

# SSL MANUFACTURING: A DECADE OF CHANGE

## DOE LIGHTING R&D PROGRAM



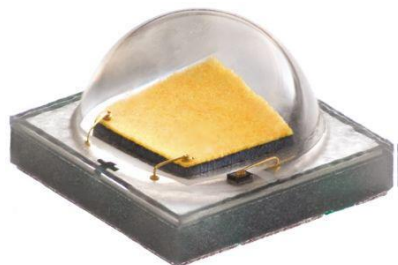
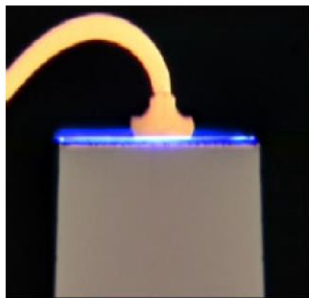
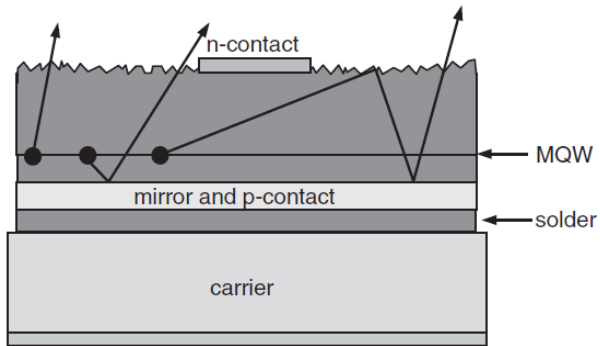
# Where Were We a Decade Ago?



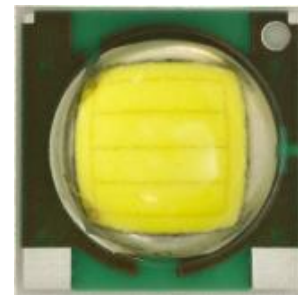
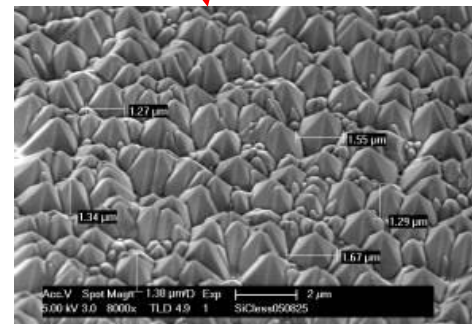
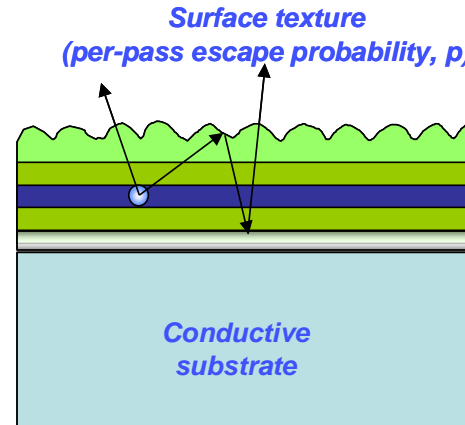
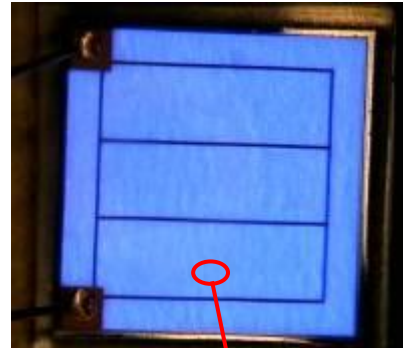
# LED Lighting = High-power LEDs in 2010



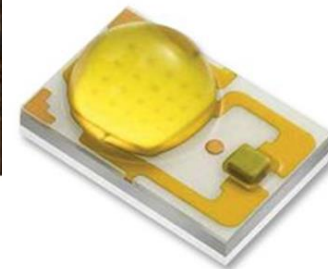
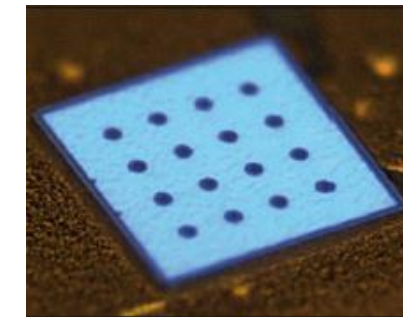
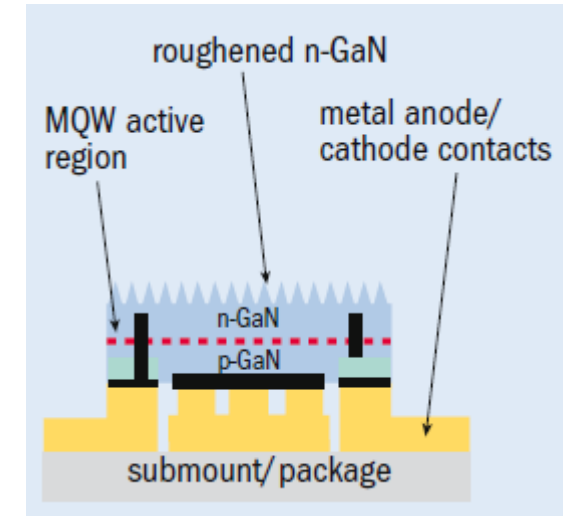
## ThinGaN - OSRAM



