Epitaxy requirements for Micro-LED Display

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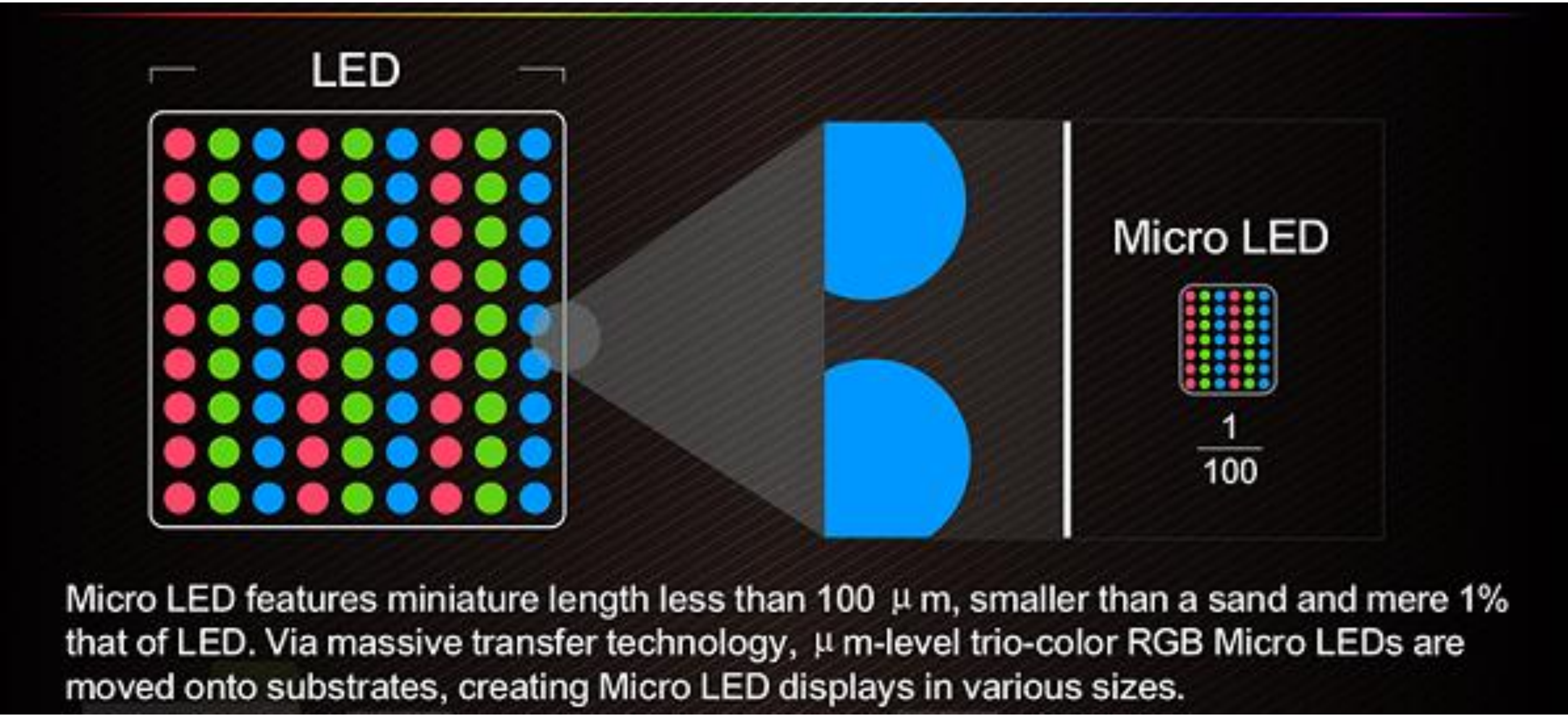
Outline

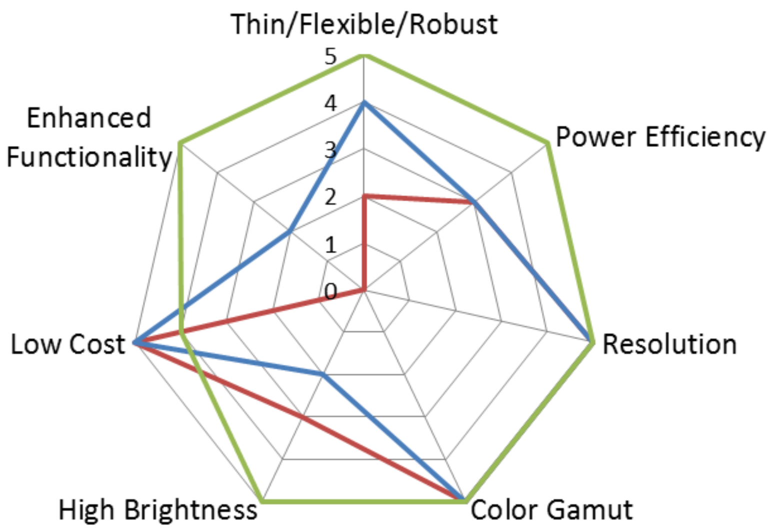
- Micro-LED Display
  - Market Opportunity & Outlook
  - Cost Roadmap Requirements
- Micro-LED Display Manufacturing
  - Key Challenges
  - Mass Transfer Approaches
  - Epitaxy requirements
- Veeco GaN MOCVD solutions
  - EPIK Batch reactor – 6” sapphire
  - Propel single wafer reactor – 8” silicon
- Summary

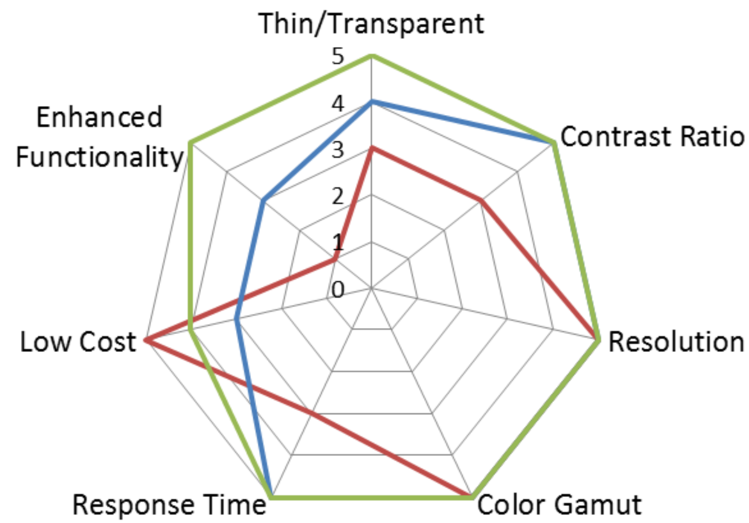
What is Micro-LED Display?



Goal: scale down commercial LED signage by 10^4 for consumer display applications (1x1mm^2 LED → 10x10μm^2 μLED)

Why Micro-LED Display?





