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WRIGHT CENTER for PHOTOVOLTAICS INNOVATION AND COMMERCIALIZATION

Perovskite/Perovskite Tandem Photoelectrodes For Low-Cost Unassisted Photoelectrochemical Water Splitting

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Project ID p191

Overview

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Timeline

- Project Start Date: 10/01/2019*
  *Actual Start Date: 12/01/2019
- Project End Date: 09/30/2022

Barriers

- Stability of perovskite against moisture and heat;
- Fabricate efficient n-i-p low-bandgap perovskite solar cells;
- Fabricate efficient n-i-p perovskite tandem solar cells

Budget

- Total Project Budget: $0.942
  - Total Recipient Share: $0.192
  - Total Federal Share: $0.750
  - Total DOE Funds Spent*: $

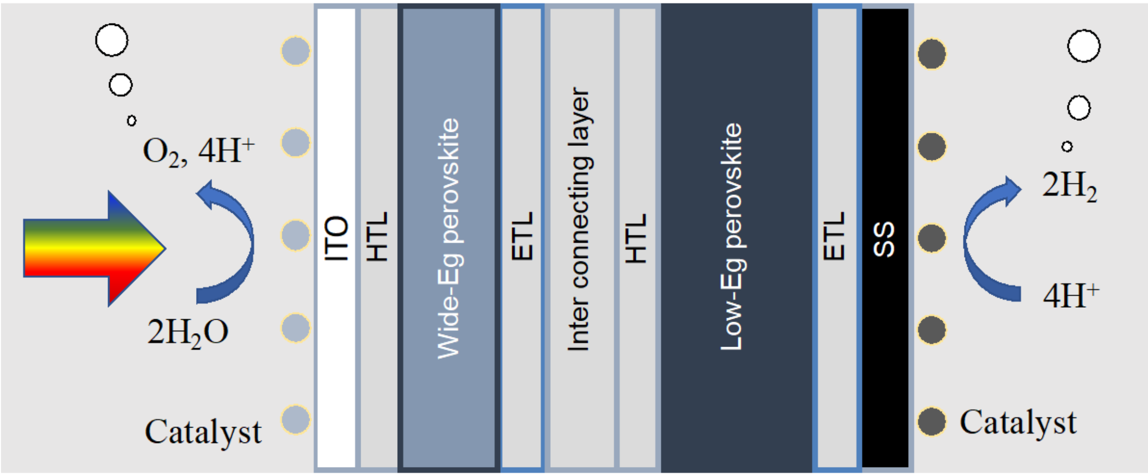
* As of 04/03/2020

Partners

- N/A
- EMN Nodes
  - Kai Zhu, Joe Berry, NREL
  - Todd Deutsch, James Young, NREL
  - Jon Lee, Tony van Buuren, Tadashi Ogitsu, LLNL

Relevance

- ***Objective:*** Develop monolithically integrated perovskite/ perovskite tandem photoelectrodes to achieve low-cost, high-efficiency (solar to hydrogen efficiency of up to 20%), and long-term stable (>1,000 hours) wireless spontaneous water splitting systems.



- ***Impact:***
  - Developed stable low-bandgap Sn-Pb perovskites
  - Demonstrated transparent n-i-p wide-bandgap perovskite solar cells

Approach

- Develop stable and efficient low-bandgap perovskite bottom electrodes
- Develop stable and efficient wide-bandgap perovskite top electrodes
- Develop interconnecting layers to integrate two perovskite layers into tandem photoelectrodes
  - Combining ALD and sputtered metal oxides
- Prepare water-resistant perovskite absorber layers
  - Modify perovskite compositions & apply surface coating
- Develop a water impermeable oxide coating to prevent photo-corrosion and water ingress.

