Perovskite Top Solar Cell Development for Monolithic Silicon-Based Tandem and Triple-Junction Solar Cell Application

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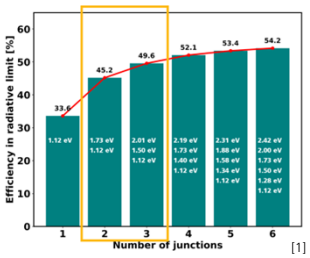
Introduction

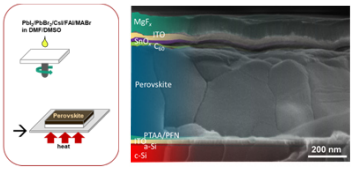
- Goal: Reduce levelized costs of electricity by increasing efficiency with multijunction solar cells
- Perovskite as partner for silicon enabling high efficiency, tunable bandgap, cheap fabrication
- Presented: Recent research on perovskite top solar cells for Si-based tandem and triple-junction devices



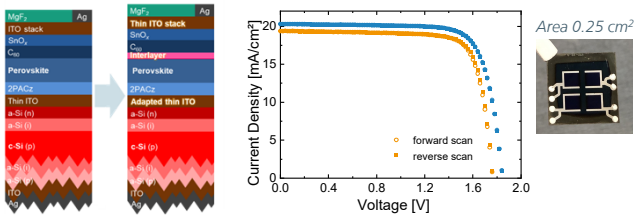
[1]

Monolithic Perovskite Silicon Tandem Solar Cells

Current Density >20 mA/cm² for Tandem Devices with Planar Front

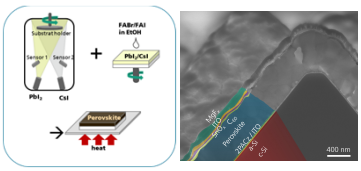


- One-step spincoating route with antisolvent method
- $Cs_{0.05}(FA_{0.83}MA_{0.17})_{0.95}Pb(I_{0.83}Br_{0.17})_3$ with lead excess → 1.64 eV[2]
- Flexible processing allows for fast material screenings

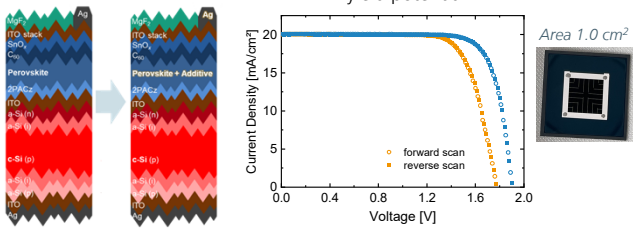


ITO process and thickness optimization[3] as well as addition of a LiF interlayer between Pero/C_{60} yields +0.9 mA/cm² and +82 mV.[4] Currently more stable interlayers such as AlO_x deposited by ALD are under investigation.

Hybrid Route for Industrially Relevant Textured Tandems



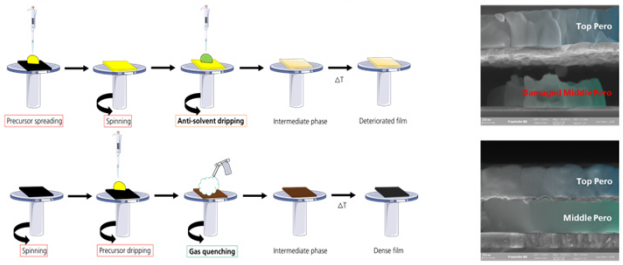
- Two-step hybrid co-evaporation/ spincoating route
- $FA_{0.85}Cs_{0.15}Pb(I_{0.78}Br_{0.22})_3$ → 1.66 eV
- Conformal perovskite films on µm-sized textured Si for high energy yield potential[5]



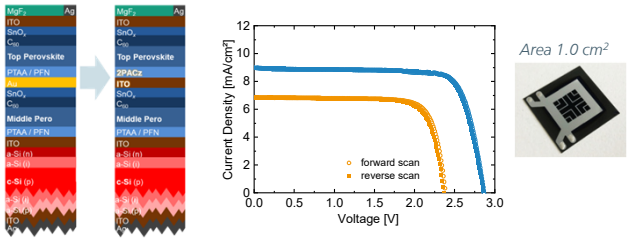
Organic additive in 2nd step solution and optimization of the 2PACz deposition and SnO_x layers yields + 1.3%$_{abs}$ PCE.[6] Currently hybrid route upscaling is under investigation.[7]

Monolithic Perovskite Perovskite Silicon 3J Solar Cells

High Open-Circuit Voltage >2.8 V for Triple-Junction Devices



- One-step spincoating route with antisolvent method for middle and adapted spincoating with gas quenching for top perovskite absorber[8]
- $Cs_{0.05}(FA_{0.90}MA_{0.10})_{0.95}Pb(I_{0.95}Br_{0.05})_3$ with lead excess → 1.56 eV and $Cs_{0.05}(FA_{0.55}MA_{0.45})_{0.95}Pb(I_{0.55}Br_{0.45})_3$ with lead excess → 1.83 eV
- Triple-junction baseline for material screening established



Using 15 nm ITO recombination layer and 2PACz hole contact yields +2.0 mA/cm² and +50 mV.[8] Moreover ITO serves as improved solvent barrier. Currently optimization of current-limiting middle cell perovskite is under investigation. Future work targets textured triple-junction solar cells.

Recent Lab-Sized Tandem and Triple-Junction Solar Cell Results at Fraunhofer ISE (Forward and Reverse Scan)

**different grid shading for devices*

Device Type	Area [cm²]	V_{OC} [mV]	j_{sc}* [mA/cm²]	*FF* [%]	*PCE* [%]	Stab. *PCE* [%]
Perovskite silicon tandem junction solar cell (planar)	$0.25_{d.a.}$	1847 1846	20.3 20.3	76.9 76.9	28.8 28.8	28.8
Perovskite silicon tandem solar cell (textured)	$1.0_{d.a.}$	1903 1903	20.1 20.1	78.7 78.5	30.0 30.0	30.0
Perovskite perovskite silicon triple-junction solar cell (planar)	$1.0_{d.a.}$	2862 2868	8.9 8.9	77.9 78.1	20.0 20.1	20.0

Perovskite solar cell processing can be successfully adapted for the use on planar and industrially µm-sized textured silicon bottom solar cells for tandem and multi-junction application. Besides optimum choice of perovskites, opto-electrical optimization of selective contacts and electrodes is key to unlock the efficiency potential.

[1] S.P Philipps, A.W. Bett, *Advanced Optical Technologies*, 2014.
[2] Mi. Heydarian et al., *SolarRRL*, 2023.
[3] C. Messmer et al., *Progress in Photovoltaics*, 2021.
[4] Ö. Ş. Kabakli et al., *under preparation*, 2023.
[5] N. Tucher et al., *Optics Express*, 2019.
[6] O. Er-raji et al., *under preparation*, 2023.
[7] O. Schultz-Wittmann et al., *WCPEC-8 Proceeding*, 2022.
[8] Ma. Heydarian et al., *ACS Energy Letters*, 2023.

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