Printing MicroLEDs and MicroICs for Next Generation Displays

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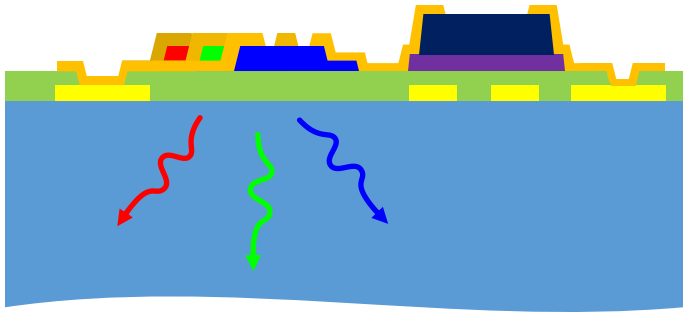

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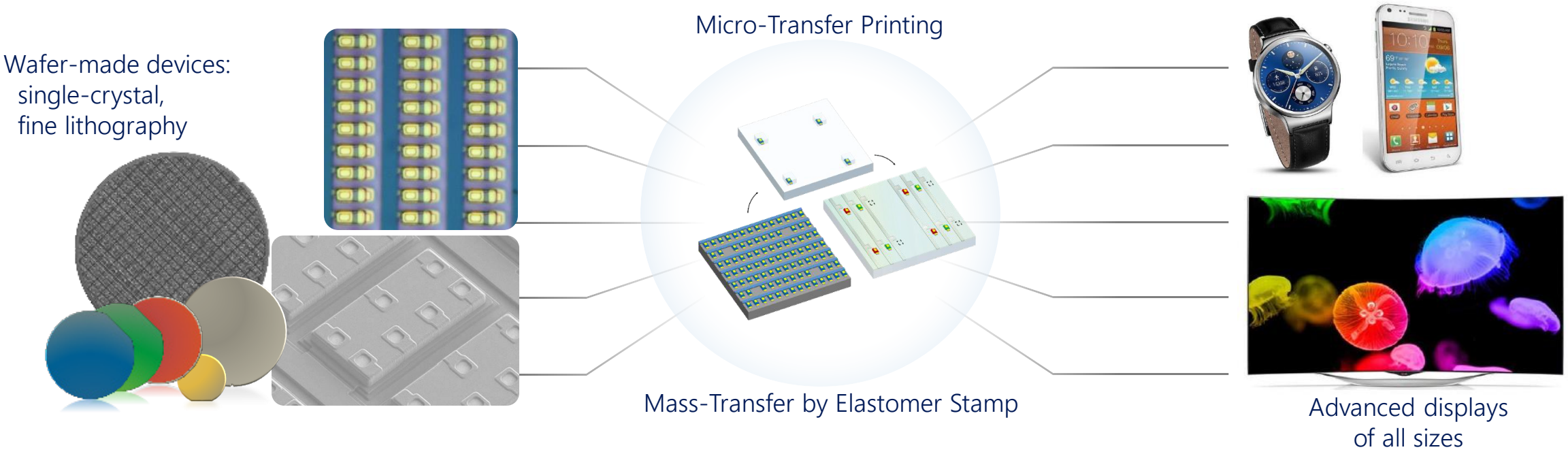
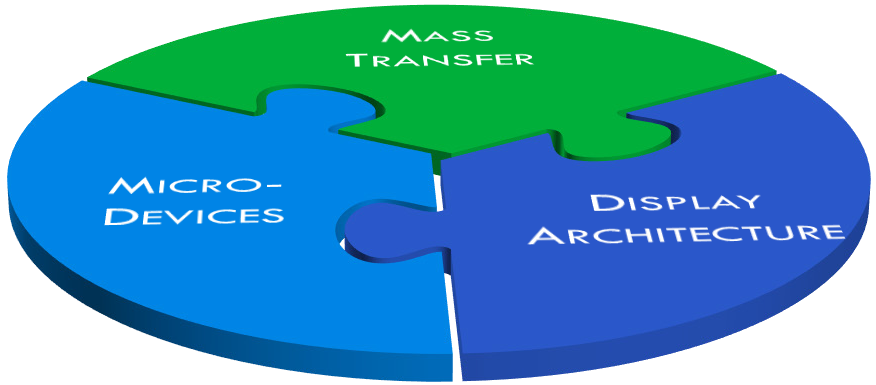
MicroLED displays are a union of different disciplines.

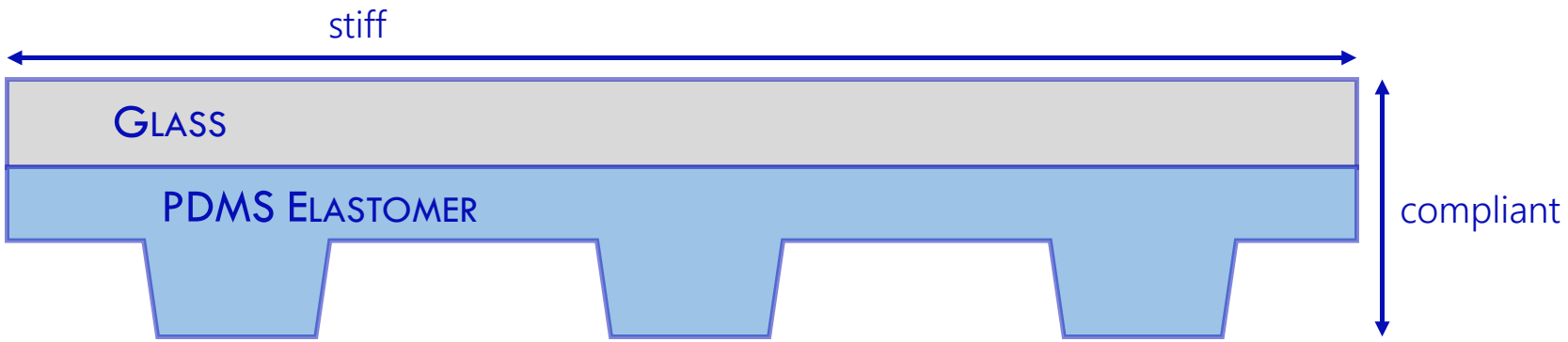


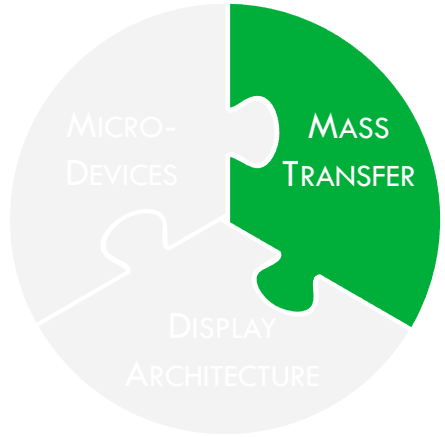
MicroLED display technology is a union of different disciplines, held together by mass-transfer micro-assembly.

Solutions are highly-integrated with interdependencies between three elements of the technology: mass-transfer, micro-devices, and display architecture.



Elastomer stamp mass-transfer fundamentals





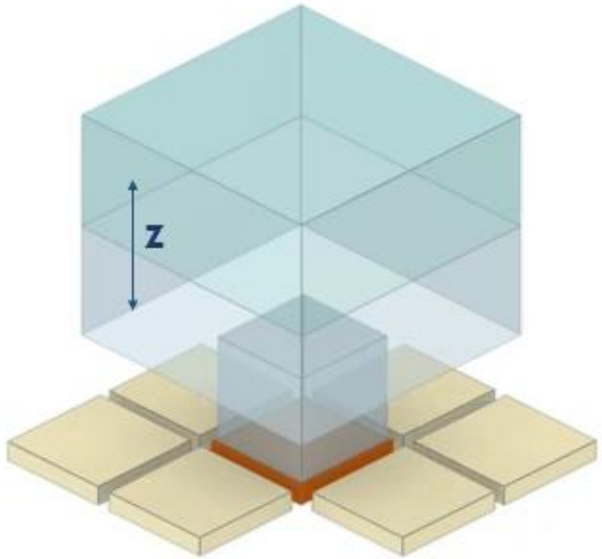
Elastomer stamp performs mass transfer by selectively retrieving an array of devices by van der Waals' adhesion and transferring the array to a display substrate (e.g. glass or plastic).

99.99% yield in multi-user R&D facility. Expect much higher in production environment.

STAMP CHARACTERISTICS:

- compliant in z-direction
- short-range, reversible adhesion
- transparent
- low-cost
- mechanically tough

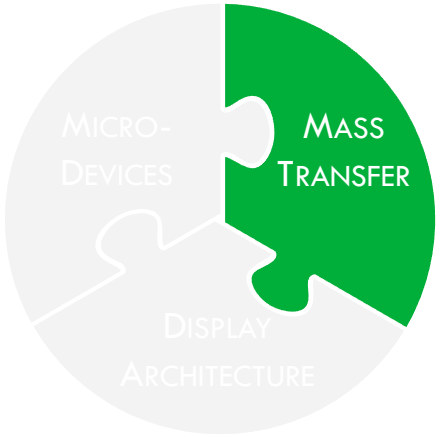
Key enablers for yield and throughput



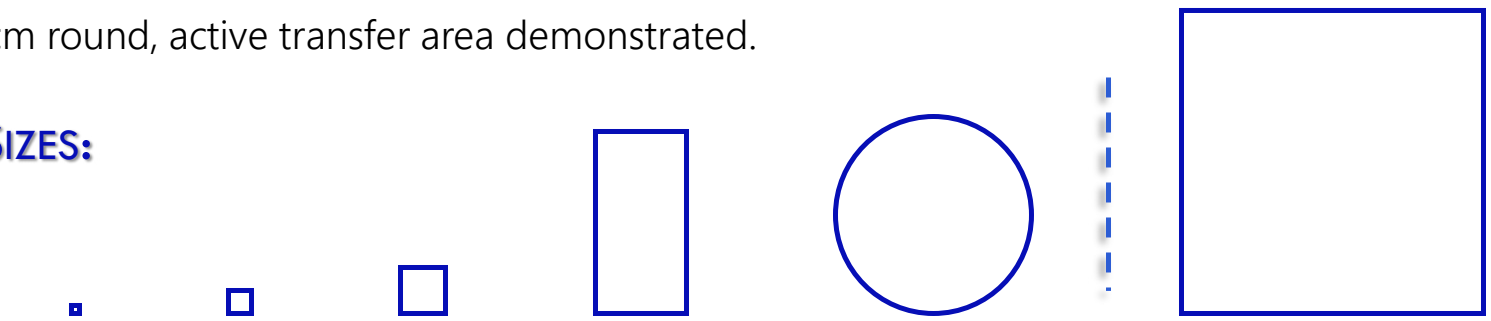
Scalability of elastomer stamp

Stamp array scales to 40000 mm^2 and beyond.

