BOISE STATE UNIVERSITY
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Conductive Effects of Aluminum-doped Zinc Oxide in Lead-halide Perovskite Solar Cells

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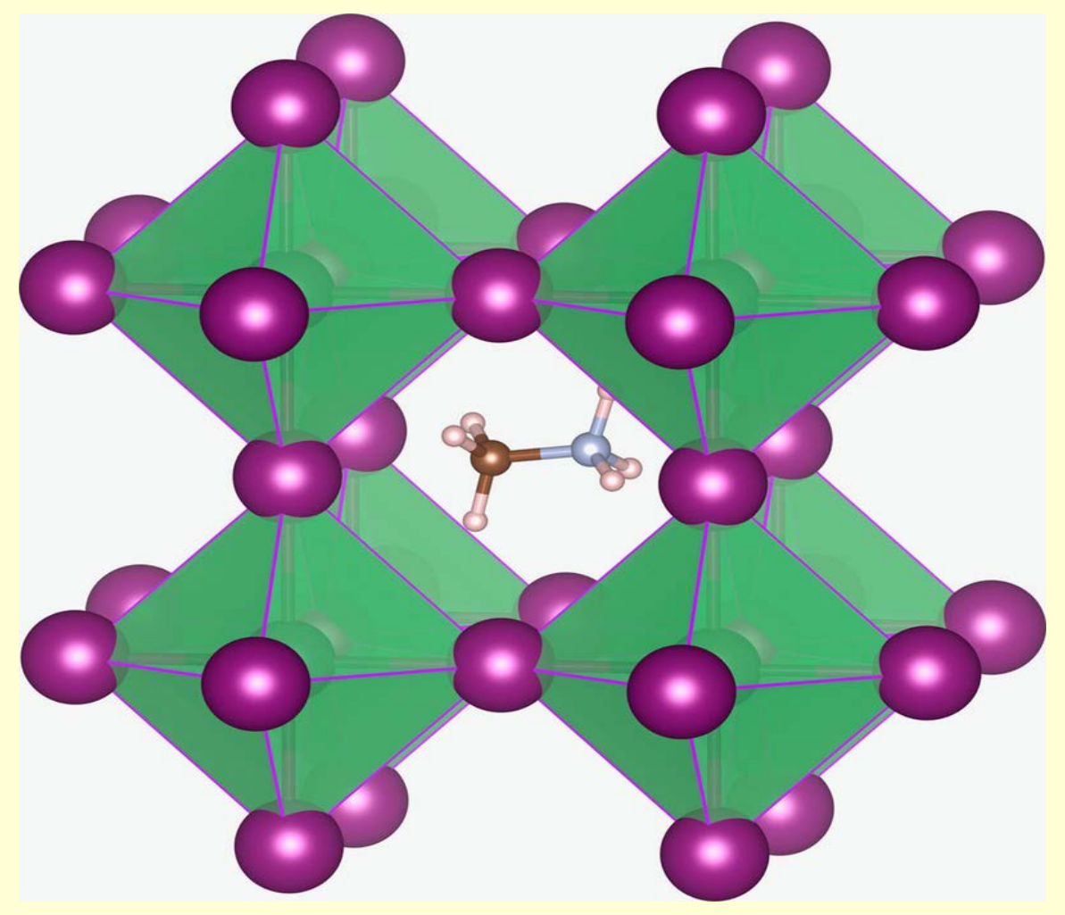
Abstract

One of the most promising contenders in the race for efficient, cost-effective solar materials is the perovskite solar cell. The solar-cell devices in this work consist of an etched glass substrate coated with indium-tin oxide, a nickel oxide layer, a hybrid organic-inorganic perovskite layer, a zinc oxide layer, and an aluminum electrode layer. The $(CH_3NH_3)PbI_3$ perovskite is the optically active layer, akin to the electron-donor material in heterojunction solar cells, absorbing light and injecting electrons (and holes) into conducting media. The addition of Al to the n-type ZnO layer can increase both conductivity and optical transmission; therefore, this research seeks to produce functional lead-halide perovskite solar cells and observe the changes in electrical conductivity and energy conversion efficiency when the zinc oxide layer is doped with aluminum. All layers were fabricated using solution processing methods.

