Inverted Colloidal Quantum Dot Solar Cells for Flexible Applications

Improving Performance of Inverted Devices through Novel Deposition

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Introduction

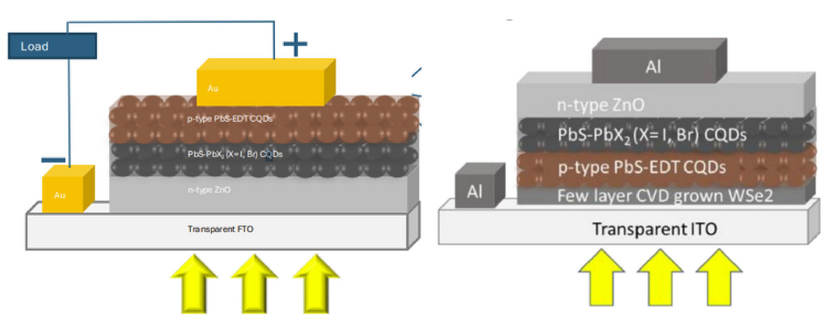
Background
PbS colloidal quantum dots (CQDs) are a quatum-confined material that exhibits useful properties such as:
- Bandgap tunability
- Infrared absorption
- Solution processability

PbS CQDS are a promising material for application in high efficiency solar cells due to the bandgap tunability through the infrared which enables their use in multi-junction photovoltaics

The Challenge
Traditionally PbS CQD solar cells are constructed with the electron transport layer (ETL) on the bottom. However, this project is focused on Inverted PbS CQD devices, where the ETL is the last layer. Inverted devices are better suited for integration into multi-junction solar cells since they can incorporate high temperature interlayers which would otherwise damage the CQDs in a standard device architecture.

Objectives

- Inverted PbS CQD architecture can cause damage to the CQD absorbing layer due to harsh solvents used in the ETL solution.
- The goal of this project is to replace solution-phase ZnO nanoparticle ETL layer with sputtered ZnO with using the AJA Magnetron Sputterer at the Materials Characterization and Processing Center (MCP)
- This method deposits the ETL without a solvent, protecting the absorbing layer from damage and improving overall power conversion efficiency (PCE).



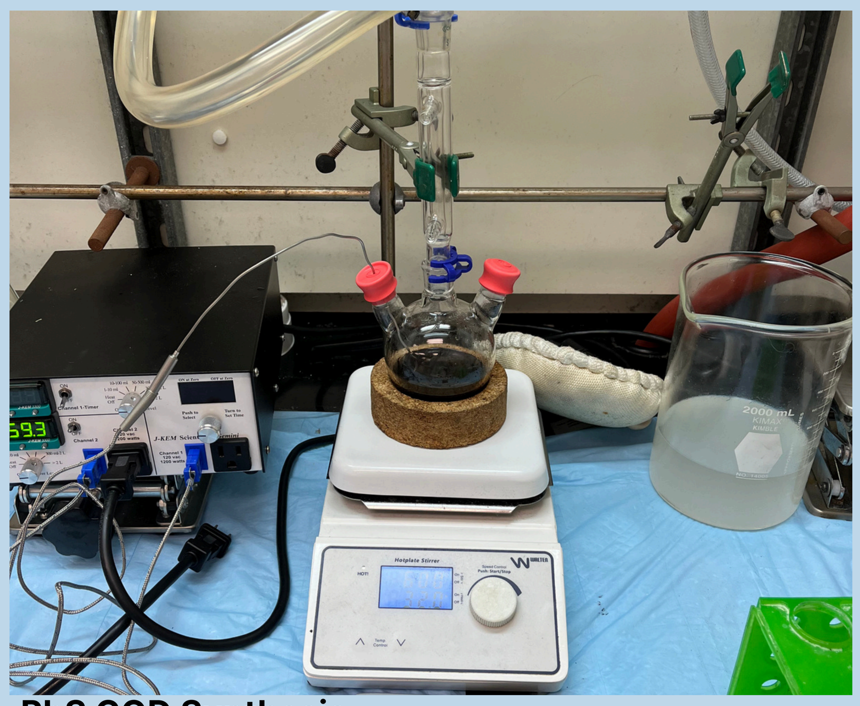
Left: Standard PbS CQD solar cell device structure
Right: Inverted PbS CQD solar cell device structure

