Perovskite quantum dots: a new absorber technology with unique phase stability for high voltage solar cells

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1,156 kW
524 kW
857 kW
720 kW
94 kW
524 kW
Best Research-Cell Efficiencies

Multijunction Cells (2-terminal, monolithic)
- LM = lattice matched
- IMM = inverted metamorphic
- Three junction (concentrator)
- Three junction (non-concentrator)
- Two junction (concentrator)
- Two junction (non-concentrator)
- Four junction or more (concentrator)
- Four junction or more (non-concentrator)

Thin-Film Technologies
- CIGS (concentrator)
- CIGS
- CdTe
- Amorphous Si:H (stabilized)

Emerging PV
- Dye-sensitized cells
- Perovskite cells (not stabilized)
- Organic cells (various types)
- Organic tandem cells
- Inorganic cells (CZTSSe)
- Quantum dot cells (various types)

Single-Junction GaAs
- Single crystal
- Concentrator
- Thin-film crystal

Crystalline Si Cells
- Single crystal (concentrator)
- Single crystal (non-concentrator)
- Multicrystalline
- Silicon heterostructures (HIT)
- Thin-film crystal

Efficiency (%)
What does PV efficiency mean?

Solar Irradiance = 1000 W/m²
20% module = 200 W/m²
Silicon – industry leader for utility/residential PV

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Efficiency (%)
III-V semiconductors – highest efficiency & cost

Typically used in space applications where fabrication cost is less critical than deployment

$25,000 to lift a pound into space
Emerging PV offers potential – but still emerging

Best Research-Cell Efficiencies

Organic semiconductors, organic dyes, nanomaterials & Perovskites

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Solar Energy Conversion Challenge

Quantum Dots for Next Generation Photovoltaics.
Approaches to breaking theoretical limit

Nanotechnology helps enable many of these concepts

Quantum Dots for Next Generation Photovoltaics.

Shockley-Queisser Limit (33%)

Ross-Nozik Limit (67%)

Tandem Solar Cells (1-Sun)
Multiple Exciton Generation (MEG) compared to Si

- Quantum Efficiency = # of electrons out / # of photons absorbed
- Certain “high-energy” photons can be split into multiple electrons.
  - Quantum Dots are one of the only materials that do this.

Multijunction

Sunlight colors can be divided up and converted independently
The more “junctions”, the more efficient it can be

InGaP - Blue/UV light, 1.45 V
GaAs - Green light, 1.1 V
Ge – Red/IR light, 0.35V

Aim to find cheap way to do this
Pb-halide Perovskite semiconductors

Perovskites: Efficient, inexpensive, flexible, radiation hard, tunable (composition, size)
How did Pb-halide Perovskite PVs get to where they are?

- Incredible rise in efficiency (<4 to 23% short time)
- More tolerant to defects than any other electronic material.
- Solution or vapor-deposited material
- New Semiconductor system poised to greatly reform optoelectronics:
  - Solar Cells
  - LED / Solid State Lighting
  - TV / Display technology
  - Lasers, photodetectors, sensors, Gamma detectors
- Stability and Phase Transitions are critical to understand before deployment!
Flexible high power-per-weight perovskite solar cells

Question:

So how has this semiconductor escaped us for so long???

Perovskite crystal

I

Pb

A-site cation
In the PbI$_3$ system, the cubic phase requires an irregularly large cation

Unique combination of organic cation and inorganic anion

Overcoming Phase Challenge in CsPbX$_3$ Perovskites


Desired Cubic Phase

Undesired Orthorhombic phase

Nanocrystals with bright light emission

Quantum Dots stable in the cubic phase at RT

Thin film (bulk) perovskites vs Nanocrystals

Solvated Perovskite precursor molecules which crystalize as the solvent dries

Perovskite nanocrystals in solution
Method to fabricate conductive CsPbI$_3$ QD films

New Material Yields record QD solar cell
God made the bulk; the surface was invented by the devil.
Conclusions / Vision

If we can “print” solar cells like we print newspaper, we could cheaply produce all the electricity we need very rapidly

1 newspaper plant could produce a TW yr

• “Free electrons” on the grid: storage options, power beaming, etc.
• Lightweight radiation hard PV could enable balloon-like modules
• PV could be manufactured where it’s needed – low CapEx
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