Technology and Latest Results on Fluidic Assembly of Micro-LEDs

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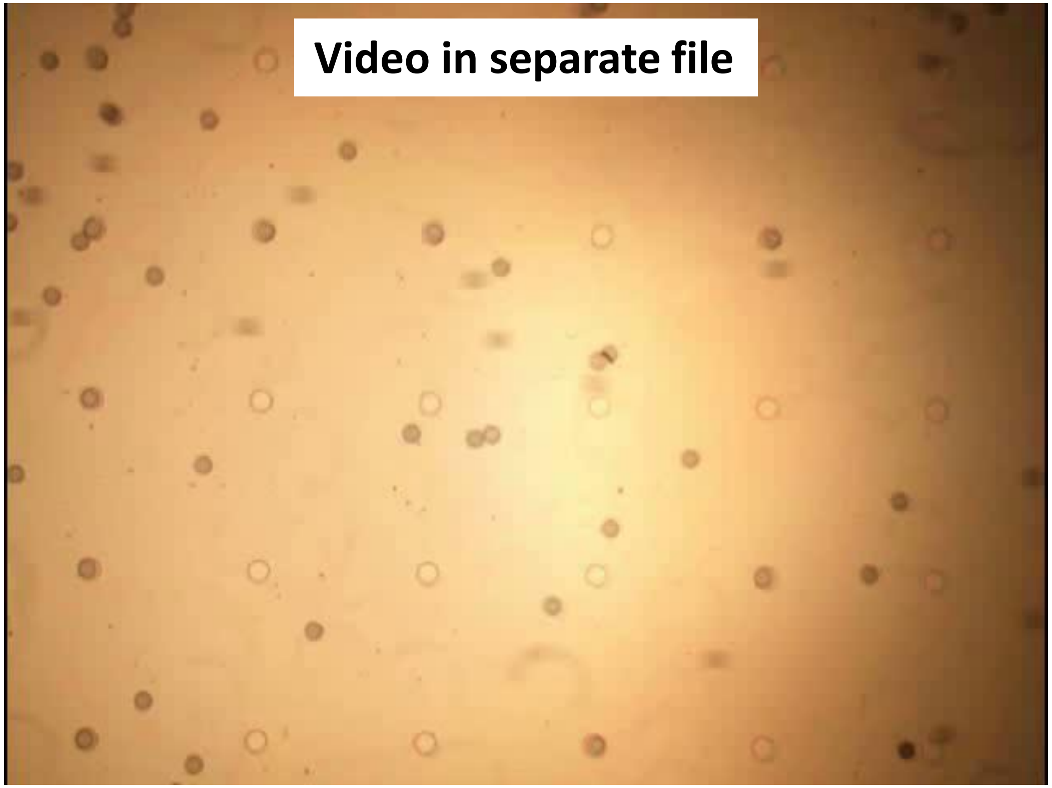
eLux

Outline

- Fluidic assembly fundamental: self alignment, orientation control
- AOI to improve fluidic assembly yield
- Mura free micro LED display
- Advantage of fluidic assembly
- Color micro LED display demonstration
- Summary

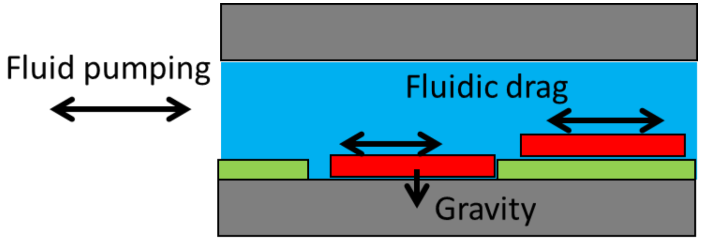
Fluidic Assembly



Dark circles are 50 µm diameter µLEDs
Light circles are 55 µm diameter wells

Oscillating flow

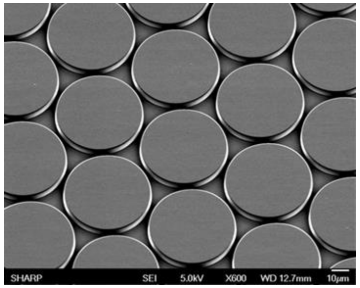
- Substrate features capture µLEDs at precise positions
- Oscillating flow yields many capture attempts
- Excess µLED disks are recycled



Good oriented fill with p-GaN up

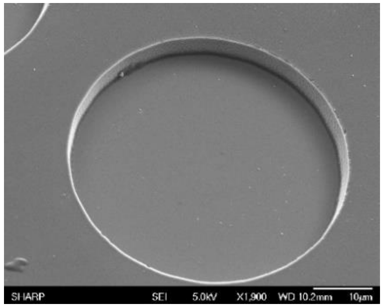
- **>99.9% fill**
- 100% correct alignment
- **Rate > 50 million µLEDs/hr on 12" tool**

