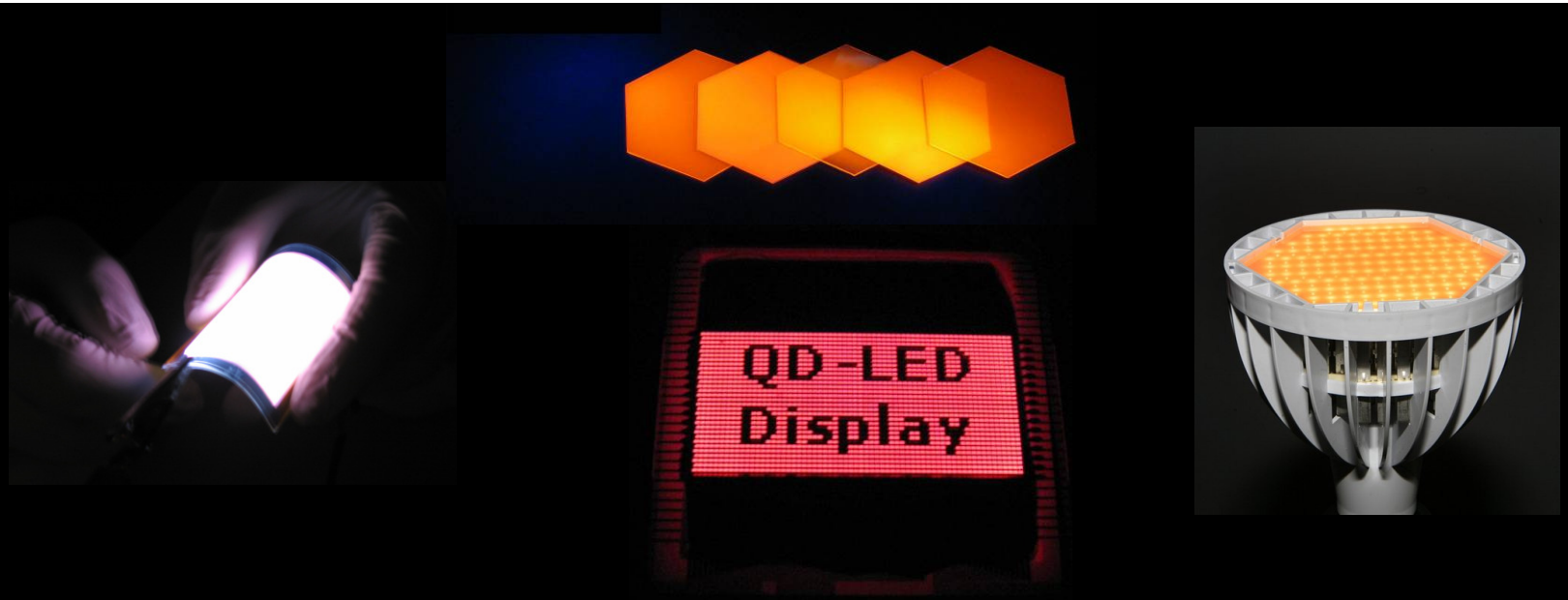


Quantum Dots: Assessing the Impact within Lighting and Displays

Seth Coe-Sullivan – Co-founder and CTO

OECD/NNI Symposium – March 27th, 2012

QD VISION

Outline

Quantum Dots & QD Vision Background

QD Products, R&D in Lighting and Displays

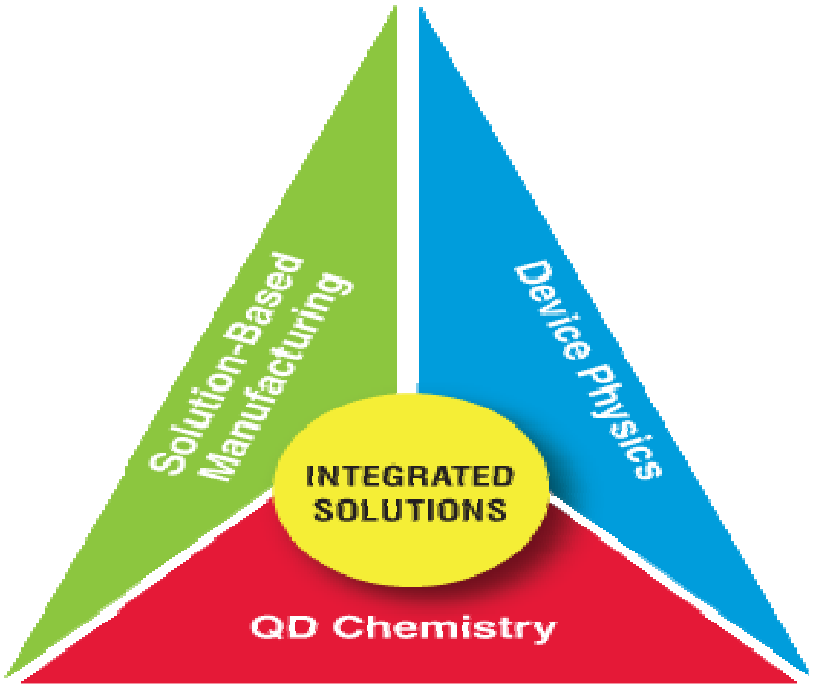
Assessing the Markets and Impact

Conclusions & Acknowledgments

QD VISION

QD Vision's Focused & Integrated Approach

The **only** quantum dot company focused solely on displays & lighting

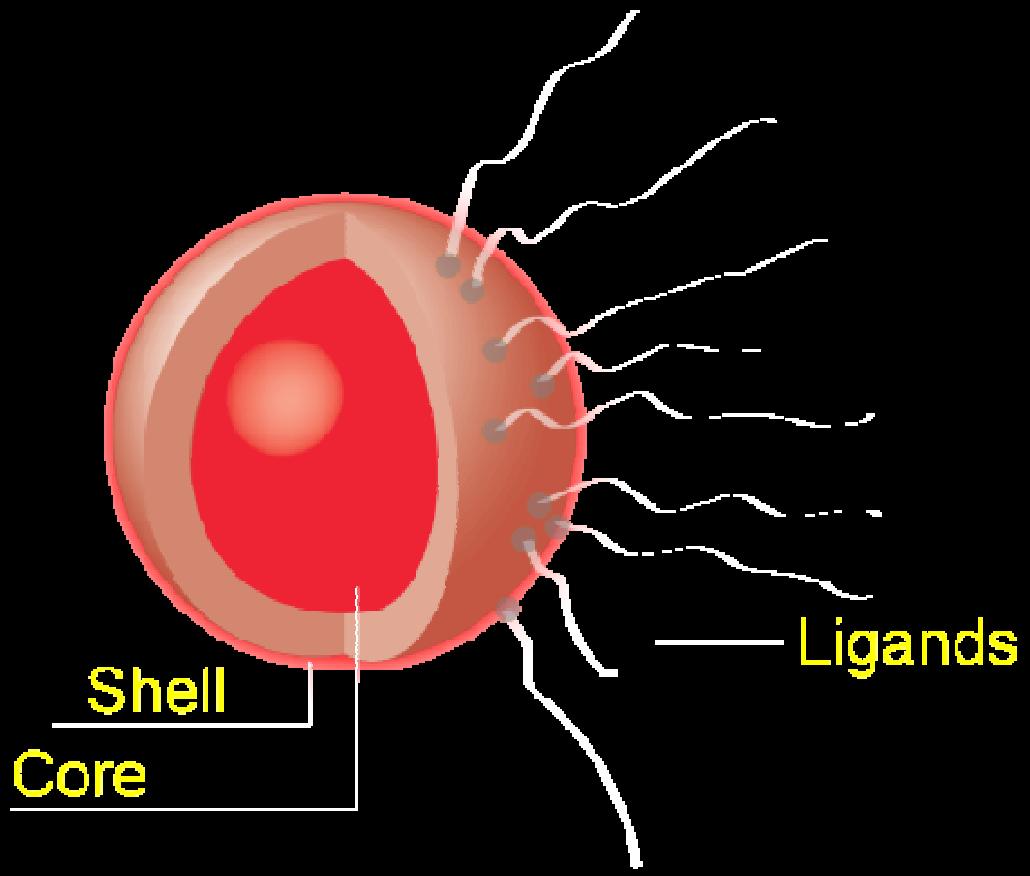


- Founded in May 2005 - MIT roots
- 80+ employees - R&D transitioning to operational focus
- Manufacturing facility in Lexington, MA
- IP from MIT license, Motorola patent acquisition, and QDV filings
- VC funded, ~$55M raised to date

