Application of Quantum Dot nanocrystal in Luminescent solar concentrators

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Abstract. The basic design of luminescent solar concentrator is a transparent plate doped with an appropriate luminescent material (organic dyes, quantum dots), which is able to absorb sunlight (direct and diffuse), and then guides photons produced by photoluminescence to its narrow edges where they are converted by photovoltaic cells. Unfortunately, LSCs have suffered from numerous efficiency losses. Therefore, new luminescent species and novel approaches are needed for its practical application. This paper deals with investigation of nonhazardous, environmental friendly luminescent species include CuInS2/ZnS core/shell QDs. The CuInS2/ZnS QDs possess advantages of Stocks shift as large as more than 130 nm and high photoluminescence quantum yield of 80%. The paper presents the effect of large stock shift CuInS2/ZnS QDs on reducing the reabsorption losses in LSC by using experimental investigation. The LSC sheets were fabricated by dispersing CuInS2/ZnS QDs particles in a polymethylmethacrylate waveguide. A series of LSCs (dimension 4.0 cm × 3.0 cm × 0.3cm) with different CuInS2/ZnS QDs particles concentration (0.015 and 0.03 wt.%) were fabricated and their optical properties (absorptions/emissions) were characterized. The results show that the CuInS2/ZnS QDs-LSC provides a promising way for the reduction of reabsorption losses in LSCs.

1. Introduction
In the 1950’s, photovoltaic cells were invented to convert light into electricity(1) and in the 1970’s one proposed method was to use fluorescent polymer waveguides to concentrate light onto traditional silicon solar cells (2-4). These devices were initially called fluorescent planar concentrators and later became known as luminescent solar concentrators (LSC). The general principle behind LSCs is illustrated in Figure 1. Incident photons from the sun are absorbed by luminophores in a waveguide, and the emitted photons are guided via total internal reflection (TIR) to an adjacent silicon solar cell where they are converted to electricity (5, 6).
The development of the LSC was initially limited by properties of organic dyes, such as narrow absorption band, large reabsorption and poor photo-stability. Recently, semiconductor QDs emerged as attractive candidates for development of stable and functional LSC devices. In 2015, the CuInS2/CdS nanocrystals (NCs) have been demonstrated to be attractive phosphors for high-gain full spectrum LSC applications. Their broad solar absorption and large photo luminescent quantum yield (PLQY) are combined to outweigh their moderate reabsorption losses.

LSCs could reduce the cost of solar energy by allowing replacement of expensive large-area PVs with cheaper solar-harvesting antennae coupled to small PVs (3, 6). LSCs are well suited for applications as semitransparent windows. They are used as exterior façade cladding, public transportation waiting area, shading device, street lightening, etc. However, they suffered from many losses. Self-absorption is an important loss factor and is thought to be a consequence of the spectral overlap between absorption and emission (3). Luminescent photons emitted in this overlap region, risk to absorbed again by another luminescent molecule and get lost instead of reaching the edge of the concentrator. By using experiments, this important loss mechanism will be studied. In this work, in order to minimize the reabsorption loss in luminescent solar concentrators, the LSC sheets in vary of quantum dots (QDs) particles concentration were investigated and their optical properties were characterized.

1.1. Quantum dots
Quantum dots are semiconductor nanocrystals that have an adjustable absorption and emission peak wavelength by varying the size of the quantum dot (Figure 2 and 3). Another advantage of quantum dots is the spectrally wide absorption band compared to organic dye molecules. QDs are more stable and less degradable than organic dyes. Several recent reports have recognized that the combination of large Stokes shifts and PL tunability displayed by copper-doped semiconductor nanocrystals makes them attractive luminophores for luminescent solar concentrators (LSCs) [6, 9-13].