Perovskite: A Solar Superstar

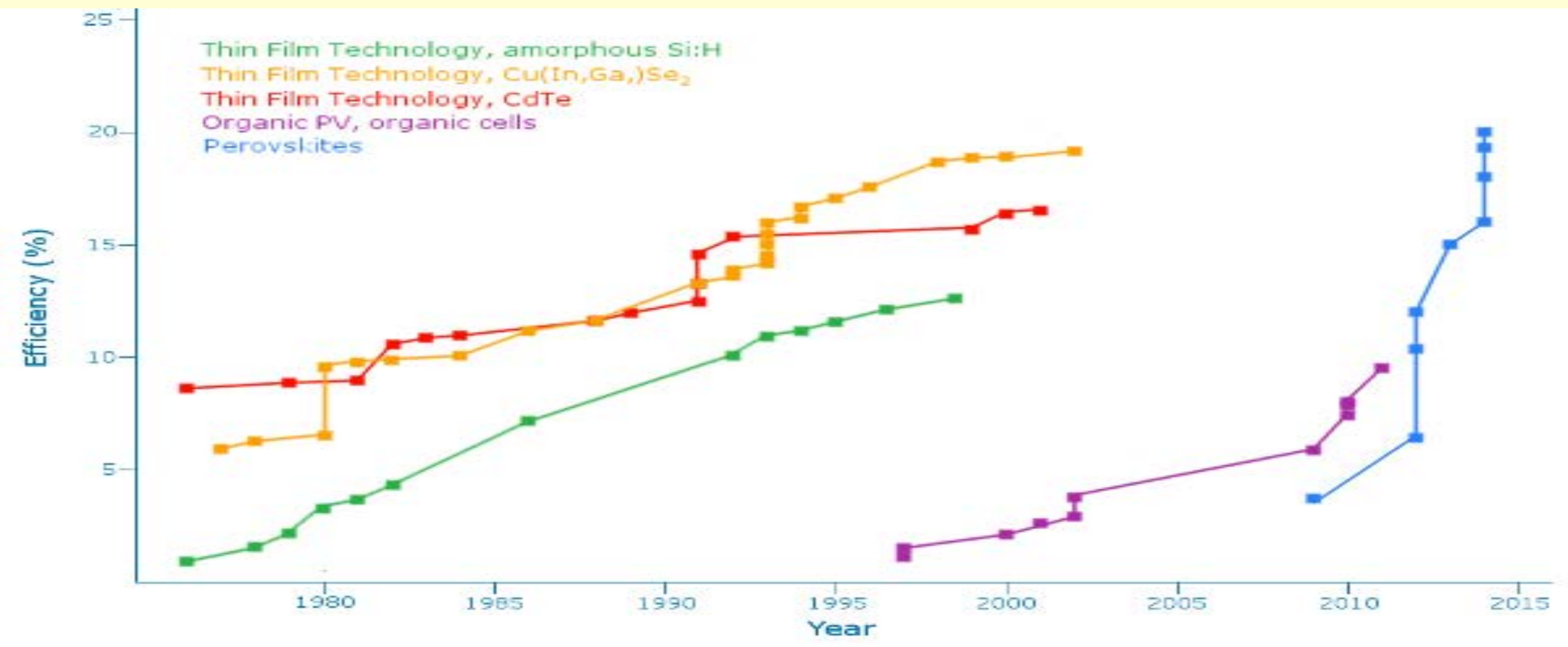
Unique Properties



"Perovskite" is not one specific material—it is a class of materials that all share a distinct chemical structure. The high coefficient of optical absorption and large dielectric constant of many perovskites make them highly useful as energy conversion materials. Due to their light-absorbing properties, they have become a hot topic in solar energy and sustainability.

RIGHT: Lead-halide ($(CH_3NH_3)PbI_3$) perovskite chemical structure. *Source: (1) Y. Jingbi et al.*

Leaps and Bounds



Perovskite solar cells have skyrocketed in efficiency compared to all other older, competing devices. The rapid advances in this field make them remarkable candidates for applied research. ***Source: (2) Ossila Ltd.***

