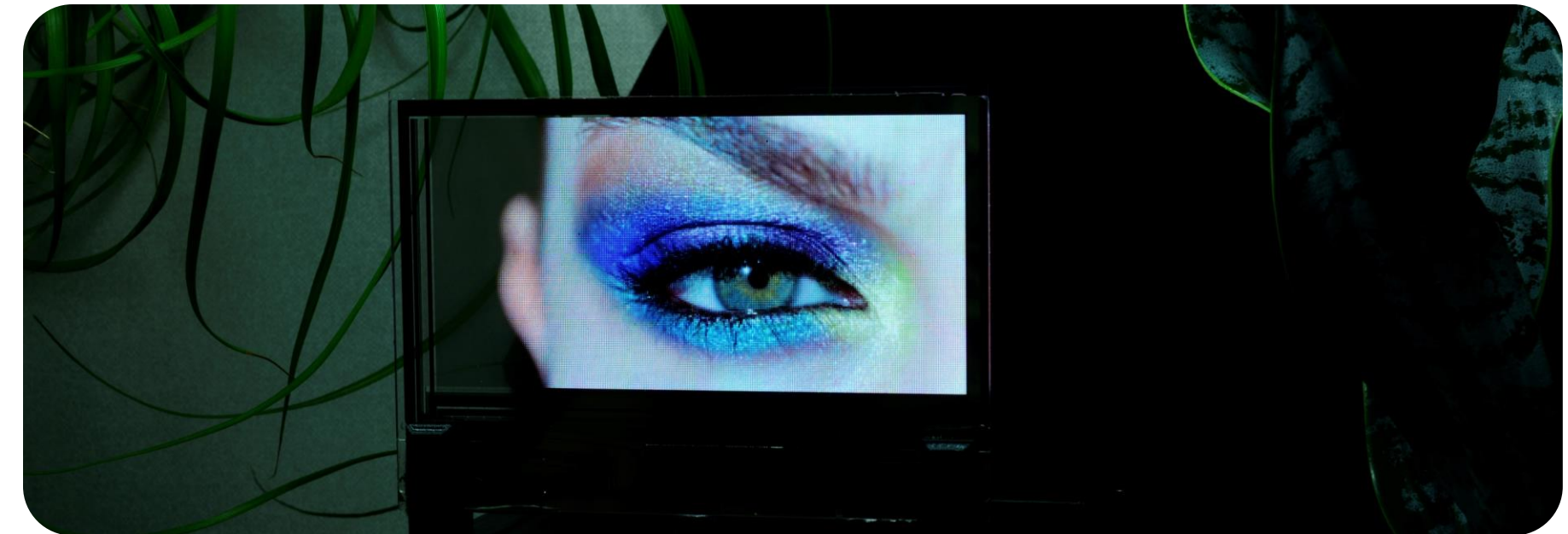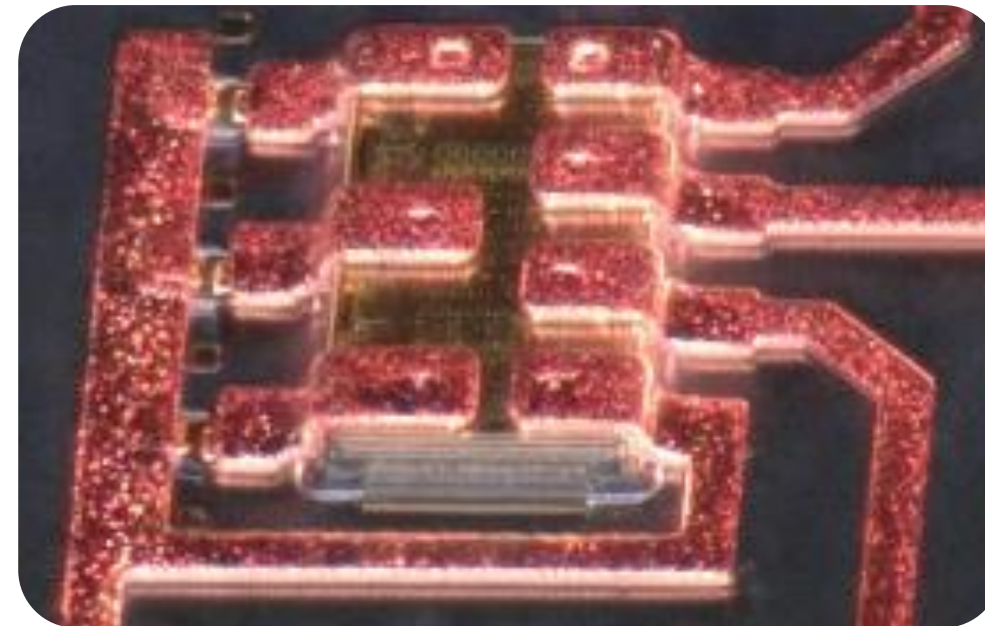# Emissive displays with transfer-printed microscale LEDs and ICs

Chris Bower

XDisplay Company (XDC)

info@xdisplay.com

The materials identify the display. The best displays will use the best materials.

Brightest, fastest, most efficient, extra-functional, multi-sensory, computational "systems on a panel".

Bridging the gap between wafer and panel is the way to get the best displays.
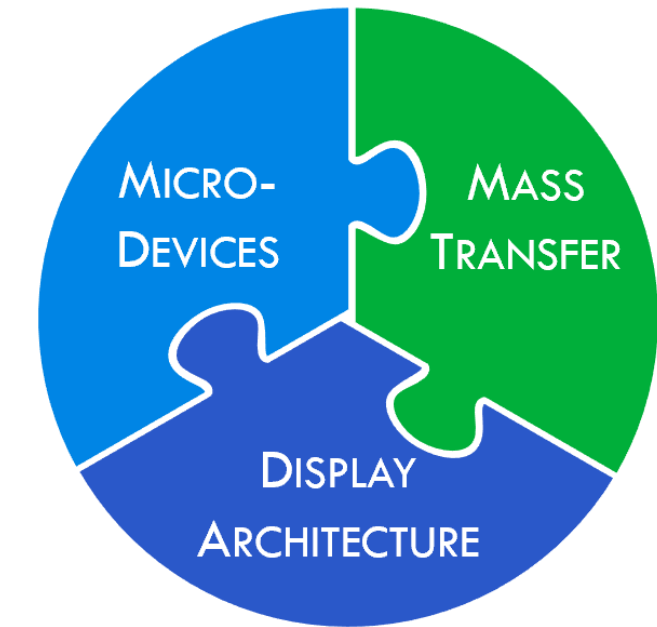
Wafer Fabricated Devices
Single-crystal Fine lithography
(ICs, LEDs, Lasers, etc...)
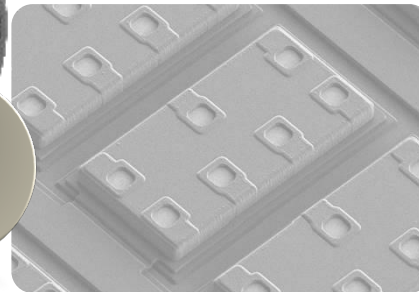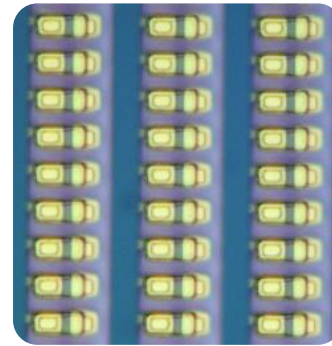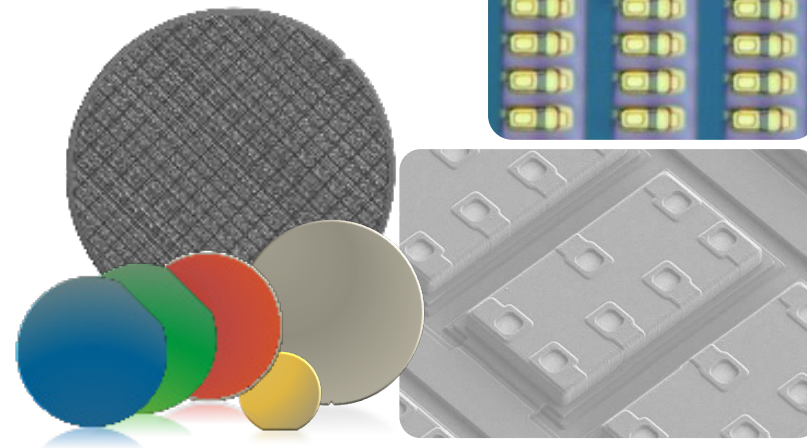
Rapid & precise mass-transfer
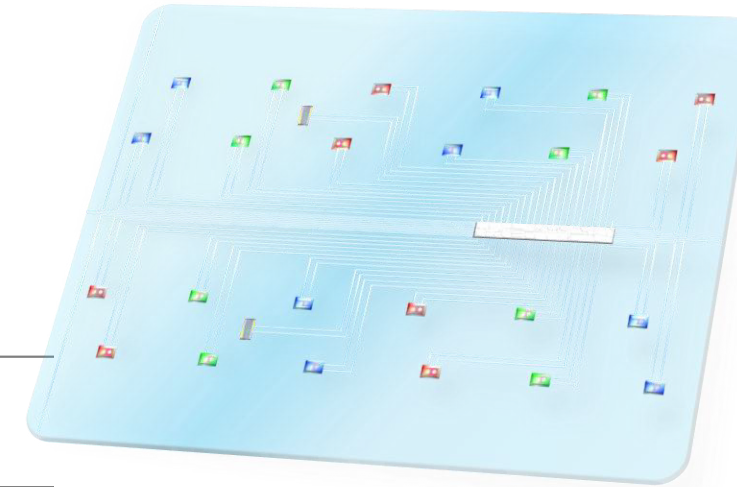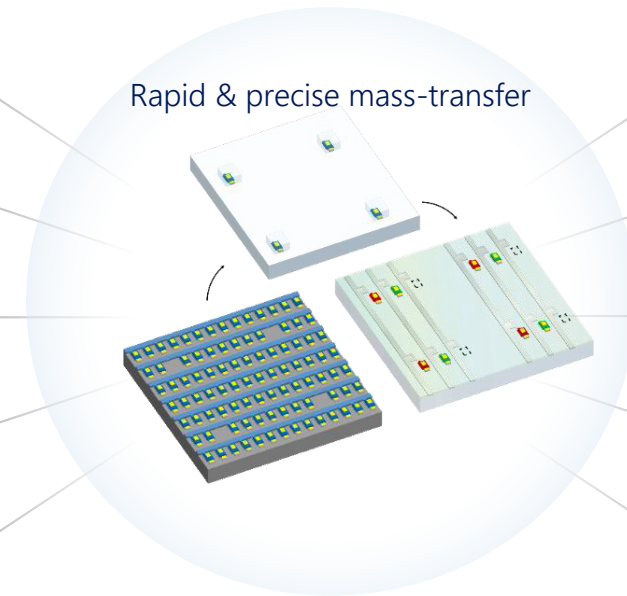
Advanced displays
of all sizes:

MICRO-DEVICES

MASS TRANSFER

DISPLAY ARCHITECTURE

MicroLED display solutions are highly-integrated with interdependencies between three elements of the technology: mass-transfer, micro-devices, and display architecture.
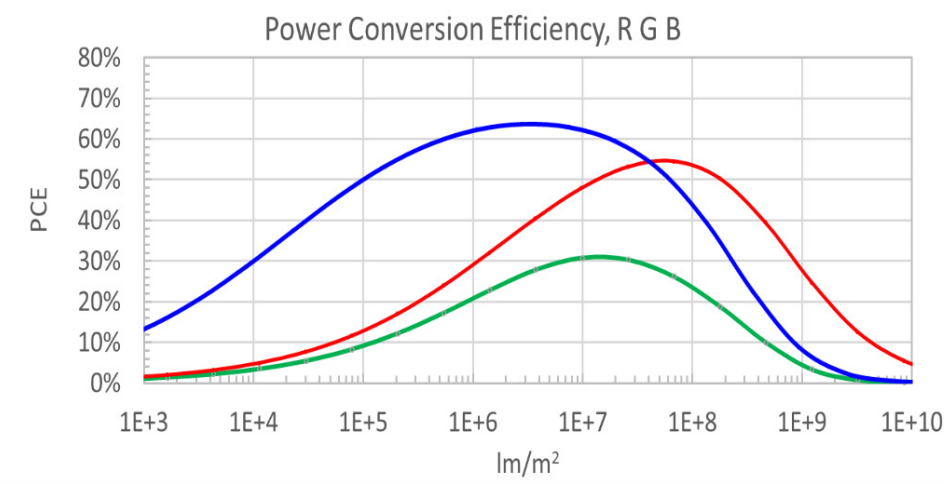
Representative behavior of modern LEDs, modeled.

Room to do more!