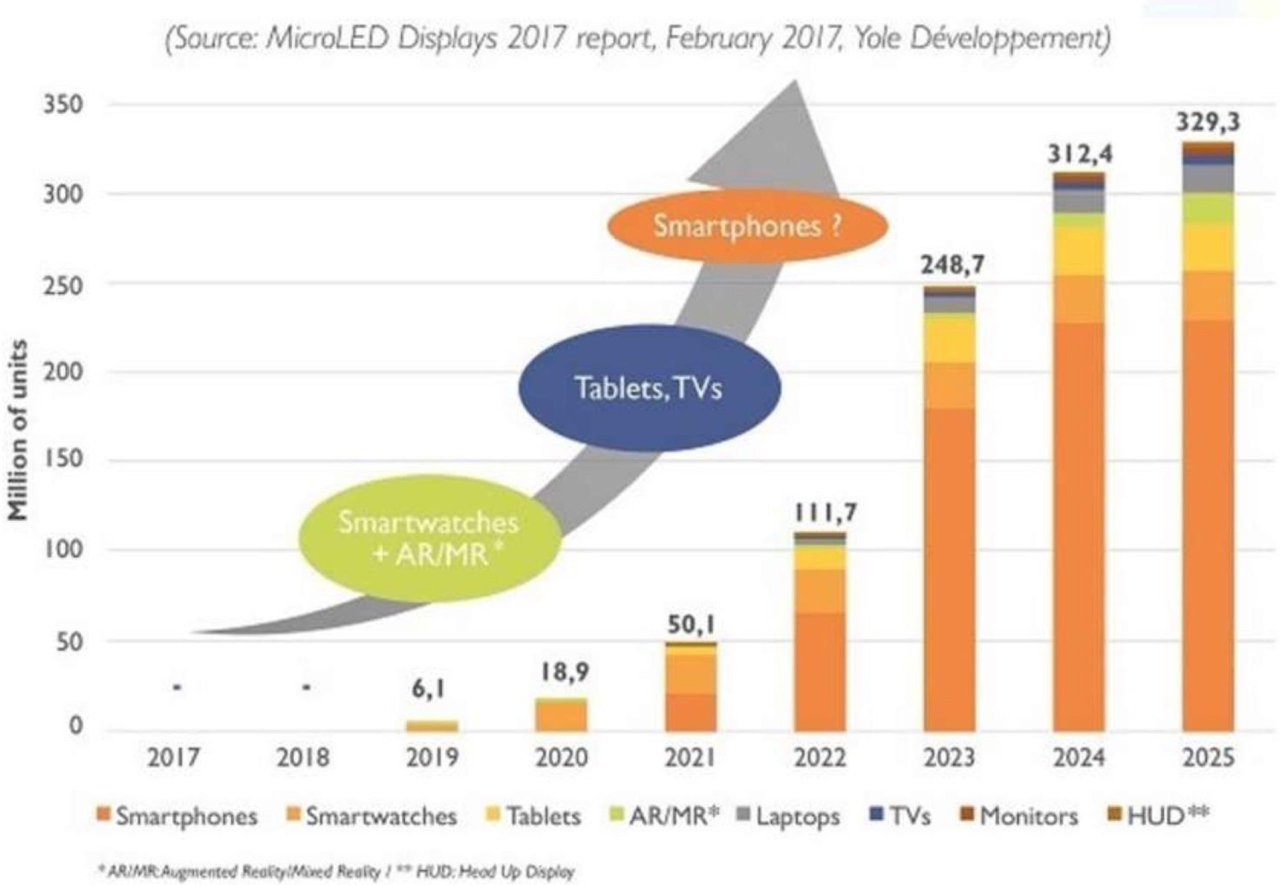
<u>Micro-LED Advantages</u>:

- **SmartPhone**: Power Efficiency, High Brightness, Flexible/Robust
- **TV**: Higher brightness than OLED at near-LCD cost

