Display Power Trends

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Introduction

Display power assessment:

- **30% ~ 40% of notebook (*) power is consumed by the display**
  - LCD the backlight vs driving circuit 2:1 ~ 5:1 (size, resolution, brightness). YOY rate of change is ~ 3% driven by light source efficiency increase
  - OLED power is consumed by the emissive material and driving circuit. Nominal power improvements is driven by generational material changes

Display performance requirements:

- **HDR eco-system requirements** - DCI-P3, 4K resolution, 1,000 nits brightness, image refresh rates
- **Color Calibration, image quality, social media**

Display power reduction potential:

- system level telemetry (ALS+C, distance, presence, etc.)
- system level AI optimization (AC/DC, image legibility vs power, foveated image processing, refresh rate optimization, etc.)
- sustainability goal (power saving with net zero performance loss)

Observations:

- **Power testing standards such as: "Mobile Mark/Video Play Back/Wireless Web Browsing" does not cover soft power gain/loss – need new power metric**

Note:
- Notebook data is used for this analysis
- Emerging displays power consumptions are estimates

Display Technology Evolution

1: Least favorable
5: Most favorable

Matured technologies — *Emerging areas*

Type		Transmissive			Self Emissive		
	Attributes	LCD	Mini-LED	QLED/QDCF	OLED	QD-EL	Micro-LED
Tech.	Visuals	2	4	3	5	5	Potentially Better
	Brightness	4	5	4	3	4	Potentially High
	Dynamic Range	2	5	4	5	5	Potentially High
	Power	2	3	4	2	3	Potentially lower
	Response		3	3	5	5	Potentially Better
	Thin & Light	3	3	3	5	5	Potentially Thin
	Flexibility	2	2	2	5	5	Potentially Flex.
Cost	Cost of ownership, Capex	Very low	Low	Low	Medium	Medium	Very High
Products	PC Segment Coverage	All	Desktop PC, Laptops - Creator, Mac (rumor)	Desktop PC, Laptops	Primary Mobile, Laptop PCs, TV	OLED compete	AR/VR, Watch Mobile sizes (R&D)
Status	R&D, Dev., MP	MP	MP	MP	Rigid & Plastic – MP FOLED – Dev.	Late R&D/Dev.	Early R&D
Major Players	Small/Medium/Big players	Several	Several	Several	SDC, LG, BOE, EDO, Sharp	SDC, BOE, Sharp	Small start-ups Display R&D

Source: Business Conference, SID 2021 DSCC

- LCD - mature display essential to PC business with limited future opportunity due to lack of research investment
- OLED - unique opportunity due to substrate flexibility and future large printing format
- µLED - will add extra performance improvements beyond OLED
- Display tech selection is based on power vs differentiated opportunity (LCD, Mini-LED, OLED and µ-LED)

NOTE:
- Updates made to the display technology matrix presented at the SID 2021 Business Conference
- Power - LCD has little improvement options. Mini-LED and QDCF have great future power potential
- Thin & Light - 2D Mini LED Backlight thickness approaching conventional LCD backlight
- QLED/QDCF - May need additional R&D time
- Lifetime – OLED, QD0EL, QDCF have similar lifetime issues

Conventional LCD vs 2D-BL LCD vs QD 2D-BL LCD power comparison

QD 2D-BL LCD emits threefold light, compared to conventional OLED

	Global BL LCD	2D-BL LCD	QD 2D-BL LCD *
Output luminance	1 1 1	1 1 1	x 3 3 3 3
	R-CF G-CF B-CF LCD TFT-Substrate Global-BL (White)	R-CF G-CF B-CF LCD TFT-Substrate 2D-BL (White)	R-QD G-QD (B-CF) LCD TFT-Substrate 2D-BL (Blue)
Input power for emission **w/o driving power**	3 3 3	3 3 3	3 3 3

* Originally proposed in US-Patent 5,926,239 (Filed Nov. 22, 1996)

NOTE:
Assumed LCD DCI-P3 color, 15.6" UHD, at 400 nits max
Display on at 100%

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Conventional OLED vs QD-OLED power comparison

QD-OLED consumes around double (x 1.8) power, compared to conventional one.

	Conventional: OLED			QD-OLED		
Output luminance	1	1	1	1	1	1
	Encap R-OLED TFT-Substrate	G-OLED	B-OLED	Encap R-QD B-OLED TFT-Substrate	G-QD B-OLED	(B-CF) B-OLED
Input power for emission w/o driving power	1	1	3**	x 1.8 → 3**	3**	3**

** Efficiency of B-OLED is about 1/3 of the other colors.

NOTE:
Assumed OLED DCI-P3 color, 15.6” UHD, at 400 nits max
Assumed display on 100%

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Display technologies power target comparison

LCD display power reduction progression: Global BL LCD ➡2D-BL LCD➡ QD 2D-BL LCD ➡μ-LED

