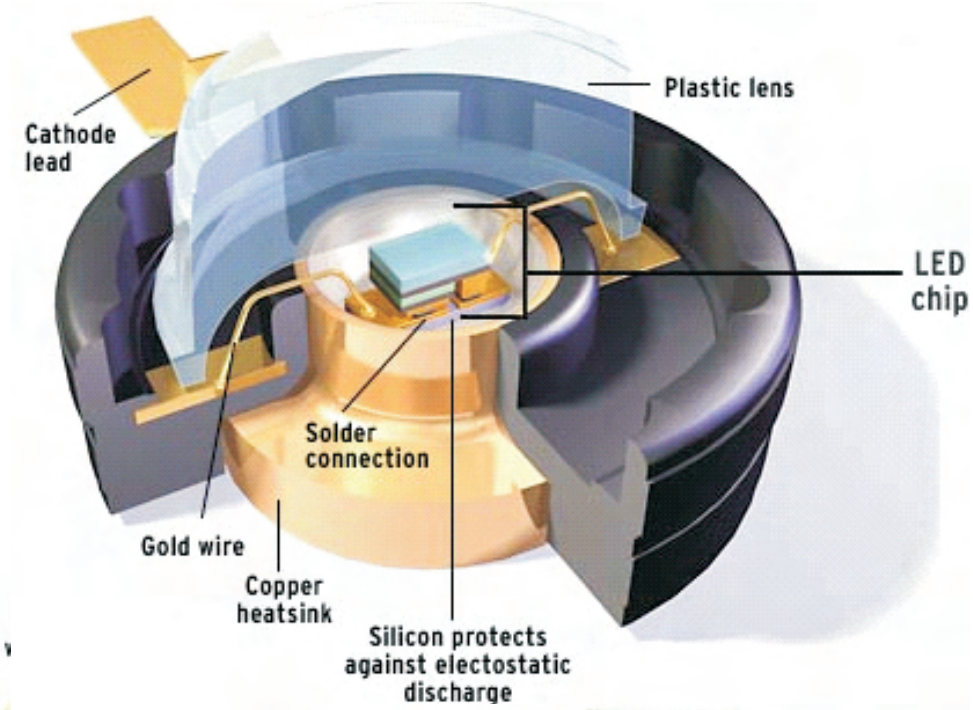




Luxeon White LED

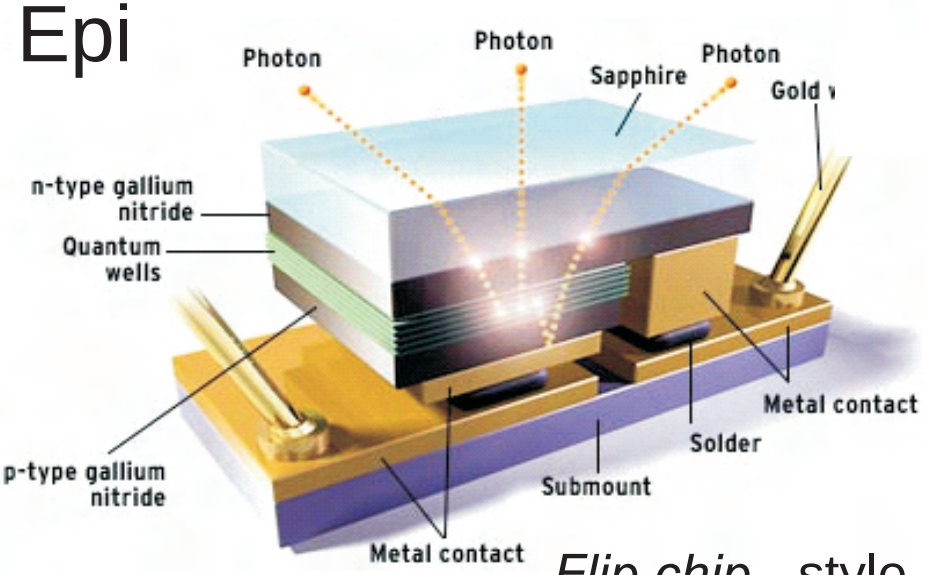
epi - chip - lamp

Chip



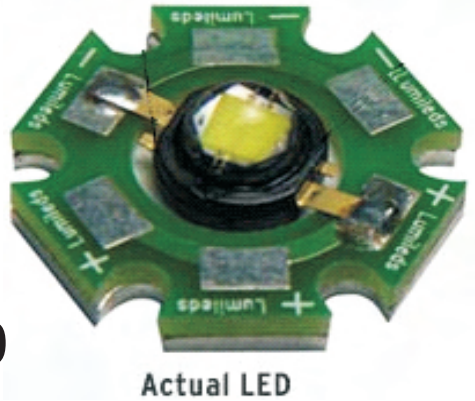
PHILIPS LUMILEDS

Epi



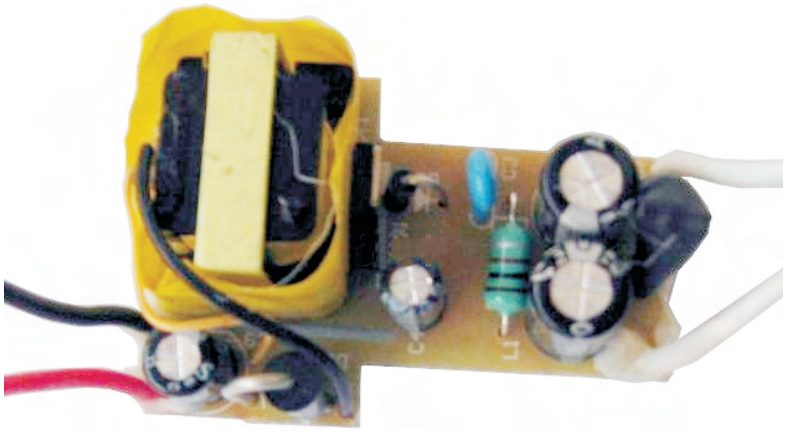
Flip chip - style

Lamp



Periphery

old world technology



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+ Driver

+ Cooling

... an awkward BOM (Bill of Materials)

Standard Bulb Replacement

fits the socket

L•PRIZE®
U.S. Department of Energy

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MR-16

PAR-38

A19

Nostalgia or Progress to Quality of Life?

as seen where people are

boutique
or
trendsetter?

