

Emerging Display Technologies @DisplayWeek 2022

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Outline

- LCD – Dominant technology
 - Quantum Dot – Enabling other technologies
 - MiniLED – Growing Demand
 - OLED – Growth with higher performance
 - Battle for application markets
 - MicroLED – Moving towards commercialization
 - NanoLED – Next generation display
-
- **Can technology innovations drive future demand?**

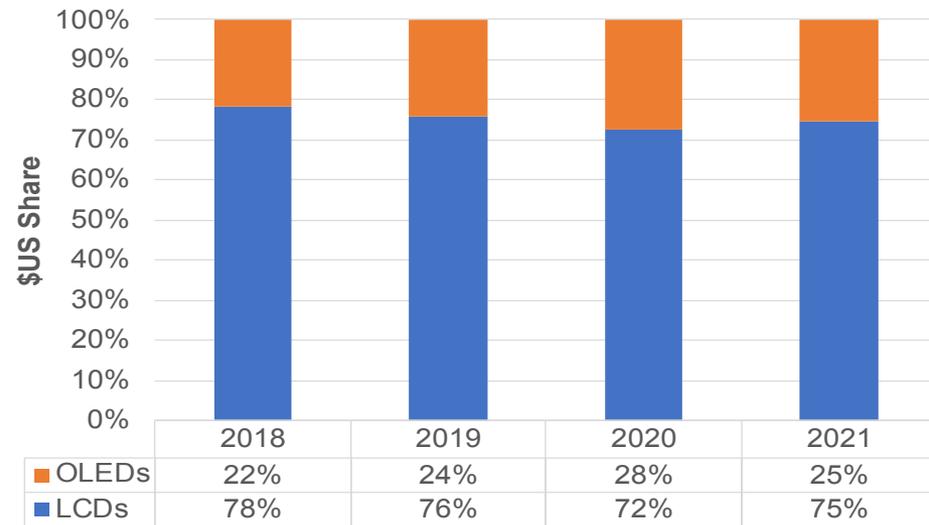
LCD: Dominant Technology

- Unprecedented demand due to WFH & LFH combined with supply constraint and panel price increases, resulted in record revenue in 2021
- LCDs outgrew OLEDs in 2021 on price increases and strong demand
- Panel price reductions that started in 2H 2021 is still continuing.

