

**NCCAUS Thin Film Users Group
(TFUG) Meeting
"Advances in Display Technology"
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Quantum Dots Moving to the Mainstream

Jason Hartlove, President and CEO, Nanosys

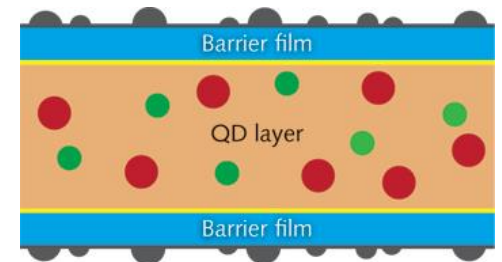
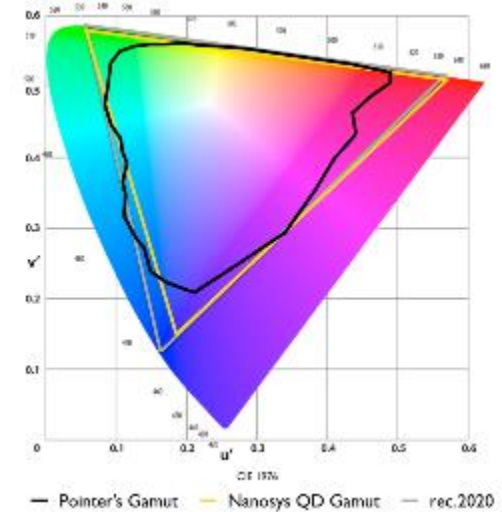
About Nanosys

- World's leading supplier of Quantum Dots, a unique and highly differentiated light emitting material which is transforming the display industry
- Founded in 2001 and based in Silicon Valley, first company to focus on Quantum Dots for electronics
- Highest volume manufacturer with over 10 tons of QD Concentrate delivered to customers
- World's Premier QD Patent Portfolio with over 230 worldwide patents granted & 90 pending
- ~100 employees



Quantum Dots

- Tremendous Advantage in Color, Efficiency over traditional phosphor and emitter materials
 - Only technology which can cost effectively meet BT.2020 color gamut requirements
- Difficult to stabilize against environmental stress
 - Leads to complex packaging and encapsulation
 - Expensive, difficult to scale



Source: 3M

QD Film Makes for Easy for Set Implementation

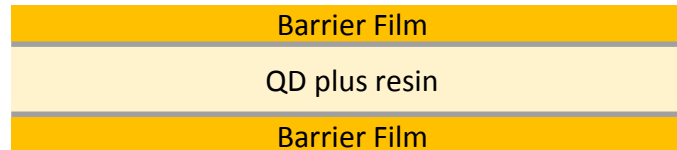


A true “drop-in” solution, each sheet of QDEF™ Quantum Dot Enhancement Film contains trillions of red and green emitting Quantum Dots. Display makers simply drop the sheet into a display’s backlight in place of a diffuser sheet with no changes required to their process

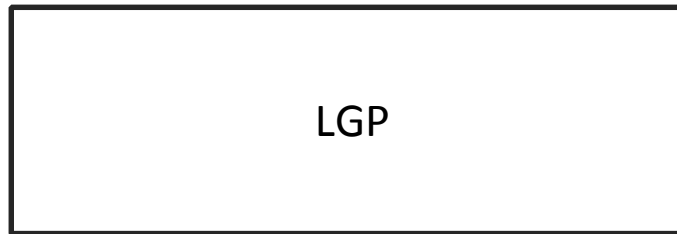
- Simple “drop-in” solution that is fully compatible with existing LCD manufacturing process
- \$0 in cap-ex required for display makers to implement Nanosys Quantum Dots, leveraging \$180 billion existing capacity investment

