Flat-Panel Display Systems With Mass-Transferred MicroLEDs And MicroICs

Chris Bower
CTO, X Display Company (XDC)
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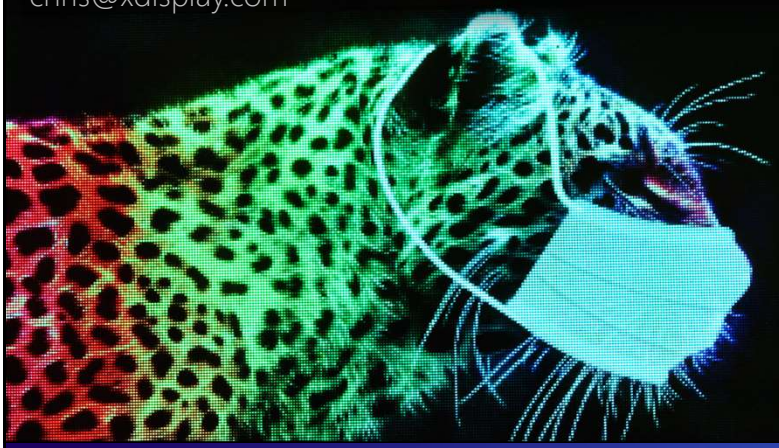

XDC
" The PixelEngine™ Company "

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Flat-Panel Display Systems With Mass-Transferred MicroLEDs And MicroICs

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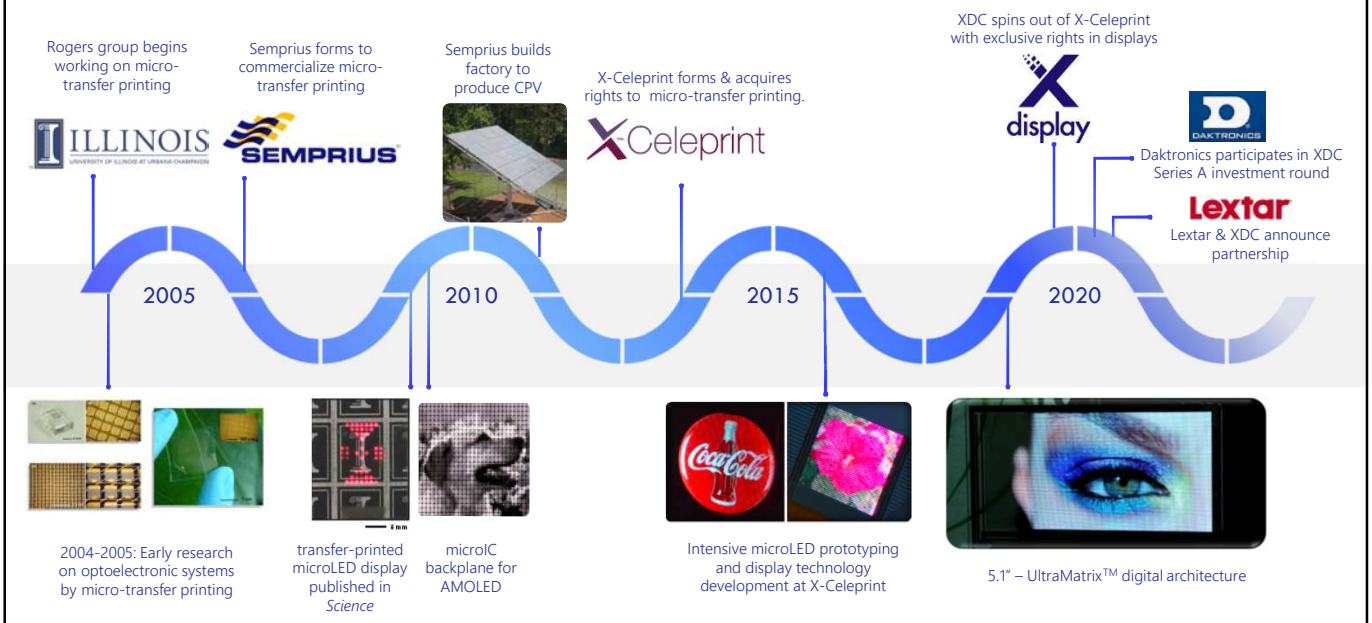
- Introducing XDC
- Elastomer stamp mass transfer
- Mass transfer for displays

2

A new display company with mass transfer heritage



3

XDC does business

Intellectual Property

500+ patents

→ LICENSING AGREEMENTS

Components

microLEDs
microICs
PixelEngine™ Devices

→ FABLESS MODEL

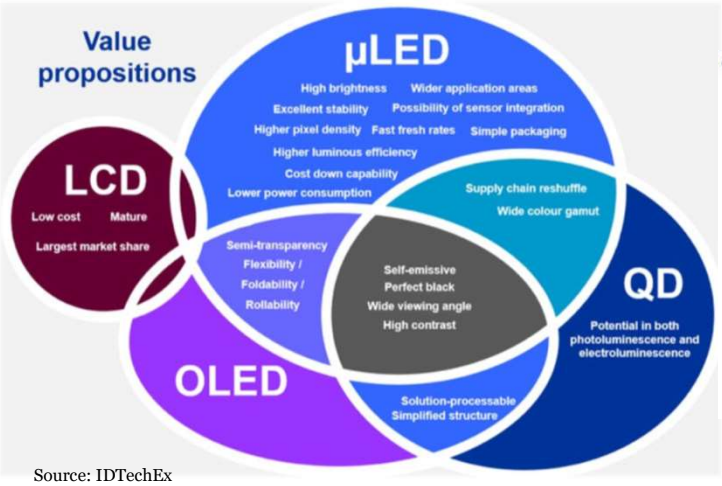
Tools for R&D

Mass transfer equipment
Stamps

→ TABLE-TOP TO PILOT-SCALE

4

Better materials make better displays



Source: IDTechEx

COMPARISONS WITH LCD AND OLED

	LCD	OLED	microLEDs
Energy consumption	Medium	Medium	Very Low
Pixel density	Up to 1000 PPI (Current commercial: 500)	2500 PPI demonstrated (MicroDisplays)	Up to 5000 PPI
Brightness	< 2000 Cd/m²	<1000 Cd/m²	Up to 1E6 Cd/m2
Contrast	Low to medium	High	High
Lifetime	Good	Medium	Best
Environmental stability	Good	Medium (with appropriate encapsulation)	Best
Refresh Rates	Low (ms)	High (µs)	Very high (ns)
Viewing angles	Low	High	High
Flexibility	Low	High	Medium
Maturity	High	Medium	Low
Cost	Low	Medium	High

Yole Development 2017 "MicroLED Displays: Hype and Reality, Hopes and Challenges"

Mass transfer brings the best materials to displays

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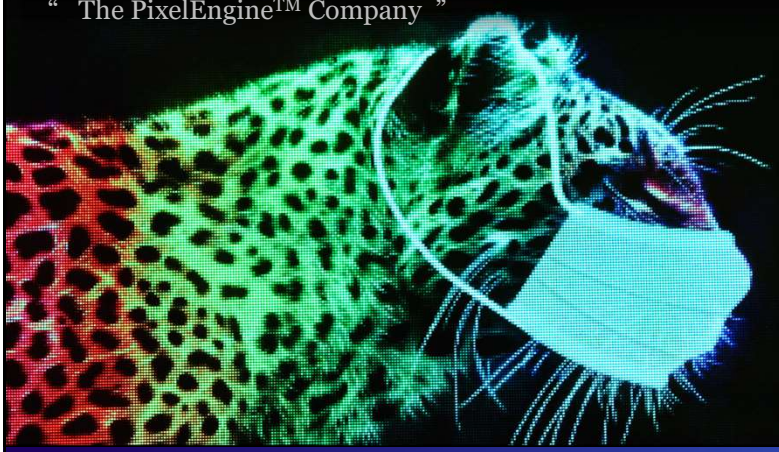