Display Revenues/Growth by Technology



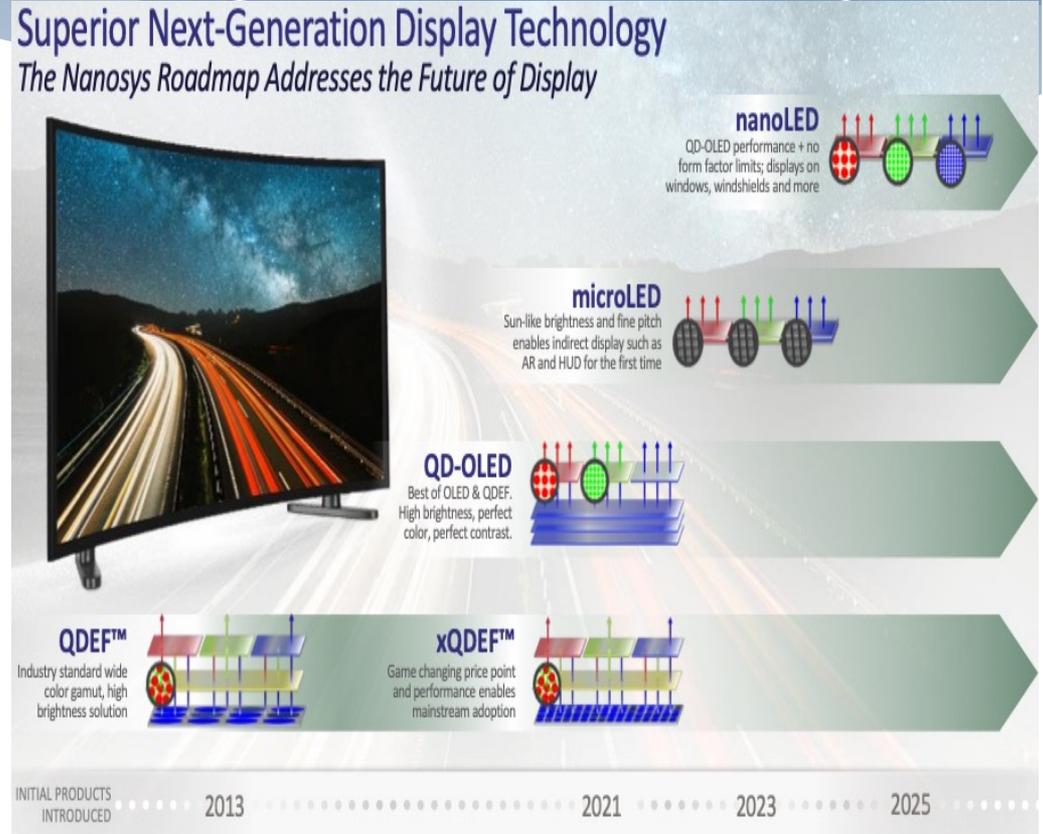
Display Revenue Share by Technology



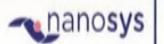
Source: DSCC's Quarterly FPD Forecast Report

Quantum Dot – Enabling Other Technologies

- Enabling LCD, OLED, MicroLED and NanoLED
- xQDEF
 - air-stable QD enable combination of diffuser plate + Quantum Dot RGB color
 - high-efficiency backlight unit with single piece, low cost construction
- Nanosys: *Quantum Dots are the perfect emitters for displays*
- QDCC
 - integrates seamlessly with OLED and MicroLED
 - simplifies the manufacturing process, enabling scalability



Source: Nanosys- DisplayWeek 2022 presentation



MiniLED – Growing Demand

- MiniLED LCDs went from a 0% share in 2020 to a 2.2% share in 2021 (DSCC)
- Multi zone blinking backlights, miniLED with QD has enabled LCD to have higher brightness, very high contrast, excellent HDR, thin form-factor, superior power efficiency and display performance close to OLED.
- BOE showcased 86” 4K active matrix backlit MiniLED on glass substrates, 1,500 nits 2,000 zones.
- TCL CSOT showed 75-inch 8K 4 mask glass based miniLED display, 34” curved miniLED for e-sports.
- AUO showcased 34” WQHD curved (1000R) miniLED gaming monitor,



TCL CSOT 34” MiniLED gaming module



TCL CSOT 75” 8K MiniLED TV



QD-OLED - Bringing Higher Display Performance

- Samsung Display **QD Display**
 - QD technology of Blue OLED display with printed quantum dot layer color conversion and sub-pixel level dimming-
 - Received DisplayWeek best new component award
 - 65-inch and 55-inch QD-OLED (QD)TV and 34-inch monitor panels
- Nanosys - QD-OLED can deliver:
 - Hyper-realistic color – 1.5X Richer Color
 - Perfect viewing angle – 36% wider
 - Brighter appearance vs WOLED – 30% brighter
 - Lower materials BOM – up to 40% less (source: DSCC)



Source: Samsungdisplay.com



Source: dell.com

OLED - Evolving to New technology

- LG Display: OLED-EX
 - Deuterium technology, narrow bezel, 30% higher brightness, 77-inch 8K OLED with 2000nits, 42-inch bendable OLED gaming monitor
- UDC PHOLED Blue - all-phosphorescent RGB stack for commercial market in 2024
 - Higher efficiency or lower power consumption
 - Higher brightness at same power level, improved HDR performance
 - Extended lifetime
- Inkjet Printing, Organic Vapor Jet Printing
- OLED Suppliers investing in 8.5 or 8.7 Gen fabs
 - high mobility IGZO, vertical FMM VTE, tandem stack structure to reduce costs