But QD Film is not inexpensive to make

QDEF

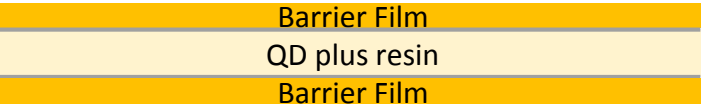
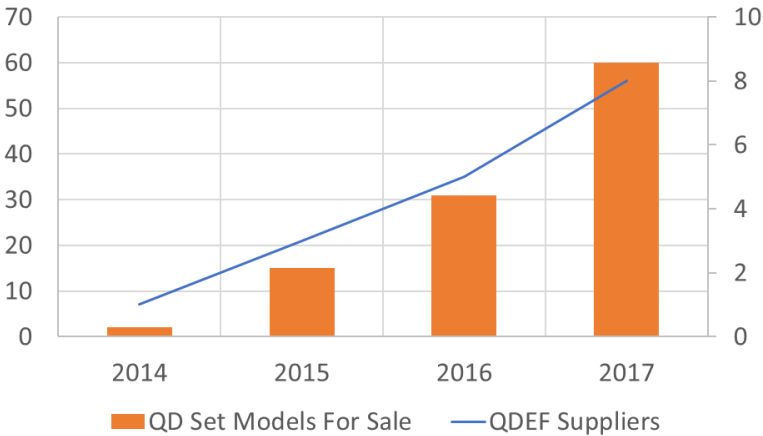
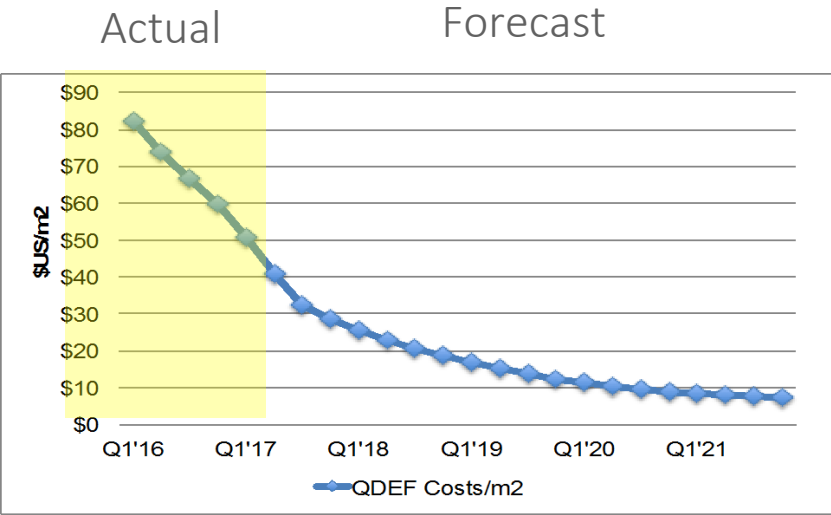