µLED Disc Array Construction

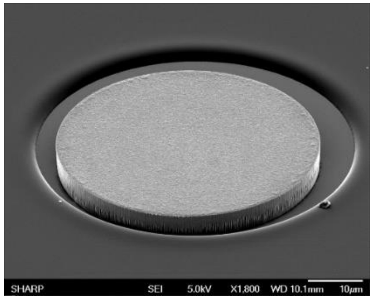


High Brightness µLED

Harvested µLED



Well on Glass



Fluidic Assembly

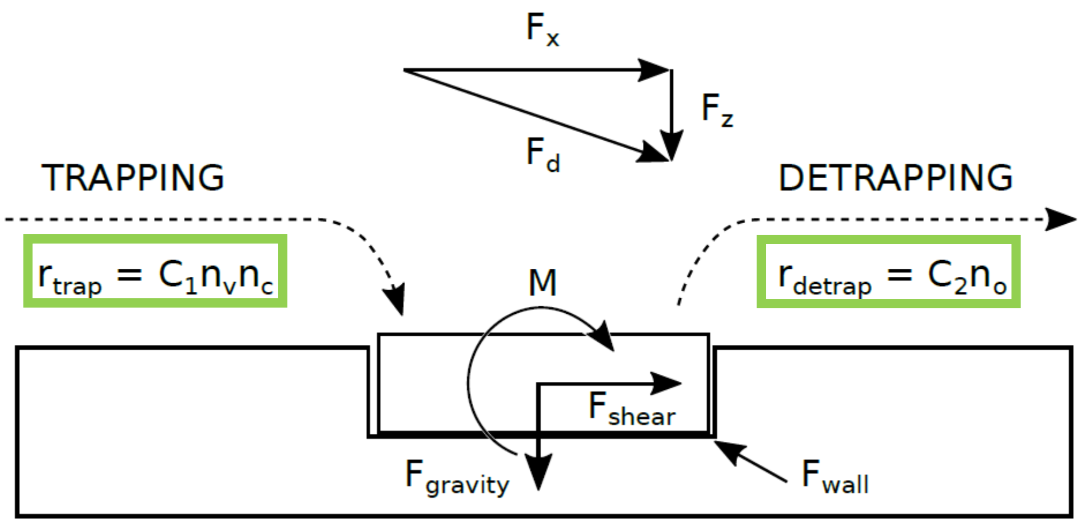
- Make µLEDs from commercially available LED wafers
- Harvest µLED disks into an ink for fluidic assembly
- High speed oriented fluidic assembly to position µLEDs in array
- **Simple, low cost high volume manufacturing**

- **µLED assembly is the critical processing technology**
  - **Motion:** Distribute µLED over the backplane to trapping points
  - **Trapping:** Position and hold the µLED precisely to make array
  - **Orientation: Orient 100% of µLED diodes for forward bias**

µLED Array

LTPS TFT driven µLED
~600,000 µLEDs at 167 ppi

Brief Fundamentals of Fluidic Assembly

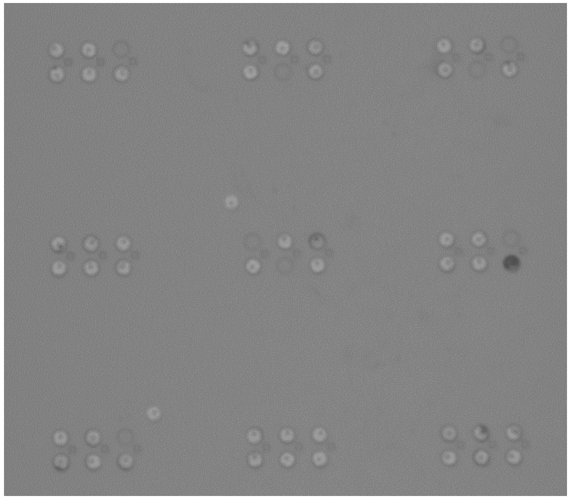


$$fill = \frac{Kn_c}{1 + Kn_c}$$

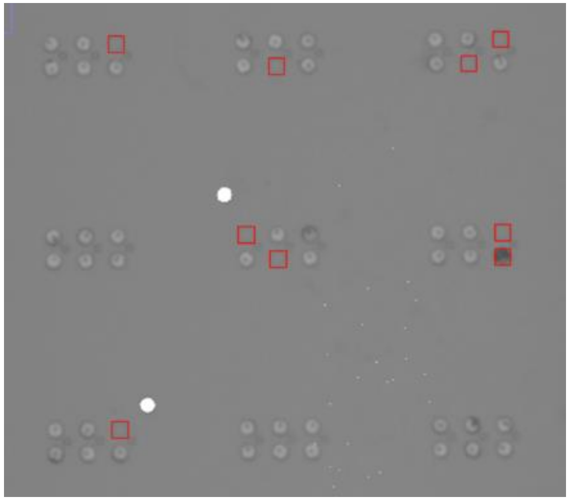
n_v: number of vacancies
n_c: number of components
n_o: number of occupied sites
C_1: trapping rate constant
C_2: detrapping rate constant
K: equilibrium rate constant C_1/C_2

