LED Light Sources for Dynamic Lighting Applications

Rajiv Pathak
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Dynamic light distributions in general illumination

Configurable spaces

Shop windows and floors

Open plan offices

Exhibition spaces

Scene setting

Hospitality

Human centric lighting

Multi-purpose rooms

Functionality and performance

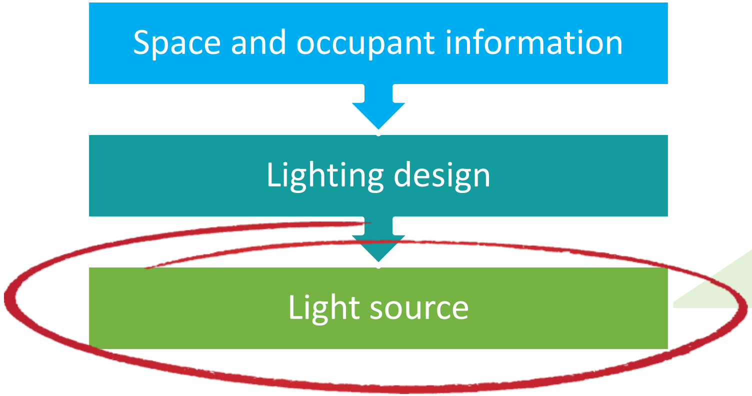
Adjust to occupants / activity / traffic

Improved uniformity

Reduced glare

Application requirements for dynamic light sources

Goal: provide the **right light** only **where** and **when** it is needed



1. The right light:

- Quantity (intensity/illuminance)
- Spectrum

2. Where it is needed:

- High resolution spatial control
- High resolution angular control

3. When it is needed:

- Dynamic control of all light source parameters

Dynamic light source technology requires

- Individually addressable LED arrays with projection optics
- Resolution and form factor drives need for mini/micro-LEDs

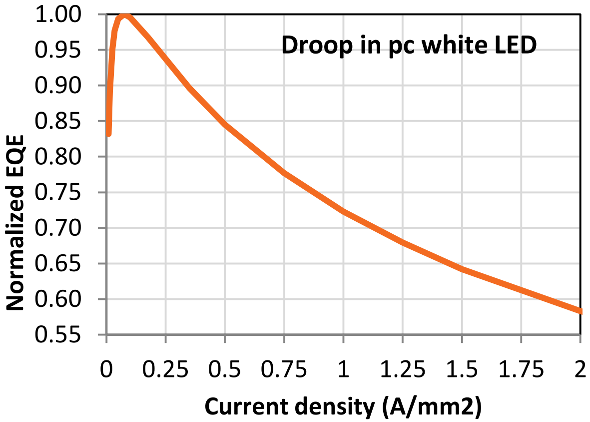
High luminance sources are a key element of directional lighting

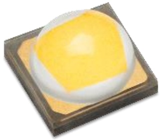
Luminance $L_v = d^2\phi / (dS\ d\Omega \cos\theta)$

Luminous flux from a given **source area** within a given **solid angle**

Lower source efficiency …

due to droop (epi/die/phosphor) and package design



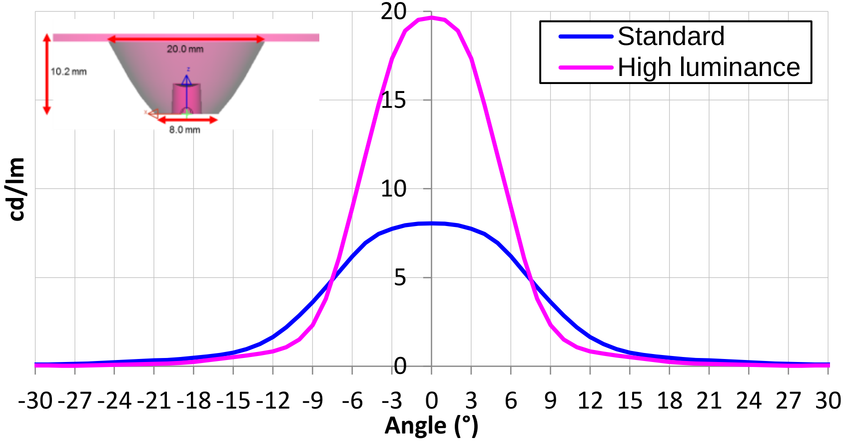


Standard

High luminance

… but higher optical delivery efficiency

through better optical control in secondary optics



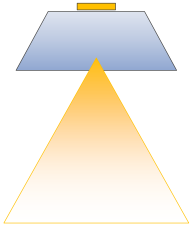
Next step in optical delivery efficiency: dynamic directional lighting

