Perovskite Solar Cell Basics

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ECE 4833 – DR. DOOLITTLE

Why Perovskite?

- Low Temperature – solution based fabrication method (inexpensive)
- High Voc
- High Efficiency – approaching 20% power conversion efficiency after only five years of development.
- High absorption coefficients
- Halide Perovskites caught on because with increasing dimensionality they exhibit a semiconductor to metal transition
- With increased dimensionality the bandgap narrows as well (good for solar) [1].

What is the Perovskite structure?

Crystal Structure

- ABX_3 (X is a halogen ion F, Cl, Br)
- Perovskite solar cells are made out of Methylammonium (CH_3NH_3) , lead (Pb), and a halogen.
- $CH_3NH_3PbX_3$
- Named after Russian mineralogist L.A. Perovski [1]

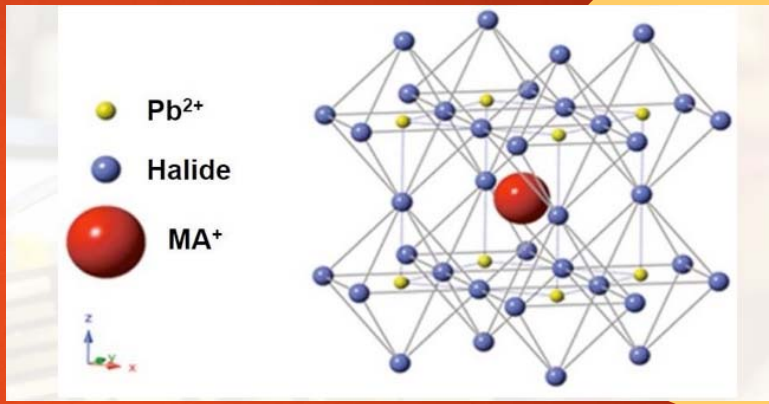

Figure 1. Crystal lattice of the Perovskite structure [2].

Perovskite Solar Cells

- $CH_3NH_3PbI_3$ is most common material for Perovskite solar cells
- ~1.5 eV bandgap
- High absorption coefficient (10^4 – 10^5 cm^{-1})
- This structure is an ionic crystal, which easily dissolves in a polar solvent, causes stability concerns.
- Solid hole conductors replaced liquid electrolytes, used in typical dye-sensitized solar cell. Allowed efficiency to increase up to 15% [1].

Schematic

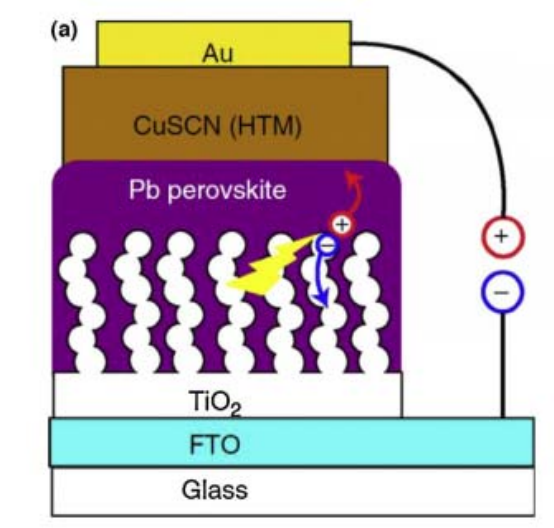

Figure 2. Cross sectional view of perovskite solar cell, using CuSCN HTM (hole transport material) [1].

How does it work?

- After sunlight reaches the perovskite light absorber, charge separation happen immediately.
- Charge transfer happens at titanium dioxide and the HTM at the sub picosecond time scale
- Charge recombination is significantly slower for titanium dioxide rather than aluminum, hence why TiO_2 is used.
- This system is very efficient for charge transfer, hence why efficiency has skyrocketed in such a short period of time. The only problem is making a reliable system, due to how sensitive the perovskite chemical structure is.

Absorption

- Typically, several hundred nm thick absorber layer, is between electron and hole transport layers.
- Intense absorptivity from visible to near-IR region
- $CH_3NH_3PbI_3$ acts as all in one light absorber, photon-charge converter, and charge transporter [3]. 550 nm light has absorption coefficient of $1.5x10^4$ cm^{-1} corresponding to a penetration depth of .66 um, 700 nm light has absorption coefficient of $1.5x10^4$ cm^{-1} , penetration depth of 2 um [1].
- Highly roughened interface of hole transport material results in increased internal light scattering, and improves charge transport [4].

Charge Transport Behavior

- Perovskite light absorbers have balanced electron and hole-transporting behavior.
- Electron diffusion length =130 nm
- Hole diffusion length = 100 nm [1]
- These lengths are given for $CH_3NH_3PbI_3$

and are much greater for different materials

Also have high electron and hole mobilities.

Shallow point defects and small surface

Recombination.

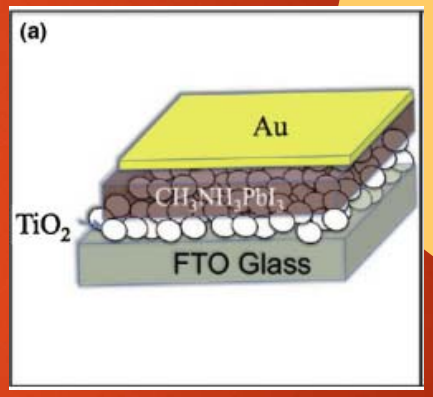

Figure 2. PN Junction, N-type TiO_2 [1].