- Primary goal is fill = 1
  - µLEDs move and trap $C_1 \neq 0$
  - µLEDs do not detrap $C_2 = 0$
- Secondary goals
  - Speed
  - Utilization

In-situ Control of Fluidic Assembly



Automated identification



9 defects, 2 residual

First assembly yield loss %

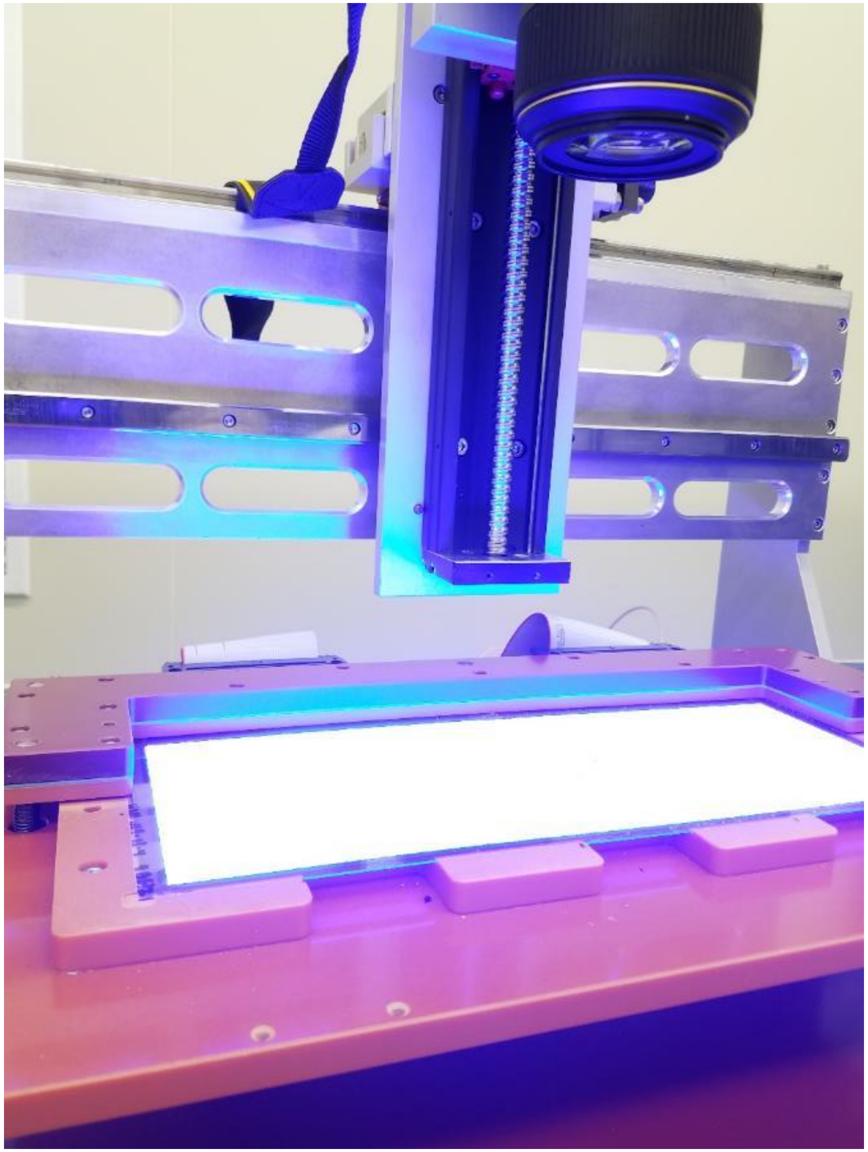
y\x	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
10	4.2%	0.0%	1.4%	2.8%	65.3%	8.3%	2.8%	23.6%	5.6%	2.8%	13.9%	4.2%	1.4%	0.0%	0.0%
20	1.4%	0.0%	0.0%	1.4%	4.2%	2.8%	11.1%	27.8%	9.7%	41.7%	9.7%	15.3%	20.8%	1.4%	1.4%
30	0.0%	0.0%	0.0%	1.4%	1.4%	0.0%	2.8%	1.4%	2.8%	4.2%	5.6%	5.6%	1.4%	2.8%	0.0%
40	0.0%	13.9%	19.4%	19.4%	8.3%	6.9%	8.3%	1.4%	1.4%	1.4%	1.4%	0.0%	0.0%	0.0%	5.6%
50	4.2%	12.5%	11.1%	9.7%	15.3%	5.6%	5.6%	15.3%	2.8%	9.7%	4.2%	8.3%	9.7%	16.7%	12.5%
60	62.5%	0.0%	4.2%	15.3%	16.7%	4.2%	19.4%	29.2%	2.8%	2.8%	12.5%	1.4%	1.4%	11.1%	23.6%
70	12.5%	9.7%	22.2%	30.6%	36.1%	26.4%	25.0%	44.4%	22.2%	23.6%	19.4%	2.8%	29.2%	29.2%	8.3%
80	20.8%	4.2%	0.0%	23.6%	38.9%	33.3%	51.4%	56.9%	11.1%	25.0%	70.8%	19.4%	34.7%	73.6%	62.5%
90	2.8%	12.5%	2.8%	11.1%	5.6%	6.9%	9.7%	13.9%	15.3%	11.1%	12.5%	5.6%	6.9%	45.8%	47.2%
100	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	1.4%