- Introducing XDC
- Elastomer stamp mass transfer
- Mass transfer for displays

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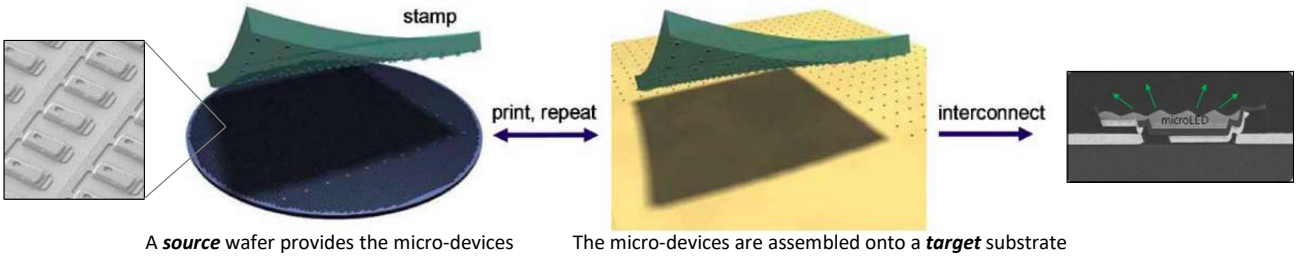
Micro-transfer printing: elastomer stamp mass transfer

1. Form undercut microdevices (LEDs, ICs, etc.), anchored at endpoints
2. Mass transfer to the target (display) substrate with a patterned elastomer stamp
3. Form interconnections to complete functional systems



A ***source*** wafer provides the micro-devices

The micro-devices are assembled onto a ***target*** substrate

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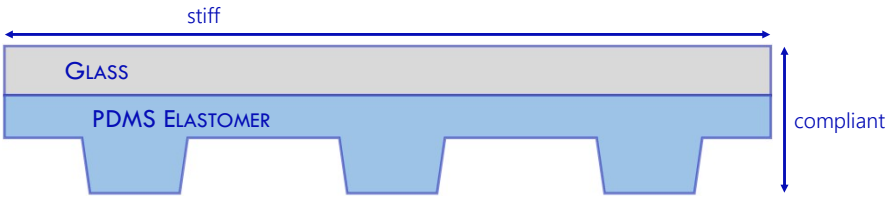
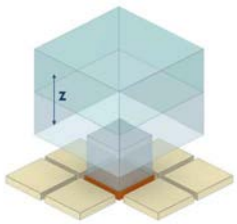
Elastomer stamp mass-transfer fundamentals





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).

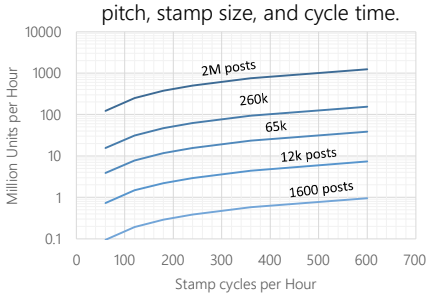
4 9s (99.99%) yield proven in R&D lab. Expect 6 9s or higher in production.

STAMP CHARACTERISTICS:

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

} Key enablers for yield and throughput

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



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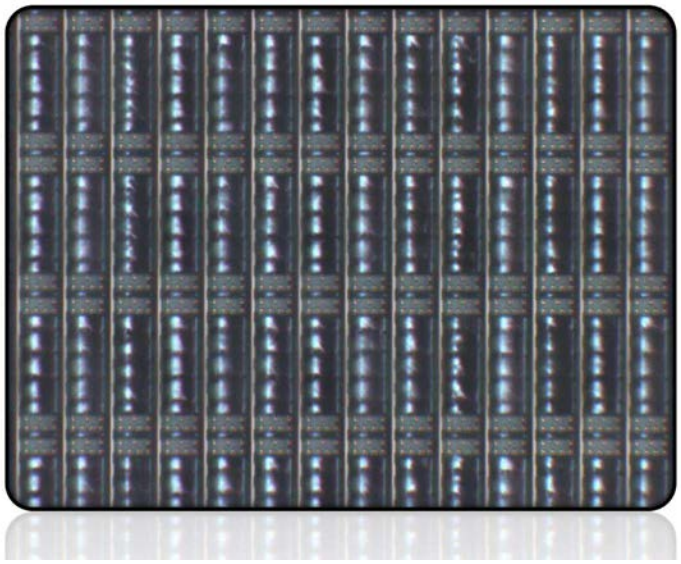
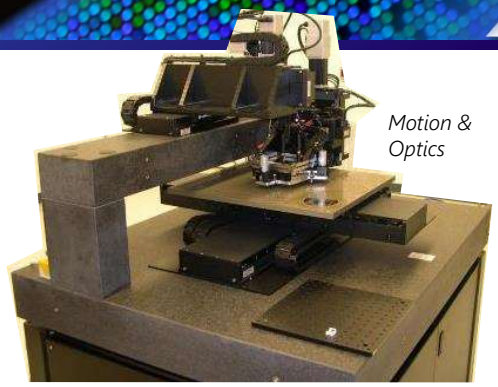
Mass-transfer in action → motion + optics

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





Motion & Optics

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).

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XDC supplies mass transfer equipment

Transfer-printer designed to populate 300mm diameter wafers

Transfer-printer with automated substrate handling

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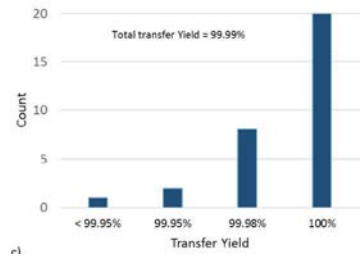
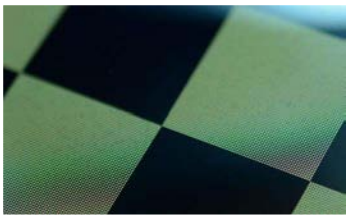
Capability demonstrations

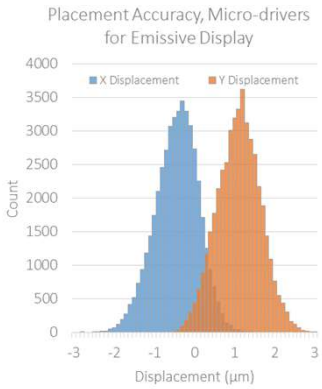
high transfer yields in R&D setting



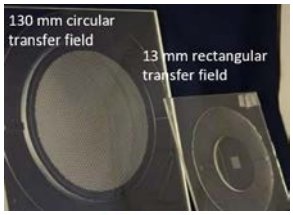


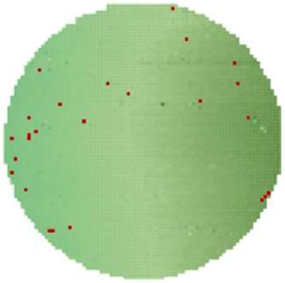
high accuracy placement

displacement at 3σ: +/- 1.5 µm



scalable transfer area





99.95% transfer yield

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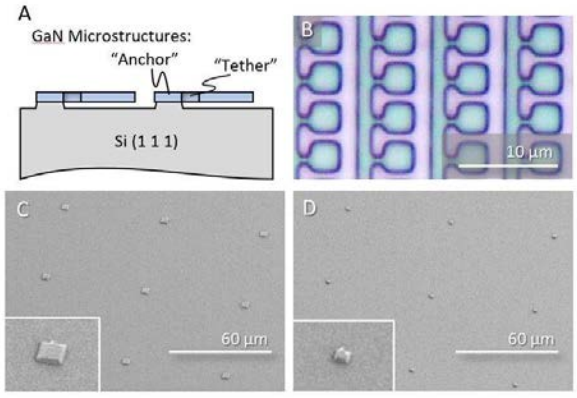
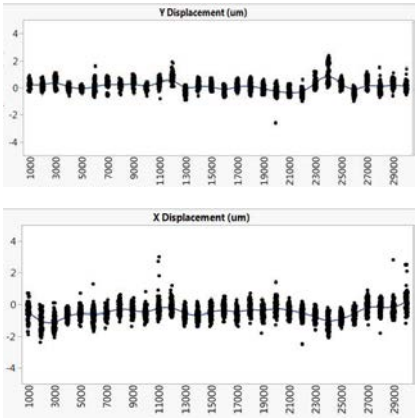
Capability demonstrations