Source dimensions for high luminance sources

LED die size

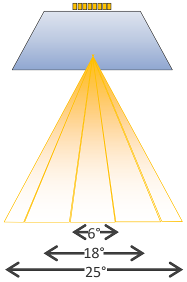
≥1000 µm

State of the art directional lighting



Improved directional lighting

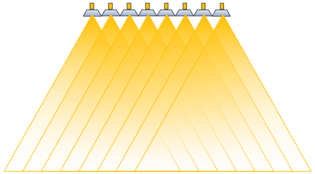
Dynamic beam shaping
Low glare
Thin form factor
Better color mixing

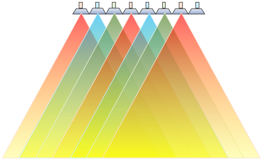


100 µm

Basic projection display

High-precision dynamic beam shaping
Walking directions, emergency lighting
Information display





Is there value in going to 10 µm?

High definition projection display

Spectral quality

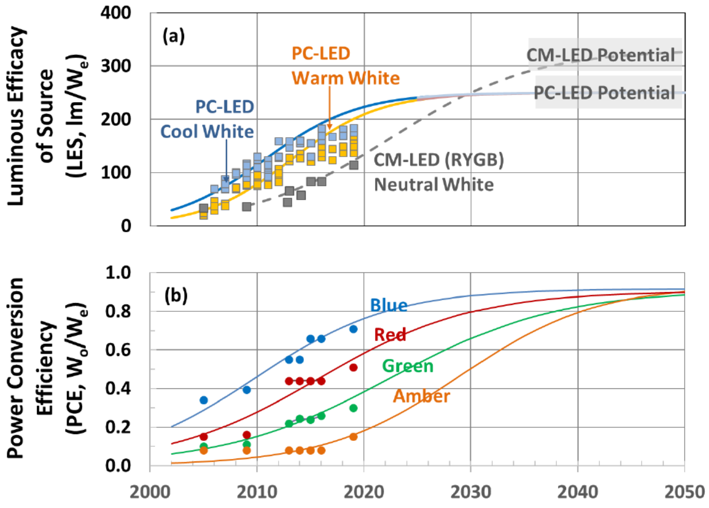
"The right light"

Illumination requires broad spectrum with high color fidelity

Two options:

1. **Phosphor-converted LED**
   Currently best efficacy but challenging for mini/micro-LED:
   - Phosphor materials, small grain size or QD
   - Phosphor integration process

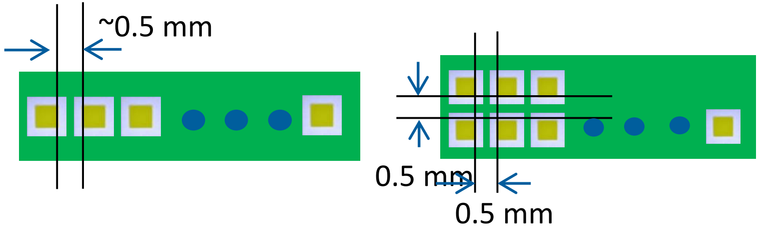
2. **Color-mixed LED**
   Direct emitter RGBA can achieve CRI>90, but:
   - Combining different emitters, challenges in control and color mixing
   - Efficiency of green and amber needs improvement

