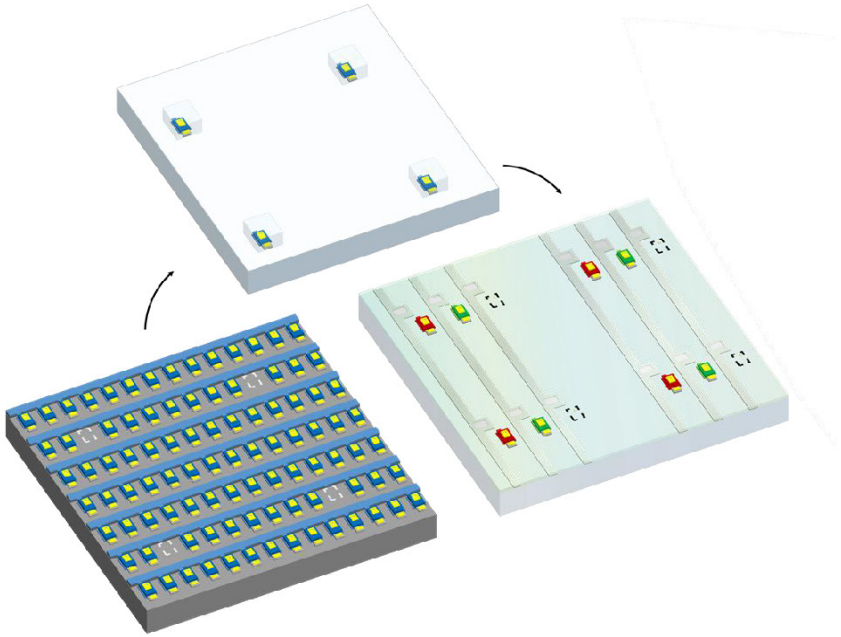
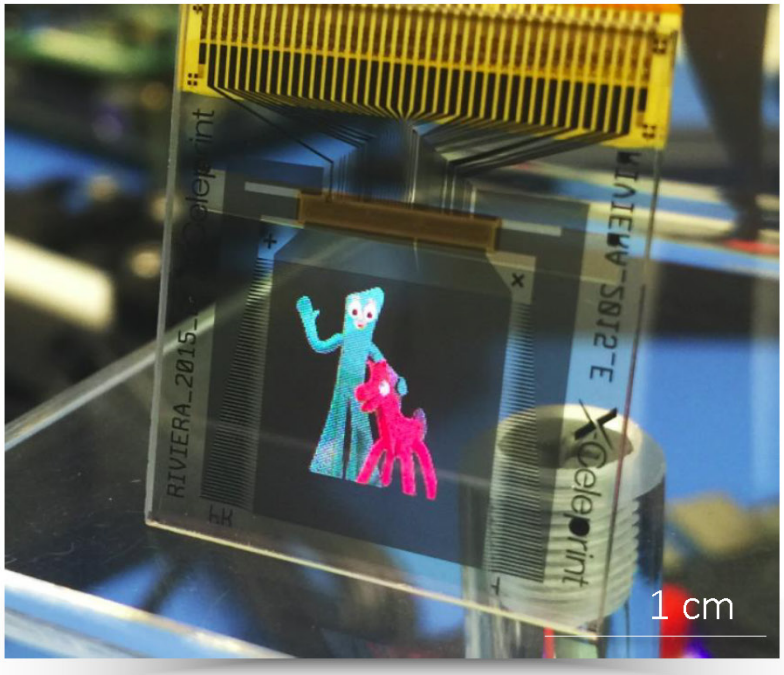
Transfer Printed Microscale Inorganic LEDs (iLEDs) for Display Applications

Chris Bower, X-Celeprint Inc.





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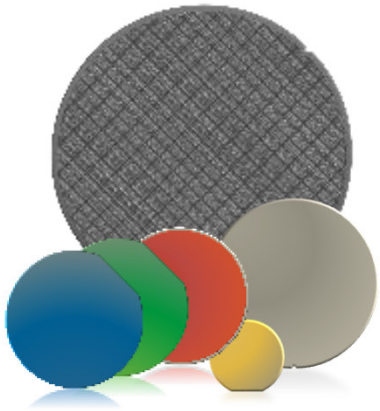
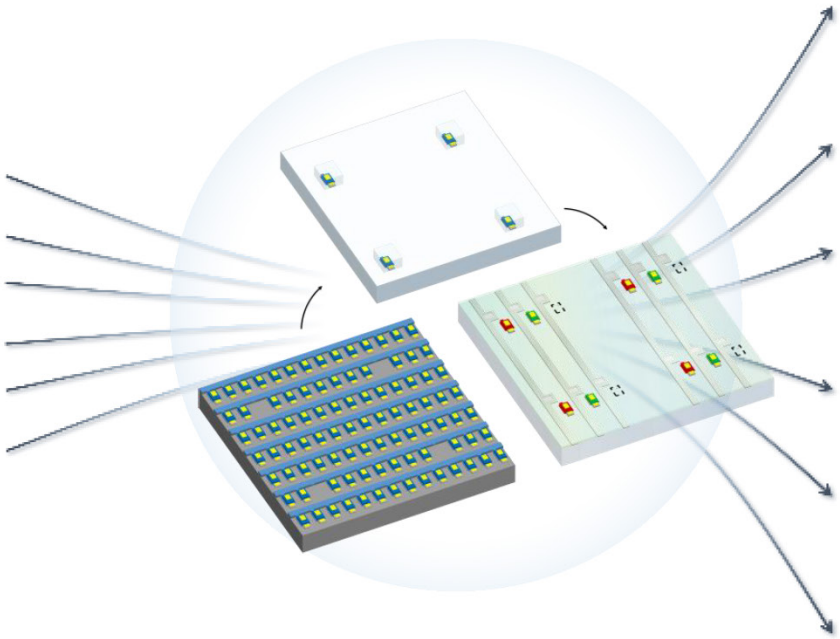
“Micro-Transfer Printing” (µTP): from wafer to panel

…for advanced displays of all sizes:





Wafer Fabricated Devices
Single-crystal
Fine lithography
(ICs, LEDs, Lasers, etc…)

- High performance,
- Large variety of function,
- Miniaturized/miniaturizable.

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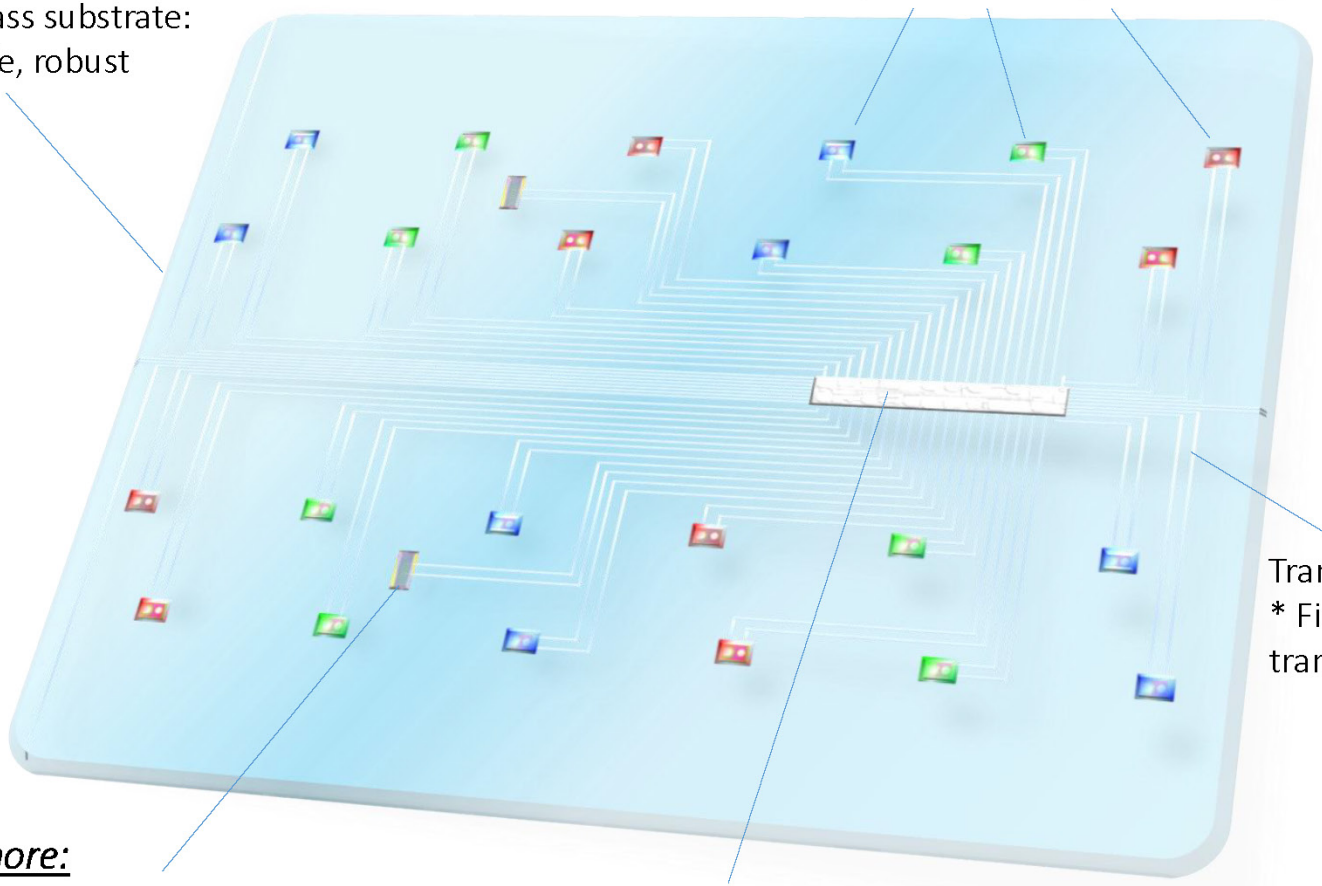
Unconstrained Material Selection for Next Generation Displays

R/G/B µ-iLEDs:
low power consumption and bright, defect tolerance

Plastic or glass substrate:
Light, flexible, robust



Transparent
* Fine and/or
transparent wiring level

Room to do more:

The sparsely integrated µLEDs allow for new functions: µ-sensors, power harvest, gesture sense, image capture, RF, etc…

µICs:
CMOS performance, embedded memory and novel design concepts
* the printed µIC should control a cluster of pixels

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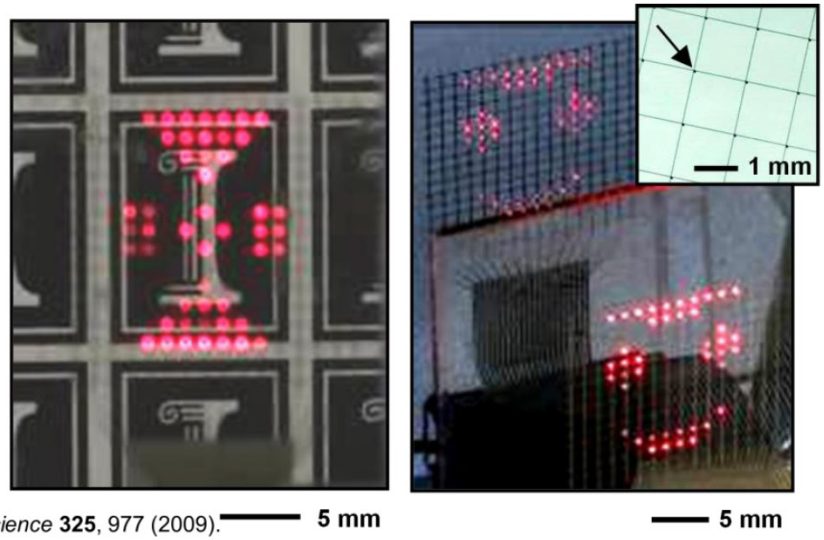
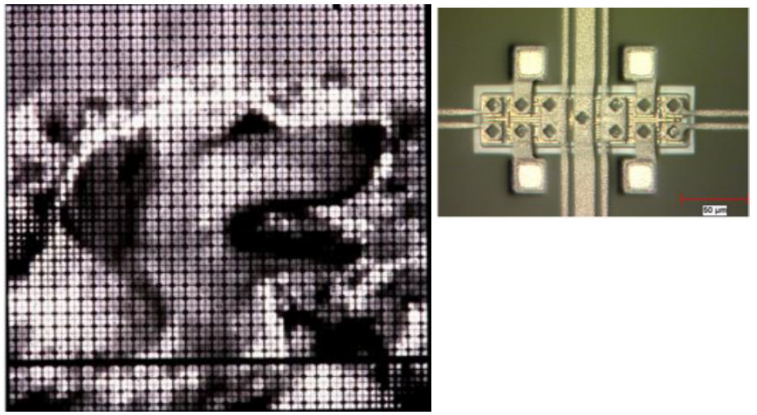
Wafer-Made Micro-Components for Displays: *where to begin?*

- Inorganic LED (iLED) emitters
- Single-crystal transistors
- Micro-ASIC pixel circuits
- Sensors and actuators
- Photodiodes and photovoltaic cells
- Light management structures
- [Transparent] conductors
- RF amplifiers
- …



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



Bower, C. A., et al. "Active-matrix OLED display backplanes using transfer-printed microscale integrated circuits." *IEEE, 2010 Electronic Components and Technology Conference*. 2010.