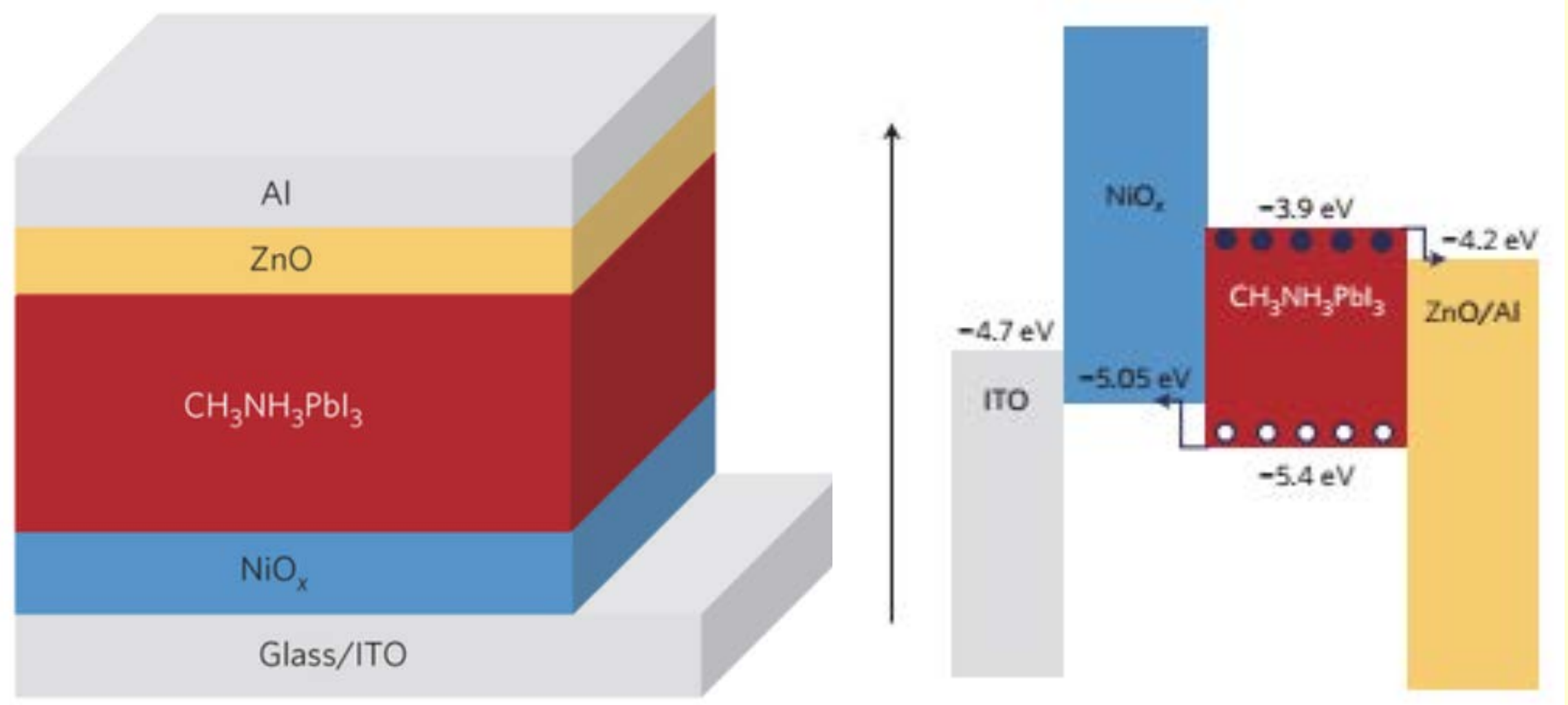
Solar Energy Extraction

Perovskite solar cells work by harvesting the energy from sunlight and converting it into electricity.

Each layer of the cell plays an important role from absorption to electron transport to extraction.

- **1:** When the cell is illuminated by sunlight, the perovskite layer separates electrons from electron holes.
- **2:** Electrons travel up through the n-type semiconducting layer and electrical energy is extracted via the electrode.
- **3:** Holes travel downward through the p-type semiconducting layer and indium-tin oxide (ITO) coating until recombination.