Milestones

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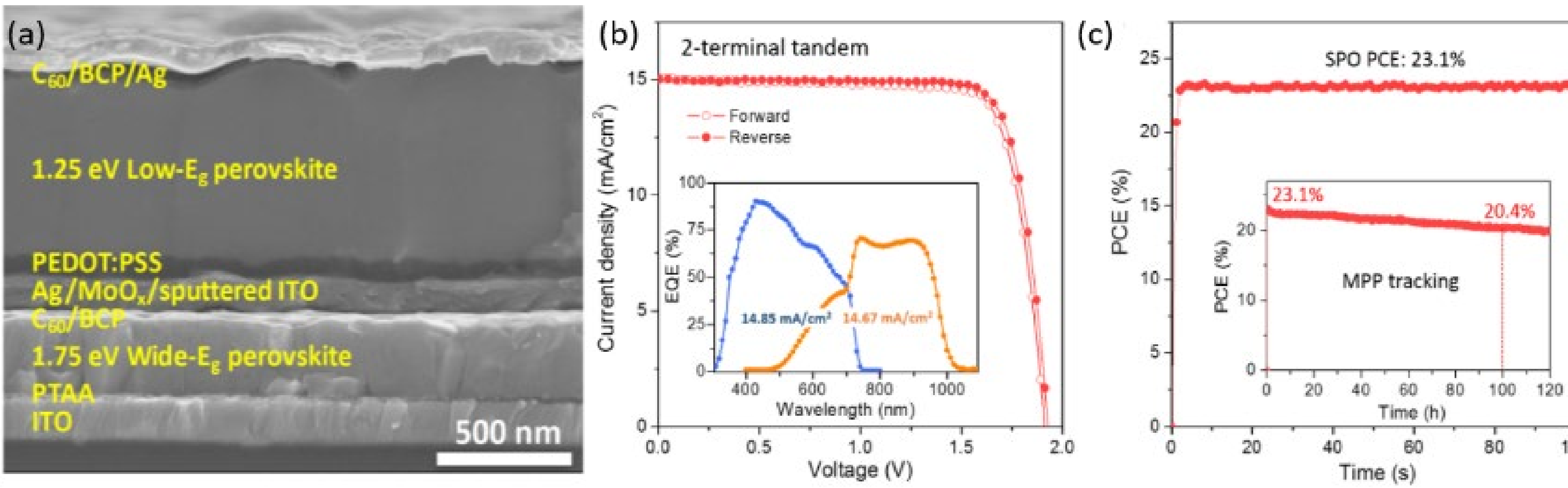
FY 2019 to FY 2020

Task	Milestone Description (Go/No-Go Decision Criteria)	Original Planned Quarter	Revised Planned Quarter	Progress Notes
1. Bottom photoelectrodes	**M1.1** Bottom photoelectrodes with photocurrent density >30 mA/cm^2.	1		Ongoing
	M1.2 Bottom photoelectrodes pass stability test at 85 °C for more than 100 hours	2		
2. Top photoelectrodes	**M2.1** Top photoelectrodes synthesized at temperatures below 100 °C	1		Ongoing
	M2.2 Top photoelectrodes deliver a PCE > 18% with a J_{SC} > 20 mA/cm^2.	2		
3. Rigid tandem photoelectrodes	**M3.1** Tandem photoelectrodes on rigid substrates deliver a PCE > 20%.	3		
	M3.2 Tandem photoelectrodes retain>90% PCEs after MPPT in the air for more than 100 hours.	4		
Budget Period 1 Go/No Go Decision Point: Double-junction tandem solar cells deliver a PCE > 20%; Double-junction tandem solar cells demonstrate stable operation in the air for more than 100 hours.		4		