Power Conversion Efficiency, R G B (PCE vs A/cm²)
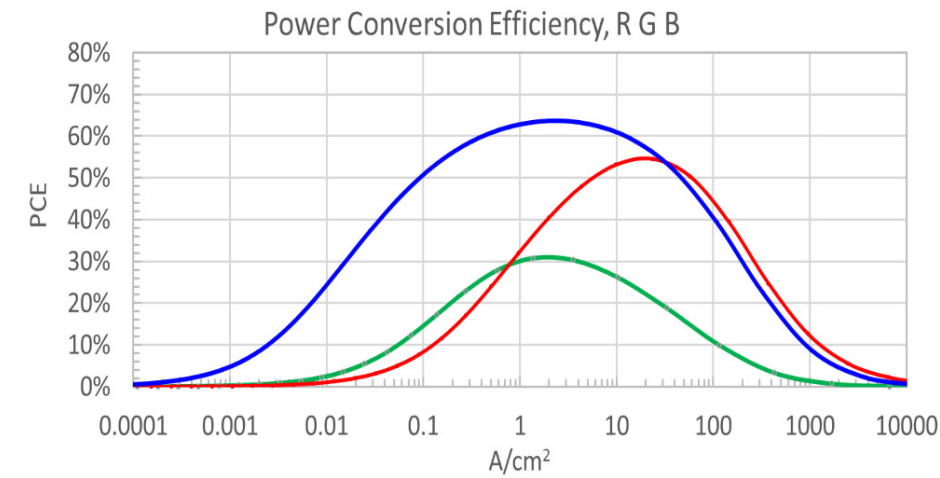
LEDs have highest PCE at current densities ~ 1 to 10 A/cm^2
- non-radiative recombination at low injection
- current crowding & droop at high injection
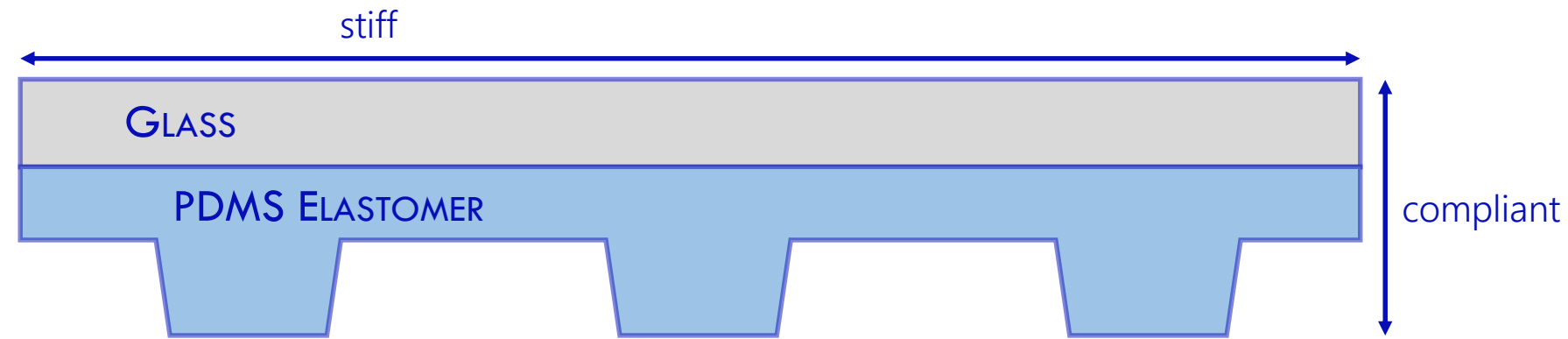

Power Conversion Efficiency, R G B (PCE vs lm/m²)

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.

THE FIRST WORLD CONFERENCE ON DISPLAY INDUSTRY

首届世界
显示产业大会

stiff

GLASS

PDMS ELASTOMER

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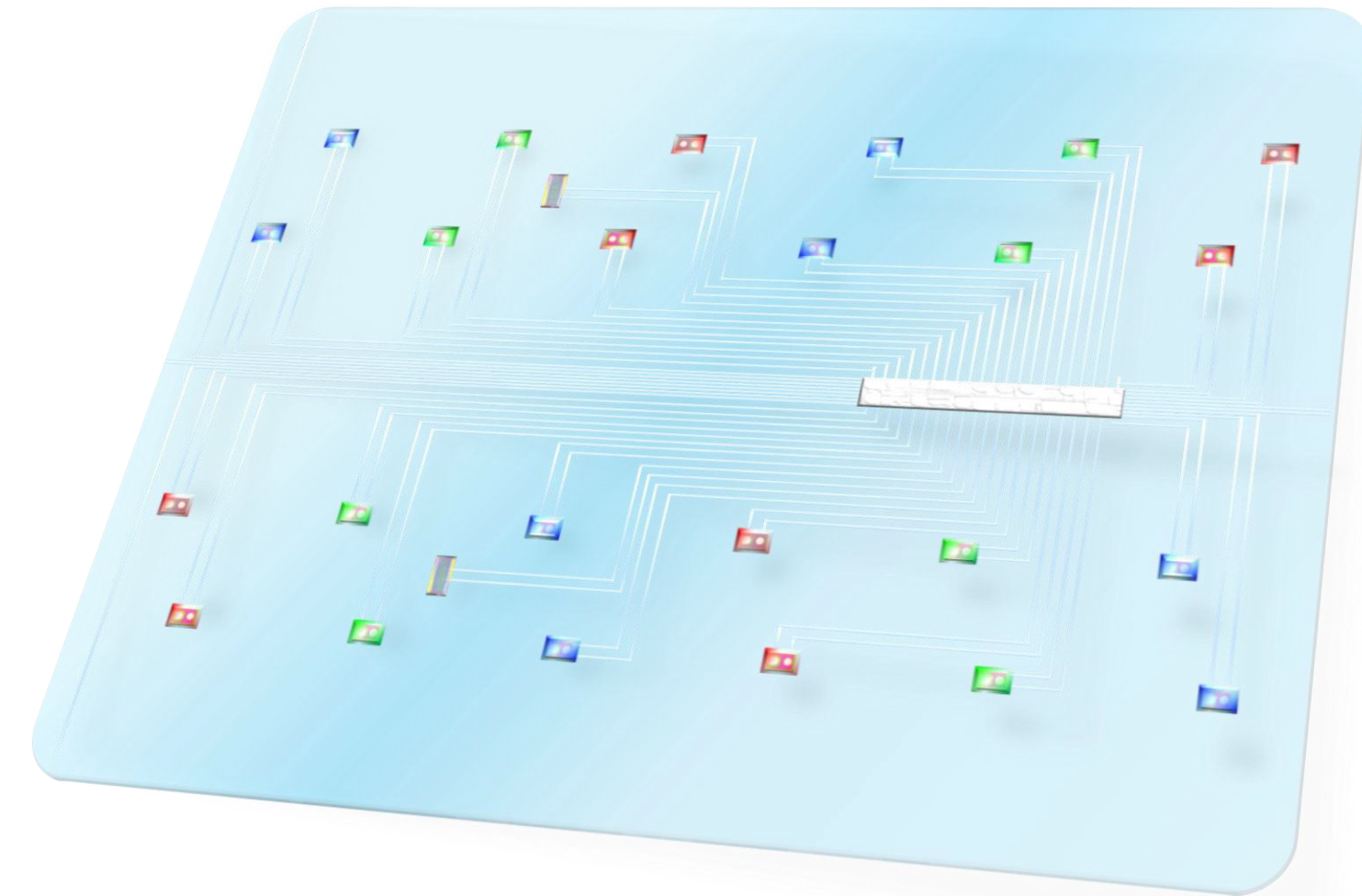
Elastomer stamp performs mass transfer by selectively retrieving an array of devices by van der Waals' adhesion and transferring the array to a display substrate (e.g. glass or plastic).

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
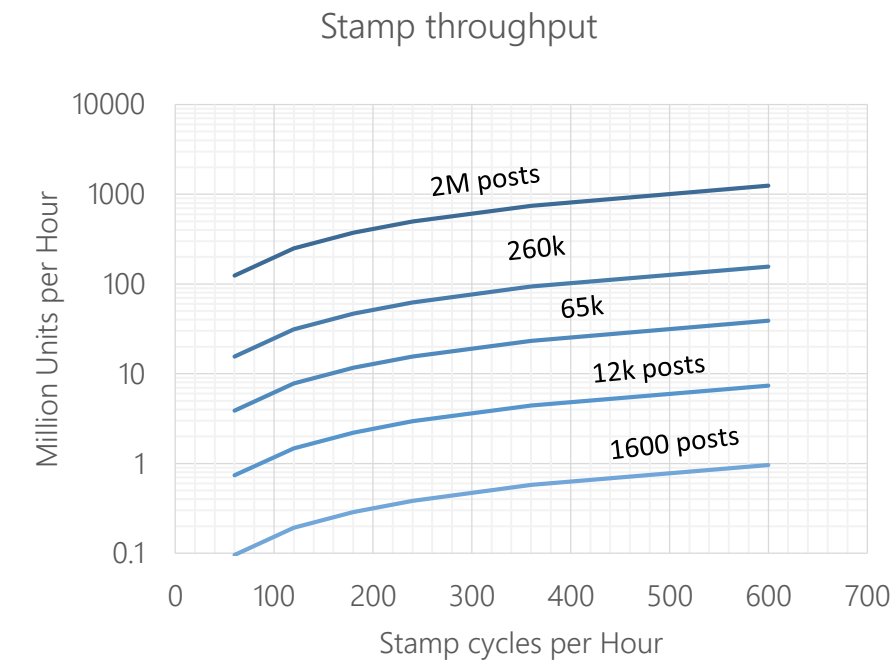• transparent
• low-cost
• mechanically tough

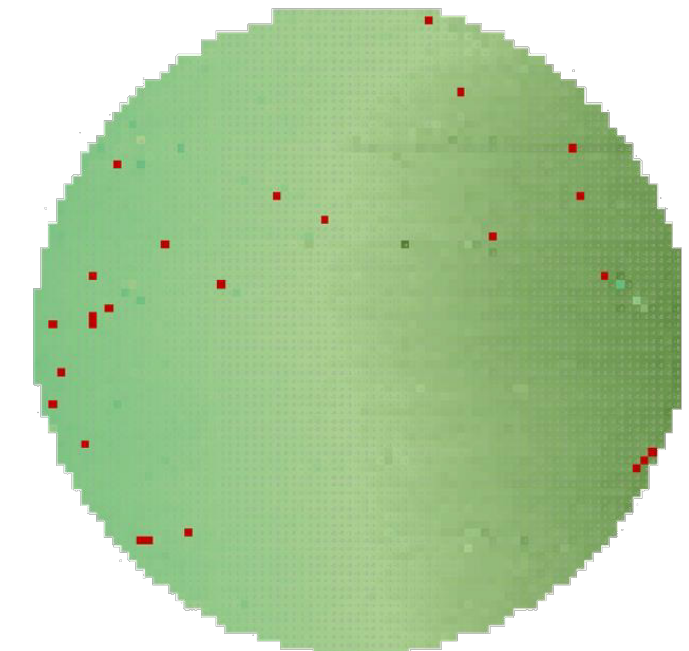Key enablers for yield and throughput

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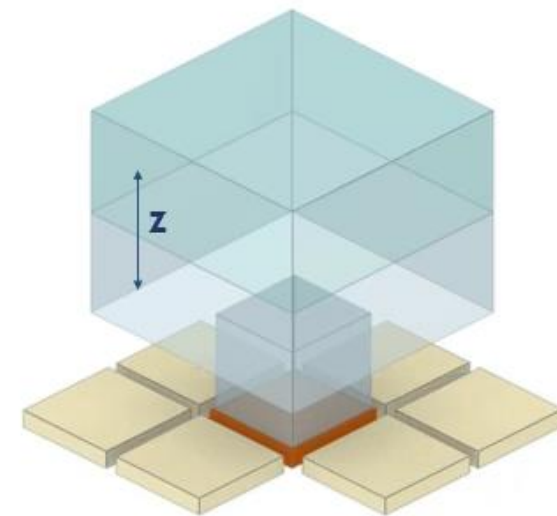
Conformability (z-direction compliance) and low-cost stamps enable scalability.

Scalability to large array enables high throughput.

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

Stamp throughput

Million Units per Hour

10000
1000
100
10
1
0.1

0   100   200   300   400   500   600   700

Stamp cycles per Hour

2M posts
260k
65k
12k posts
1600 posts

Yield map, 150 mm wafer array transfer:

> 82,000 sites; 99.94%
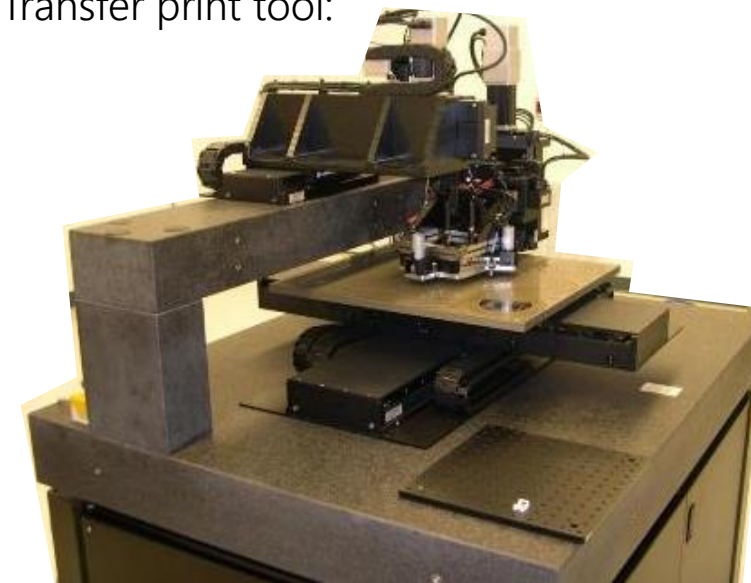
Looking through the stamp:
Retrieve ICs with stamp, print to display, loop video.