LG Display 97" OLED-EX

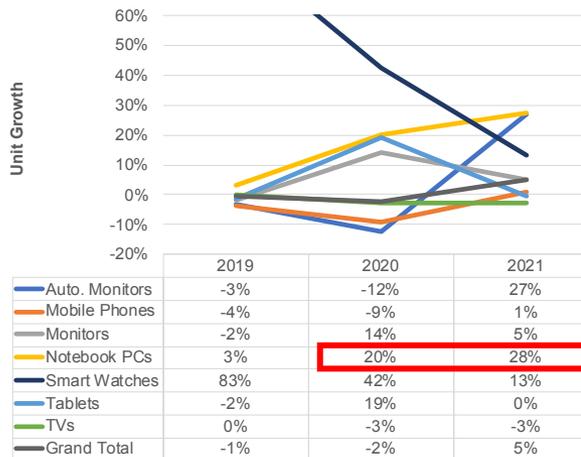


LG Display 42" bendable Gaming Monitor

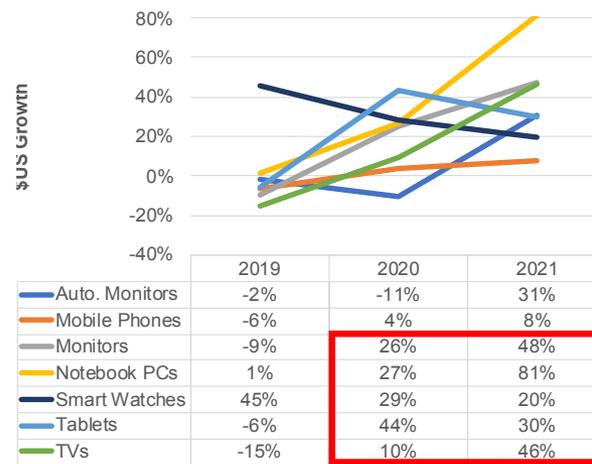
Application Market Dynamics Changing

- IT panels revenue shares surged with strong unit growth, price increase and miniLED adoptions.
- TV revenue shares surged in 2021, mobile phone shares went down

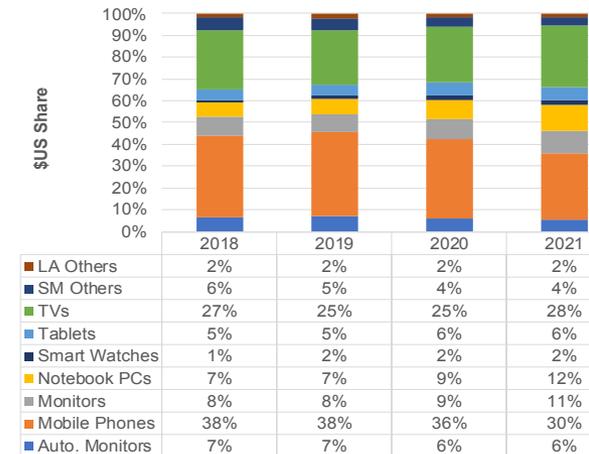
Unit Growth by Application



Display Revenue Growth by Application



Display Revenue Share by Application



Battle in TV Market

- Global TV market slowing – 212m (2022), 223m (2026, same as 2019) (OMDIA)
- Battle for the premium TV market
 - MiniLED/QD (32”- 97”, 8K)
 - WOLED (42”- 97”, 4K some 8K)
 - Now QDOLED (55”- 65” 4K)
- DSCC forecast:
 - Advanced TVs for all technologies to grow by 22% CAGR from 2019-2026 to 39M units.
 - LCD to grow by 21% driven by MiniLED and 8K.
 - OLED to grow by 23% with QD-OLED and Inkjet Printed OLED adding to WOLED.
 - MicroLED will remain a miniscule fraction of Advanced TV units

Battle in IT Market

DSCC (2021 Estimates)