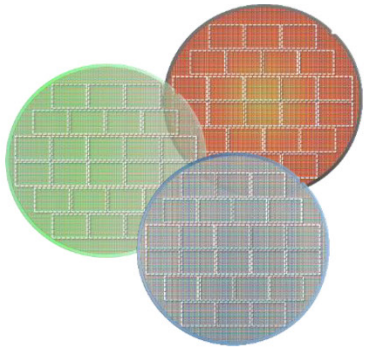
PMiLED Fabrication Overview

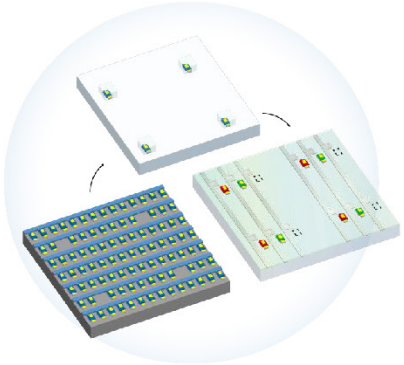
Micro LED source wafers:
(one per color)

Micro Transfer Printing
to display substrate

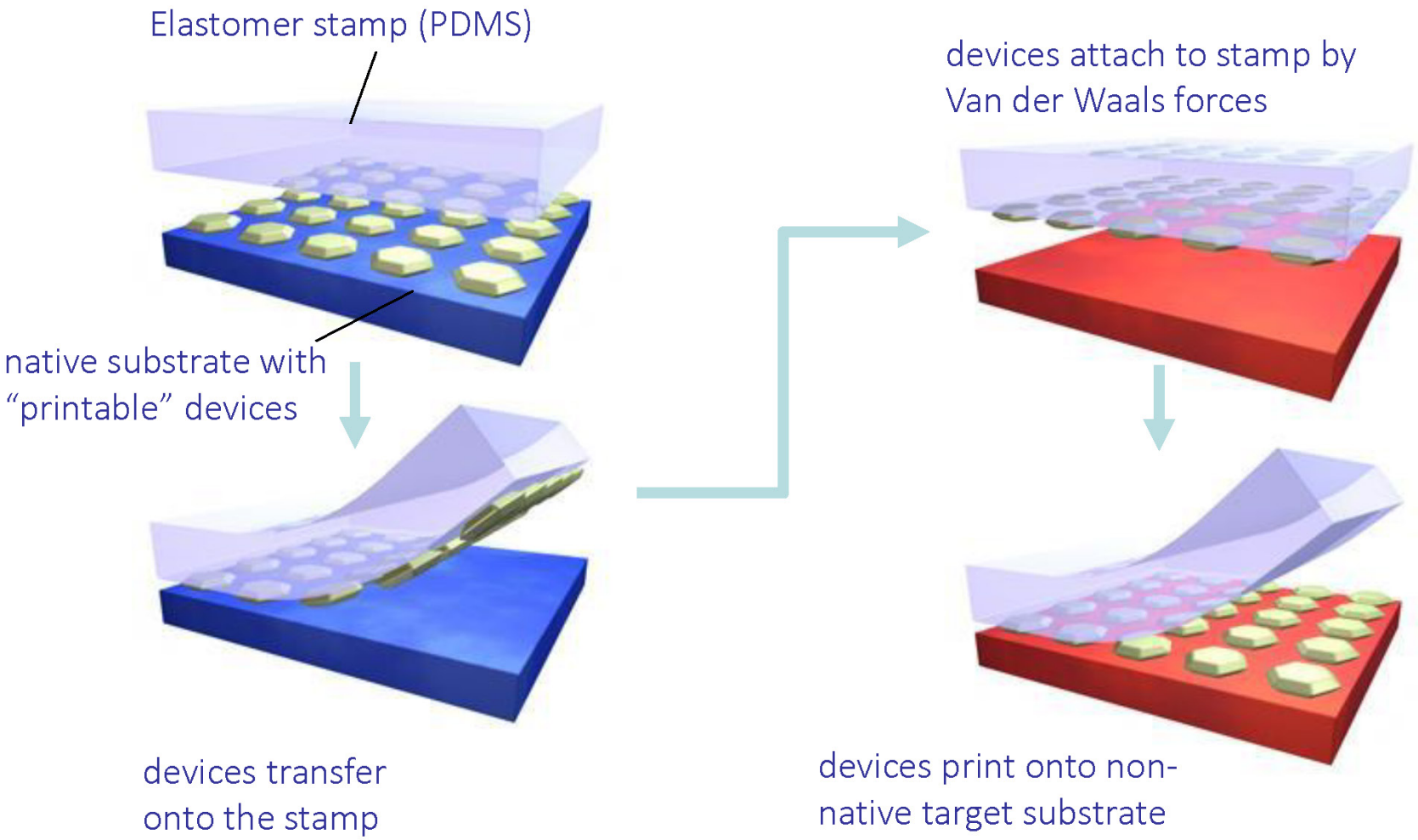
Interconnection on Display
Substrate

→ Large-area displays
→ Many panels per source wafer



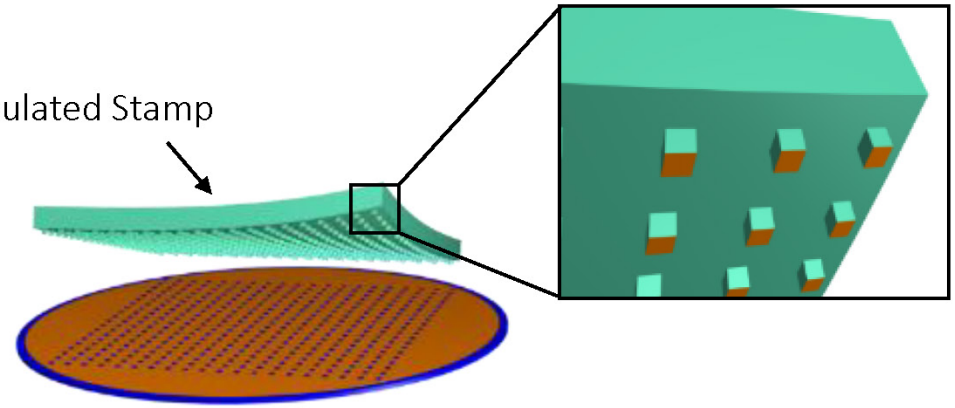


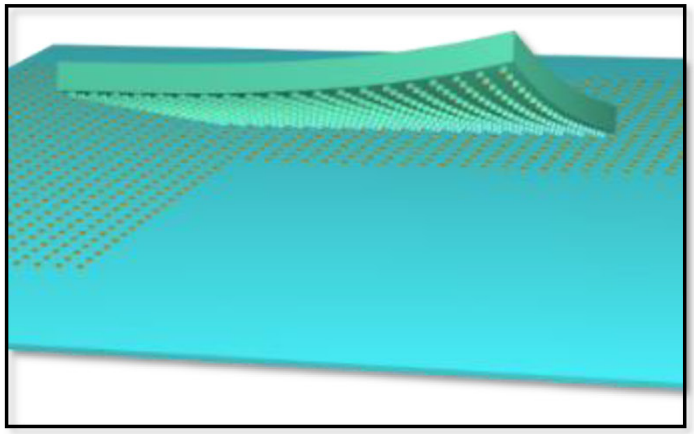
Micro assembly with an elastomer stamp



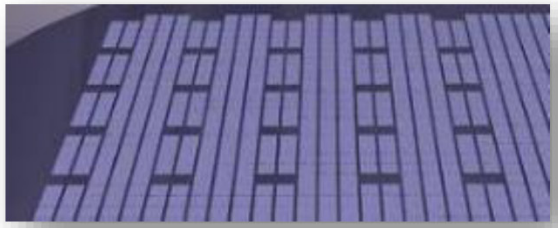
Nature Mater. **5** 33-38 (2006)

*Precise, **Deterministic** Dispersal of Micro Devices*





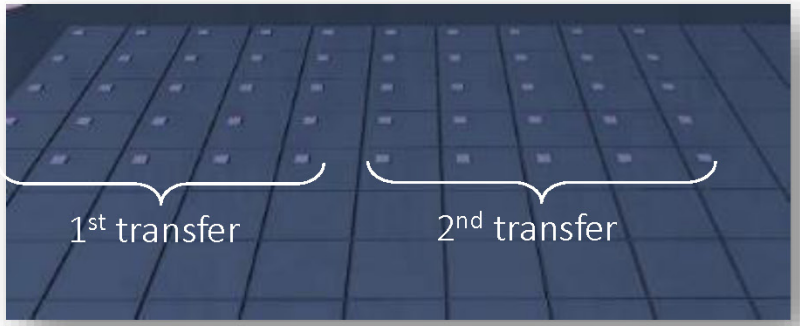
Source Wafer



Densely packed micro components

Printing

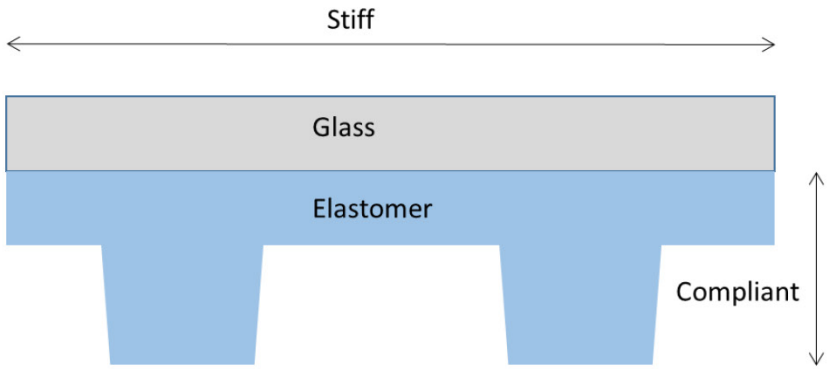
Non-native “Target” Substrate



Dispersed micro components

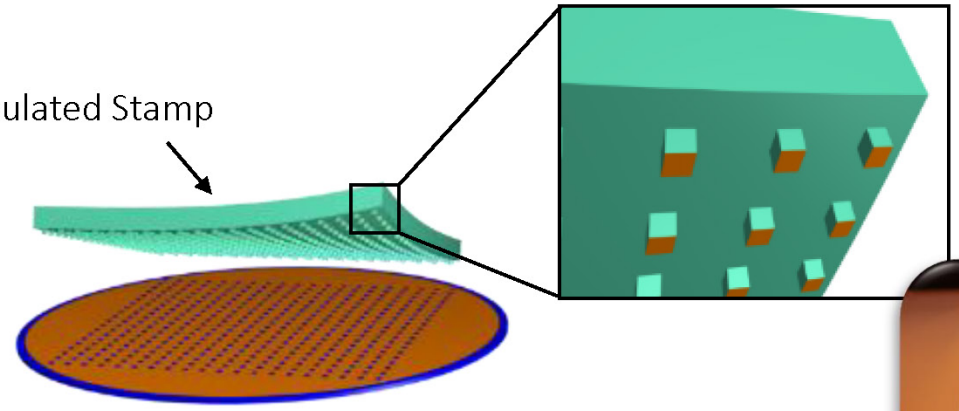
Elastomer Stamp:

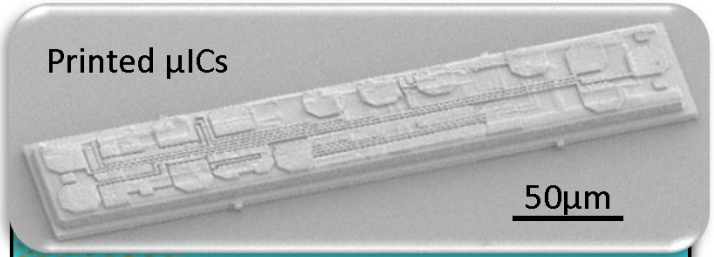
Microscale manipulation with macroscale scalability



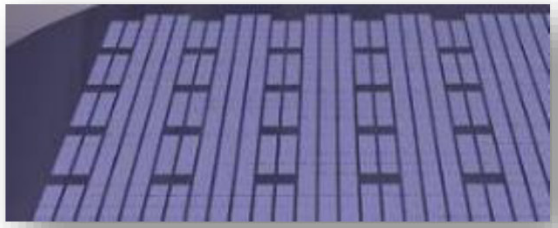
- Naturally compliant in the Z Direction: contacts real-world surfaces over large areas
- Laterally stiff: maintains lateral registration
- Soft contact: Ideal for handling fragile & thin semiconductor devices
- Transparent: Facilitates optical alignment through the stamp during printing
- Low cost: Injection molded with inexpensive materials (glass & silicone)