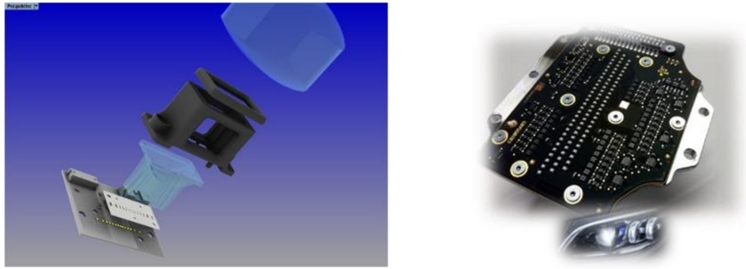


Roadmap from DOE Lighting RDO

Individually addressable arrays with projection optics

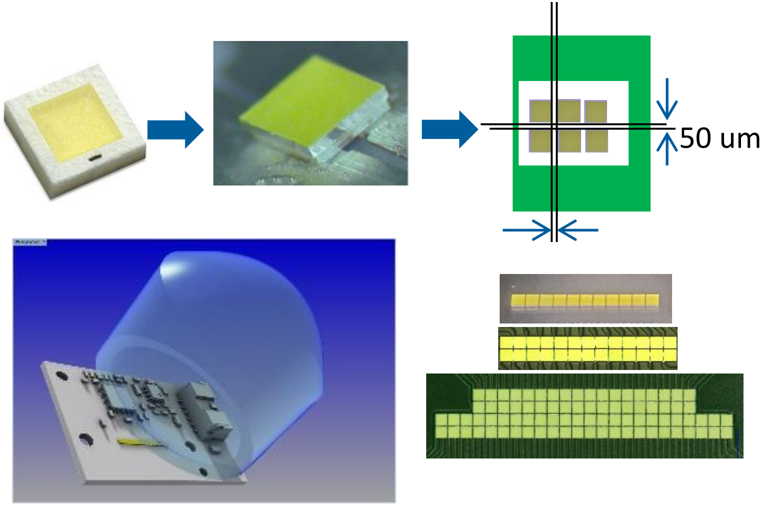
Light "where it is needed"





Optical system requires pre-collimation

- Close coupled pre-collimation optics are used to create homogeneous headlighting
- Module of 3 rows of 84 discrete high-luminance LEDs



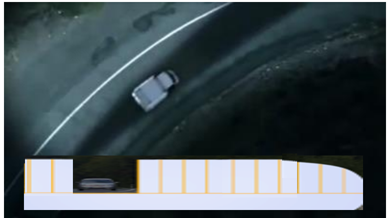
Optical system no longer requires pre-collimation

- Smallest package: Light emitting area and package same as chip size
- Enable higher pixel count with more functionality
- Provide higher resolution
- Ease of array layout customization