## EZBright - Cree



## TFFC - Lumileds

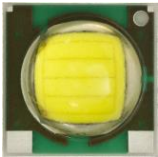


Warm White (3000 K) ~ 90 LPW  
Cool White (6000 K) ~ 120 LPW

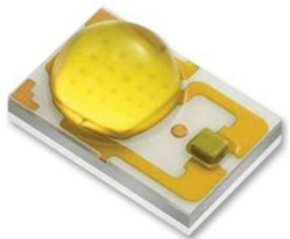
# Evolution of Substrates

2010

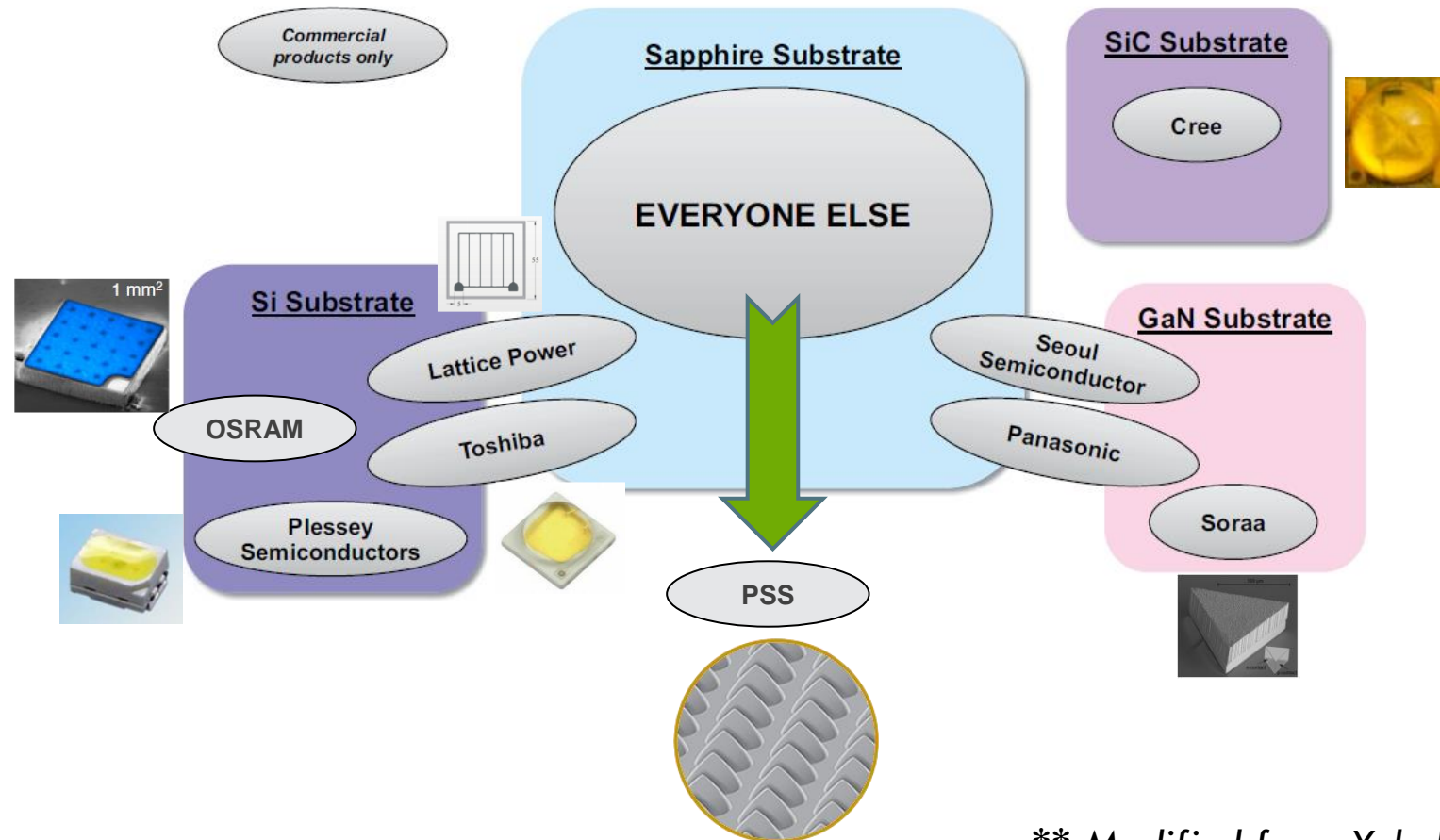
SiC



Sapphire



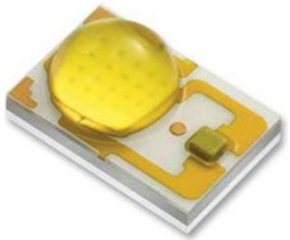
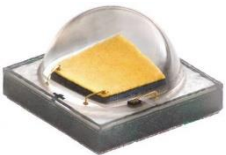
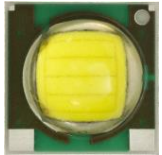
2014 Status



