Perovskite PV (SUN UP)

SuNLaMP project 30291
Best Research-Cell Efficiencies

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 (CZTSn)
- Quantum dot cells

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

Multijunction Cells (2-terminal, monolithic)
- LM = lattice matched
- MM = 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)

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

http://www.nrel.gov/ncpv/

Note on emerging PV: Lab scale, “un-stabilized” or other caveats
Before Perovskite PV and post 2009

Conducting tin halides with a layered organic-based perovskite structure

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Abstract

A convenient two-step dipping technique for preparing high-quality thin films of a variety of perovskites is provided by the invention. These films of Mx(NH3)2Pbl3 (M=Sn, Pb) were first prepared by vacuum-depositing Ml onto ash glass or quartz substrates, which were subsequently dipped into a solution containing the desired organic ammonium cations for a short period of time. Using this technique, thin films of different layered organic-inorganic perovskites (RNH3)(CH3NH3)xPbl3, M=Sn, Pb, Sn and x=1, 2, and three-dimensional perovskites CH3NH3Pbl3(M=Sn, Pb, Sn, i.e. n=7) were successfully prepared at room temperature. The lattice constants of these slip-processed perovskites are very similar to those of the corresponding compounds prepared by solution-growth or by solid state reactions. The layered perovskite thin films possess strong photoluminescence, distributed uniformly across the film area. Similar results are achieved starting from spin-coated Ml films, which were dipped into appropriate solutions of the organic ammonium cations. The process of the invention can be used for a variety of organics and inorganics, even if they have incompatible solubility characteristics or even if the organic component is susceptible to thermal decomposion on heating. Thin perovskite films prepared by the method are attractive candidates for emitter materials in electroluminescent devices.

19 Claims, 10 Drawing Sheets


Meteoric rise of efficiency in PV Performance

CH3NH3Pbl3

22.6-23%

21.07%

17.9 %

+23%??

United States Patent

Liang et al.

Patent Number: 5,871,579

Date of Patent: Feb. 16, 1999


NATIONAL RENEWABLE ENERGY LABORATORY
Solar ‘Perovskite’

A = \{\text{Methylammonium, Formamidinium, Cs} \ldots\}

B = \{\text{Pb, Sn, } \ldots\}

X = \{\text{Br, I, } \ldots\}

\text{Generic formula: } ABX_3

Notable work by Mitzi in transistors

Band gap tuning (solution processed GaAs)

Formamidinium lead trihalide: a broadly tunable perovskite for efficient planar heterojunction solar cells

Fig. 1 Tuning perovskite bandgap by replacing the A cation. (a) The ABX$_3$ perovskite crystal structure. (b) The atomic structure of the three A site cations explored. (c) UV-Vis spectra for the APbI$_3$ perovskites formed, where A is either caesium (Cs), methylammonium (MA) or formamidinium (FA).

Relative sizes of all components determine strain and optoelectronic properties

Requirements

- Three critical elements required of any PV:
  - Stability
  - Efficiency
  - Scale

Perovskites are cutting edge cell nano technology that offer potential for significant cost reductions. For hybrid/halide perovskite materials as well as resulting HPSCs, connections between material, processing, properties/performance are closely linked.
Approach to Pevoskite PV for SuNLaMP

- NREL SuNLaMP program focus on three key requirements of successful PV technologies
- Emphasis near term is on stability (not neglecting other components)

Credible applied science efforts require the ability to maintain core activities for advances in these areas with agility to change emphasis as required to advance this technology to market.

Goal: Enable HPSCs Technology
Core HPSC efforts

• Stability
  – active stability
  – +16% PAL
  – Stable in high (90%) humidity

• Efficiency and stability
  – Understanding of band alignments
  – Clearer identification of performance limitation of contacts

• Stability & scalability of devices
  – Improved stability with contact choice
  – Lower cost contact with better stability
Key findings/results

- Foundational insight into PAL material formation
- Basic information to enable interface engineering
- Critical information regarding PAL optical properties
- Demonstrate impact of contacts in HPSC device stability

New capabilities

- Scalable processing of HPSC in development (Blade and R2R based synthesis with NREL LDRD)
- SPA capabilities (operational with additional bandwidth being constructed)
Q4FY16 publications

- Additional 8 publications
  - 4 relating to stability
  - 3 relating to scaling
  - 3 basic science innovations
    (Multiple cross cutting publications)
SuNLaMP activities

- Performance and Stability (perovskite active layers = PAL)
  - $\text{Cs}_x\text{FA}_{1-x}\text{PbI}_3$ device demonstration and initial stability
  - $\text{Cs}_x\text{FA}_{1-x}\text{PbI}_3$ microstructure control
    - Impact of structure on electronic properties
  - $\text{MA}_x\text{Cs}_y\text{FA}_{1-x-y}\text{PbBr}_\alpha\text{I}_{3-\alpha}$
  - Sn based alloys
  - Baseline studies of $\text{MAPbI}_3$

- Performance and Stability (interfaces and contacts)
  will be discussed at ONR workshop
  - Spiro acid doping
  - Spiro-free/Alternate HTMs (organics)
  - SWCNTs (Blackburn)
  - $\text{MAPbI}_3$ vs Alloys Interfaces (performance and stability)
    - $\text{Cs}_x\text{FA}_{1-x}\text{PbI}_3$, $\text{MA}_x\text{FA}_{1-x}\text{PbI}_3$, $\text{MA}_x\text{Cs}_y\text{FA}_{1-x-y}\text{PbBr}_\alpha\text{I}_{3-\alpha}$
  - Phosphonic acid modified interfaces (Q2 call)

- Scaling activities
  - +6 volt mini-module (Nat. Lab Day)
  - $1\text{cm}^2$ devices (Q2 call)
  - Characterization and process development
  - PAL formation

- Cross cutting studies (stability)
  - In-operando experiments at SLAC
    - $(\text{Cs}_x\text{FA}_{1-x}\text{PbI}_3, \text{MA}_x\text{FA}_{1-x}\text{PbI}_3, \text{MA}_x\text{Cs}_y\text{FA}_{1-x-y}\text{PbBr}_\alpha\text{I}_{3-\alpha})$
    - Different contacts/device architectures
  - SPA and Combi-degradation experiments
    - $(\text{Cs}_x\text{FA}_{1-x}\text{PbI}_3, \text{MA}_x\text{Cs}_y\text{FA}_{1-x-y}\text{PbBr}_\alpha\text{I}_{3-\alpha})$
    - Different contacts/device architectures
  - Materials formation

HPSC Activities

- Device Area: 1.2 cm$^2$
  - Blade coated device ~13.8% PCE
Goals for SUN UP

• **Scientific publication is targeted outcome**
  o High technical merit (compelling research idea/topic)
    – Not already under investigation
  o Materials characterization based projects
  o Device characterization based projects

• **If one or both of the following is true**
  – Narrow project scope (i.e. specific technical question)
  – Existing/Prior Perovskite Material/PV experience
    – Technical Merit
  o Then 6 month term is reasonable

• **If these are not the case then it will likely take additional time to do something publishable**

• **Everything is negotiable but you will have to make a good case for the benefits**