Note: Program started in December, 2019

Accomplishments and Progress

All-perovskite tandem solar cell benchmark



In the p-i-n configuration

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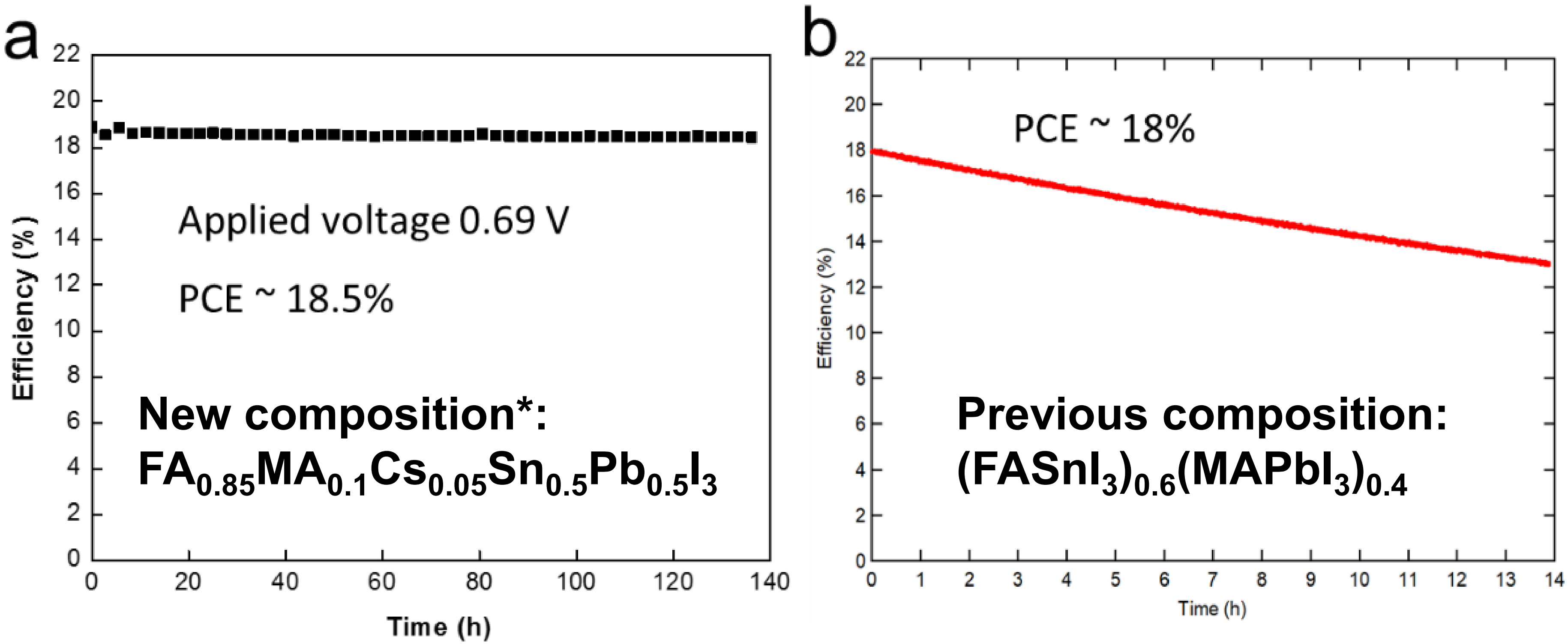
- Can be used for spontaneous solar water splitting (three-electrode cell)