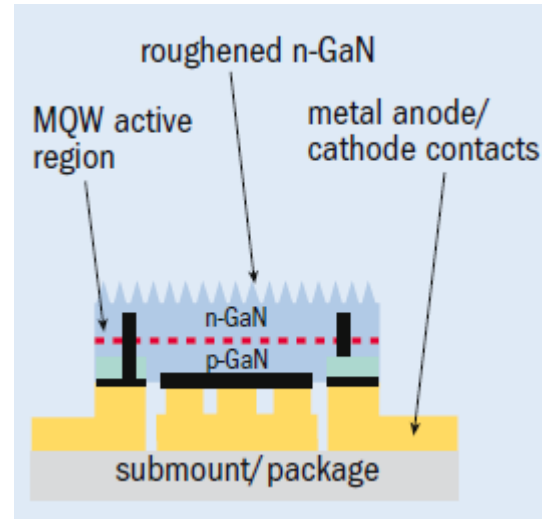
\*\* Modified from Yole Developpement

# 2010 → 2015: Chip Designs

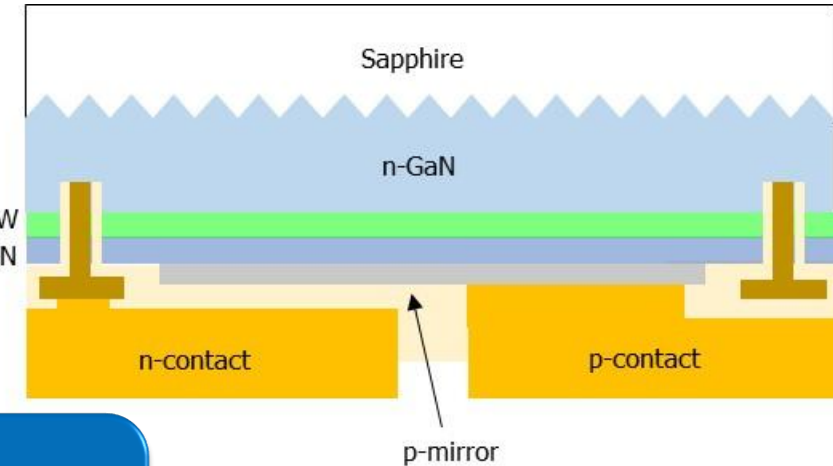
2010



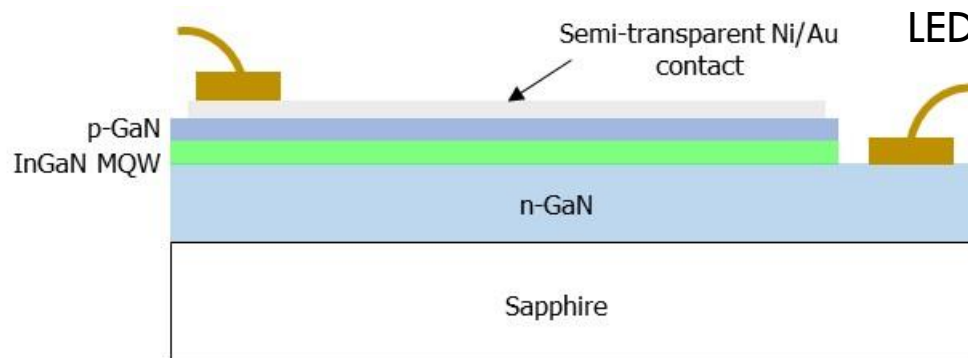
COBs Emerging



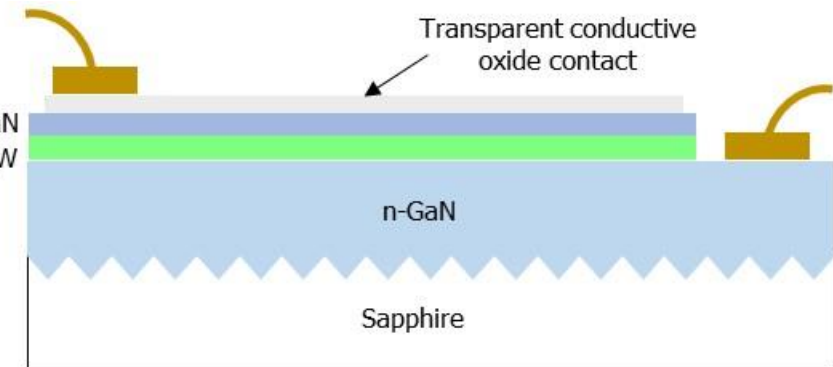
LED power chip



PSS:  
Lower Cost Power die  
Brighter small die



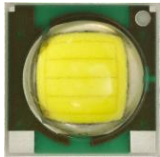
LED small die



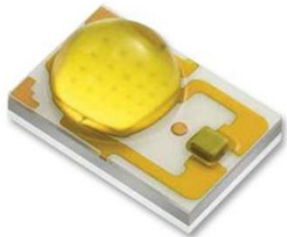
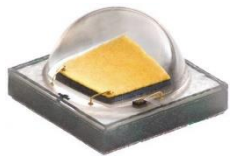
# Evolution of Substrates