Up to 13 cm round, active transfer area demonstrated.



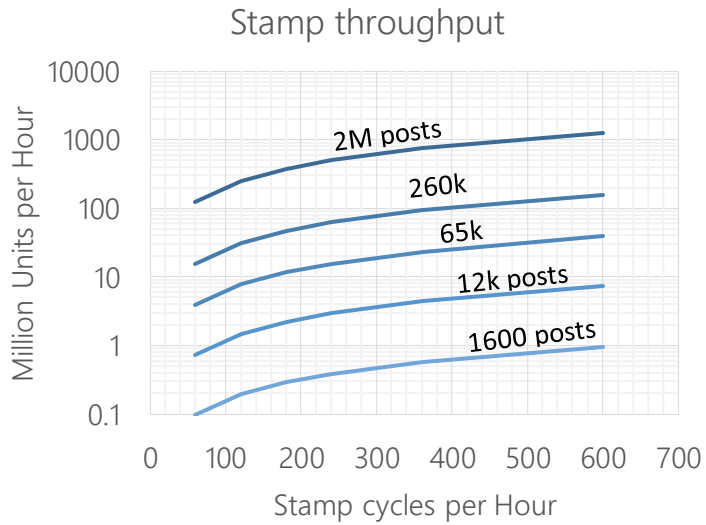
Stamp Sizes:



Conformability (z-direction compliance) and low-cost stamps enable scalability.

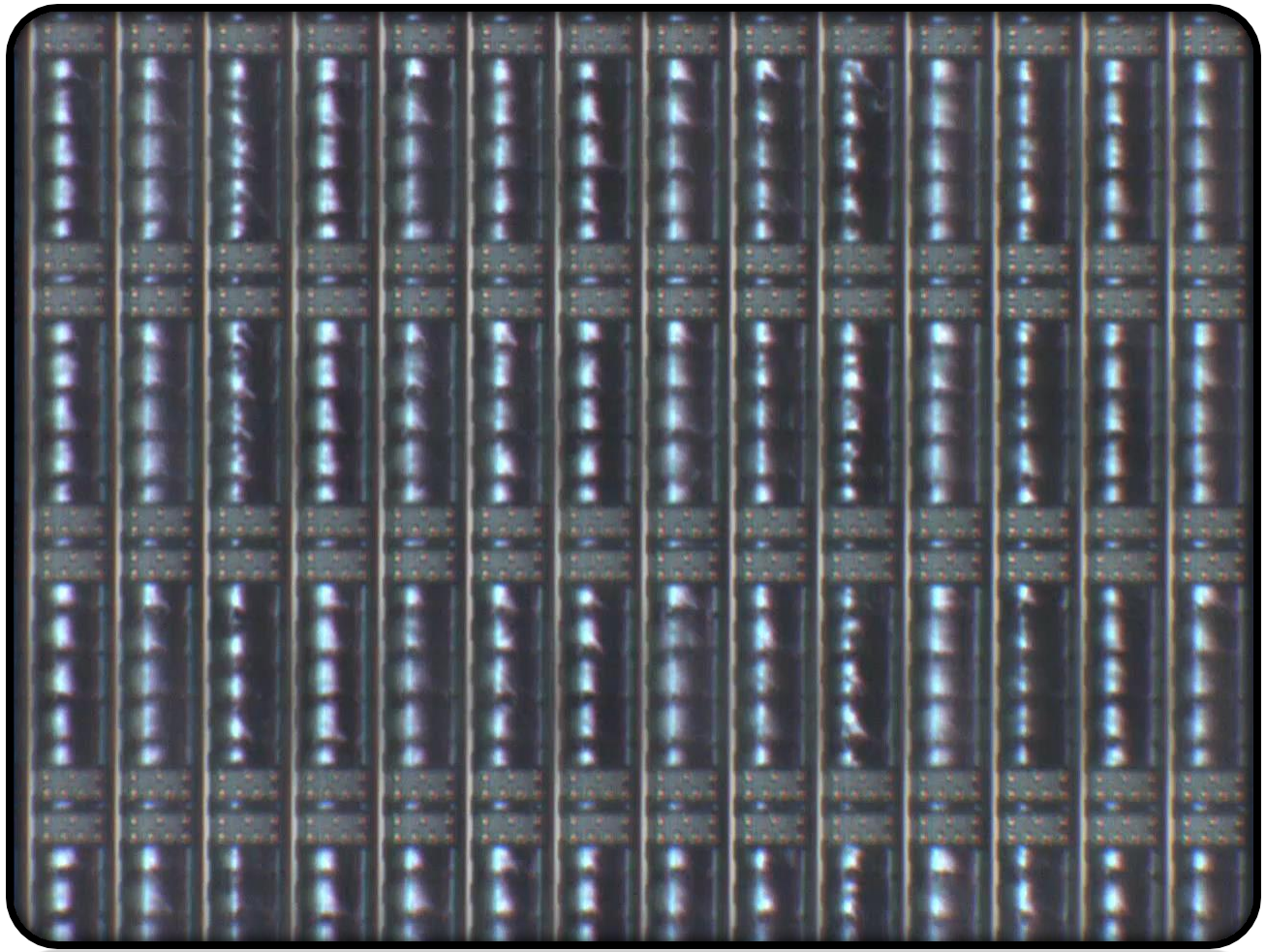
Scalability to large array enables high throughput.

Throughput (UPH) determined by array pitch, stamp size, and cycle time.

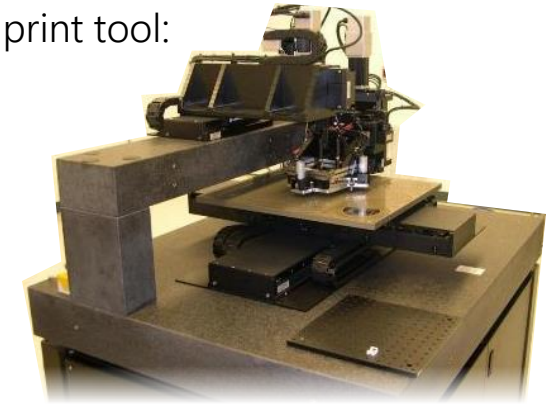


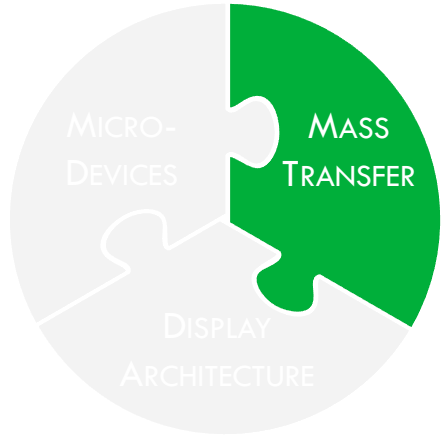
Mass-transfer in action

Looking through the stamp:
Retrieve ICs with stamp, print to display, loop video.



Transfer print tool:





This video shows 20 second cycle time.

Note orientational control (7 contact pads on IC).

Mechanical array alignment can define the rate of deterministic mass-transfer micro-assembly.

Transfer forces act only for a few seconds of the cycle (very fast).

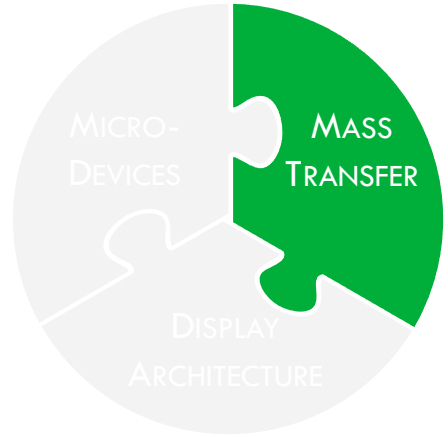
Precision handling of micron-scale chips

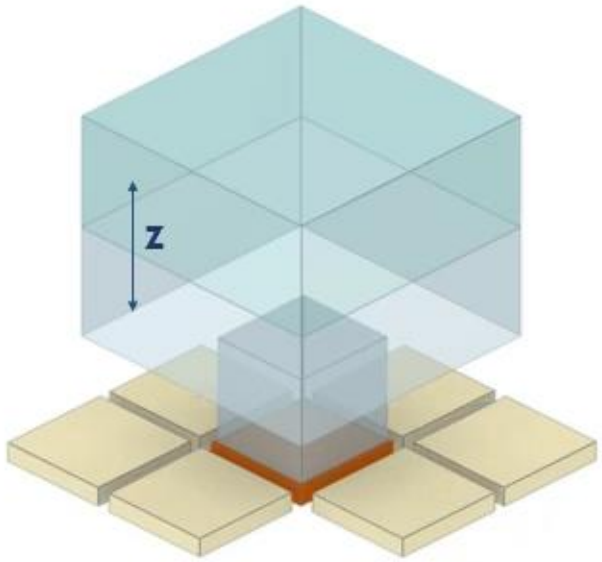
Short-range forces allow precise retrieval and placement: σ = 0.5 µm

Use active optical alignment for best placement accuracy.