*Precise, **Deterministic** Dispersal of Micro Devices*





Source Wafer

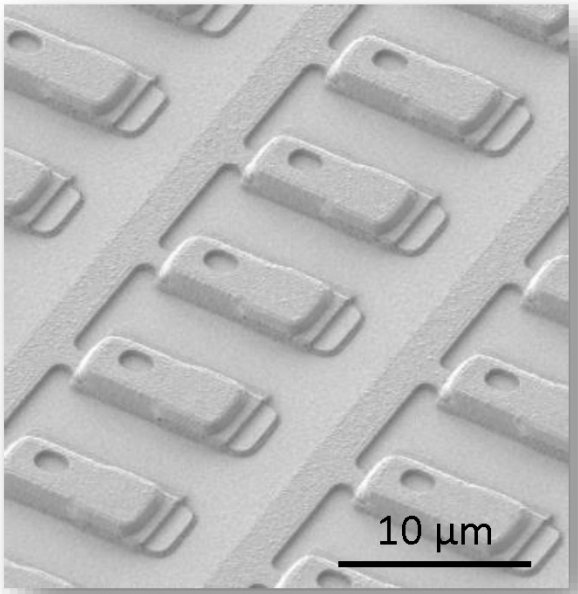


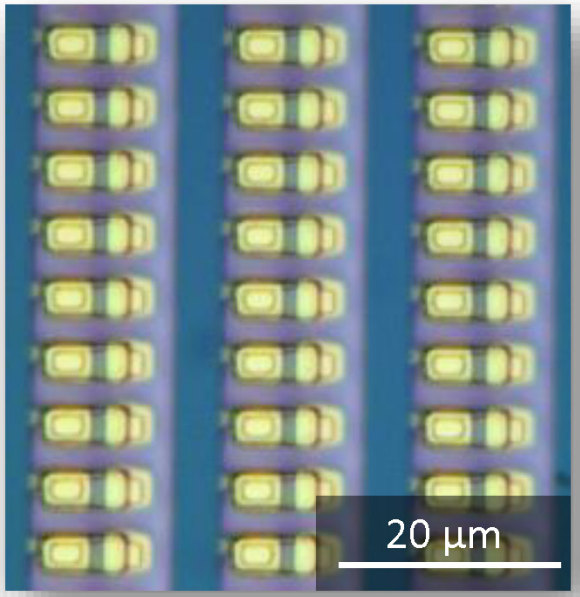
Densely packed micro components

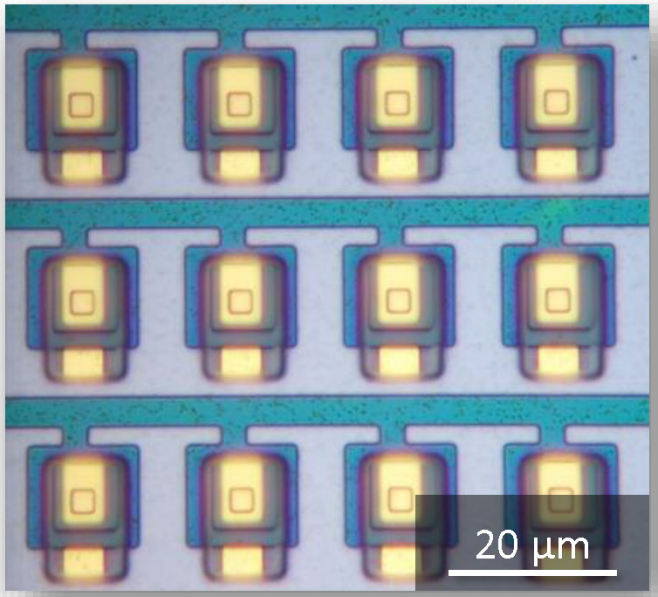
Printing

µ-LEDs Fabricated on Native Substrate

Horizontal iLEDs, variety of shapes & sizes.