3 x 3 µm chips printed at 60um pitch



stamp lifetime studies

> 30,000 transfers without performance degradation



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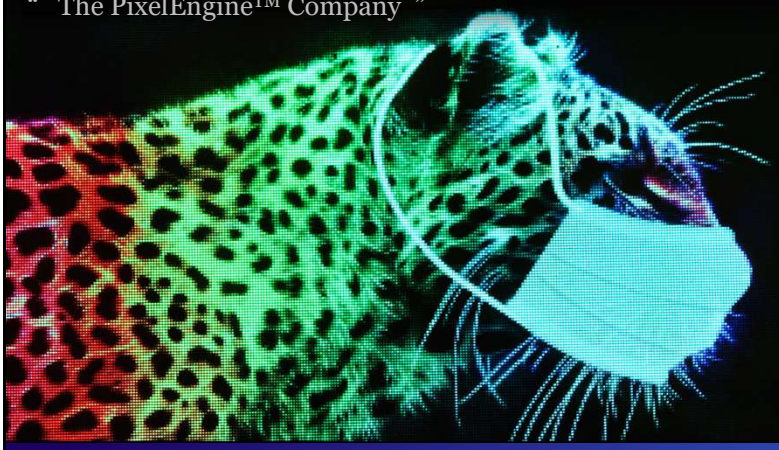

- Introducing XDC
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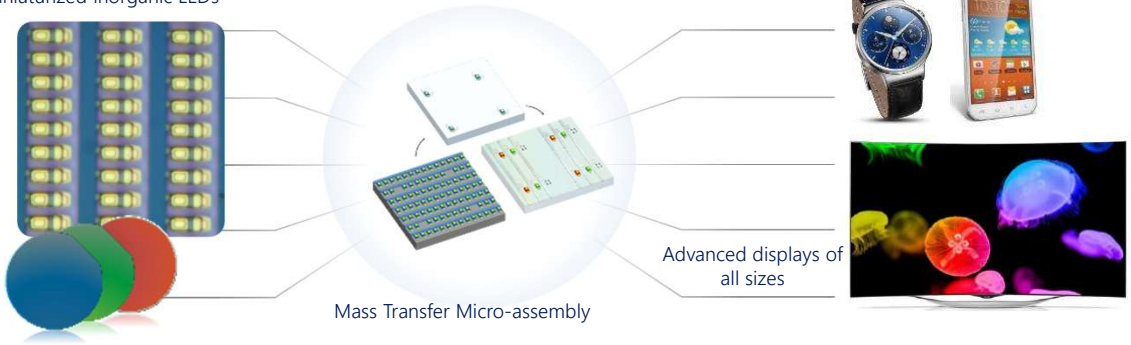
Better materials make better displays

Ultra-miniaturized inorganic LEDs



MicroLEDs for displays that…

…use less energy; have brightness suitable for the outdoors; are environmentally robust and long-lived; have high refresh rates; have wide viewing angles; have great contrast, etc…

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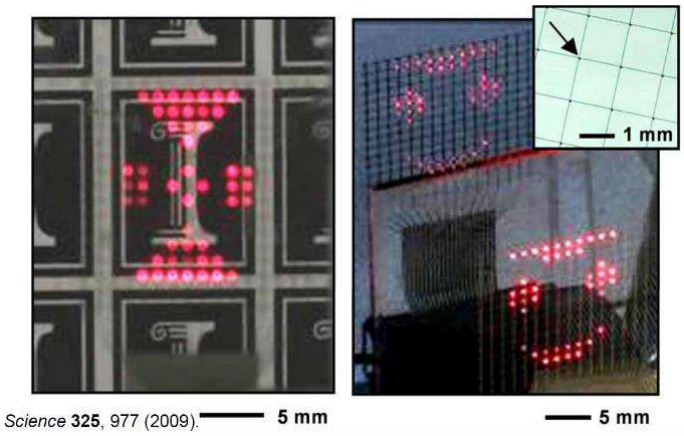
Transparent, bi-directional microLED display



Science **325**, 977 (2009).

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Brighter idea for bendy displays

The technology behind giant video billboards can now be made into flexible and even transparent displays.

These could be used to create brakelights that fit the curves of a car or medical diagnostics that envelop a patient like a blanket.

It has been made possible by a new technique, outlined in Science, for manufacturing so-called inorganic LEDs.

The new method allows these tiny light-emitting diodes (LEDs) to be attached to materials such as glass or rubber.

One of the researchers' prototypes wraps neatly around a thumb

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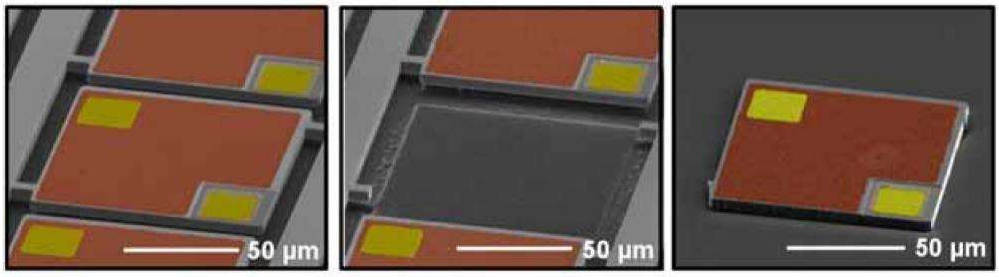
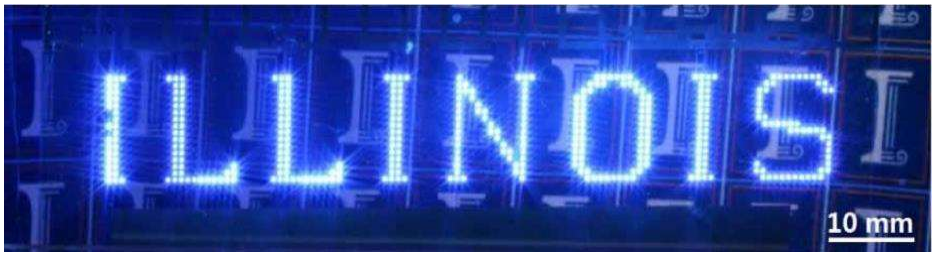
Printable InGaN microLEDs and display





PNAS **108**, 10072 (2011).