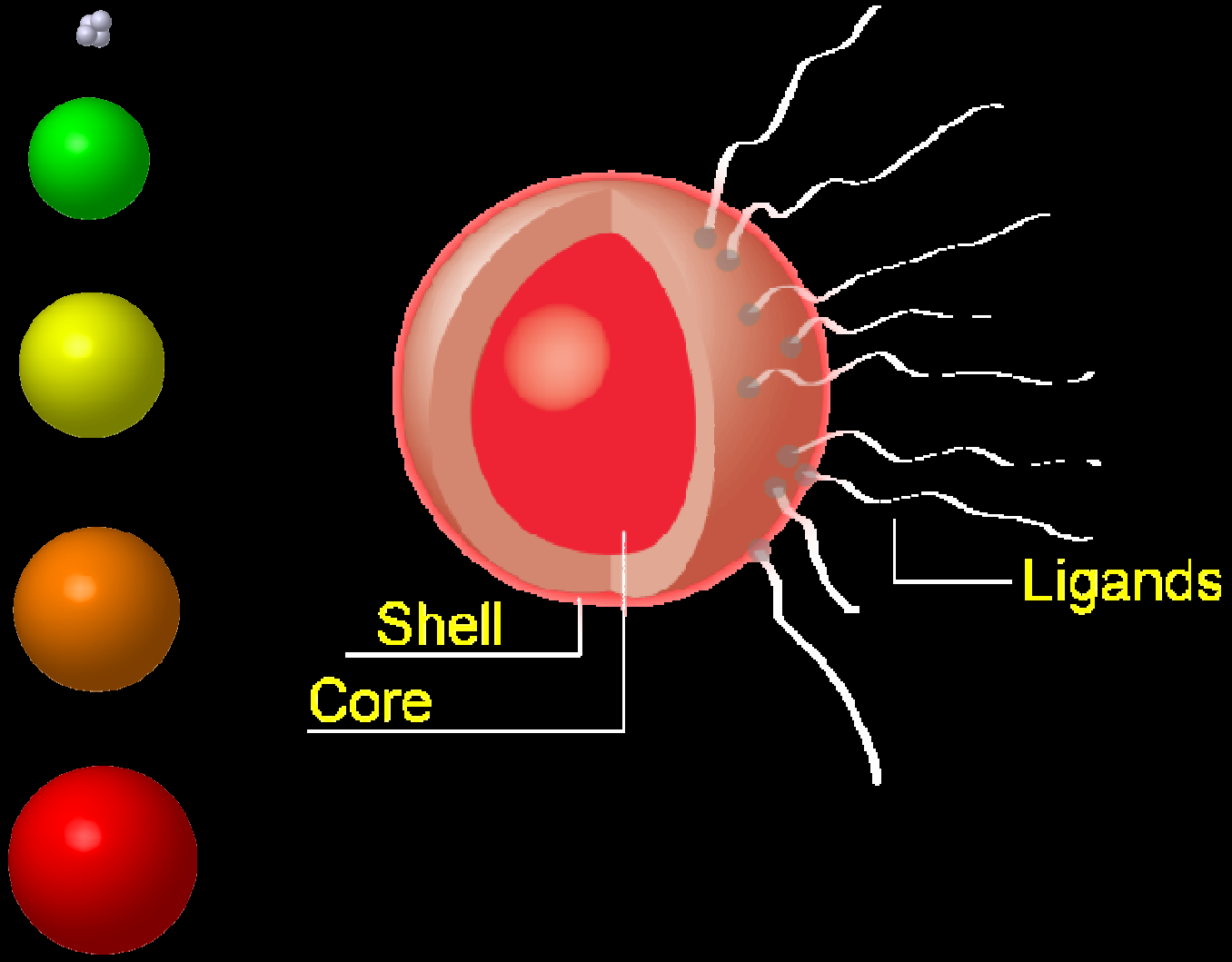
The 1st quantum dot company to market in lighting & displays

