Presented at the 29th European PV Solar Energy Conference and Exhibition, 22-26 September 2014, Amsterdam, The Netherlands

ROBUST MODULE INTEGRATION OF BACK CONTACT CELLS BY INTERCONNECTION ADAPTERS

M. Ebert[1], M. Seckel[2], L. Böttcher[2], M. Hendrichs[1], F.Clement[1], I.Dürr[1], D. Biro[1], U. Eitner[1], M. Schneider-Ramelow[2]
1 Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstraße 2, 79110 Freiburg, Germany
2 Fraunhofer Institute for Reliability and Microintegration IZM, Gustav-Meyer-Allee 25, 13555 Berlin, Germany

Matthieu Ebert | Phone: +49 (0)761 4588 5024 | e-mail: matthieu.ebert@ise.fraunhofer.de

ABSTRACT:
The large-scale production of highly efficient back-contact solar cells and their module integration is a promising route for the reduction of cost per watt peak of photovoltaic modules. Back-contact solar cells contain complex contact structures all located on the rear side posing new challenges for interconnection and encapsulation. The goals of our work are the development and demonstration of an interconnection adapter in cell size with an integrated circuitry to stabilize the fragile back contact solar cell and to enable a simple and robust subsequent cell-to-cell interconnection process. We demonstrate a first version of the adapter in form of a TPU (Thermoplastic polyurethane)-copper laminate. An electrically conductive adhesive is applied onto the cell rear side as a lead-free, flexible and gentle solder replacement to connect the cell metallization with the copper circuitry of the adapter. Moreover, interconnection losses vs. material consumption of the adapter are analyzed by electrical FEM simulations. We show a proof of concept with PV modules having cell-to-module losses in power below 1% proving the feasibility of the concept. Preliminary thermal cycling and damp heat test are passed with power loss of modules after degradation of less than 3.2%

Keywords: Back contact, Module Integration, Module Manufacturing

1. INTRODUCTION

The cost per watt of PV modules is reduced by the integration of high-efficient solar cells. Today, highest conversion efficiencies on crystalline silicon solar cells are achieved with back contact cell structures. Back-contact cells with efficiencies over 20 % are expected to gain increasing market share [1].
The main advantage lies in the reduced shading of the cell front side. In order to obtain low ohmic losses and thus high overall conversion efficiency, the rear side of present back contact solar cells such as the IBC cells contain a complex metallization pattern using more metallization than conventional solar cells [2]. To limit the lateral current flow at cell level, a large number of small contact points are an alternative to fully metallized back side. In such way the current is transferred to the interconnection components on module level over a shortened path. For the sake of cost reduction of the cell production process, it is desirable to simplify the metallization at cell level and transfer major parts into the module integration.

With our presented interconnection technology the backside metallization can be reduced for a BCBJ solar cell. However, these complex contact structures pose new challenges for the cell interconnection and encapsulation. CTE mismatch between the different materials used have to be overcome. Further, the general severe cost reduction pressure in the photovoltaic industry is limiting the deployable materials.

In this work we demonstrate a cost-efficient packaging technology transferred from microelectronics for the module integration of back-contact solar cells into easy-to-handle sub-assemblies. The method is based on the surface mounting process of the solar cell on an adapter containing copper circuitry and a thermoplastic polymer substrate. With the proposed adapter the fragile solar cell is interconnected and encapsulated partially prior to module integration. This adapter provides two contact leads at the edges for simplified interconnection during module production and is scalable in format.

2. MATERIALS AND METHODS

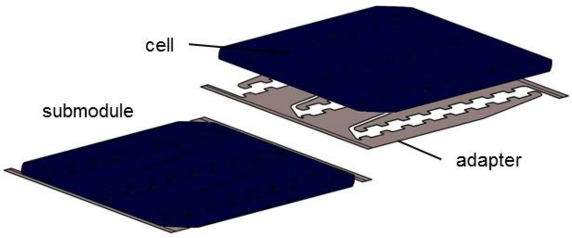

Figure 1: Module integration concept for back-contact solar cell. The cell is laminated on an interconnection adapter based on a polymer sheet and a copper circuitry.

2.1. Materials

For demonstration purpose, thermoplastic polyurethane (TPU) is used as a base material for the adapter for its elasticity and dielectric properties. The adapter's electric circuit is made of a 70 µm thick structured copper layer coated with immersion silver providing the electrical circuit for the mounting of the solar cell and two outgoing leads for further interconnection of the submodule.
The solar cell used to demonstrate the proof on concept is a mono-crystalline metal-wrap-through (MWT) solar cell [3] with an efficiency in the range of 17.7% to18.2%. Emitter and base contacts of the solar cell are located on the rear-side as oval (emitter) and round (base) pads which are connected with a silver-filled conductive epoxy to the Cu circuit on the TPU-adapter.

2.2. Design

The layout of the electric copper circuit has been optimized with respect to material consumption and resistive loss.

