Quantum Dots: Next Generation Downconverters for High Efficiency and High Color Quality SSL

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Quantum Dot Down Converters in Solid State Lighting

Critical Need: High Efficiency, Stable, Narrow Red and Amber Down Converters

Comparing QD Products

QD Film
- QDs in O₂ barrier films
- Film covers entire BLU
- Large amount of QD material per display
- In line roll process
- Operates at temperature of BLU surface

QD Edge Optic
- QDs sealed inside glass optic
- Optic used on 1 or 2 edges of BLU
- Highly efficient use of materials per display
- Highly flexible white point options
- Operates at temps. near but not on LED

QD On LED Chip
- QD materials mixed in LED encapsulant
- Packaged LEDs used in BLU
- Packaging costs per LED unclear
- Must survive LED junction temperature and O₂ exposure

BELIEVE YOUR EYES

Slide Courtesy of Seth Coe-Sullivan
Auger Recombination Reduces PLQY
Leads to Photoionization

Photodegradation Mechanism I: Multiexciton Mediated Photoionization

Carriers trap at mid-gap electronic states derived from surface atoms.

Ligands “passivate” these traps by removing them from the optical gap.

Photoluminescence quantum yield very sensitive to surface structure.
Nanocrystal ionization and internal charge reorganization / surface trapping can both lead to long-lived “OFF” states.

Ionized Nanocrystals Undergo Fast, Nonradiative Auger Decay

Each type of multiexciton has its own decay dynamics and PLQY.
Core-Shell Nanocrystals Isolate Excitons From Surfaces

Energy level landscape localizes excited electron and hole within the crystal core

Photoluminescence quantum yields remain sensitive to surface chemistry

Auger recombination dominates PLQY at high flux “on chip”
Colloidal QD R&D Synthesis and Surface Chemistry

PLQY = 85%
2007
Talapin, Alivisatos, Manna
(Seeded Rods-CdSeCdS)

PLQY = 80%
2005
Mews
(Core-Shell-Shell)

PLQY = 50%
1996
Guyotte-Sionnest
Alivisatos
(CdSe/ZnS)

Non-Blinking Fraction
2008
Hollingsworth
Dubertret
(Thick Shell)

1982
Brus, Ekimov,
Henglein

'80 '90 '00 '10 '20

1993
Bawendi

2001
Peng

1993
Peng

R3P=Se
CdMe2

2002
S8

2003
Peng

SILAR

2009
QDVision
Nexxus
(remote bulb)

2013
QDVision
Sony
(ColorIQ)

2014 - 3M, Sony, LG,
(many others)
Colloidal QD R&D
Synthesis and Surface Chemistry

Talapin, Alivisatos, Manna
(Seeded Rods-CdSeCdS)
PLQY = 85%
2007

Hollingsworth
Dubertret
(Thick Shell)

Non-Blinking Fraction
2008
Hyeon Buhro, Dubertret
(Ribbons, Sheets)

G Guyotte-Sionnest
Alivisatos
(CdSe/ZnS)
PLQY = 50%
1996

Mews
(Core-Shell-Shell)
PLQY = 80%
2005
Brus, Ekimov, Henglein
1982

Dubertret, Talapin
(Core-Shell, Core-Crown)
PLQY 80%
FWHM = 20nm
2013

Biexciton
2015

QDVision Nexxus
(remote bulb)
2009

QDVision Sony
(ColorIQ)
2013

2014 -
3M, Sony, LG,
(many others)

CdMe₂ + R₃P=Se
1993
Bawendi

CdO + R–PO₃H₂
2001
2002
2003
Peng
Peng
SILAR

Full Gamut with Blue LEDs
Blue LEDs
QuantumDot TV
Graded Alloy QDs with Suppressed Auger Recombination

- Large, graded CdSe/CdS interface reduces Auger recombination.
- Reduced Auger rate gives 100% PLQY of Biexciton, Non-Blinking fraction of QDs.

- Alloy leads to increased FWHM.
- Lengthy stepwise synthesis difficult to optimize.
- Atomic structure difficult to determine and optimize.

Opportunities in The Synthesis of Core Shell QDs

- difficult to control precursor reactivity leads to irreproducibility.
- linear sequence compounds irreproducibility
- managed with engineering controls, little knowledge of underpinning chemical reactions.
- Nanosys: “25 tons of QD material annually”

http://www.nbclearn.com/nanotechnology
Fine Control Over QD Se/S Alloys with Precursor Library

Surface Metal Ions Prove Labile

**Prevailing model of Quantum Dot surface chemistry** has changed dramatically.

**Metal ion coverage** crucial to blinking statistics and PLQY.

Surfaces and trapping remains largely a mystery.

QDs with improved stability under high flux are being discovered.

- Increasing shell and core dimensions and graded alloy interfaces reduce Auger recombination kinetics, improve flux stability.

- Understanding of synthesis and reagents have improved, allowing performance to be optimized by design rather than by an Edissonian approach.

- Cd-free QDs (InP, CuInS) lag far behind Cd-QDs, (FWHM > 40 nm, PLQY < 90%). Greater focus on fundamental understanding of synthesis is needed to gain fine control.

Long-Term Environmental Stability by Encapsulation.

- Surface passivation remains largely a mystery. Fundamental studies of surface ligand interactions needed as well as R&D on new surface passivation strategies.

- Ultra-barrier layer surface coatings need to be developed.