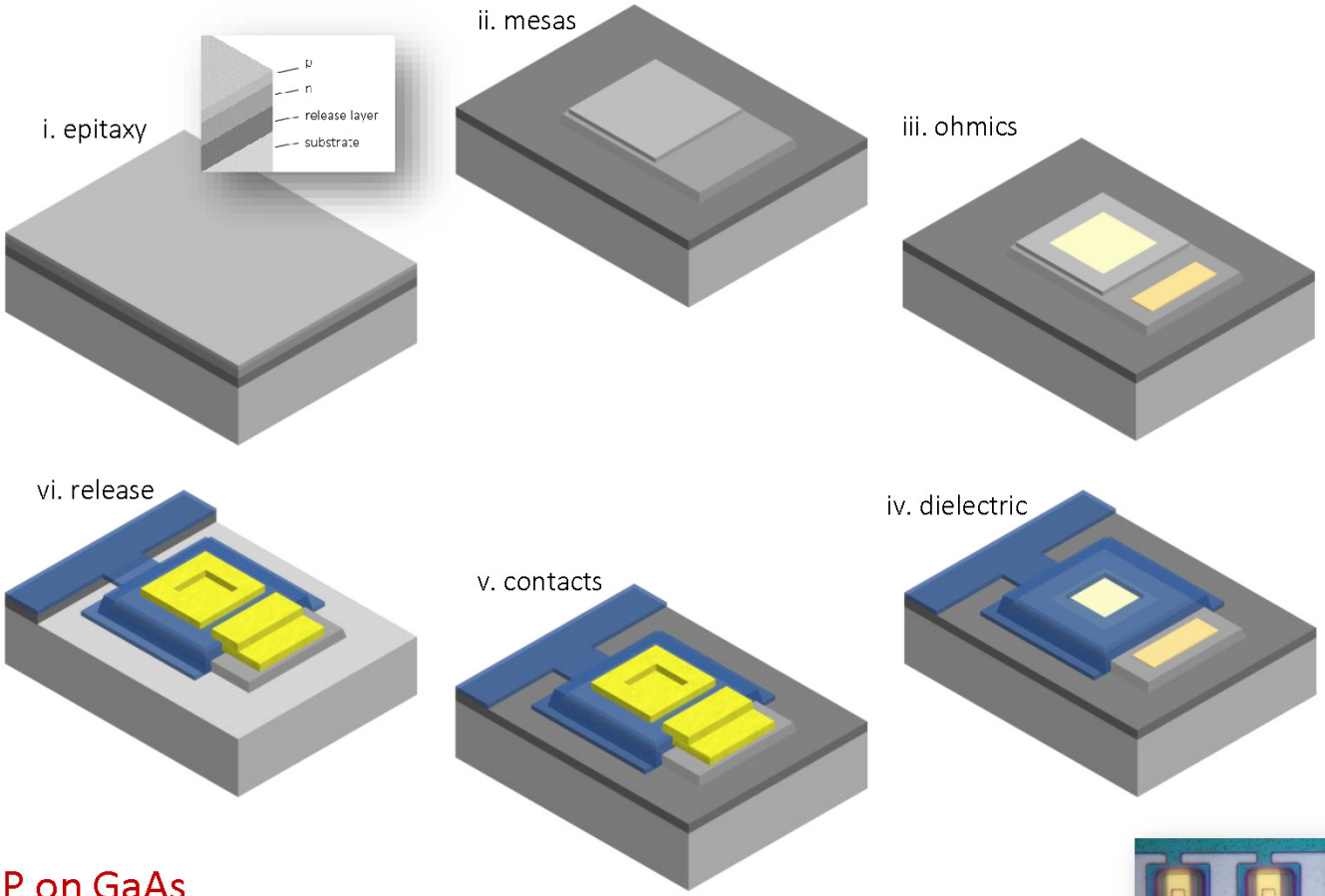




3 x 10 μm^2

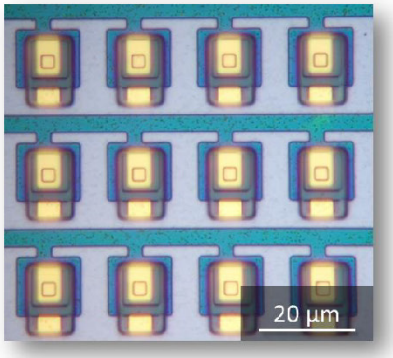
8 x 15 μm^2

LED Fabrication Sequence

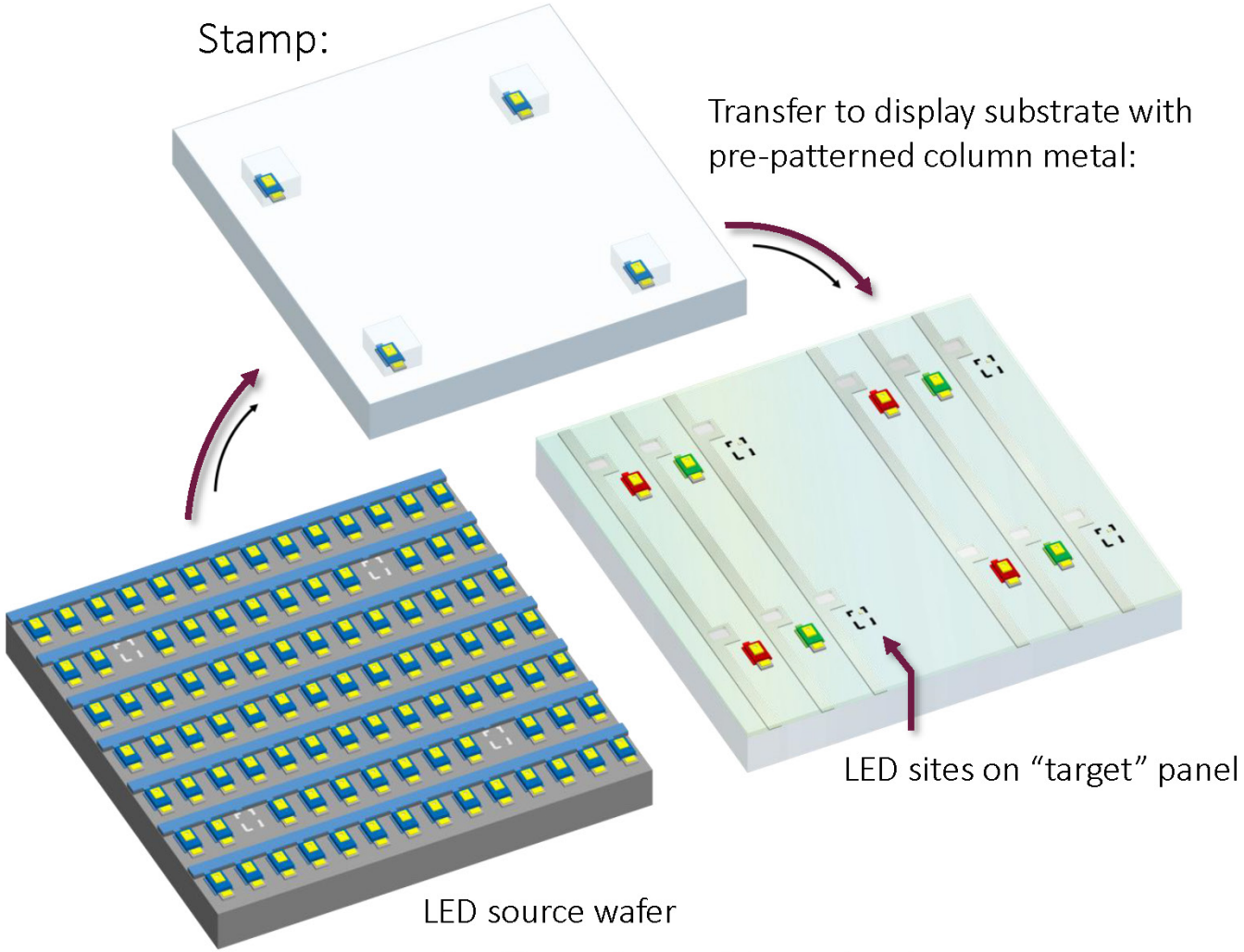


Red: InGaAlP on GaAs

Blue, Green: InGaN on Si



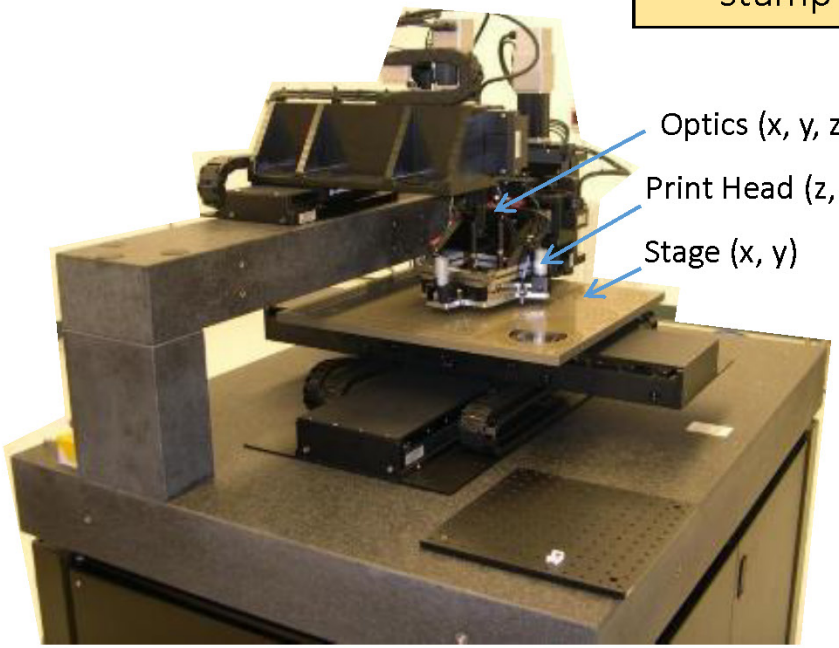
Transfer to Display Substrate

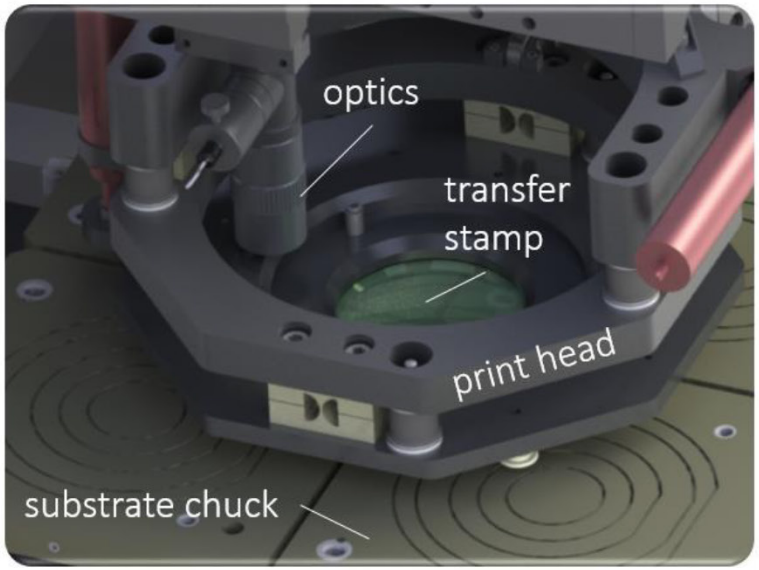


→ *Different “source” for each color*

Automated Micro Transfer Printing

stamp + motion + optics





Henderson, NC

Durham, NC

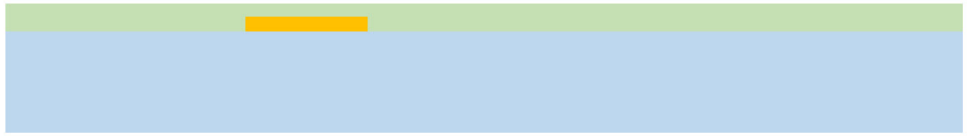
Tyndall, IE

RTP, NC

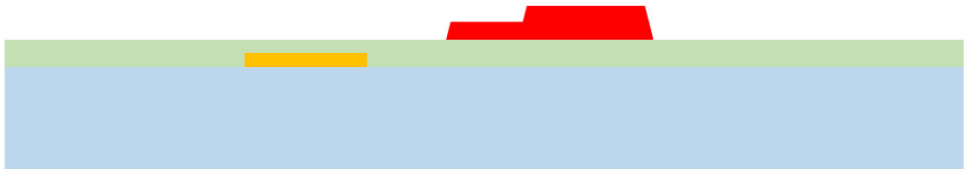
X-Celeprint

Micro Transfer Printed PMiLED Display Process Flow

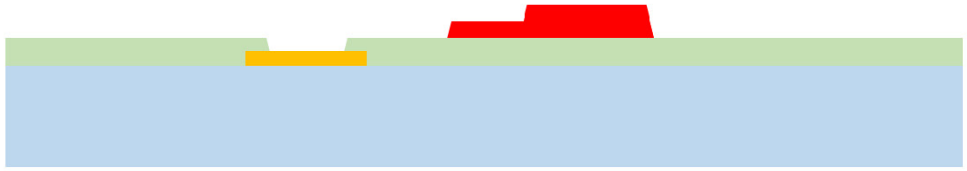
form first metal on substrate and apply a dielectric layer



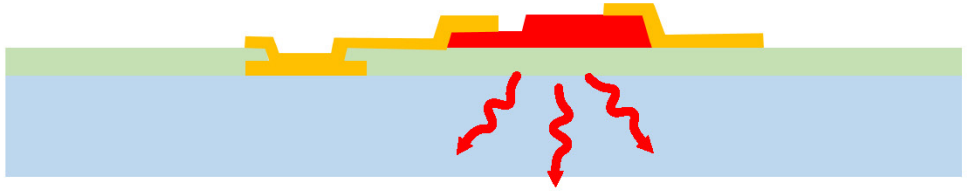
micro-transfer-printing of iLEDs



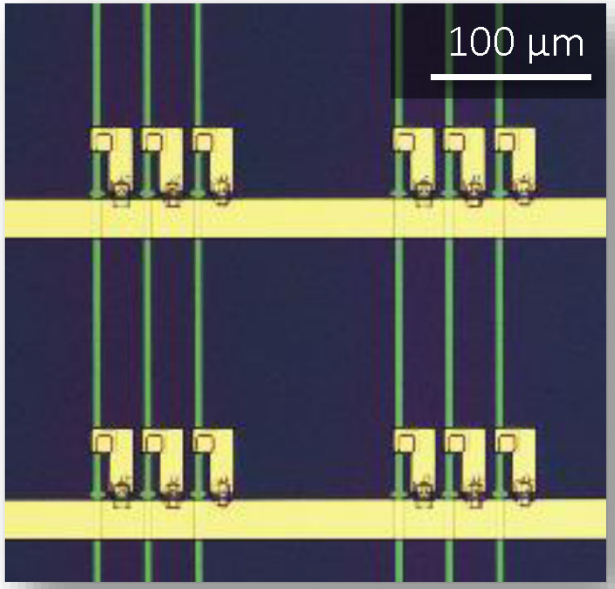
open via to first metal

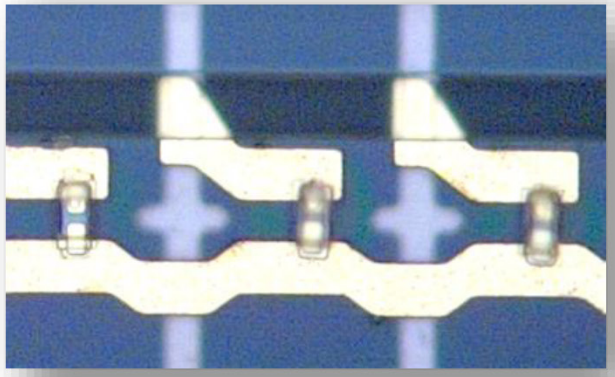


form second metal that can connect iLED to first metal



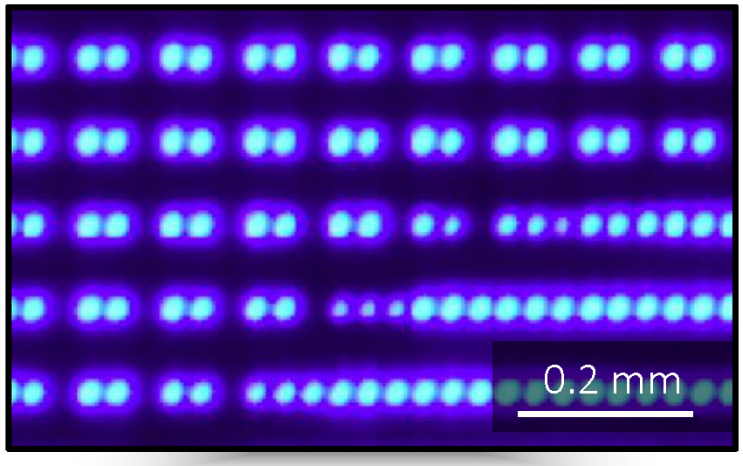
- substrate can be glass or plastic
- 3 photolithography levels

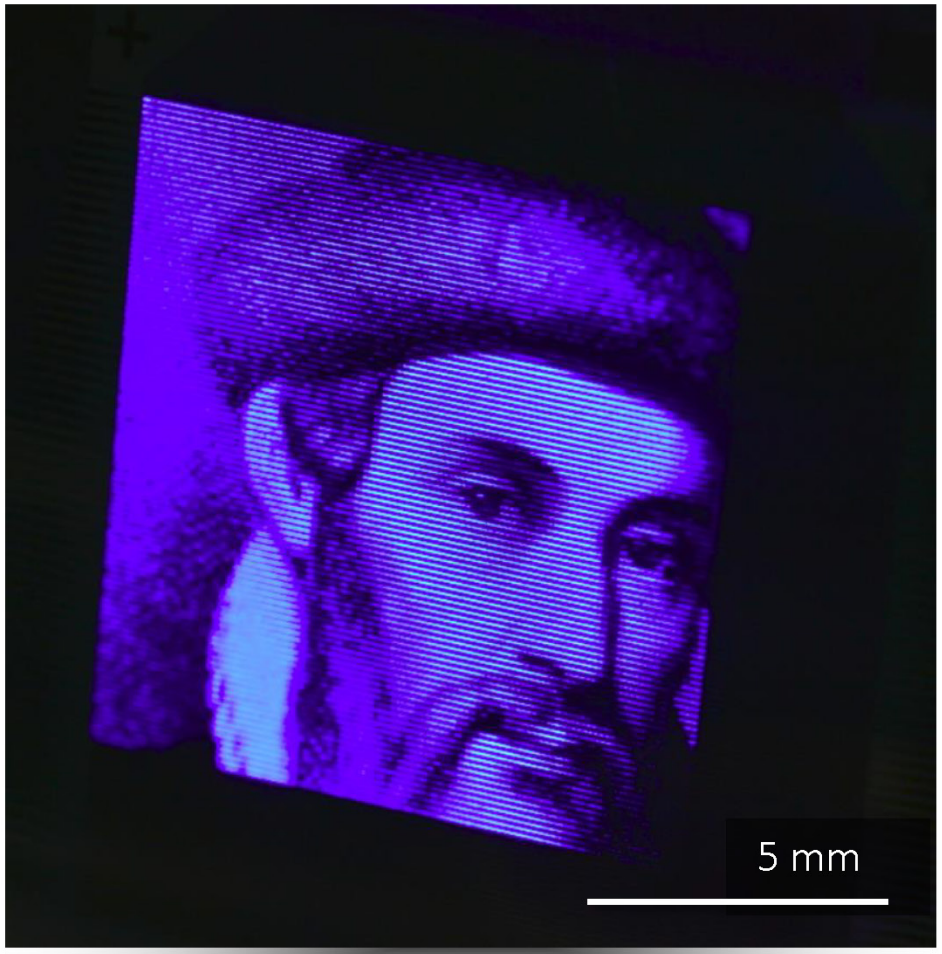




Monochrome Blue PMiLED

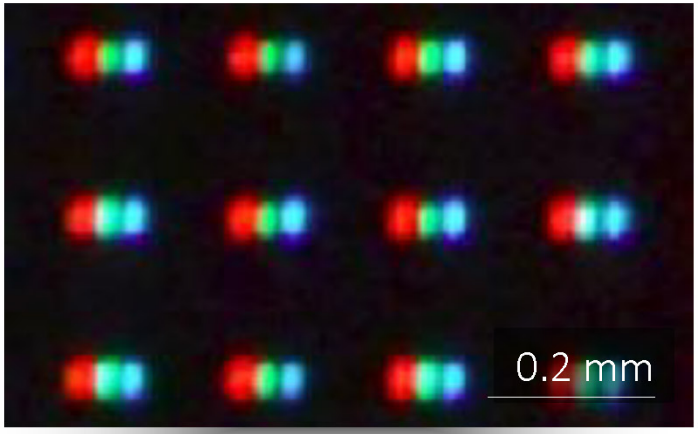
- 100 BBB x 100 pixels
- (3 blue LEDs per pixel)
- 100 µm pixel
- 10,000 posts on stamp
- 3 print operations





RGB PMiLED

- 100 RGB x 100 pixels
- 200 µm pixel
- 2,500 posts on stamp
- 12 print operations