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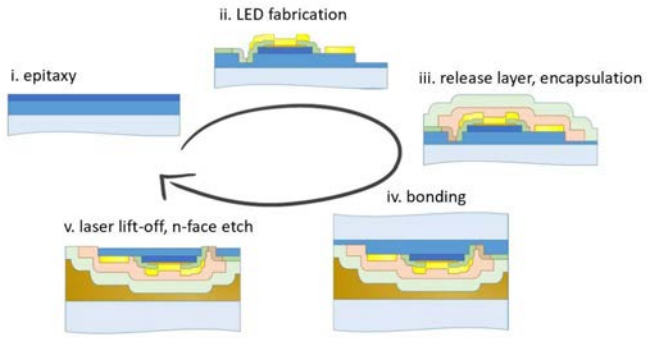
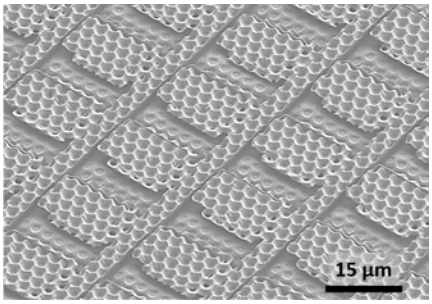
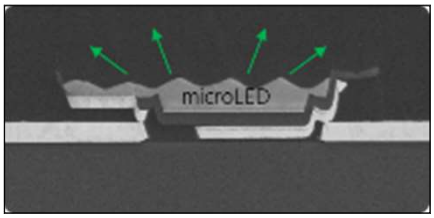
Print-ready 8 x 15 μm² flip-chip microLEDs

Flip-chip "pads down" microLED







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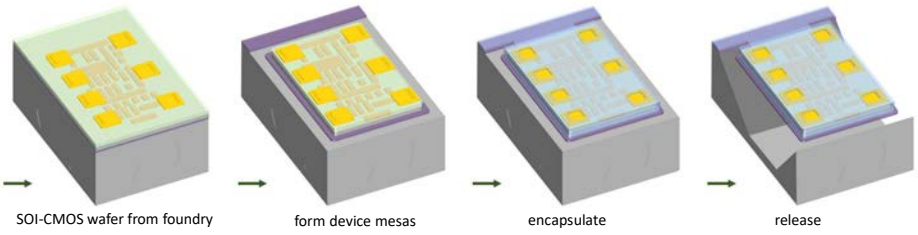
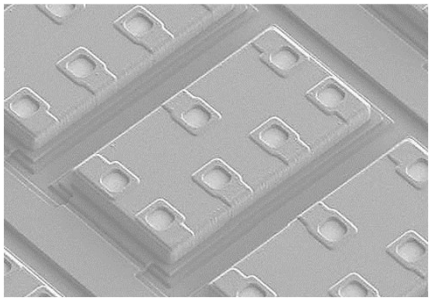
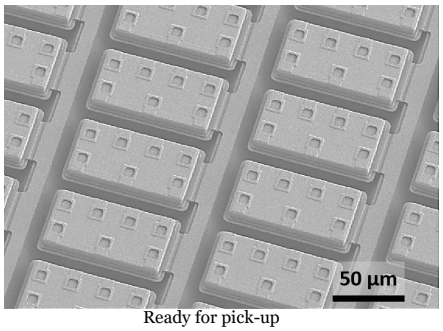
Print-ready microICs





Ready for release



Ready for pick-up

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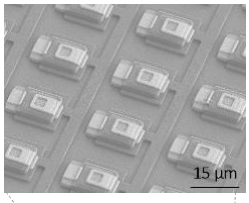
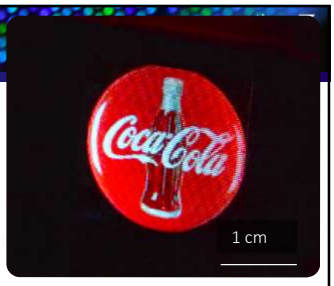
Passive matrix microLED displays by printing

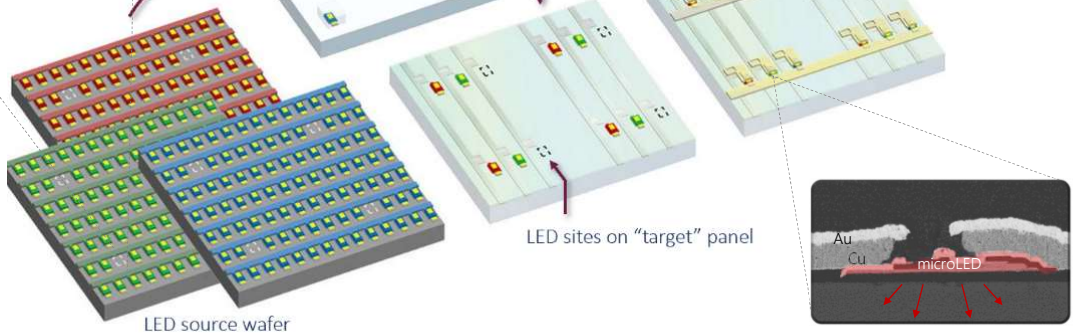


Transfer to display substrate with pre-patterned column metal:

PMiLED array fabrication:



100RGB x 100; 127 PPI



→ *Different "source" for each color*

SID 2016 DIGEST

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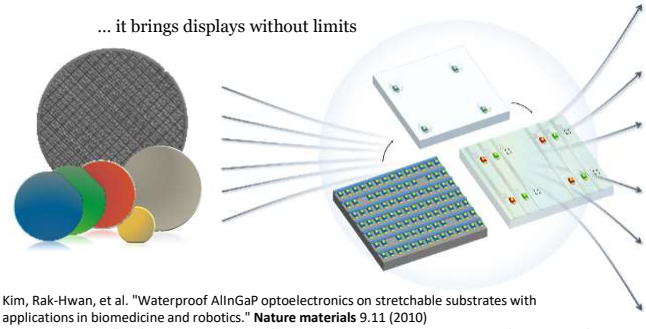
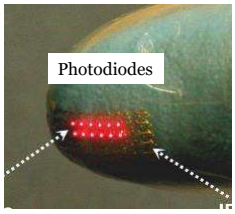
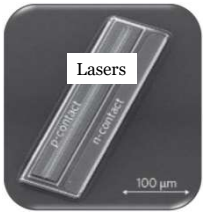
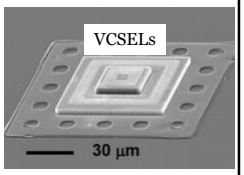
Mass transfer brings more than microLED…

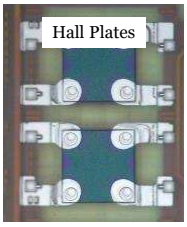
… it brings displays without limits

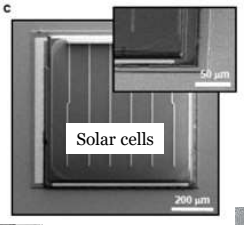


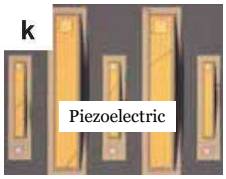


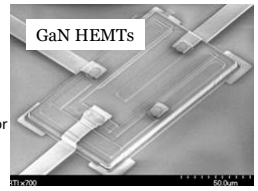


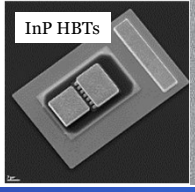


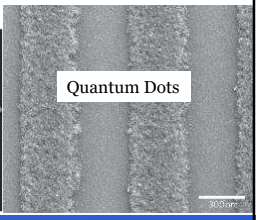












Kim, Rak-Hwan, et al. "Waterproof AlInGaP optoelectronics on stretchable substrates with applications in biomedicine and robotics." **Nature materials** 9.11 (2010)

Justice, John, et al. "Wafer-scale integration of group III–V lasers on silicon using transfer printing of epitaxial layers." **Nature Photonics** 6.9 (2012)

Kang, Dongseok, et al. "Compliant, heterogeneously integrated GaAs micro-VCSELs towards wearable and implantable integrated optoelectronics platforms." **Advanced Optical Materials** 2.4 (2014)

Bower, Christopher A., et al. "Heterogeneous integration of microscale compound semiconductor devices by micro-transfer-printing." 2015 **IEEE 65th ECTC**, 2015.