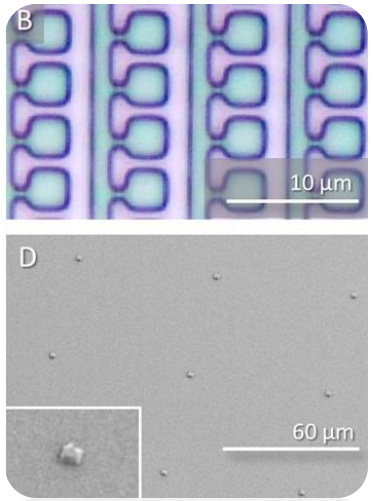
Transfer devices as small as 3 µm or smaller.

Conformability enables transfer of devices with topographic surfaces.



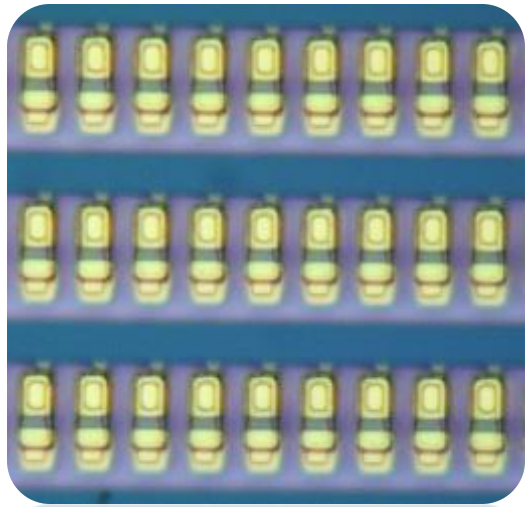


3 µm GaN transferred with stamp:

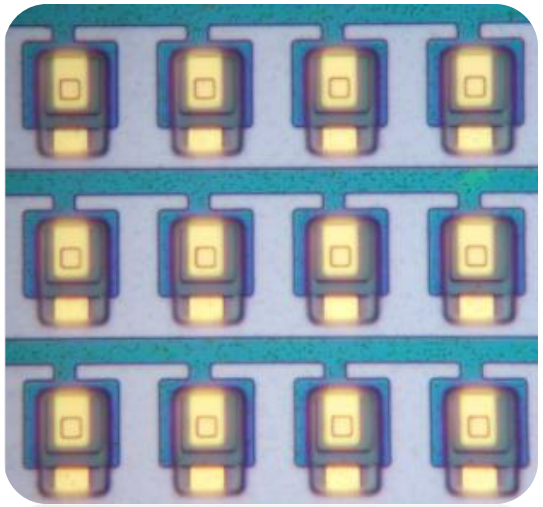


microLEDs ready for mass-transfer with elastomer stamp:

3 x 10 µm^2

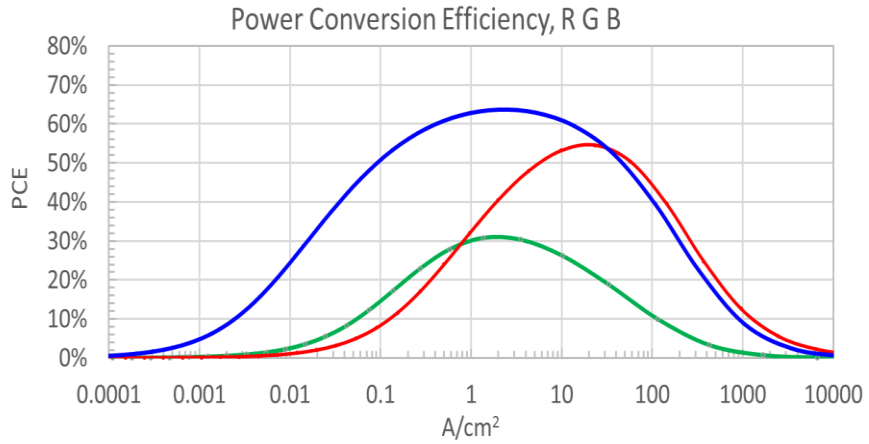


8 x 15 µm^2



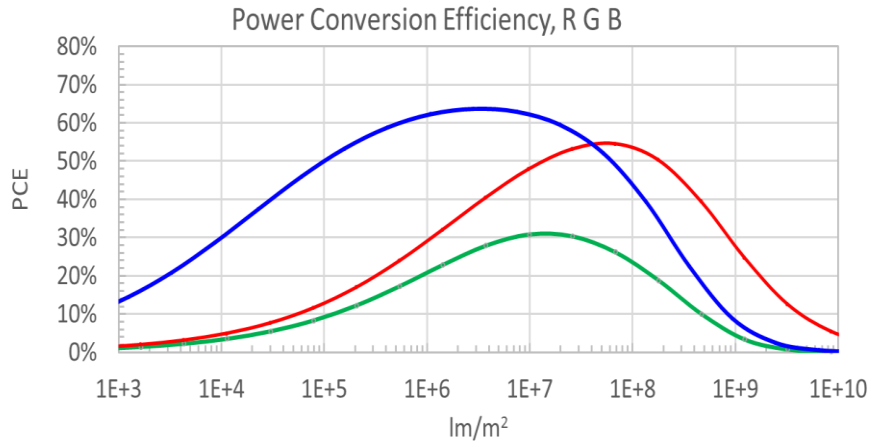
MicroLEDs as self-emitting sub-pixels

Representative behavior of modern LEDs, modeled.



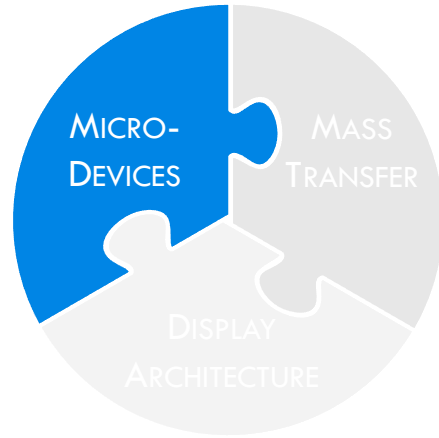
LEDs have highest PCE at current densities ~ 1 to 10 A/cm^2

- non-radiative recombination at low injection
- current crowding & droop at high injection

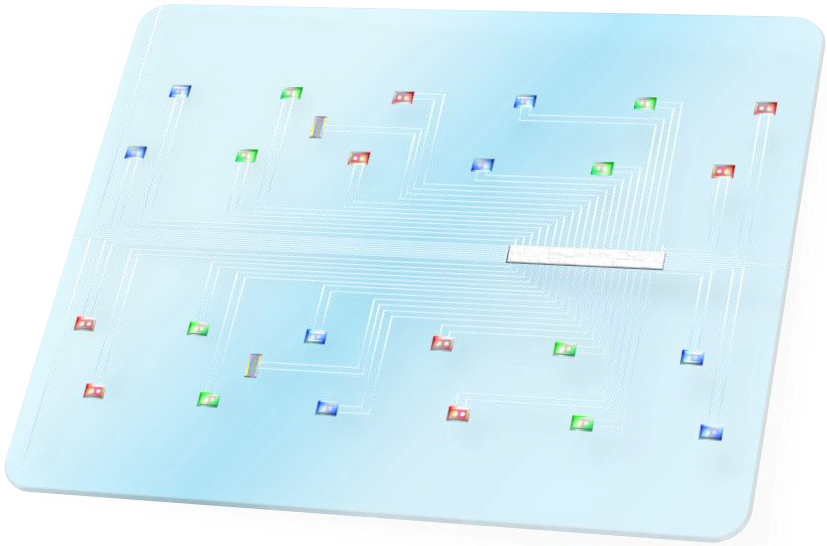


Designing for display operation at optimal current density:

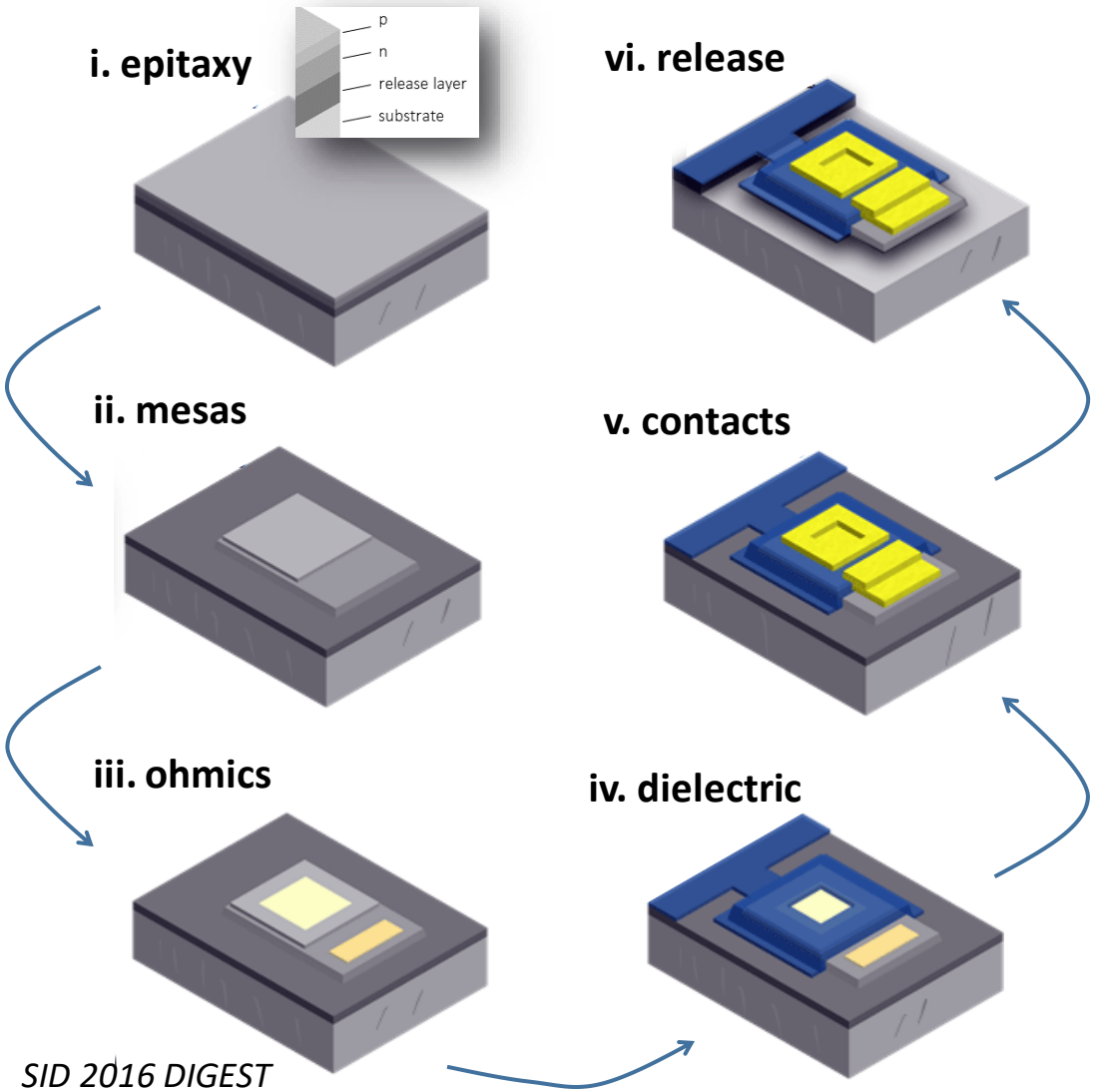
- ~ 0.2% pixel area coverage for 5000 nit µILED display
- ~ 0.02% pixel area coverage for 500 nit µILED display.