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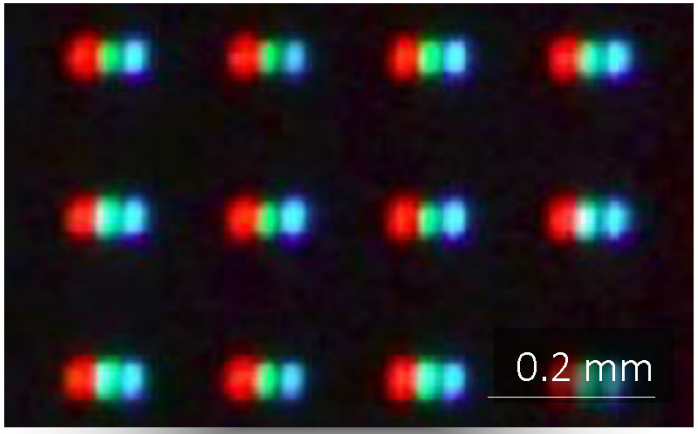
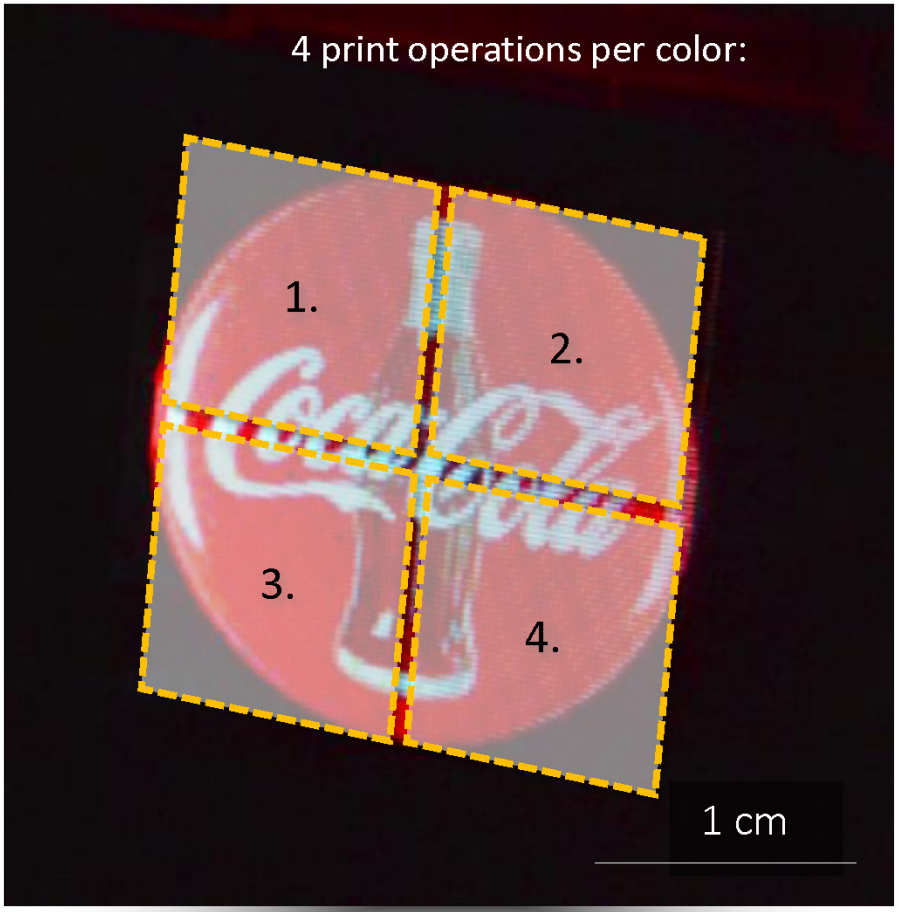
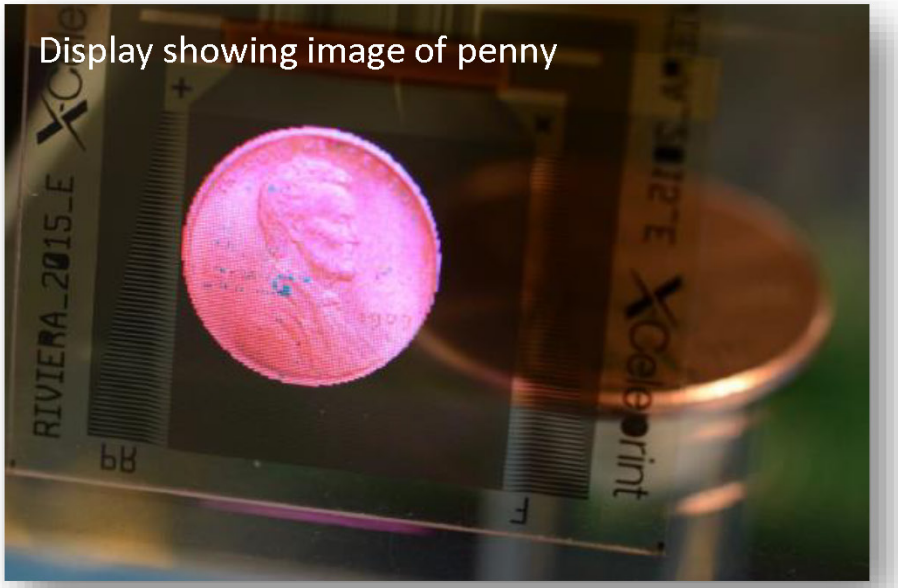
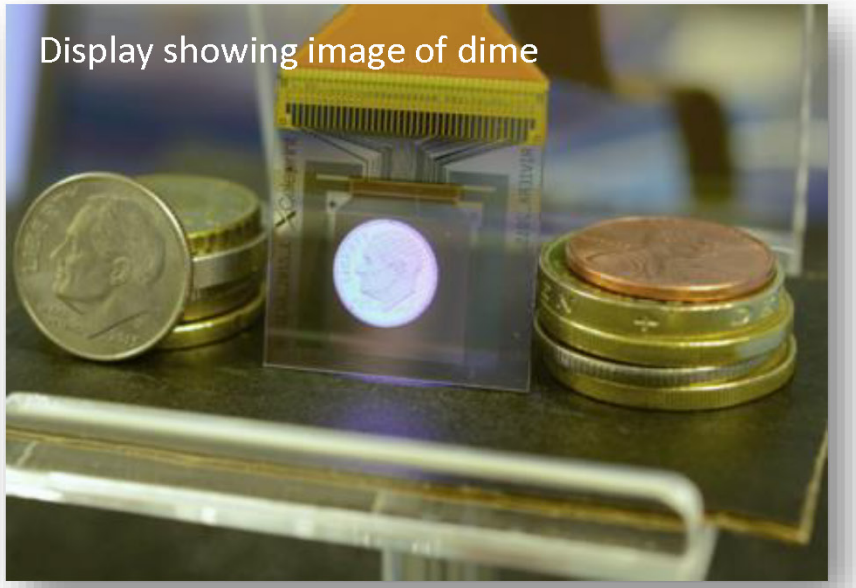
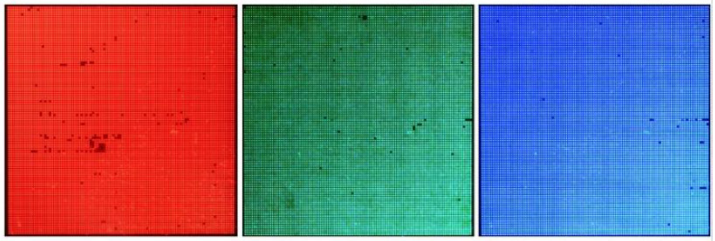




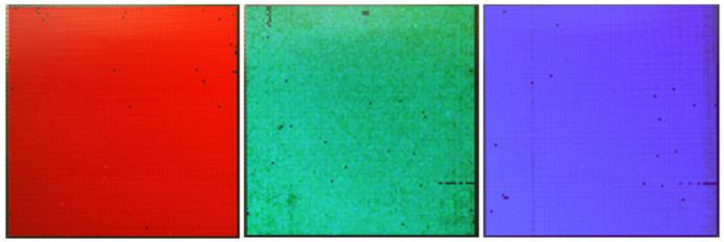
RGB PMiLED: Sub-Pixel Functional Yield







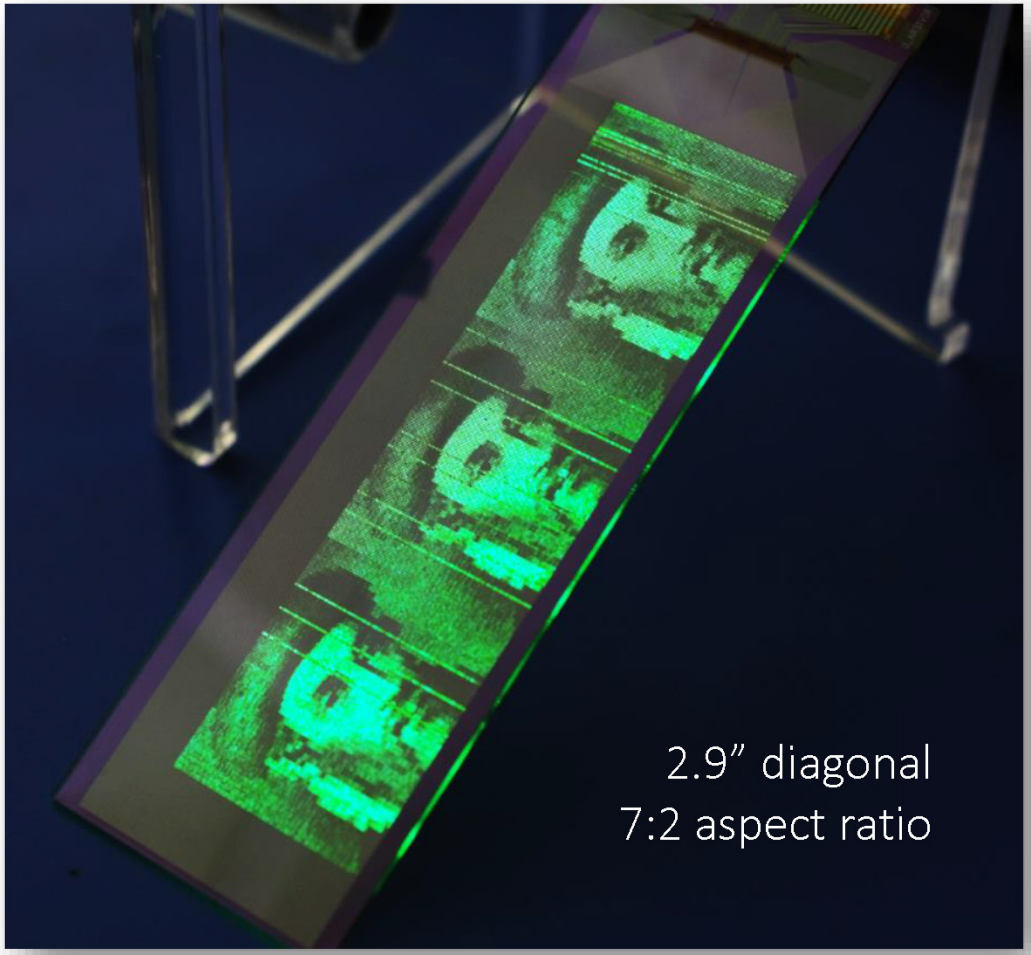
98.6% 99.7% 99.8%



99.7% 99.5% 99.7%

Band-Shaped Display

- 350 x 100 monochrome pixels
- 200 µm pixel
- 14 “prints” to populate display
  - 1 cm^2 stamp
  - 2,500 LEDs per print
- 7 x 2 cm^2