Materials and Methods

Materials
- Fluorine-doped tin oxide (FTO) coated glass substrates
- Indium tin oxide (ITO) coated glass substrates
- ZnO sputtering target
- PbS CQDs with 950 nm exciton peak wavelength
- Ethanedithiol (EDT) ligands
- Ag/Au top contact evaporation materials

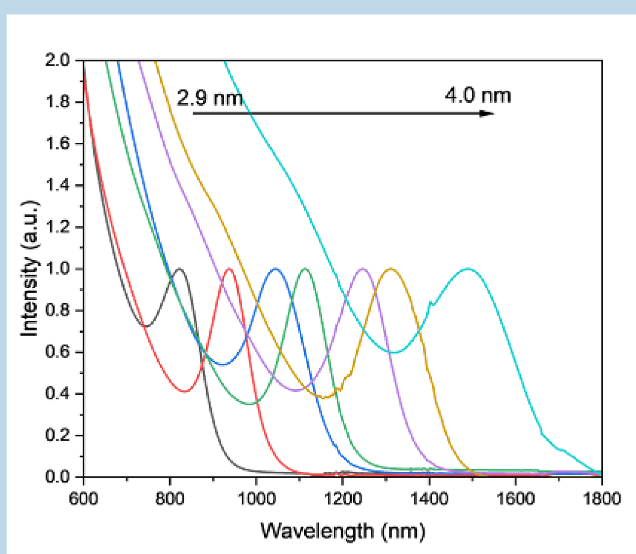
Methods
- Laurell Spin Coater
- AJA Magnetron Sputterer
- Angstrom Electron Beam Evaporator
- Keithley 2400 Sourcemeter
- Sciencetech Solar Simulator
- Temperature Controller

Results or Findings



PbS CQD Synthesis
Some parameters that impact size include:
- Injection temperature
- Temperature ramp rate
- Reaction time

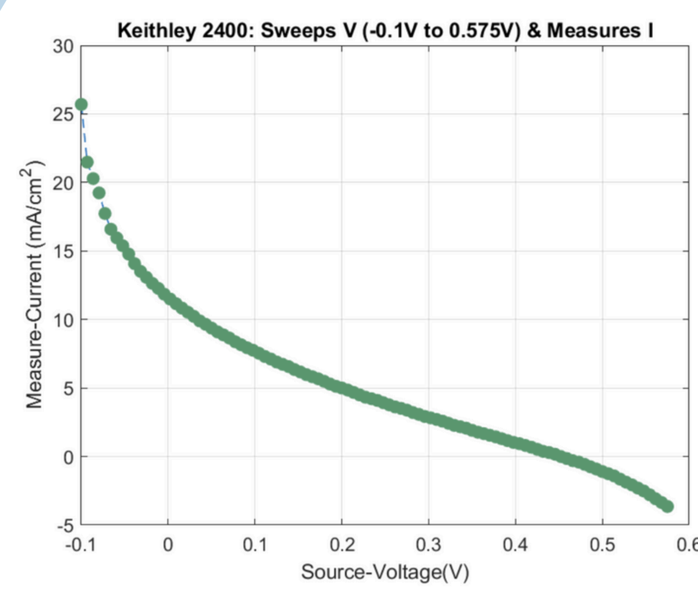
For this project 950nm (1.3eV) dots were made, with an injection temperature of 125C.



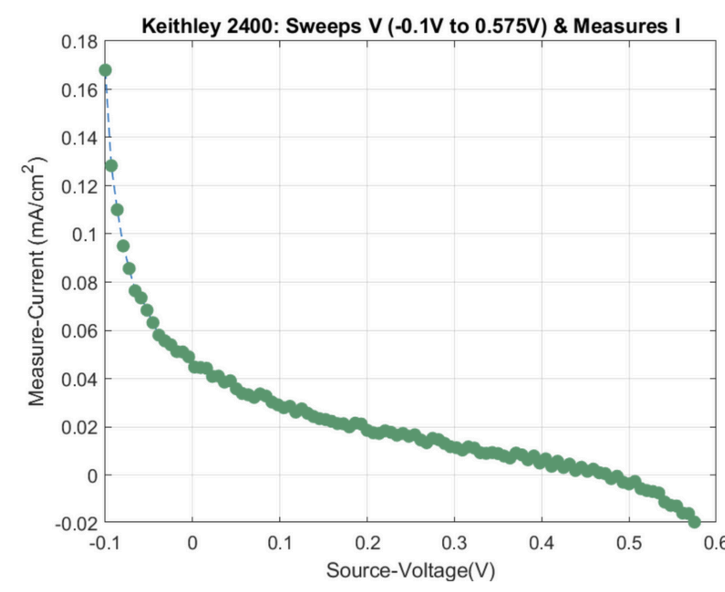
Tunability of PbS CQDs
Solution-phase absorption spectra of PbS CQDs of varying diameter as indicated, synthesized in our lab, illustrating the tunability of their band gap