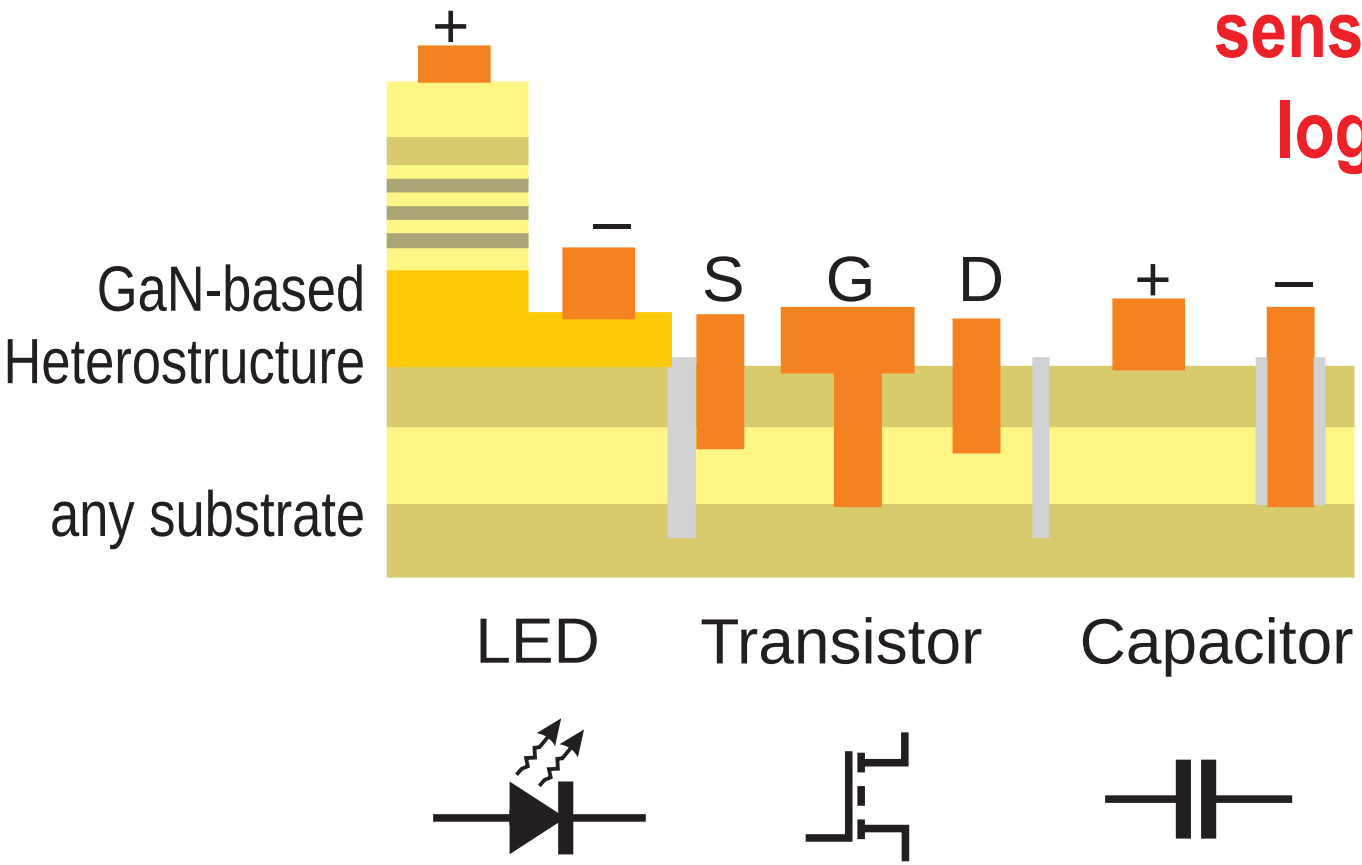
The Charles F. Lucas
Confectionery & Wine Bar
Troy, NY