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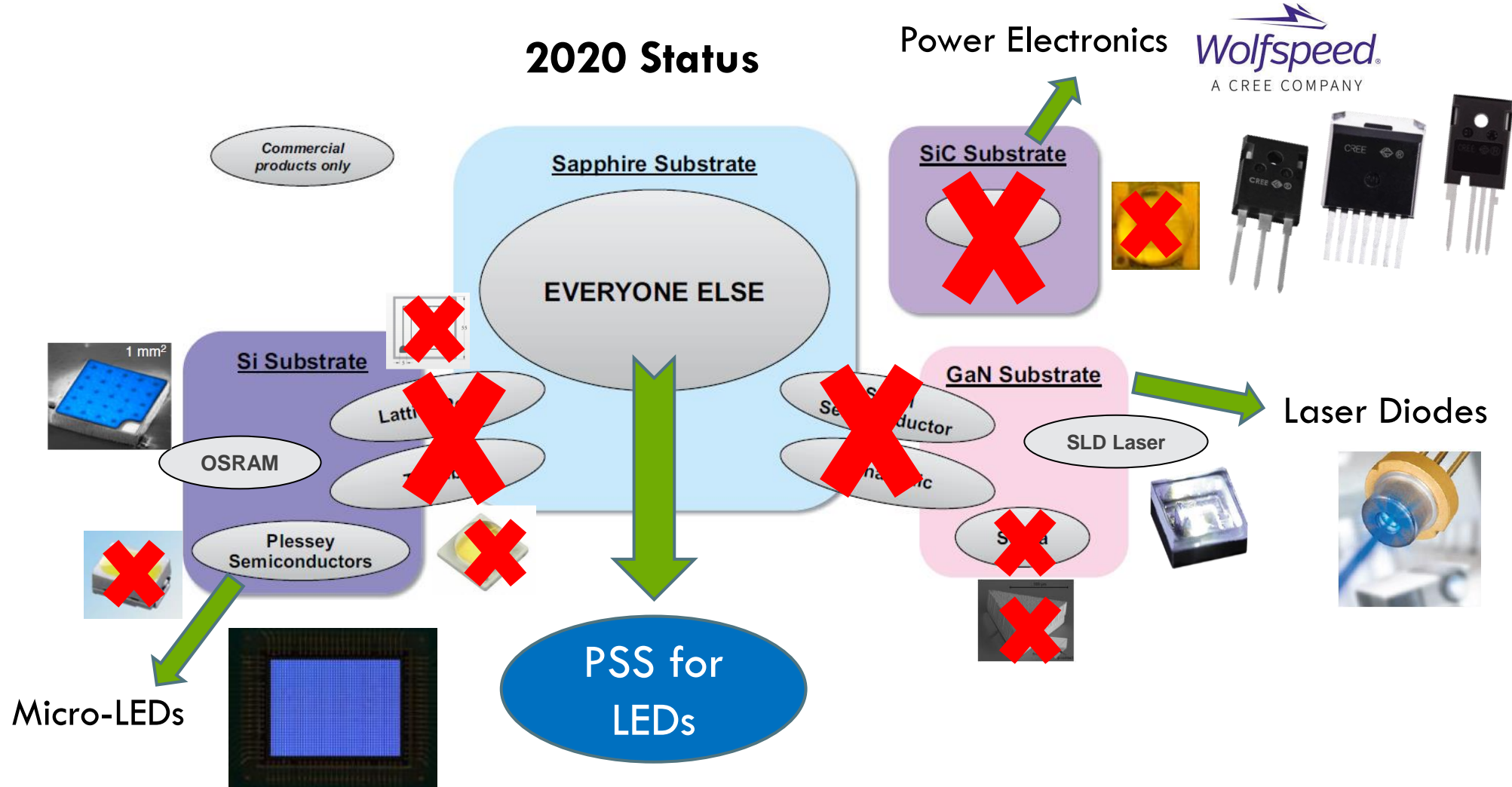
SiC



Sapphire



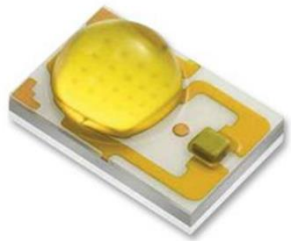
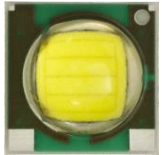
2020 Status



\*\* Modified from Yole Developpement

# 2010 → 2015: Package Designs

2010



COBs Emerging

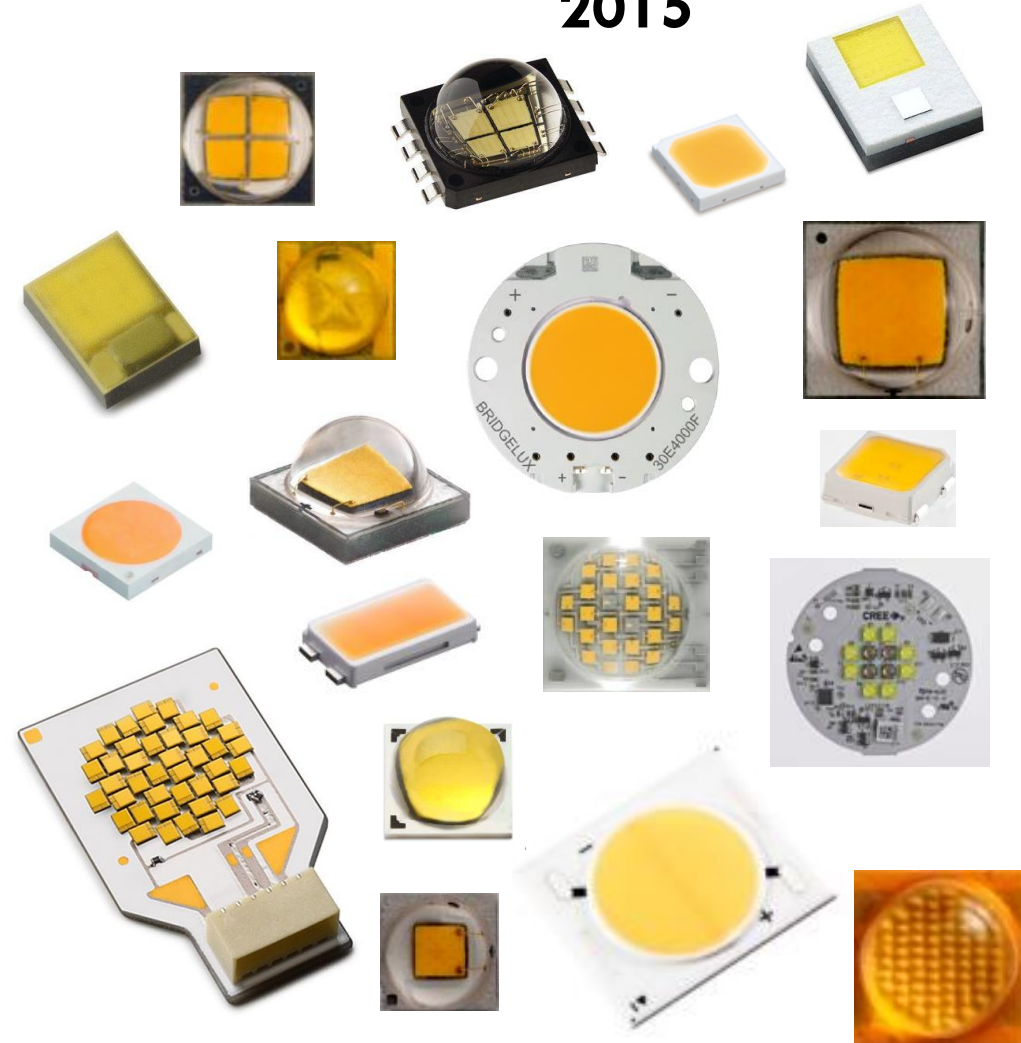
MOCVD Government Subsidies from China Lead to Overcapacity (2010-2011)

