Eindrapport - OPENBAAR

(Final report - public)

Flexible Tandem PSC-CIGS
(FLEX-Tandem PV)

Projectnummer:	TEUE 1821103
Penvoerder:	TNO
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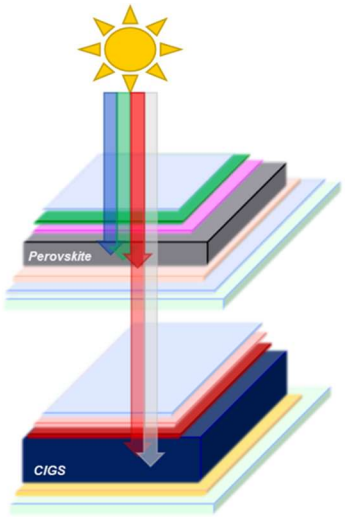
Projectperiode:	1 Septemebr 2019 t/m 31 december 2020

Deelnemers:	TNO
	SolayTec
	MiaSolé’



Dit project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, subsidieregeling Top Sector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

1 SAMENVATTING (SUMMARY)

In this project we have demonstrated a four terminal architecture flexible perovskite (PSC)-CIGS solar cell with an efficiency of 23% on small area, well beyond the performance of the single junctions, and the initial PCE prior the project (21.5%). Furthermore, a value of 24.3% was achieved when coupling the optimized lower band gap CIGS provided by MiaSolé with a perovskite solar cell fabricated on a glass substrates where low temperature and industrially relevant processes compatible with the use of plastic substrates have been used for each cell component.
The typical spatial ALD metal oxide layer adopted in the perovskite solar cell architecture and deposited via small area lab scale reactor was successfully transferred to two different large area tools, one located in TNO and the other one located in SolayTec. The spatial ALD layers were additionally tested for the first time to fabricate the current generation of semitransparent large area perovskite modules.

2 OVERZICHT BEHAALDE RESULTATEN

The results in this project could be roughly divided in three categories:

a) Development of low band gap CIGS on stainless foils
b) Optimization of semitransparent perovskite solar cell using industrial relevant methods
c) Testing sALD buffer layer adopted on small area lab scale reactor on large area tool

A large effort driven the transfer or CIGS absorber from rigid to flexible steel foils using MiaSolé materials as benchmark. Highly efficient flexible CIGS samples was received by the partner MiaSolé and used in combination with the flexible perovskite semitransparent cell. The 4T efficiency of this architecture achieved 23.0%. A value of 21.1% was also calculated when using TNO developed flexible CIGS fabricated on metal foil.

Cell type	Description	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF	PCE (%)
Flexible ST-PSC (1.6eV)	Backward scan	1052	19.9	71.0	15.0
	Forward scan	1051	19.8	71.0	15.0
	3 min MPPT	-	-	-	14.9
Flexible CIGS cell (1.1eV)	single junction	702	37.8	75.7	20.0
	bottom cell	675	15.5	77.4	8.1
4T Tandem cell	-	-	-	-	**23.0**

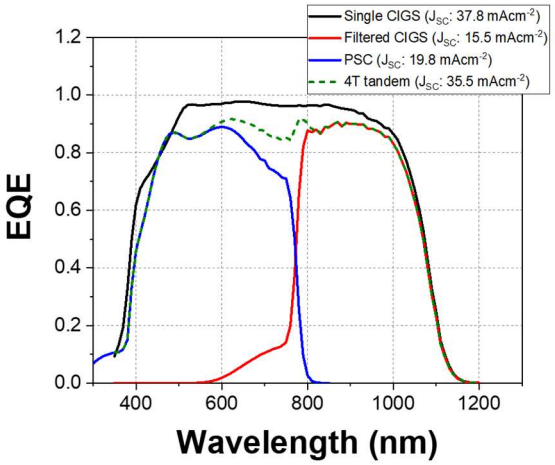


***Figure 1**: PV parameters and EQE curves of the flexible ST-PSC, flexible CIGS and filtered CIGS by the ST-PSC. The sum of the perovskite PCE and the PCE of the filtered bottom CIGS give the PCE of the 4T architecture.*

Perovskite solar cells based on low temperature processes and materials compatible with the use of PET foil have been developed. In particular we replaced the conventional lab scale quenching method commonly used in literature to produce high quality perovskite absorber

with the gas quenching method since it is more suitable for R2R manufacturing processing. The combination of the optimized flexible CIGS sample received by the partner in this project MiaSolé with the optimized semitransparent perovskite solar cell still on a glass substrate provided 4T architecture efficiency of 24.3%

Cell type	Description	V_{oc} (mV)	J_{sc} (mA/cm^2)	FF	PCE
Low-T Glass perovskite top cell	Backward scan	1148	15.1	78.2	13.7
	Forward scan	1148	15.1	76.1	13.3
	2 min MPPT				13.4
Flexible CIGS cell	single junction	702	37.8	75.7	20.0
	bottom cell	682	20.8	77.2	10.9
4T Tandem cell	-				24.3

+4.3%

Fig. 2: *PV parameters of: i)the single junction best glass based ST-PSC using low temperature ITO and perovskite absorber based on gas quenching ii)the best flexible CIGS provided by MiaSolé partner iii) filtered flexible CIGS.*

Finally during the project we transferred the spatial ALD metal oxide buffer layer used in the perovskite architecture from a lab scale reactor (substrate size 9 cm^2) to large area reactors: TNO S2S tool (Gen-1) with a max substrate size 1300 cm^2, and SolayTec tool (400cm^2). The as developed layers have been introduced for the first in a Solliance semitransparent perovskite large area module and compared with a standard device where the metal oxide layer is deposited by conventional ALD. The efficiencies on aperture area for the modules with sALD metal oxide deposited on the large area reactors are in the range of 10%, close to the value of the reference module (12%).

3 CONCLUSIE EN AANBEVELINGEN

In the project we have reported the development of the sub cells to deliver high performance hybrid 4T architecture based on a perovskite semitransparent solar cell and a flexible CIGS solar cell. Specifically advancement by TNO and MiaSolé have been achieved in the fabrication of more efficient flexible CIGS targeting lower band gap. Using a novel 1.14eV CIGS provide by MiaSolé a world record of 23% has been calculated for a complete full flexible 4T architecture using a perovskite semitransparent solar cell fabricated prior to this project. A value of 21.1% was also calculated when using TNO developed flexible CIGS fabricated on metal foil.

New low temperature semitransparent perovskite solar cells have been developed with the perovskite absorber quenched via N_2 gas method instead of conventional antisolvent. 4T PCE of 24.3% was calculated by coupling a rigid semitransparent PSC based on room temperature ITO, and gas quenched perovskite absorber and the record cell provided by MiaSolé. The transfer of these new materials and processing to fabricate flexible semitransparent perovskite cells was delayed and hindered by the poor mechanical and chemical stability of the highly infrared ITO deposited on PET, which will require further investigations and studies to be tackled.

Finally, in the view of upscaling the processes and the materials developed in this project, the process of spatial ALD for the metal oxide used in the perovskite architecture has been transferred from a small scale reactor towards two large area reactors, one in TNO and one in SolayTec, and eventually the layers were included for the first time in the current generation of large area perovskite modules developed in TNO.

4 PUBLICATIES

The results from this project were shared in the following publication:

- M. Simor et al, Oral presentation at EUPVSEC, Marseille, September 2019
- P.J. Bolt et al., Oral presentation at PVSEC-29, November, 2019