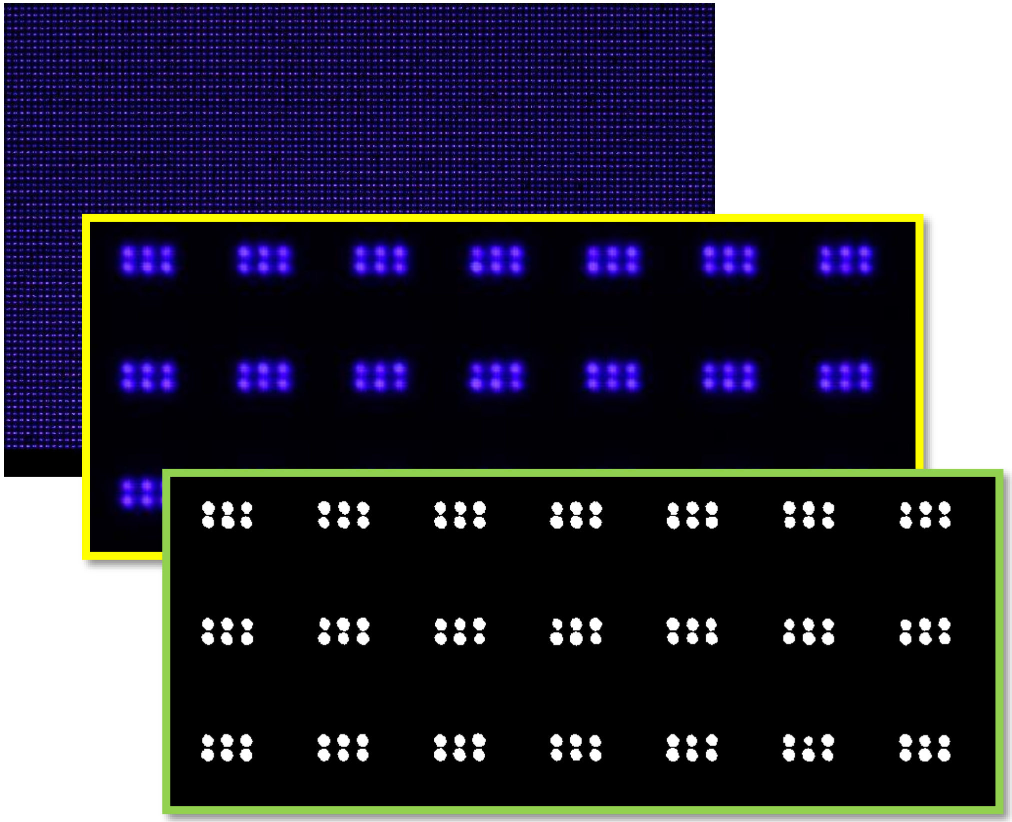
Assembly after parameter tuning

y\x	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
10	0.0%	0.0%	0.0%	0.0%	11.1%	0.0%	0.0%	0.0%	1.4%	0.0%	4.2%	1.4%	1.4%	0.0%	0.0%
20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.8%	1.4%	0.0%	0.0%
30	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
50	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	5.6%	0.0%	1.4%	0.0%
60	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
70	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
80	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
90	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
100	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

- Full display can be monitored during processing
- In-situ tuning of assembly parameters
  - Improved fill yield and assembly speed
  - Decrease residual µLEDs on surface
- End point control for completed assembly