2×10^{-3} WVTR Barrier 125um PET
100um (100 grams/sqm) resin + 0.3grams QD



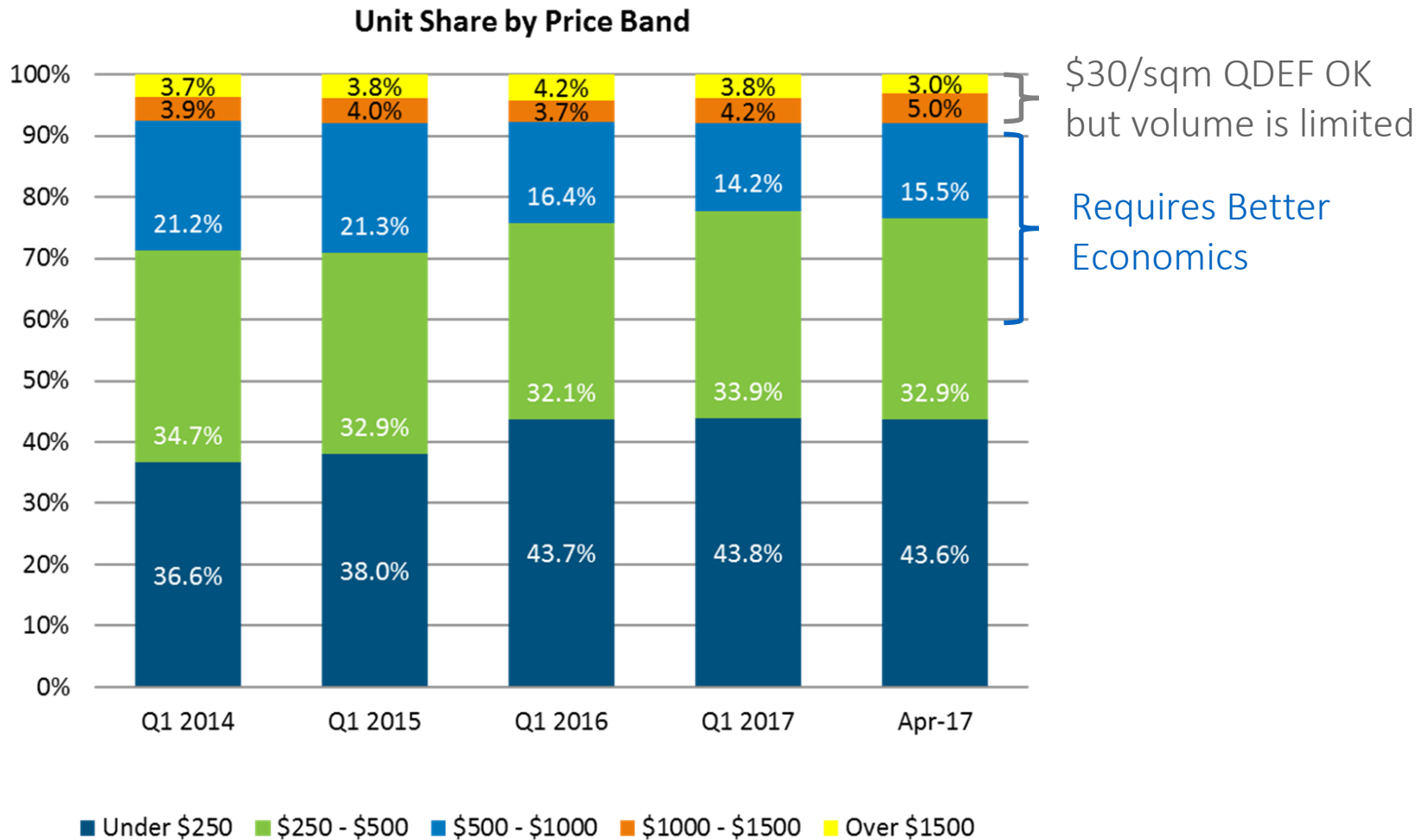
- QDEF made by R2R slot coating, then cut to sheet size, then placed into BLU
- Yield losses at coating, cutting and inspection. ~100um thick QD/resin layer due to poor coating process thickness control
- Barrier film expensive and limited availability

QDEF Price Has Been Brought Down Dramatically



- Thinner and Lower Grade Barrier Film
- 50um (50 grams/sqm) resin + 0.3grams QD
- Improving coating line speed and yield by moving from thermal curing resin to UV curing resins
- Increasing lamination strength allowing move from laser to die-based cutting
- SCM Development and Volume Ramp Up

Moving to mainstream

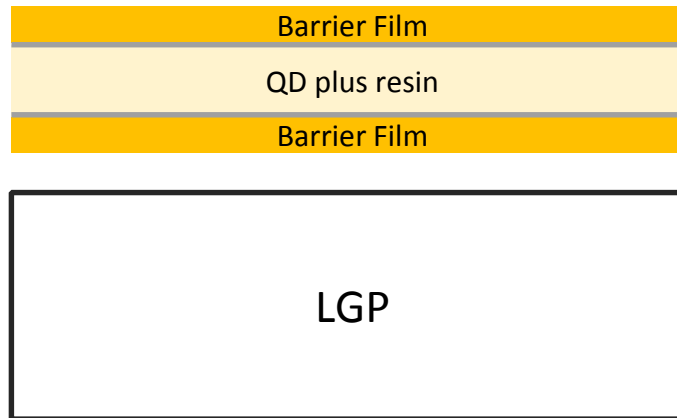


Improving Implementation Cost for QD

- Reduce QD Usage
 - Implement on LED QD Phosphor
 - TPRL, auger recombination limited
- Further Reduce Packaging/Encapsulation Cost
 - New Architectures, Use of Thin Film Encapsulation
- Further Improve Efficiency to Reduce System Costs
 - New Architectures, Thin Film Devices

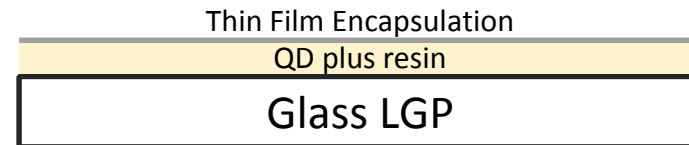
QDOG – Further reducing packaging costs

QDEF™



- QDEF made by R2R slot coating, then cut to sheet size, then placed into BLU
- Yield losses at coating, cutting and inspection. ~50um thick QD/resin layer due to poor coating process thickness control
- Barrier film expensive and limited availability