Methods



The Device Stack

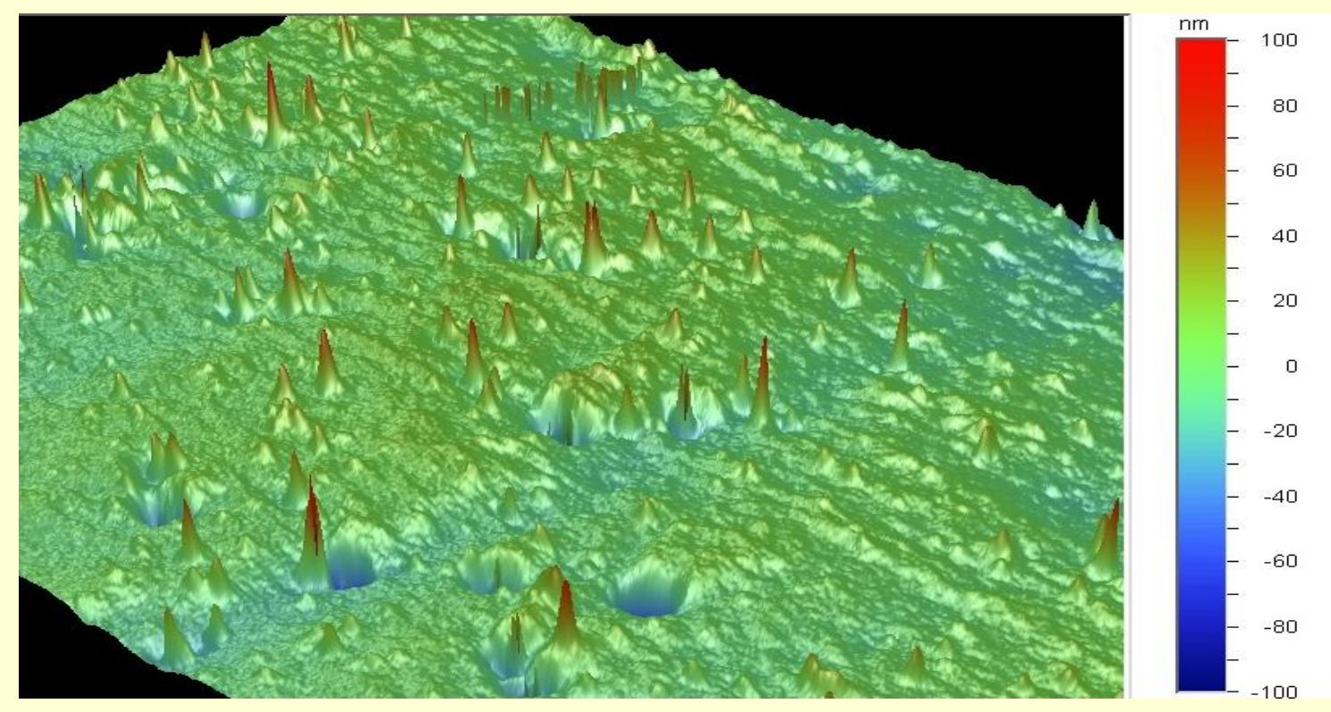
LEFT: Our structure is a thin film made of a p-type hole conductor, perovskite, n-type electron conductor, and a metal electrode layer on an ITO-coated glass substrate.

RIGHT: Energy band alignment, corresponding to ease of electron transport. *Source: (1) Y. Jingbi et al.*

Fabrication Process

- **1:** Etch half of the ITO substrate to prevent short-circuiting.
- **2:** Synthesize nickel stock solution and spin-coat NiOx solution onto substrate. Anneal at 300°C for 1 hour.
- **3:** Synthesize perovskite precursors. Spin-coat and combine solutions; anneal at 100°C until dark and opaque.
- **4:** Synthesize ZnO particles; suspend in chlorobenzene; sonicate the solution. Spin-coat and anneal at 100°C for 30 minutes.
- **5:** Mask substrate and deposit the Al electrode via thermal sputtering.