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.
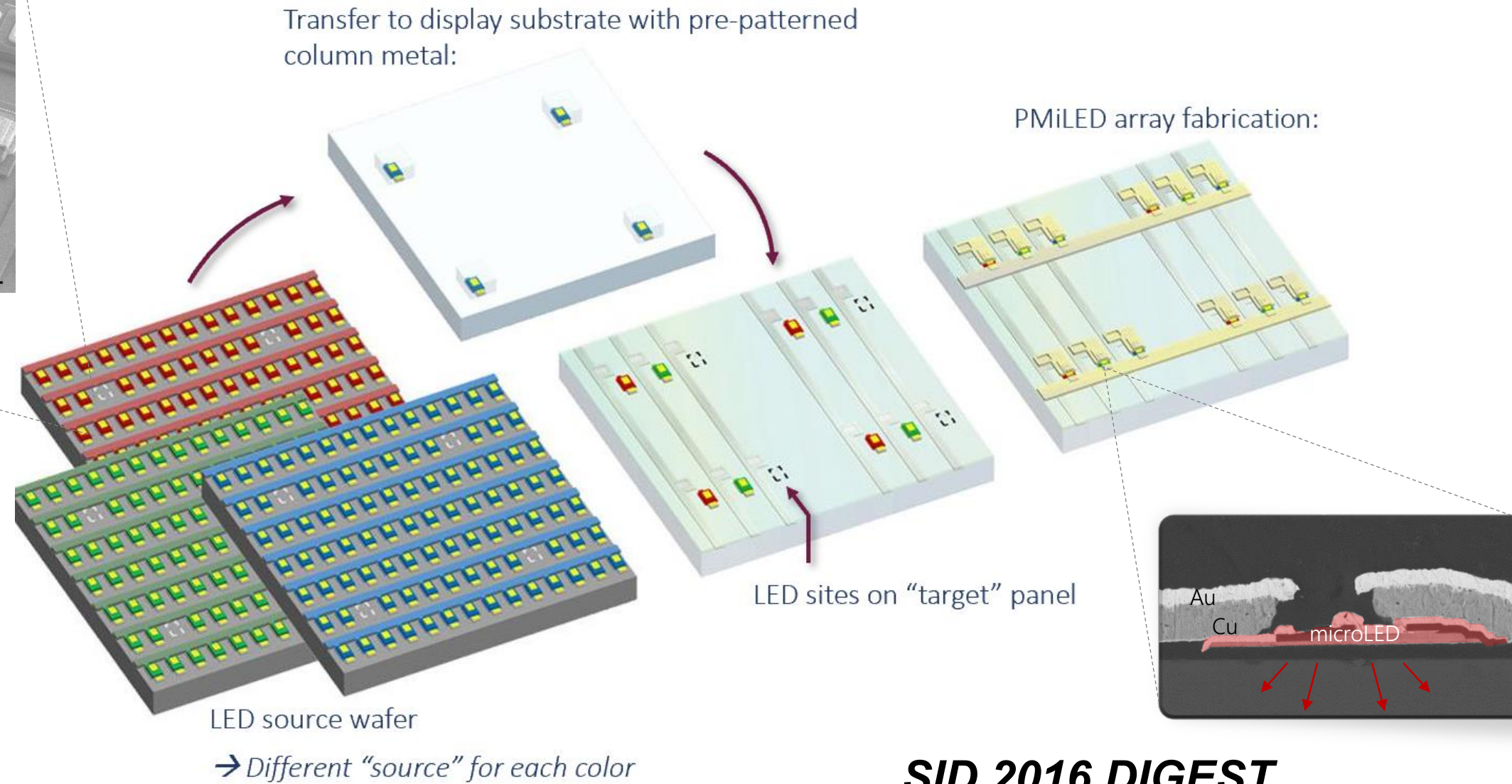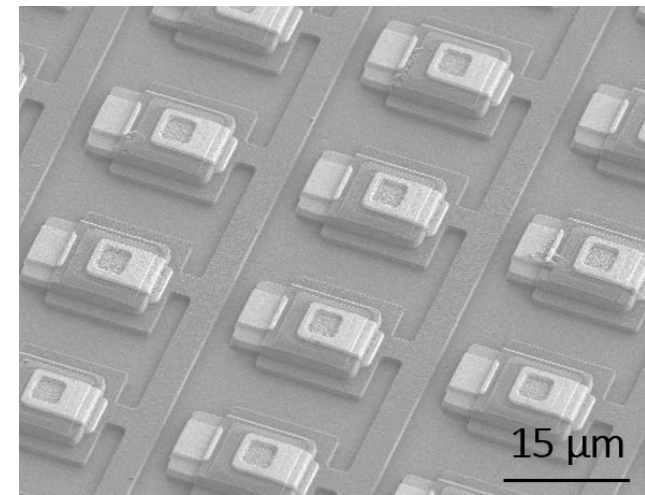
Transfer forces act only for a few seconds of the cycle (very fast).
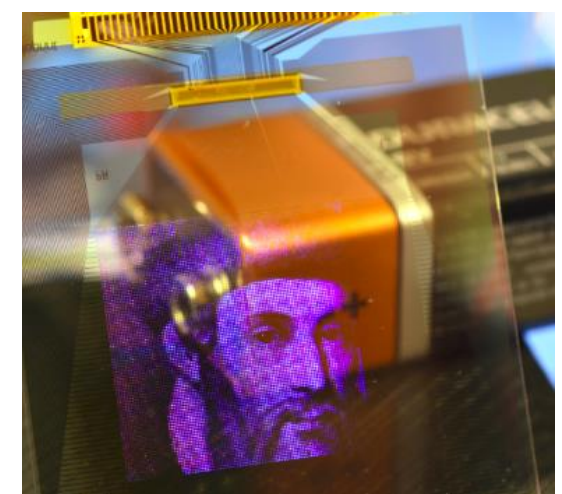
Fully automated transfer-printer

100RGB x 100; 127 PPI

1 cm

Transfer to display substrate with pre-patterned column metal:

PMiLED array fabrication:

LED sites on "target" panel

Au
Cu
microLED

LED source wafer

→ Different "source" for each color

SID 2016 DIGEST

plastic display

70% transparency

15 µm

traces + insulator on panel substrate

print iLEDs

print μ-ICs

interconnect, operate

Au
Cu
microIC

Stamp:

Transfer to display substrate with pre-patterned column metal and LED Array:

μ-IC sites on "target" panel
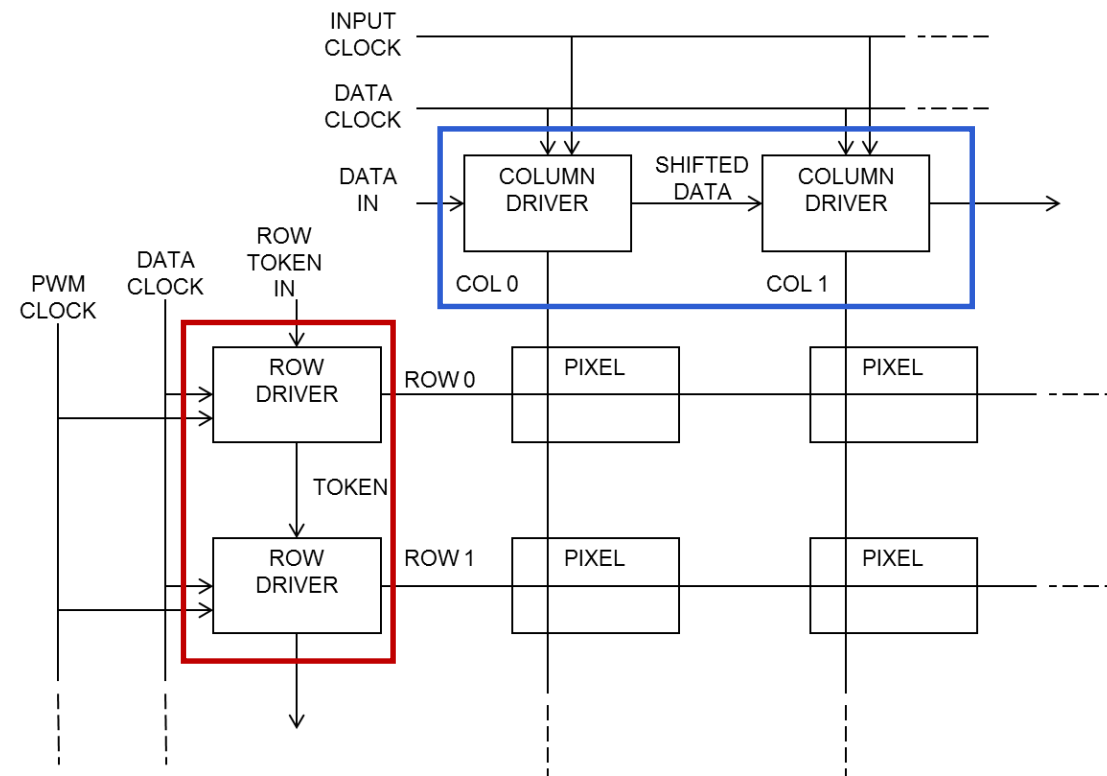
μ-IC "source" wafer
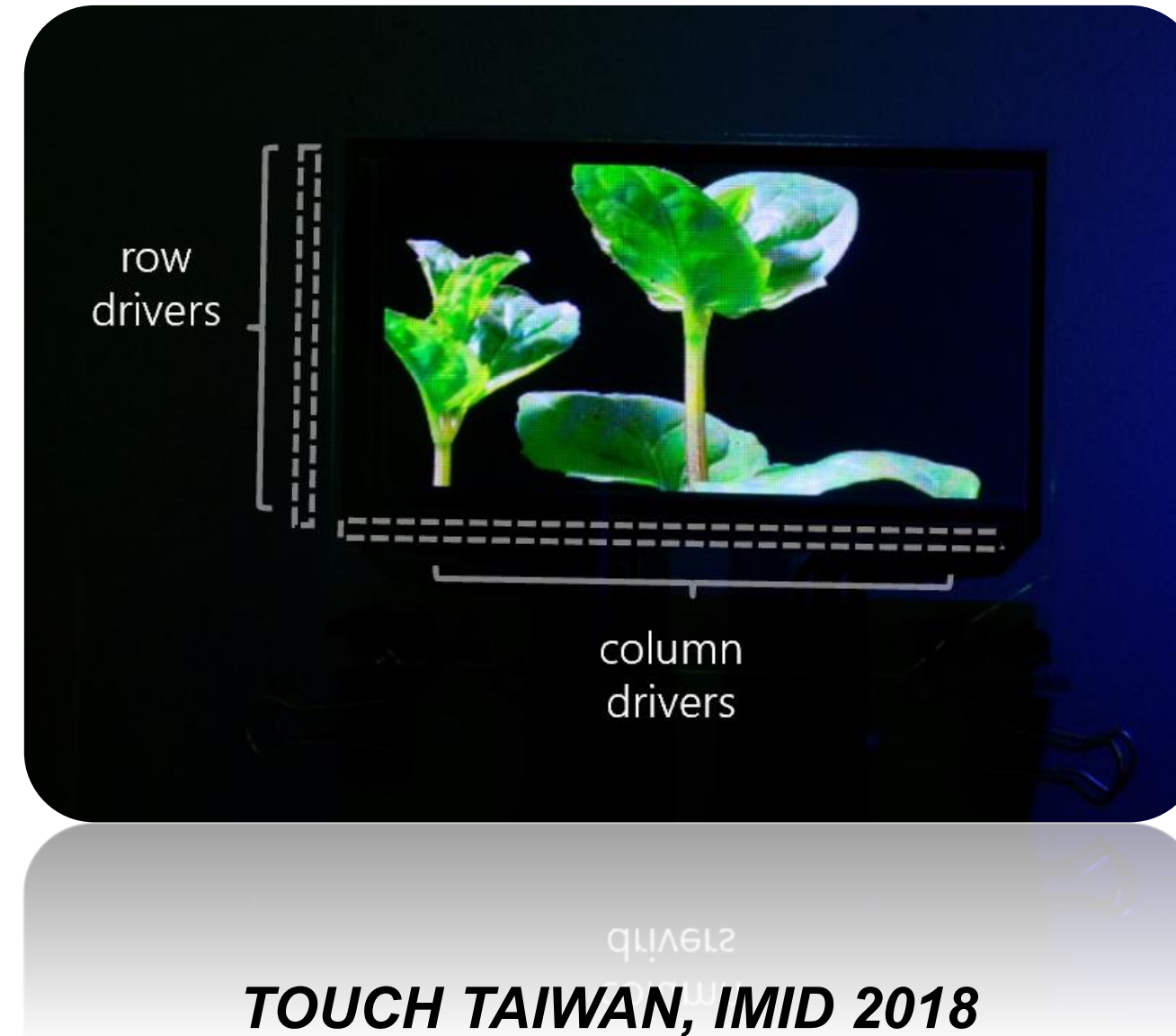
1 cm

