# Optimizing Colloidal Quantum Dot Synthesis Conditions for Tandem CQD Solar Cells

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## Abstract

**Motivation.**

- First generation solar cells based on silicon are limited by a maximum theoretical efficiency of 32.5% [1]
- Multijunction solar cells can theoretically achieve efficiencies up to 68.7% but require multiple bandgaps, which cannot be achieved by silicon alone [2]
- Colloidal quantum dots (CQDs) exhibit size dependent bandgap tunability, making them ideal candidates for multijunction cells
- The solution processability and low-cost fabrication of CQDs make them ideal candidates for affordable, versatile, and high efficiency solar cells

**Methods.**

Fabrication: Colloidal synthesis, spray casting, electron-beam evaporation

Measurements: Illuminated current-voltage (JV) testing, Ultraviolet-visible (UV-vis) spectroscopy

**Results.**

- Synthesis of ultrasmall PbS CQDs with bandgaps in the visible region
- Optimization of 1 eV and 1.5 eV CQD synthesis, for use in multijunction solar cells

## Introduction

Tandem solar cells are a promising technology to improve the efficiency of solar energy harvesting beyond traditional single junction silicon solar cells. A typical tandem solar cell structure is shown in figure 1a. The PbS-PbX2 layers act to absorb the sunlight and the PbS-EDT layer and ZnO layer selectively transport holes and electrons, respectively in order to facilitate the flow of current through the device.

A variety of novel materials have been proposed as the absorbing material in tandem solar cells. PbS CQDs are of special interest because their absorbance spectrum can easily be tuned over the visible and near-infrared region by changing the size of the quantum dot (figure 1b). In this poster, we explore CQD synthesis towards the fabrication of a tandem PbS CQD solar cell using the structure depicted in figure 1a.

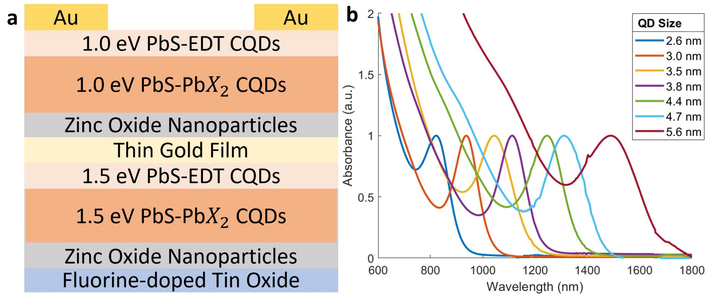



*Figure 1*. (a) Structure of a tandem CQD solar cell. The thin gold film acts as a recombination layer to enable the flow of charges between both sub-cells. (b) Plot showing the change in absorbance as the diameter of the CQD is changed. CQD sizes calculated based on work by Moreels et al. and absorption peaks observed in the UV-Vis spectra [3].

## Ultra-small PbS CQDs

While optimizing the synthesis of 1 eV CQDs, I discovered the existence of a red material suspended in the supernatant solvent. I further optimized the synthesis to select for a higher concentration of this red supernatant (fig 1a). The red supernatant was determined to be approximately 2.25 eV (550 nm) CQDs. I isolated a high concentration of 2.25 eV CQDs by rapidly cooling the CQD solution in an ice bath after synthesis.

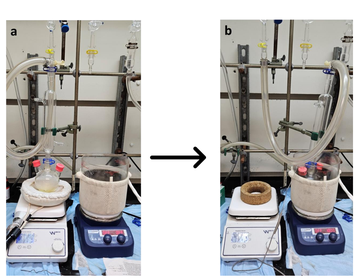



*Figure 2*. Set up for CQD synthesis on a Schlenk line. (a) Set up before synthesis with the flask on a heating mantle. (b) Flask suspended in an ice bath following synthesis.