Problems with Pinholes



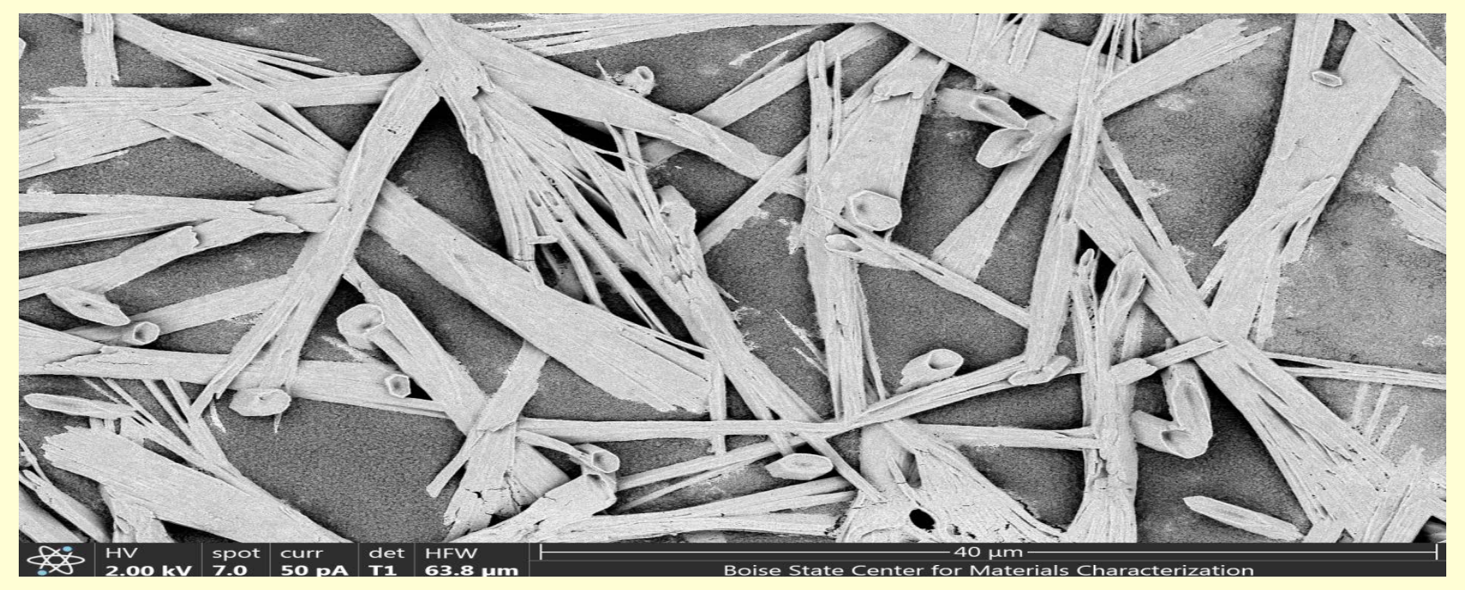
3-D profilometry map showing the surface morphology of a perovskite layer on top of NiOx and ITO substrate. Pinholes visible!

Pinholes form due to surface contaminants and solutions evaporating during annealing. Minimizing these pinholes is crucial to get current. These pinholes allow electrons and holes to recombine, ceasing their flow.