The aim is to maintain the CTA (Cell To Adapter) power-losses below 1 $\%_{rel}$ with minimal material consumption. We use the solderable interconnector for MWT cells from Fraunhofer ISE [4] as a benchmark mark as power loss limit. Different layouts are evaluated using finite-element-analysis (FEM). Fig. 2 shows the simulated electrical loss analysis of the preferred layout and fig. 3 shows the power loss versus the copper thickness for several simulated layouts.

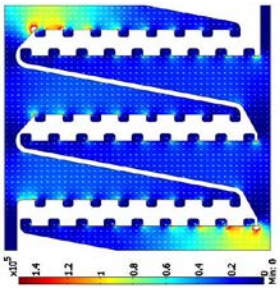

Figure 2: FEM analysis of the structured copper layer in 75µm thickness of the TPU-adapter: ohmic loss in W/m³

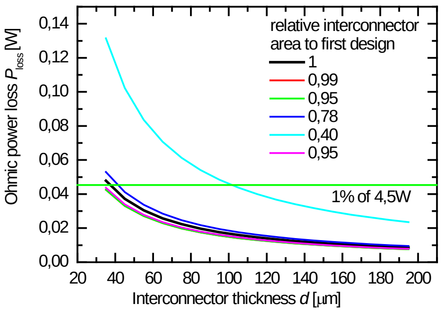

Figure 3: Simulated absolute power loss in watt for different circuit designs as a function of the copper thickness. The targeted power loss of $1\%_{rel}$ is indicated by the green line.

We found several designs meeting the required power loss limit of $1\%_{rel.}$ in power with a copper thickness around 40 microns at Standard Testing Conditions (STC). However PV modules only operate for a small fraction of time at STC irradiance levels in the field. Most of the time the PV modules generate less current and suffer less from resistive power losses. A thinner copper circuit thickness can be considered as a cost reducing option. In the electronics industry 35µm is a standard and cost effective copper foil thickness which could be used for the adapter.

2.3. Process

The electrically conductive epoxy (Heraeus PC3001) is first jetted on the contact pads of the back-contact solar cells with an Asymtek system. 7 mg epoxy per n-pad and 3 mg per p-pad is used.

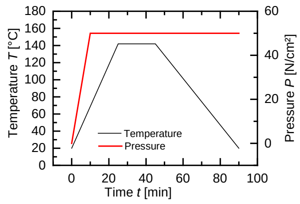

Figure 4: PCB Lamination Press used for submodule assembly Figure 5 Lamination Profile of temperature and pressure during submodule lamination

Mounting of the cell, interconnection and encapsulation into the submodule is done during one single process in a vacuum lamination press that is also used for printed circuit board manufacturing.

For the exact alignment of the cell and TPU-adapter, a set of fiducials hole pairs is used here allowing to use the high placement and alignment precision of electronic manufacturing processes. Pick and place precisions smaller 50 microns are standard in the electronics industry, necessary for the dense and complex rear contact structure of high efficiency solar cells. The use of well-established electronics industry processes is a key advantage of the proposed interconnection and assembly technology.

The standard PCB lamination and pressing process is modified in a way to enable the curing of the electrically conductive epoxy simultaneously to the melting and structural joining of the cell to the TPU-adapter. The cell and adapter are laminated at 140°C for 15 min under approximately 45N/cm².

The PCB press and process temperature/time ramp is shown in figure 4 and 5. The process is not optimized to typical series production cycle times of PV industry. Three generations of submodules where manufactured.

2.4. Module Integration

The sub-modules are soldered together at the copper circuit edge with a resulting cell distance of approximately 1.5 mm. The rest of the module manufacturing process is similar to a standard process. The strings of submodules are handled like conventional soldered strings, followed by the standard lamination process. We fabricate two eight-cell modules, one for demonstration purpose (module A), the other for reliability testing (module B).

Figure 6 shows a photograph and an electroluminescence image of module A.

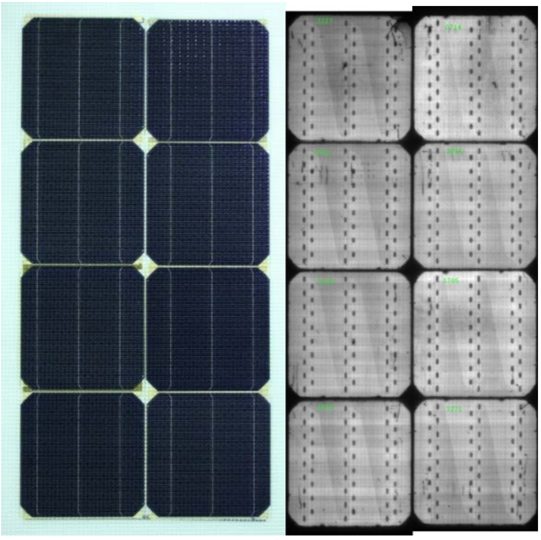

Figure 6: Photograph (left) and electroluminescence image(right) of module A

3. RESULTS

3.1. Minimization of the CTA-losses

The first generations (gen. 1 and gen. 2) of submodules suffer from high CTA-losses in the range of 6 to 8% relative in efficiency. The CTA of the different generations is shown in Figure 7. Photographic x-ray analysis (fig. 8 a)) of the submodules and microscopic cross sectional analysis (fig. 9) shows that the formation of voids and an incomplete coverage of the contact pads with conductive epoxy are the reasons for the poor electrical performance.