– Advanced IT display units increased 237%Y/Y

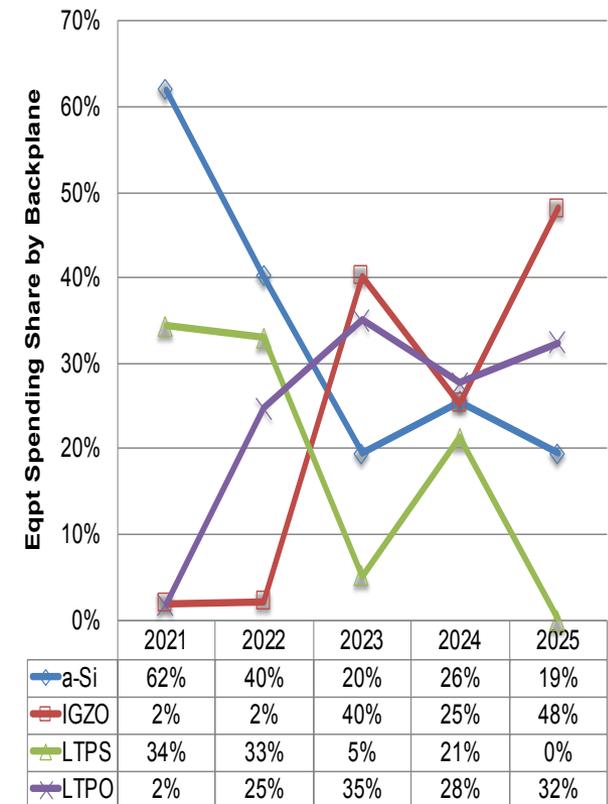
- Advanced notebook PC units increased 645% Y/Y
 - OLEDs outpaced MiniLEDs by a 2:1 margin
- Advanced monitor units increased 402% Y/Y
 - MiniLEDs outpaced OLEDs by almost a 10:1 margin
- Advanced tablet units increased 99% Y/Y
 - MiniLEDs outpaced OLEDs by a 40% margin
- Intel®Evo™ design foldable display : one physical device can have many postures: laptop, table top, tablet and others.
- BOE: 17-inch foldable OLED notebook – best technology demo award
- AUO : 16-inch 240Hz MiniLED gaming notebook, >1000nits
- Tianma: “0” border MiniLED, 16-inch AM-TFT MiniLED
- LGD 17-inch foldable OLED laptop

Backplane Technologies for IT Market

OLED suppliers are investing in 8.5 or 8.7 Gen fabs

- High mobility IGZO backplane with low mask count to improve cost.
- Higher cost saving by shifting to rigid+TFE
- Shifting towards tandem stack structure to improve performance over single stack structure
- **LTPO:** (Lower power consumption, VRR)
 - Samsung Display, LGD, BOE, China Star, Visionox and others converting capacity to LTPO
- **IGZO:** (Scalable, VRR, fewer masks)
 - Samsung Display, LG Display, and Visionox all planning IGZO RGB OLED (Rigid + TFE) in 8.x Fabs

Display Eqpt. Spending by Backplane Tech.