Room to do more!



8 x 15 µm² lateral microLEDs



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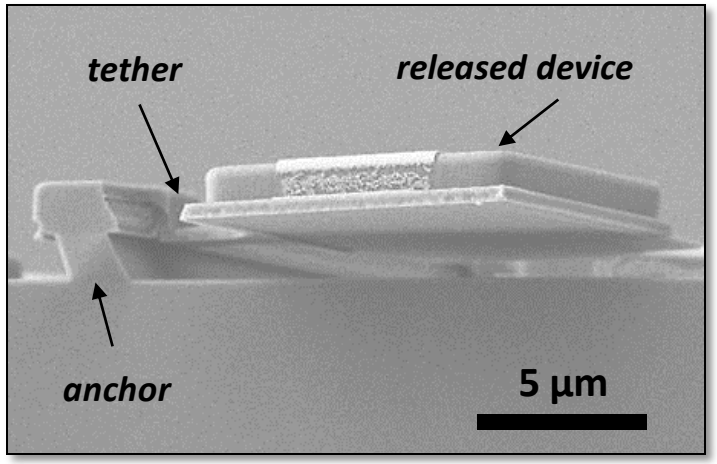
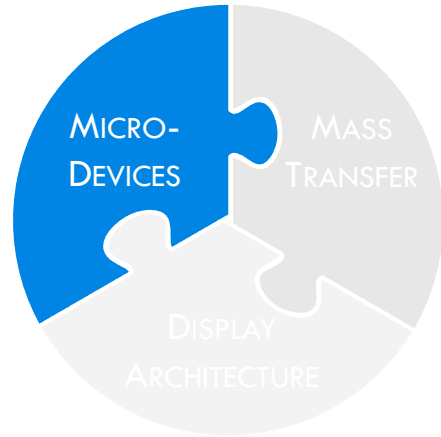
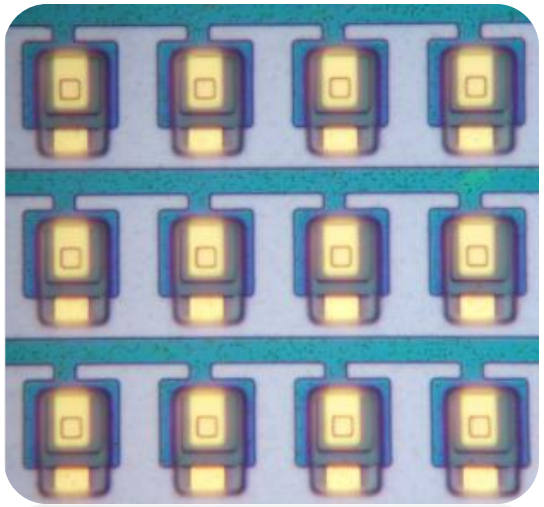
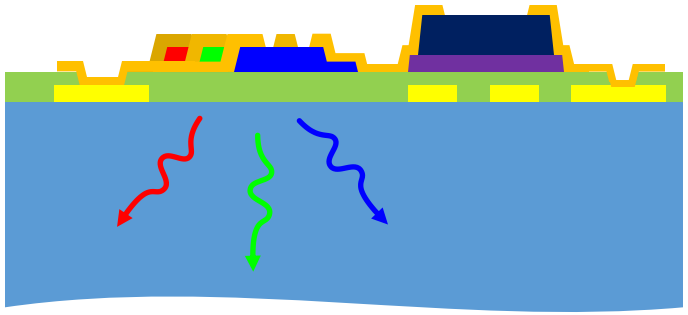








Light emission through substrate.

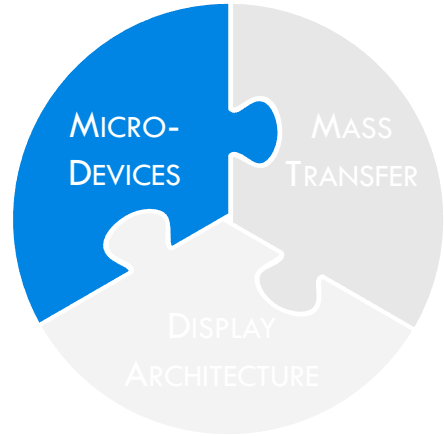
8 x 15 μm² flip-chip microLEDs

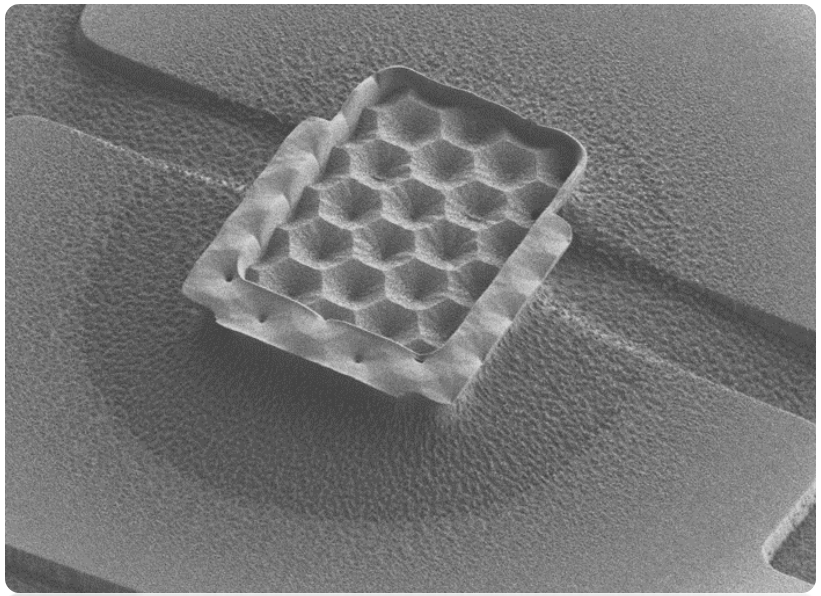
Flip-chip LEDs produced on patterned sapphire substrate and transferred to metal traces on glass.

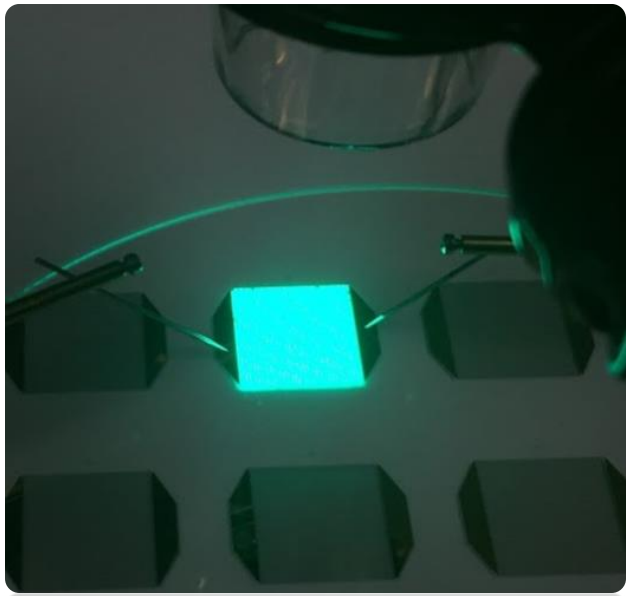
1600 devices interconnected in parallel, 8 x 8 μm² p-n junction area on each.

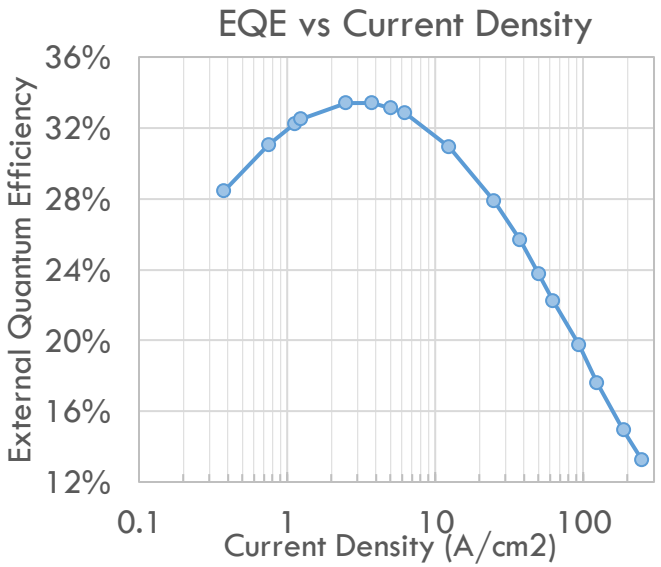
Measure EQE in integrating sphere.