SID 2017 DIGEST

AMiLED

Rec. 2020
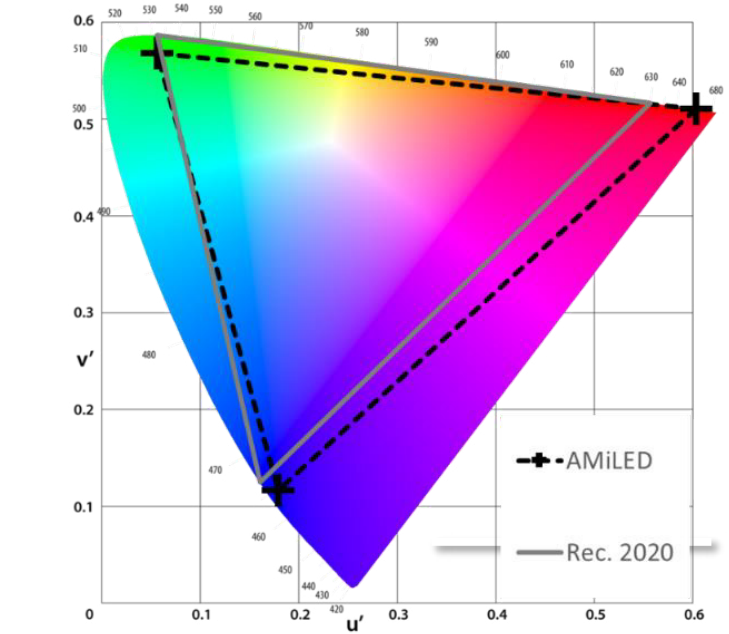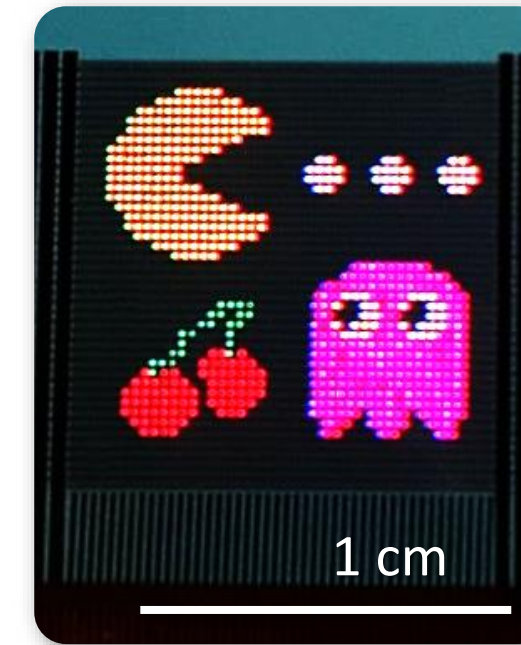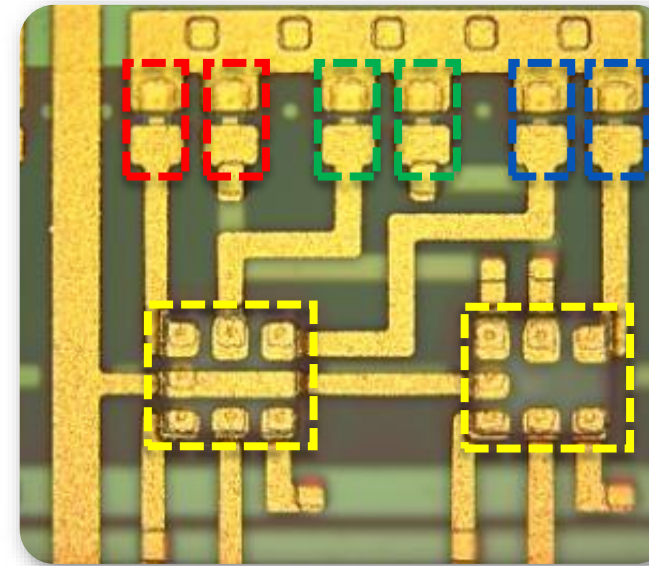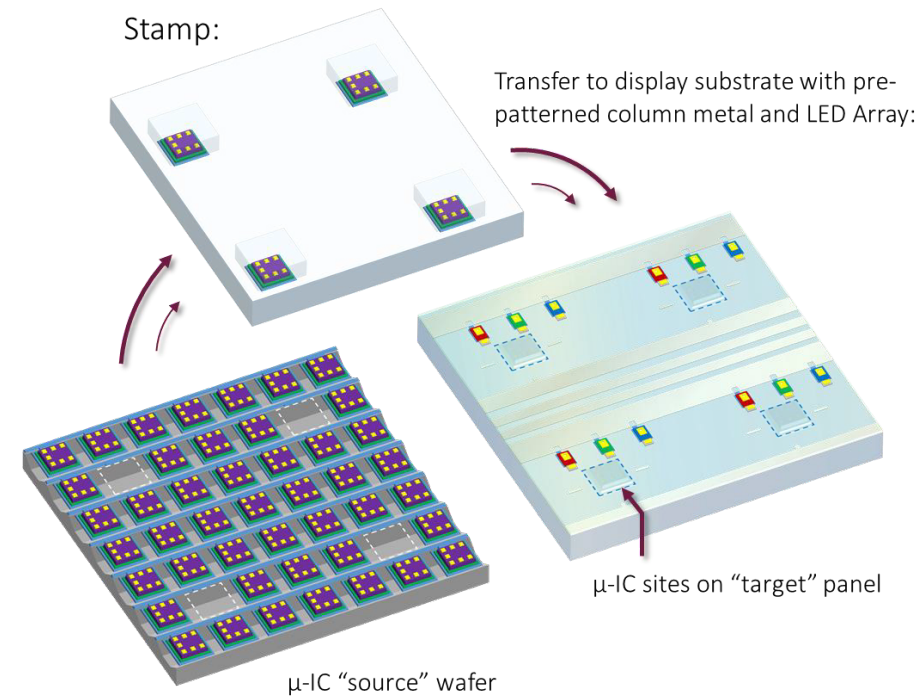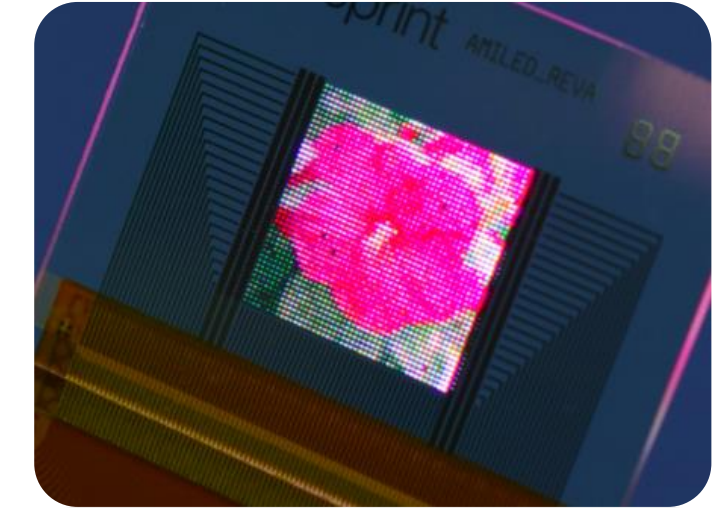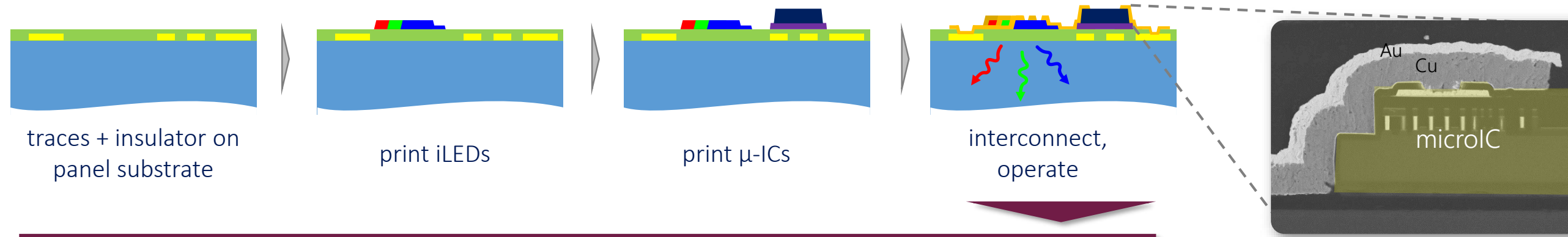
Print row drivers and column drivers to reduce external I/O count:

- Column drivers demultiplex data
- Row drivers run progressive scan of data load and PWM

5.1" Diagonal AMILED display 320 x 160, 70 ppi:

row drivers

column drivers
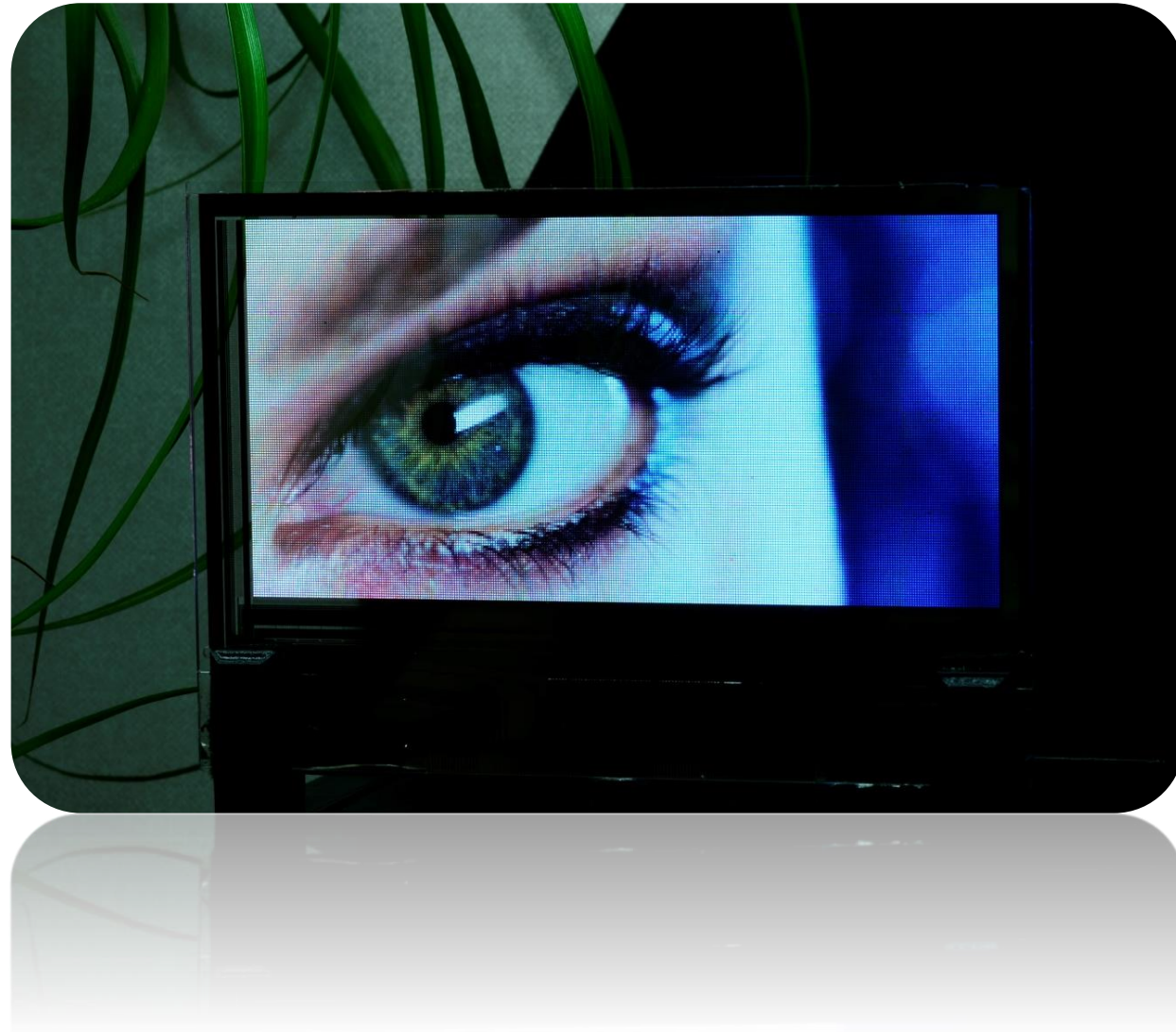
TOUCH TAIWAN, IMID 2018

Print microICs and microLEDs to make active matrix display

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

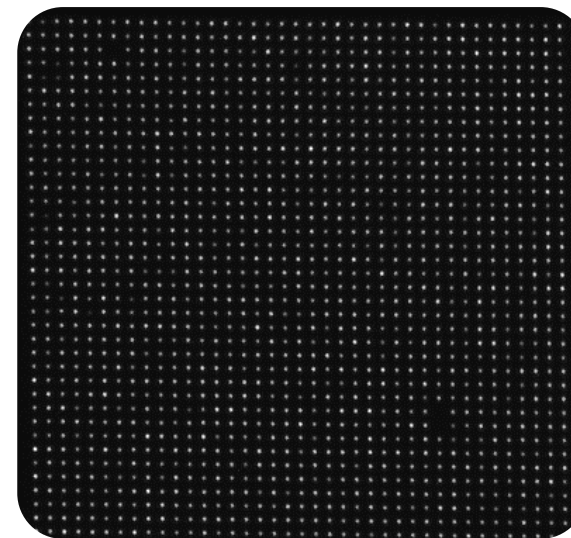Row, column, power, and ground into each pixel:
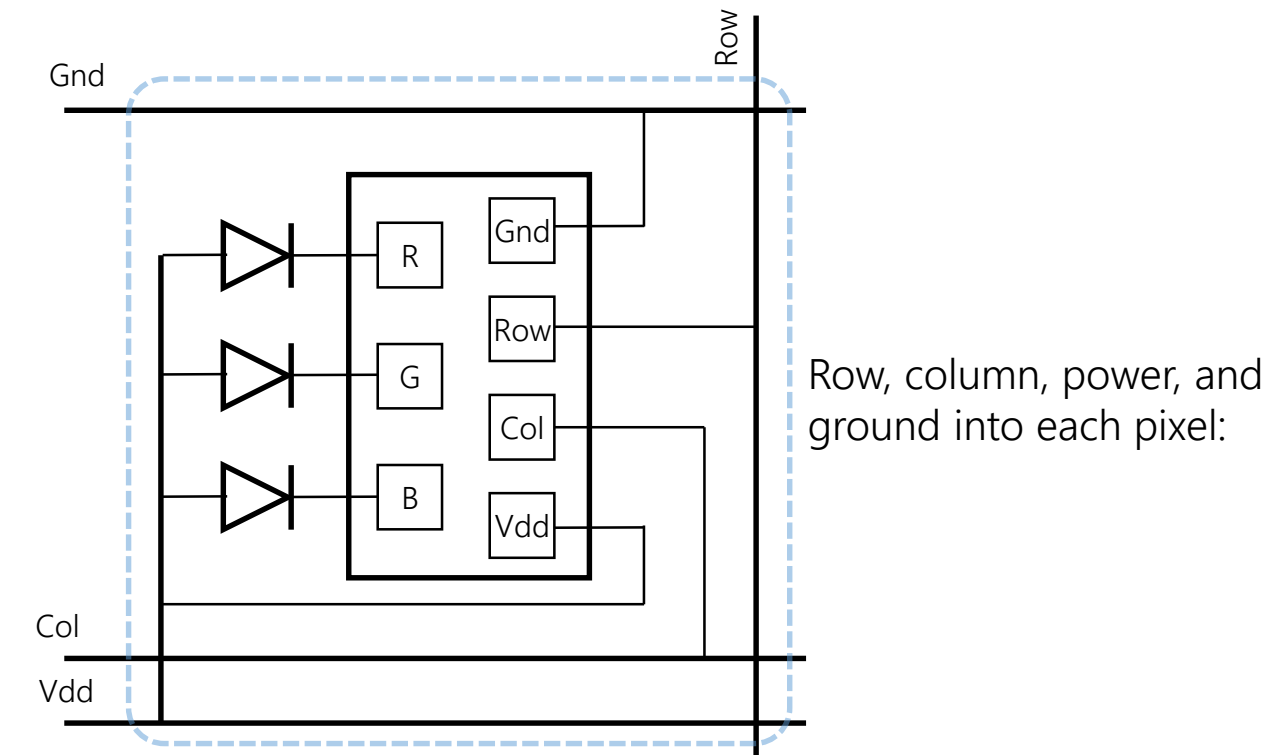
Video data stream runs through off-panel memory multiplier table with unique factor for every pixel.
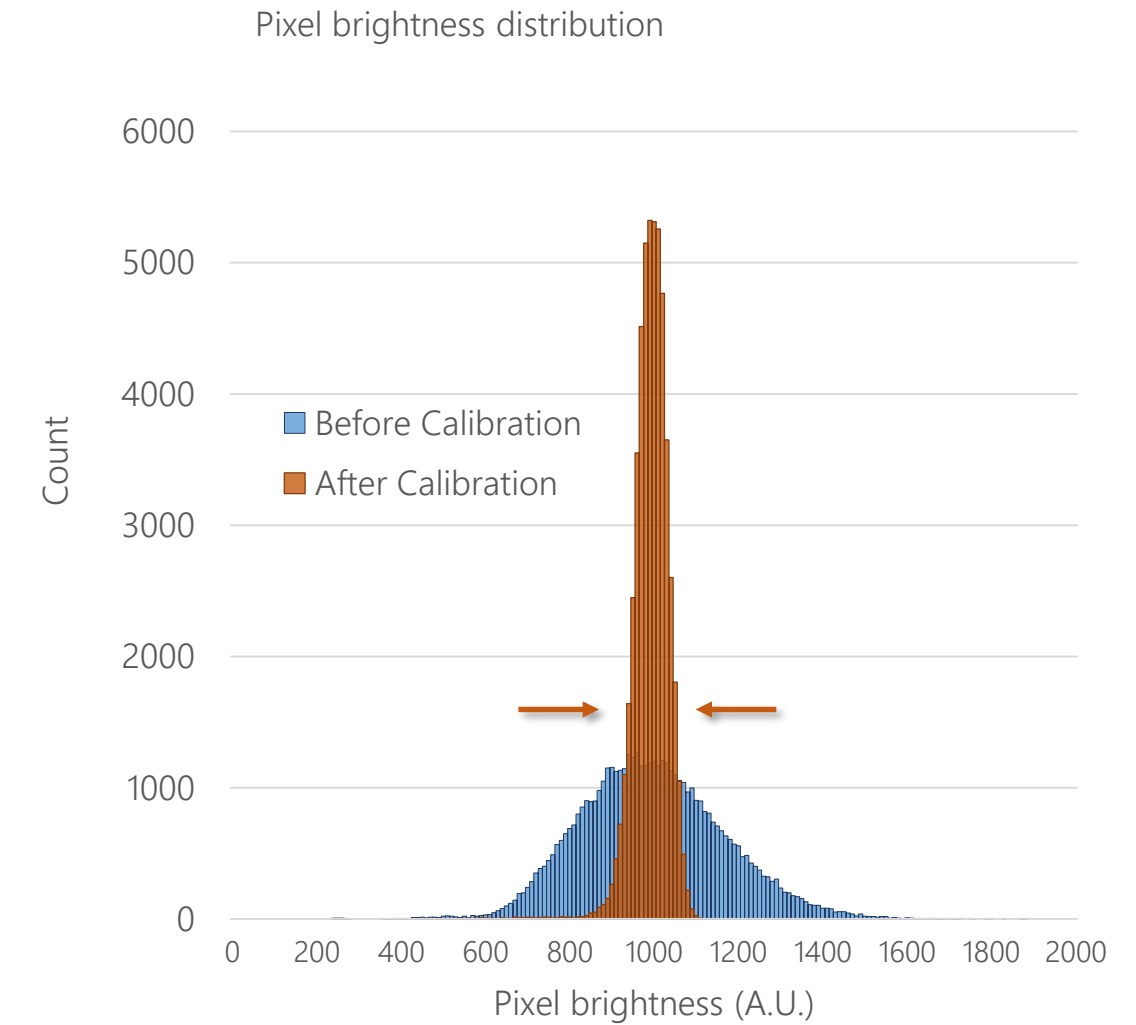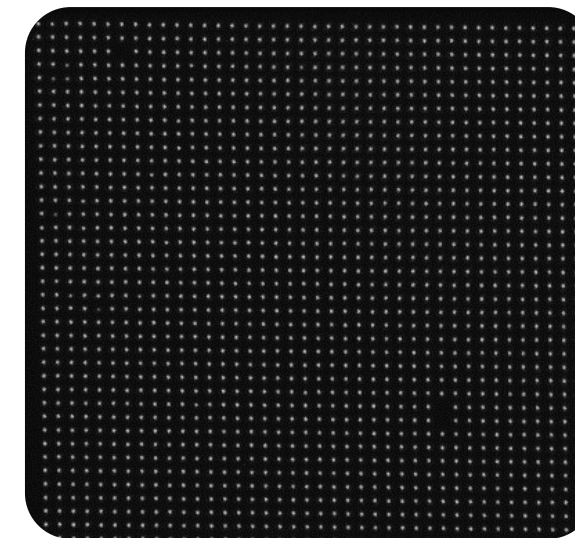
Measure brightness of every pixel, calculate calibration factor table, and re-measure.

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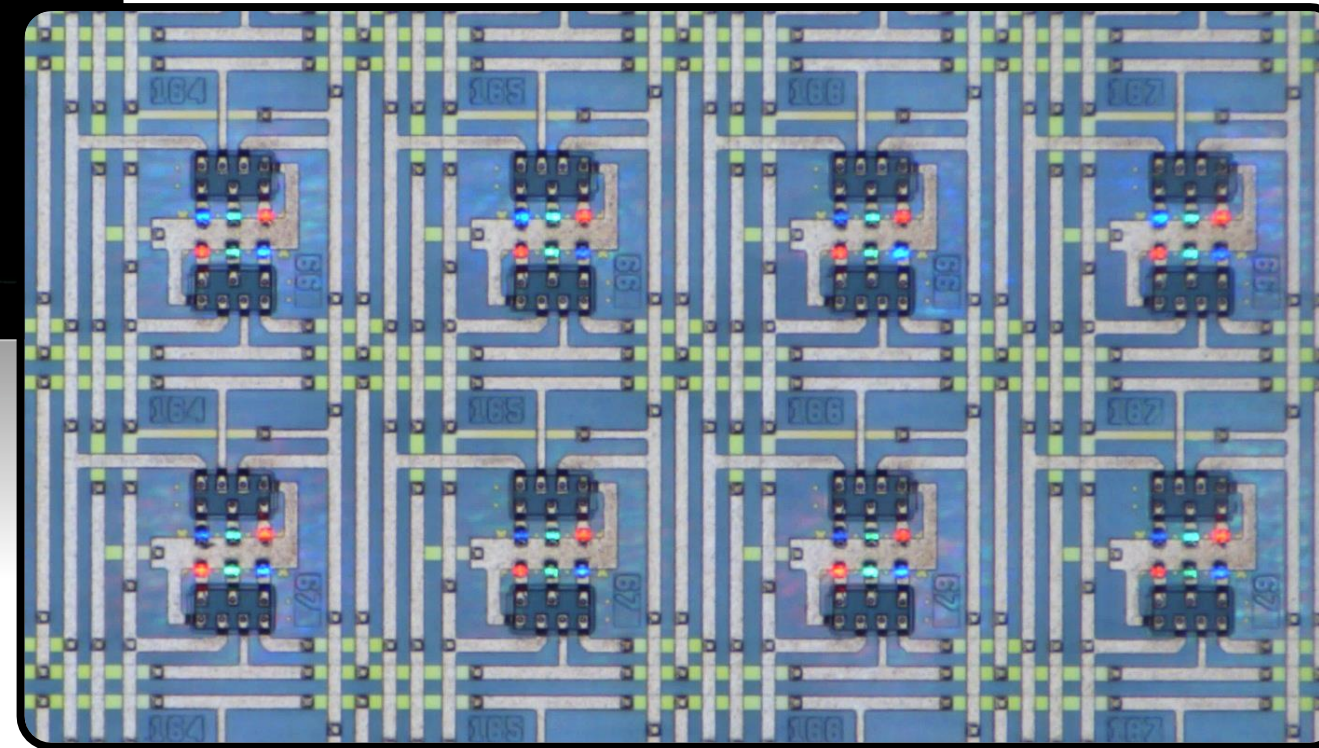
Before calibration

After calibration

Pixel brightness distribution

Count

Pixel brightness (A.U.)

■ Before Calibration
■ After Calibration

320 x 160 sub-pixels

Implementation of redundancy in microICs, microLEDs, row & column lines.

Remaining yield impactors:
- Forward voltage of LEDs
- Metallization defects (laser cut)
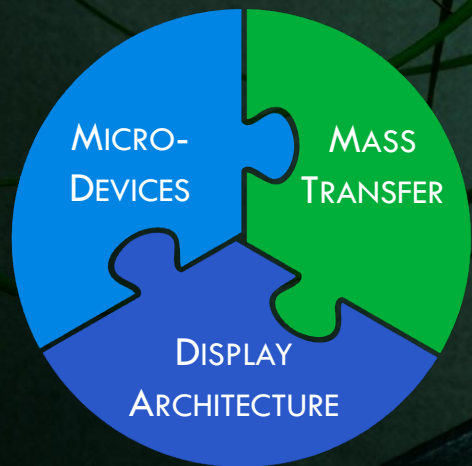- Transfer (typ. < 3 sub-pixels)