Towards high spatial and angular resolution

Digital headlighting roadmap

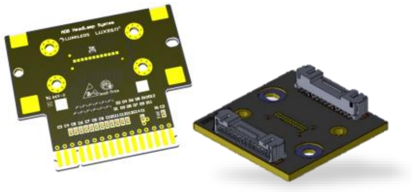
Basic ADB Matrix



Audi A8 Matrix Light

ADB Glare free high-beam
with horizontal beam segmentation

~10-25 LEDs



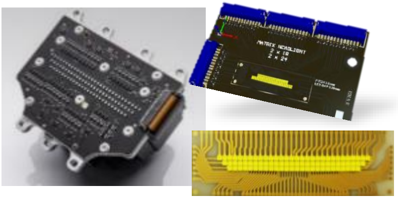
Advanced ADB Matrix

Daimler, Multibeam LED HL

ADB LED Matrix

additional vertical segmentation

~100-200 LEDs



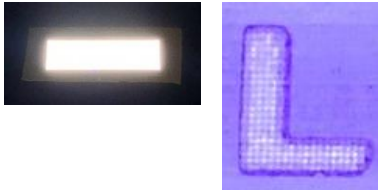
HD Digital Beam

Daimler Digital Light

DIGITAL HL

high resolution

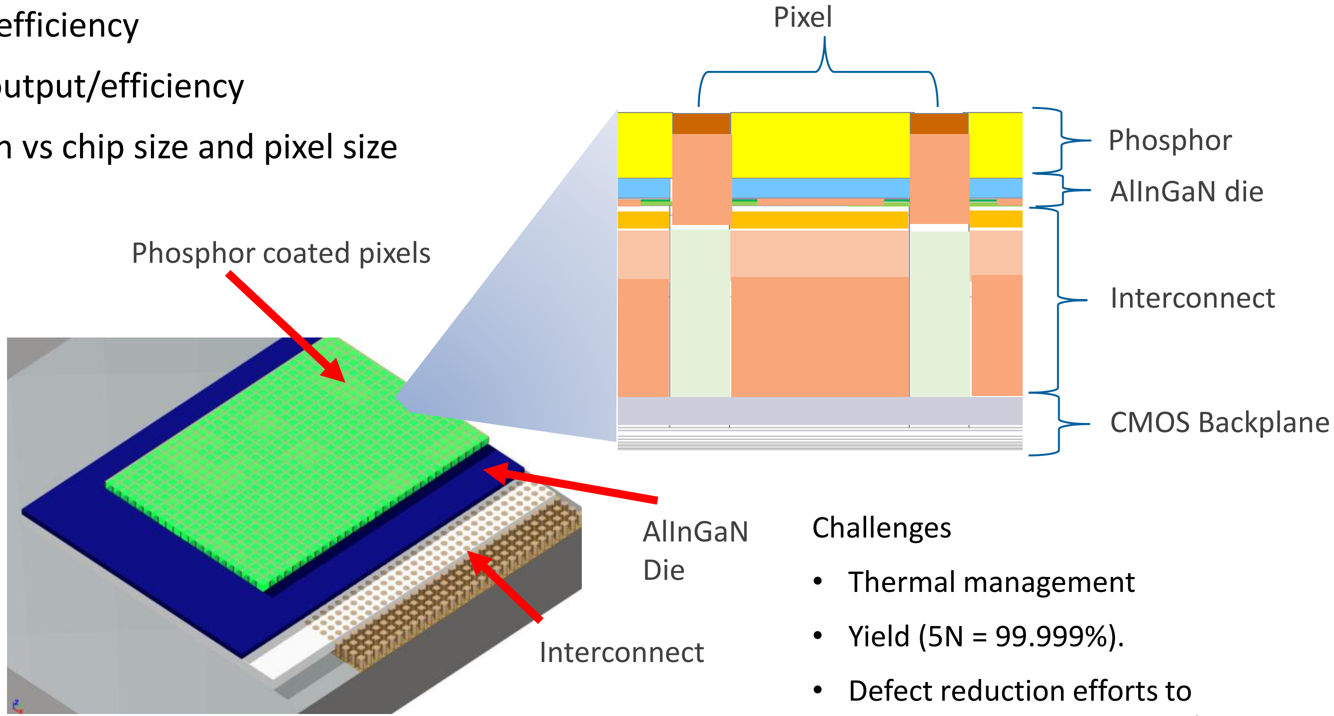
~ 1K -1M pixels



Automotive microLED Array Architecture

Design compromise between

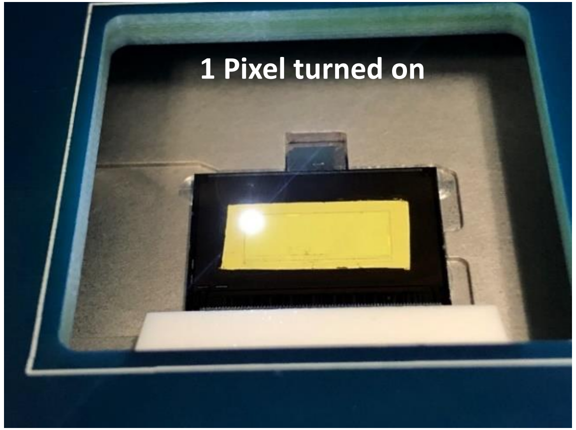
- Pixel size vs light output/efficiency
- Optical contrast vs light output/efficiency
- Pixel count and resolution vs chip size and pixel size

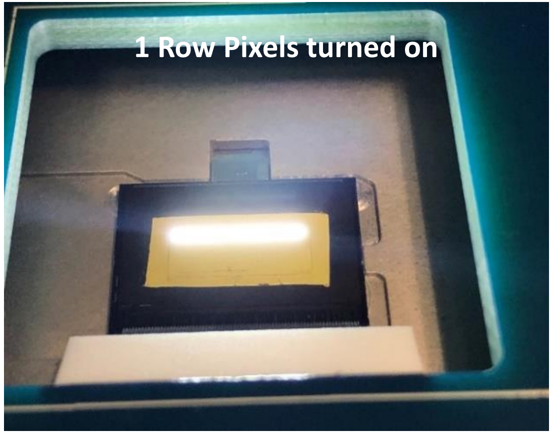


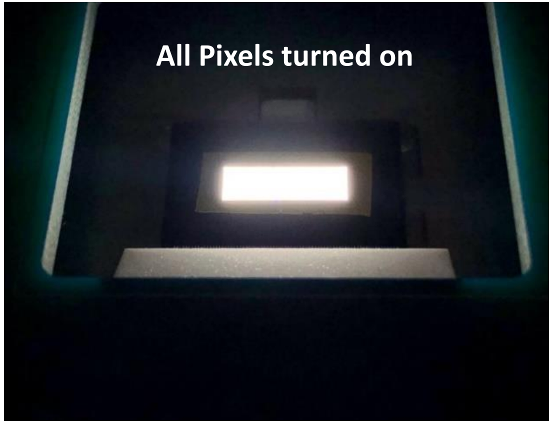
Challenges

- Thermal management
- Yield (5N = 99.999%).
- Defect reduction efforts to support large die (~50 mm^2).