Accomplishments and Progress

Stable mixed Sn-Pb perovskites



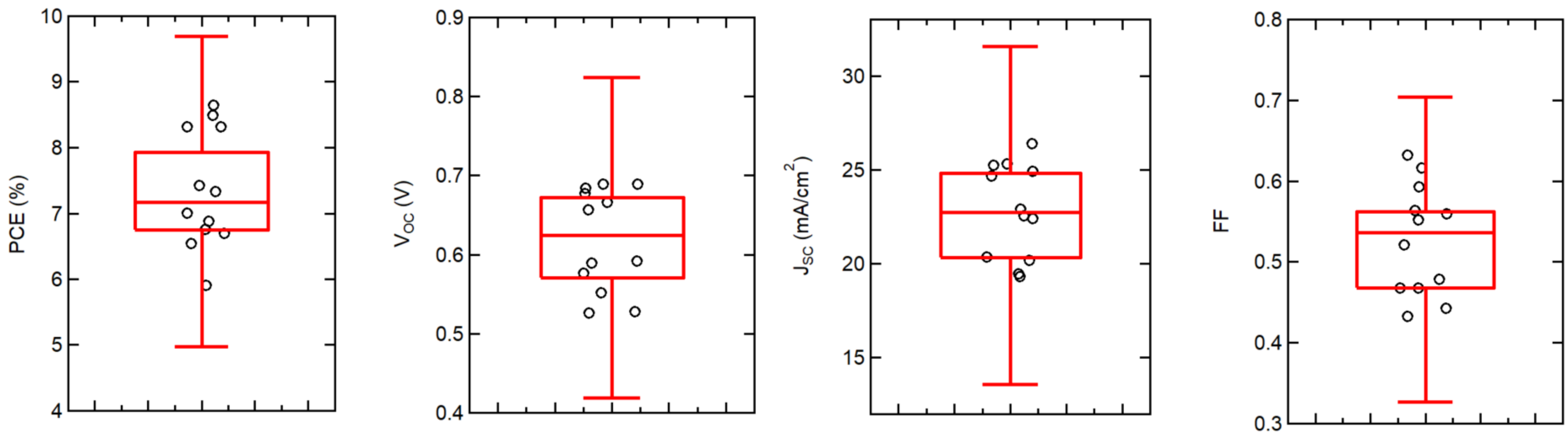
- Synthesize stable low-bandgap Sn-Pb perovskites

* FA = formamidinium; MA = methylammonium

Accomplishments and Progress

Issues with n-i-p type Sn-Pb perovskite cells

Device structure: glass/ITO/SnO_2/PCBM/perovskite/PTAA/Au



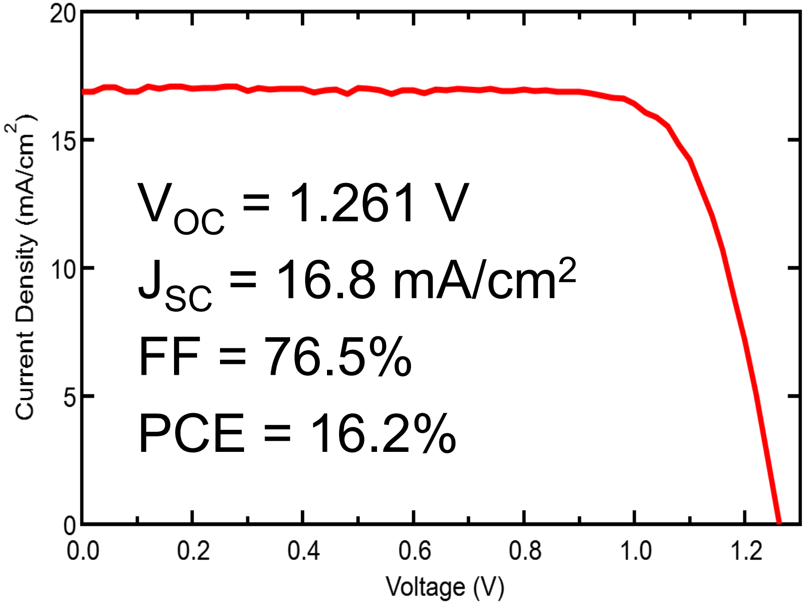
Note: Average PCE for p-i-n type Sn-Pb cells is ~19%

