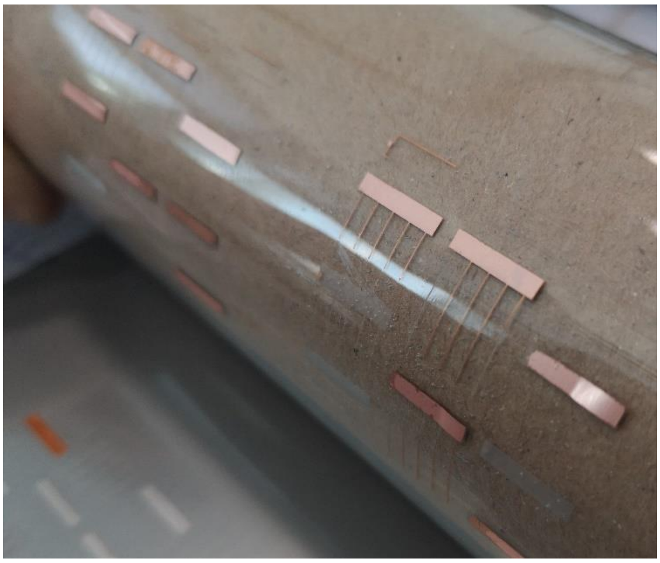
Openbaar eindrapport

SHAPE

Shadow tolerant customizable thin-film PV **p**an**e**ls

Projectnummer:	TEUE118007
Penvoerder:	TNO
Contactpersoon:	Veronique Gevaerts (TNO)
Projectperiode:	1 maart 2019 t/m 30 november 2021

Deelnemers:	Innplate Henkel N.V. TNO (partner in Solliance) Imec (partner in Solliance)



Het project is uitgevoerd met subsidie van het Ministerie van Economische Zaken, Nationale regelingen EZ-subsidies, Topsector Energie uitgevoerd door Rijksdienst voor Ondernemend Nederland.

1 DOELSTELLING VAN HET PROJECT

The main goal of this project was to apply metal grid fingers to monolithically interconnected thin film PV panels in order to increase efficiency and facilitate the application of bypass diodes for increased shadow tolerance.
A schematic representation of the monolithic interconnection scheme can be found in Figure 1. Cells in a monolithically interconnected panel are long and narrow and are connected in series by a set of patterned structures (P1, P2, P3) over the length of the solar cell. The cell area is determined by the width of the cell and is a trade-off between optical transmission and electrical resistance of the TCO front contact. In this project, metallic grid structures were applied on the TCO to increase the cell width. The additional shading losses from the metal grids were compensated for by using more transparent TCOs.
The introduction of grids also opens the possibility to integrate bypass diodes in monolithically interconnected panels, to protect the individual cells from harmful reverse bias voltages resulting from partial shading. Firstly, for economic reasons, wider cells means less cells in a panel and less bypass diodes. Secondly, for technological reasons, there are electrical connections easily available for each cell which is not the case in the traditional design.

The technical approach has been divided into two parallel paths based on the deposition method of the metallic structures.

1. Electroplating.
   Electroplating of copper grid structures on a temporary substrate, the grid structures are transferred to the PV device. Combining the expertise of electroplating at Innplate with that of encapsulation and cell/module manufacturing at TNO partner in Solliance. This approach was mainly focused on using flexible commercial CIGS material on conductive metal substrates to fabricate flexible free-form panels.
2. Screen-printing.
   Application of silver directly onto the TCO of the PV device by screen printing. This was a combined effort of IMEC and Henkel. The CIGS material on glass substrates were supplied by TNO.

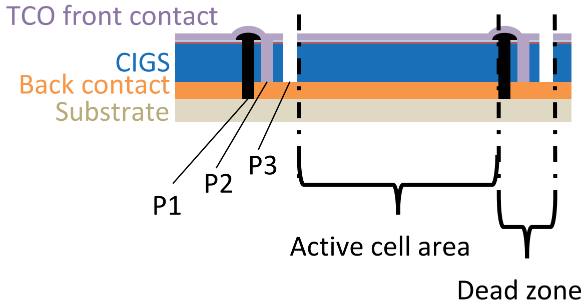


Figure 1 Schematical cross section representing a monolithical interconnection.

2 OVERZICHT BEHAALDE RESULTATEN

In the project, we have shown that Copper grids electroplated on a stainless steel substrate can be transferred, to be used in both monolithically interconnected modules as well as in flexible modules with cells on a conductive substrate. The plating and transfer process is explained in the schematic of Figure 2.