TheRecord Published: Friday, October 26, 2012

Complete Integration on the Materials Level

the better way to go

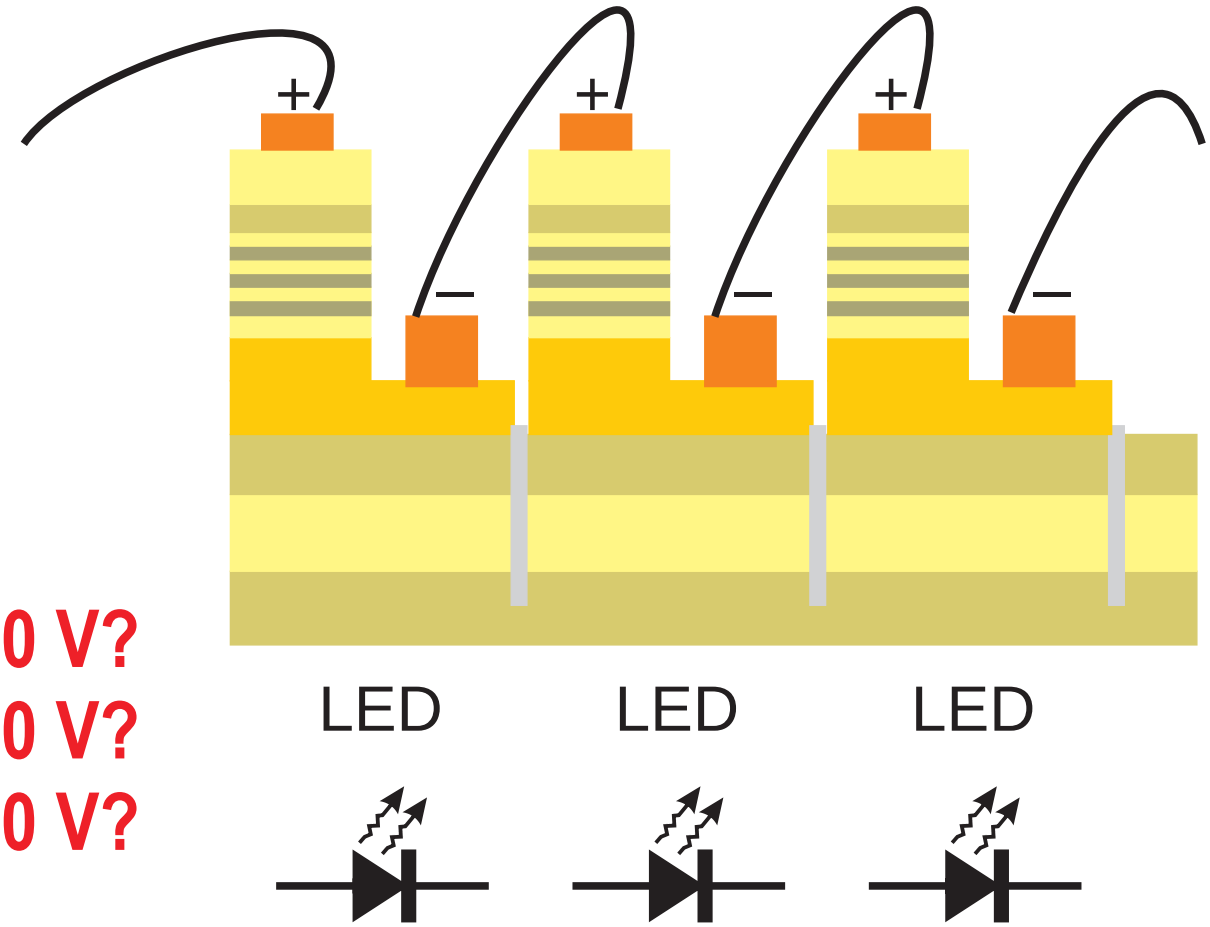
Integrated driver
sensor
logic



schematic

High Voltage LED, AC LED

daisy chaining



Why not 60 V?
110 V?
240 V?

High Voltage LED, AC LED

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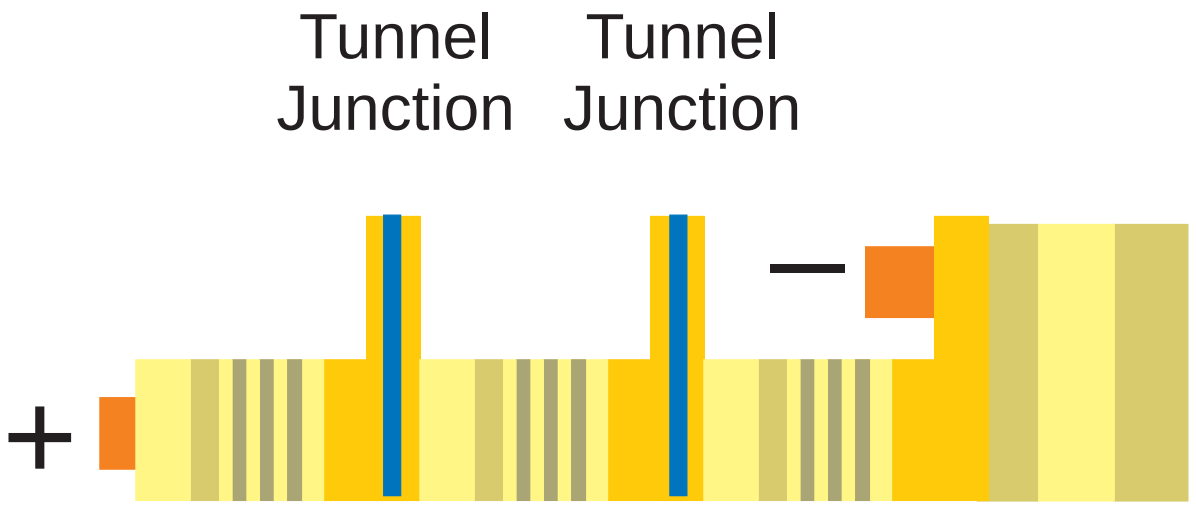