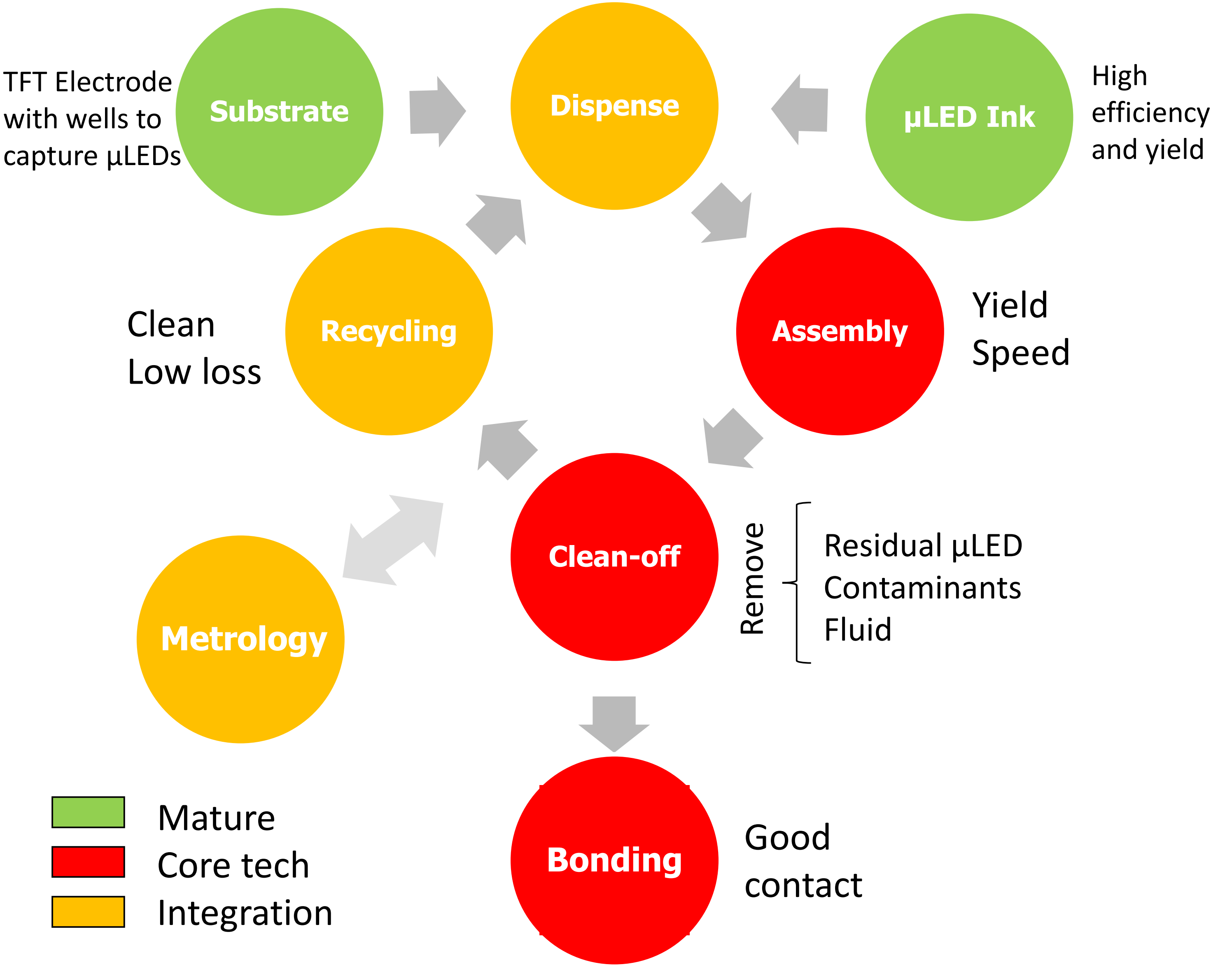
µLED Yield Metrology

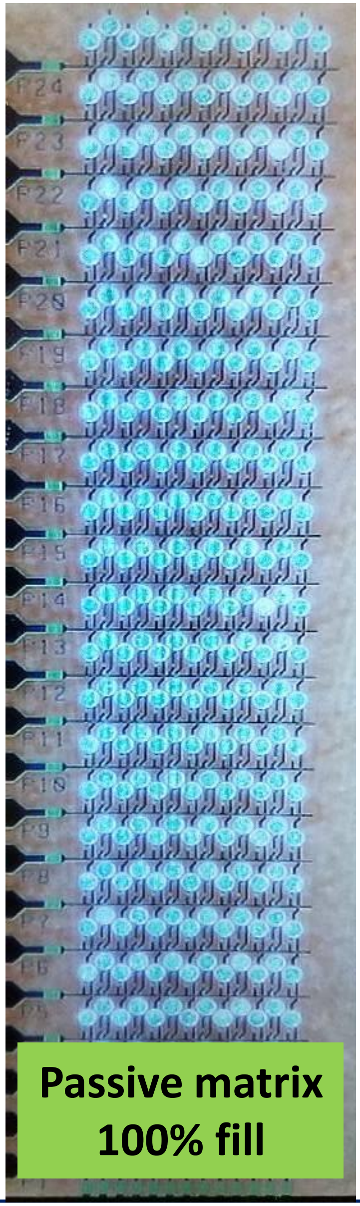




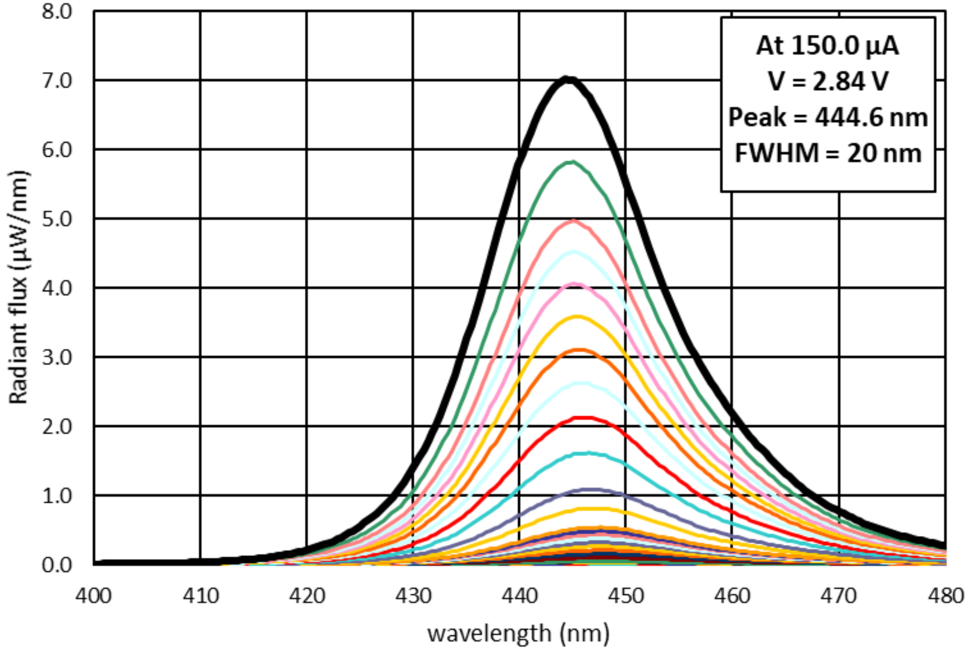
- DSLR image of µLED emission
- FOV > 45 cm^2 in less than a second
- Yield feedback for fabrication
- Repair map and Mura correction (next)

