Development of Perovskite (PVSK) Technology Related to Solar Cell Manufacturing Equipment

Cooperative Research and Development Final Report

CRADA Number: CRD-18-733

NREL Technical Contact: Maikel Van Hest

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5K00-76729
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Cooperative Research and Development Final Report

Report Date: 3/27/20

In accordance with requirements set forth in the terms of the CRADA agreement, this document is the final CRADA report, including a list of subject inventions, to be forwarded to the DOE Office of Scientific and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

Parties to the Agreement: Energy Everywhere™

CRADA Number: CRD-18-733

CRADA Title: Development of Perovskite (PVSK) Technology Related to Solar Cell Manufacturing Equipment

Joint Work Statement Funding Table showing DOE commitment:

No NREL Shared Resources

Estimated Costs	NREL Shared Resources a/k/a Government In-Kind
Year 1	$.00
TOTALS	$.00

Abstract of CRADA Work:

This CRADA between Energy Everywhere™ and NREL is to develop a process to fabricate flexible photovoltaic modules using a solution coated PVSK absorber with interlayers comprising materials deposited by economically feasible methods. Energy Everywhere™ will replicate and scale this process in Berkeley, California where it will ultimately commercialize the process, fabrication equipment, and PV modules.

Summary of Research Results:

The tasks laid out in the statement of work (SOW) were:

1. Materials Selection, Procurement, and Compatibility
2. Deposition (all layers) Process Development & Characterization
3. Series Interconnection Development
4. Encapsulation & Electrical Connections

The work as it was originally laid out in the SOW was not completed due to the fact that only a fraction of the agreed upon money was made available to do the work. Due to this lack of funding, the work was stopped before any work was started on items number 3 and 4.

Considering the limited effort, significant progress was still made. More details about work performed on task 1 and 2 can be found below.

In conjunction with cooperative development, Energy Everywhere required an ongoing technology transfer effort, which included:

1. NREL staff training Energy Everywhere's technical staff to enable reproduction of NREL small PVSK devices at Energy Everywhere's California laboratory by Energy Everywhere's technical staff.

2. Frequent fabrication of samples to be shown to Energy Everywhere's customers and investors in conjunction with the data associated with the samples.

The first requirement was accomplished. Energy Everywhere located two full time employees at NREL to work alongside NREL's staff. This allowed them to learn in detail the process required to make high efficiency perovskite solar cells. The Energy Everywhere staff transferred the knowledge to their California Laboratory. The second requirement was not implemented as the project was stopped before any request for specific samples was received.

Task 1: Materials Selection, Procurement, and Compatibility

Early on it was determined that the materials that should be selected would have to result in a stable device stack. Therefore the materials targeted for the transport layers were chosen to be oxides and the targeted material for the absorber was chosen to be the most stable perovskite at that point in time. A p-i-n device configuration was chosen as the most promising to work on. Initial material for the hole transport layer (HTL) was NiOx and for the absorber a modified triple cation, aka 'Kitchen Sink', perovskite. No work was started on development of a unique electron transport layer. Over time it was expected that the materials would be modified based on the findings within the project and/or findings reported in literature. The project did unfortunately not make it to a point where any significant modification was made.

Task 2: Deposition Process Development

To optimize the chemistry and processing conditions for the HTL and the absorber layer, many device builds (batches) were performed. The quality of the absorber material was tested using Time Resolved Microwave Conductivity (TRMC) spectroscopy. This method is able to determine the carrier lifetime and mobility of the absorber, without the need for making full devices. Figure 1 shows TRMC data for the optimization process of a blade coated absorber. A true spin coated kitchen sink stack is included for comparison. Parameters modified in the optimization process, include, but are not limited to, blade speed, blade gap and ink concentration.

The NiOx deposition process was optimized, in a similar way, by testing various ink concentrations and post deposition annealing processes. It was determined that the ink concentration has a significant effect on the quality of the final HTL film. This is in part a film thickness effect, but also the difference in drying influences the quality of the final film significantly.

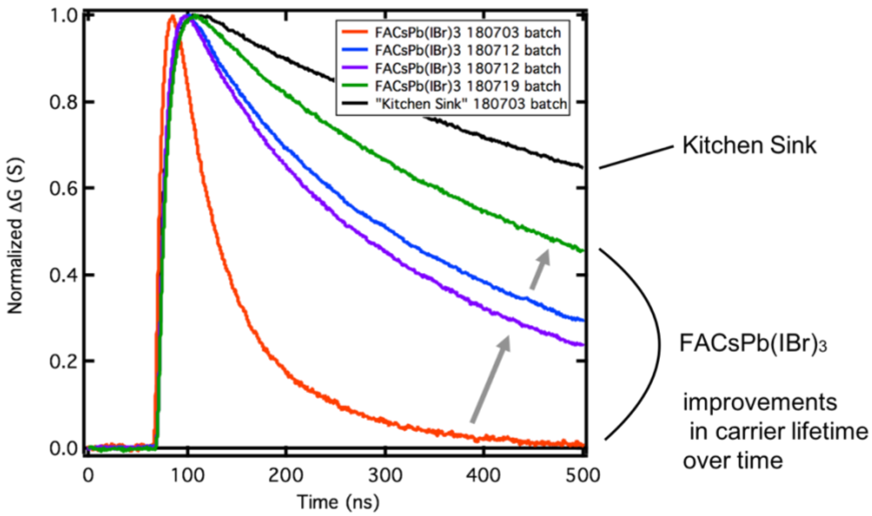

Figure 1: TRMC data for a series of optimization steps of the absorber deposition process.