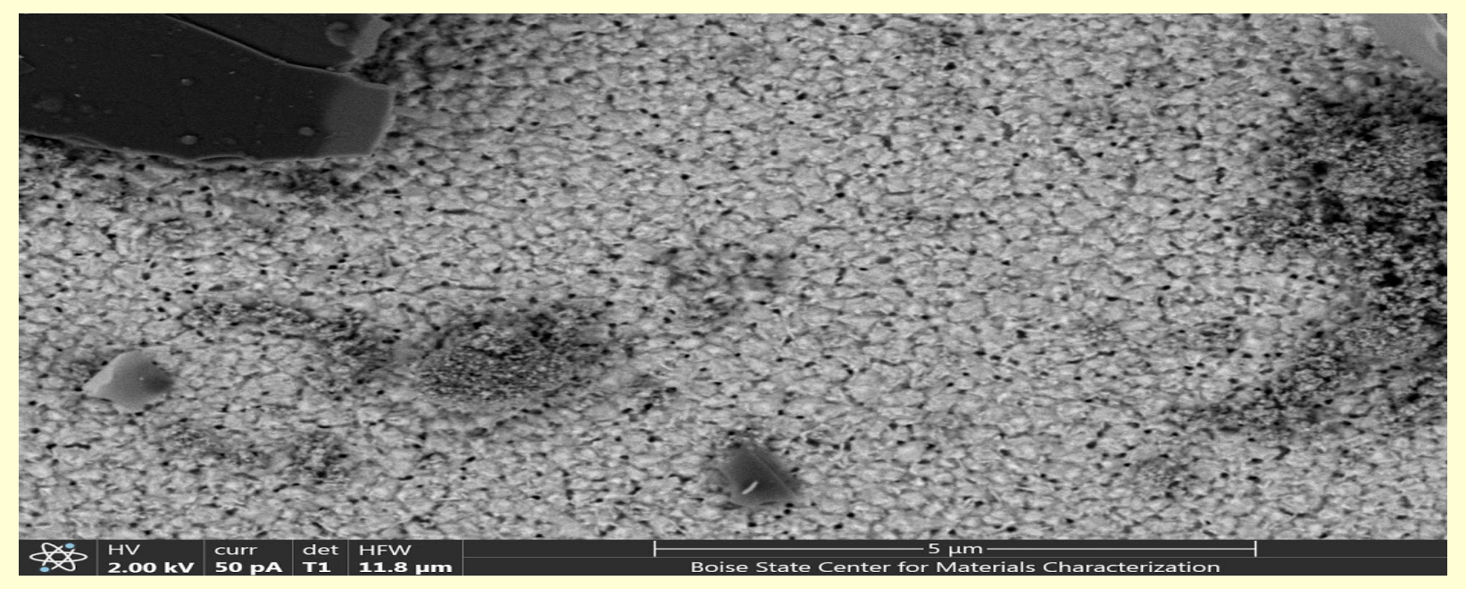
The Two-Step Advantage

Forming the perovskite layer in a two-step process yields better results than a one-step method. The lead iodide and methylammonium iodide precursors are deposited in separate steps rather than combined before spin-coating.

Benefits: Increased coverage, higher energy conversion efficiency. This method, along with a glove box environment, produced our most efficient solar cells.

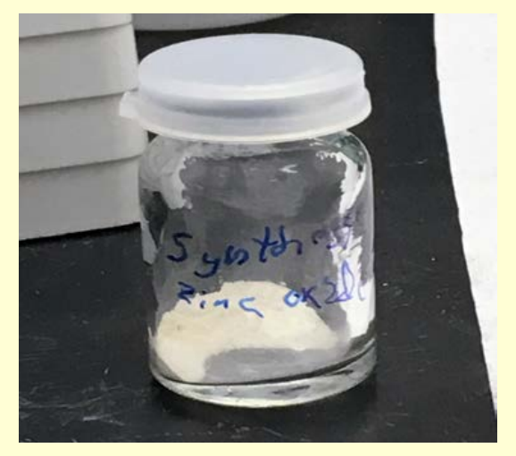


Teneo SEM image: 1-step perovskite layer.



Teneo SEM image: 2-step perovskite layer.

Zinc Oxide Synthesis



To ensure the integrity of our ZnO layer, ZnO nanoparticles were synthesized in the lab rather than purchased pre-made.

Results

Perovskite solar cell: 0.202V Silicon solar cell: 0.265V

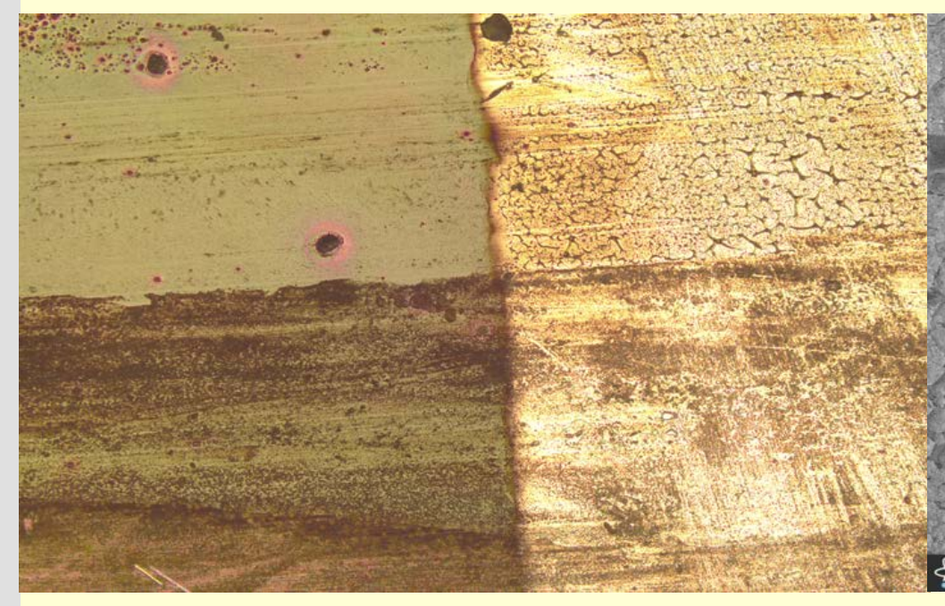
The highest performing device had an open circuit voltage that is 76% as efficient as the Si cell, which was 17% efficient.

