BAPVC Annual Project Report

Project Title: Hybrid Tandem Photovoltaics Using Organometallic Perovskites on Top of Silicon and CIGS

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Summary:

Hybrid tandem photovoltaics, two different semiconductor technologies used in a single tandem device, can improve the efficiency of solar modules without greatly increasing the module cost. They mechanically stack a semi-transparent perovskite device in a 4-terminal tandem configuration onto CIGS and Si solar cells and demonstrate net efficiency improvement. They monolithically integrate a perovskite solar cell with a silicon solar cell using a tunnel junction to make a 2-terminal tandem device.

Key Accomplishments:

In a continuation of the year one accomplishments, they have continued to improve the semi-transparent perovskite cell, achieving 12.7% efficiency with a peak transmission of 77% at 800nm. When paired with a 17.0% CIGS solar cell, they upgrade the cell to a tandem stack with 18.6% efficiency. They sent a separate semi-transparent perovskite cell to NREL for certification using a 17.0% silicon solar cell as the bottom cell, and certifying the tandem at 17.9% (Figure 1). These devices were reported in the journal *Energy and Environmental Science* (DOI: 10.1039/C4EE03322A) and a patent was sponsored by BAPVC and filed through Stanford concerning the method of depositing the transparent electrode. This work was featured by Science Magazine and Stanford News and subsequently reported by multiple news organizations.

As indicated in the future work section of last year's report, they designed and tested a monolithic 2-terminal tandem in collaboration with the Buonassisi group. Monolithically integrated tandems have design constraints that differ greatly from mechanically stacked tandems. The two most obvious design constraints are current density-matching of the subcells and the need for a transparent electrical connection between the subcells. For the electrical connection, they employ band-to-band tunneling on the top of the silicon wafer. They build the monolithically integrated tandem on an n-type silicon wafer, with a tunnel junction on the surface, a compact TiO_2 layer deposited by ALD, and the remainder of the perovskite cell deposited subsequently on top (Figure 2). Initial prototypes yielded respectable efficiencies, up to 13.7% at steady state. The V_{OC} of these tandems ranges from 1.55 to 1.65V. These devices were reported in the journal Applied Physics Letters (DOI: 10.1063/1.4914179) and a patent was sponsored by BAPVC and filed through Stanford concerning the method of electrically connecting the subcells with a silicon tunnel junction. This work was featured by *MIT News*, the American Institute of Physics, *The Conversation*, and *Scientific American*, and was subsequently reported by multiple news organizations including *The Economist*.

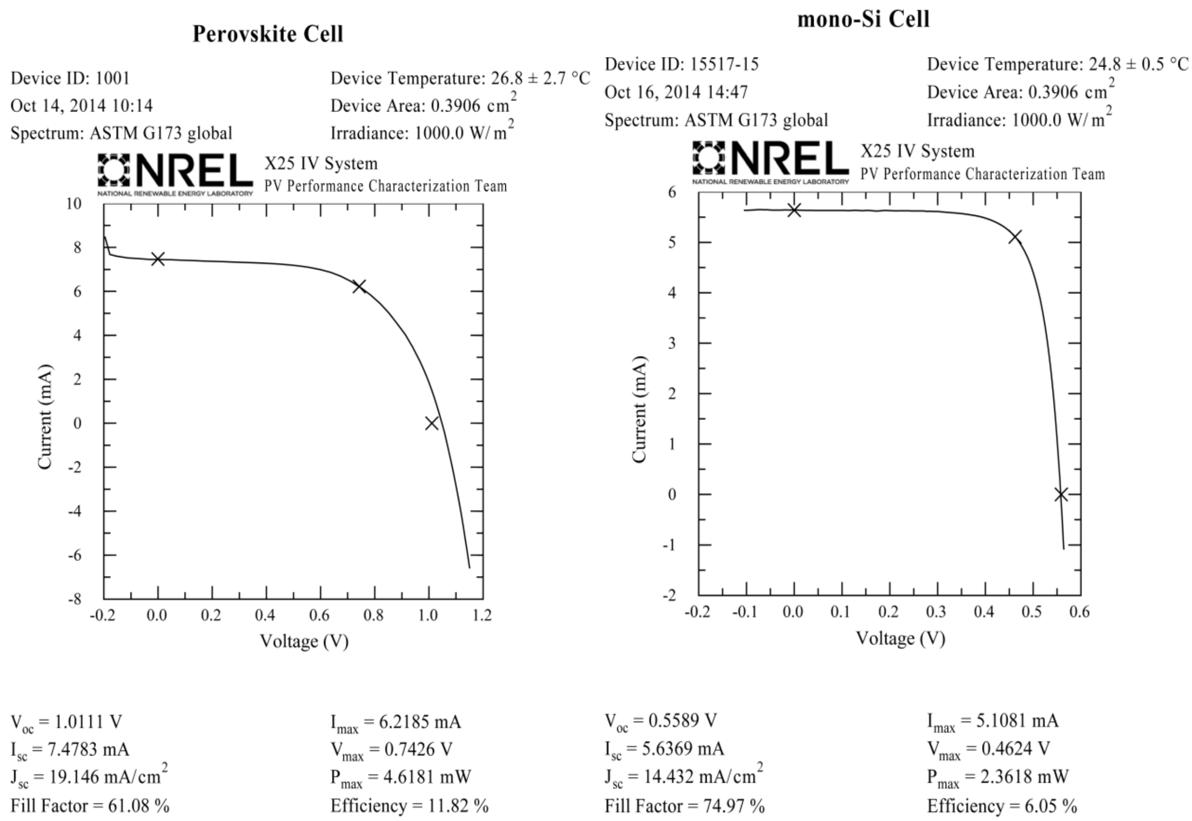

Figure 1. NREL certification of a mechanically-stacked tandem. The tandem efficiency is the sum of the individually measured cells, 17.9%.

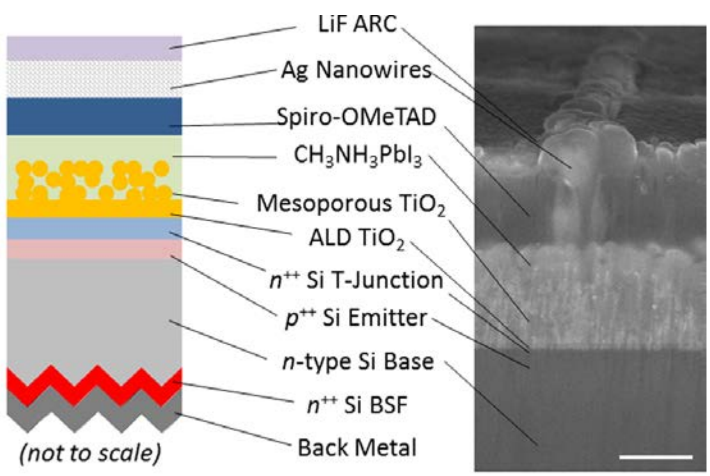

Figure 2. A schematic and SEM cross section image of a 1x1cm^2 monolithically integrated perovskite/silicon tandem achieving 13.7% efficiency.

Future Work:

They plan to certify the performance of the 2-terminal tandem and explore new 4- and 2-terminal tandem architectures including using inverted perovskite architectures and HIT silicon architectures. They will continue to work on cost modeling with Mike Woodhouse at NREL.