QDOG™



- QDOG made by slit coating on master glass sheet LGP, then cut to panel size. ~10um thick layer uses less resin due to much better thickness control
- Minimal Yield Loss and much thinner with higher efficiency
- Uses inexpensive OLED Thin Film Encapsulation technology. Glass LGP plus QD increases efficiency even more eliminating need for DBEF

Technology Roadmap

2021 -

Electro-Emissive

Use solution printed QDs as the emitter material in Type 4 AMQLED displays



2018 -

Photo-Emissive

Use QDs in LCD and uLED panels to convert and emit superior RGB color with very high efficiency



2013 -

Photo-Enhanced

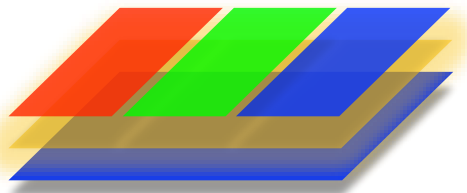
Use QDs in Optical Films and Components to Enhance LCD Performance



Roadmap of Innovative Products

Photo-Enhanced

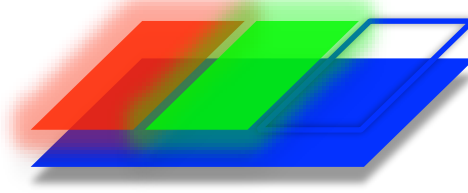
QDEF® Today



- Increasing commercial availability and scale enable greater adoption
- QDEF-enhanced LCD TV beats OLED on color, brightness, power efficiency and cost
- New products like Hyperion™ offer improved performance and open new markets

Photo-Emissive

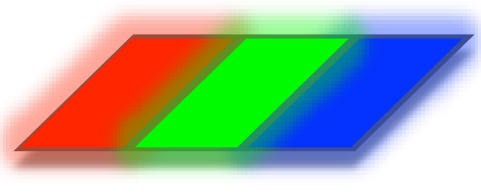
Phase II



- Replacing Color Filter Array with Sub-Pixel Patterned Cd-free QDs
- Compatible with multiple display architectures including LED, Micro-LED and OLED
- Could enable ~5000 nit peak luminance without increasing power consumption

Electro-Emissive

Phase III



- Cd-free QDs as a near-future emitter material for electro-luminescent
- Printable, low-cost materials with superior performance to OLED emitter materials
- Printed, flexible displays will change how we think about displays, opening up new markets

Photo Emissive Technologies

Photo-Enhanced

Use QDs in Optical Films and Components to Enhance LCD Performance



Photo-Emissive

Use QDs in LCD and uLED panels to convert and emit superior RGB color with very high efficiency



Electro-Emissive

Use solution printed QDs as the emitter material in Type 4 AMQLED displays



Photo-emissive LCDs

- Photo-emissive QD technology involves moving the light conversion from the backlight (as in QDEF) to the front of the LCD.
 - This provides an improved viewing experience, as the display shows much greater viewing angle than a typical LCD
 - Photo-emissive QDs also provide much greater efficiency, as less light is lost through filtering, and LCD module can be optimized for blue light