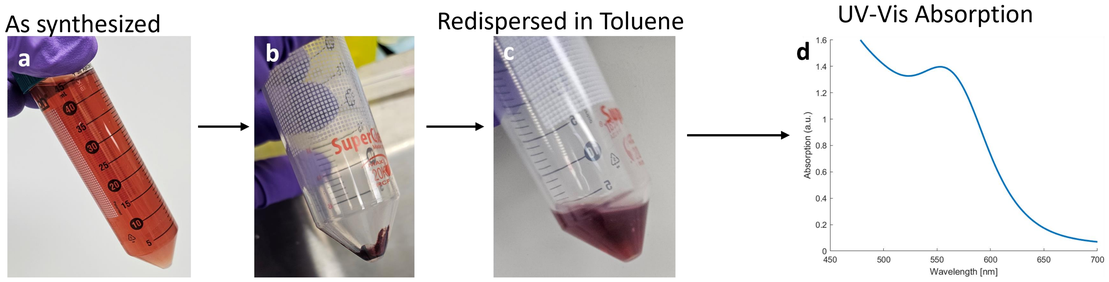
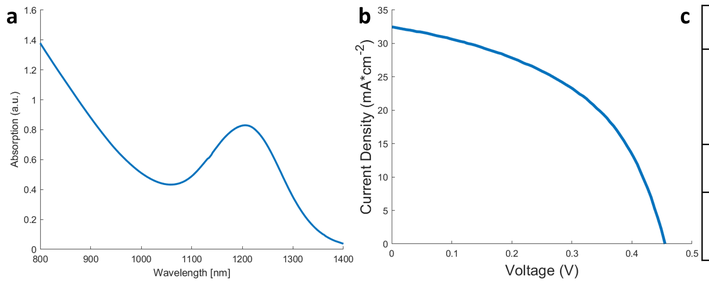



*Figure 3*. (a) Resulting solution after the removal of 950 nm dots. The remaining dots exhibit an absorption peak around 550 nm, resulting in a red solution. (b) Isolated dots after centrifugation to remove excess solvent. (c) CQDs redispersed at higher concentration in toluene. (d) Ultraviolet-visible absorption spectrum of the resulting dots in toluene.

## 1 eV CQD Solar Cell Fabrication




c

| PCE (%) | 7.05 |
|---|---|
| $J_{sc}\left(\frac{mA}{cm^2}\right)$ | 32.4 |
| $V_{oc}\ (V)$ | 0.46 |
| FF | 0.48 |

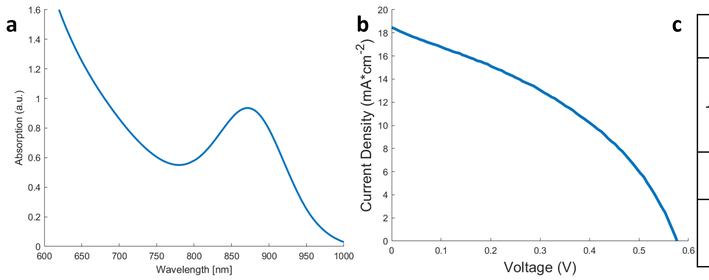
*Figure 4*. (a) UV-vis spectrum for approximately 1 eV (1210 nm) CQDs. (b) JV curve for a fabricated 1 eV sub-cell and (c) photovoltaic performance petameters for the same cell. PCE = power conversion efficiency; Jsc = short-circuit current density; Voc = open-circuit voltage; FF = fill factor.

We successfully synthesized CQDs with an absorption peak at 1210 nm, which correspond to a bandgap of approximately 1 eV. This was achieved by tuning the injection temperature for the sulfur precursor in the CQD synthesis process.

After the successful synthesis of the CQDs, we fabricated 1 eV sub-cells as a first step towards tandem solar cell fabrication. The sub-cell structure was FTO/PbS-$PbX_2$/PbS-EDT/Au.

We observed good performance for our 1 eV sub-cells, achieving a power conversion efficiency of 7.05%, indicating that these 1 eV CQDs can be used in a tandem solar cell.

## 1.5 eV CQD Synthesis




c

| PCE (%) | 4.14 |
|---|---|
| $J_{sc}\left(\frac{mA}{cm^2}\right)$ | 18.5 |
| $V_{oc}\ (V)$ | 0.58 |
| FF | 0.39 |

*Figure 5*. (a) UV-vis spectrum for approximately 1.4 eV (870 nm) CQDs. (b) JV curve for a fabricated 1.5 eV sub-cell and (c) photovoltaic performance petameters for the same cell.

We successfully synthesized CQDs with an absorption peak at 870 nm, which correspond to a bandgap of approximately 1.4 eV. This was achieved by tuning the injection temperature for the sulfur precursor in the CQD synthesis process. Further optimization of the synthesis to achieve a 1.5 eV bandgap is ongoing.

The fabricated 1.4 eV sub-cells had lower performance then the 1.0 eV sub-cell. Future improvements could be achieved by optimization of the CQD synthesis. Additional improvements could also be achieved by optimizing the ligand exchange and thin film deposition for the CQD films.

## Acknowledgements

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## References

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[3] Iwan Moreels et. al., "Size-Dependent Optical Properties of Colloidal PbS Quantum Dots", ACS Nano (2009), 3,10, 3023-3030