Sheng, Xing, et al. "Printing-based assembly of quadruple-junction four-terminal microscale solar cells and their use in high-efficiency modules." **Nature materials** 13.6 (2014)

Dagdeviren, Canan, et al. "Conformal piezoelectric systems for clinical and experimental characterization of soft tissue biomechanics." **Nature materials** 14.7 (2015)

Lerner, Ralf, et al. "Flexible and Scalable Heterogeneous Integration of GaN HEMTs on Si-CMOS by Micro-Transfer-Printing." **physica status solidi (a)** 215.8 (2018)

Carter, Andrew D., et al. "Microtransfer-Printed InGaAs/InP HBTs Utilizing a Vertical Metal Sub-Collector Contact." **2019 Device Research Conference** (DRC). IEEE, 2019.

Kim, Tae-Ho, et al. "Full-colour quantum dot displays fabricated by transfer printing." **Nature photonics** 5.3 (2011)

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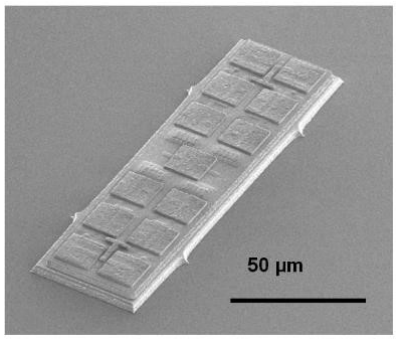
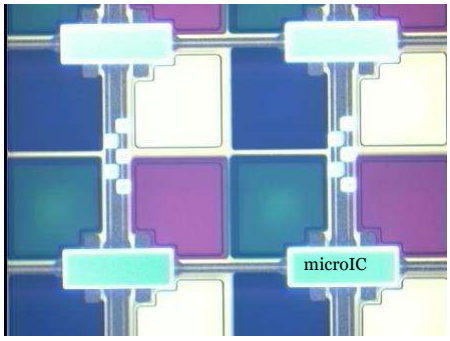
Mass transfer brings microICs to displays

Kodak and Semprius demonstrated AMOLED backplanes using mass transferred microICs in the late 2000s.



A transferred pixel driver microIC



Looking through the down-emitting full-color AMOLED.

November 2008

63.2 AMOLED Displays using Transfer-Printed Integrated Circuits, *SID 2009*

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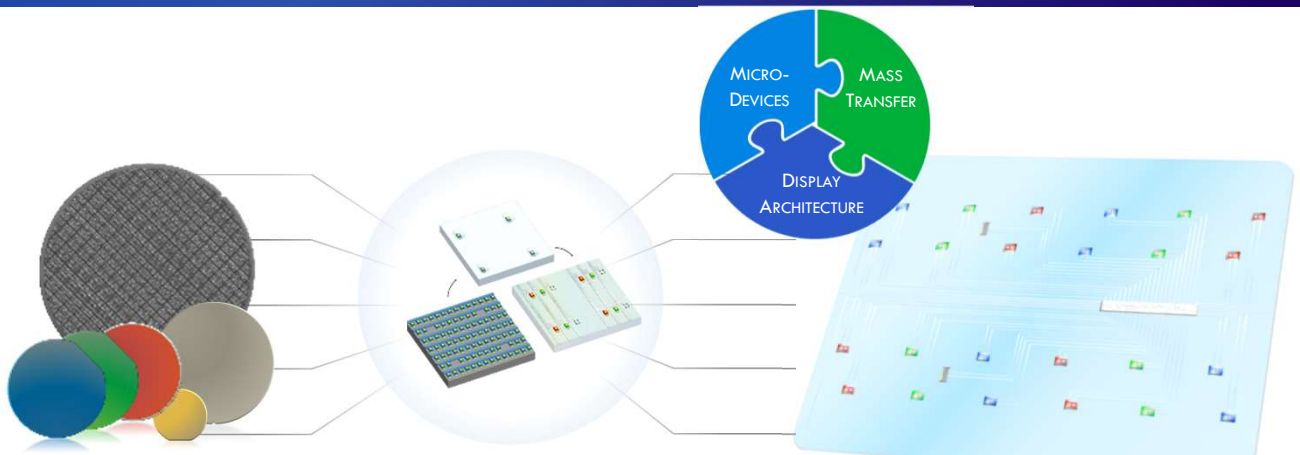
microLED displays are a union of different disciplines.



the best devices

elastomer stamp mass transfer "micro-transfer printing"

room to do more

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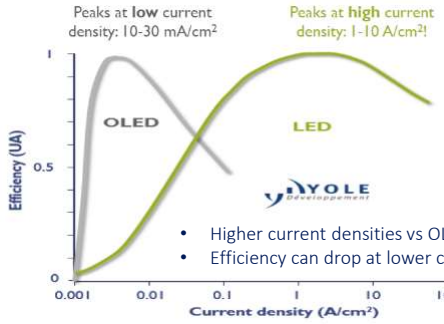
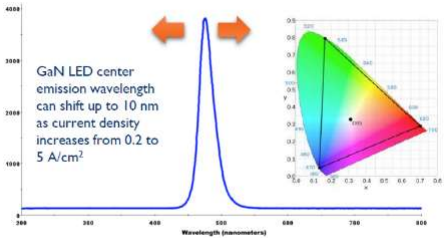
Drive currents and microLEDs



- Higher current densities vs OLED
- Efficiency can drop at lower currents



- Emission wavelength shifts with current

MicroLED Displays 2019 | www.yole.fr | ©2019

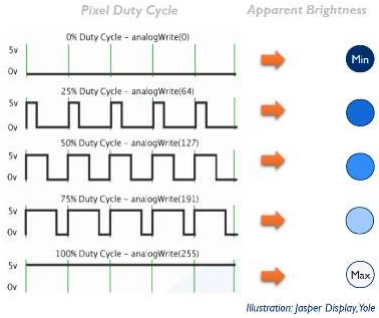
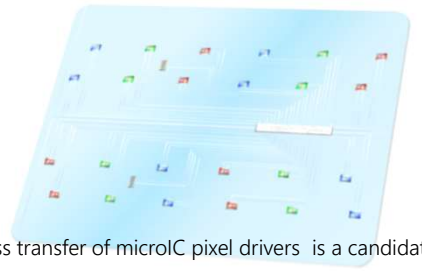


Illustration: Jasper Display, Yole

- More complex digital PWM drive to maintain efficiency and color quality

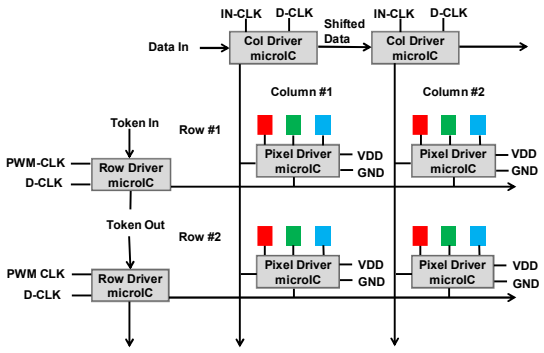


- Mass transfer of microIC pixel drivers is a candidate solution

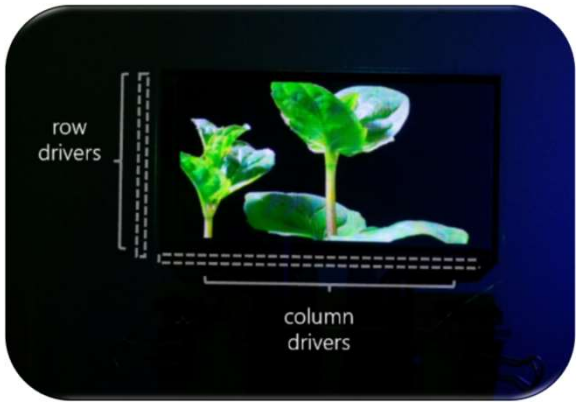
The UltraMatrix™ digital display architecture

