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 replace the opaque evaporated metal back electrode of perovskite solar cells with a solution processed silver nanowire transparent top electrode and achieve a semi-transparent perovskite solar cell. They mechanically stack the semi-transparent device in a 4-terminal tandem configuration onto CIGS and Si solar cells and demonstrate net efficiency improvement.

Key Accomplishments:

4-terminal hybrid tandems require a semi-transparent top cell. Typically, a perovskite solar cell is opaque because it is completed by the thermal evaporation of a metal back electrode, either Au or Ag, on the order of 100nm thick. To enable the transparency required to make a 4-terminal tandem, they have replaced this opaque electrode with a silver nanowire (AgNW) mesh that has a low sheet resistance and high transmission. The semi-transparent device is nearly as efficient as its opaque Au electrode counterpart (Figure 1/Table 1), exhibiting only a slightly lower photocurrent due to the lack of a back reflector. Their semi-transparent cell, at 11.6%, is much more efficient than other research-stage solid-state thin film solar cells, with the best semi-transparent bulk heterojunction cell at 5.0% and the best semi-transparent solid-state dye cell at 3.6%. The small decrease in photocurrent even without the back reflector speaks to the strongly absorbing nature of the perovskite material. Notably, the series resistance of the semitransparent device matches that of the control device with an opaque thermally evaporated Au electrode. The transmission through the semi-transparent device peaks at 73% around 800nm, the center of the critical 600-1000nm transmission window. Uniquely, this semi-transparent device has both a high transmission and a high efficiency.

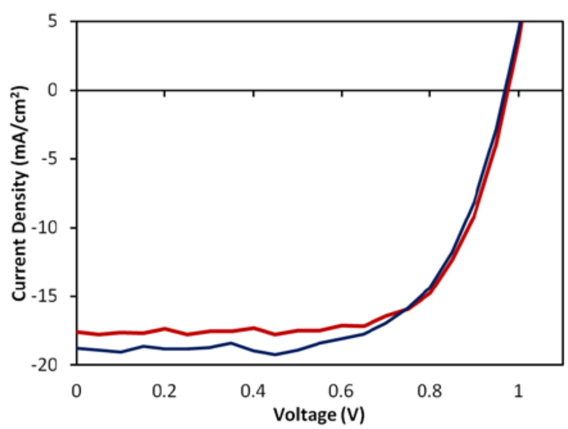

Figure 1. IV curves comparing best opaque vs. semi-transparent perovskite devices.

Table 1. Performance metrics of semi-transparent and opaque perovskite devices.

	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (-)	Efficiency (%)	R_s (Ω-cm^2)
Semi-Transparent Perovskite	16.8	977	0.704	11.6	1.8
Opaque Electrode Perovskite	18.6	967	0.693	12.5	1.6

They consider both Si and CIGS as bottom cells. Both have a bandgap around 1.1eV and are commercially successful solar cell technologies. They show that they can improve even a state-of-the-art CIGS by placing it in a hybrid tandem. They improve a CIGS cell from 16.7% alone to 17.1% in a tandem (Figure 2/Table 2), to their knowledge the highest efficiency for a 4-terminal multijunction polycrystalline solar cell reported in literature. Perovskite solar cells are already efficient enough to upgrade the performance of silicon solar cells made with inexpensive silicon using the hybrid tandem approach. An example of an inexpensive source of Si is upgraded metallurgical grade Si (UMG-Si) (Table 3).

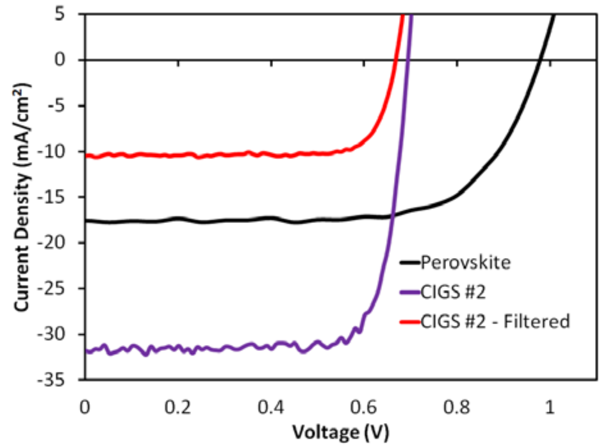

Figure 2. IV curves and of semi-transparent perovskite cell, unfiltered CIGS cell, and CIGS cell filtered by the perovskite cell.

Table 2. Performance metrics of semi-transparent perovskite cell, unfiltered CIGS cell, CIGS cell filtered by the perovskite cell, and the resulting 4-terminal tandem efficiency.

	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (-)	Efficiency (%)
Perovskite	16.8	977	0.704	11.6
CIGS - Unfiltered	30.9	694	0.78	**16.7**
CIGS - Filtered	10.3	667	0.80	5.5
4-Terminal Tandem				**17.1**

Table 3. Performance metrics of semi-transparent perovskite cell, unfiltered UMG-Si cell, UMG-Si cell filtered by the perovskite cell, and the resulting 4-terminal tandem efficiency.

	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF (-)	Efficiency (%)
Perovskite	16.8	977	0.704	11.6
UMG-Si - Unfiltered	28.7	546	0.68	**10.7**
UMG-Si - Filtered	9.7	501	0.70	3.4
4-Terminal Tandem				**15.0**

Future Work:

They plan to certify the performance of the 4-terminal tandem, then shift gears to pursue 2-terminal tandems of perovskites on Si. They will design and test 2-terminal tandems in collaboration with the Buonassisi group and in parallel will work on cost modeling with Mike Woodhouse. Fast progress is expected since perovskite cells are rapidly improving.