Veeco

µLED Display Shipment Forecast

- Micro LED display volume forecast –Aggressive scenario



Car Display

Phone

Watch

TV

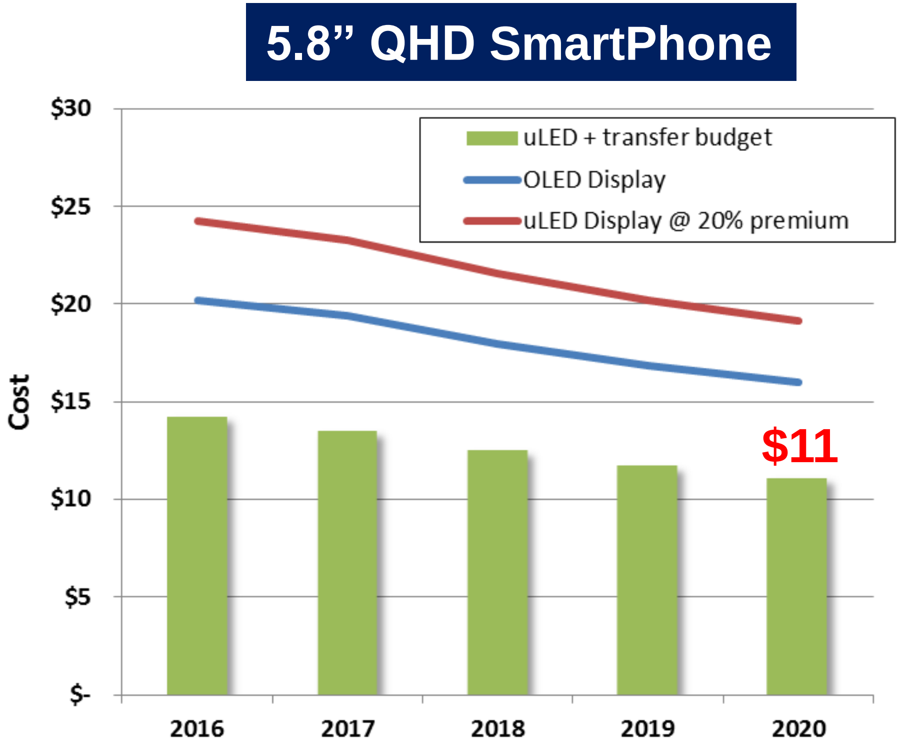
AR/VR

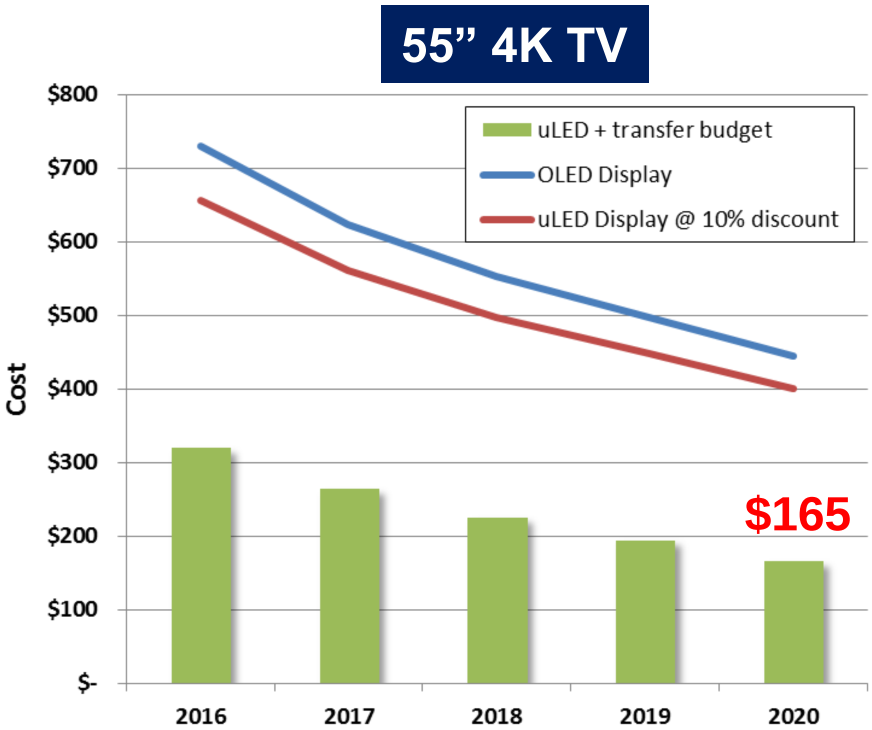
Signage

Upside µLED forecast: >300M displays by 2025

Source: Yole

Micro-LED Display Cost Targets – TV & Smartphone





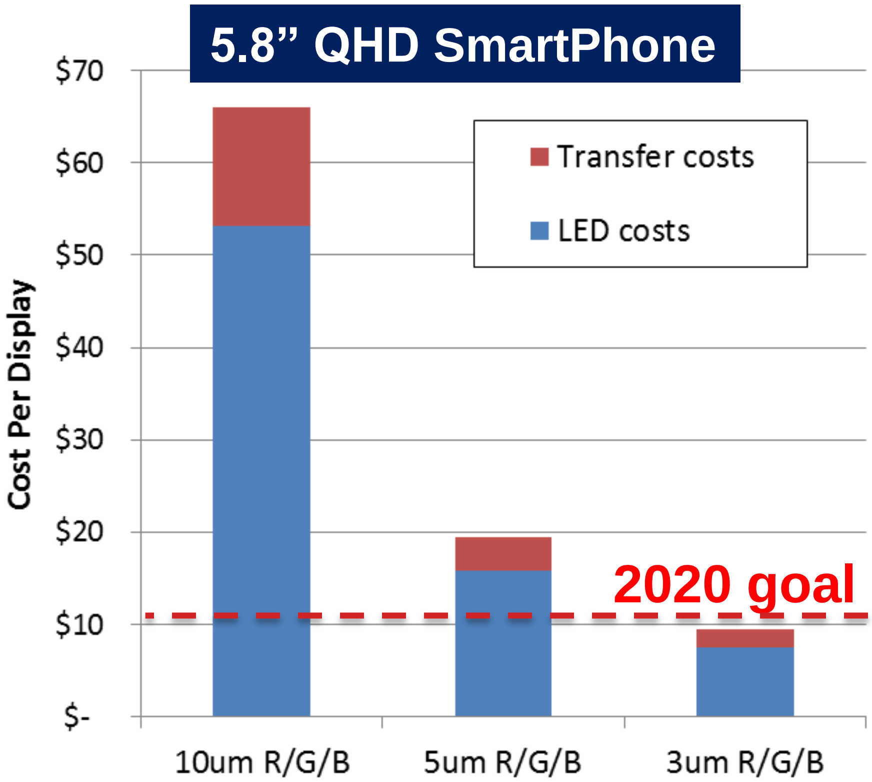
Allowable LED and transfer costs (2020)

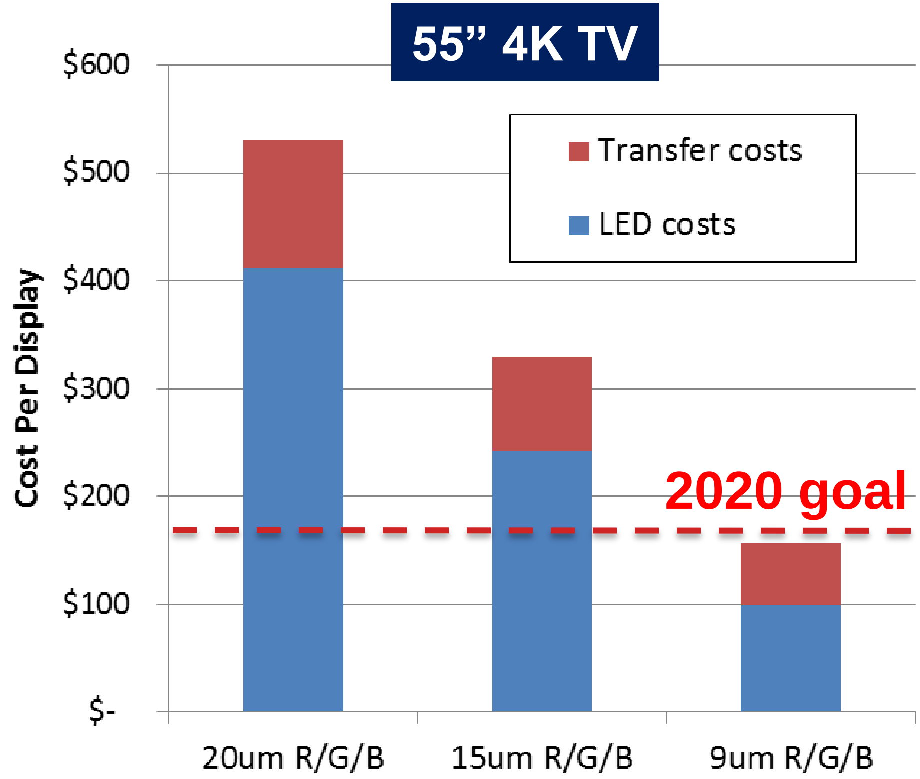
- TV: $165; Smartphone: $11

SOURCE: IHS Markit 2017, Veeco estimates

QHD: 2560x1440 pixels

Micro-LED Display Cost Roadmap – TV & Smartphone





<10x10μm² μLED size needed to meet TV cost target

~3x3um² μLED size needed for smartphone

Assumptions: $400 per processed 6” Epi wafer
2um EPI street width, interposer transfer $0.30 per field