An active-matrix PWM architecture using mass transferred microICs

- Column driver microICs demultiplex data
- Row driver microICs run progressive scan of data load and PWM
- Pixel driver microICs receive and store 48-bit digital data per frame
- Pixel driver microICs drive three subpixels using 14-bit PWM
- The subpixel current level is set using 2-bits

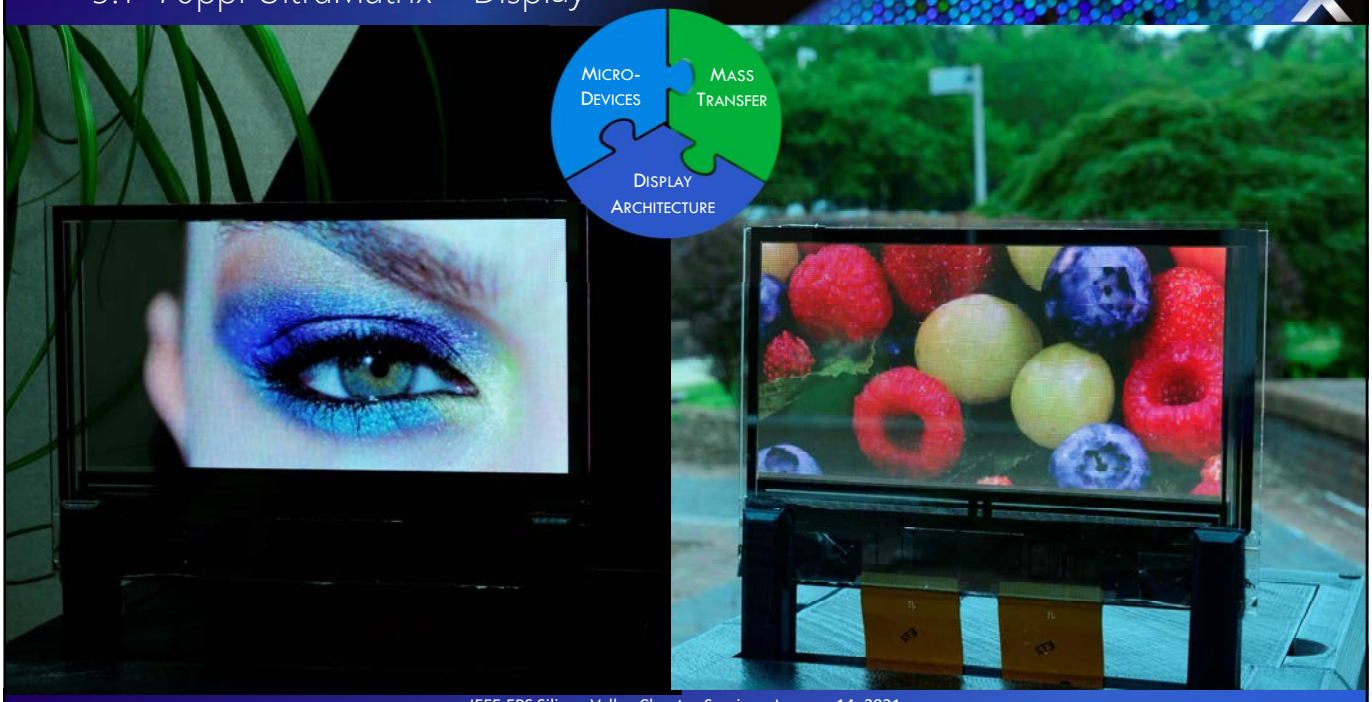


5.1" 70ppi microLED display



TOUCH TAIWAN and IMID 2018

5.1″ 70ppi UltraMatrix™ Display



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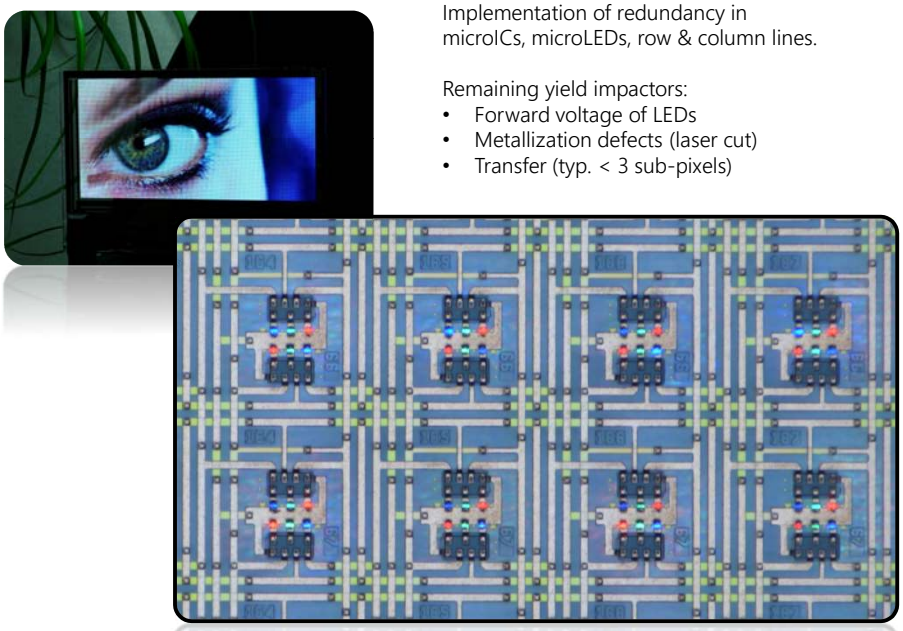
Functional Yield of Sub-Pixels in 5.1″ display



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)

320 x 160 sub-pixel yield maps

RED, 0 dark subpixels
100% yield

GREEN , 2 dark subpixels
99.996% yield

BLUE , 1 dark subpixels
99.998% yield

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Transparent displays

320RGB x 160; 70PPI, fully redundant microIC and microLED architecture
~ 73% transparency

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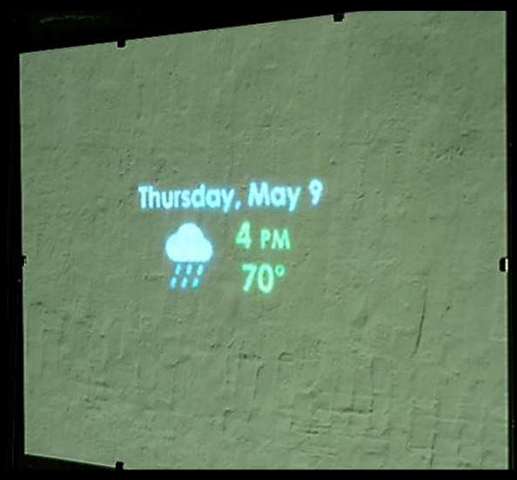
High brightness displays