Mid-power packages pivot from TV backlighting to general lighting (2011-2012)

LED TV Backlight supply exceed market growth: Mid-Power LED Oversupply (2011)

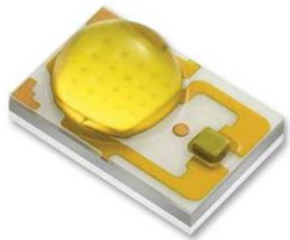
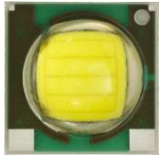
LED Commoditization begins

2015



# 2010 → 2015: Package Designs

2010



COBs Emerging

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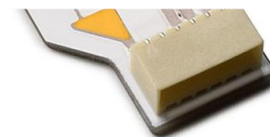
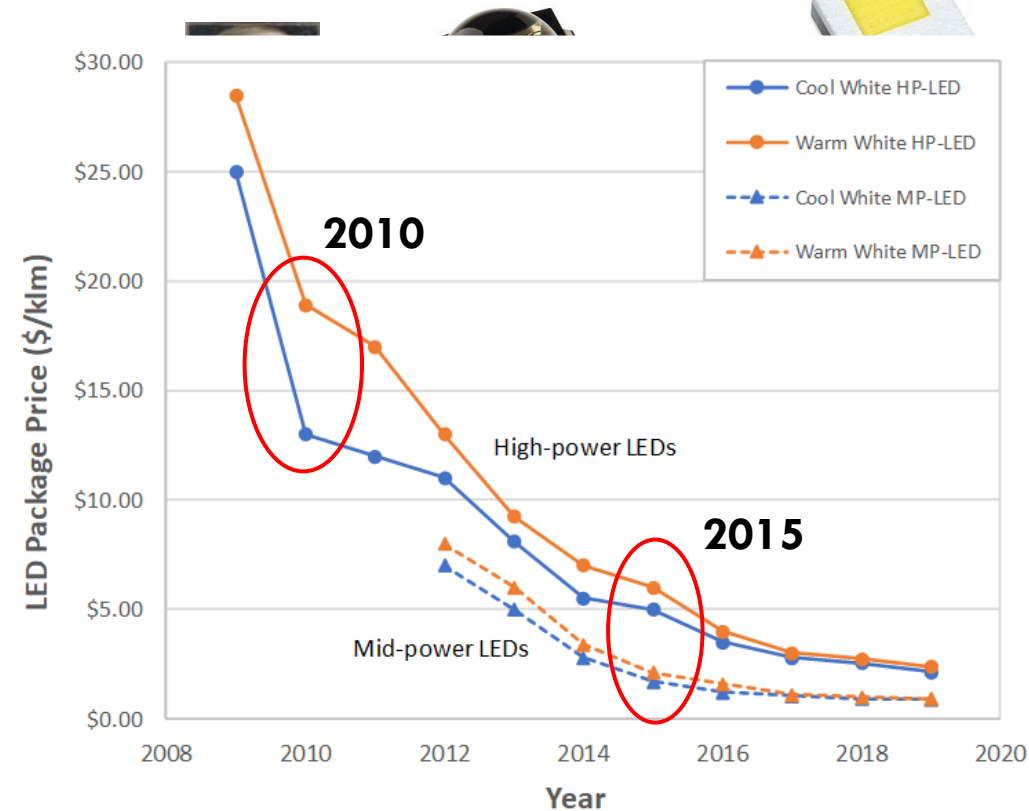
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LED TV Backlight supply exceed market growth: Mid-Power LED Oversupply (2011)