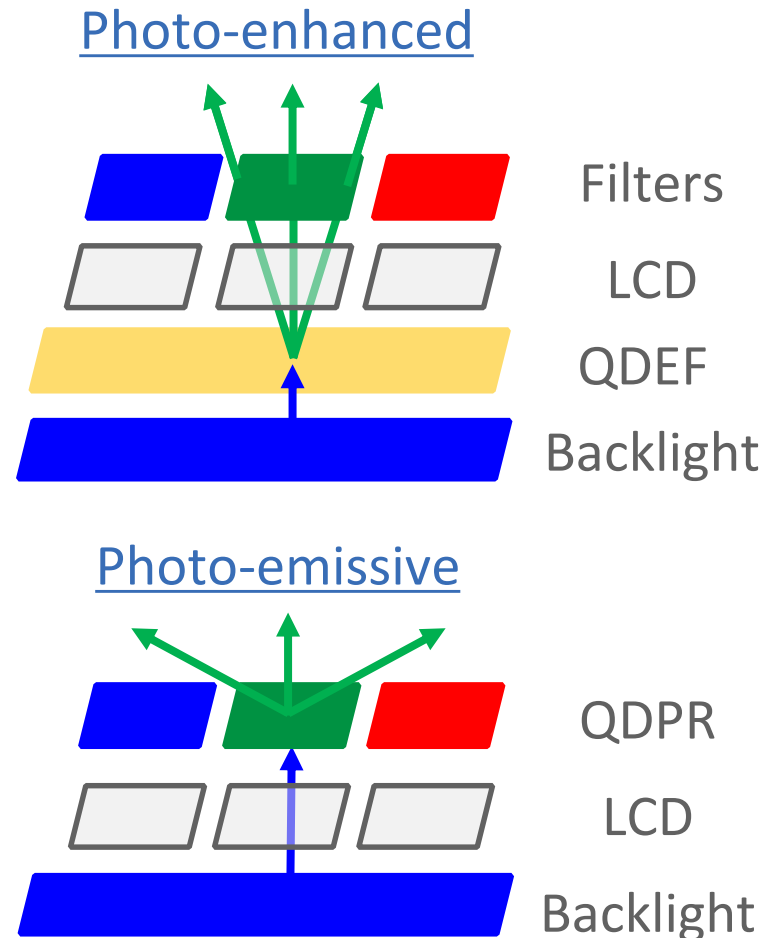


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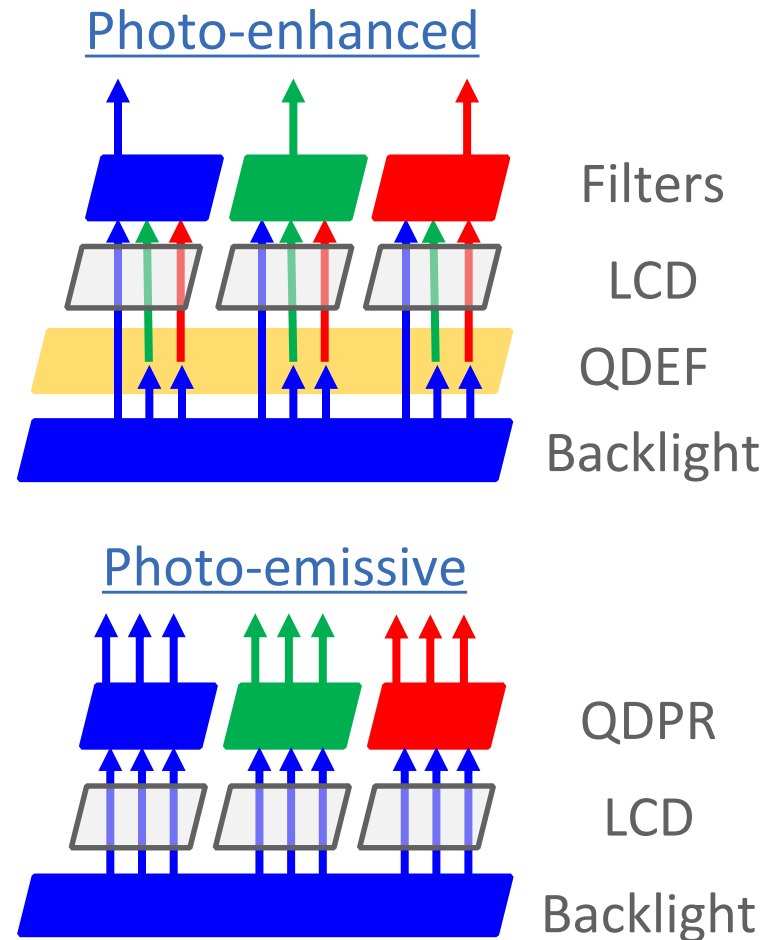
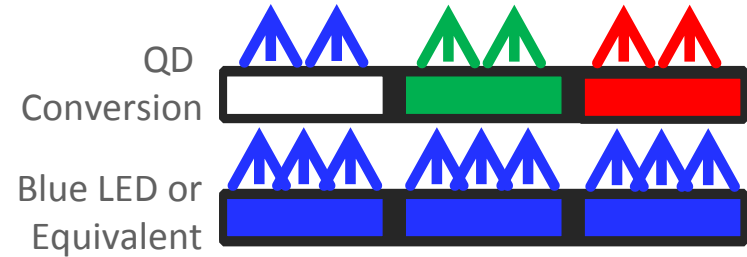
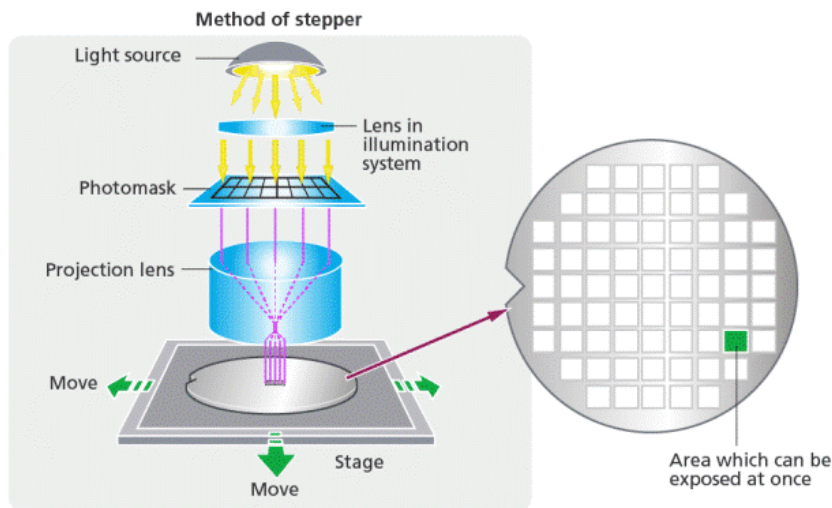