30 Minute Sputtered ZnO vs Solution-Phase Deposited ZnO

Device Z21 - Sputtered



Device A17 - Solution

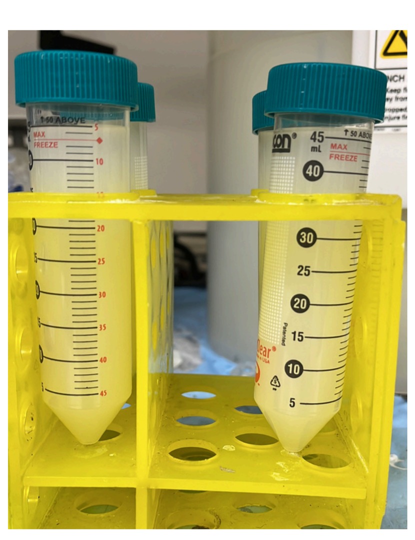


Representative illuminated current-voltage characteristics for devices with both sputtered and solution deposited ZnO ETLs.

A table comparing the performance of devices with sputtered ZnO ETLs of varying deposition times to devices with solution deposited ZnO ETLs.

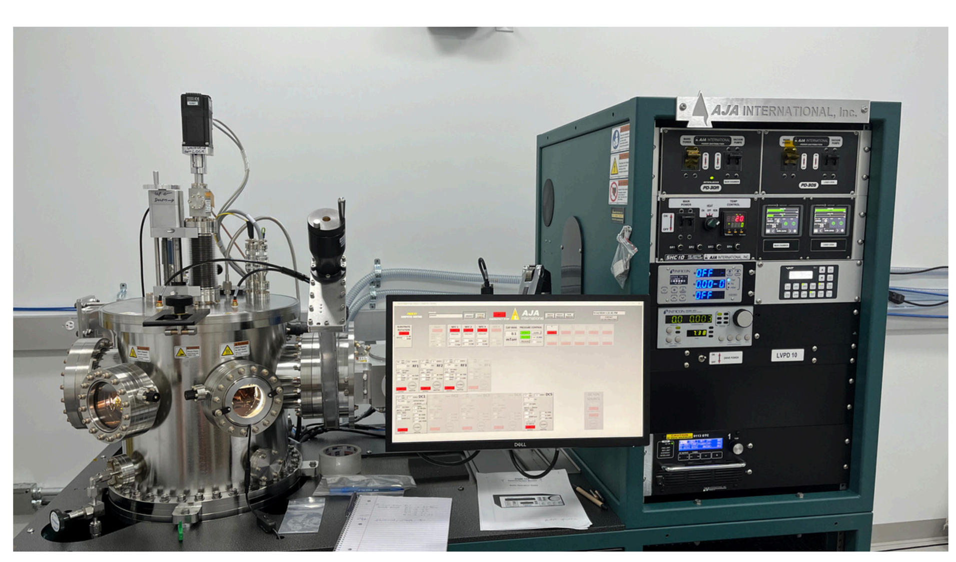
Device	PCE (%)	FF	Jsc	Voc
A17-Solution	0.004	0.189	0.046	0.4849
T33-60mins	0.390	0.223	3.885	0.457
W4-30mins	0.186	0.181	2.422	0.415