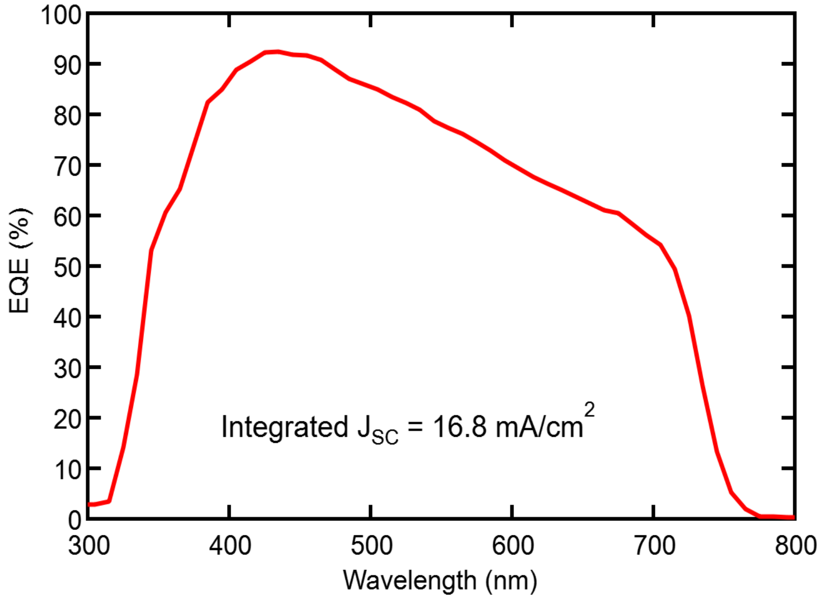
- The performance of n-i-p type Sn-Pb perovskite solar cells is much worse than expected.
- Sn^{2+} oxidation and undesired charge selective contacts limit the device performance.

Accomplishments and Progress

Efficient perovskite top cells

Device structure: glass/ITO/SnO_2/C_{60}-SAM/
$FA_{0.75}Cs_{0.2}MA_{0.05}Pb(Br_{0.3}I_{0.7})_3$/Spiro-OMeTAD/$MoO_x$/ITO





- **Demonstrate efficient semitransparent n-i-p wide-bandgap perovskite solar cells**

*with butylammonium bromide (BABr) surface treatment

Responses to Reviewers’ Comments

- This project was not reviewed last year

Collaboration and Coordination

- **The role of HydroGEN Consortium resources**
  - Kai Zhu, Joseph Berry (NREL): Help develop efficient n-i-p low-bandgap perovskite solar cells; develop ALD deposition of moisture barriers.
  - Todd Deutsch, James Young (NREL): Provide measurement of efficiency and stability of perovskite photoelectrodes for water splitting.
  - Jonathan Lee, Tony van Buuren, Tadashi Ogitsu (LLNL)): Provide in-situ/operando X-ray characterization of electronic properties of perovskite electrodes.

Remaining Challenges & Barriers

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- Demonstration of low-bandgap Sn-Pb perovskite solar cells in the n-i-p configuration is very challenging due to the ease of Sn^{2+} oxidation and unsuitable charge selective contacts.

- Demonstration of n-i-p type perovskite/perovskite tandem solar cells is challenging due to lack of success in n-i-p type Sn-Pb perovskite solar cells.

- Demonstration of perovskite-based photoelectrodes for water-splitting is challenging due to the instability of halide perovskites in aqueous electrolytes.

- A conformal and dense surface protection layer is needed to prevent water ingress into the active layers.

Proposed Future Work

- Remainder of FY 2020
  - Continue the fabrication of 1.25-eV mixed Sn-Pb n-i-p perovskite cells
  - Optimize transparent wide-bandgap (1.75 eV) n-i-p perovskite cells
  - Explore alternative 1.4-eV Pb-based n-i-p perovskite bottom cells
  - Explore alternative 2.3-eV $CsPbBr_3$ n-i-p perovskite top cells
  - Fabrication n-i-p type perovskite/perovskite tandem solar cells

- FY 2021
  - Develop water-resistive coating for perovskite solar cells
  - Develop three-electrode unassisted water splitting cells using conventional p-i-n perovskite/perovskite tandem photoelectrodes.

Any proposed future work is subject to change based on funding levels.

Technology Transfer Activities

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- This project has just started and technology transfer activities will be considered as the program proceeds.

Summary

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Objective:	Develop monolithically integrated perovskite/ perovskite tandem photoelectrodes for wireless spontaneous water splitting systems.
Approach:	Develop efficient and stable top and bottom perovskite photoelectrodes; develop n-i-p perovskite/perovskite tandem solar cells; develop surface protection layers.
Accomplishments:	Synthesized stable low-bandgap Sn-Pb perovskite solar cells; demonstrated transparent wide-bandgap n-i-p perovskite top subcells.
Collaboration:	Strong collaboration with EMN node experts at NREL and LLNL.