RED, 0 dark subpixels
100% yield

GREEN , 2 dark subpixels
99.996% yield

BLUE , 1 dark subpixels
99.998% yield

MICRO-DEVICES

MASS TRANSFER

DISPLAY ARCHITECTURE

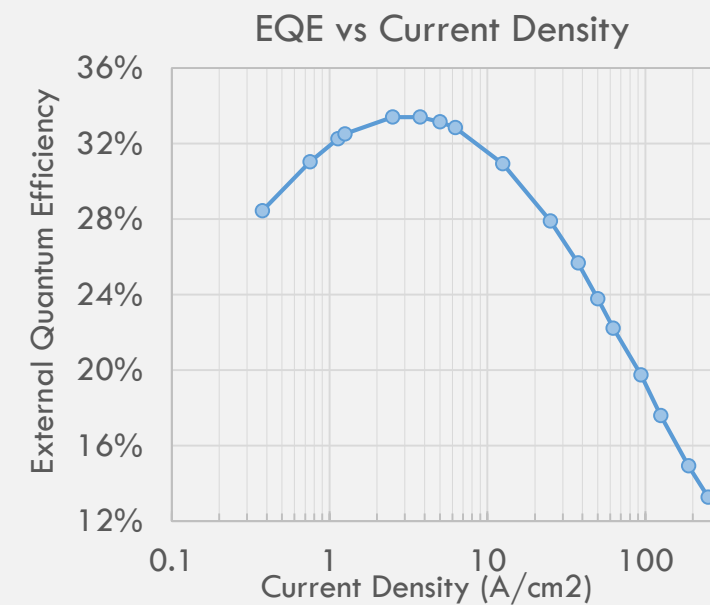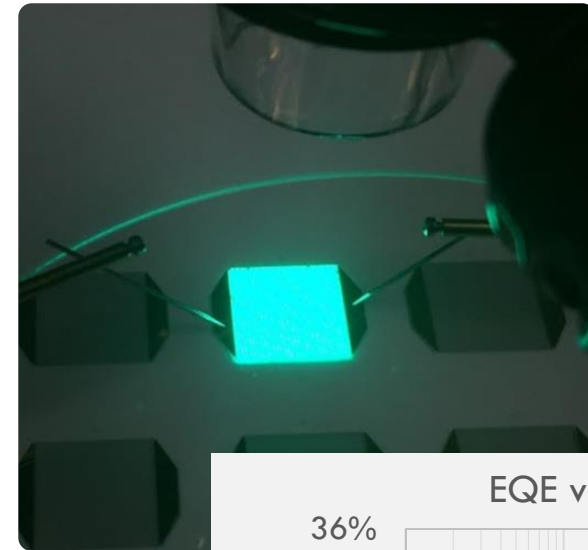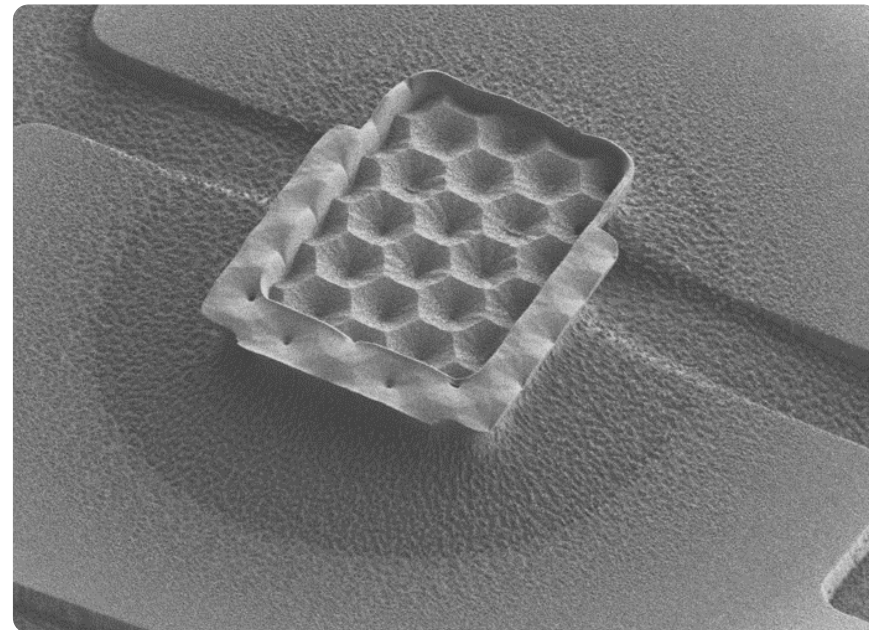14 bit PWM, 2 bit current select
60 frames per second
> 3,000 nits

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

1600 devices interconnected in parallel, 8 x 8 μm^2 p-n junction area on each.

Measure EQE in integrating sphere.

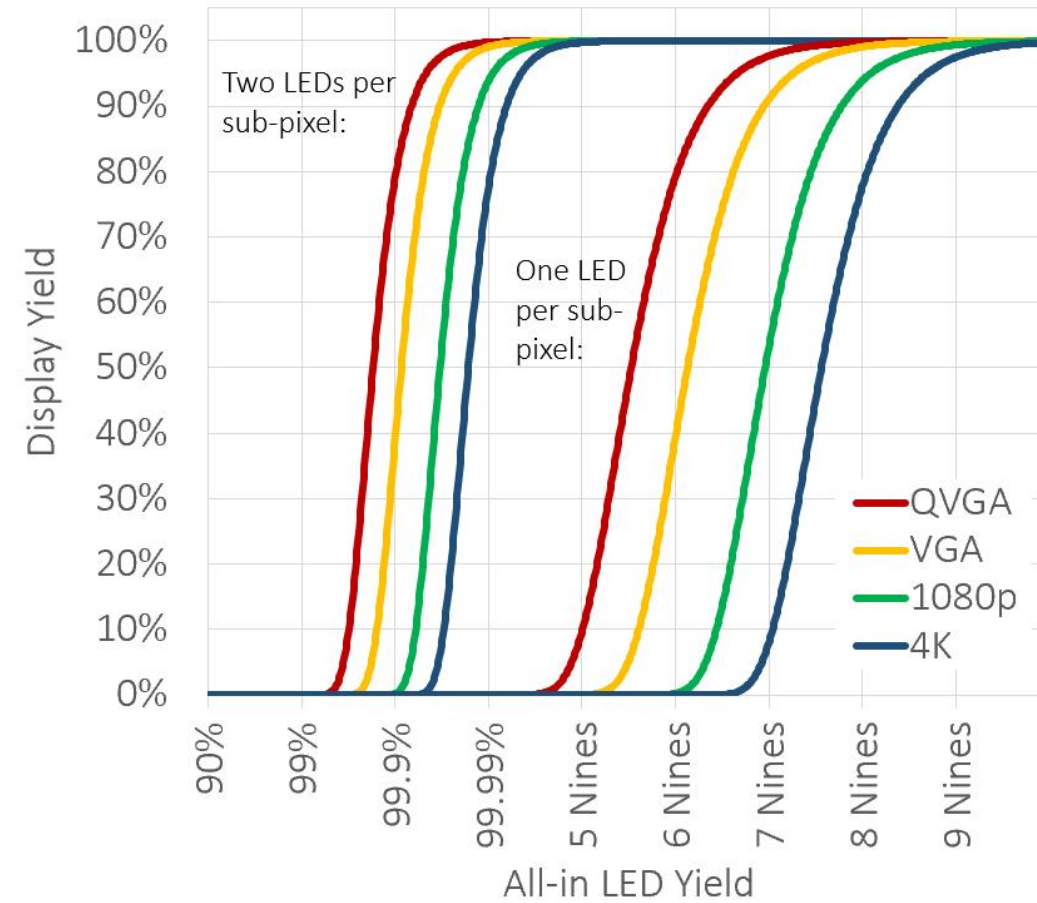33.4% peak EQE at 2 A/cm^2. >28% at 0.3 A/cm^2.

EQE vs Current Density

Monochrome Green 5.1" 70ppi display; > 30,000 nits

Display test and additive repair

Perfect Display Yield versus LED Yield

Two LEDs per sub-pixel:

One LED per sub-pixel:

QVGA
VGA
1080p
4K

Display Yield (y-axis): 0% – 100%

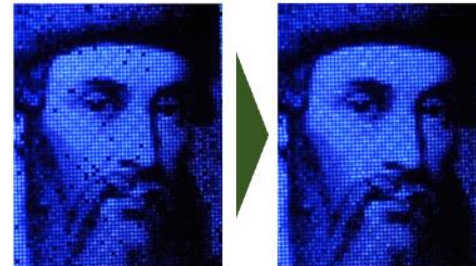All-in LED Yield (x-axis): 90%, 99%, 99.9%, 99.99%, 5 Nines, 6 Nines, 7 Nines, 8 Nines, 9 Nines

Avenues:
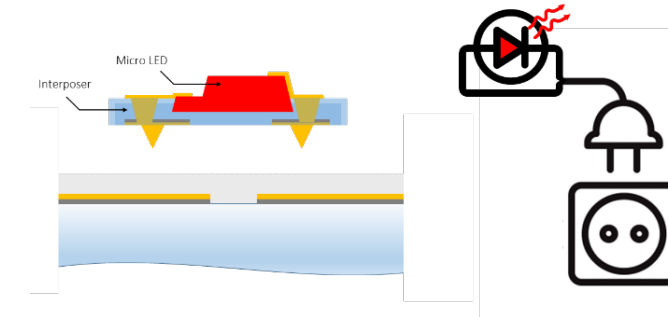
1. Excellent first-pass yield
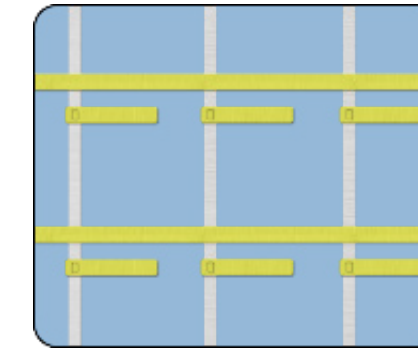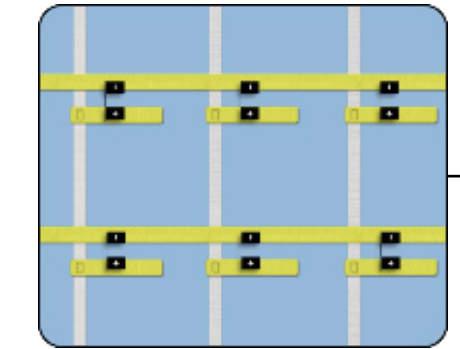
2. Physical Repair
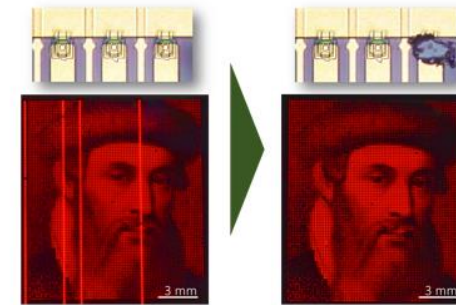
3. Redundancy

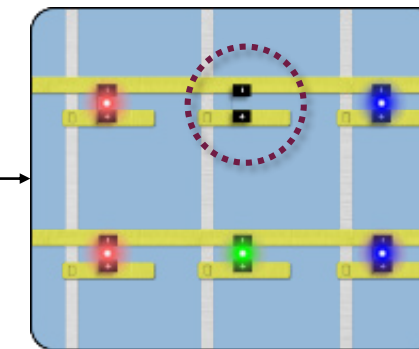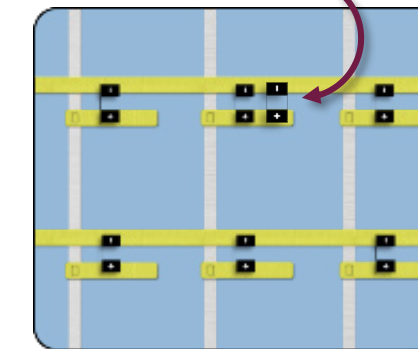printable components with interconnection structures

target substrate

populate target

Operate display; identify defects

repair by print

repaired system

Interconnect-at-print with spikes

As Printed

After Reflow

After Hard Cure and Removal of Polymer in Field

Applied Physics Letters 108.20 (2016): 203503.

Metal

Target

140°C

Metal

Target

175°C; O$_2$ Plasma

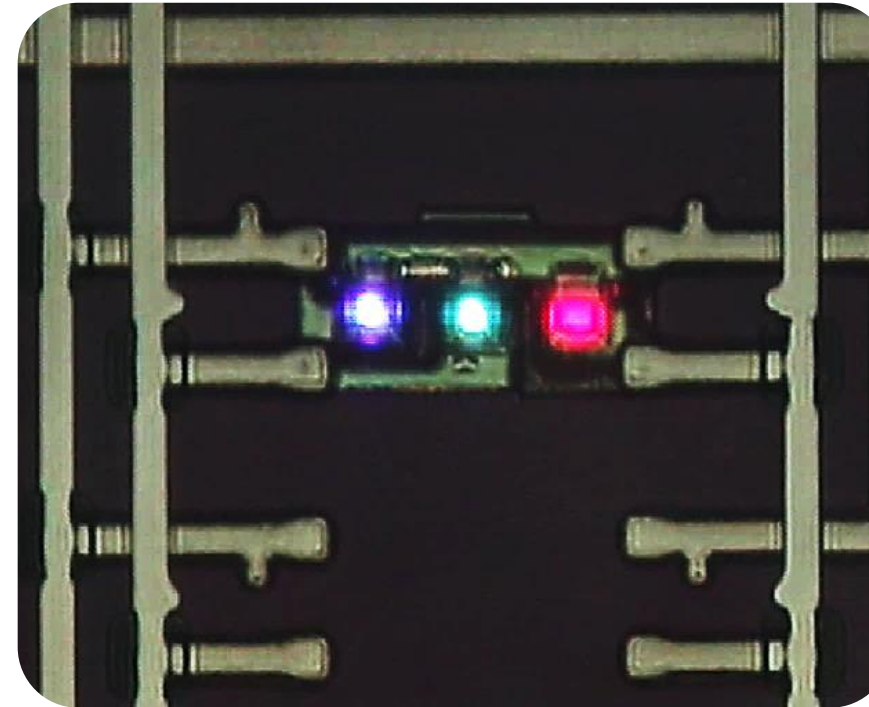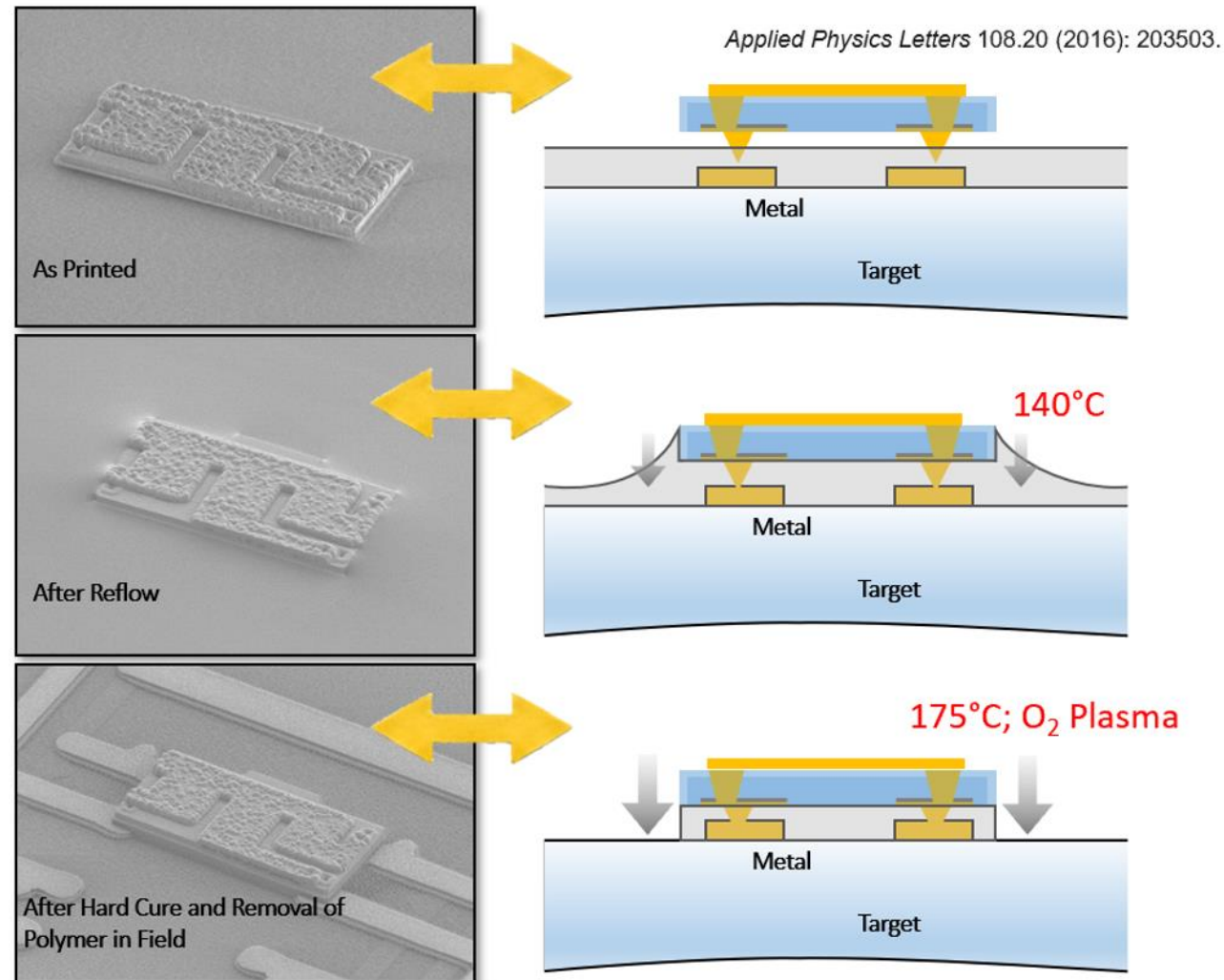Metal