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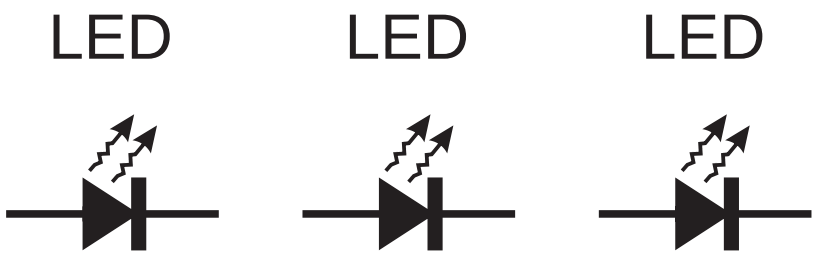

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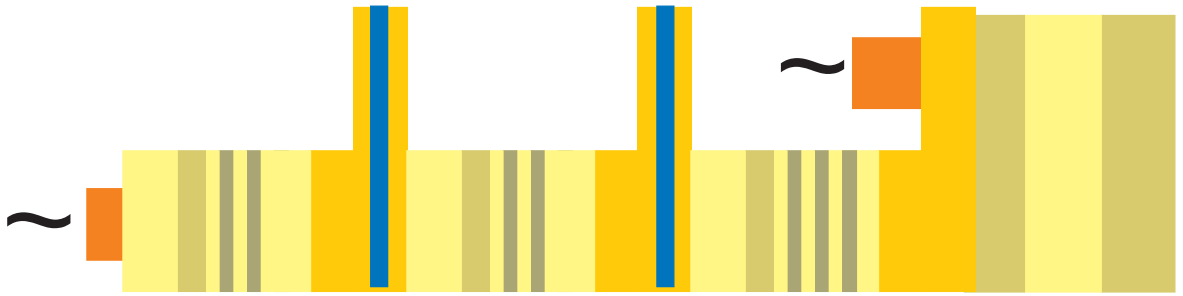
Reversible Tunnel Junction