Photo-emissive μ LEDs

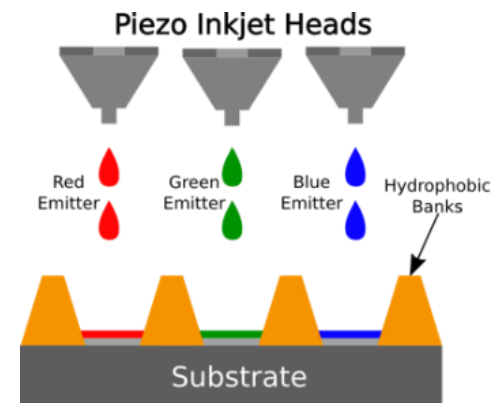
- Requires patterning of QD layer at sub pixel pitch scale, total thickness of a few microns with high OD
 - QDPR for Photolithography
 - QD ink for Inject Printing



Schematic of Application for μ LED



Schematic of Photolithography



Schematic of Inject Printing

Electro Emissive Technologies

Photo-Enhanced

Use QDs in Optical Films and Components to Enhance LCD Performance

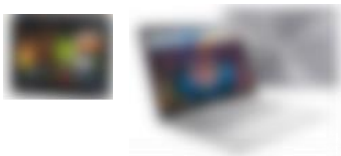


Photo-Emissive

Use QDs in LCD and uLED panels to convert and emit superior RGB color with very high efficiency



