CONNECT PV

Conductive Transparent Electrodes: a Competence Cluster for Highly Efficient Thin Film Photovoltaics

Co-financed by Swiss Federal Office of Energy (SFOE)

List of Abbreviations

BZO Boron doped Zinc Oxide
CIGS Copper indium gallium (di)selenide
FTO Fluorine Tin Oxide
ITO Indium Tin Oxide (InSnO)
IZO Indium Zinc Oxide (InZnO)
MAF Methylammonium Formate
OPV Organic Photovoltaics
PE-DOT:PSS Poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate)
Spiro-OMeTAD 2,2′,7,7′-Tetrakis-(N,N-di-4-methoxyphenylamino)-9,9′-spirobifluorene
SHJ Silicon Heterojunction
TCO Transparent Conducting Oxides
ZrInO Zr-doped Indium Oxide

Major Partners in the ETH Domain

- Empa – Laboratory for Thin Films and Photovoltaics (TFPV)
- Empa – Functional Polymers (FP)
- EPFL – Laboratory of Photonics and Interfaces (LPI)
- EPFL – Photovoltaics and Thin Film Electronics Laboratory (PV-Lab)
- CSEM – PV-Center
- ZHAW

Main Investigators

Stephan Buecheler, Empa
Thomas Feurer, Empa

Project Partners

Empa
EPFL
CSEM
ZHAW

Time Frame of Project

2014–2017

Thematic Relationship to SCCER

FEEB&D (Buildings & Districts)

Scope of project

The main project goal has been to explore new transparent contact layers for solar cells. This includes mainly materials for replacement of commonly used indium tin oxide (ITO) as transparent electric contact, but also alternative scaffold materials in perovskite solar cells and the development of scalable low temperature options that can improve temperature sensitive solar cells like organic photovoltaics (OPV).
Together with light management schemes and design optimizations identified by device modeling and simulations, these layers should surpass the existing transparent contact layers and even enable new applications for this kind of contacts.

Status of project

The final six months of the project were dedicated to the implementation of the newly developed contact materials into solar cells for all different technologies in the consortium.

The resulting solar cells exhibited excellent performance above or on par with the state of the art technology.

All major project targets have been met and reported.

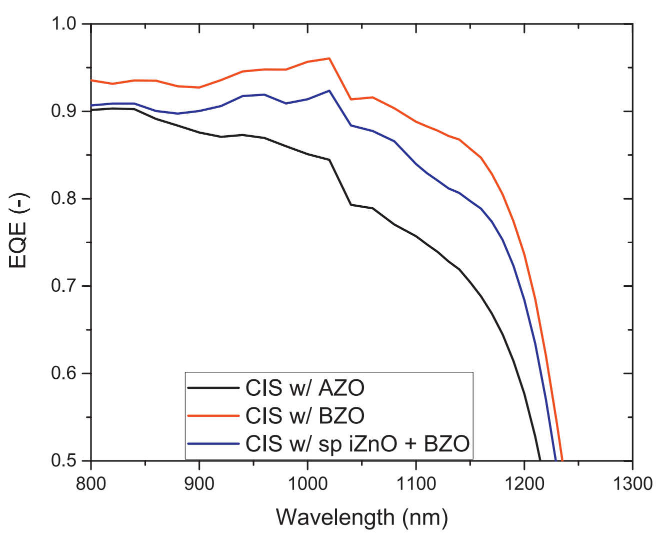

Figure 1:
External quantum efficiency (EQE) of low bandgap CIS solar cells with different combinations of transparent front contact materials. The spectral response in the near infrared region is improved by the use of BZO, due to the lower absorption in the TCO compared to the low mobility aluminium doped zinc oxide (AZO).

Main scientific results of workgroups

Vacuum based transparent conductive oxides

The implementation of the new vacuum based transparent conducting oxides (TCO) has improved the solar cells in various ways. High mobility materials like indium zinc oxide (IZO), Zr-doped indium oxide (ZrInO) and boron doped zinc oxide (BZO) show improved near infrared transmission, increasing the short circuit current of low band-gap solar cells considerably. As one example, figure 1 shows the improvements in low band-gap copper indium gallium (di) selenide (CIGS) materials by the implementation of BZO as transparent front contact. Similar improvements can be seen when using ZrInO in silicon heterojunction (SHJ) solar cells or IZO in CIGS.

Additionally, some of the new TCOs show superior damp heat stability and promise better flexibility due to their amorphous nature.

Metallic wire based transparent contacts

The previously reported wire based front contact for OPVs (Activity Report 2016) still required an evaporated layer of MoO_3 as mediator between the absorber and the hole-transport layer. In order to prevent the need for any vacuum step, solution based WO_3 buffer layers have been developed and combined with a binary fullerene:polymer active layer. The resulting laminated solar cells show comparable efficiency to regular semitransparent devices using PE-DOT:PSS and about 80 % of the efficiency of opaque cells using evaporated silver electrodes.

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Low temperature planar perovskite solar cells

Using a new PbI-enriched composition, perovskite solar cells with an Au/Spiro-OMeTAD/perovskite/mesoporous TiO_2/compact TiO_2/FTO structure were deposited in a single step solution process.