Micro-LED Display Challenges

High EQE μLED chips at <10x10μm^2

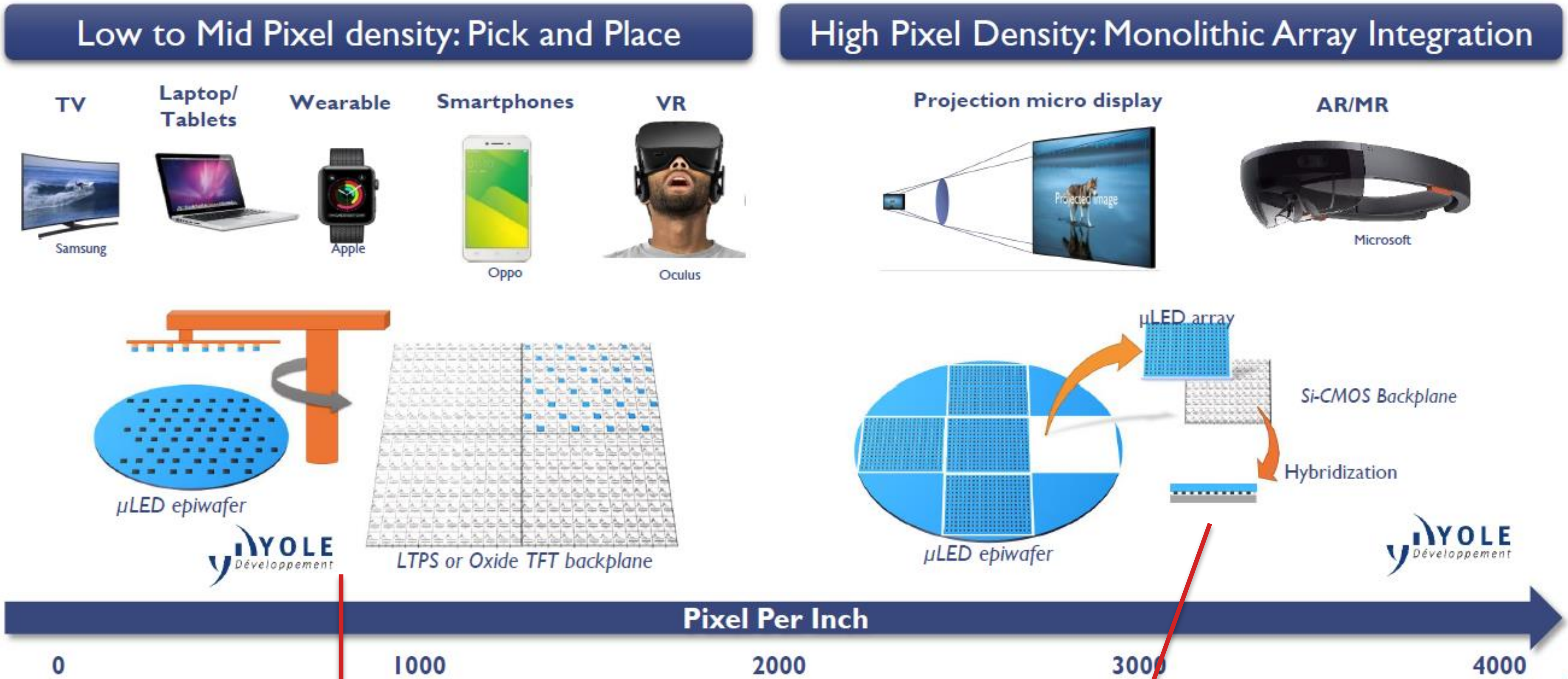
High Quality Epitaxy (defectivity, uniformity**)**

High yield, low cost **transfer** from wafer to backplane

Specialized drive circuitry with uniformity correction

Test and repair of defective pixels

Mass Transfer Approaches



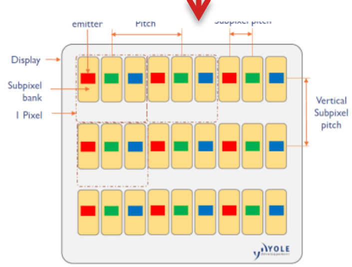
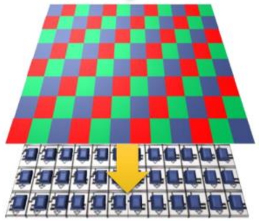


Illustration: top view schematic of a RGB microLED display.

Red + Green + Blue LED

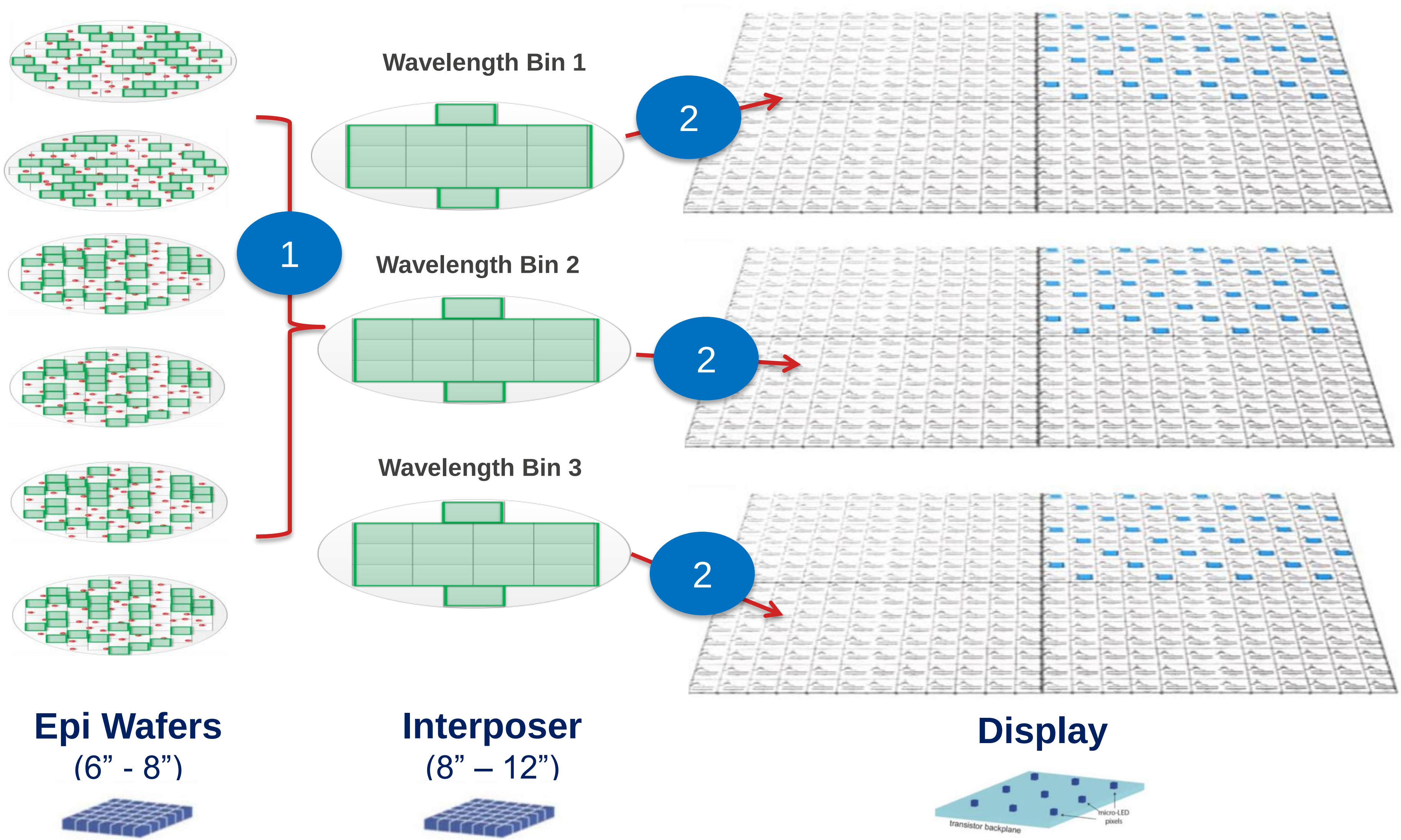

Concept of a color converted MicroLED Display

Blue/UV + color conversion (e.g. quantum dot)