Source: DSCC's *Quarterly Display Capex and Equipment Market Share Report*

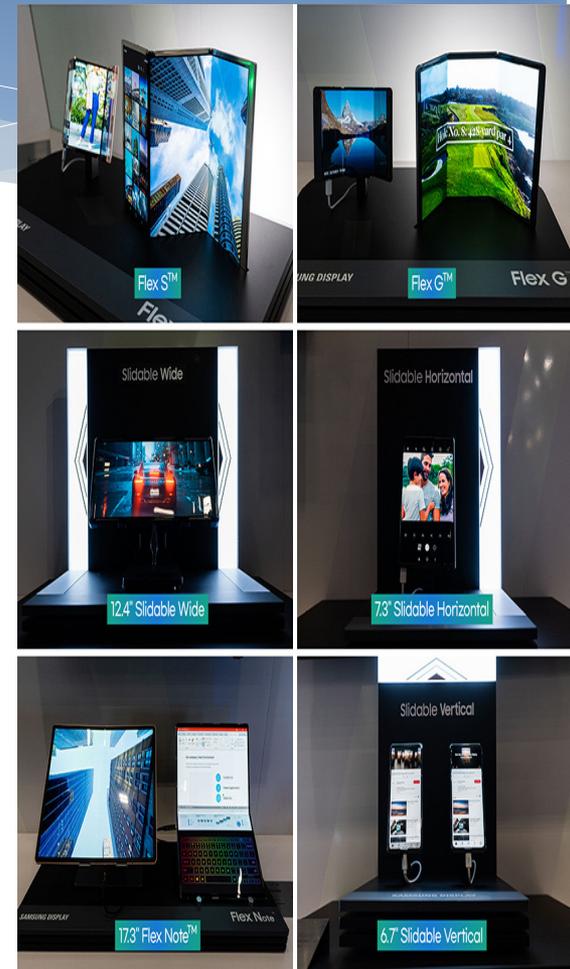
Battle in Smartphone Market

DSCC: Smartphone is the top application market for Display Revenue

- 2021 – Smartphone panel shipments rose 4% to 1.52B.
- AMOLED shipments rose 26% to 634M (42% units shares)
- Smartphone panel shipments 2% CAGR from 2021 to 2026
 - LCDs declining at a 6% CAGR
 - OLEDs rising at an 11% CAGR
- 5G-based products needing slimmer displays will continue to increase flexible OLED demand
- Integration of new technology - under panel camera (UPC), fingerprint under display, integrated touch, power saving, variable refresh rates, and other features will make flexible OLED more critical for 2022 and beyond

Foldable Smartphone – increasing adoption

- **Omdia** : Foldable smartphone shipments
 - 9 million units in 2021, up 309% year-on-year.
 - 8 million units were sold in the 2H2021.
 - Samsung Galaxy Z-Flip3 (52%), Galaxy Z-fold (27.8%)
- Flexible OLED gaining shares with Apple and Samsung products and new technologies
- LTPO (LTPS + Oxide TFT) enables variable refresh rates
- Y-OCTA (Youm On-Cell Touch AMOLED) enable thinner OLED
- Samsung Display ‘Eco² OLED™’ Awarded ‘Display of the Year’ (Integrated polarizer - improves light transmittance rate by 33%, consumes up to 25% less power)



Battle in AR/VR

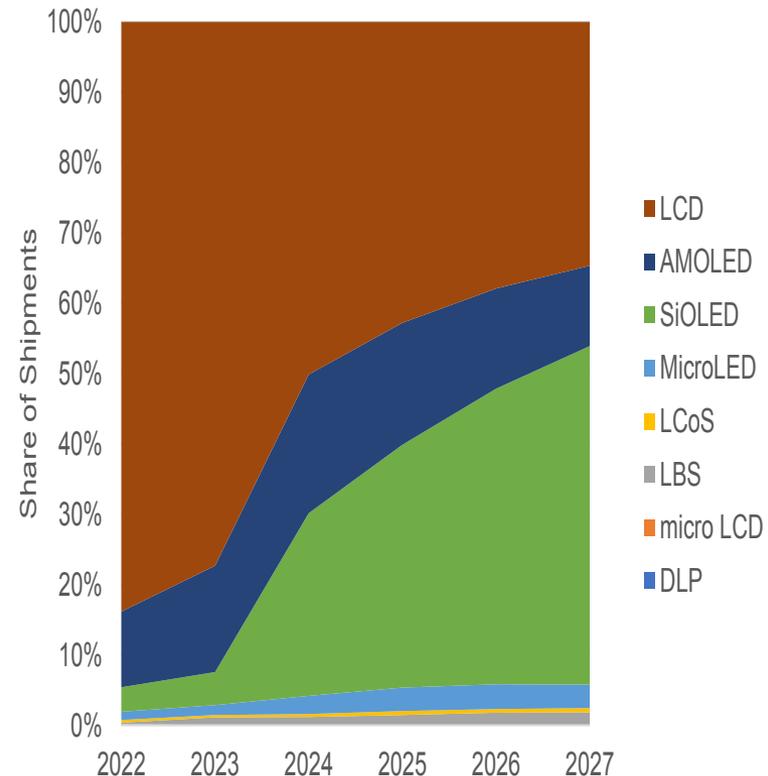
- eMagin's: Best New technology award for Direct Patterning (dPd) OLED Microdisplay (10,000 nits)
- AR/VR Requirements – high resolution, high brightness, high contrast, no motion artifacts

SiOLED micro display (Higher efficiency and longer lifetime) gaining share

- Apple: high end VR headset expected to use SiOLED in 2022
- Meta, Magic Leap, Snap, ByteDance (Tiktok), Nreal and others - all investing in AR/VR