Prototype addressable microLED array die on CMOS



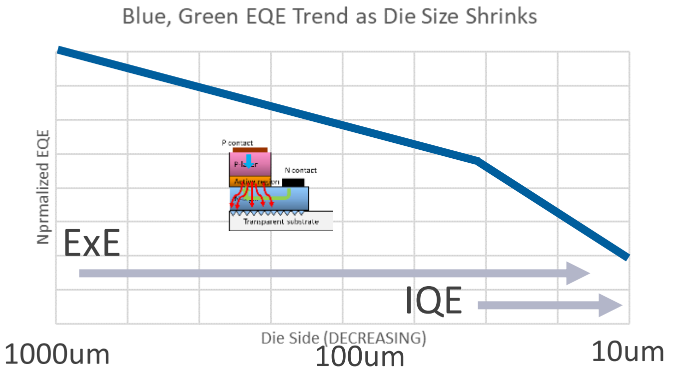




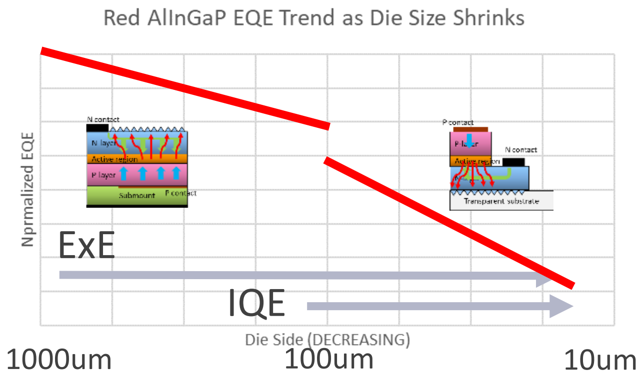
Light "where it is needed" requires further LED miniaturization

Challenges:

- As device dimensions shrink, perimeter to area ratio increases, device EQE decreases in both InGaN and AlInGaP material systems.
- The reduction in EQE is especially pronounced for AlInGaP material system where surface recombination velocities are an order of magnitude higher than for the InGaN material system.



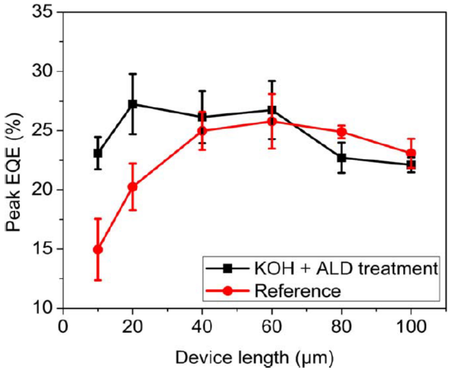
Reduction of EQE in Blue and Green devices is largely a result of a drop in ExE.



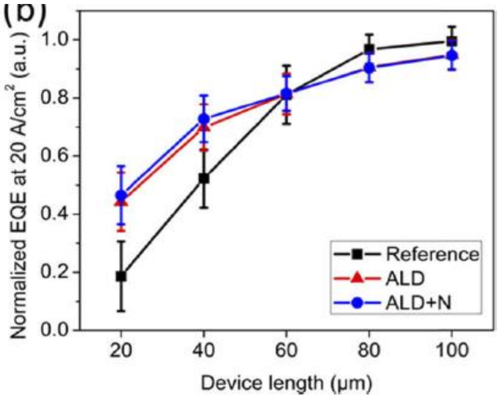
VTF architecture is typically employed for larger devices. There Is a discontinuity at ~ 100um die sizes where lateral architectures need to be employed. Any improvement to IQE will help EQE of smaller devices.

Efficiency improvements for mini/micro LED's

- ExE improvements – reflective contacts, surface texturing etc. to enhance light extraction
- IQE improvements – largely focused on surface treatments with dielectric sidewall passivation



Mathew S. Wong et al "Size independent peak efficiency of III-nitride micro-light-emitting-diodes using chemical treatment and sidewall passivation" 2019 Appl. Phys. Express 12 097004



Mathew S. Wong et al "Improved performance of AlInGaP red micro-light-emitting diodes with sidewall treatments" Optics Express

➢ Research is required to understand and mitigate the reduction in efficiency that arises from die miniaturization through advances in processing (etch/dielectric), characterization and epi

Summary

- Lighting is moving to higher levels of functionality and technology integration
- In automotive forward lighting, new technologies advance miniaturization and greater functionality of compact ADB sources
- In general lighting, light-source technology can be further paired with electronic and optical systems to extend the dynamic capability of the source
- High color quality will require novel pc-LED architectures or RGBA cm-LED systems

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