SOURCE: YOLE

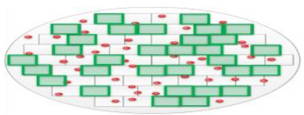
Mass Transfer with Interposer

= “Good” Epi field (defectivity, uniformity)



Epitaxy Defectivity and Uniformity Requirements

Epi Wafer

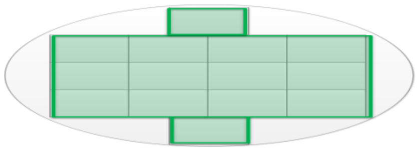


≤ 1 Defect per Transfer field

(~1 cm^2 for 6" wafer)

1 - 2nm wavelength range
(within transfer field)

Interposer

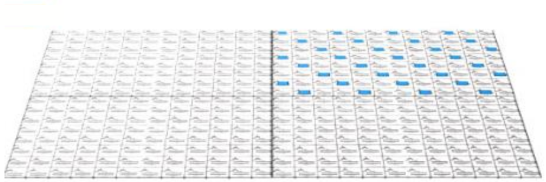


≤ 1 Defect per Donor field

(Phone: ~1 cm^2)
(TV: ~10 cm^2)

1 - 2nm wavelength range

Display



≤ 1 Defect per Color

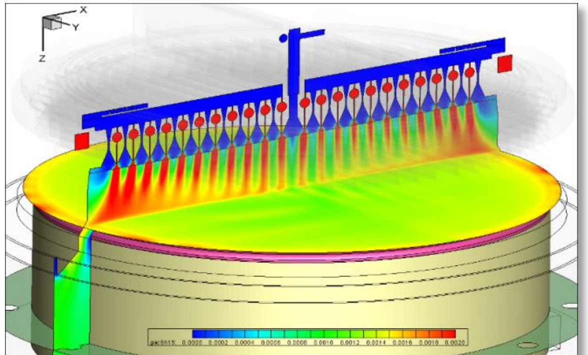
1 - 2nm wavelength range
(before correction)

Epitaxy specifications are calculated at transfer field level

Veeco MOCVD Solutions

Veeco MOCVD… *Cleanest* Production Technology

Veeco TurboDisc™ Technology



- Uniform deposition by design
- Wide process window
- **Low defectivity: < 1 / cm^2**
- **Longest run campaigns**
- **Ultimate process repeatability**

EPIK™ 700

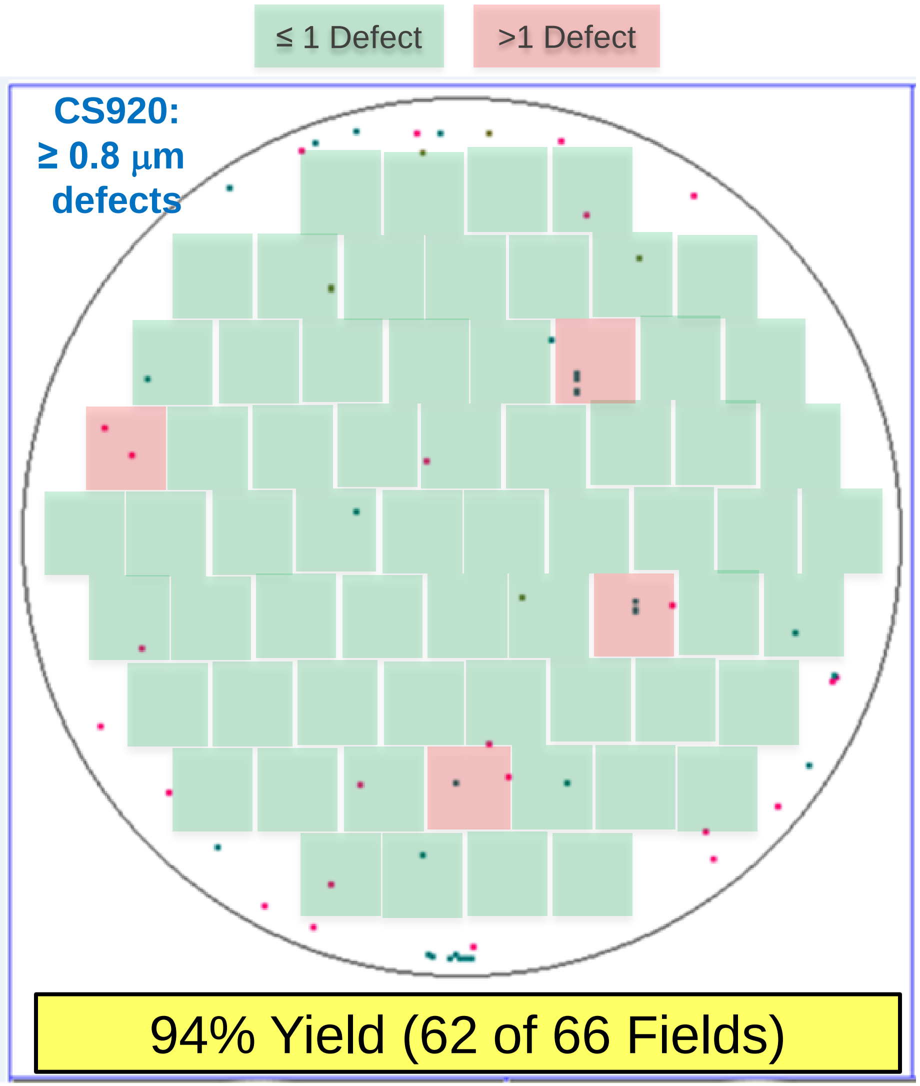
Propel™

K475i™

- **High capacity Batch Reactor** for 6” sapphire (28x6”)
- **Single Wafer Reactor** for 8” Si or sapphire
- **Batch Reactor**: 7x6” GaAs

Veeco EPIK – Defectivity yield for smartphone

3x3μm^2 μLED → 1μm killer defect size



Display assumptions:

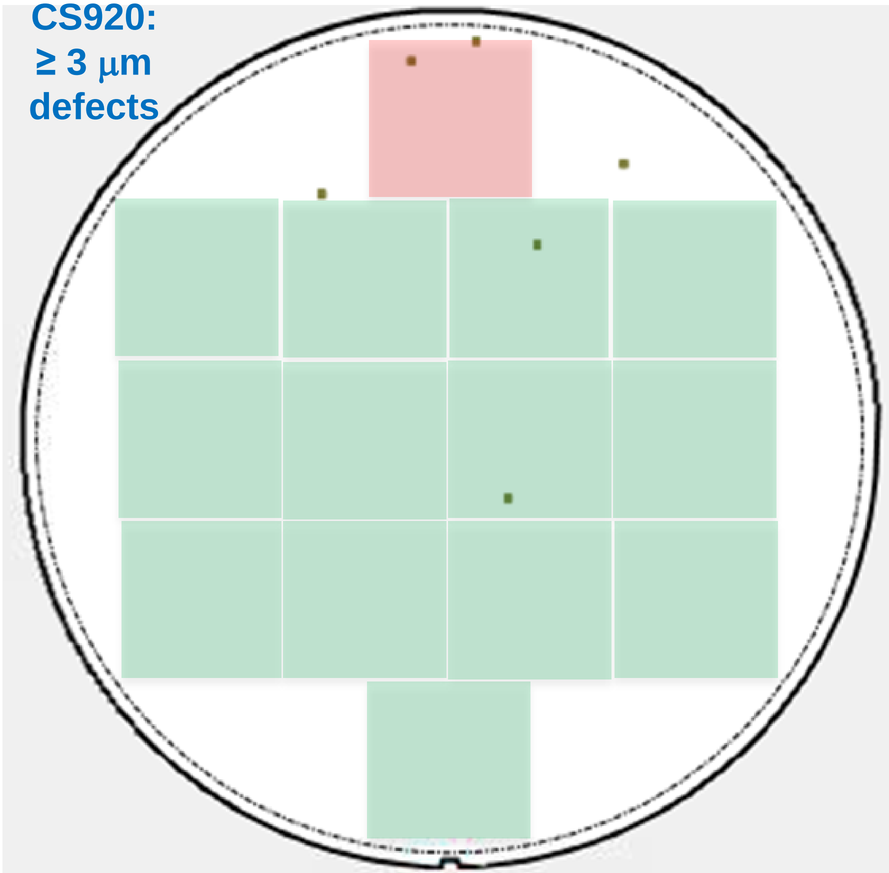
- QHD resolution (2,560 x 1,440)
- 3x3μm^2 LED size
- 2μm street width

→ 0.92 cm^2 Epi donor field per color

Veeco EPIK – Defectivity yield for TV

9x9μm² μLED → 3μm killer defect size

≤ 1 Defect   >1 Defect



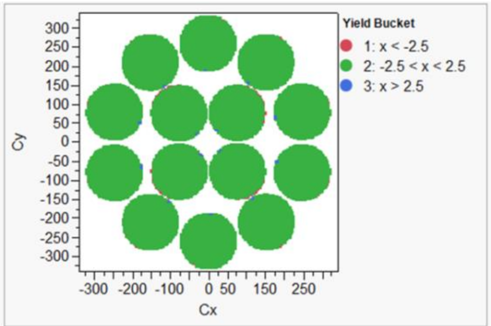
93% Yield (13 of 14 Fields)

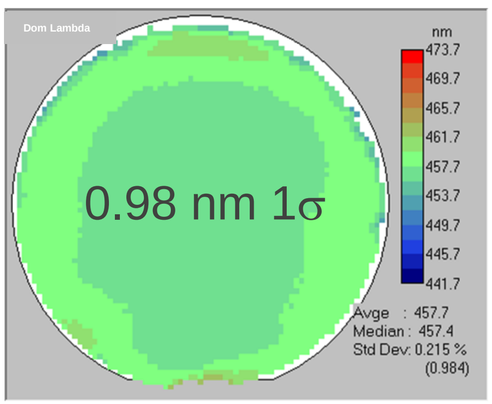
Display assumptions:

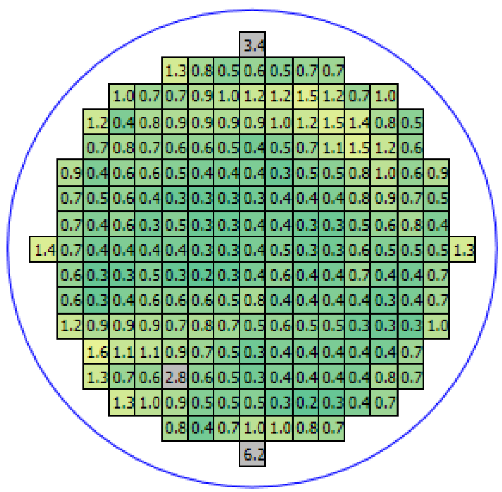
- 4K2K resolution (3,820 x 2,160)
- 9x9μm² LED size
- 2μm street width

→ 10 cm² Epi donor field per color

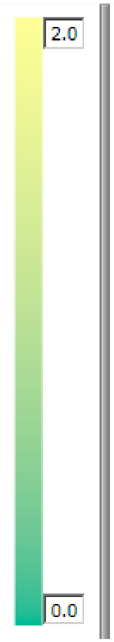
EPIK – 14x6” Wavelength Uniformity (Blue LED)