QD VISION

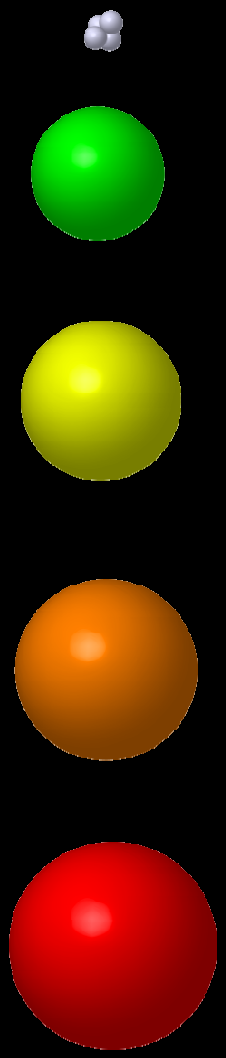
Introduction to QDs

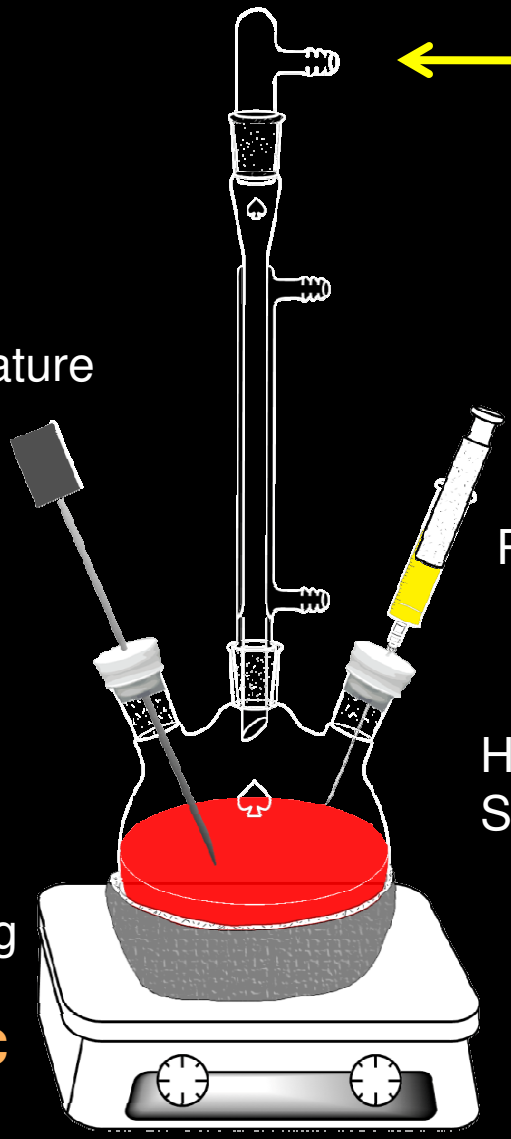


Introduction to QDs



Introduction: QD Core Synthesis





N_2

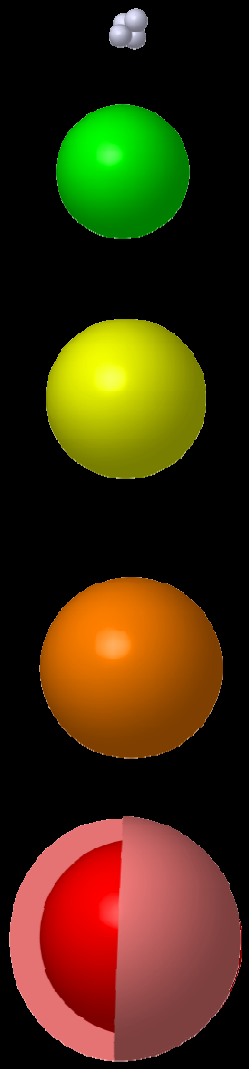
Temperature sensor

Precursors

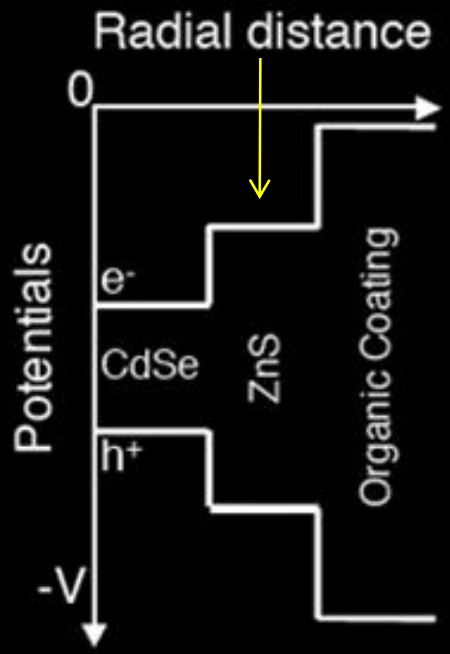
High boiling point Solvent mixture

Heating Mantle **>200 C**

Introduction: QD Core-Shell Synthesis

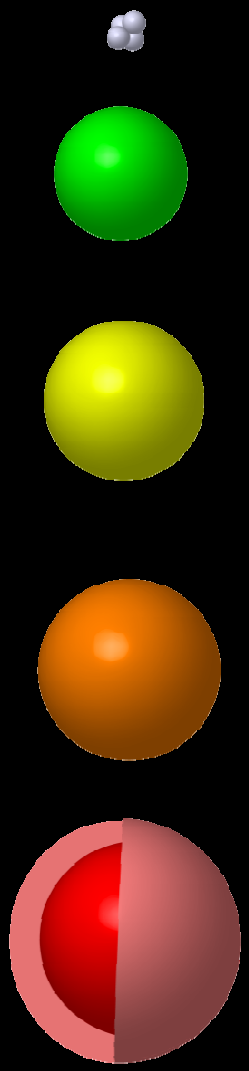


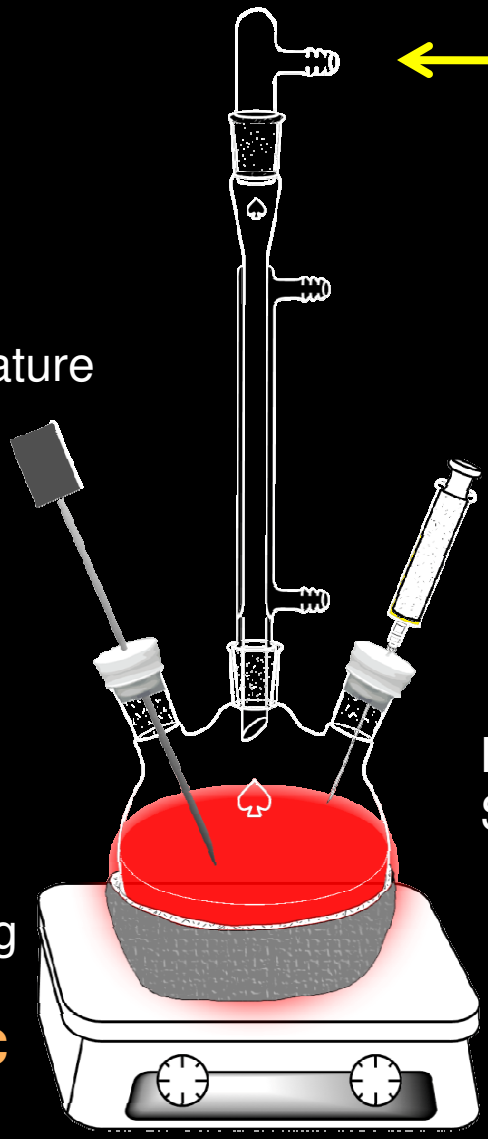
Shell: e.g. ZnS, CdS



- Surface passivation of trap states
- Confinement of e/h pair to the core; isolation from environment

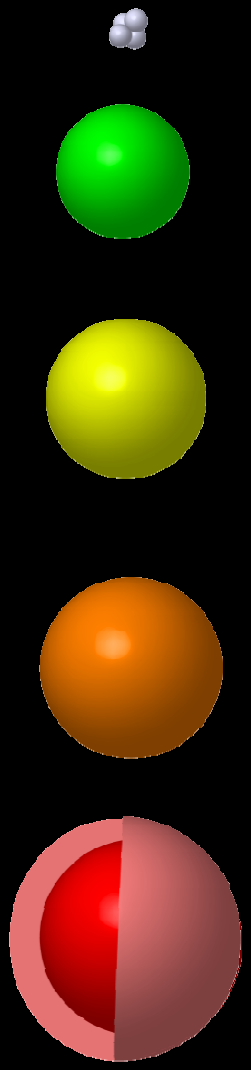
Introduction: QD Shell Synthesis

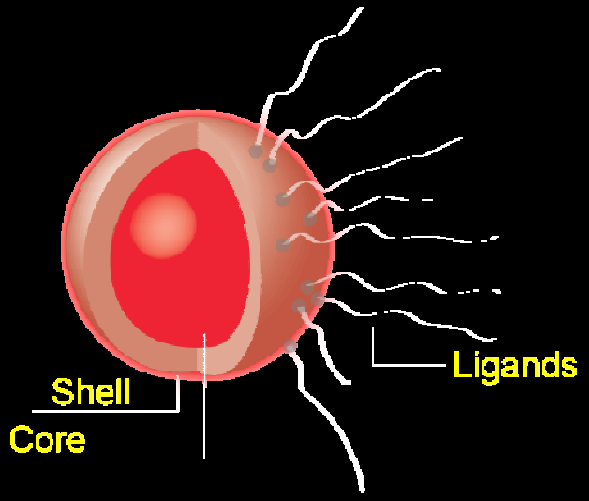




Quantum Yield:
<5% before to >90% after overcoating

Introduction: QD Shell Synthesis



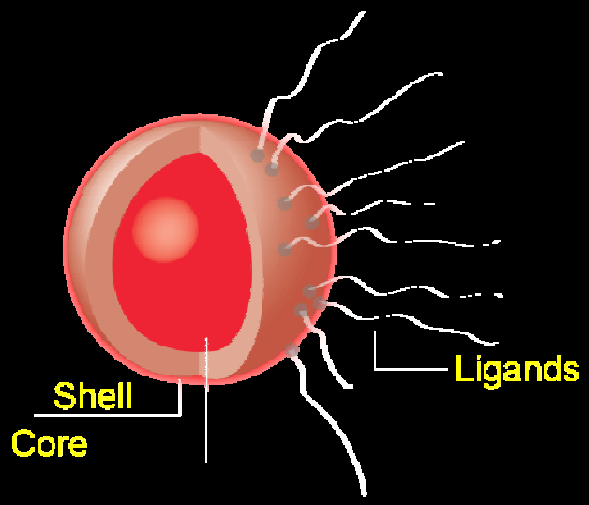


Introduction: QD Advantages

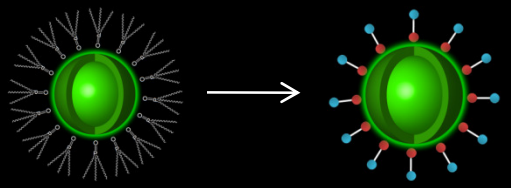
Tunable Optical Properties

Photo by J. Steckel

- Tunable Color
- Narrow FWHM
- High Photostability

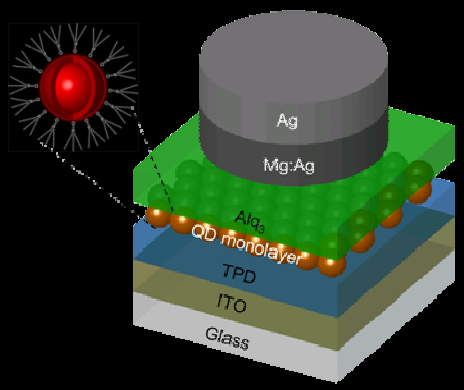


Tunable Surface Properties

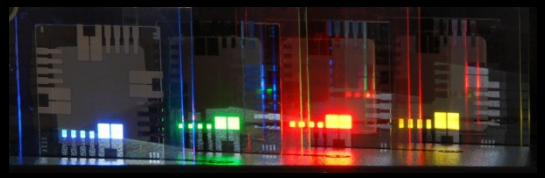


- Polarity
- Surface Charge
- Size

Electroluminescence



QD-LEDs:



AM-QLED:

- Tunable Color
- Narrow FWHM
- Solution processability

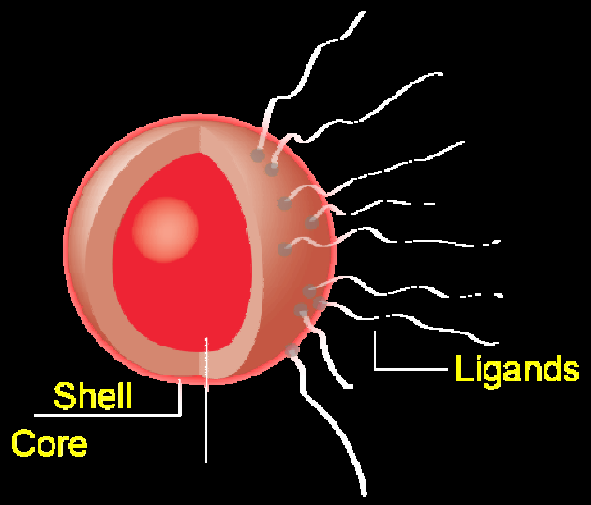
Coe-Sullivan S, Woo WK, Steckel JS, Bawendi M, Bulovic. *Organic Electronics* 2003, **4**: 123-130.
Steckel JS, Zimmer JP, Coe-Sullivan S, Stott NE, Bulovic V, Bawendi MG. *Angew. Chemie* 2004, **43**: 2154-2158.

Introduction: QD Advantages

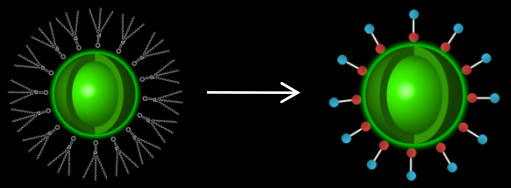
Tunable Optical Properties

Photo by J. Steckel

- Tunable Color
- Narrow FWHM
- High Photostability



Tunable Surface Properties

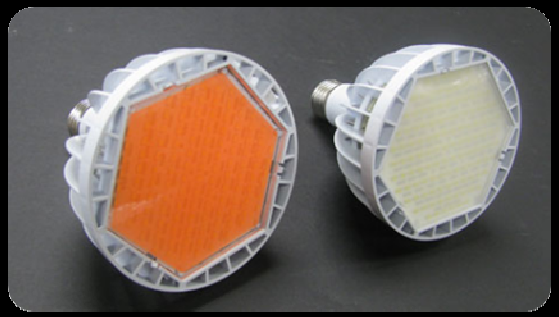


- Polarity
- Surface Charge
- Size

Downconversion

Incandescent LED LED + QDs

The Economist (2010)



Nexxus Lighting

- Tunable Color
- Narrow FWHM
- Photostability
- Solution processability

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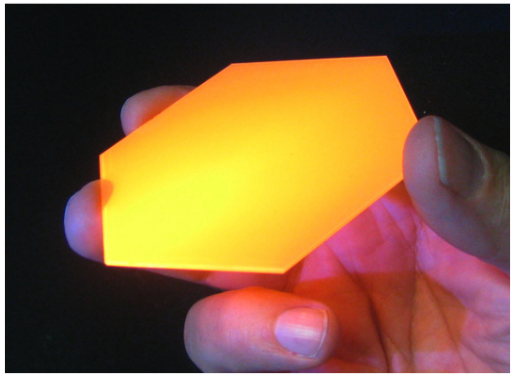
QD VISION

QDs operate in two modes

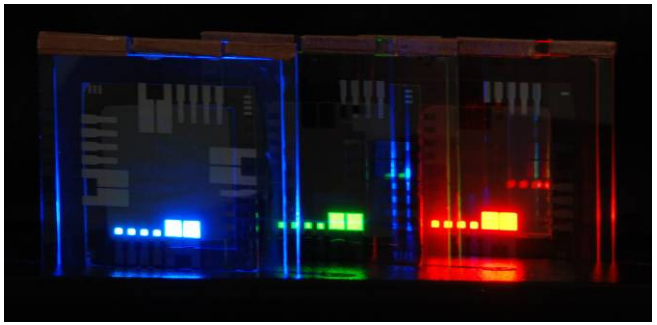
Photoluminesence (PL mode)

- Activated by light energy
- Conversion of color from other light sources
- Any light with shorter wavelength (higher energy)



Electroluminescence (EL mode)

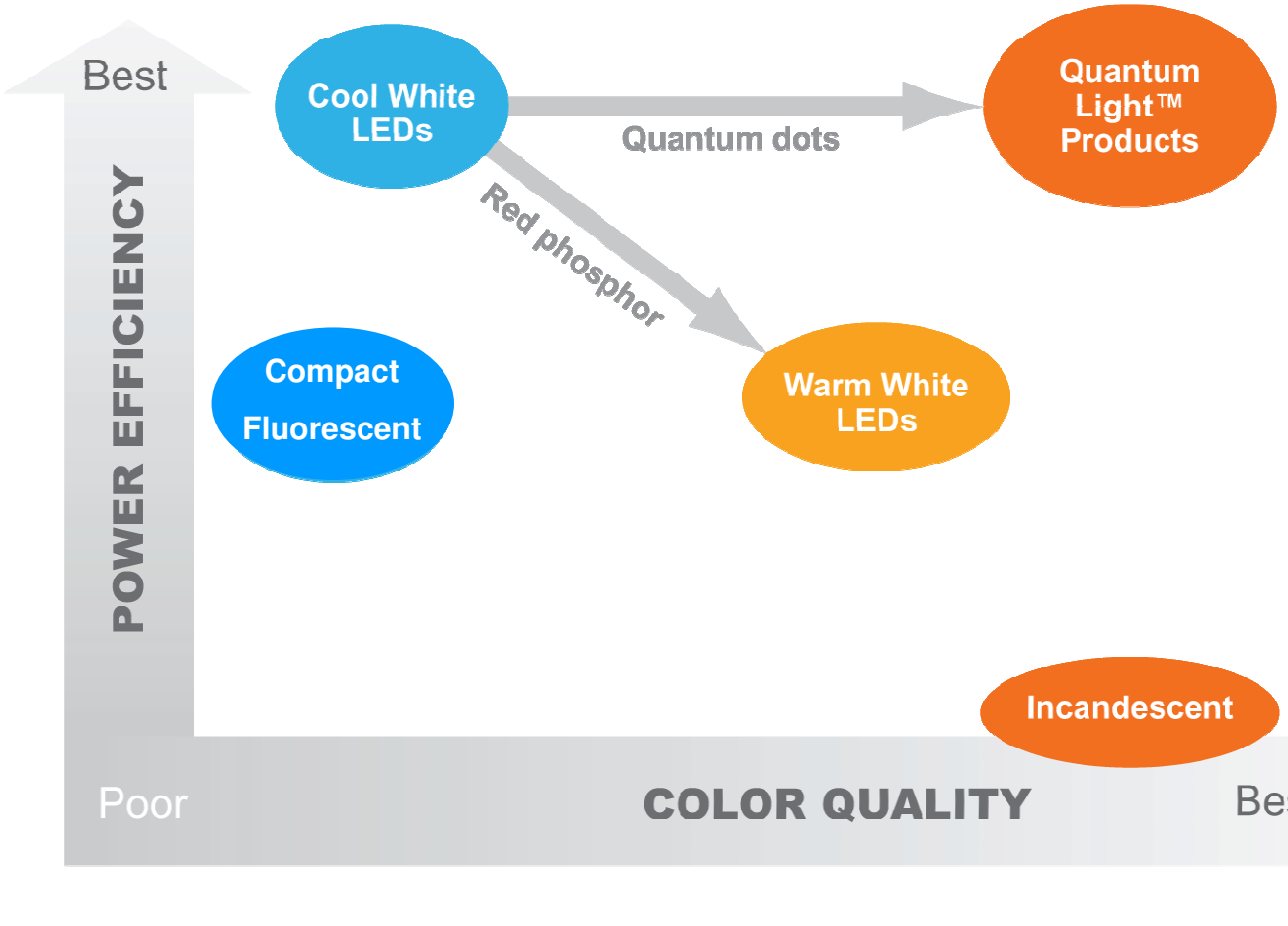
- Activated by electronic energy
- Direct emission of colored light
- Requires charge transfer films
- “QLEDs”

