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Synergy RTD 2013

FNSNF

Development of Near Infrared Transparent Perovskite Solar Cells for Tandem Application with $Cu(In,Ga)Se_2$

EMPA Materials Science & Technology

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Abstract

An effective approach for highly efficient photovoltaics is to combine solar cells with wide and narrow band gap to tandem devices. The high efficiency of perovskite solar cells and the wide band gap of the absorber which is tunable over a large range (≥ 1.57 eV) make them well suitable for the application as top cells in a tandem structure with CIGS bottom cells. A prerequisite for such tandem cells is the development of high efficiency perovskite solar cells with high near infrared (NIR) transmittance and low sheet resistance of the transparent electrode.

Here we show that sputtered ZnO:Al is a suitable transparent electrode for planar perovskite solar cells with high transmission in the NIR region. The NIR transparent perovskite was implemented as a top cell together with a CIGS bottom cell in a 4-terminal tandem device.

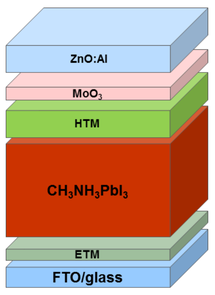
NIR-Transparent solar cells with ZnO:Al electrode

Transparent electrode requirements:

- High transmission in the NIR region
- Low sheet resistance

Advantages of ZnO:Al transparent electrode:

- Earth-abundant raw materials
- Low deposition temperature
- Scalable deposition method



ZnO:Al: RF sputtering

MoO_3: thermal evaporation

Spiro-OMeTAD: spin coating

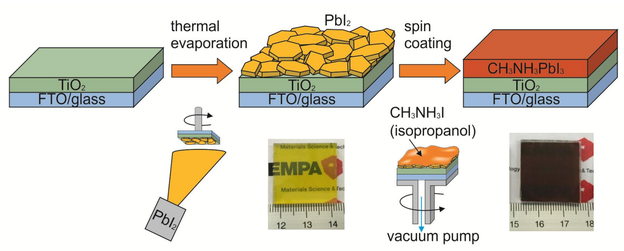
$CH_3NH_3PbI_3$

TiO_2: sputtering

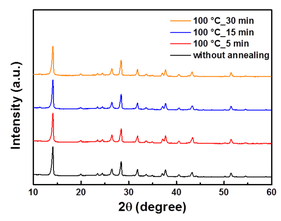
TEC15

Planar perovskite solar cells

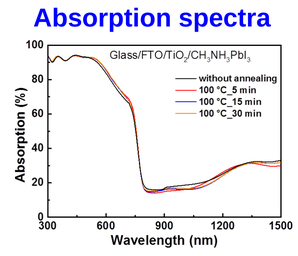
Thermal evaporation + spin coating



XRD

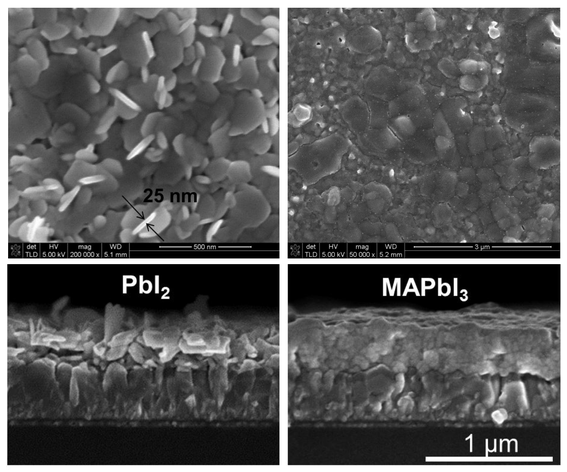


Absorption spectra



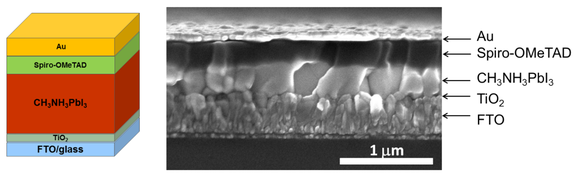
- Single phase perovskite obtained after spin coating without annealing step
- Annealing applied to increase the grain size

Microstructure

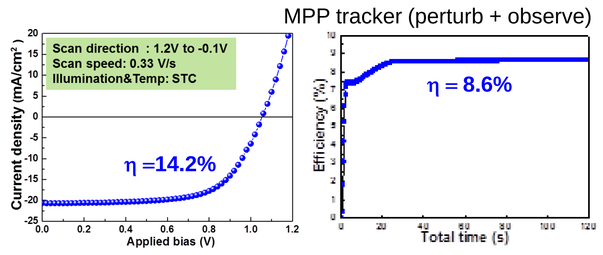


- PbI_2 nanoplates for rapid perovskite formation

Perovskite solar cell



MPP tracker (perturb + observe)