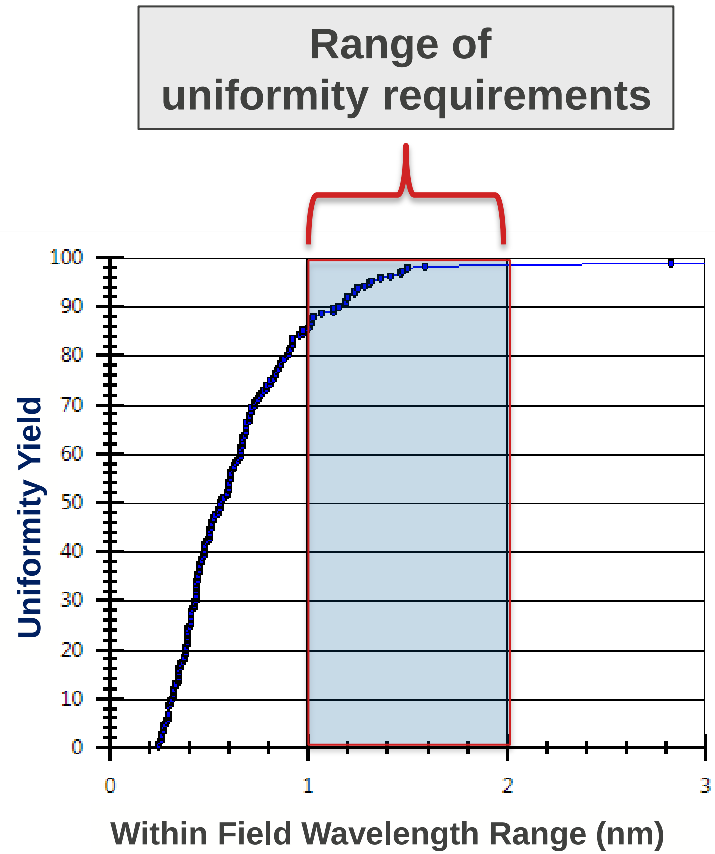






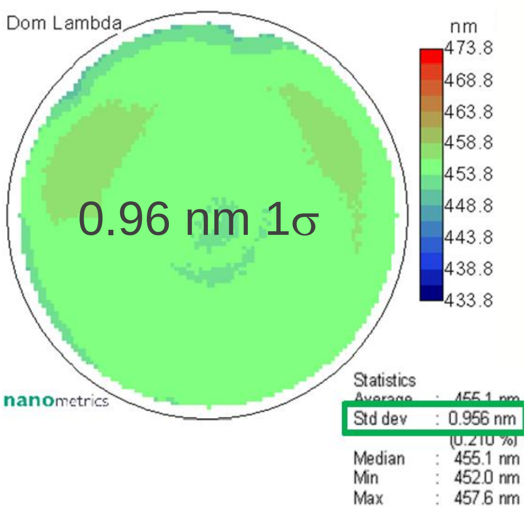
8x8mm² transfer field

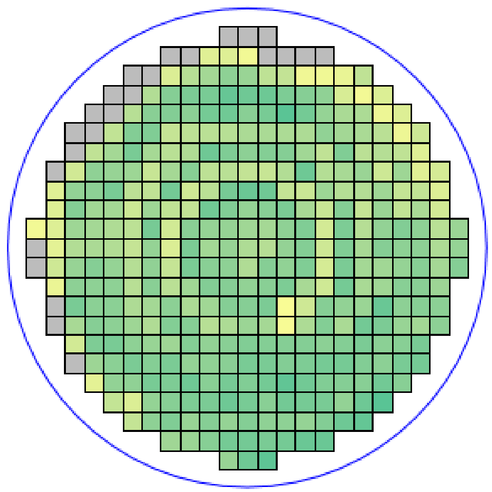




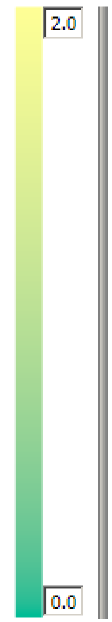
Veeco EPIK can achieve >80% uniformity yield for μLED Display

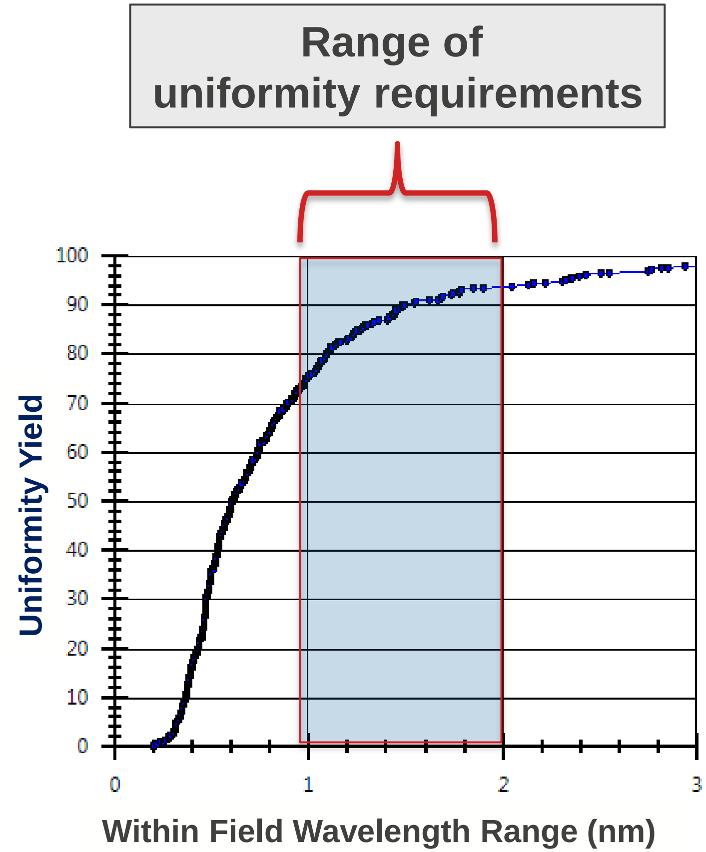
Propel – 8” Si Wavelength Uniformity (Blue LED)





8x8mm^2 transfer field





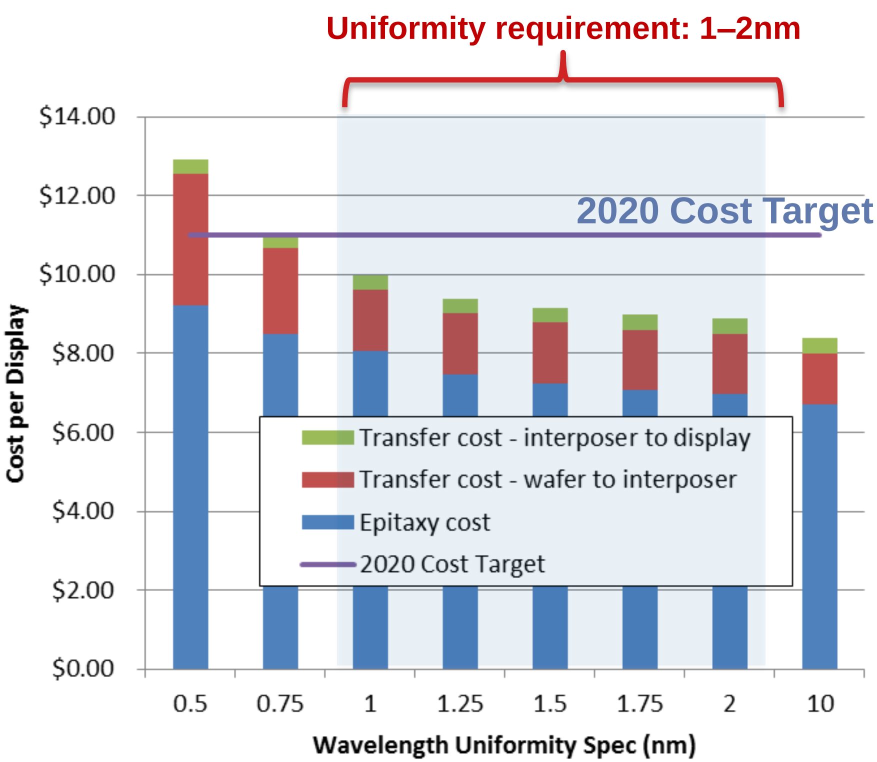
Veeco Propel can achieve >80% uniformity yield for μLED Display