Estimated power (W)	Global BL LCD *	2D-BL LCD *	QD 2D-BL LCD	μ-LED Display	OLED *	QD-OLED
Input power for emission	5.5	5.6	1.8	0.4**	7.6	13.6
Input power for driving	1.0	1.0	1.0	0.4***	2.5	2.5
Total power	6.5	6.6	3.8	0.8	10.1	16.1

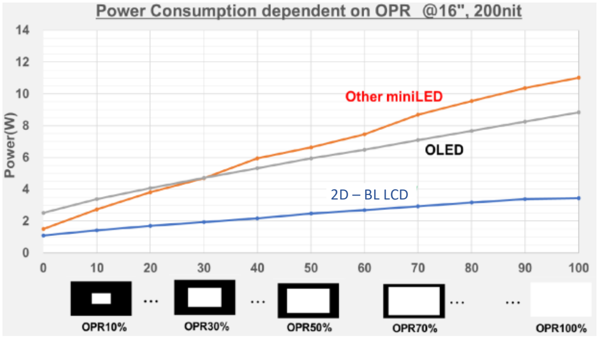
Assumptions and Calculations

Display specification used: 15.6inch, UHD, 400nit, DCI-P3, display on100%.
Assumed 100% QD Conversion efficiency (Although recent data show 60% ~ 80%)

(*) Measurement data

(**) μ-LED calculation:
Assume LED Lambertian illumination output 100lm/W LED which will be 100/3.14 nits/W or (100/3.14/5) 6.37nits/0.2W
6.37 nits/0.2w for 1m² sq – 15.6 = 0.07m² 6.37/0.07 = 91 nits/0.2W at 100 OPR% so at 50% it will be 182nits/0.2W
Each LED using micro-lens to double to brightness output as it will focus the light to the viewer
4K 24 Millions μ-LED – 12 Millions for half display
Vf = 2.8V is the same across R,G,B LEDs
0.2W ÷ 12M LEDs = 1.66x10^-8 W/LED
(1.66x10^-8 for LED)/2.8 V = 5.95x10^-9 A (5.8 nano-A each LED)
Assume DC current at 100% duty however we will use a PWM with a duty of 6msec/1sec yielding 0.001 mA/LED

(***) w/ micro-driving IC chips, target data.
Use a micro-IC driver + controller in proximity to the LEDs (parasitic capacitance reduction)
Assumed that the driver power is equivalent to the LED's power consumption plus overhand



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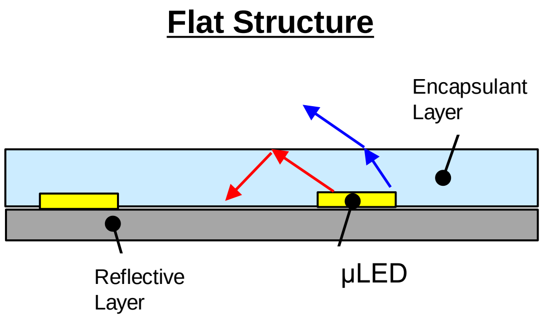
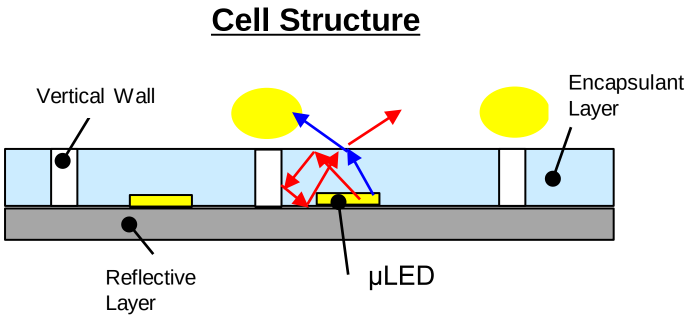
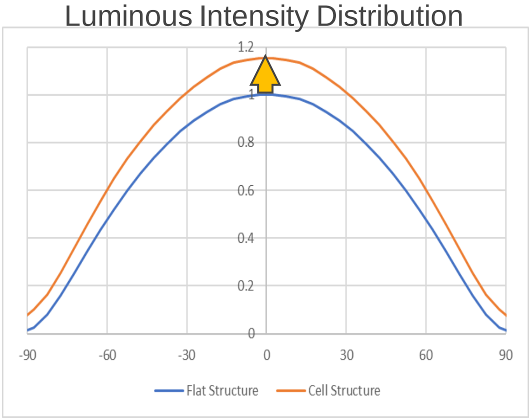
Efficiency Gain from Cell Structure Design