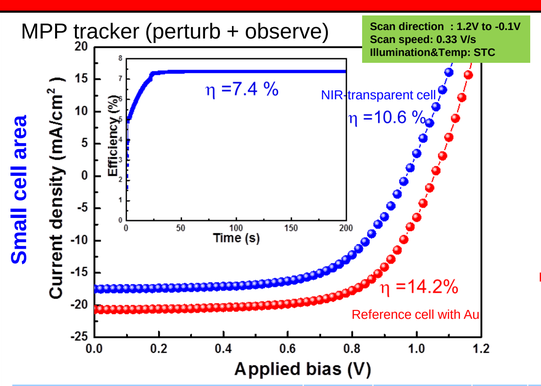


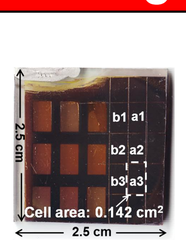
- Planar perovskite solar cell exhibits steady state efficiency of 8.6% (14.2% from J-V curve)

Development of high efficiency polycrystalline thin film tandem solar cells

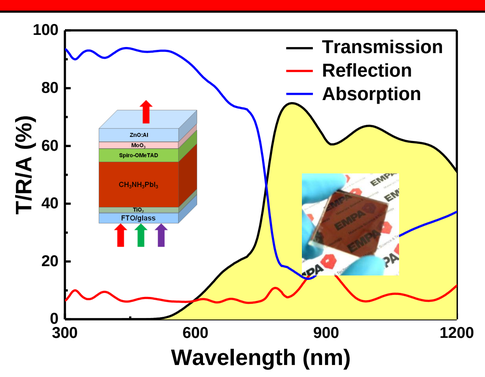
Perovskite solar cells with high NIR transmittance

Small cell area





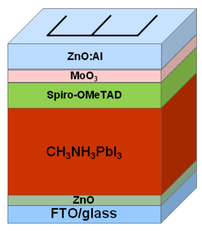
- Cell area is defined by mechanical scribing

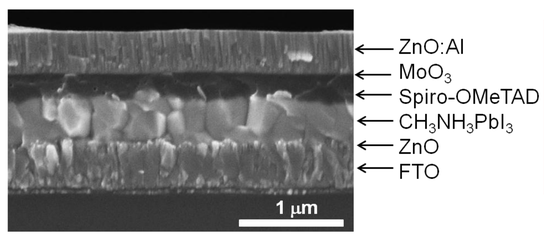


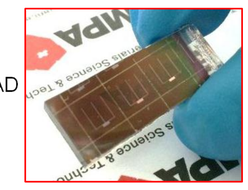
	V_{oc} (V)	J_{sc} (mA/cm²)	FF (%)	Eff. (%)	Steady state Eff. (%)	Area (cm²)
Perovskite reference with Au	1.053	20.68	65.2	14.2	8.6	0.15
NIR-transparent perovskite cell	0.969	17.5	62.3	10.6	7.4	0.142

- 7.4% steady state efficiency (10.6% from J-V curve) perovskite with high transmission in NIR region was obtained by employing AZO as transparent contact