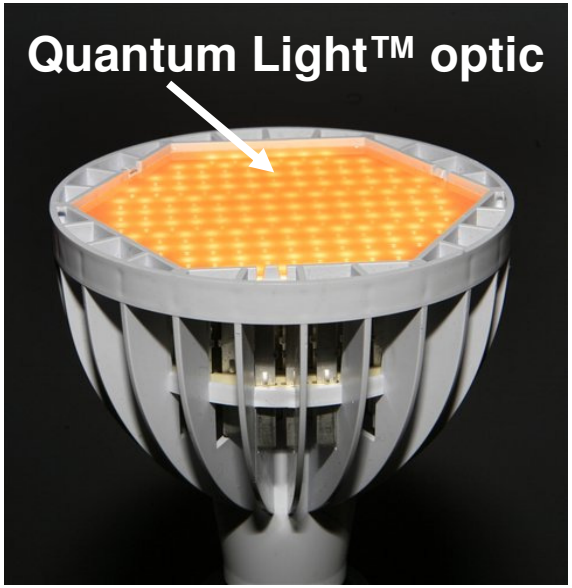


QD VISION

Printed QD Optic For High Performance Lighting

Quantum Dots break tradeoff paradigm





Nexxus R30 LED Array
2700K, 90+ CRI,
>60 LPW

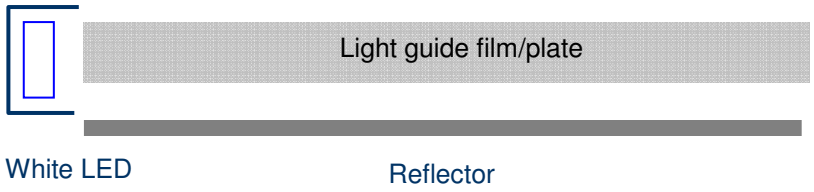
QD VISION

Nexxus Lighting and QD Vision Unveil World's First Commercial Quantum Dot/LED Lamp Line -- May 5, 2009

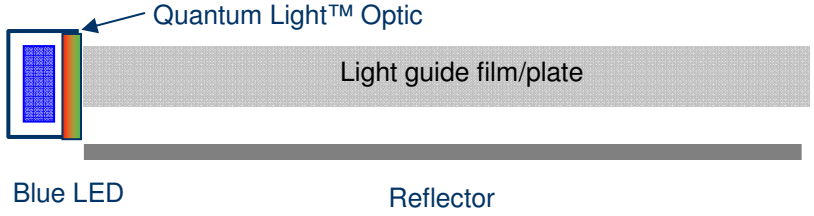
Quantum Light ™ Optic for LCD Backlighting

A drop in solution with disruptive benefits

- **Current White LED Solution**



- **Quantum Light™ Solution in an LCD Backlight Unit**



- **Design:** Drop-In solution; ultra-thin form factors
- **Color:** Visually impressive improvement (70's% → 100+% gamut)
- **Power:** Possible savings of up to 33% (H-K effect)
- **Cost:** Possible savings of up to 50% in LEDs (fewer, cheaper)
- **Enviro:** RoHS Compliant

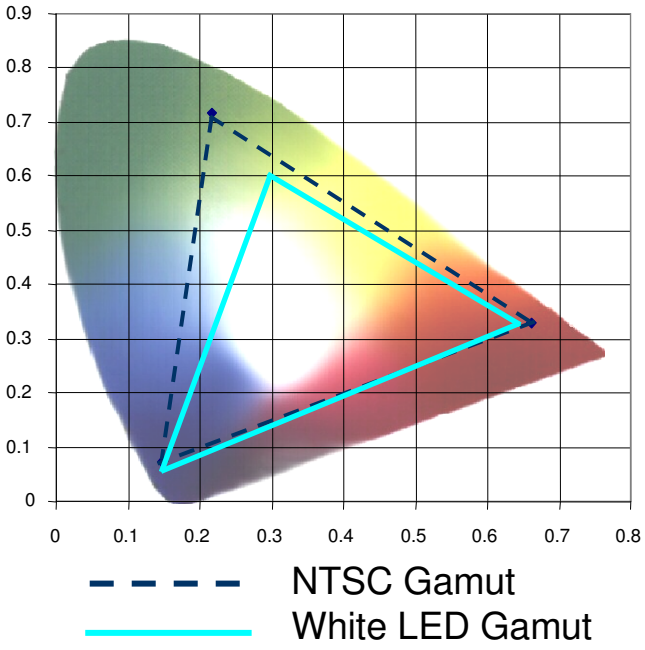
QD VISION

Quantum Light™ ink widens LCD color gamut

Dramatically improves color vs. white LEDs

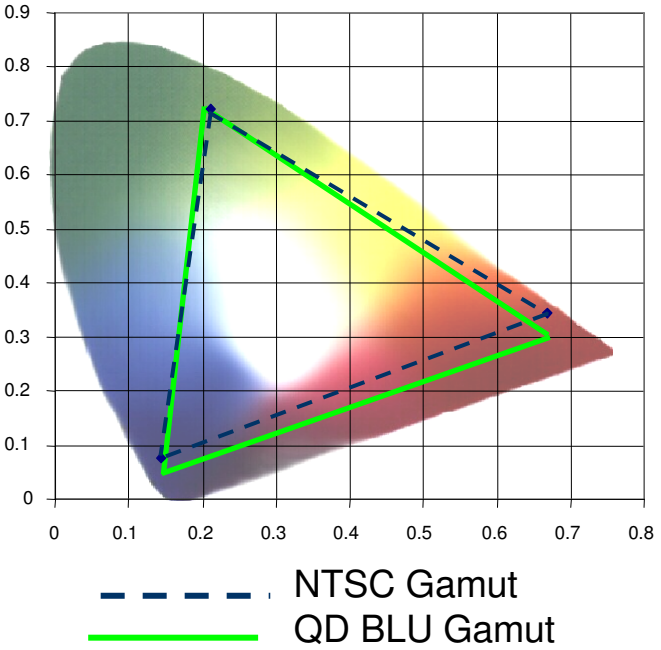
White LED BLU

mid-70% NTSC



QD-enhanced BLU

>100% NTSC



QD VISION

Summary of Gen 2 QDs for PL Applications

Property	Red Phosphor	Gen 1 QDs	Next Gen QDs
Efficiency (EQE)	>90%	>80%	>96%
Wavelength Tunability	600-670nm	600-640nm	600-640nm
FWHM	90-100nm	30-40nm	30nm
Efficiency droop @140C	<15%	**>30%**	**~3%**
Lifetime @ 2W/cm^2, 110C	>10,000hr	**<150hr**	**2500+**

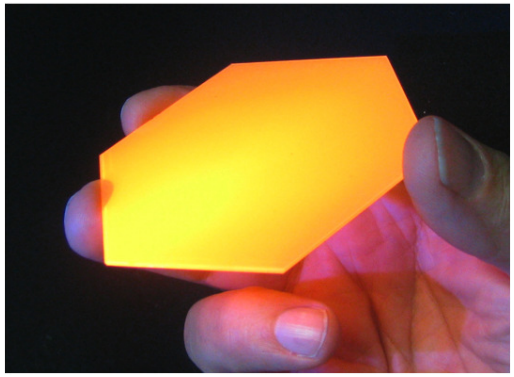
- Manufacturability
  - Lexington, MA manufacturing facility has the installed capacity to serve a significant portion of the display and lighting industries
- New applications enabled by low thermal droop and high stability QDs:
  - BLU and displays: >100% NTSC gamut for TVs and monitors
  - SSL Lighting: maintain efficiency advantage over phosphor while delivering superior color for remote “phosphor” SSL applications with broader flux and temperature range

QD VISION

QDs operate in two modes

Photoluminesence (PL mode)