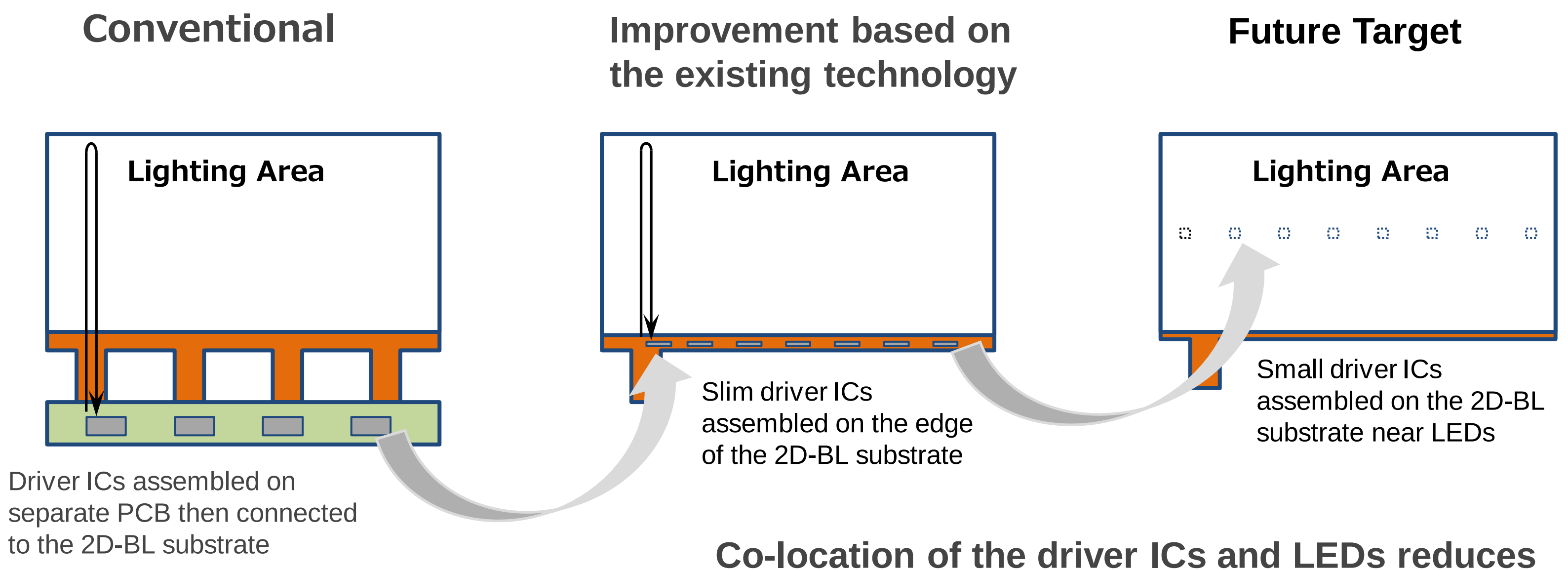
- For flat structure lights get trapped within the encapsulation layer
- For cell structure additional light is directed upwards resulting in 15% on axis (0 deg) luminous intensity increase
- Cell structure help maximize light output efficiency and LED reduction



Efficiency +15%

Power Loss Reduction from the System's Perspective

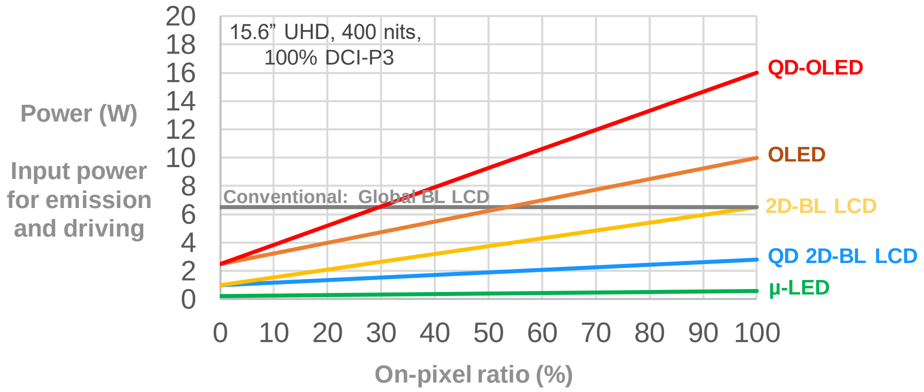
- It is important to consider power loss reduction from a system's perspective in order to bring out the full potential of the LCD w/2D-BL by achieving a higher peak brightness
- The ideal method of reducing the system power is by integrating the driving system onto the substrate of the 2D-BL



Co-location of the driver ICs and LEDs reduces current path hence lower power loss

Power summary and recommendations

Power consumption of Display Modules



Power Summary:

- Power reduction across technologies:
  - ✓ Global BL LCD = 6.5W 100%
  - ✓ 2D-BL LCD - 6.6W 100%
  - ✓ QD 2D-BL LCD – 3.8W ` - 52%
  - ✓ μ-LED = 0.8W - 12%

Emissive μ-LED key to realizing future optimum high performance low power display

- 88% power consumption

Transitional technology such as 2D-BL LCD will help resolve fundamental assembly challenges in support of future μ-LED display

- LED chip assembly process and interconnect technology

The addition of QD material to 2D-BL LCD will improve display performance and material reliability need it for μ-LED display

- color uniformity, leakage, reliability, and deposition process