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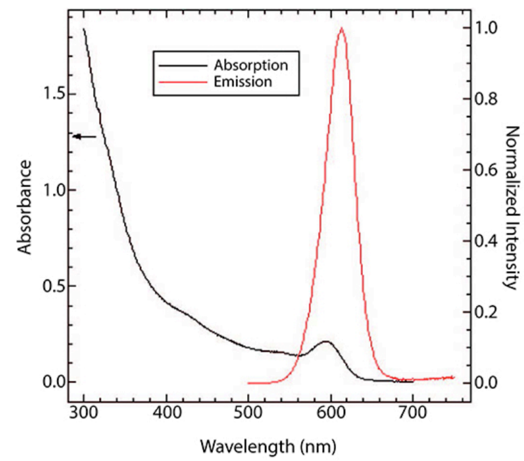
Sandia Develops a Synthesis of Quantum Dots that Increases the Quantum Yield to 95.5%

White light-emitting diodes (LEDs) based on blue indium-gallium-nitride (InGaN) LEDs that excite yellow-green-emitting yttrium-aluminum-garnet: cerium phosphors (YAG:Ce, a nonhygroscopic, chemically inert inorganic scintillator) have a cold white emission that can be made warmer with the addition of a red-emitting component. Unfortunately, red emitters that satisfy all criteria for use in solid-state lighting (SSL) applications are not yet available.



The absorbance and photoluminescence emission of Type 1 quantum dots (QDs). Excitation wavelength is 460 nm. Even with multiple shells, these QDs have red emission that is ideal for SSL applications.

The ideal red emitter would have broad blue absorption and narrowband emission that peaks at ~610–630 nm and lacks the deep red emission to which the eye is insensitive. The narrowband red emission criterion enables

- a high luminous efficacy of radiation (LER)—defined as the lumens of light emitted per Watt of light emitted and
- warm white light with a high color rendering index and a low correlated color temperature.

Some additional criteria that red emitters must satisfy relate to their performance in a device and include

- high quantum yield under blue excitation;
- low thermal quenching;
- photostability;
- low scattering losses; and
- resistance to saturation under high excitation fluences.

Our goal is to develop red emitters that satisfy all of these criteria for SSL.

For quantum dots to be suitable for demanding applications, such as SSL, heterostructures must be developed that consist of a group II–VI semiconductor core (e.g., cadmium telluride, CdTe) surrounded by one or more group II–VI shell materials, whose purpose is to (a) enhance the quantum yield, (b) reduce thermal quenching, and (c) enhance the thermal and photostability of these materials so that they have a suitable lifetime (target: >30,000 hrs) when subjected to the high excitation fluences characteristic of lighting applications.

CdTe-based quantum dot heterostructures have shown potential as the red-emitting component for warm white LEDs. They have broad blue absorption, narrowband red emission, quantum yield as high as 95.5%, and significantly higher luminous efficacy of radiation than that of the current red LED phosphors. The photoluminescence emission from Type 1 quantum dots is ideally located at 613 nm and its LER is 227 $lm/W_{emitted}$, which is an 87% improvement over a broadband red-emitting Eu^{2+}-doped nitridosilicate phosphor.

CdTe	cadmium telluride
CdSe	cadmium selenide
CdS	cadmium sulfide
ZnS	zinc sulfide
ZnSe	zinc selenide

CdTe-Based Quantum Dot Heterostructures

Type 1: CdTe | 2 CdSe | CdS | 5 ZnS
Type 2: CdTe | 2 CdSe
Type 3: CdTe | 2 CdSe | CdS
Type 4: CdSe | ZnSe

The effects of aging include a blue-shift and broadening of the photoluminescence, blue-shift of the absorbance, and an increase in the photoluminescence lifetimes. We measured the smallest photoluminescence blue-shift (5 nm) for the Type 2 quantum dots that were aged for one year. Quantum dot polymer encapsulation is expected to improve their photostability and will be a subject of future work.

Type 2 and Type 3 quantum dots that are one year old have significantly less thermal quenching than Type 4 quantum dots at 100 °C. The thermal quenching of Type 1 quantum dots is comparable to that of the Type 2 and Type 3 quantum dots, but is completely reversible. Understanding the mechanisms responsible for thermal quenching in CdTe-based quantum dots above room temperature will help us design heterostructures for SSL applications that minimize or eliminate this effect.

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