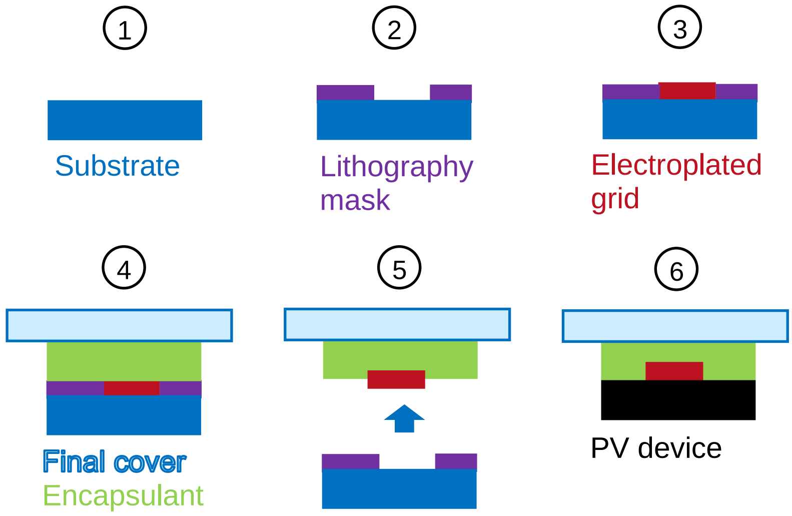


Figure 2: Schematic representation of the process steps needed to apply electroplated grids on a PV device. 1 substrate preparation. 2 application of lithography mask. 3 selective electroplating of metal grid. 4 application of the front encapsulant. 5 lift-off process, the grid is transferred to the encapsulation material. 6 lamination of the grid to the final PV device.

The main focus has been on interconnection schemes for flexible modules as the market for thin film PV is shifted towards flexible substrates. High-efficiency flexible modules with commercial bypass diodes were made with electroplated grids. Figure 3 shows a picture of a flexible PV laminate with hexagonal cells, showing the potential of this technology for use with free form PV devices.

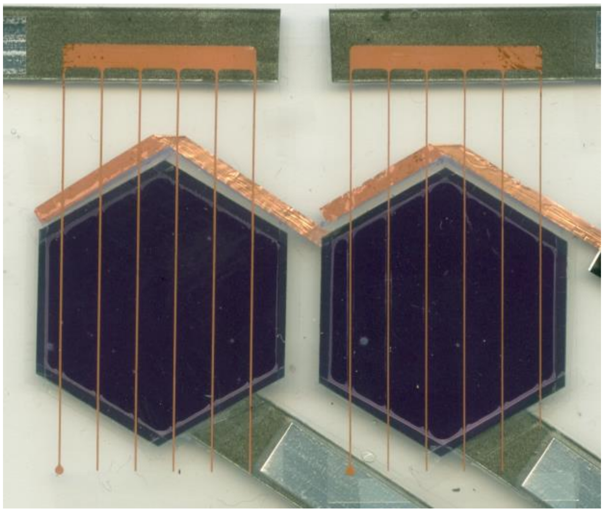


Figure 3: picture of a test structure using hexagonal shaped flexible cells. This module has several different back contacts to investigate the resistive losses at the back contact.

Compared to the wires currently used as grids for flexible solar cells the plated grids did show slightly lower resistive losses but also more shading losses. To reduce the shading losses, thinner structures need to be tested and the contact resistance must be reduced. In the project it was shown that the contact resistance can be reduced by adding an intermediate layer of Ni or Mo.

For the classic monolithically interconnected modules it was found that increasing the cell width using plated grids did not lead to additional resistive losses in the cells. However, the increased current in the P2 interconnect makes the resistance losses in the P2 much more pronounced.

The main bottleneck for the industrialization of this technology is the release of the grids from the temporary substrates. There are indications that this can be solved by reducing the roughness of the substrates and switching to a different type of lithography mask. A follow-up project for upscaling the production of electroplated grids at Innplate was recently granted.

The second technology route followed in the project was screen-printing of grid structures. For this topic, a silver paste was selected, and the printing conditions optimized for use in CIGS solar cells. An experimental layout was made based on analytical equations. The experimental results using this layout showed good agreement with the analytical model. Integration of bypass diodes was challenging with printed silver busbars, both shading and resistive losses were too high. Therefore, an alternative interconnection method using low temperature soldering of thin copper wires to the printed silver fingers was investigated.

The disadvantage of the current commercial bypass diodes is that they have a thickness of ~0.5 mm, which is almost as thick as a flexible PV laminate. Therefore, the feasibility of depositing alternative bypass diodes directly on the electroplated grids has been explored. This seems to be a promising technique to implement bypass diodes in future flexible PV modules.

3 CONCLUSIE

In this project we have shown that both screen printing and transfer of plated grids can be used to increase the cell width in monolithically interconnected PV panels. During the project the focus of the application of the electroplated grids has shifted towards flexible PV laminates as this is the direction the thin film PV market is moving towards.

As a direct result of the project the knowledge position of all partners has been increased.

A step in the commercialization of the plating and transfer technology developed within the project will be made at Innplate in a follow-up project granted by the MRE (Metropool Regio Eindhoven).

4 PUBLICATIES

Results from this project were shared in the following publication:

- Conference proceedings: B. Sesli, J. Carolus, J. D. Haen, D. Reenaers, V. Gevaerts, and S. Sente, "A study of Ag paste contacts on various TCO layers for $Cu(In,Ga)Se_2$ thin film modules," in 38th European Photovoltaic Solar Energy Conference and Exhibition, 2021, pp. 467–470.