30,000 nits (peak) green 5.1", 70ppi display outdoors



10,000 nits full color 5.1", 70ppi display behind paper veneer

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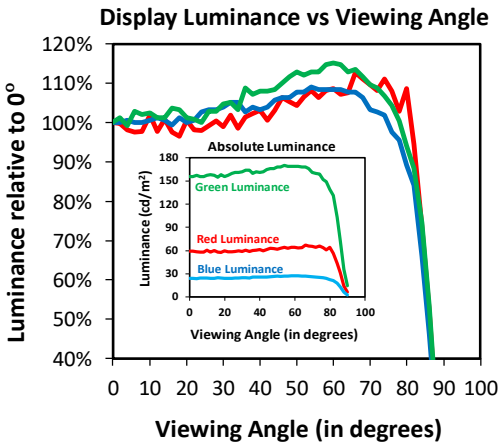
Wide viewing angle from point-like emitters

5.1" 70ppi display with 8 x 15 μm² microLEDs



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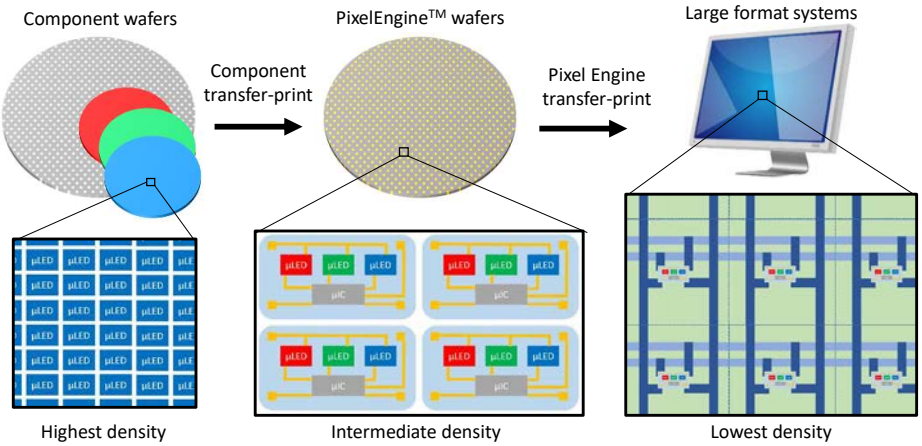
PixelEngine™ displays



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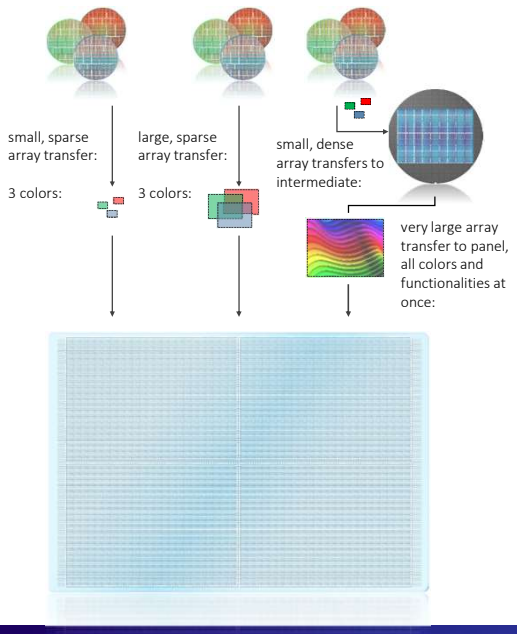
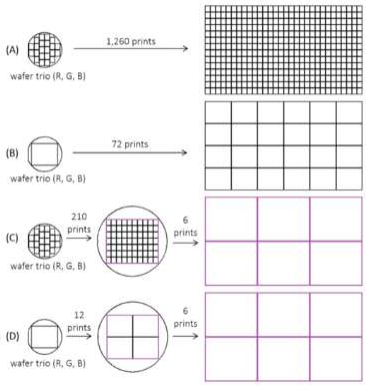
Intermediate substrates can reduce transfer steps



30.4" 1920 x 1080 µILED Display



Requirements for 1M displays per year

Scenario	µILED Wafers	Package Wafers	Prints per Display	Transfer Machines
A	15,625	-	1,260	888
B	20,000	-	72	51
C	15,625	122,400	31.7	23
D	20,000	122,400	7.5	6

Miniature Heterogeneous Fan-Out Packages for High-Performance, Large-Format Systems, Proc. ECTC, 2017

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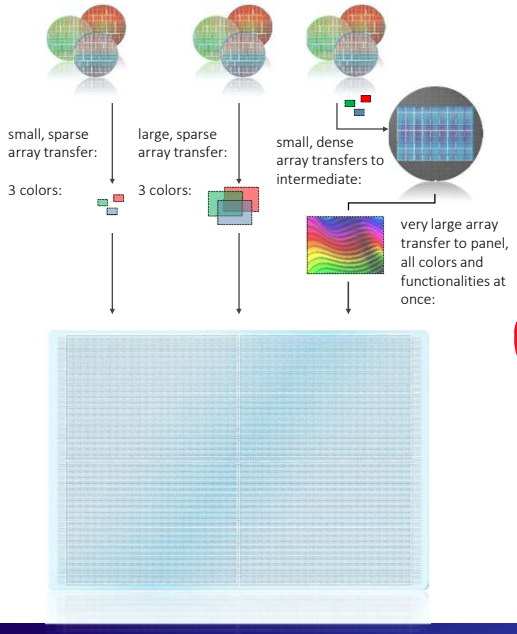
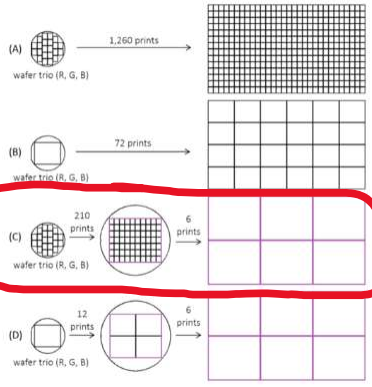
Intermediate substrates can reduce transfer steps



30.4" 1920 x 1080 µILED Display



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38x reduction in transfer steps

Miniature Heterogeneous Fan-Out Packages for High-Performance, Large-Format Systems, Proc. ECTC, 2017

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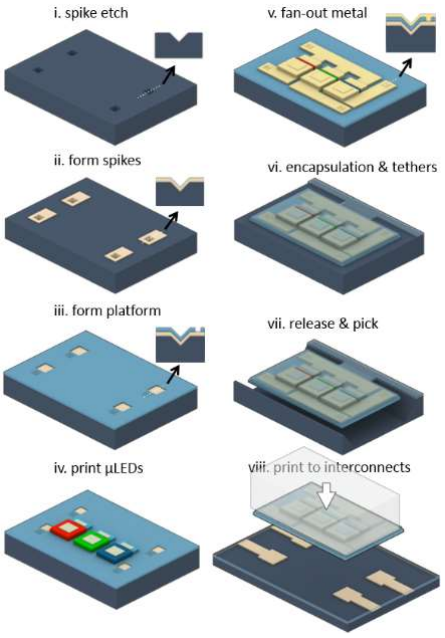
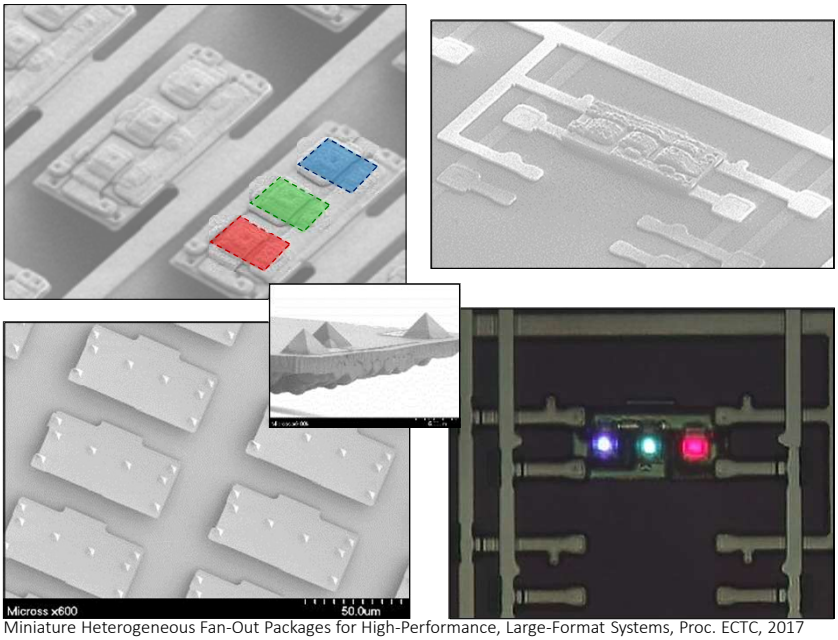
PixelEngine™ RGB package