Sputtered vs Solution-Phase Deposition



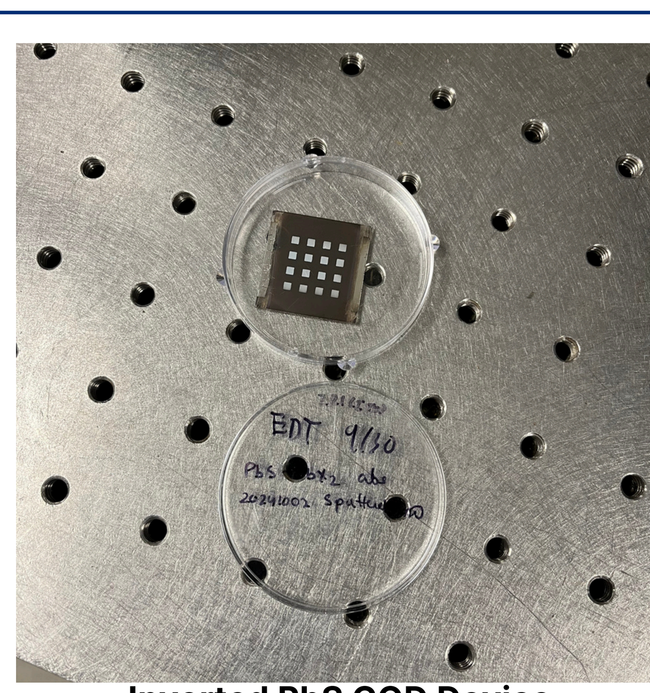
Solution-Phase ZnO
Left: an image of ZnO nanoparticles dissolved in chloroform ready for deposition.

On a standard device the deposition of ZnO in solution poses no risk to damaging the absorbing layer underneath, as it is the first layer

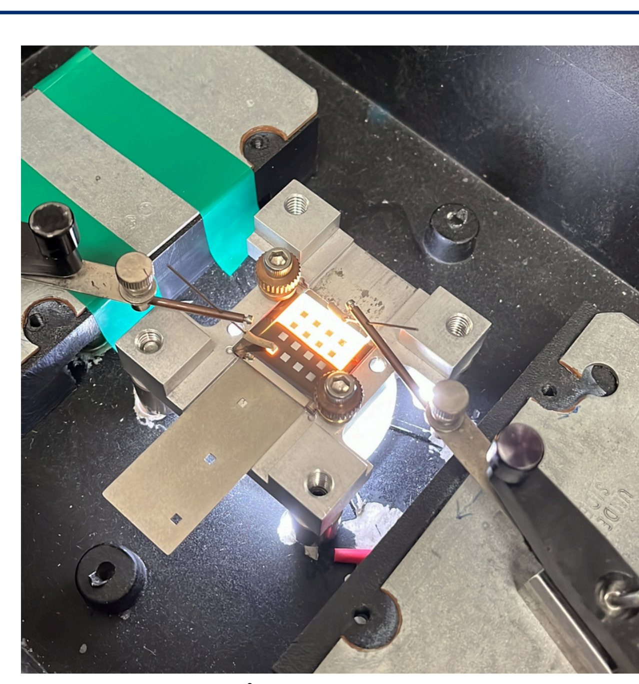


AJA Magnetron Sputterer
Left: an image of the AJA Magnetron Sputterer at the MCP that was used to deposit ZnO on sputtered devices.

The sputterer is able to deposit ZnO directly without the use of solvents, limiting potential damage done to the underlying absorbing layer.



Inverted PbS CQD Device
Photograph of a substrate with 16 PbS CQD inverted solar cell pixels.



Testing Apparatus
Photograph of a PbS CQD solar cell device being tested under AM1.5 solar simulated illumination

Testing and Evaluation

To test and evaluate device performance, a current-voltage (JV) curve of each pixel is measured under solar simulated illumination using a Keithley 2400 sourcemeter. After the measurements are finished, a MATLAB script is used to process the data.

Solar cell figures of merit
- Open Circuit Voltage (Voc)
- Short Circuit Current (Jsc)
- Fill Factor (FF)
- Power Conversion Efficiency (PCE)

Conclusion

- PbS CQD based solar cells were fabricated in the inverted device architecture.
- Devices with a sputtered ZnO ETL performed better than devices with a solution-phase nanoparticle ZnO ETL with a 0.2% increase in PCE.
- Future work involves optimizing the sputtering deposition process with the addition of oxygen during deposition to improve the quality of the ZnO layer
- Future work would also include augmenting hole transport layer (HTL) with NiO to obtain better energy bandgap matching to improve efficiency

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