LED Commoditization begins

2015





# 2015 → 2020: Package Designs

2015



CSPs Emerging

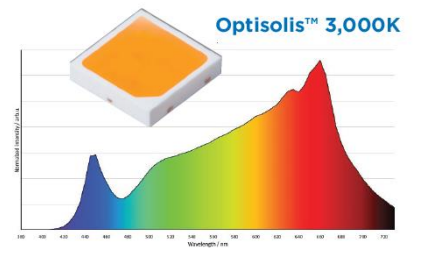
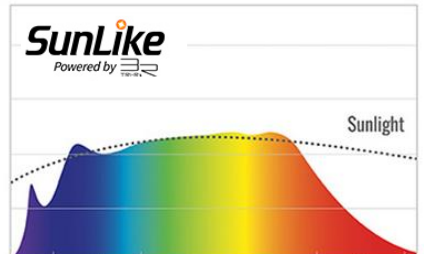
2020



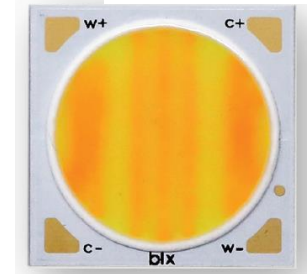
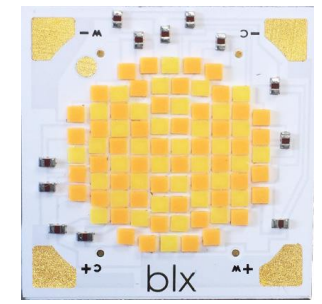
Improved mid-power reliability with EMC



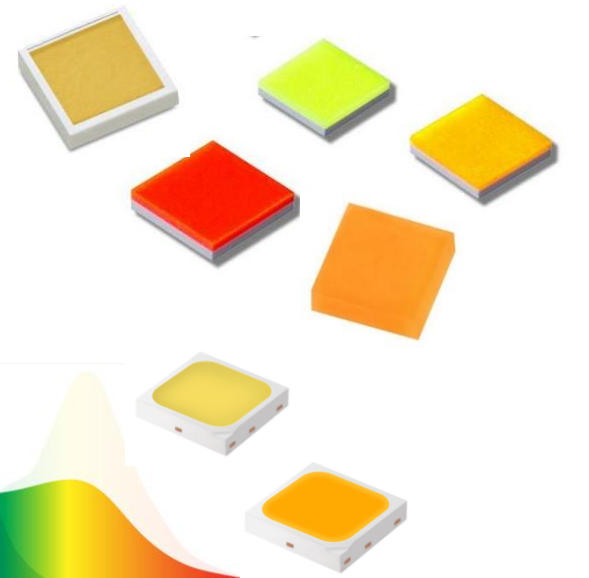
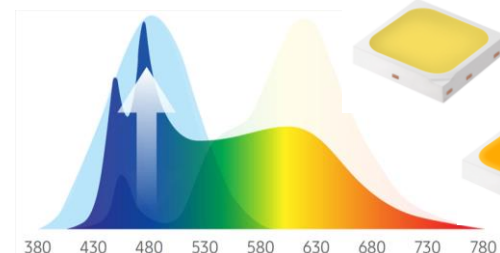
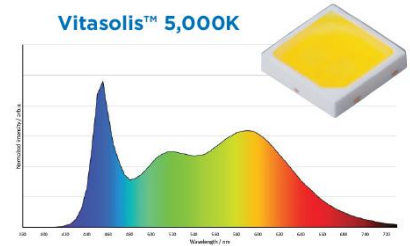
Full Spectrum LEDs