33.4% peak EQE at 2 A/cm². >28% at 0.3 A/cm².







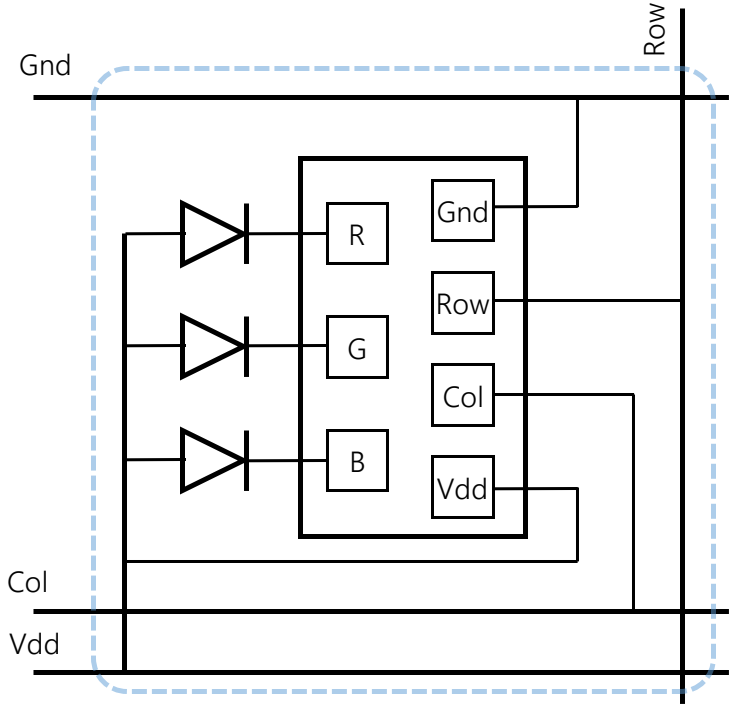


MicroIC driving for microLED displays

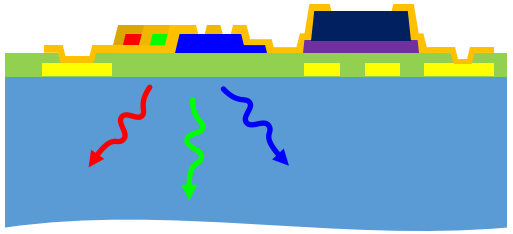
Print microICs and microLEDs to make active matrix display

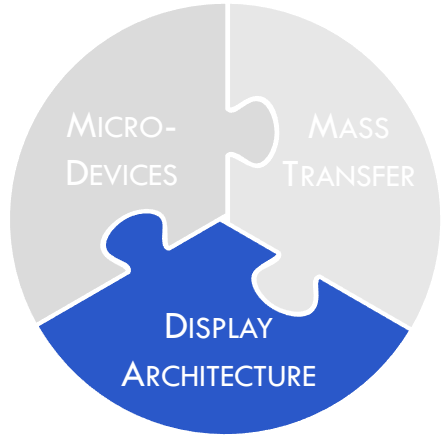
- Row, Column, Power, and Ground to each IC
- Each pixel IC drives three microLEDs (three sub-pixels)
- 16 bit per color (14 bits PWM, 2 bits current selector).

Row, column, power, and ground into each pixel:

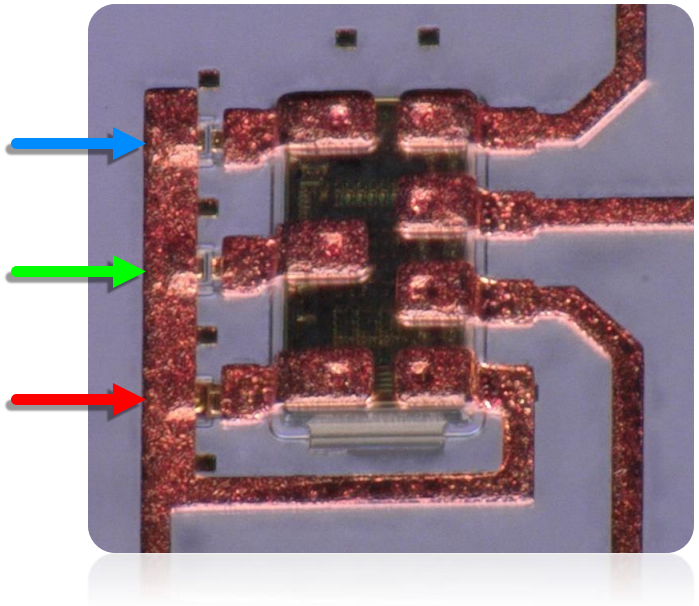


Light emission through substrate:





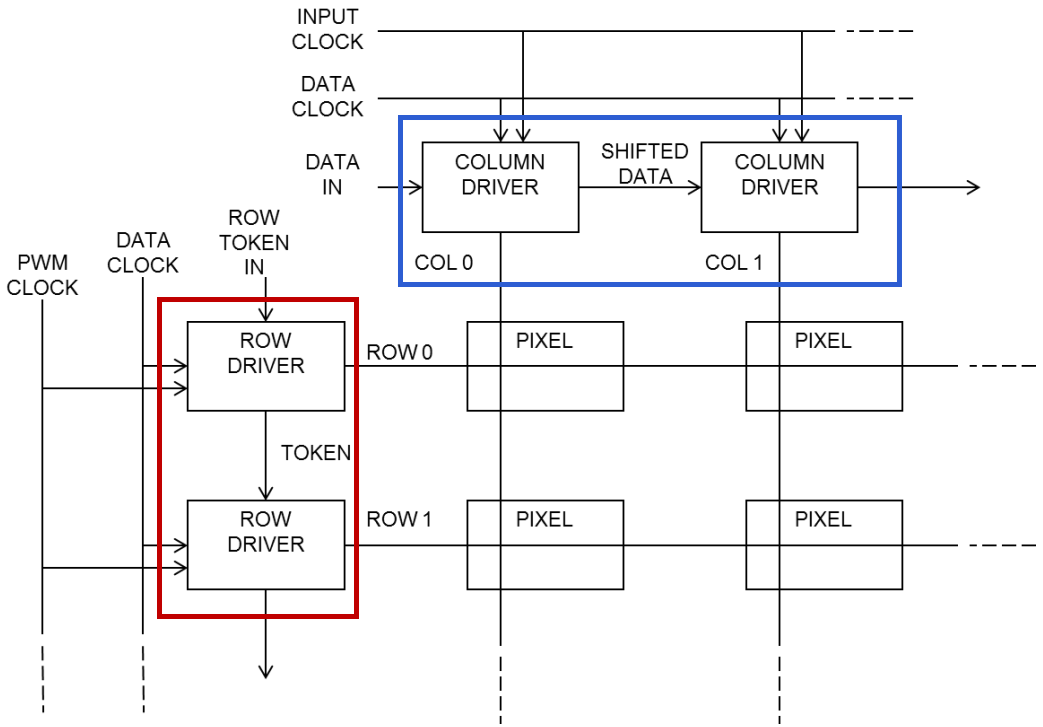
Interconnected IC (0.18 µm) and LEDs:



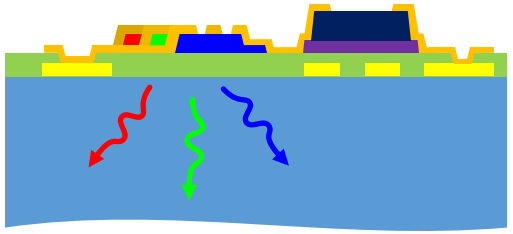
MicroIC driving for microLED displays

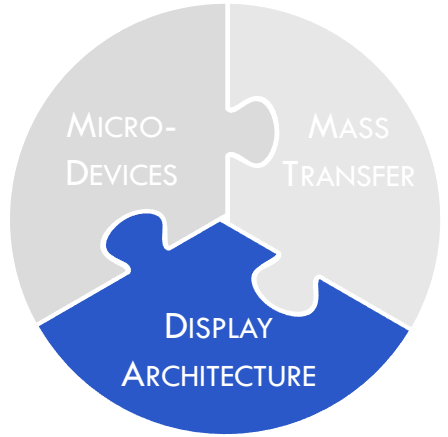
Print microIC row & column drivers to reduce display I/O count:

- Column drivers demultiplex data
- Row drivers provide clocking for data load and PWM



Light emission through substrate:





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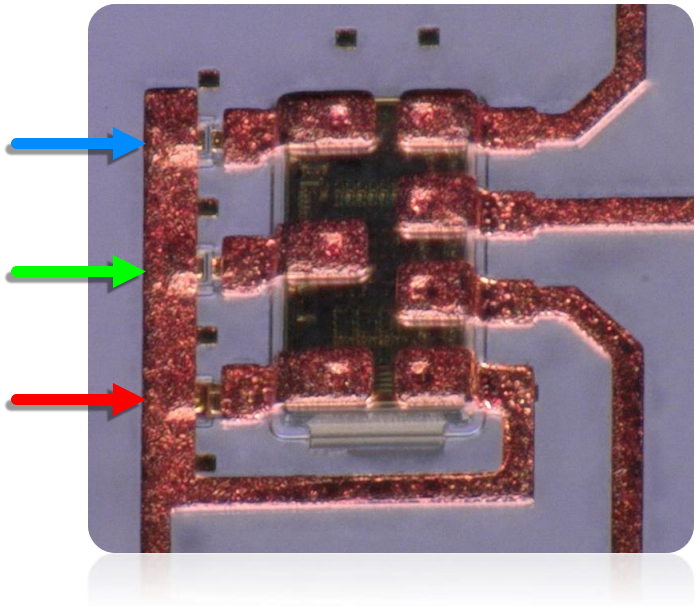
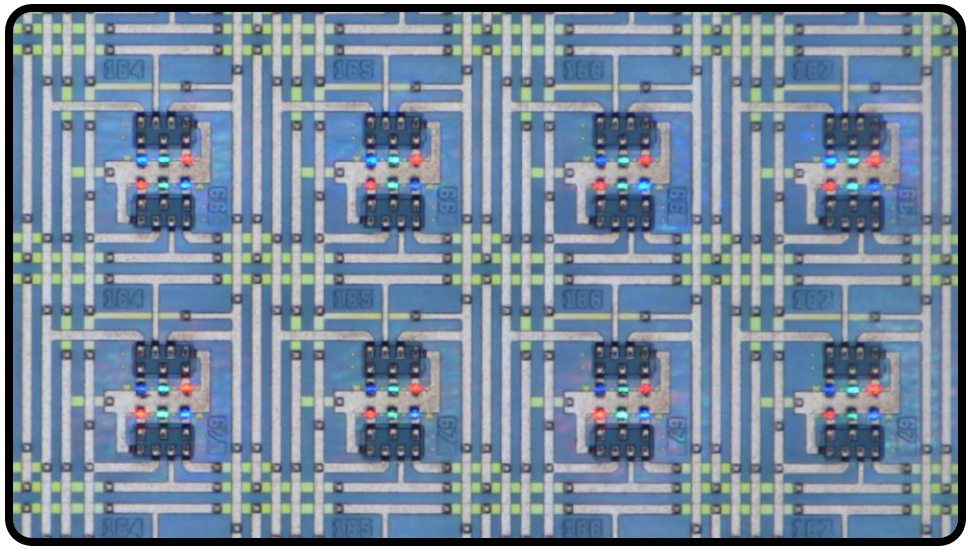


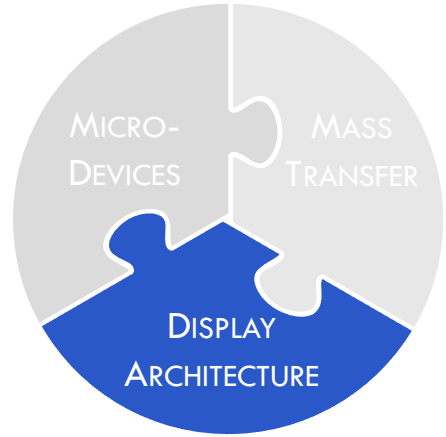
Redundancy & sub-pixel functional yield

Redundancy in pixel:
- microICs
- microLEDs
- row lines
- column lines

Yield limited by metallization defects.

Use laser cutting to remove metal shorts.





Red: 99.98% (9 dark)

Green: 99.95% (28 dark)

Blue: 99.95% (24 dark)

Pixel-to-pixel calibration

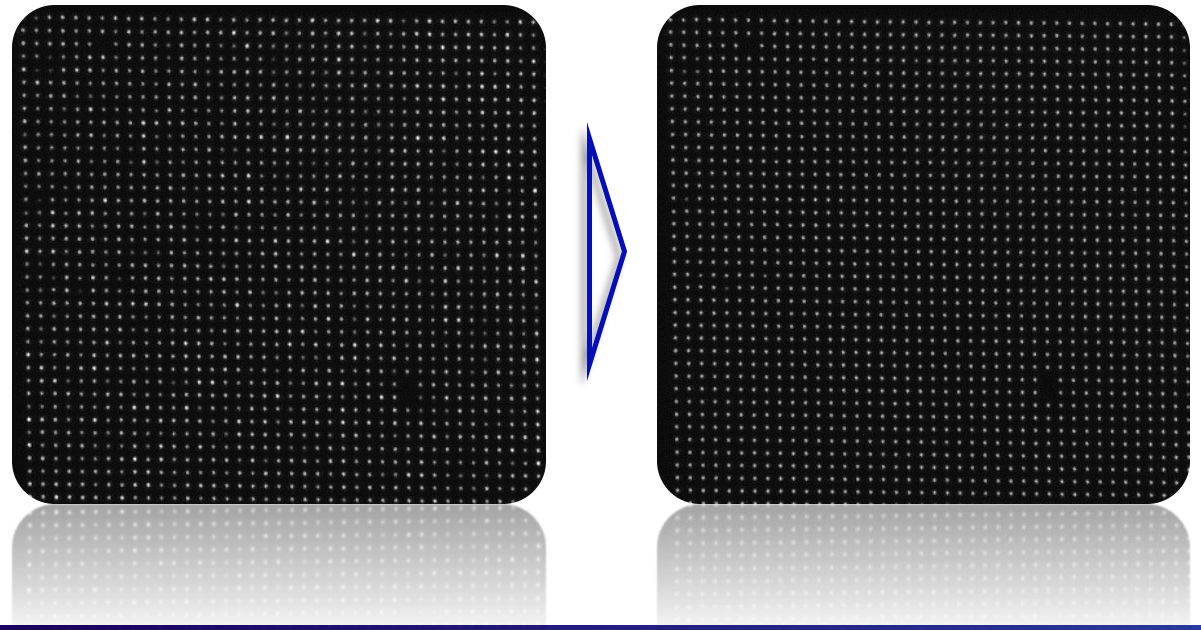
Video data stream runs through off-panel memory multiplier table with unique factor for every pixel.

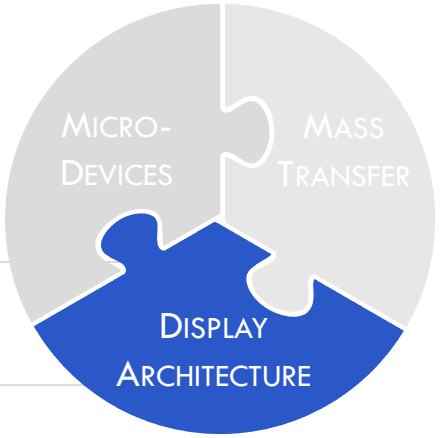
Measure brightness of every pixel, calculate calibration factor table, and re-measure.

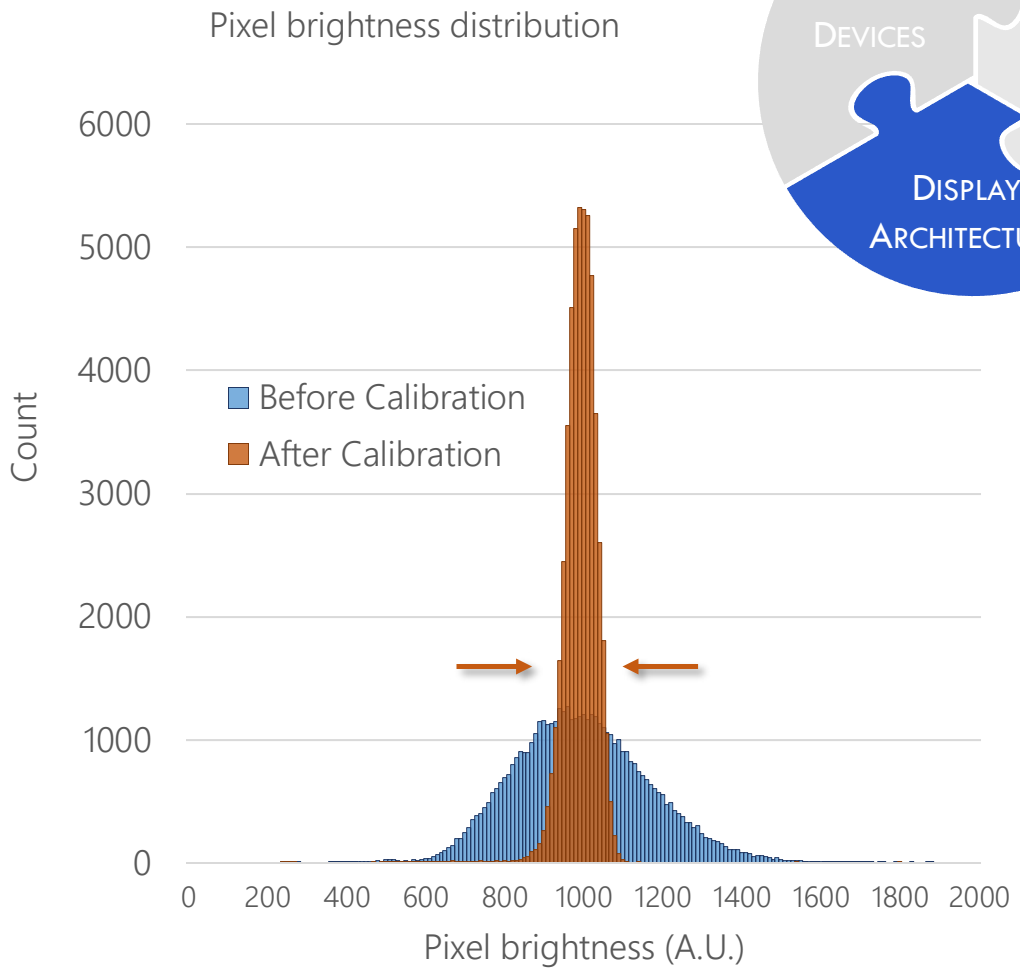
Reduces variability $\left(\frac{\sigma}{\mu}\right)$ from 25% to 7%.