X-Celeprint

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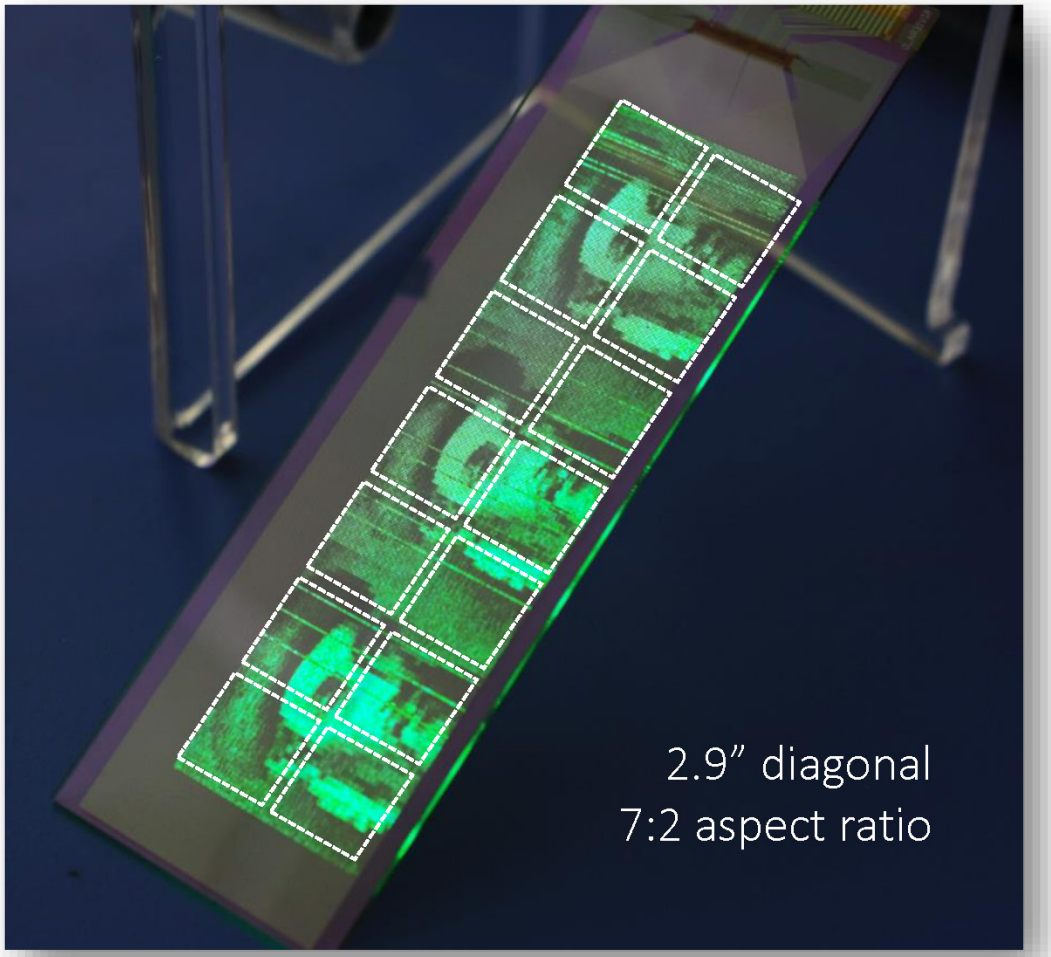
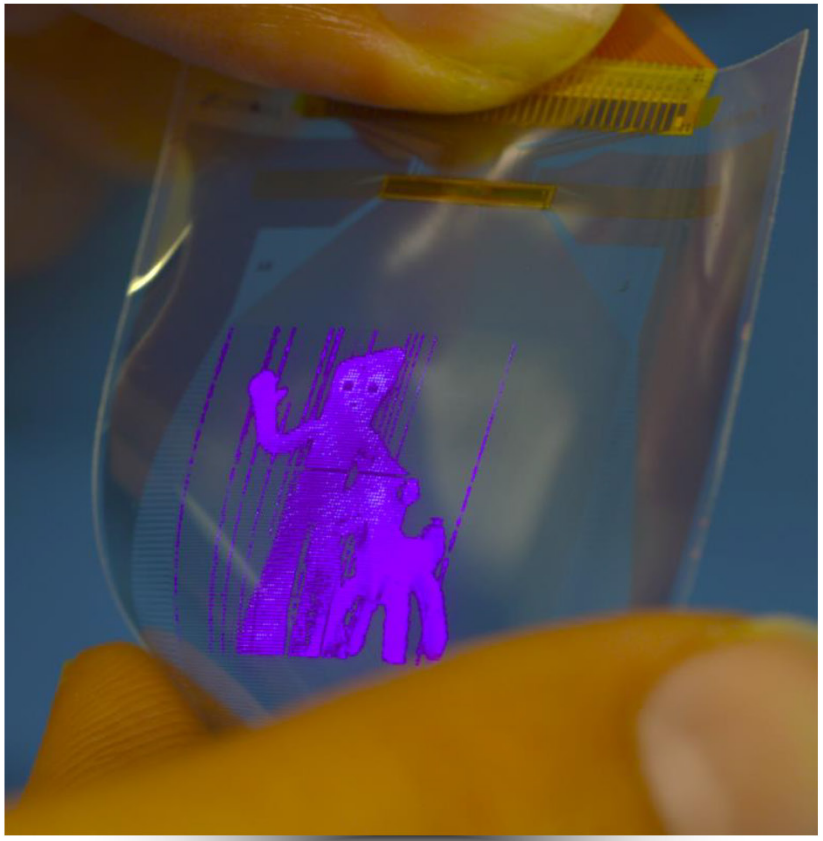
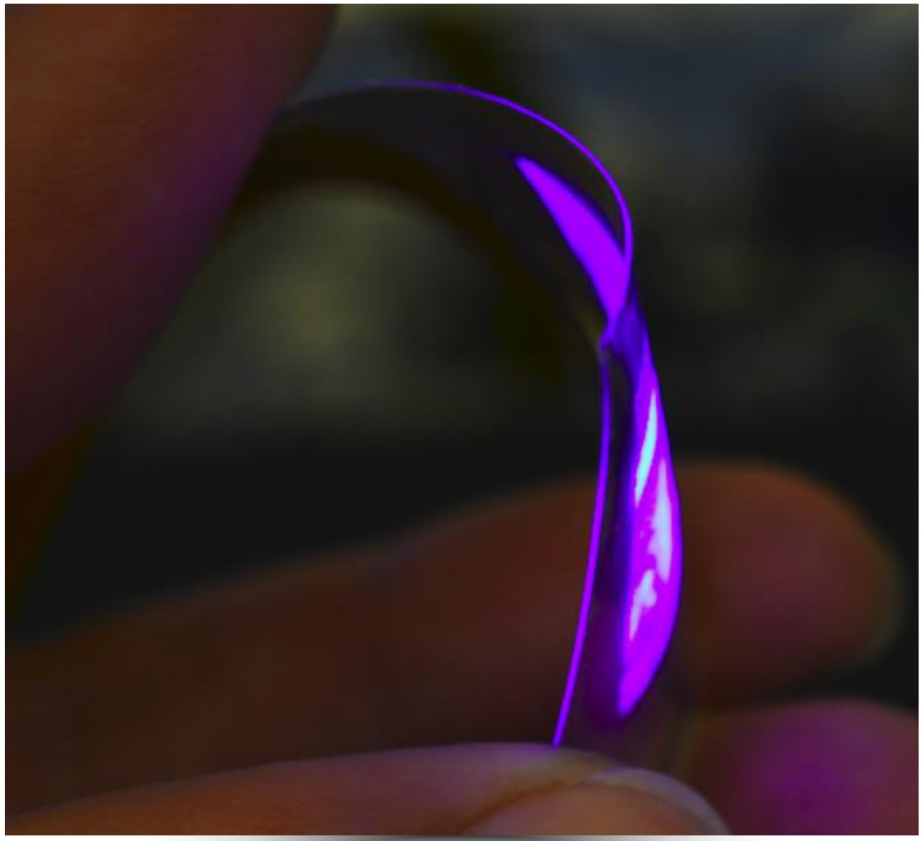


Band-Shaped Displays in Different Colors

X-Celeprint

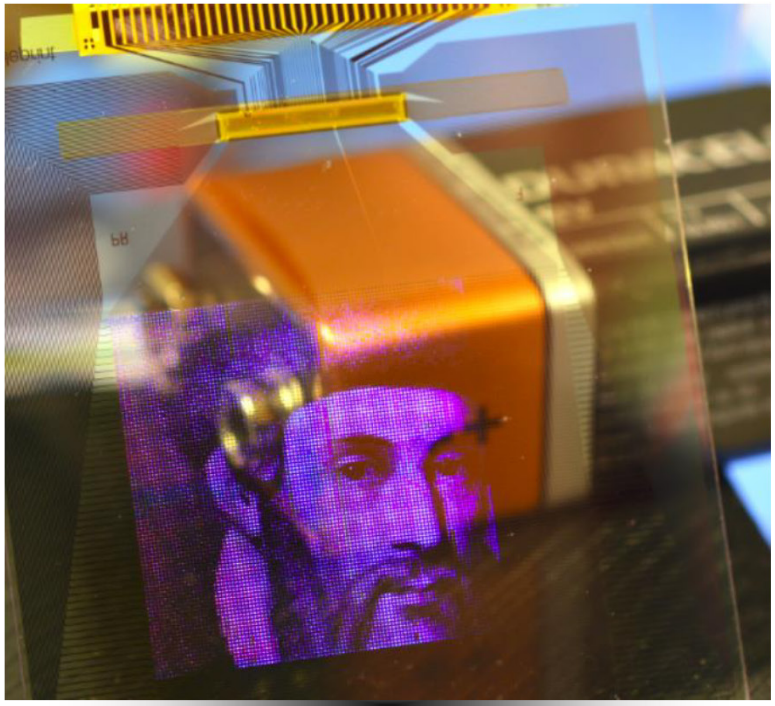
BBB PMiLED on Flex

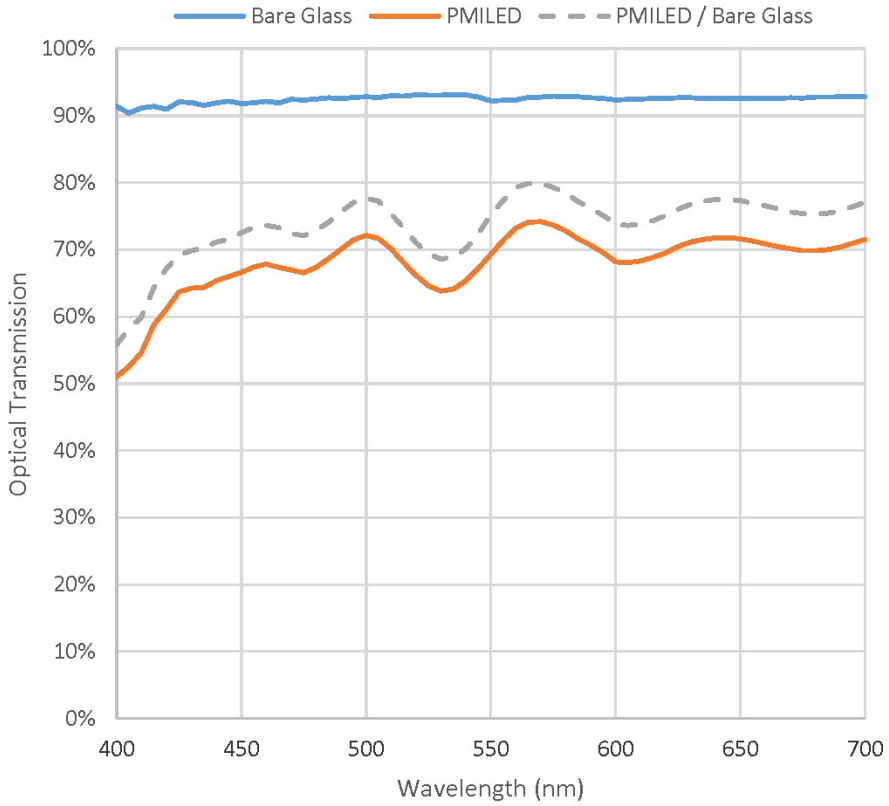




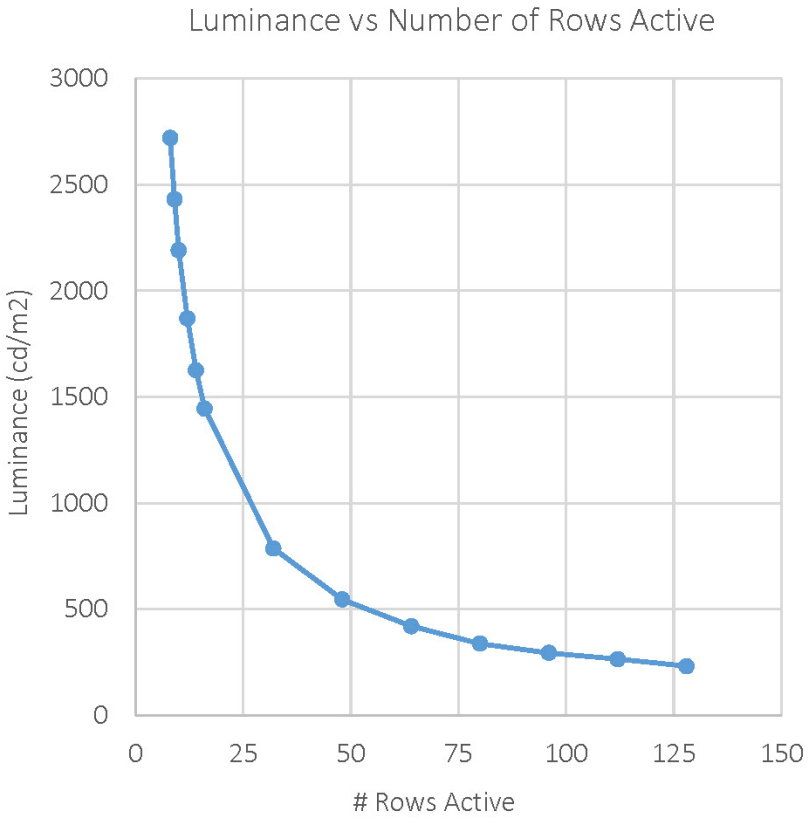
Transparency Monochrome Blue Display, 127 ppi