By using nanotechnology and some special polymer components and quantum dots nanocrystals, the reabsorption loss of LSCs can be lessened. This fundamental study will investigate special quantum dot nanocrystals to reduce re-absorption in future work to design a new LSC with minimum re-absorption losses.
1.2. The effect of stoke shift on reabsorption
A critical property of every fluorophore is its Stokes shift, which is the wavelength gap between the absorption and emission peaks; the bigger the Stokes shift, the smaller the overlap between the two spectra will be which will result in lower re-absorption as shown in Figure 4.

![Stokes Shift Diagram](image)

**Figure 4.** Absorption (orange) and emission (blues) spectra of Coumarin 153(10).

2. Experiment
LSCs were prepared with fixed dimensions of 4.0 cm × 3.0 cm × 0.3cm and varying concentration of CuInS2/ZnS QDs particles. These particles are purchased from a commercial supplier (UbiQD, USA) with a quantum efficiency of 80%. To fabricate the LSC, the ratio was set as 9:1 MMA: PMMA. The
CuInS$_2$/ZnS QDs particles were first dispersed in a methyl methacrylate (MMA) monomer solution by ultrasonic stirring, then polymethylmethacrylate (PMMA) is added and stirred until all PMMA granules were dissolved completely. The mixture is cooled and azobisisobutyronitrile (AIBN) was added to the solution at an AIBN/MMA weight ratio of 0.1 wt.%. The mixture is heated to 60 °C by using a heater for more than 3hrs and then is cooled to room temperature. The solution is poured into molds (0.3 cm thick) and then placed in a water bath for longer than 18 hours to complete polymerization. Finally, the PMMA plate was cut with areas of 4 cm × 3 cm × 0.3 cm by laser cutting. By controlling the CuInS$_2$/ZnS QDs particles concentration, a series of LSCs were fabricated at 0.015wt%, and 0.03 wt.%.

3. Result and discussion
Semiconductor crystalline CuInS$_2$/ZnS core/shell QDs with QY 80% were fabricated in PMMA sheet at different concentration of 0.015 wt. % and 0.03 wt. %. Figure 5 and 6 show the absorption and emission spectra of CuInS$_2$/ZnS QDs at different concentrations in PMMA sheet. The emitting peak of CuInS$_2$/ZnS QDs observed at 625 nm with large Stocks shift 130 nm. These QDs are able to convert light with wavelength of less than 500 nm into around 630 nm effectively (Fig. 5), which could be absorbed by the c-Si PV cells more efficiently.

![Absorption spectra](image_url)

**Figure 5.** Absorption spectra of CuInS$_2$/ZnS QDs at concentration of 0.015 wt. and % 0.03 wt. %.

![Emission spectra](image_url)

**Figure 6.** Emission spectra of CuInS$_2$/ZnS QDs at concentration of 0.015 wt. and % 0.03 wt. %

Figure 7. shows spectra of photoluminescence measured at one of the slab edges (4 × 0.3 cm$^2$) using optic fiber at 427 nm excitation positioned at different distances d (0-4cm) from the sample.
edge. By increasing distance (d), the PL intensity is observed to drop because of reabsorption by the quantum dots and by the polymer matrix and light escaping from the waveguide.

![Graph showing photoluminescence spectra](image)

**Figure 7.** Photoluminescence spectra (excitation at 410 nm) as a function of distance (d) by increasing from 0 to 4 cm from the edge.

The shape of the photoluminescence spectra shows only a small change with d, suggesting that losses to reabsorption are not significant.

4. Conclusion
In this research, heavy metal free CuInS2/ZnS core/shell QDs with the large Stokes shift (130 nm) and high PLQY (80%) has been proposed. The QDs-doped PMMA LSCs were fabricated in 0.03 Wt. % and 0.015 Wt. % concentrations. Their large stock shift and broad solar absorption combined to reduce self-absorption losses in the LSCs sheet. Therefore, the CuInS2/ ZnS NCs can be attractive luminescent material to be used in LSCs applications and we can expect to see LSC-based products in the energy and built environment markets soon.

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