The solar cells do not have photocurrent—we suspect that this problem arises from pinholes facilitating electron and hole recombination. Doping the ZnO layer with Al cannot begin until we achieve consistent finite current readings.

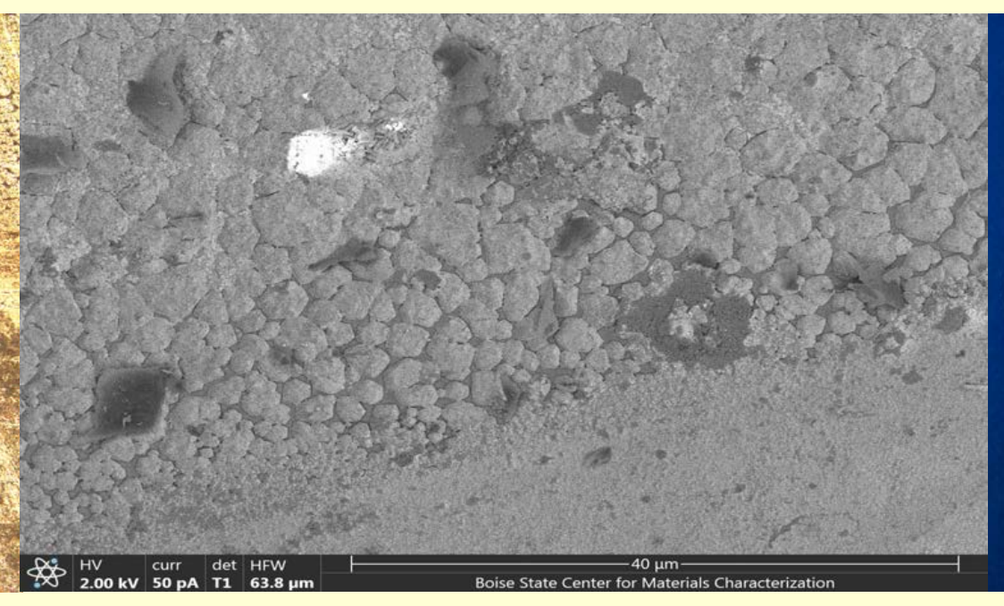
Materials Characterization

This project involved various characterization techniques to detect surface uniformities, layer thickness, element composition, and chemical structure.

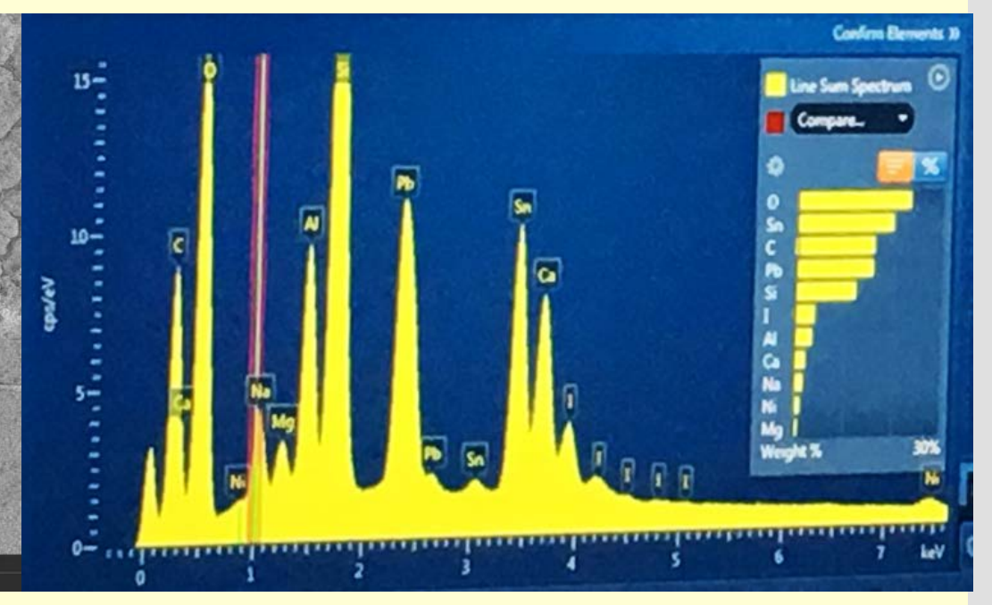
- Optical microscopy
- Scanning Electron Microscopy (SEM)
- Energy-dispersive X-ray spectroscopy (EDS)
- Contact profilometry
- Optical profilometry



Optical microscope image of etch and Al electrode boundaries of a cell.