- Activated by light energy
- Conversion of color from other light sources
- Any light with shorter wavelength (higher energy)



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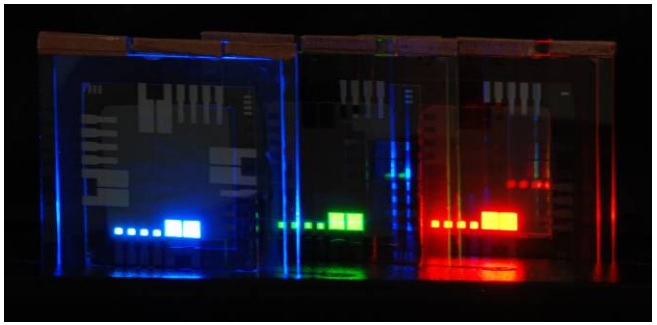
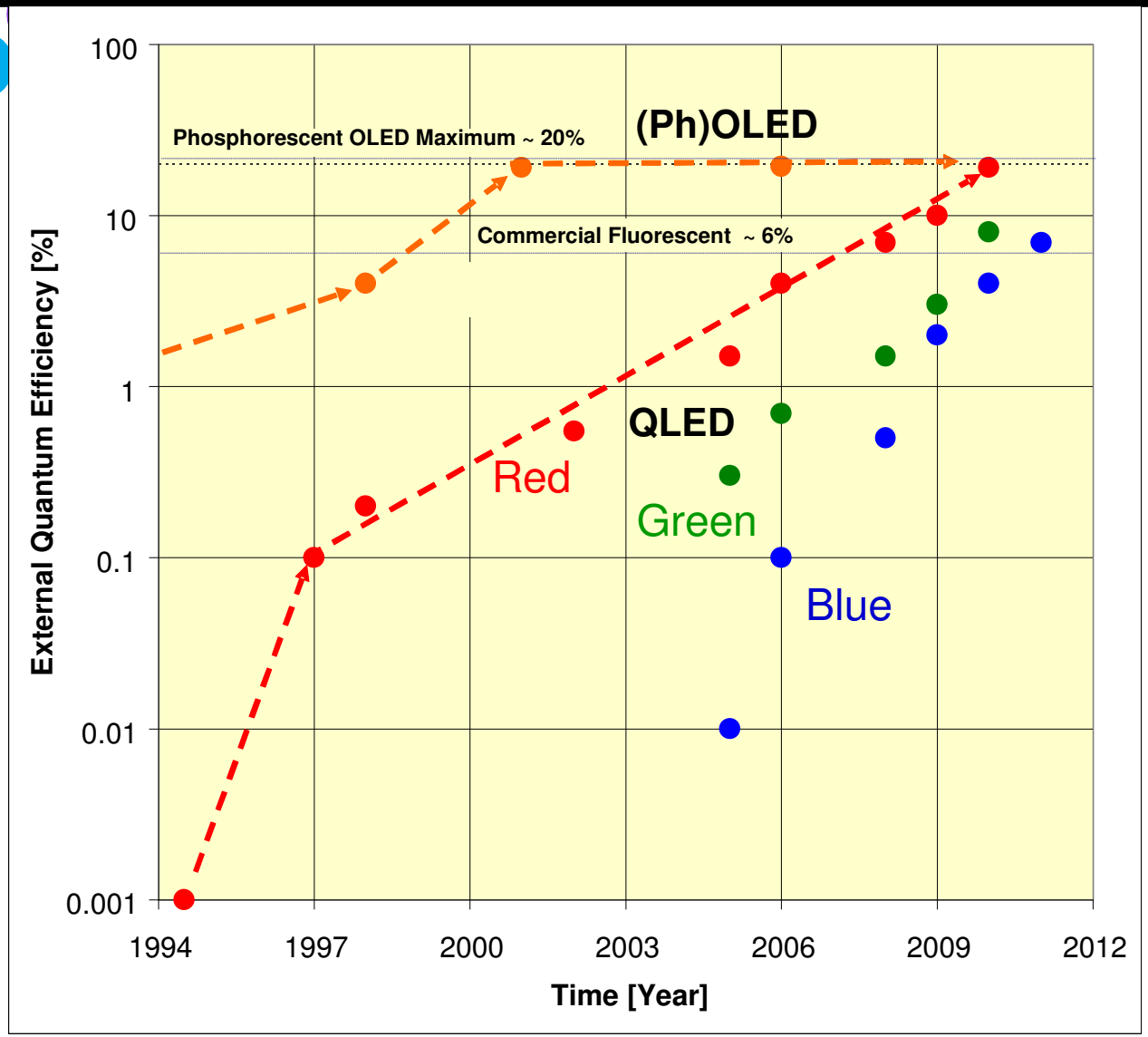


QD VISION

Progress in QLED Development

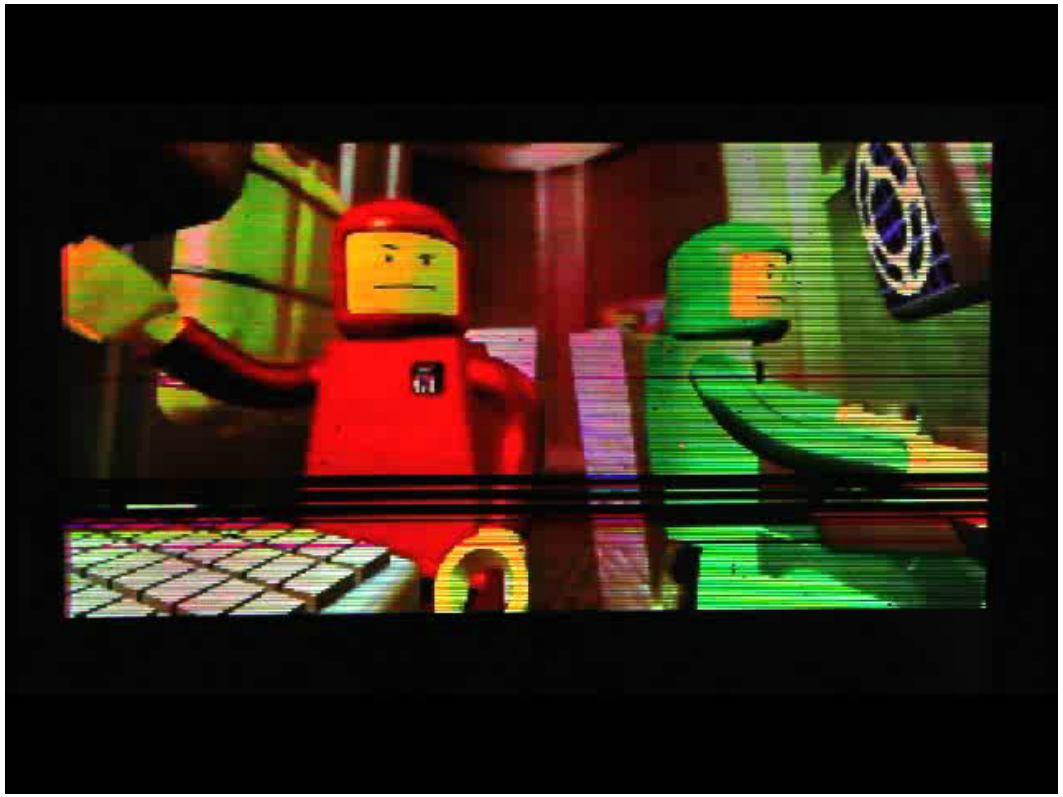


EQEs shown are without outcoupling enhancements

QD VISION

Full-Color AM-QLED

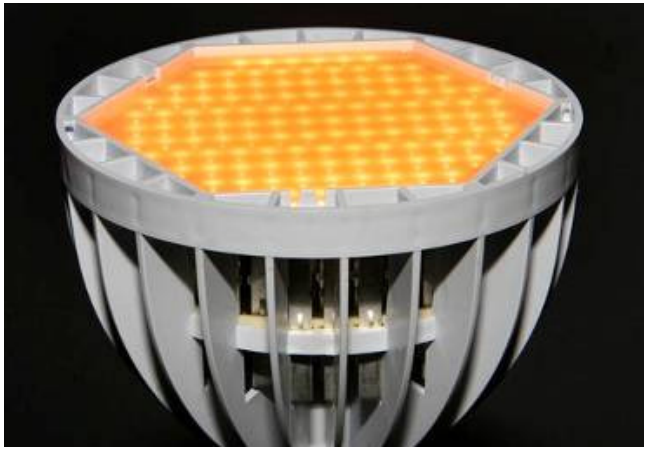
- Why QLED?
  - **Best-in-class color**
  - **Best-in-class power**
  - **All the benefits of printable displays**
  - **All the benefits of emissive displays**