LGD showed: 0.42-inch OLEDoS (OLED on Silicon) display for AR, 3,500PPI

AR/VR Display Market Share by Technology



Battle in Auto Display Market

- LCD dominant technology, OLED designer's choice, MicroLED next gen products
- New functionality, increase in display sizes, higher performance & higher # displays per vehicle. operate in extreme temp ranges, longer lifetime, low costs
- AUO: front-seat 22" & 30" miniLED curved display
- Innolux: 34-inch 8K miniLED curved display
- LGD: 34-inch P-OLED display, curvature of 800R
- AUO & Playnitride: 12.1-inch dashboard, 9.4-inch S-shaped flexible CID, 14.6-inch rollable, 17.3-inch transparent, 3.5 stretchable MicroLED display



AUO MicroLED display for Auto

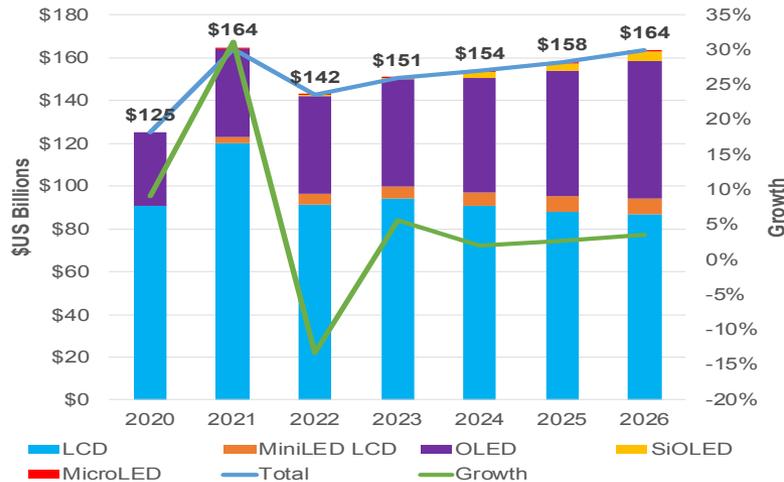


Innolux: 34-inch 8K miniLED auto display

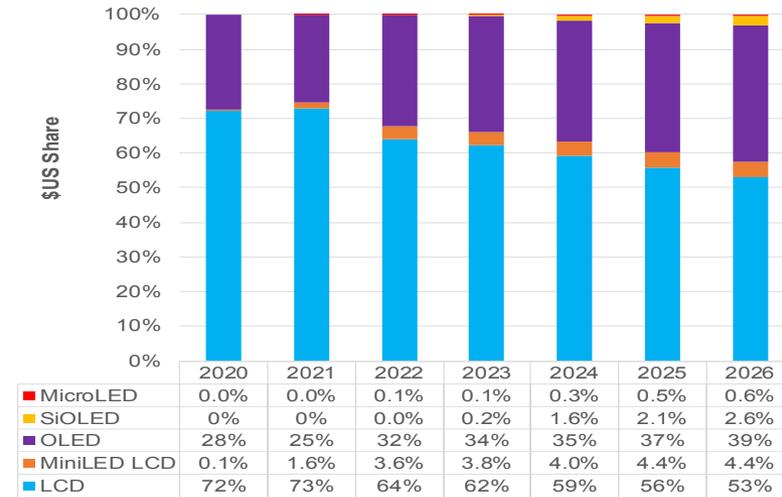
Display Technology – OLED Gaining Share

- Technology developments, materials improvements, product innovations combined with capacity expansion will help OLED display to gain higher shares