SEM image of ZnO layer on top of perovskite. Scale bar: 40 microns.



Spectroscopic analysis of the elements in a perovskite solar cell.

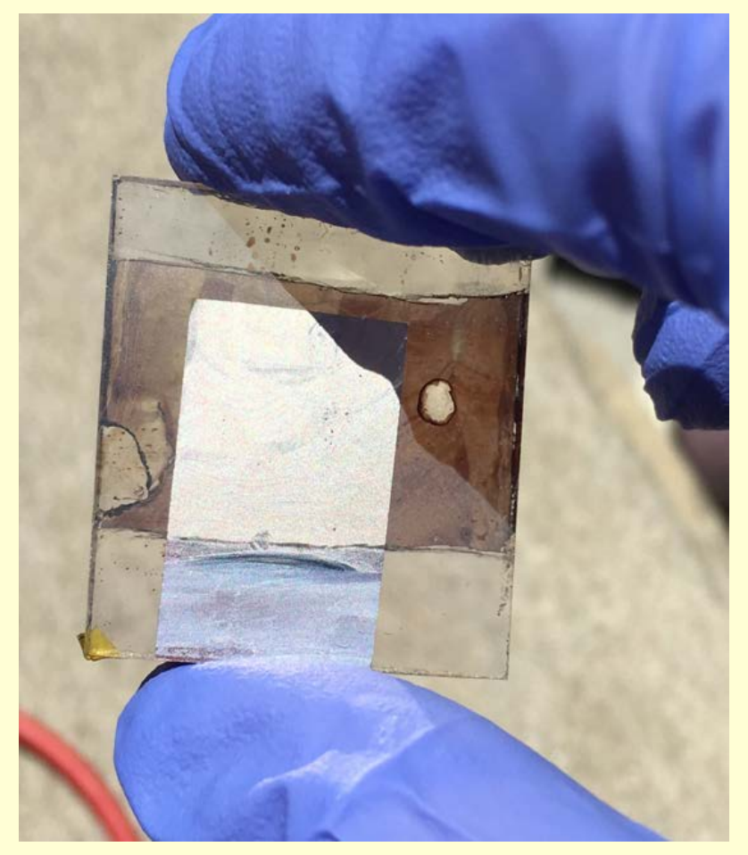
Summary & Conclusions

The greatest challenge was preventing the solar cells from short-circuiting due to contact between the Al electrode and the ITO coating. With structural modifications via etching and changing the area of each layer, the solar cells are now able to collect voltage in the sunlight!

These readings are in the ~200 mV range—this achievement is a decent foundation, but with further modifications, we expect to increase the efficiency of our cells.

Doping ZnO with Al has been shown in previous studies to increase the layer's conductivity; however, this process has not yet been tested in the creation of perovskite solar cells.

Our work seeks increased efficiency.



Future Studies

This is an ongoing project. In its continuation in the fall, the lead-halide solar cells will continue to be refined for consistency, thus the doping process of Al in the ZnO layer can begin.

- Fabricate devices with useful voltage and current readings and collect these results.
- Study a range of dopant (Al) concentrations in the ZnO solution, produce batches of solar cells and record current readings.
- Determine if Al-doped ZnO contributes to increased energy conversion efficiency in devices and determine the most efficient concentration of the dopant.

Acknowledgments & References

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Literature and Web Citations

(1) Y. Jingbi, M. Lei, S. Tze-Bin et al. 2016. *Improved air stability of perovskite solar cells via solution-processed metal oxide transport layers.* Nature Nanotechnology. (11):75—81.

(2) Ossila Ltd. – *Perovskites and Perovskite Solar Cells: An Introduction.* https://www.ossila.com/pages/perovskites-and-perovskite-solar-cells-an-introduction

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