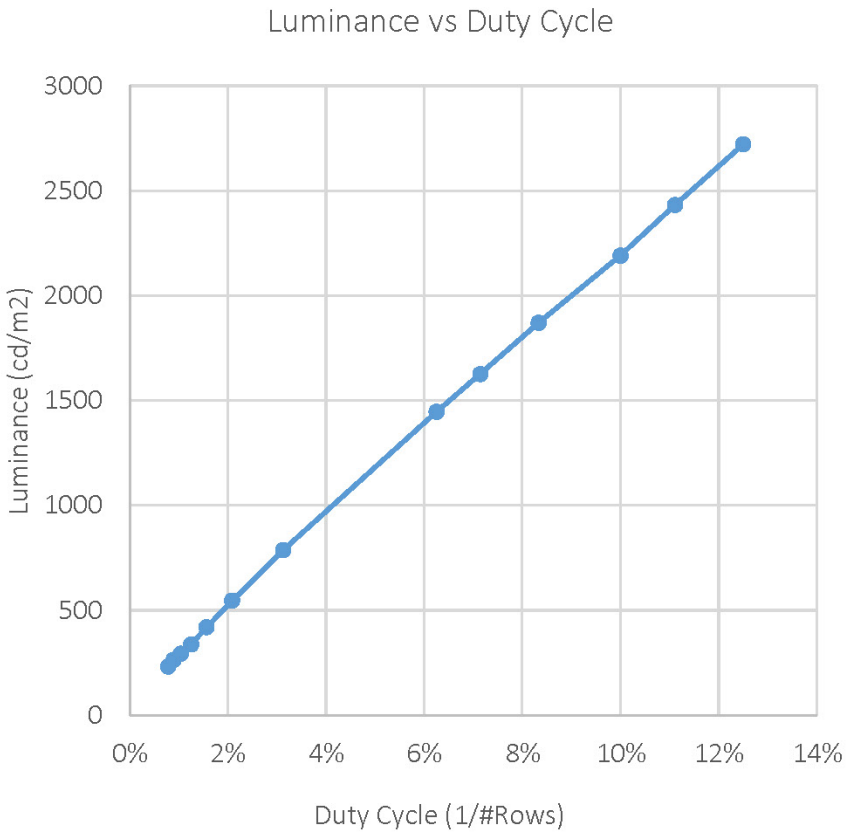
28 mm diagonal array of LEDs





Brightness, Row Reduction



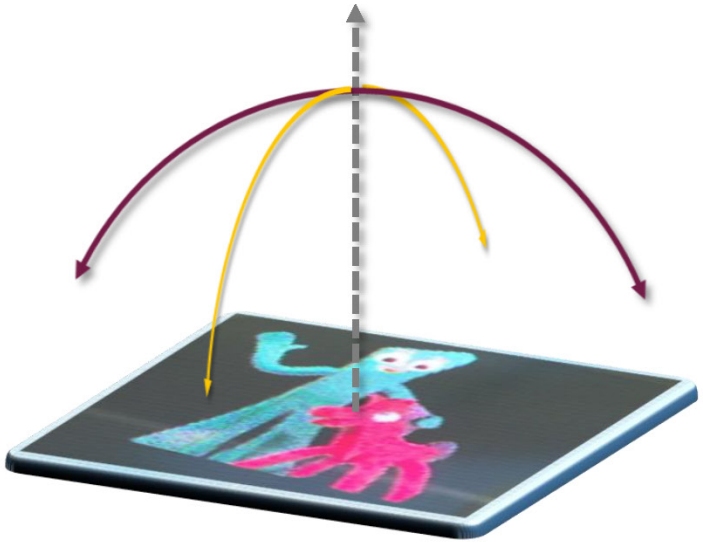


KONICA MINOLTA

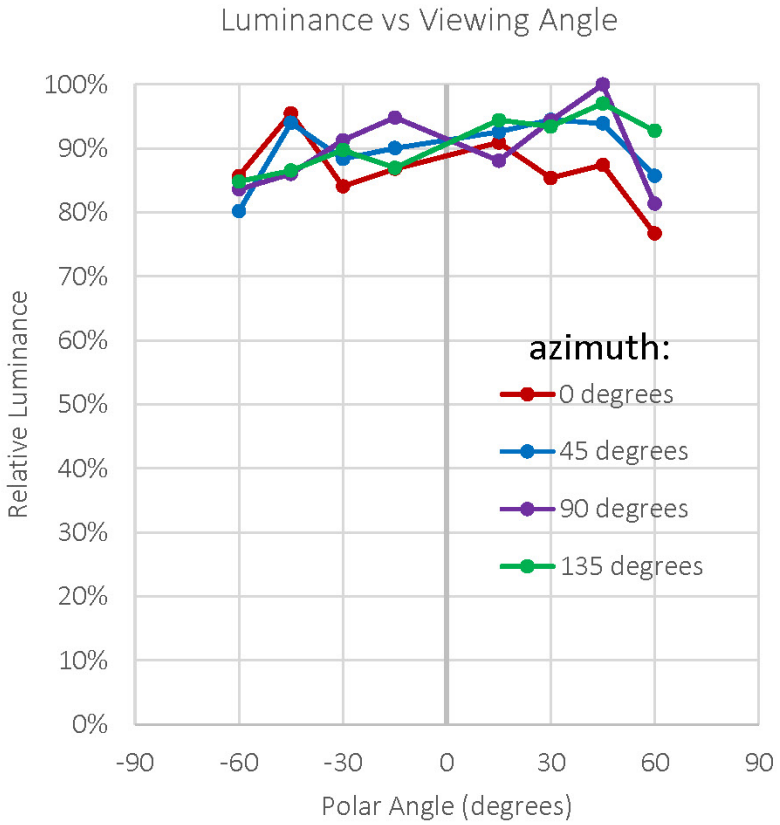
LS-110 Luminance Meter

X-Celeprint

Effect of Viewing Angle on Luminance

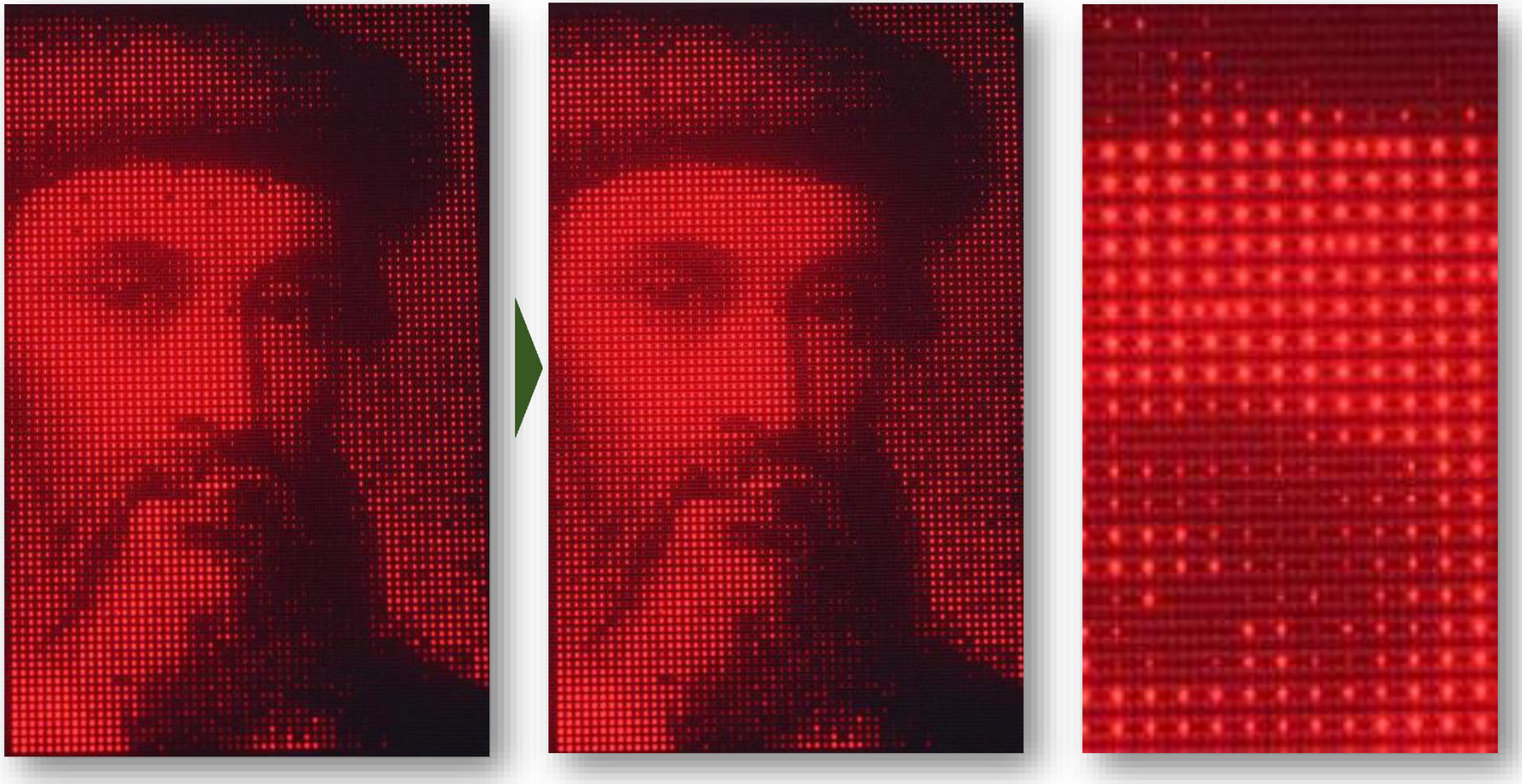


LS-110 Luminance Meter



Luminance remains ~constant to +/- 60°

Electronic Repair: Activating Spare iLEDs

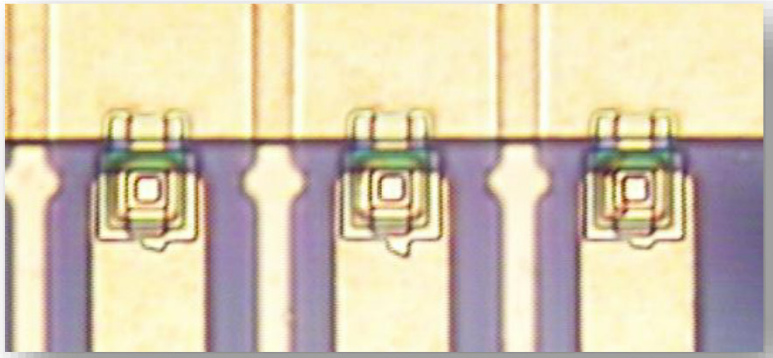


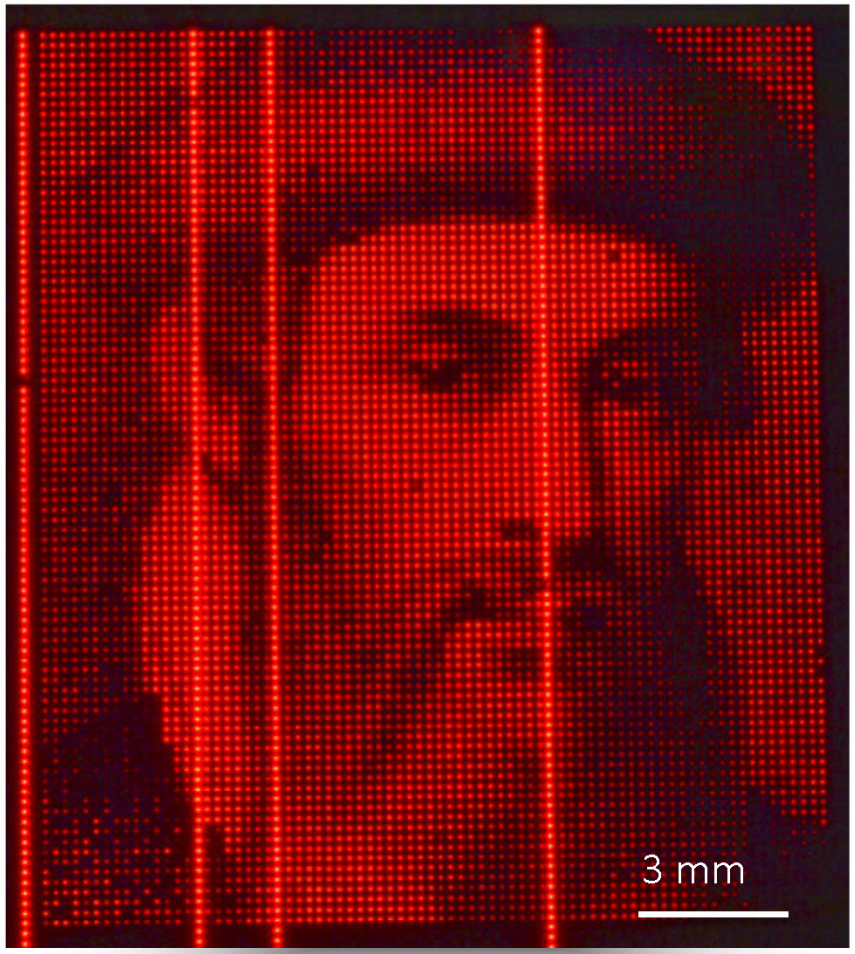
Activating Spare LEDs in BBB Display

Physical Repair

Shorted LEDs in PMiLED displays typically result in “always on” columns.