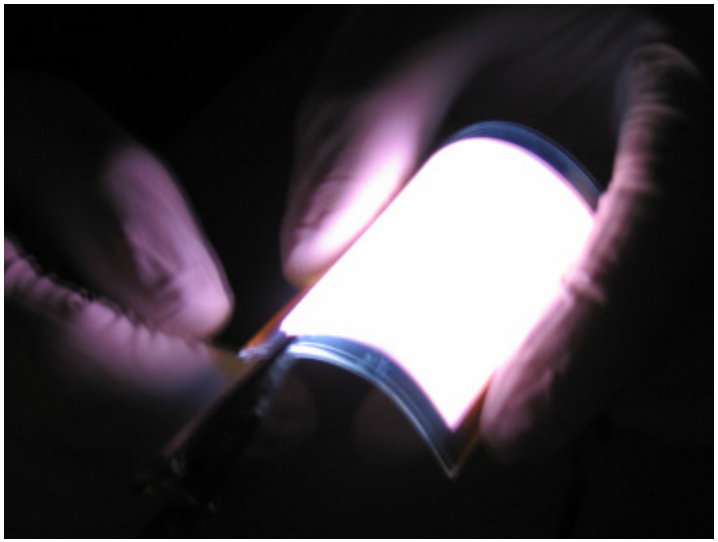


QD VISION

Quantum Dot Solid State Lighting

Today, QuantumLight™ optic products enable breakthrough performance and cost benefits in LED lighting.





Why QLED?

- **Form Factor**
- **Precision color and color quality**
- **Best-in-class lumens per optical Watt (lm/W_{opt})**

QD VISION

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QD VISION

Economic Impacts of 'QD Industry'

- **Direct - now**
  - Jobs: collectively industry employs several 100 to 1,000 worldwide
  - Equity Capital: raised $300-500M in private capital
  - Corporate Value: approaching ~$1B in combined market cap (all but one is private)
  - Products: QDs will be embedded in approaching $10B of end-product in 2013
- **Direct – future**
  - Lighting and Displays each represent $100B markets
  - At QD material and component level, this is a roughly $5-10B revenue opportunity
  - Solar, security, thermoelectric, magnetic markets easily double this in aggregate
- **Indirect**
  - Rare-earth replacement
  - Energy efficiency
  - Security

QD VISION

Rare-Earth Availability Concerns

Figure 1. Short-Term (present–2015) Criticality Matrix

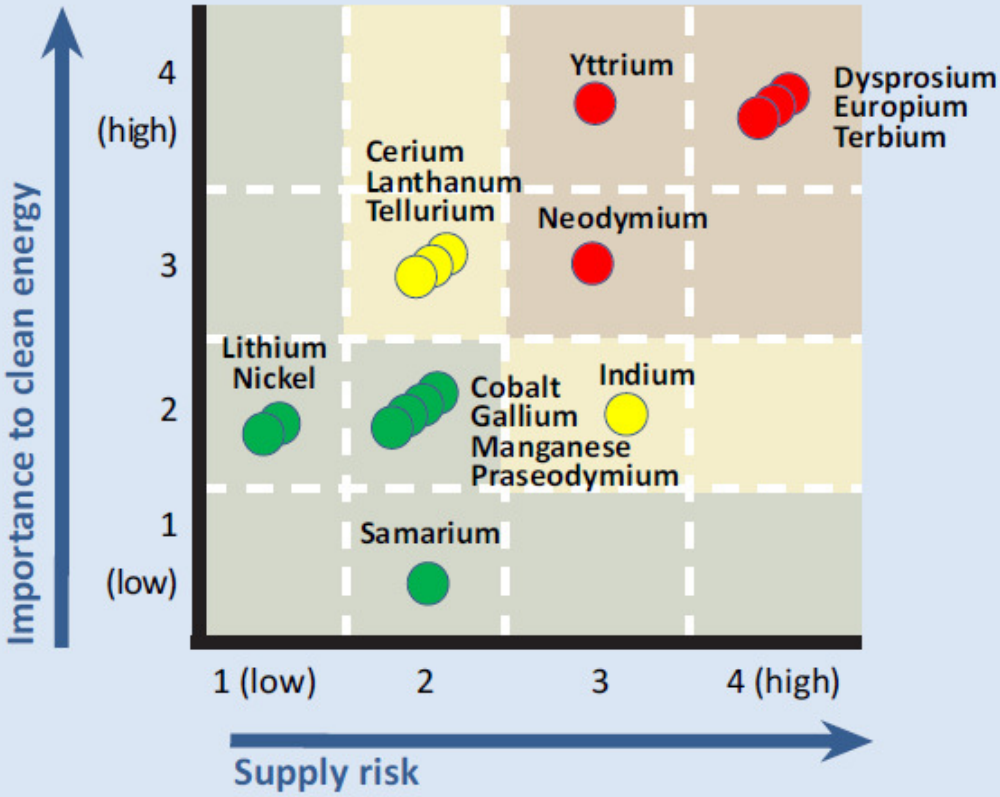
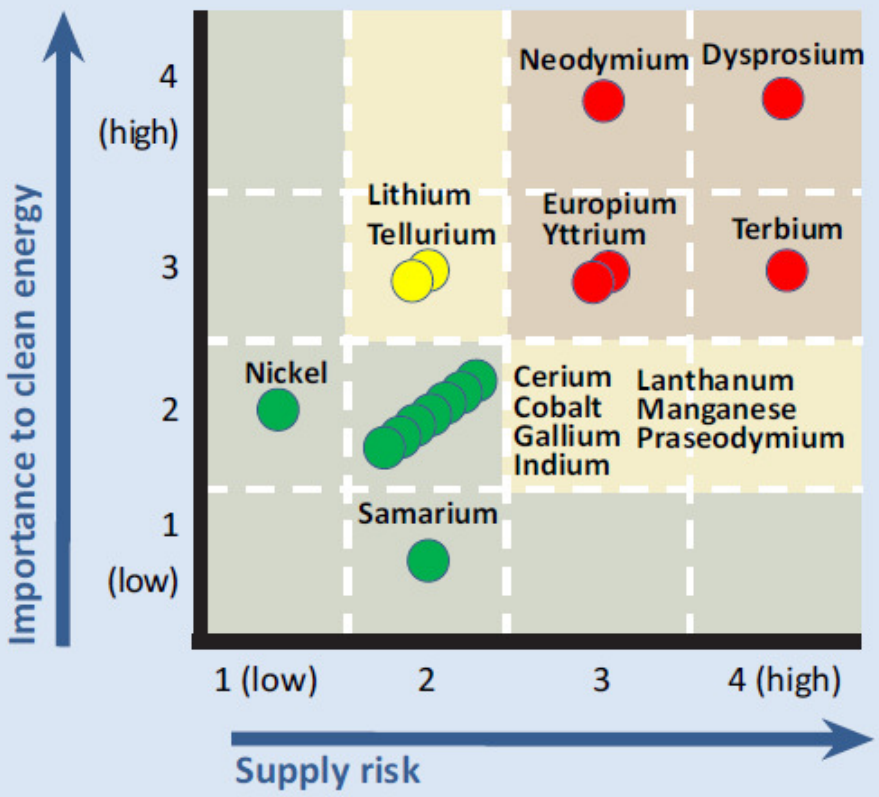