The cells show a power conversion efficiency (PCE) of up to 20.8 % and a remarkably high voltage at open circuit (VOC) of 1.18 V. It has been found that ionic liquids, such as methylammonium formate (MAF), enable a further improvement of the stabilized power conversion efficiency for a planar perovskite solar cell. Subsequently planar perovskite solar cells with a record stabilized power conversion efficiency of 19.5 % and a low temperature (below 120 °C) fabrication process have been developed.

Outreach

Within this project a number of important developments have been realized that would not have been possible without the collaborative platform enabled by the CONNECT-PV project. This project has not only fertilized the knowledge exchange between the Swiss research institutes active in thin film photovoltaics but also allowed more efficient use of infrastructure and equipment. Below is a selection of important results achieved by the CONNECT-PV consortium:

- EPFL-LPI has reached record level triple cation perovskites with 21.1 % efficiency and improved stability over the typical composition. At the same time, Empa-TFPV has shown semi-transparent perovskites on flexible substrates with efficiency over 12 %. They have been combined with CIGS bottom cells to all flexible 4-terminal perovskite/CIGS tandem devices.
- In the area of sputtered transparent contacts the teams at EPFL-PVLab and Empa-TFPV have explored several new high mobility TCOs, leading to the implementation of IZO into SHJ solar cells and subsequent transfer of the process onto CIGS devices. The high near infrared (NIR) transmission and damp heat stability of this material is beneficial for both technologies. Other TCOs like ZrInO are also promising and will be closely investigated in the future.
- On the topic of non-vacuum depositions, a process to laminate metal wire contacts on top of OPV and perovskite solar cells has been developed by Empa-FP and CSEM. It has shown comparable efficiency to evaporated metal electrodes and could be a low cost scalable alternative to those.

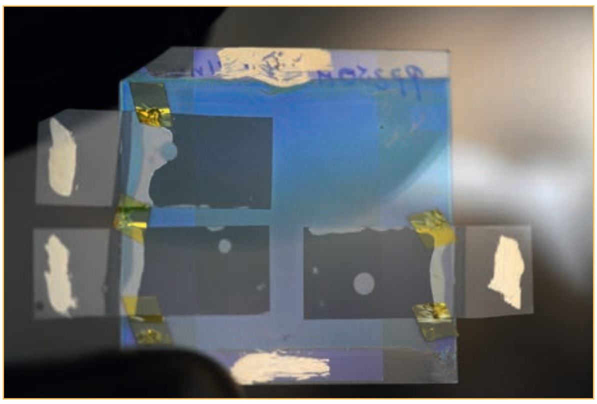

Figure 2:
Photograph of a semitransparent OPV solar cell using a laminated metal-mesh contact. The air bubbles visible in some cells stem from small particles present during the lamination process.

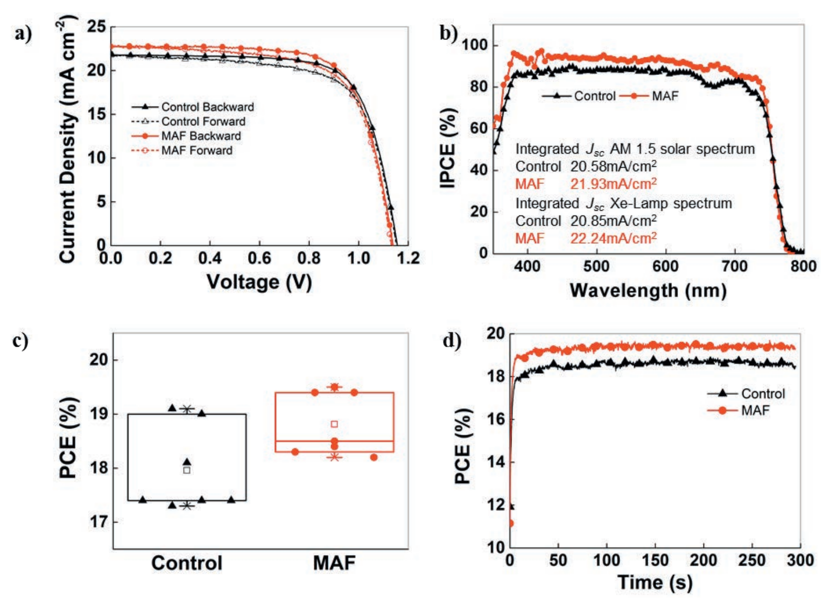

Figure 3:
Photovoltaic metrics of perovskite solar cells prepared with and without MAF.

a) J–V curves were measured from forward bias to short circuit condition and vice versa at the scan rate of 10 mV s⁻¹ under AM1.5 simulated solar light (94.8 mW cm⁻²). The device active area was defined using a black metal shadow mask with an aperture of 0.16 cm².
b) Incident photon-to-current efficiency (IPCE) curves for the MAF and control device.
c) Box plot of the photon-to-current efficiency (PCE) collected from seven devices.
d) Maximum power conversion efficiency as function of time from the maximum power point tracking under AM1.5 simulated solar light.