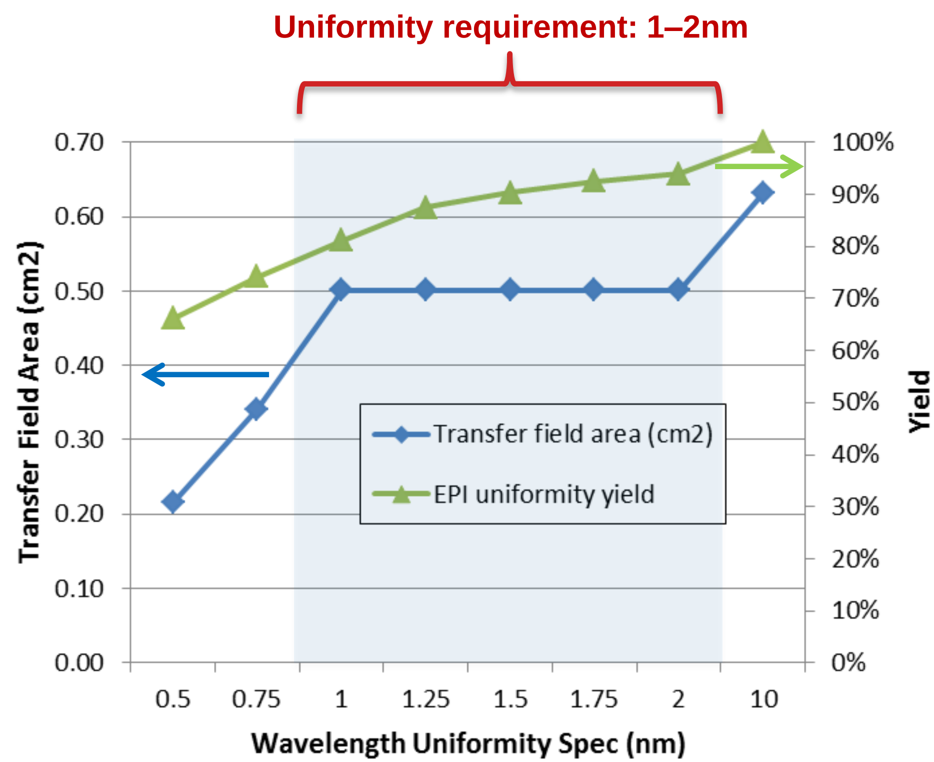
ALLOS Semiconductors

Veeco

Impact of Wavelength uniformity requirement

5.8" QHD Smartphone



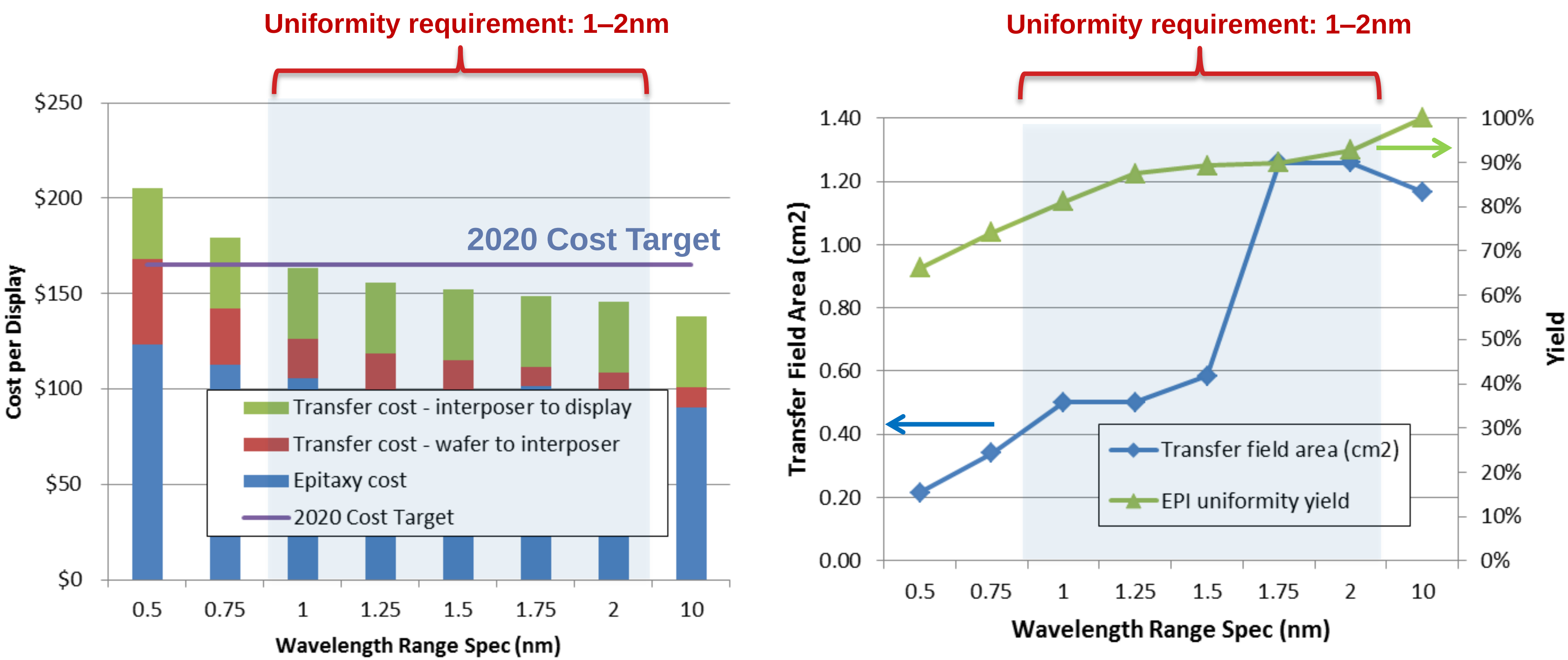


- $11 cost target (LED + transfer) for μLED smartphone is achievable
  - Optimal Epi transfer field → 7x7mm^2 to 8x8mm^2

Assumptions: 3x3um^2 LED; EPIK 14x6"; Epi wafer cost $400; $0.30 transfer cost per field; interposer transfer field 5x5cm^2

Impact of Wavelength uniformity requirement

55" 4K TV



- $165 cost target (LED + transfer) for μLED TV is achievable
  - Optimal Epi transfer field → 7x7mm^2 to 11x11mm^2

Assumptions: 9x9um^2 LED; EPIK 14x6"; Epi wafer cost $400; $0.30 transfer cost per field; interposer transfer field 5x5cm^2

Summary & Conclusions

- Micro-LED Display has significant advantages over LCD & OLED
  - Brightness & efficiency (smartphone)
  - Higher brightness than OLED and near-LCD cost (TV)
- Small LED size with high EQE is key to enable consumer applications
  - ~3x3μm^2 for smartphone; ~10x10μm^2 for TV
- Epitaxy requirements (for mass transfer with interposer)
  - Defectivity: ≤1 per Epi <u>donor</u> field (1 – 10 cm^2)
  - Uniformity: 1-2 nm range over Epi <u>transfer</u> field (0.5 – 1 cm^2)
- Veeco's MOCVD solutions meet cost and yield requirements for µLED smartphone and TV
  - EPIK for 6" sapphire; Propel for 8" silicon