Film Formation

- Solution processing – either one or two step.
- Vacuum deposition
- Vapor assisted solution processing
- Perovskite materials form with crystallinity even when processed at low temperatures
- Deposition method makes a huge difference on later power conversion efficiency

Film Formation

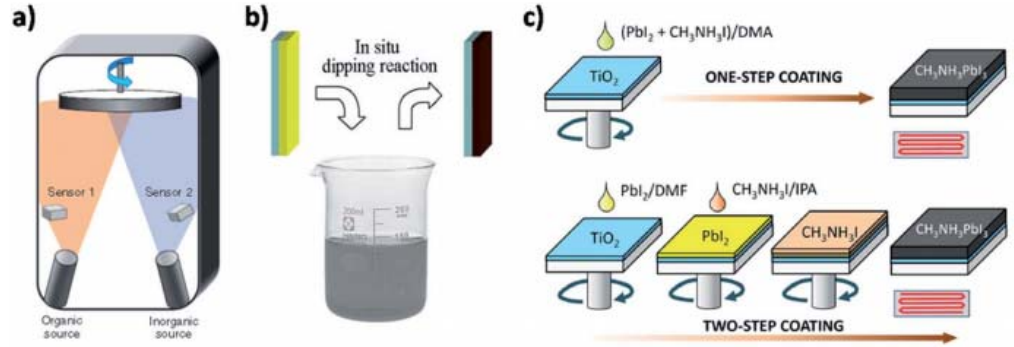

Fig. 3 The preparation of $MAPbI_{3-x}Cl_x$ film from different deposition methods: (a) Dual source coevaporation using $PbCl_2$ and MAI source. (b) Sequential deposition by dipping the PbI_2 film into MAI solution. (c) One-step solution process based on the mixture of PbI_2 and MAI, and sequential coating of PbI_2 and MAI (d) Vapor-assisted solution process using the MAI organic vapor to react with the PbI_2 film. Adapted with permission from ref. (32, 33, 44 and 45). Copyright 2013 Nature Publishing Group, 2014 American Institution of Physics, 2014 American Chemical Society.

[6]

Moisture Assisted Crystal Growth

- Moisture damages perovskite crystalline structure
- Anneal the precursor film in a humid environment (ambient air) to increase grain size, carrier mobility, and charge carrier lifetime
- A and B – Nitrogen annealment
- C and D – Humid annealment
- E and F – Dry Oxygen annealment
- Same results when annealed in humid Nitrogen

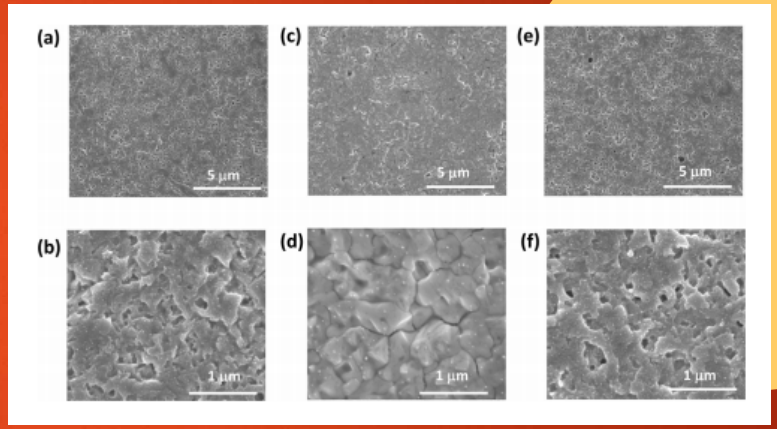

Figure 4. Perovskite films under different annealment conditions [5].

Device Structure

- Blue layers are electron and hole transport layers. Yellow layer assits in electron extraction to Al contact.

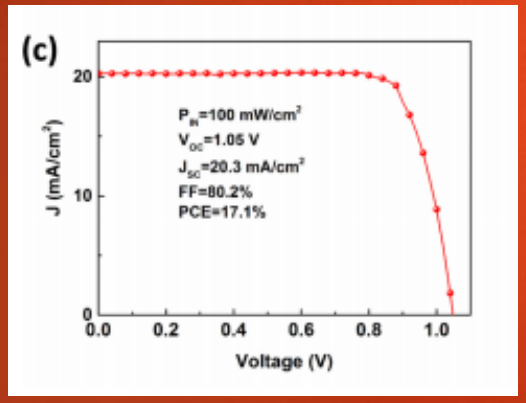

Figure 3. IV curve for best performance under 1 sun [5].

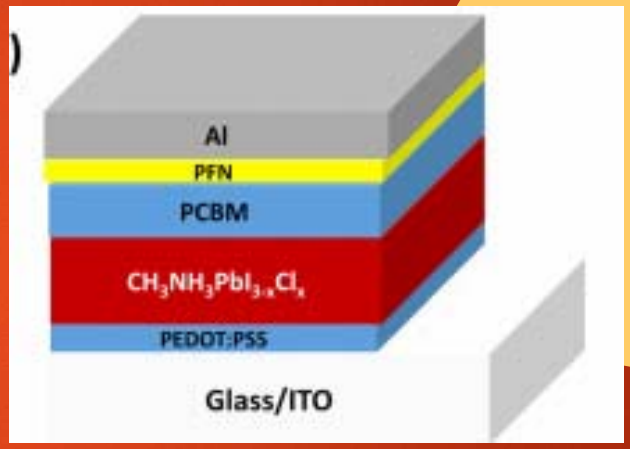

Figure 4. Device structure for humid annealing method [5].

Stability Improvement

- Perovskite is instable at high relative humidity
- Mixing $CH_3NH_3PbI_3$ and $CH_3NH_3PbBr_3$ resulted in a solid solution perovskite that was stable in a humidity soaking test [5].
- This gives hope for the future that including bromide can enhance stability.
- Encapsulation technology must get better as well as scale up technologies.

References

- [1] http://www.sciencedirect.com/science/article/pii/S1369702114002570
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