LCD, OLED, SiOLED and MicroLED Panel Revenue Forecast

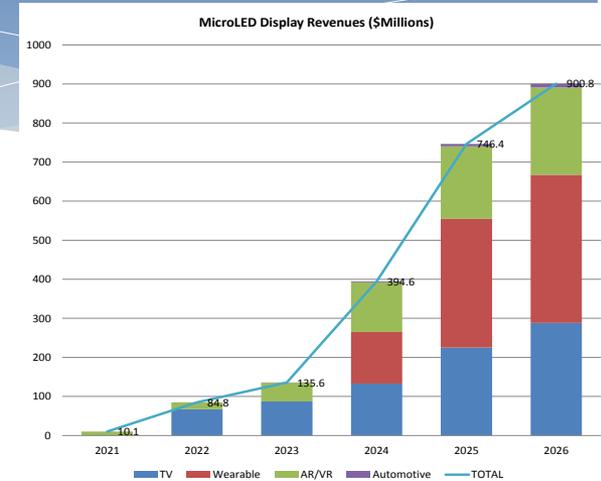


LCD, OLED and MicroLED Panel Revenue Share



MicroLED – Moving Towards Commercialization

- Complex manufacturing process: high-speed transfer, assembly technologies, yield, and defect management need to improve.
- Nanosys: QDMicroLED: Blue MicroLED+QDCC
 - >10X brighter for red than current solutions, Ultra high brightness and pure color with very high contrast
- SmartKem + Nanosys: OTFT QD partnership
- PlayNitride: best new display technology award 0.49-in. full-color MicroLED (4,536 PPI Micro-display)
- Porotech: best prototype MicroLED for achieving color tuning in one monolithic *InGaN* layer



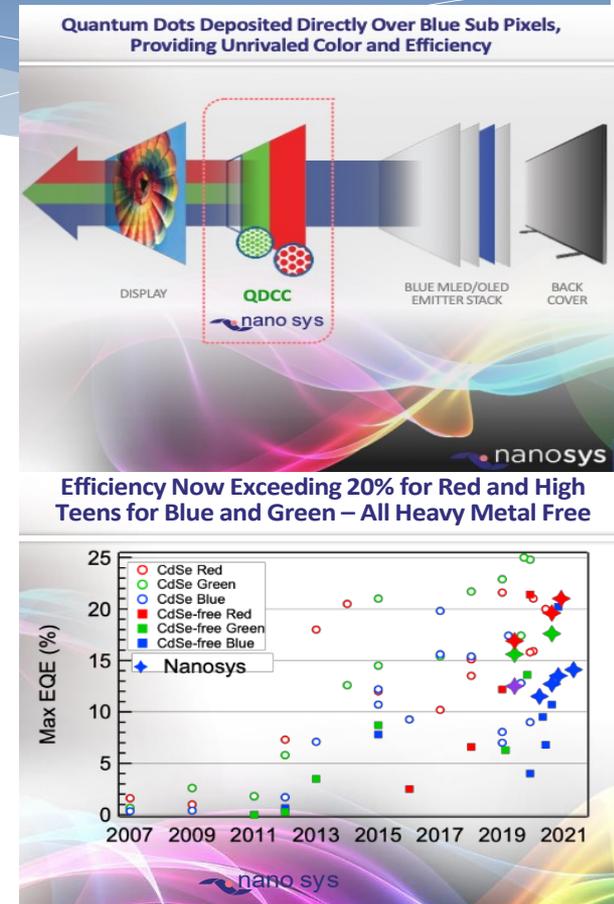
Source: DSCC MicroLED & MiniLED



PlayNitride :4,536 PPI Full Color MicroLED Micro-display

NanoLED - Next Generation Display

- NanoLED (EL-QD): an emissive display, perfect black, better color, and wider viewing angle, true HDR luminance and higher reliability (inorganic materials)
 - Potential for low cost with solution process printed manufacturing
- Nanosys: NanoLED expected in 2025/26
- SmartKem +Nanosys OTFT QD NanoLED
- BOE : 55-inch 8K AMQLED display showed @Displayweek
- Samsung Display: Distinguished paper by M.Park:
 - demonstrated ink-jet printed Cd-free EL-QDs based on the optimized ink formulation.



Can Technology Innovation Drive Future Demand?

LCD – Reinvention with Quantum Dot and MiniLED backlight technology helped to create replacement demand

MiniLED – Enabled LCD to be more competitive with OLED, strong shipments growth

Quantum Dot – Enabled LCD to compete in premium market

- QD OLED - products will help to increase market share
- QD MicroLED - simplify manufacturing process
- Nano-LED - emissive display will come in future

OLED- New materials, process and higher gen fabs will help create new replacement demand for TV and IT.

- Foldable creating new market demand

MicroLED – Expected to open up new applications to drive demand

Dash-Insights

Actionable Insights

Thank You

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