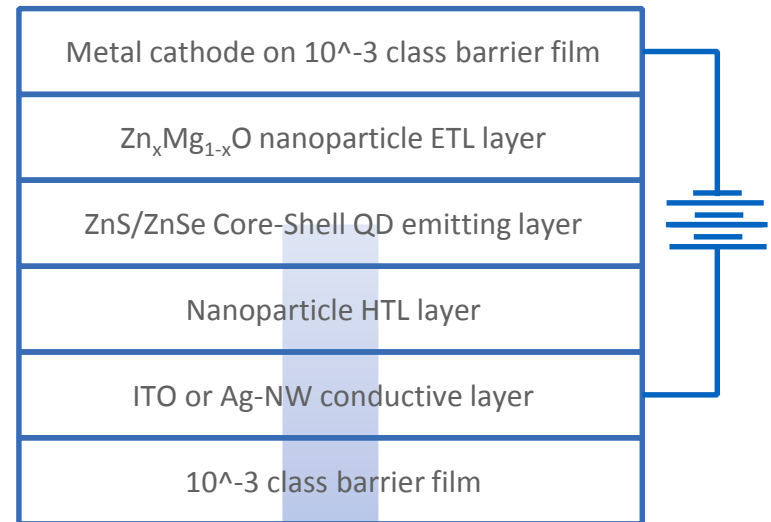
Electro-Emissive

Use solution printed QDs as the emitter material in Type 4 AMQLED displays



Inorganic QLEDs

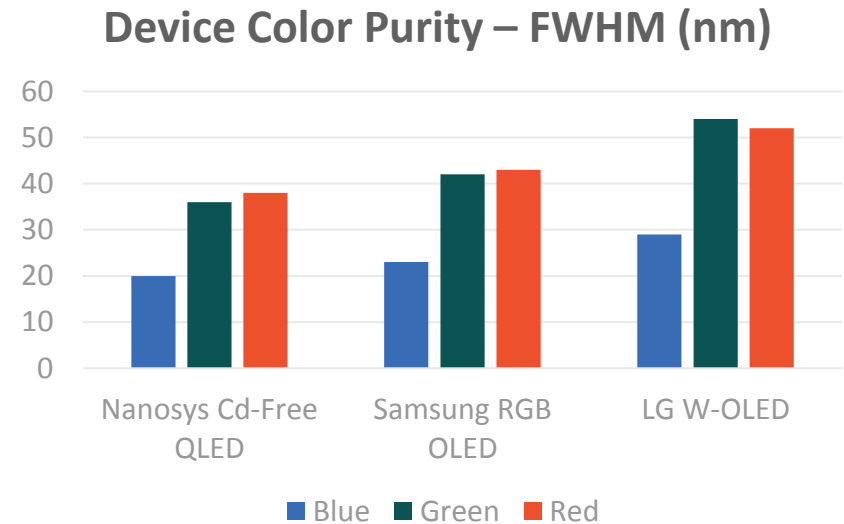
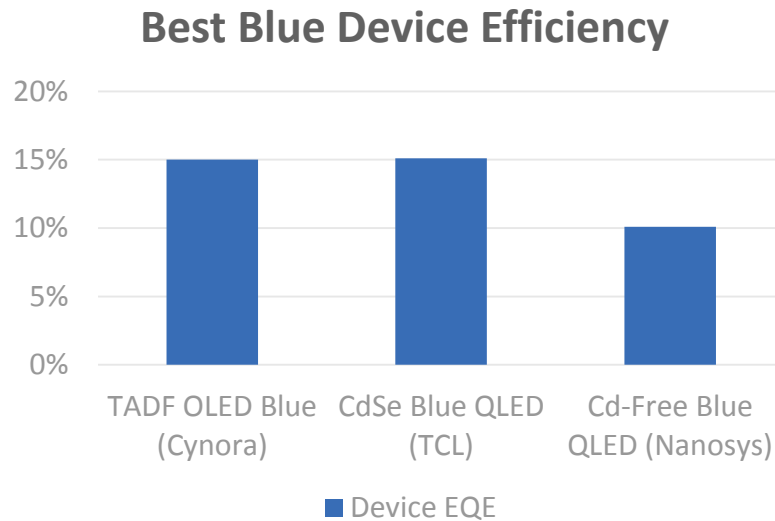
- EML quantum dots sandwiched between layers of inorganic electron-transporting and hole-transporting materials
- Narrow emission spectrum tunable to color standard
- Advantages over OLED
 - **100% of Development Work is Ink Jet Deposition Based**



Nanosys Approach Uses

- All inorganic, “green” material system
- Bandgap Engineered ETL and HTL layers
- Full solution printability maintained

Where are QLEDs today vs OLEDs?



- Cd-free blue QLED from Nanosys <2 year behind BIC OLED Blue EQE
- Already superior to all OLED in production for color purity

Summary

- Nanosys is executing on a long-term business and technology roadmap to transform the display industry
 - Quantum Dots have arrived. Market demand, technology, product superiority and effectiveness of business model are proven
 - Quantum Dots will continue to improve LCD and uLED displays with proven performance and supply chain
 - In the near future, Quantum Dots will replace LEDs with a new generation of printed ultra-thin and flexible displays

Quantum Dots are transforming the display industry by providing solutions to unmet needs for ease of integration, color and efficiency

Thank You



For more information:

nanosysinc.com

nanosysinc.com/blog