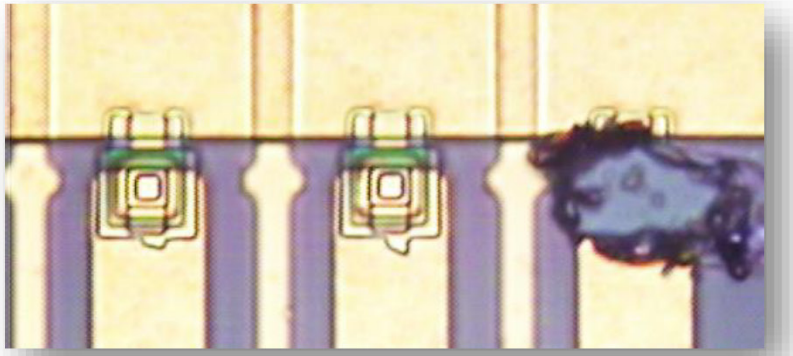
LEDs easily accessible during/after operation:

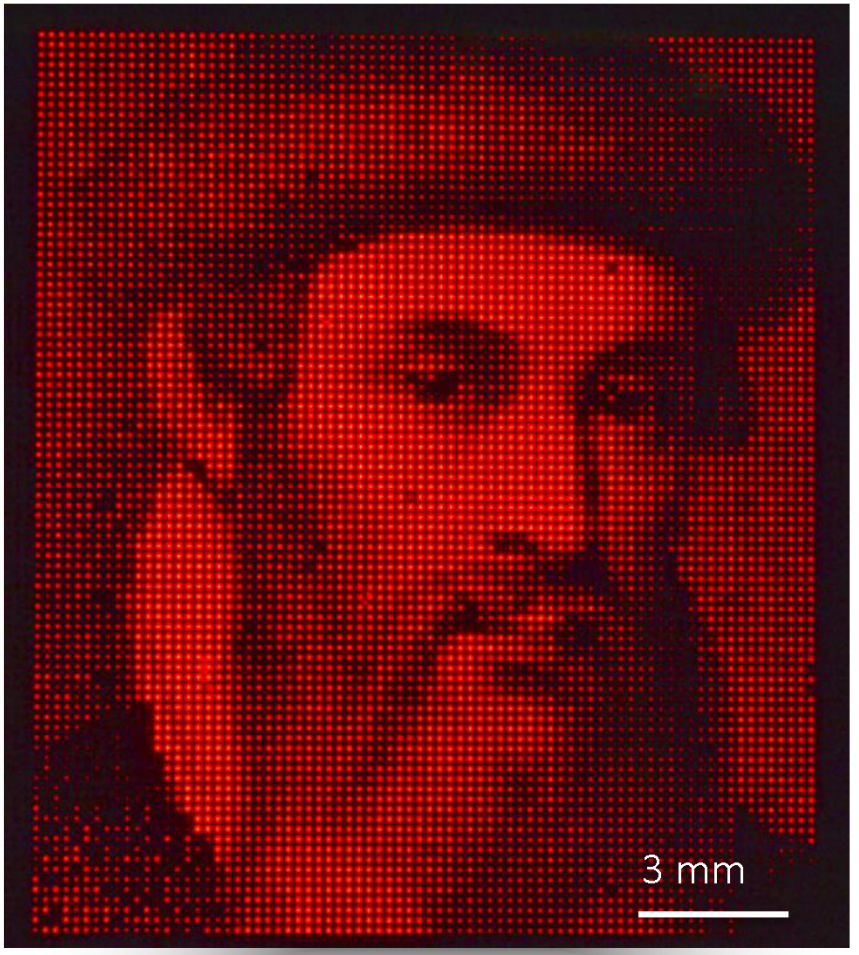




Physical Repair

Remove or disconnect shorted LEDs to clear column defect.

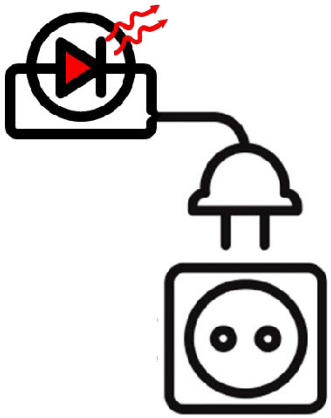


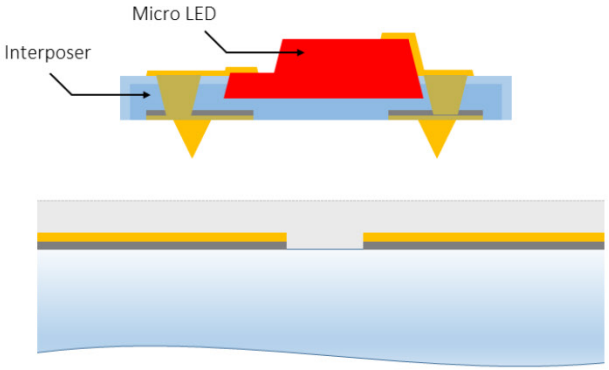


Current developments

36 mm displays:
Finished at printer

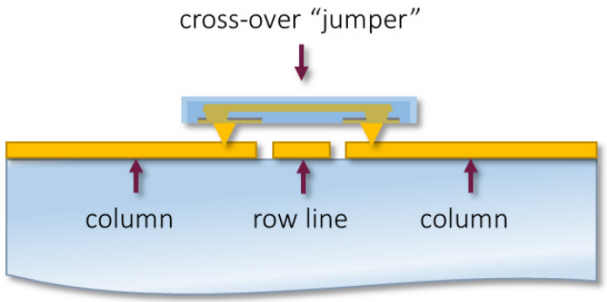
- Finish display at printer: interconnect at print. Manufacture and repair.

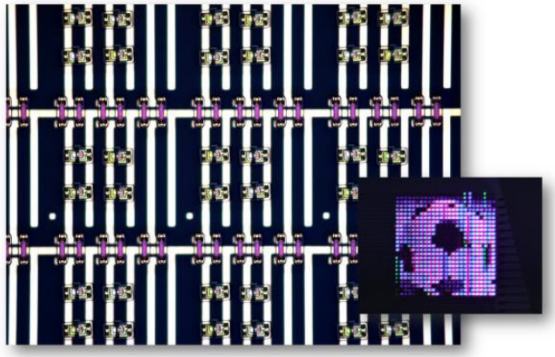




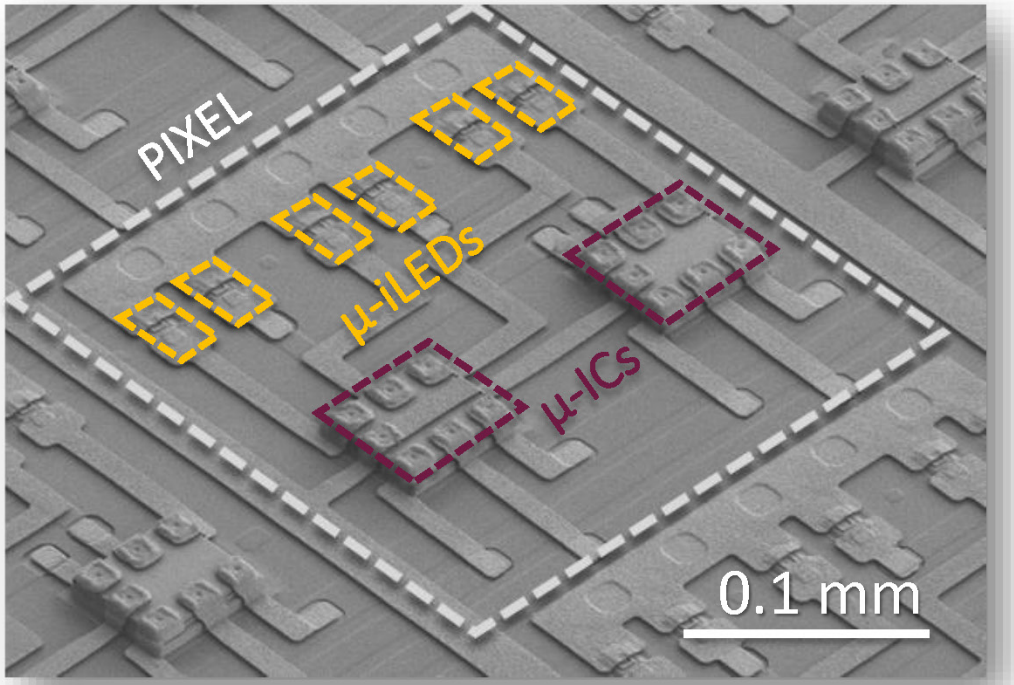
Prevatte, Carl, et al. "Pressure activated interconnection of micro transfer printed components." *Applied Physics Letters* (2016)

- Single-layer metal passive matrix with printed cross-overs:





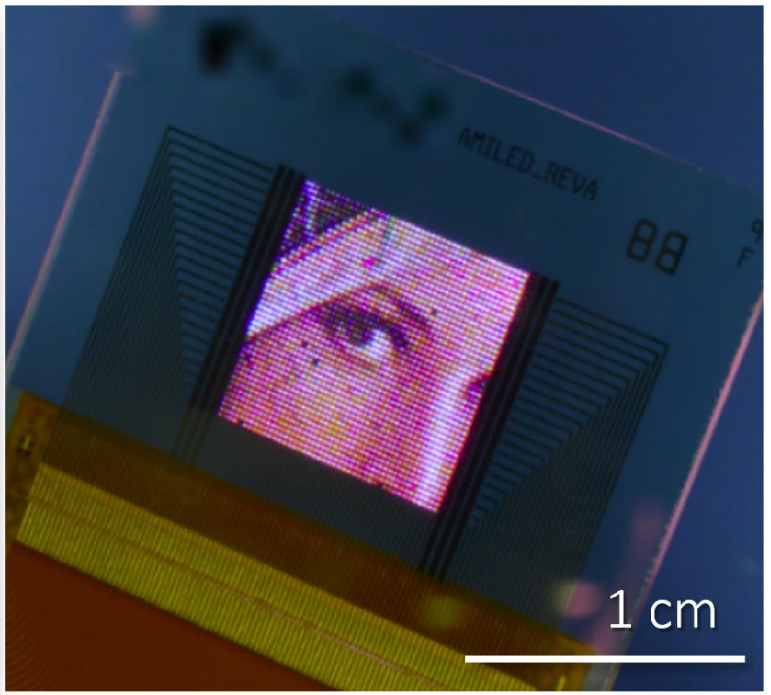
Current Developments (2): Micro iLEDs and Micro Driver ICs for AMiLED



200 μm pixels, six μ-iLEDs and two μ-ICs in each.

412 transistors per pixel; 1.8V & 5V, 180 nm CMOS.

Digital row and column inputs; current set in μ-ICs.



44 x 44 pixel display.

Active Matrix, Pulse-Width-Modulated.

Summary:

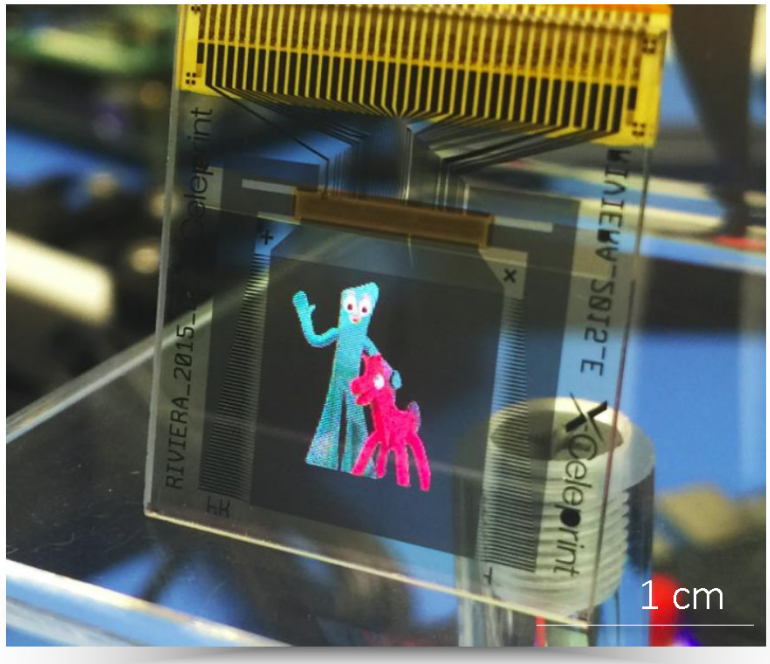
Passive matrix emissive displays fabricated on glass & plastic using arrays of transfer-printed inorganic LEDs.

- Variety of shapes and sizes, large-area processes
- RGB on non-native substrate

Interesting properties:

- Transparency, stacking, brightness, viewing angle.
- Repairable arrays, simplified panel fabrication.

Platform for advanced, multi-functional emissive displays.



Thanks from the X-Celeprint Team!

Matt Meitl, Dave Kneeburg, Dave Gomez, Sal Bonafede, Carl Prevatte, Paul Hines, Scott Goodwin, Kanchan Ghosal, Antonio Jose Trindade, Alin Fecioru, Bob Rotzoll, Sam Barnhill, Brad Krongard, Erich Radauscher, Brook Raymond, Tanya Moore, Ron Cok, Steven Kelleher, Raja Gull, George Melnik, Alexandre Chikhaoui, Kyle Benkendorfer

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