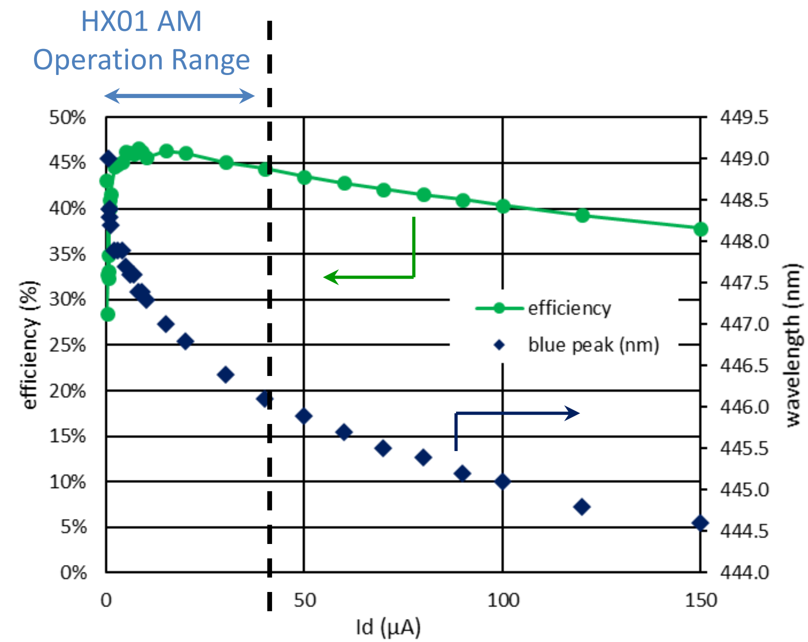
Brief Process Flow for Fluidic Assembly

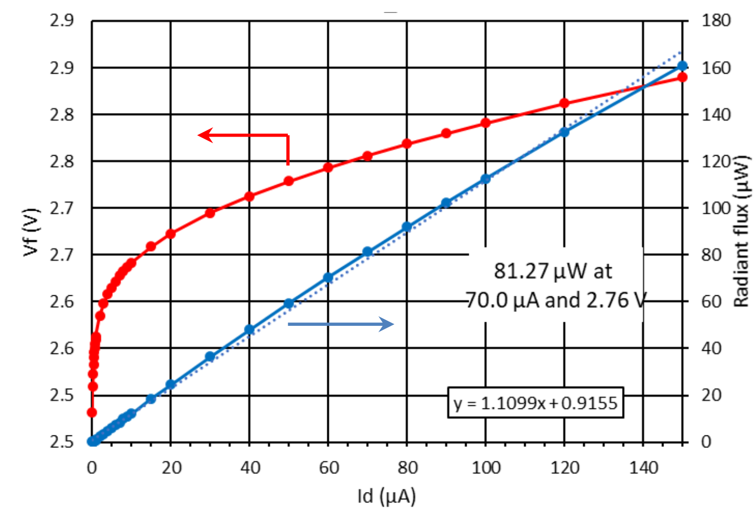




µLED Performance

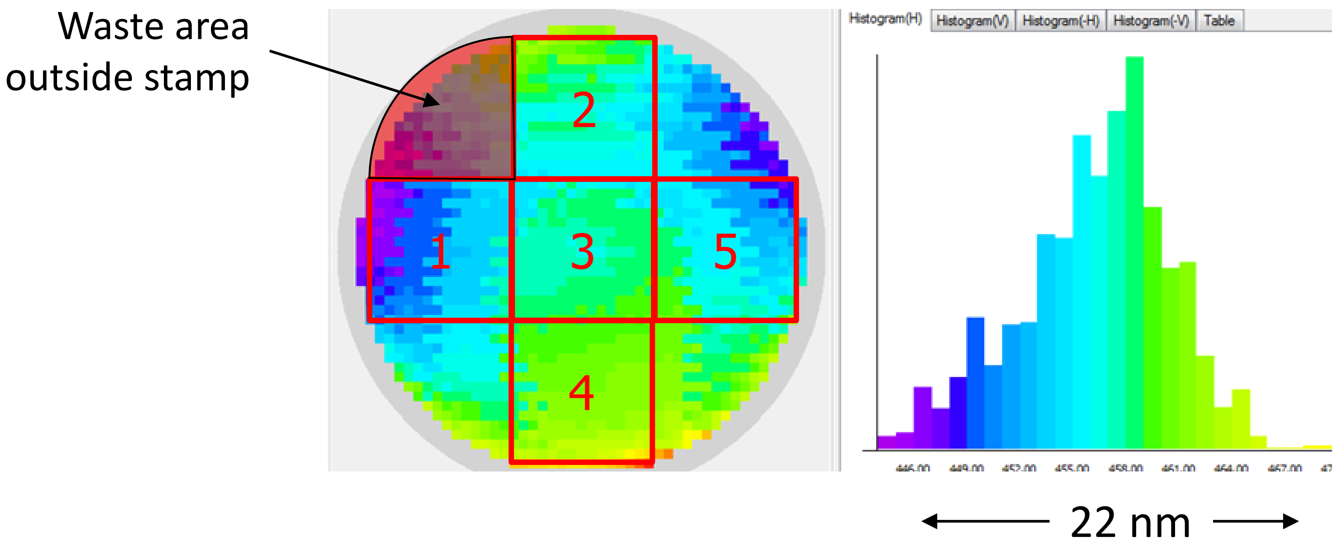






- Blue LED wafers by conventional GaN MOCVD process on sapphire
- 40 µm diameter planar µLEDs
- Harvested by laser lift off
- Higher efficiency ~45% with lower droop
- Narrow range of electrical properties with Vf at 2.75 V
- **Performance similar to general lighting LEDs**

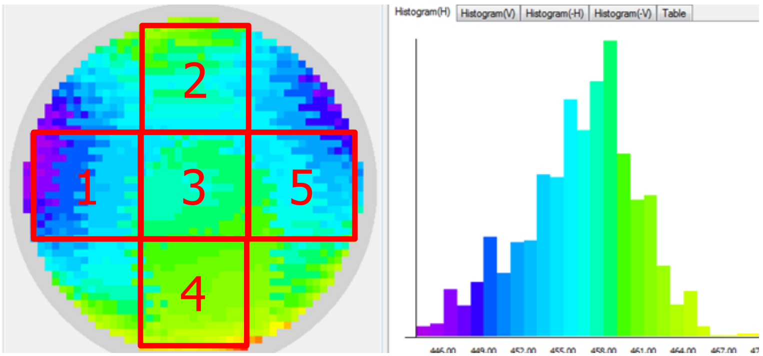
Wavelength Variations on an Epi-wafer



- Wavelength distribution
  - Conventional MOCVD has wavelength distribution > 5 nm
  - Sorting and binning is not suitable for mass transfer technology using for µLED
  - Current method is to select stamps with proper emission wavelength and discard others
- Defect management
  - Sorting can exclude the defect dies in conventional LED industry because each die is tested
  - Defective µLED dies can be detected and excluded from transfer
  - Current strategy is to repair defects on stamp area with good yield, discarding stamps with higher defectivity
- Edge exclusion
  - For faster transfer, large stamp size is preferred, but waste area is large

