CUSTCO
Cost efficient, upscalable and stable transparent conductive oxides for silicon solar cells based on passivated contacts.

Project duration: from 09.2019 to 02.2023
Report submitted: 03.2023

Publishable Summary

This project aimed to develop industrially feasible transparent and conductive oxides (TCOs) to lower the cost and market entry barriers for high-efficiency silicon solar cells with "Passivating Contacts".

For the emerging solar cell technology of "Passivating Contacts" and especially for Silicon Heterojunction (SHJ) solar cells, Tin Doped Indium Oxide (ITO) is the current standard TCO material. For the expected very high production volumes (multi GW range), the indium demand of the TCO electrodes will be a roadblock for the upscaling of this technology due to the limited indium supply, the lack of options for end-of-life recycling from the solar module, price fluctuations and the competition with other applications. This challenge is shared with other established and upcoming (thin film) solar cell technologies aiming for high volume production.

To tackle this challenge different strategies have been addressed in the framework of this project, targeting the device structures shown in Figure 1. Some highlights are:

- Structure C): Proof-of-principle for SHJ cells with TCO-free front side → **100% Indium reduction**

  We evaluated processes routes with respect to their potential for upscaling and gained understanding how to efficiently utilize the lateral charge carrier transport provided by the Si absorber. While the absorber is the only lateral conductive layer in such a TCO-less device architecture, unlike other absorber materials used in thin film devices, the Si absorber can provide similar low sheet resistance as the typically additionally applied TCO films (e.g. structure A)). Ensuring a very low contact resistance at the direct contact between metal and doped silicon thin film for using an industrial metallization scheme was identified as one important building block to fully utilize the lateral transport provide by the Si absorber.

- Structure D): Thin ITO films combined with non-vacuum based dielectric capping layer → **70% indium reduction**

  In this configuration a thin TCO remains which can be beneficial with respect to good contact between metal and the doped silicon thin film and lateral transport. However, the need of having a second thin film layer deposited on top of the finished solar cell at the end of the cell process adds complexity, e.g. with respect to the process flow which needs to be considered for the techno-economical evaluation of such an approach. We showed that use of spray

coated TiOx could be an interesting alternative to the established vacuum based deposition of dielectrics.

- Structure F): While further research is needed for the aforementioned approaches towards higher TRL, we successfully established TCO multilayers as an effective means to balance the trade-off between indium-lean devices and process complexity and resulting techno-economical aspects. For sandwich structures using an indium-free TCO bulk layer (AZO) with thin ITO layers at the interface we managed → **75% indium reduction**

  We gained a thorough understanding on the role of each layer, e.g. that for a zinc oxide (ZnO) based TCO bulk layer an ITO capping is vital for (chemical) long term stability and that further research is needed for the explored tin oxide (SnO) based indium-free TCOs and more disruptive material alternatives.

- Structure B): We also highlighted that a straightforward approach, actually the first step that should take towards indium reduction, is to focus optimization on the final use case of the solar cell, the solar module. Mainly due to relaxed requirements on the anti-reflection properties of TCO, depending on the targeted module design this opens up some design freedom to thin down the front and rear side TCO (ITO) layers.

  → **~25% indium reduction at the front**

  → **>25% indium reduction at the rear**

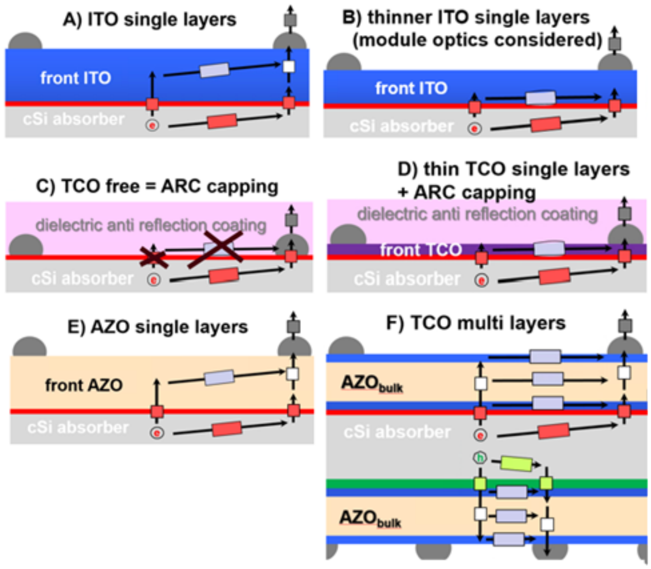

Figure 1: Schematic representation of the approaches for indium reduction pursued in the project. For simplicity only the front side is shown. Red layer: ETL at front side of SHJ cell. Possible carrier transport path is indicated.

Project consortium

Coordinator and all contact details:

Full name of organisation	Fraunhofer Institute for Solar Energy Systems
First and family name of coordinator:	Dr Martin Bivour
Full address:	Heidenhofstr. 2, 79110 Freiburg
E-mail:	martin.bivour@ise.fraunhofer.de

Participating countries and financing:

Country	Number of organisations involved	Project costs in EUR	Public funding in EUR
Germany	2	1 172 494	874 955
The Netherlands	2	691 427	410 624
France	1	257 299	156 019
Switzerland	1	312 570	76 530
Total	***6***	***2 433 790***	***1 518 128***

Funding agencies involved and contracts

Funding Agency	Contract N° and Title
Project Management Jülich (PtJ)	03EE1032 - CUSTCO
RVO	SOL193VU6U – CUSTCO SOL18001 - CUSTCO
ANR	ANR-19-SOL2-0002-01
Project Management ETN (NRW)	EFO 008 - CUSTCO
OFEN	SI/501917-01