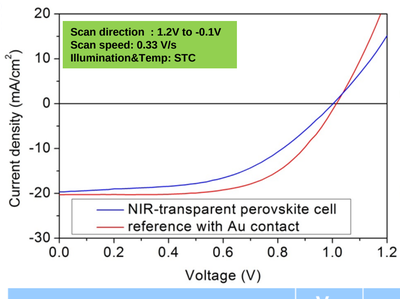
Increased cell area/grid

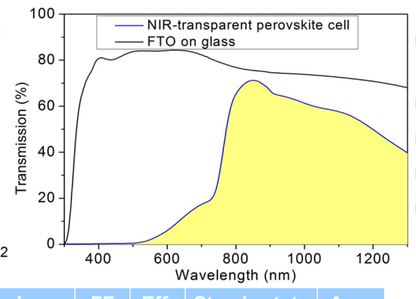






Cell area: 0.331 cm²



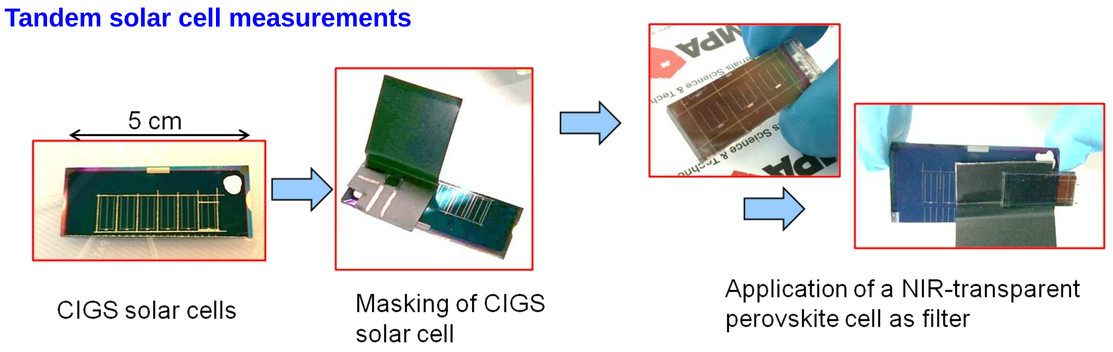


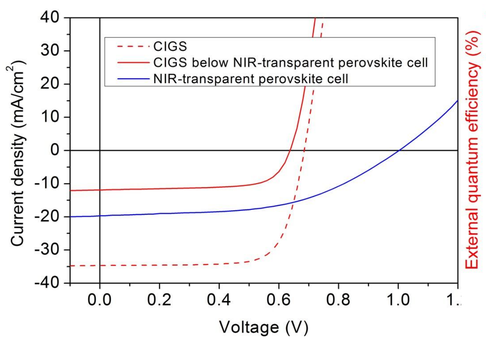
- ZnO was used as electron transporting layer
- Ni/Al grid applied
- AZO sheet resistance: 14 ohm/sq.
- Cell area defined by mechanical scribing
- 5.3% (10.1% from J-V curve) steady state output NIR-transparent perovskite cell achieved with ~ 0.3 cm^2

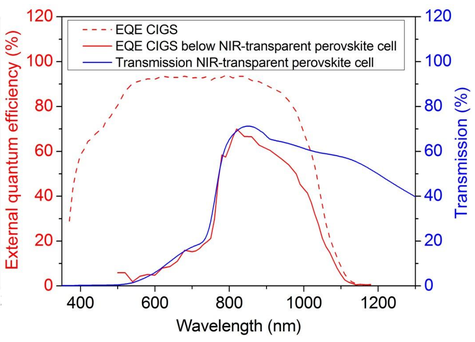
	V_{oc} (V)	J_{sc} (mA/cm²)	FF (%)	Eff. (%)	Steady state Eff. (%)	Area (cm²)
Perovskite reference with Au	1.015	20.3	61.2	12.6	7.3	0.15
NIR-transparent perovskite cell	1.003	19.6	51.4	10.1	5.3	0.331

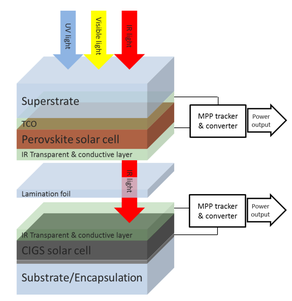
Perovskite-CIGS tandem solar cells

Tandem solar cell measurements









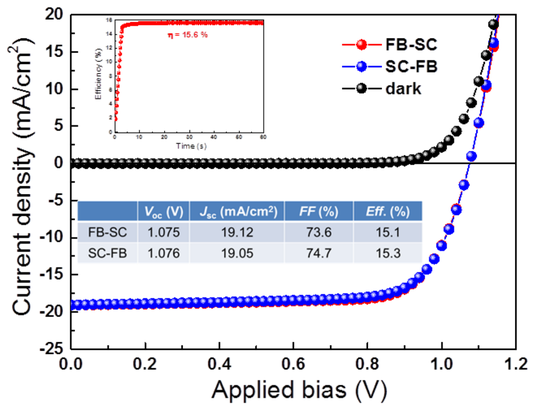
	V_{oc} (V)	J_{sc} (mA/cm²)	FF (%)	Eff (%)	Steady state Eff. (%)	Area (cm²)
CIGS	0.687	34.7	73.8	17.6	17.6	0.416
CIGS with perovskite filter	0.637	11.9	69.3	5.3	5.3	0.196
NIR-transparent perovskite cell	1.003	19.6	51.4	10.1	5.3	0.331

- 4-terminal Perovskite-CIGS tandem solar cell demonstrated with steady state efficiency of 10.6% (15.4% from J-V curve)
- Steady state efficiency of perovskite solar cell needs to be improved

Outlook

- 15.6% steady state efficiency planar perovskite solar cell was obtained, and application of NIR transparent electrode would further boost the overall efficiency of tandem solar cell .
- TCO with high mobility to be investigated.
- AR coating and Index matching media to be applied.
- With further improvements, efficiencies towards 30% are feasible for perovskite-CIGS tandem device

- **15.6% planar perovskite solar cell**



	V_{oc} (V)	J_{sc} (mA/cm²)	FF (%)	Eff. (%)
FB-SC	1.075	19.12	73.6	15.1
SC-FB	1.076	19.05	74.7	15.3

Conclusions

- **NIR transparent electrode**
  ZnO:Al was successfully applied as transparent electrode for perovskite solar cells, showing transmission as high as 75% for the whole perovskite cell
- **NIR transparent perovskite solar cells**
  7.4% steady state output (10.6% from J-V curve) NIR-transparent perovskite cells achieved with Spiro-OMeTAD/MoO_3/ZnO:Al
- **Perovskite-CIGS tandem solar cells**
  4-terminal perovskite-CIGS tandem solar cell demonstrated with steady state efficiency of 10.1% (15.4% from J-V curve). Further efficiency improvement will be feasible by increasing the steady state efficiency of the perovskite solar cell.

IMPORTANT: **Present steady state efficiency for perovskite solar cells and report the measurement conditions**

Acknowledgements

- NRP 70 (Swiss national science foundation): PV2050
- NanoTera and Swiss Federal Office of Energy: SYNERGY
- China Scholarship Council (CSC)

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