White Tunable



Circadian Lighting



# 2010 → 2020: Lamp Trends



Color Tuning & Connectivity

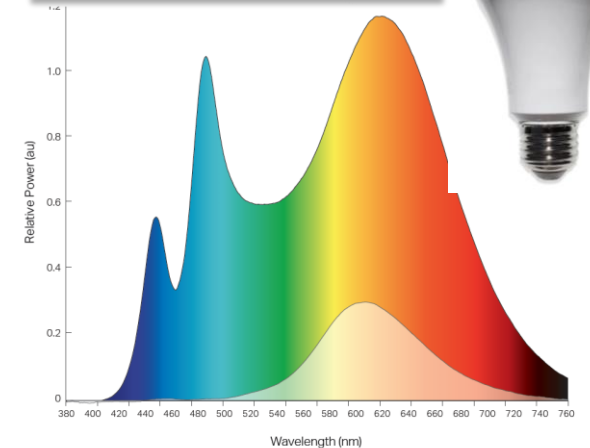


New Form Factors

Filament LEDs



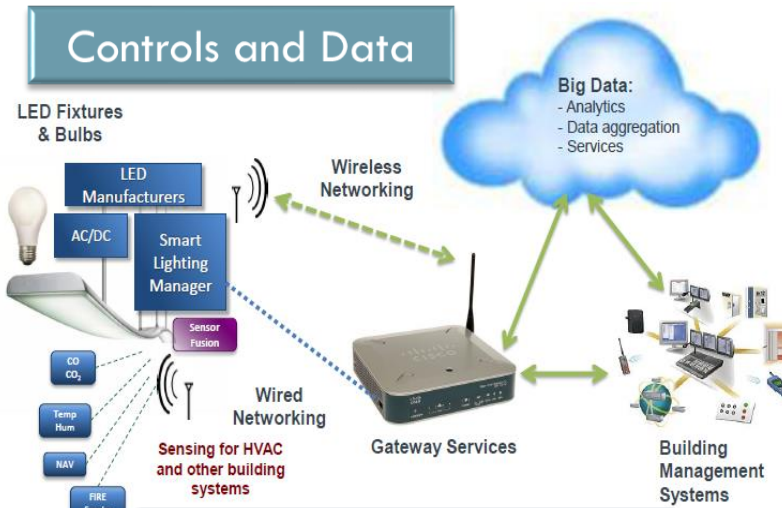
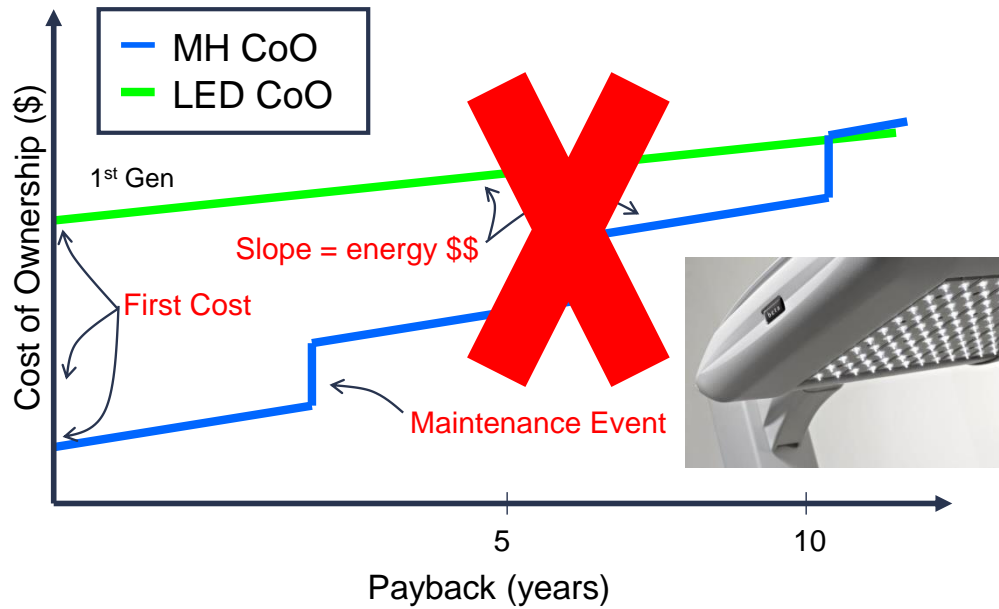
Circadian Lighting



Connected Lighting

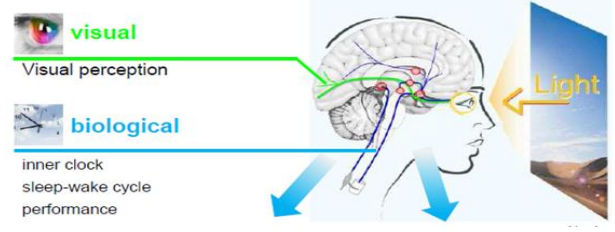
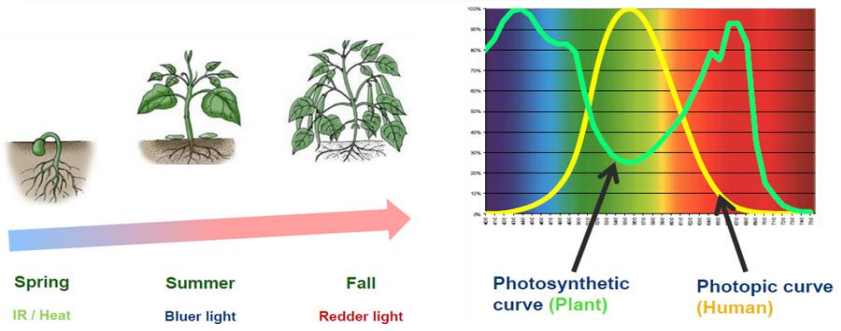