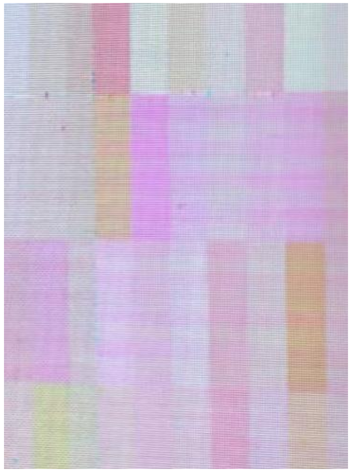
Mura Free µLED Display

Wavelength & Emission Variations on an Epi-wafer



Conventional P&P Mass Transfer

Mosaic and Non-uniform

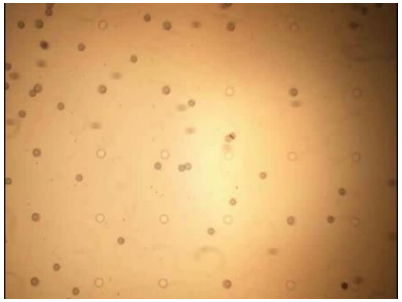


Fluidic Assembly

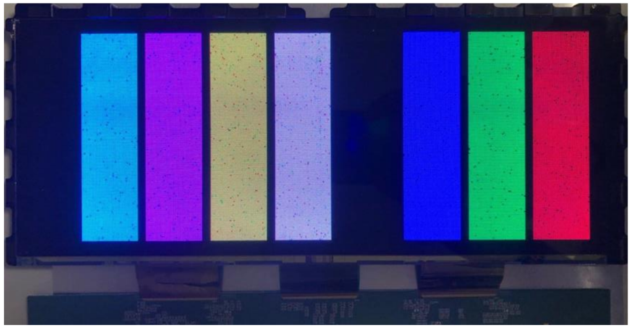
Uniform Color and Luminance

µLEDs in Liquid

Fluidic Assembly on TFT Glass

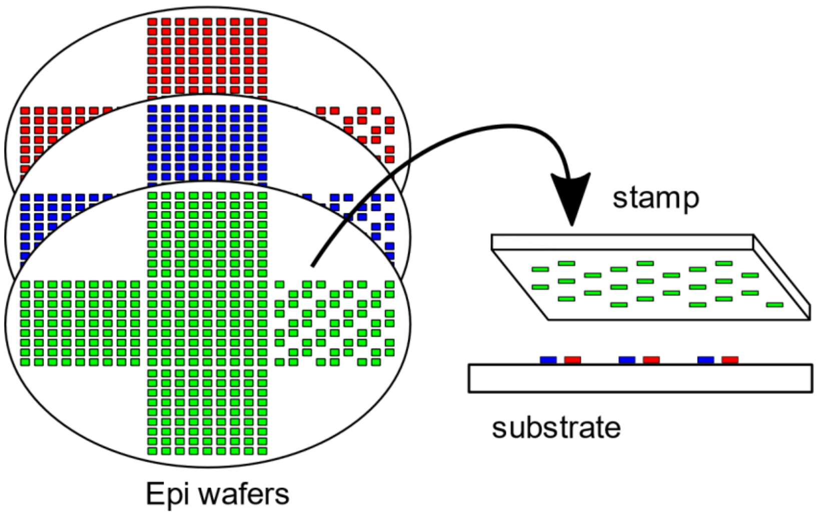


Proprietary Fluidic Assembly

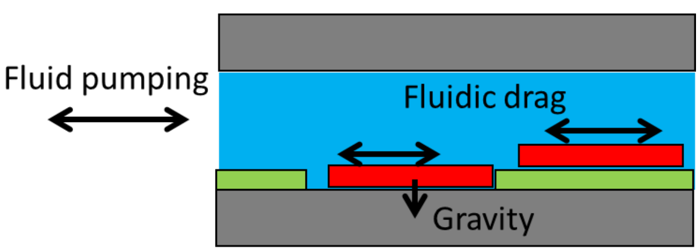


Comparing to Pick-and-Place Mass Transfer (1/2)

P-P Mass Transfer



eLux Fluidic Assembly



P-P Mass Transfer		eLux Fluidic Assembly
µLED Chip Process → Wafer Bond to Temporary Carrier → Laser Liftoff		Same
COB Process: Pick up and Bond to 2nd Temporary Carrier Tool cost: $2M	1000x Simpler & Cheaper →	Harvest Tool cost: $1K (glass beaker)
COB Transfer to TFT Glass - Group Bonding Tool cost: $2M	Faster & Cheaper →	Fluidic Assembly and Bonding Tools cost: $100K

SWOT Analysis

Strengths
- ~100% µLED utilization
- Moderate requirement for epi quality
- No mura due to randomizing
- Low fluidic assembly cost
- Active matrix ready
- IP (~40 patent families)

Weaknesses
- eLux focus on 20 to 100 µm µLED is not suitable for small display

eLux µLED

Opportunities
- µLED can replace LED displays over 32 ppi due to better performance and lower manufacturing cost
- µLED can replace OLED in high end displays due to better performance, long lifetime, and environmental stability

Threats
- Sony / Samsung have demonstrated µLED display since CES 2012
- Samsung, LG and many others are pursuing µLED display vigorously
- **Time to market**

Summary

- eLux technology is positioned to enable µLED display for PID
  - The best µLED entry point is at 0.6 mm pitch where standard technology fails
  - 4K and 8K displays are 110”and 220” for retail and theater applications
- µLED display fluidic assembly has advantages over technologies
  - Randomize µLED in fluidic assembly prevents mosaic and non-uniform illumination.
  - Low cost of assembly tools and fast (low cost) process
  - Able to use ~100% low cost epi wafers

Thank You!

eLux

Display