Before calibration

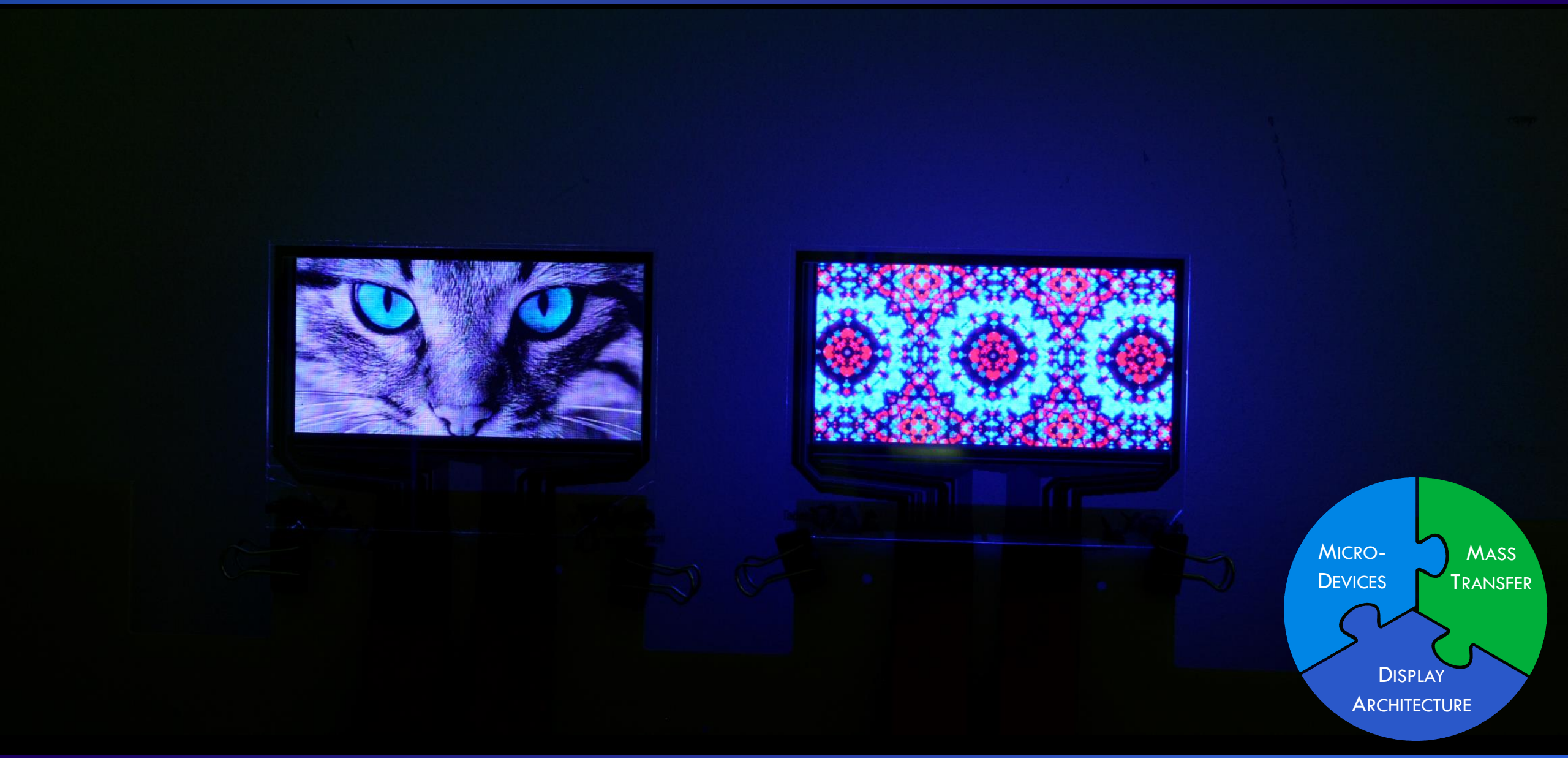
After calibration



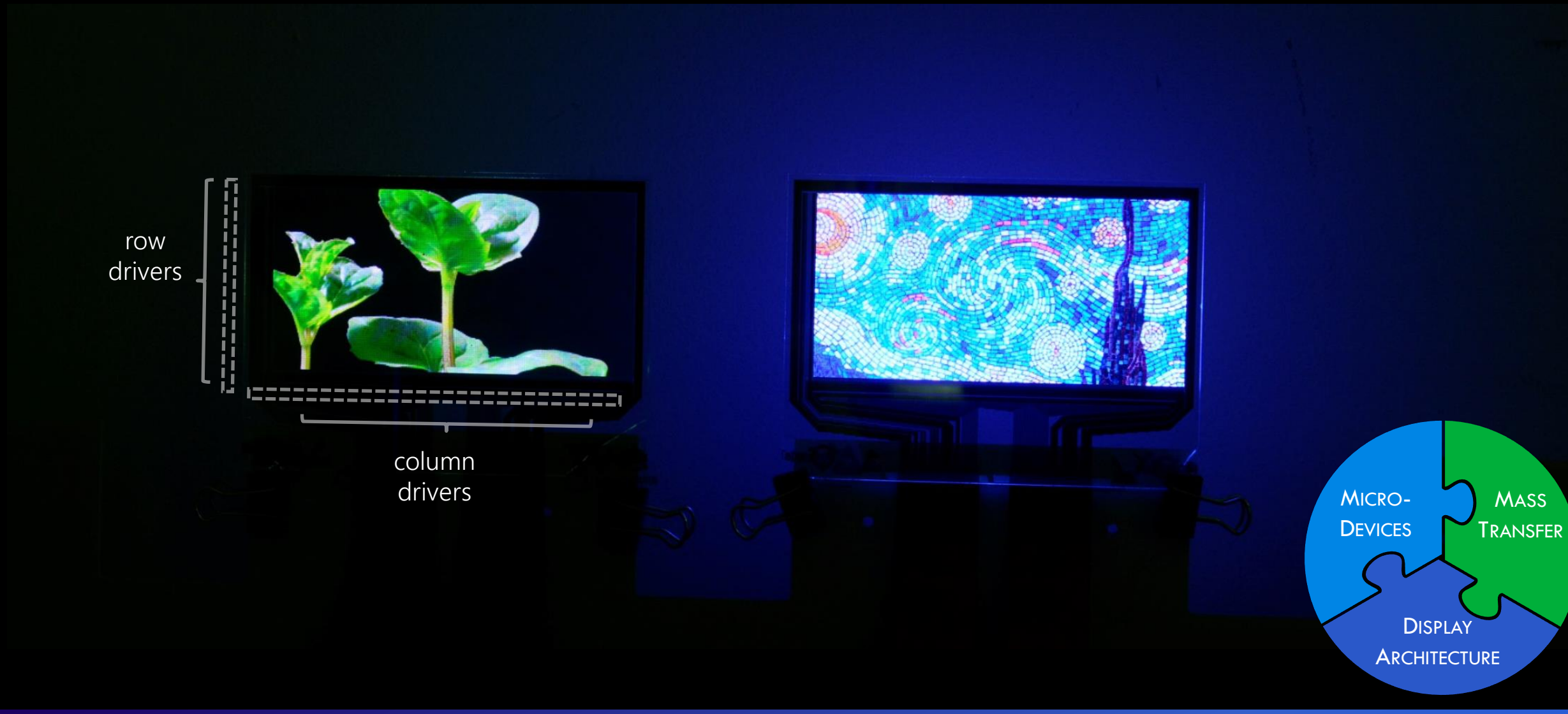




5.1″ diagonal AMILED displays, 320RGB x 160



5.1″ AMILED displays, 320RGB x 160 (slide 2)

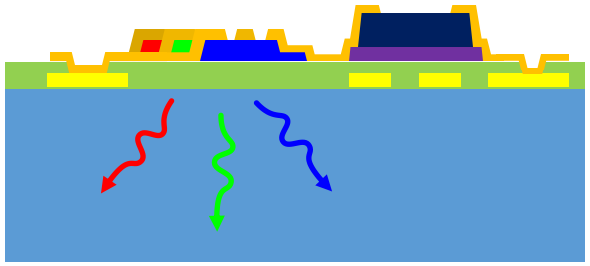


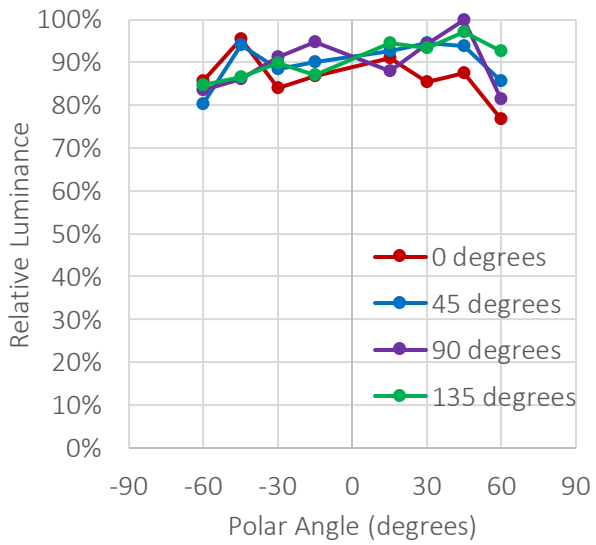
5.1″ AMILED displays, 320RGB x 160 (slide 3)

Demonstrated luminance: 3500 cd/m^2

MicroLED display optical properties.