Figure 2. Medium-Term (2015–2025) Criticality Matrix



Critical Near-Critical Not Critical

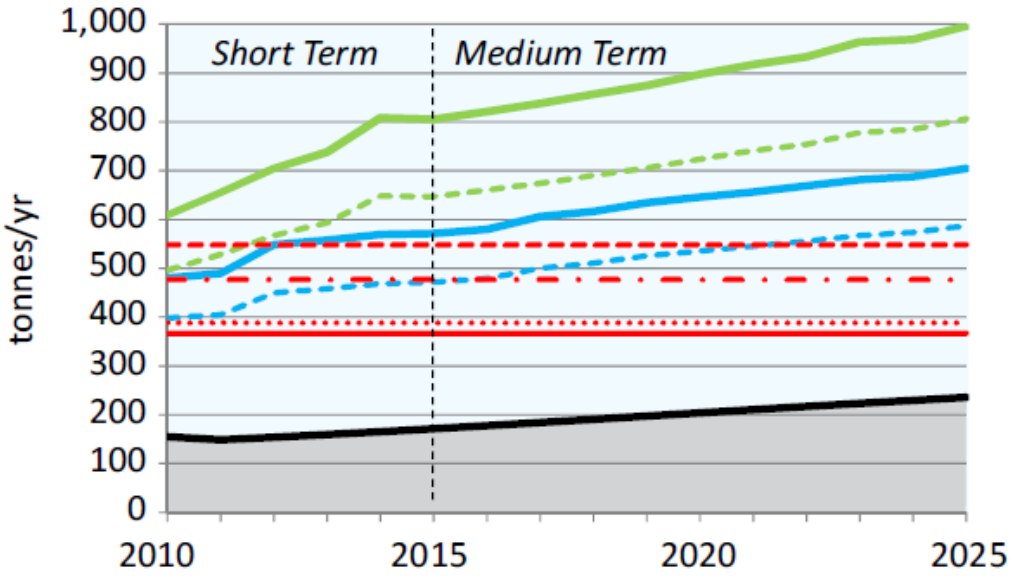
From DOE's Critical Materials Strategy, 2011

QD VISION

Rare-Earth Availability Concerns

Figure 3. Future Demand and Supply for Europium

From DOE's Critical Materials Strategy, 2011



Demand

- High Deployment, High Material Intensity
- High Deployment, Low Material Intensity
- Low Deployment, High Material Intensity
- Low Deployment, Low Material Intensity
- Non-Clean Energy Use

Supply

- 2015 Estimated Supply
- Plus Mount Weld
- Plus Mountain Pass Phase I
- 2010 Supply

- **Rare-earth Metal Supply Concerns**
  - >90% of REMs are currently mined in China, Russia
  - Represents a clear price, and possible supply concern
  - USG committing significant funding to develop alternatives

QD VISION

Lighting's Impact on Energy Consumption

- 22% building electricity spent on lighting
- Conversion to efficient lighting underway
- Fluorescent & LEDs offer huge savings
  - with power efficiency gains 22% → 7% overall savings
- But, hindered by poor color, mercury
- Governments still forcing conversion

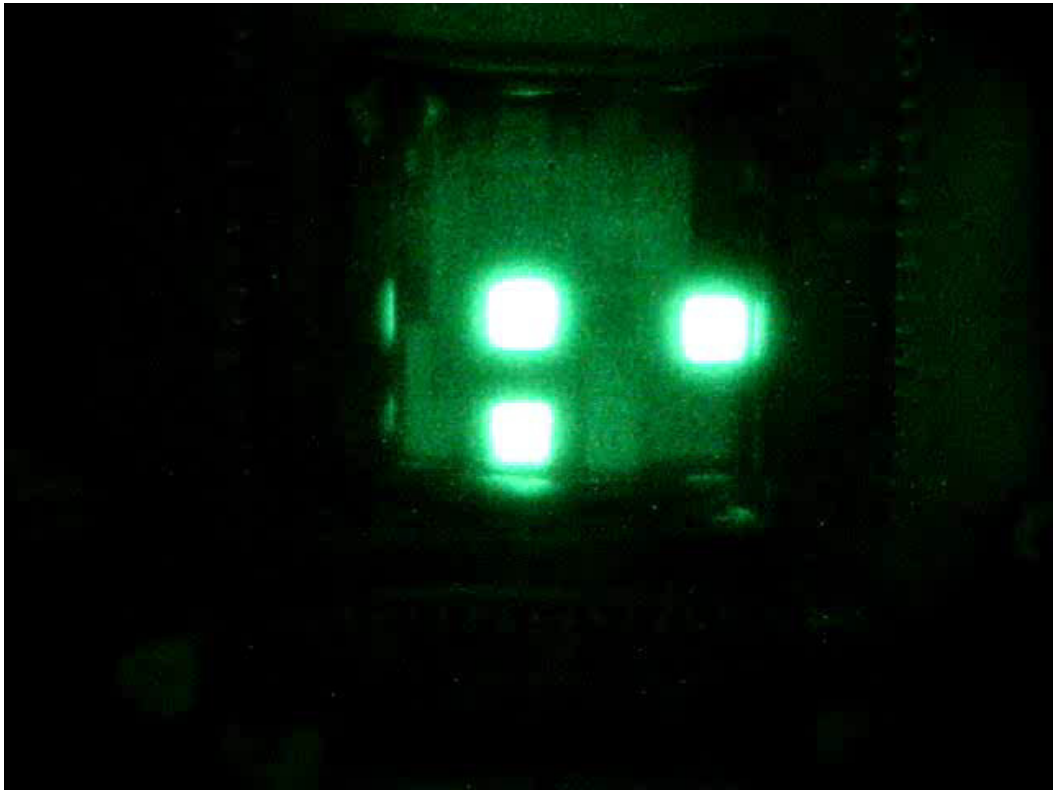
QD Vision's Quantum Light™ optics eliminate the tradeoff — Great color with step changes in power & cost savings

OECD/NNI – March 2012

QD VISION

Security Application

- DoD has been early adopter of QD materials.
- Deployed solutions are increasing security worldwide.



QD VISION

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Acknowledgments

Thank You!

Supporting Contracts:

- **Air Force Contract No. FA9550-07-C-0056.**
- **Active-matrix QLED display research was sponsored by the Army Research Laboratory and was accomplished under Cooperative Agreement Number W911NF-09-2-0049.**
- **Arizona State University Flexible Display Center for a-Si TFT backplane and display electronics.**

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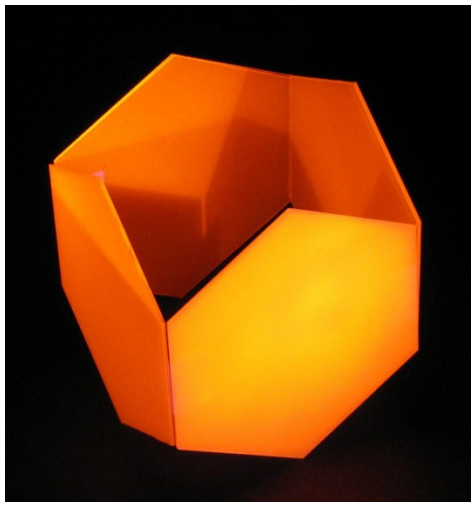
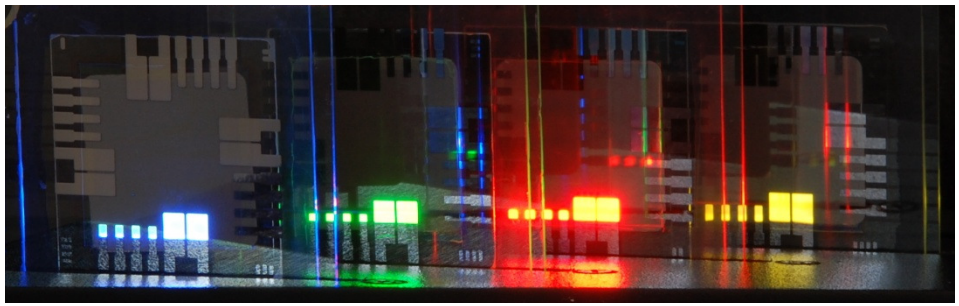
QD VISION

Conclusions

QDs are a nano-material technology that will have great economic impact on the lighting and display markets, and hence on energy.

- **Lighting products are on the market today**
- **Display products are entering**
- **Lighting represents single greatest potential impact on energy consumption WW**
- **Applications in solar may impact energy production, too**
- **By 2013, economic impact is clearly measureable in the $10B's**





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Co-founder and CTO
scoe-sullivan@qdvision.com

QD VISION