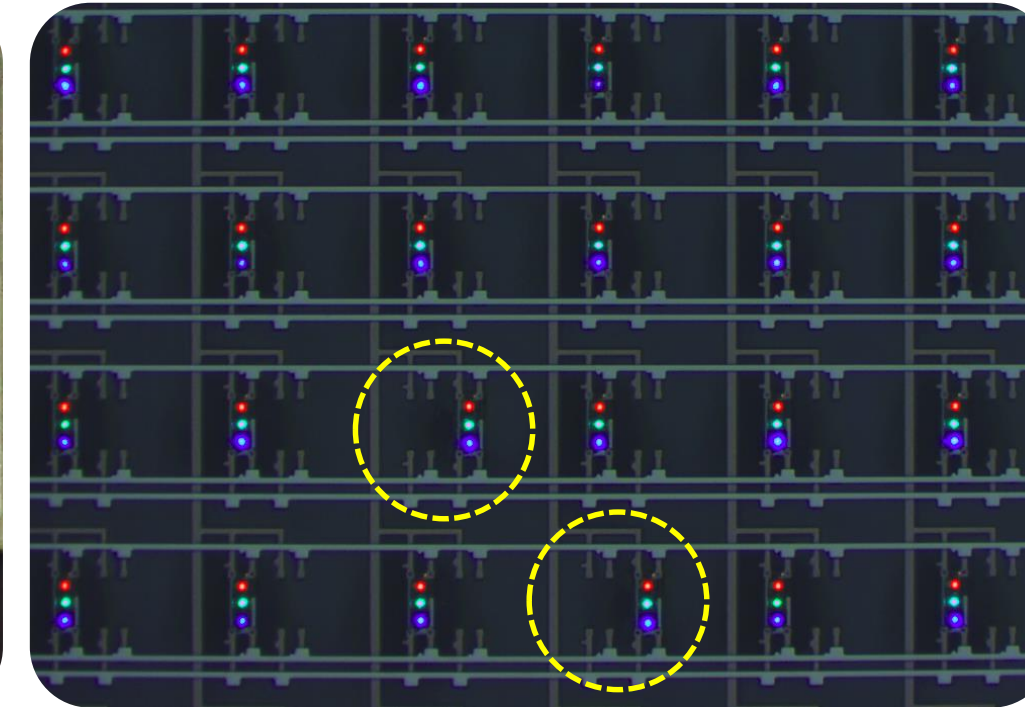Target

Looking through substrate, see "divots" produced by spikes contacting metal at four corners of interposer.

Note repaired pixel on 2nd row from bottom, 3rd column from left: engine printed in redundant site by single-post stamp.
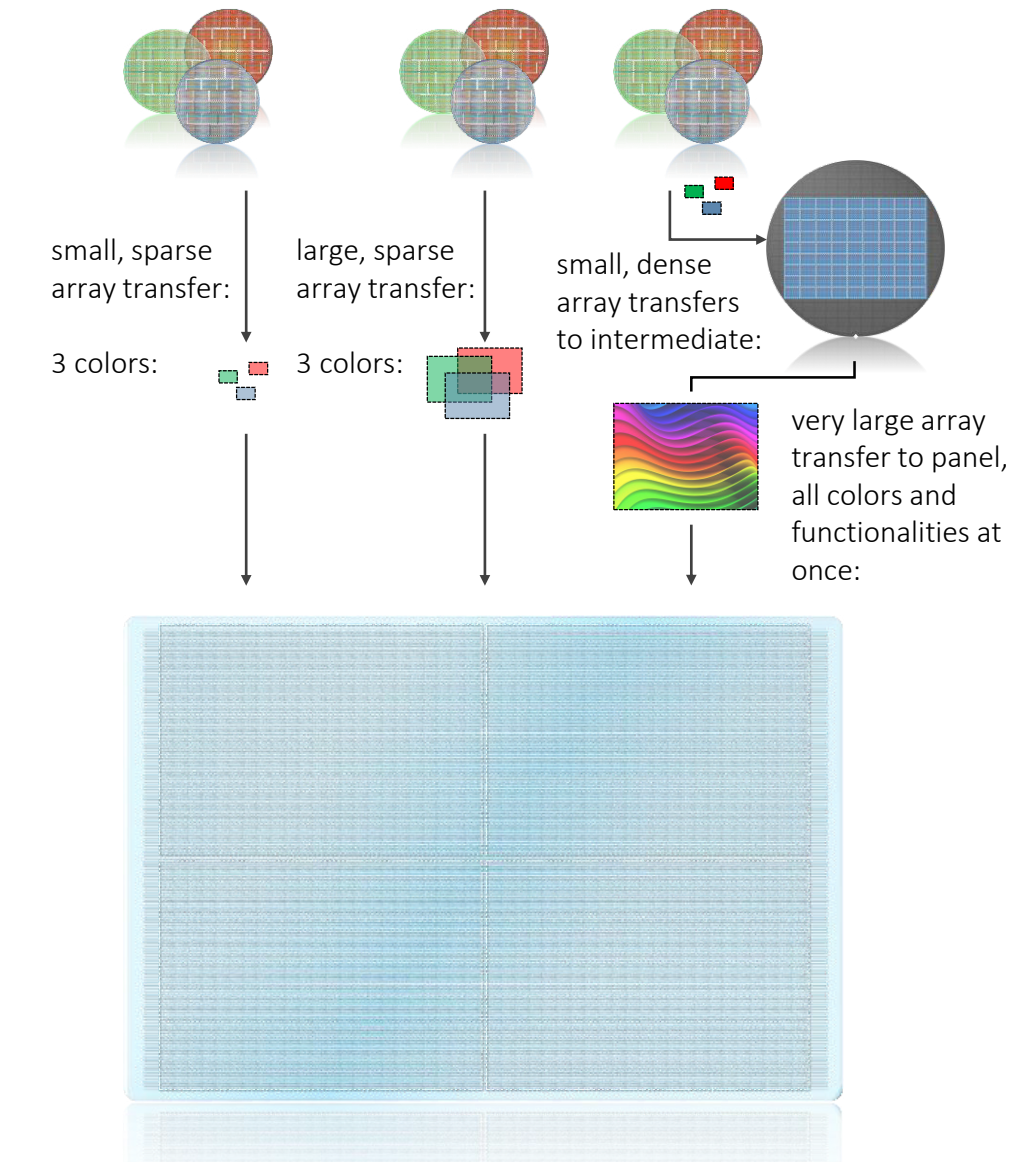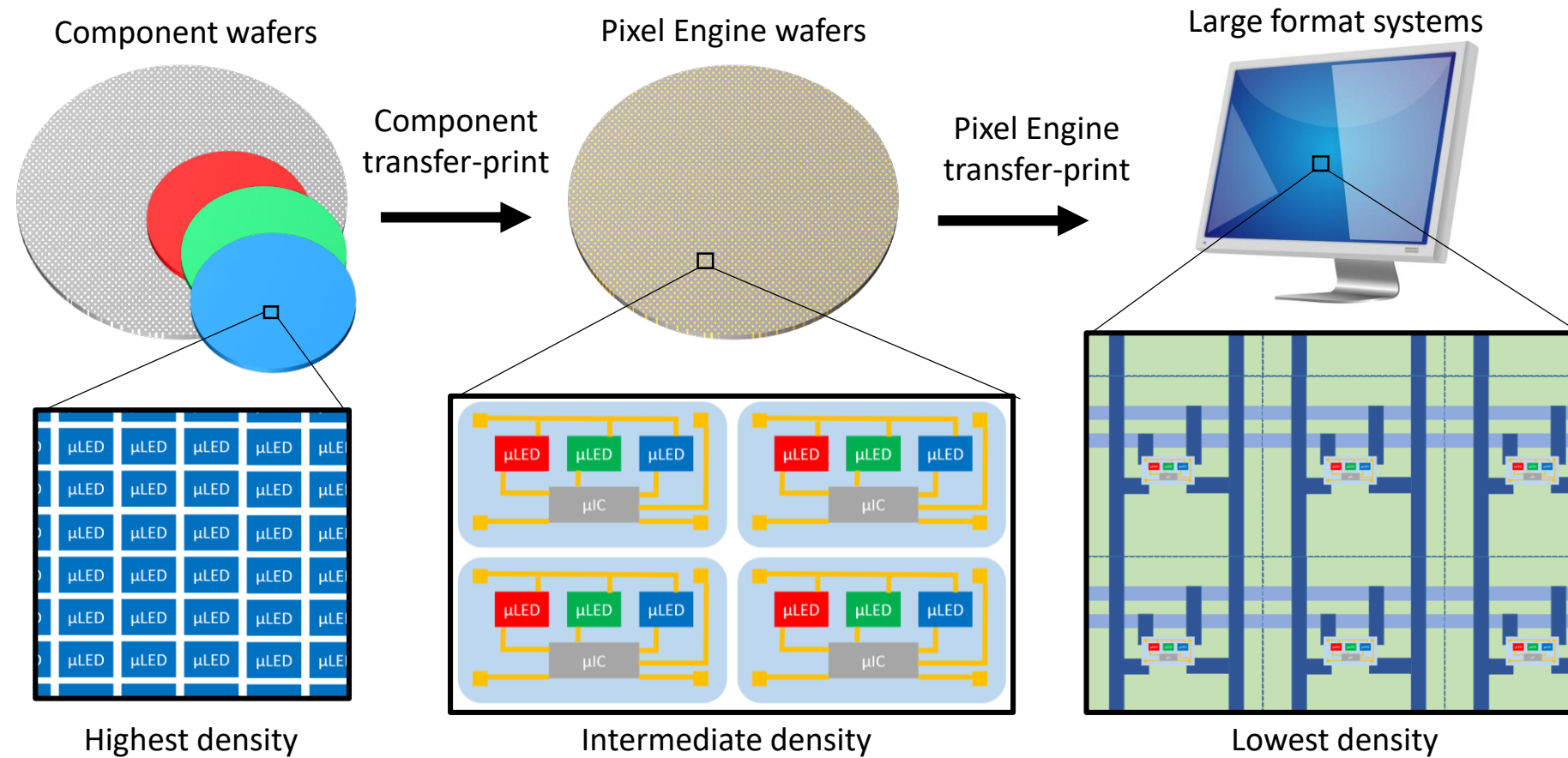

Simple passive matrix display prototype after additive repair.