Miniature Heterogeneous Fan-Out Packages for High-Performance, Large-Format Systems, Proc. ECTC, 2017

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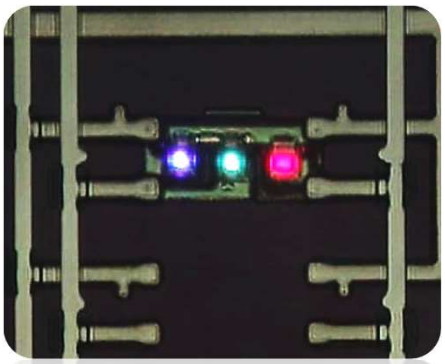
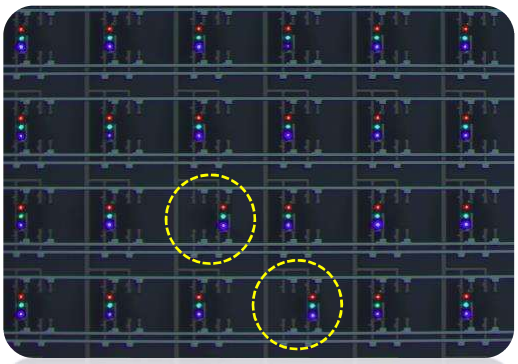
Demonstration of plug-in repair using connection "spikes"



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.

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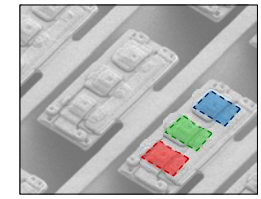
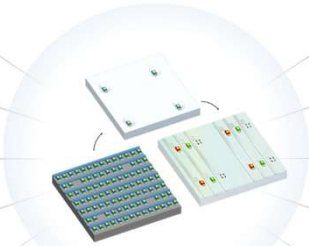
Assembly-centric display manufacturing

Additive assembly with electrical interconnection can finish displays at the "print, test & repair" process modules.



PixelEngine™ devices (supplied on wafer)

Backplane



Mass-transfer Micro-assembly, Test & repair.

Advanced flat panel displays…

…of all sizes.

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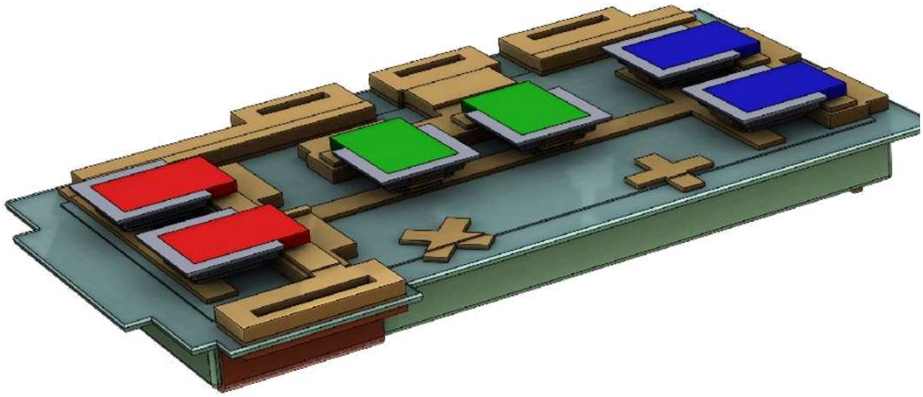
Combining microLEDs & microIC in a PixelEngine™ package

One micro transfer printable package that provides all active pixel components:

- pixel-level circuitry: pulse-width and/or –amplitude modulation.
- (redundant) set of flip-chip 8 x 15 μm^2 microLEDs
- pressure concentrators for electrical contact



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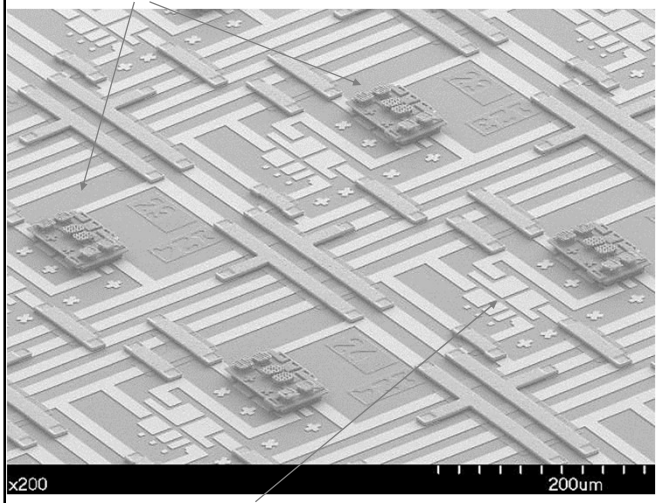
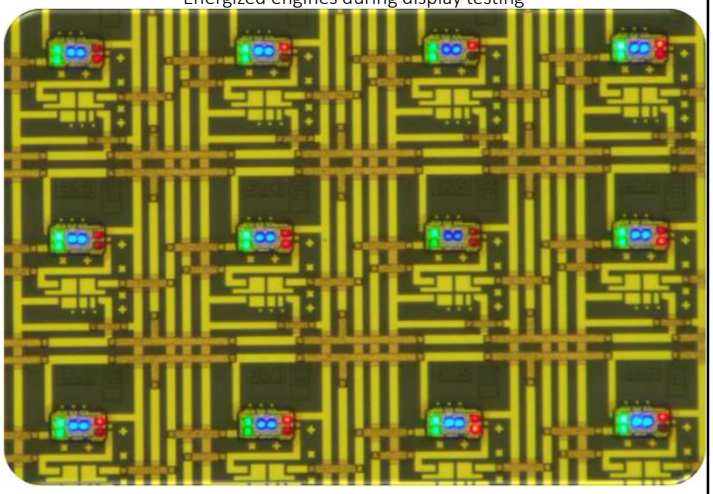
70ppi PixelEngine™ display

Engines transferred onto a backplane with two-wiring levels



Site for redundancy or repair

Energized engines during display testing



Sequence of colors from a redundant PixelEngine™ display

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Thank you for watching!

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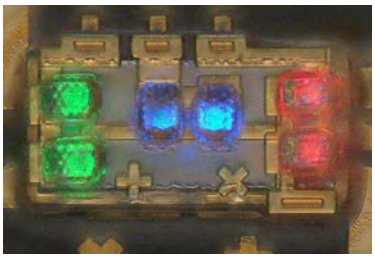

The PixelEngine™ company. Contact us at info@xdisplay.com

Intellectual Property

500+ patents

Components

microLEDs
microICs
PixelEngine™ devices

Tools for R&D

Mass transfer equipment
Stamps

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