# 2010 → 2015: Luminaire Trends



## New Functionality in Lighting

### Horticultural Lighting Emerging



### Circadian Lighting Emerging

### Smart Cities: Connectivity



# 2015 → 2020: Luminaire Trends

## Dynamic Lighting



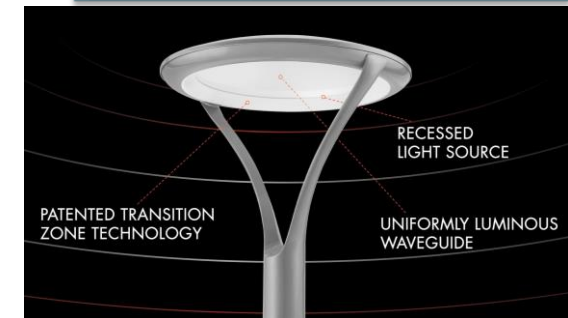
## White Tunable Lighting



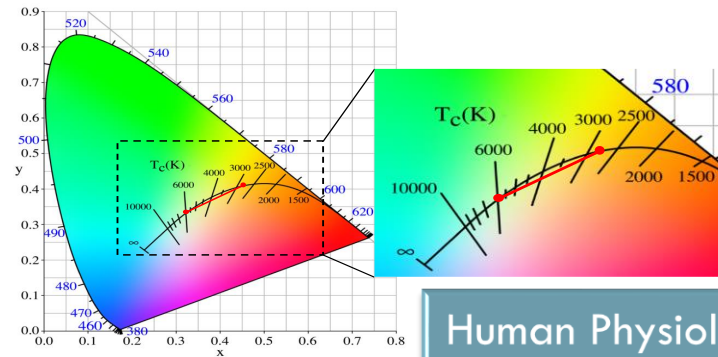
## Flat Panel Lighting



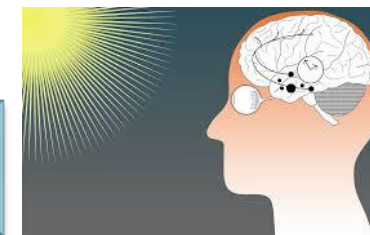
## Visual Comfort



LiFi



## Human Physiological Response to Light



## Horticultural Lighting



# DOE Manufacturing Projects 2010-2012



## 2010 Manufacturing R&D Priority Tasks

Luminaire/Module Manufacturing

Driver Manufacturing

Test and Inspection Equipment

Tools for Epitaxial Growth

Wafer Processing Equipment

LED Packaging

Phosphor Manufacturing and Application

## KLA-Tencor Candela 8620 Wafer Inspection Tool



## Ultratech Sapphire 100 Stepper Tool



## Veeco MaxBright MOCVD Platform



# Mfg Opportunity: Wafer Fab Automation



Manual Wafer Loading



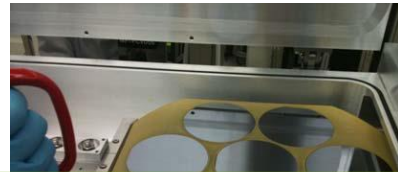
Cassette Loading



- MES (manufacturing execution system), tool-to-tool wafer movement, communication platforms, SPC control – no turn-key solutions for 150mm → leverage 200 mm silicon fab knowledge?
- Work is needed for 150 mm wafer fabs to improve factory automation to enable US manufacturing

- 150 mm compound-semi wafer fabs require labor to run the equipment.
- Manual loading or moving cassettes is still required

# Mfg Opportunity: Wafer Fab Automation



Cassette Loading



## Cree, NY State Form \$1B Partnership To Create World's Largest Silicon Carbide Device Facility

*More than 600 Cree jobs will be created at the Marcy Nanocenter on SUNY Poly Campus in collaboration with the New York Power Electronics Manufacturing Consortium.*

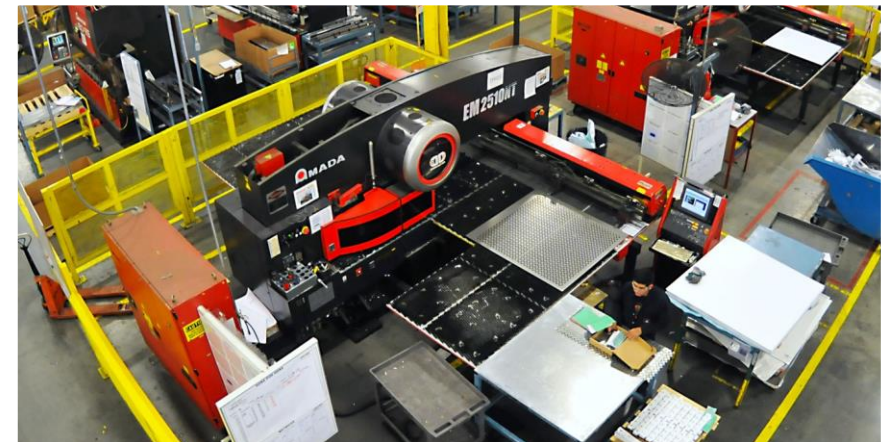
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- Work is needed for 150 mm wafer fabs to improve factory automation to enable US manufacturing

- 150 mm compound-semi abs labor to ent. loading ng cassettes is still required

# Mfg Opportunity: Automation for Luminaires



- Factory automation for assembly of LED lamps and some basic products such as small downlight has become common.
  - Smaller variability in product designs and high volumes
  - Lamps have more similar size scales of housings, drivers and optics parts
  - Mechanics is a smaller part of lamp assembly compared to luminaires
- Automated luminaire assembly is not used – assembly cells common
  - Huge dimension and performance SKU variability between products
  - Mechanics can be very difficult to automate (e.g. screws, pressure sensitive adhesives, wiring)



Opportunity: Design for Automated Manufacturing



# Mfg Opportunity: Additive Manufacturing



## Additive manufacturing benefits for lighting products:

- Fast, flexible, cost-effective prototyping
- Direct CAD to fabrication without tooling or inventory
- More product performance options:
  - Unique designs
  - High configurability ... low parts inventory



*Interplay Lighting (Acuity Brands)*

## Challenges:

- Faster additive processing: increase print speeds, systems with larger print beds
- Develop new printable materials with improved optical, thermal, electrical properties
- Reduce or eliminate post-processing on printed parts

# Mfg Opportunity: Sustainability



- Develop eco-friendly designs with low-embodied energy materials, recycled materials, or bioderived materials.
- Design for deconstruction to disassemble and recycle luminaire materials when the lighting is removed from the built environment.
- Provide materials transparency through certification bodies.



# Manufacturing R&D Opportunities: 2021



- Factory Automation
  - Wafer Fab
  - Luminaire Assembly
- Reduce LED distribution
  - MOCVD uniformity
  - Phosphor deposition uniformity
- Additive Manufacturing
- Sustainable Materials

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Luminaire/Module Manufacturing

Driver Manufacturing

Test and Inspection Equipment

Tools for Epitaxial Growth

Wafer Processing Equipment

LED Packaging

Phosphor Manufacturing and Application