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

Component wafers

Component transfer-print

Pixel Engine wafers

Pixel Engine transfer-print

Large format systems

Highest density

Intermediate density

Lowest density

small, sparse array transfer:

3 colors:

large, sparse array transfer:

3 colors:

small, dense array transfers to intermediate:

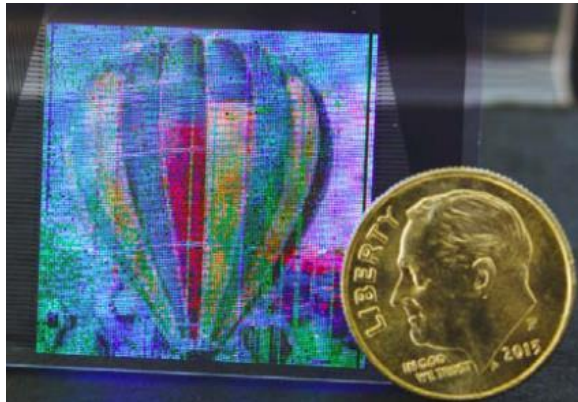very large array transfer to panel, all colors and functionalities at once:

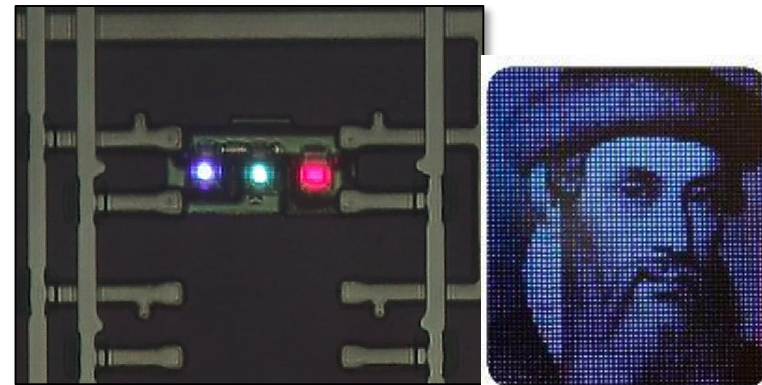*Micro-transfer printing to intermediate substrates enables a variety of "pixel engines" useful for displays.*
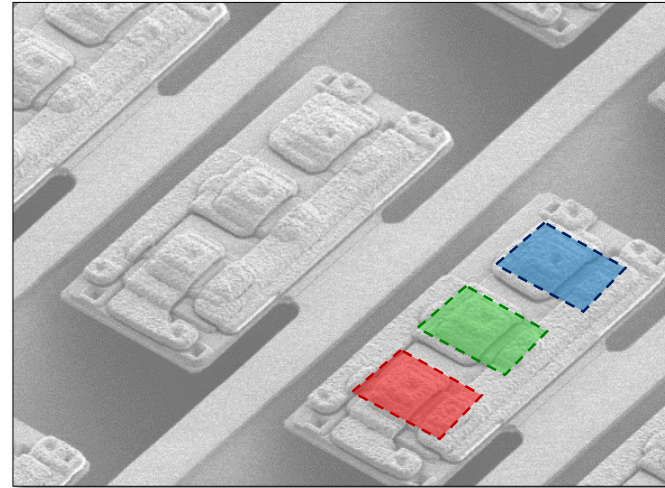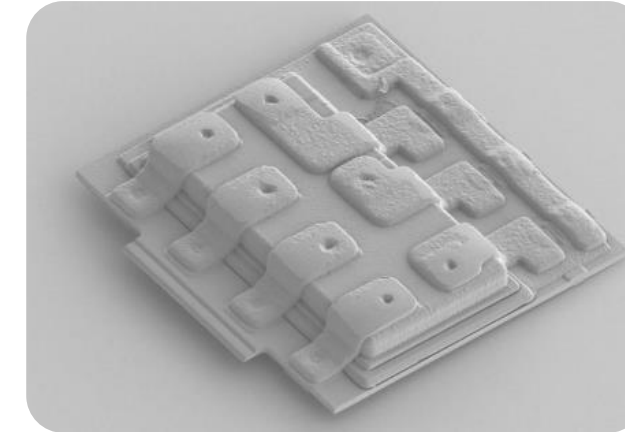
Single microLED package with "spikes"
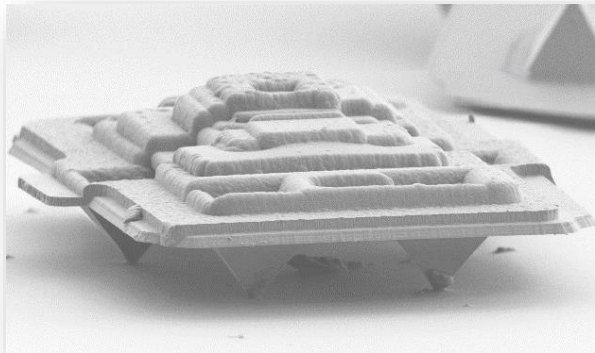
A passive matrix microLED display "finished at the printer"
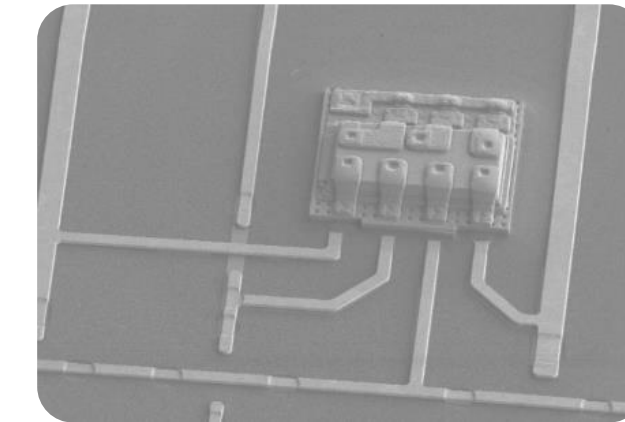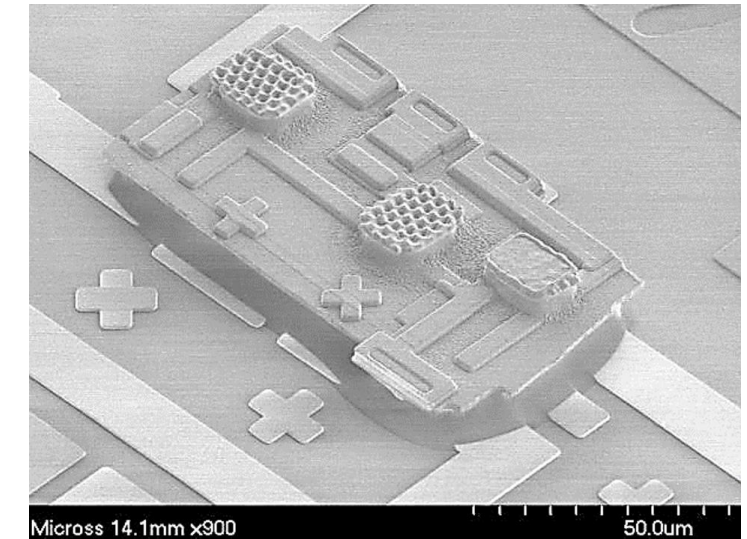

RGB **Pixel Engine**™

2D (side by side) RGB+IC **Pixel Engine**™

Printed to wiring backplane (no TFT) for active matrix microLED displays.
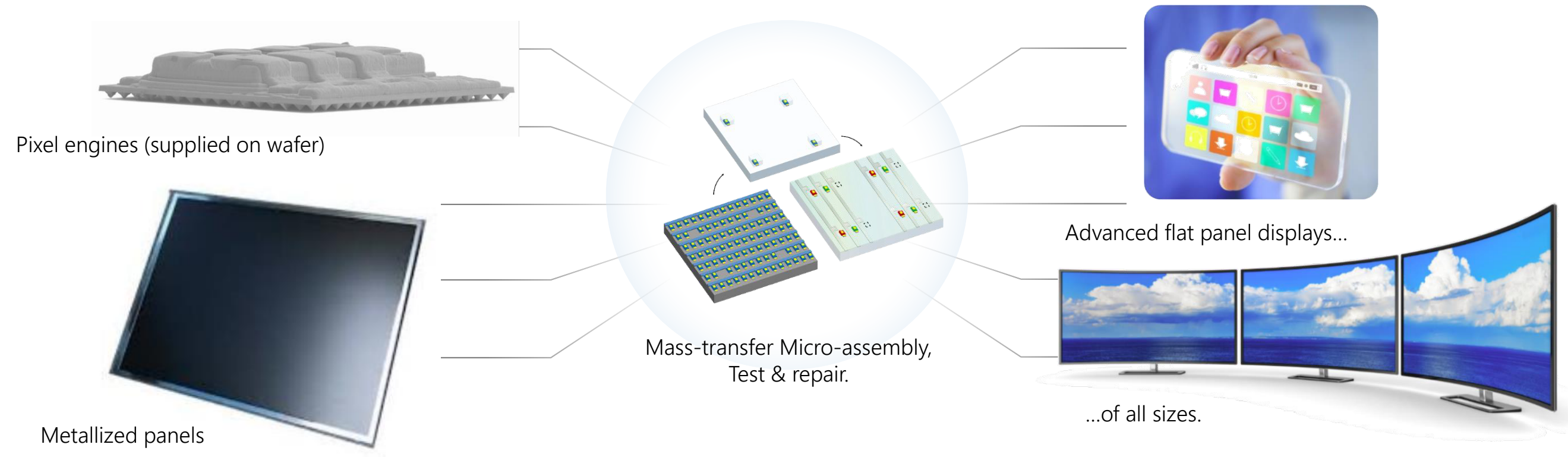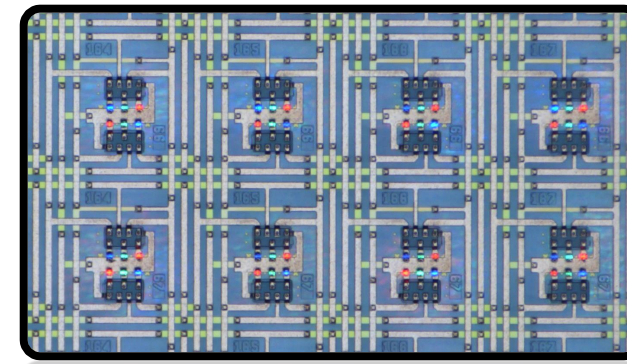

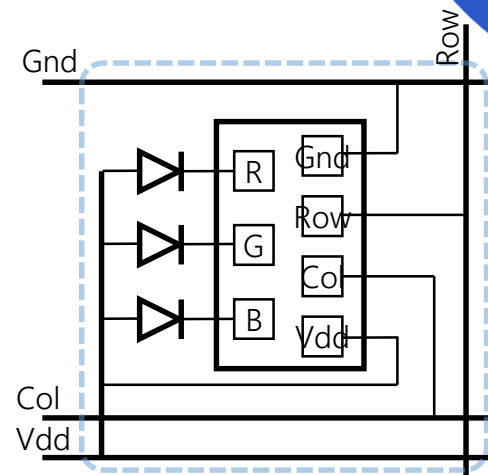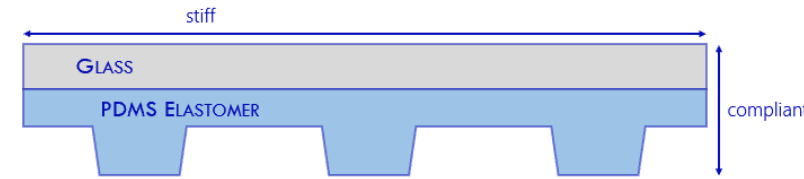3D (LED on IC) RGB+IC **Pixel Engine**™
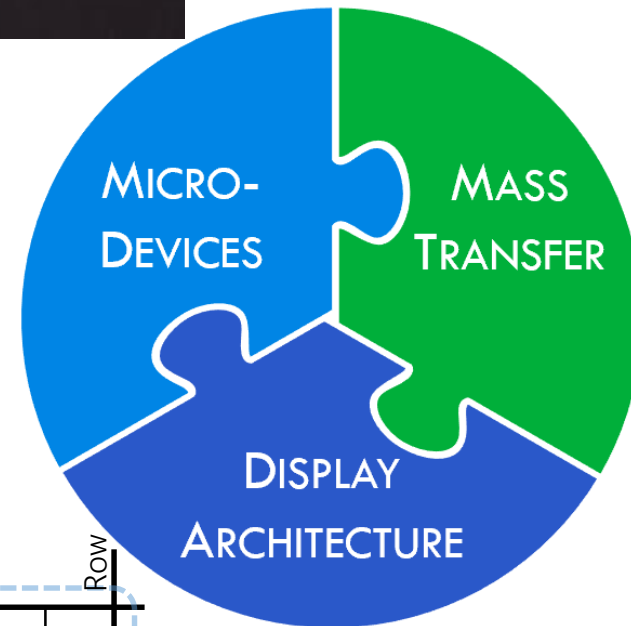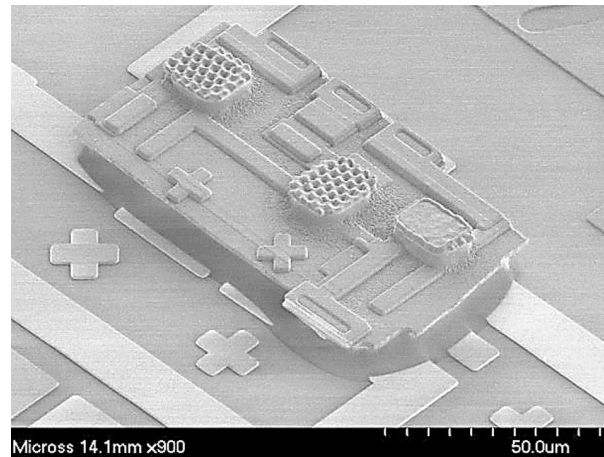
Additive assembly with electrical interconnection can finish displays at the "print, test & repair" process modules.

Pixel engines (supplied on wafer)

Metallized panels

Mass-transfer Micro-assembly, Test & repair.

Advanced flat panel displays...

...of all sizes.

stiff
GLASS
PDMS ELASTOMER
compliant

MICRO-DEVICES

MASS TRANSFER

DISPLAY ARCHITECTURE

Micross 14.1mm x900   50.0um

Gnd

Row

R   Gnd
G   Row
B   Col
     Vdd

Col
Vdd

Thank you from team

Xdisplay

info@xdisplay.com