Wide Viewing Angle:

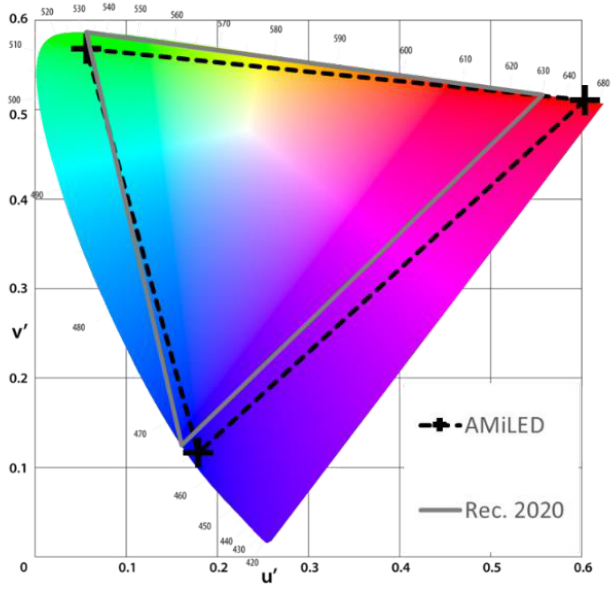


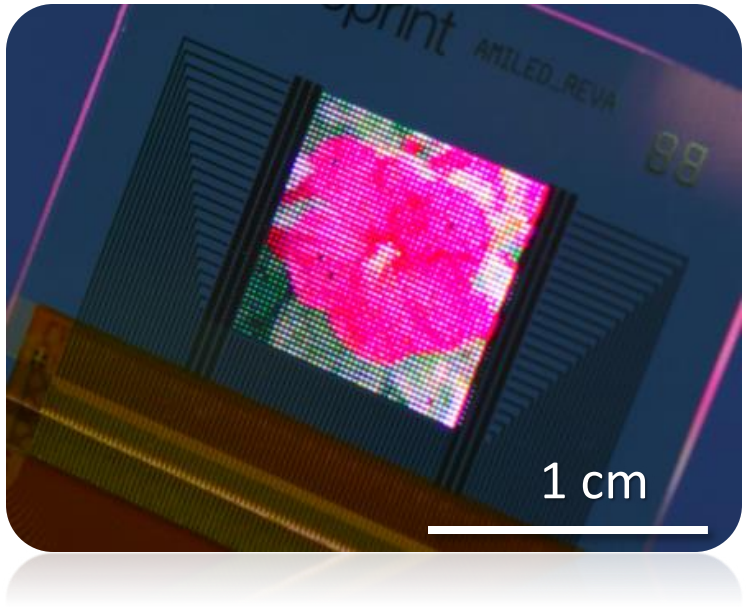


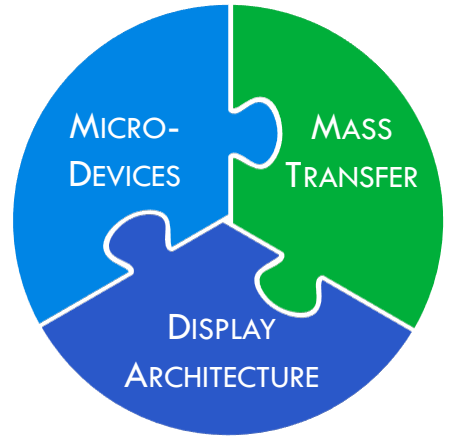
Strong Color Gamut:

Relative to Rec. 2020:

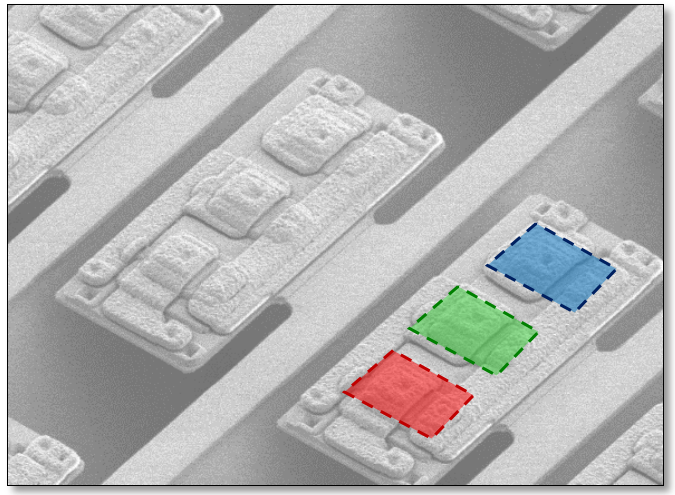
	u′ v′	x y
Area	107.1%	90.6%
Overlap	93.3%	84.1%







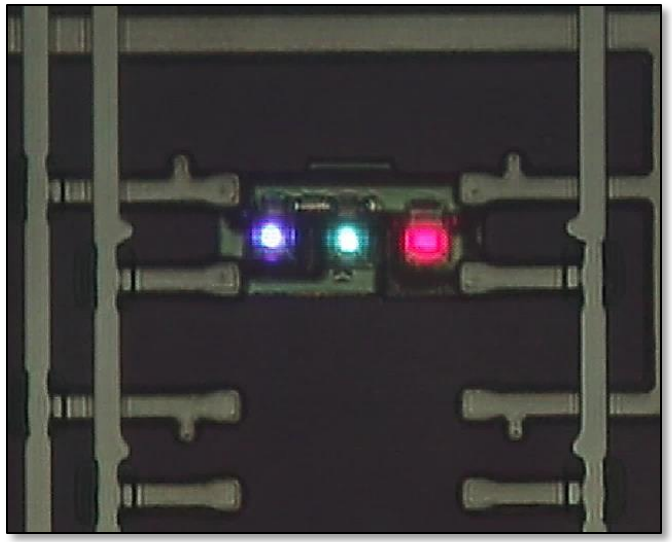
Pixel engines, interconnect at print & intermediate substrates



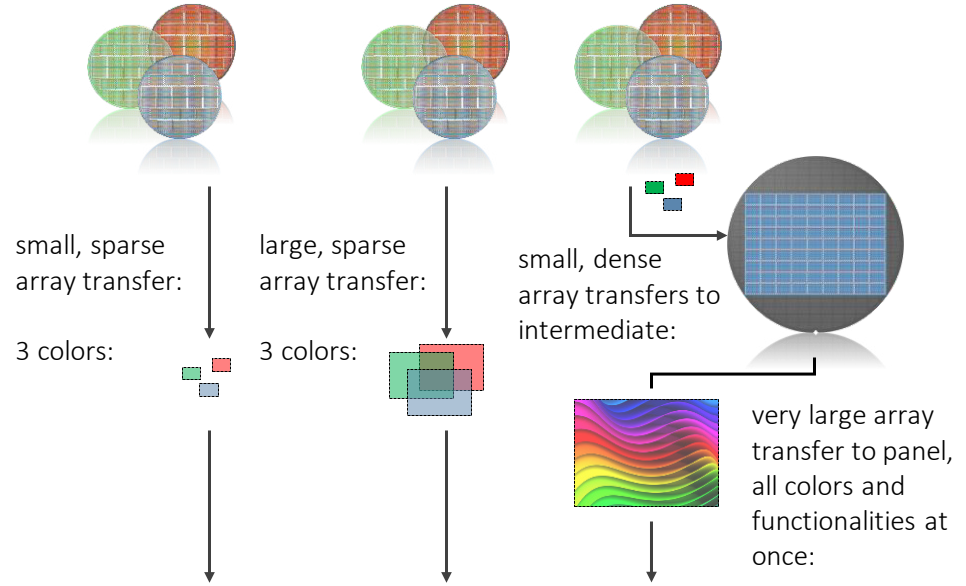
Mass transfer can be used to make "pixel engines" that contain all functional elements of the display pixel.

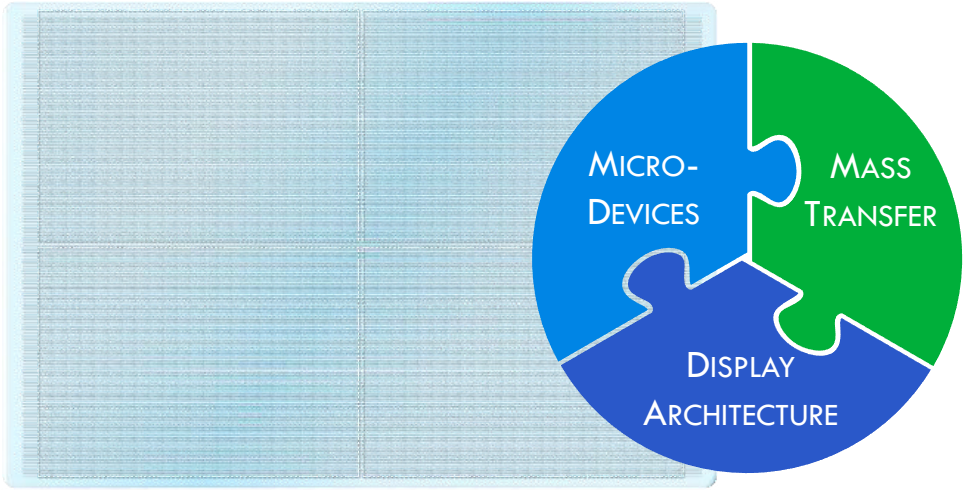
Sharp integrated conductors enable electrical interconnections to be formed during the assembly process.

This allows displays to be finished at assembly, and enables additive repair.



Pixel engines made on intermediate substrate can reduce number of required transfers to make displays.



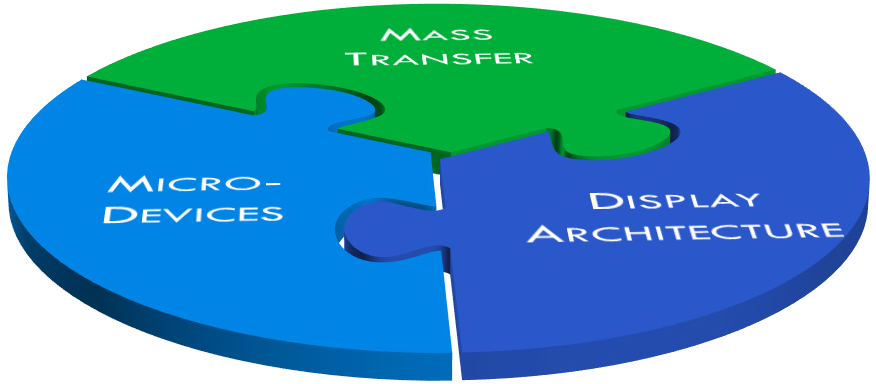


Major integration efforts, major progress for displays.

MicroLED display technology involves deep interdependencies between LEDs, display architecture, and mass-transfer.

With high-performance micro-devices and capable transfer processes, microLED will enable display performance beyond LCD and OLED.

Thank you from the X-Celeprint Team!



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