Reversible Tunnel Junction



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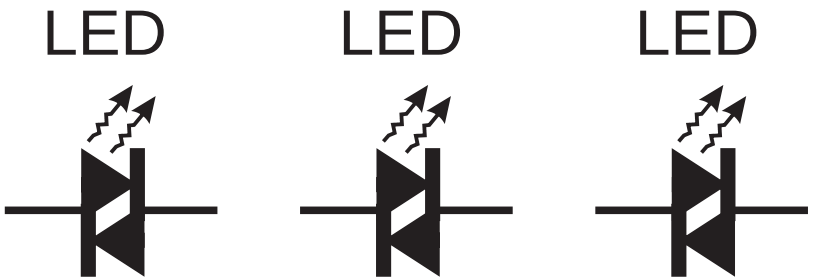
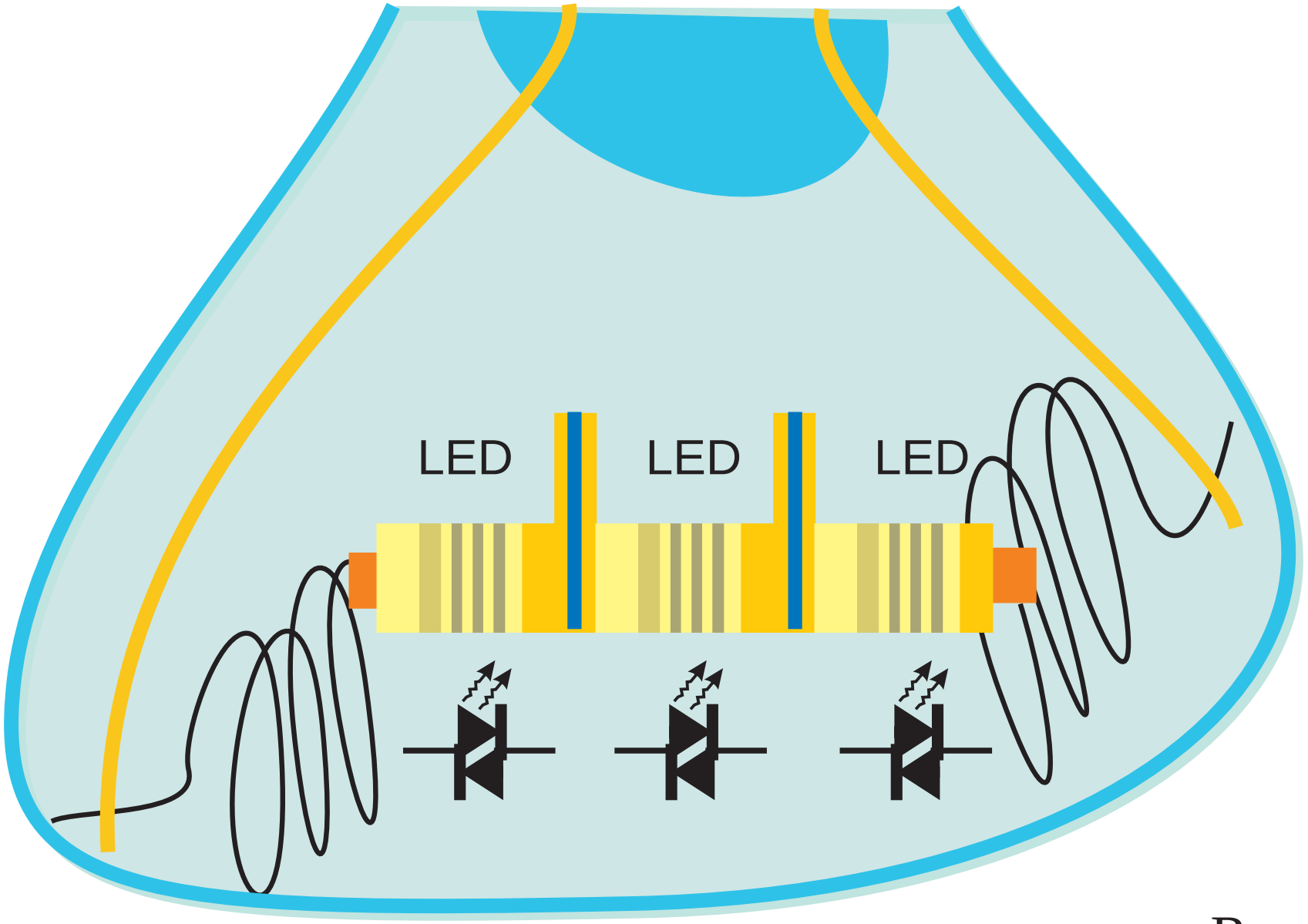