Film stability is important for a commercial product. As such the perovskite absorbers were tested for stability in light. NREL's light stability setup was used for this. In this setup materials are continuously exposed to UV containing light and regularly the film absorption is determined. Whereas the absorber directly deposited on quartz was determined to be stable, the absorber with transport layers was very unstable (See Figure 2). Part of the work performed focused on eliminating the instability. Work was stopped before an acceptable solution could be found.

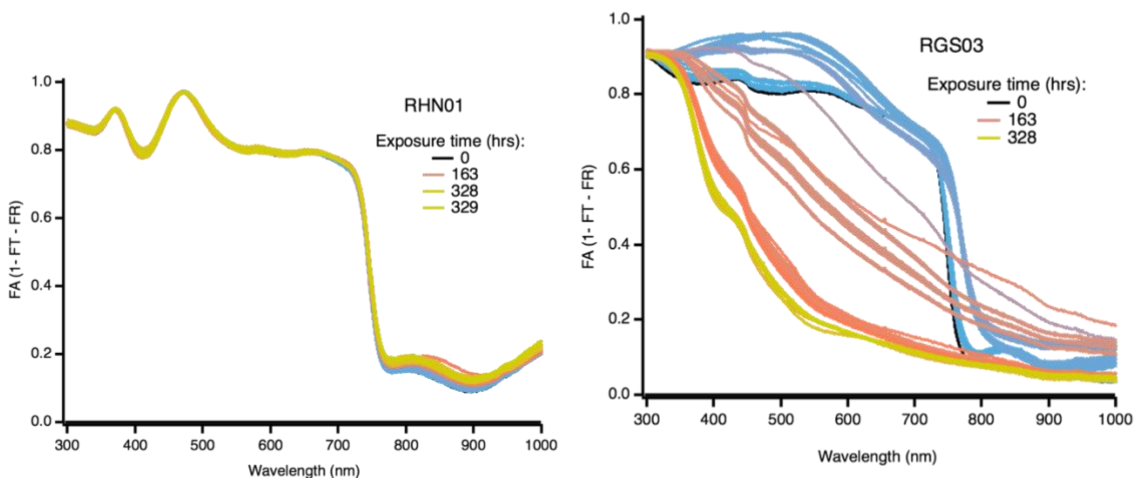

Figure 2: Absorption evolution of absorbers exposed to UV containing light. Left: Absorber only. Right: Absorber and transport layers.

For a commercial product ink stability is an important parameter as well. To determine the stability of the ink a series of device builds was performed based on an earlier study at NREL that showed, for another chemistry, that ball milling could be used to create a stable precursor powder. For the device build performed here the same ball milling process was used with the chemistry that was determined to perform the best. Figure 3 shows the film mobility determined by TRMC as function of the number of days the ball milled precursor was aged. It can be seen that for the optimized chemistry the ball milling approach works well, as there is no statistical difference found between the device builds at different times.

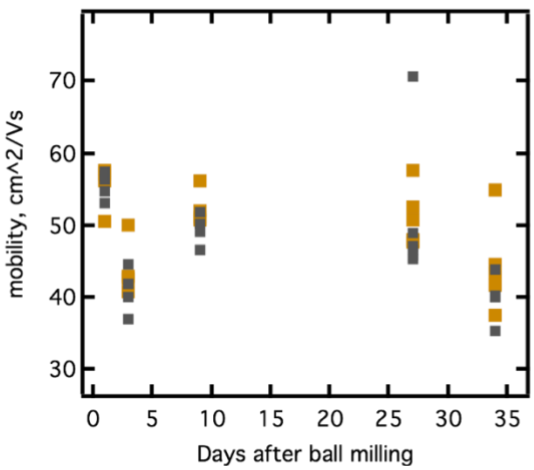

Figure 3: Absorber film mobility, as determined by TRMC, for films made using an aged ball milled powder precursor.

Task 3: Series Interconnection Development

The project was stopped before work on this task could get started. It was planned to used the monolithic interconnect structure, which would require optimization of the laser processing steps needed to make three scribes, all with different depth, in the material stack.

Task 4: Encapsulation & Electrical Connections

Again, the project was stopped before work on this task could get started. This task would have tested existing and novel encapsulation materials and methods of applying those to a fully build mini-module.

Subject Inventions Listing:

None

ROI #:

None

Responsible Technical Contact at Alliance/NREL:

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Name and Email Address of POC at Company:

The US part of the company folded. Matthew Robinson was our contact. In the last communication he provided the following contact information: Nancy Hartsoch | nancy@eeverywhere.com. She is non-technical.

DOE Program Office:

Office of Energy Efficiency and Renewable Energy (EERE), Solar Energy Technologies Office (SETO)