schematic

The New Bulb

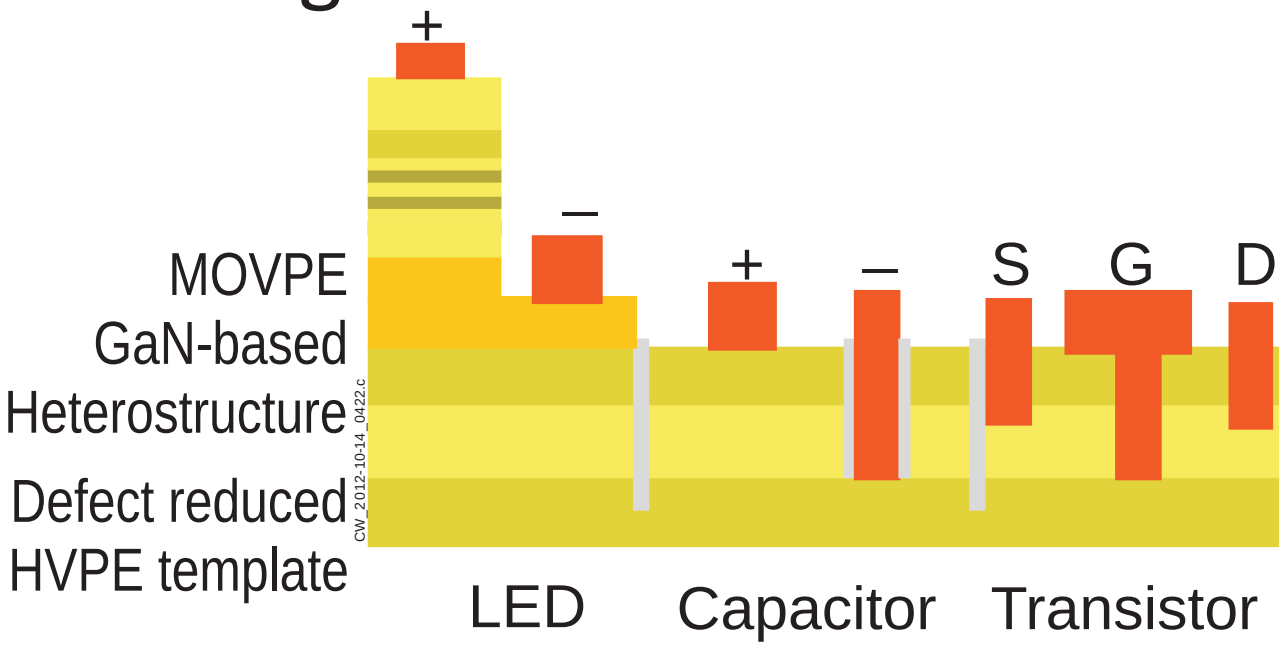
the way you gonna know it



schematic

AC LED System

- Convergence
  - LED + FET,
  - FET + Capacitor
  - Sensors + Logic
- Integration
  - Monolithic
  - Epitaxial
  - Same Materials



Materials Development Needs

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  - => Higher Efficiency
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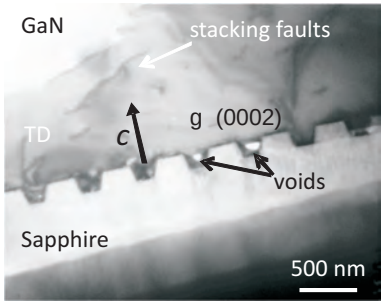
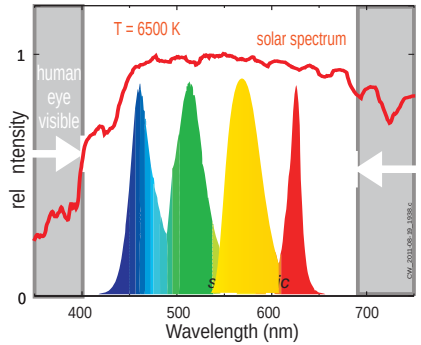
      - => Less Cooling



Yufeng Li, *et al.*
Appl. Phys. Lett, **98**(15), 151102 (2011)

- Integration LED + Phosphor
  - => Direct Spectrum LED



- Integration LED + Driver + Sensor + Controls
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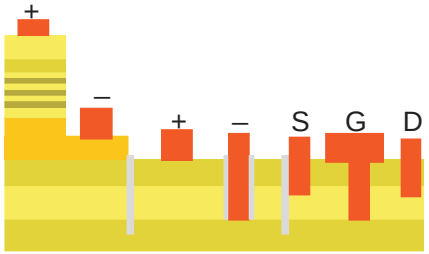

10th International Conference on Nitride Semiconductors

ICNS-10

Christian Wetzel
Jaime A. Freitas, Jr.

Asif Khan – Honorary Chair

Washington DC, USA
August 25-30, 2013
www.icns10.org

expected attendance: >1000

- Bulk Crystal Growth
- Epitaxial Growth
- Optical and Electronic Properties
- Processing and Fabrication
- Defect Characterization and Engineering
- Structural Analysis
- Theory and Simulation
- Nanostructures
- Light Emitting Devices
- Electron Transport Devices
- Photovoltaics and Energy Harvesting
- New Materials and New Device Concepts

MRS Materials Research Society