Improvements in the ECA application process and further optimization of the vacuum lamination press process yield uniform and void-free joints. Figure 8 b) shows fully covered contact pads and void free cured conductive adhesive joints. The CTA-results for efficiency of the submodules are depicted in Figure 7. After the optimization cycles ("gen 3") we achieve a efficiency CTA of 1.2%

The CTM-loss (from Cell To Module) of an eight-cell module and the corresponding individual eight submodules is presented in table I. The module integration process leads to a fill factor reduction of $0.48\%_{abs}$ and a corresponding efficiency loss from cell to module of $0.75\%_{abs}$ of the unmasked module at STC.

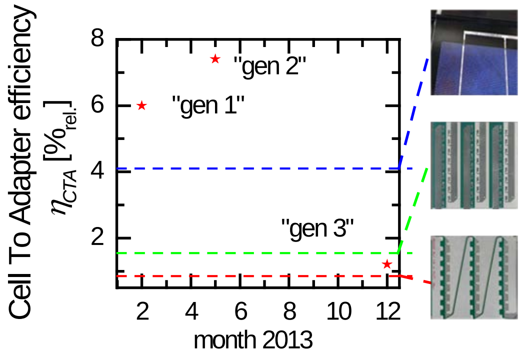

Figure 7: Evolution of the relative efficiency CTA-losses for the submodules generations 1-3. The red stars represent the achieved CTA efficiency on submodule level within the project. The continuous lines display the calculated CTA efficiency losses based on analytical and numerical calculations.

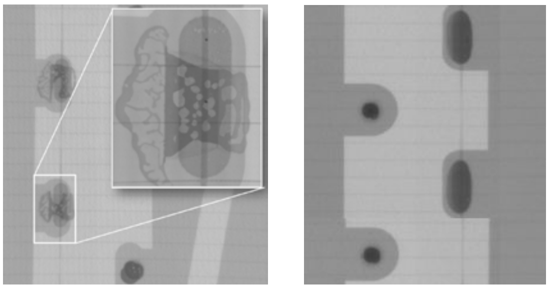

Figure 8 a) (left): Radiographic x-ray image of interconnection joints of a submodule of the first generation (gen 1) showing incomplete coverage of the contact pads with conductive adhesives and void formation. b) (right): showing optimized conductive adhesives joint without voids and with optimal coverage of contact pads.

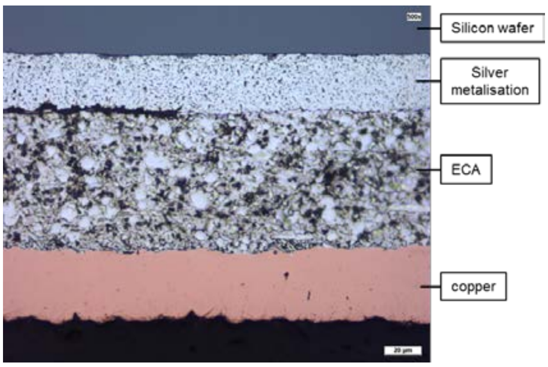

Figure 9: Cross section image of a TPU-adapter/conductive epoxy/cell contact (500x magnification) showing void

Table I: IV data of used submodules and Module A

	V_{oc} (V)$_{Sum}$	I_{sc} (A)$_{Min}$	V_{mpp} (V)$_{Sum}$	I_{mpp} (A)$_{Min}$	P_{mpp} (W)$_{Sum}$	FF (%)$_{AVG}$	η (%)$_{AVG}$
Individual 8 submodules measured against air	5,03	9,02	4,03	8,39	34,15	74,52	17,86
Module A*	5,03	9,11	4,02	8,44	33,96	74,04	17,11
Difference *relative*	0,0%	0,9%	-0,2%	0,6%	-0,6%	-0,6%	-4,2%

*Eta: efficiency related to cell area + 0.75 mm margin without mask module IV data at STC, measured by ISE CalLab PV Modules

3.2. Reliability testing

Module A is exposed to a thermal cycling (TC) and subsequently damp heat (DH) testing sequence according to IEC 61215. After each test the IV curve at STC is measured at the Fraunhofer ISE CalLab PV Modules. The change of the IV characteristics after each test is shown in Figure 10.

After the two testing sequences (TC + DH) the relative power loss is 3.1%. This power loss can be attributed to a reduction in transparency of the front cover leading to a short circuit current reduction of 3.4%. The stable fill factor (relative difference > 0) shows that the interconnection does not suffer from the thermo mechanical load or potential water vapor ingress into the module. We assume the positive fill factor difference to be due to the decrease in current and thus reduced serial losses.

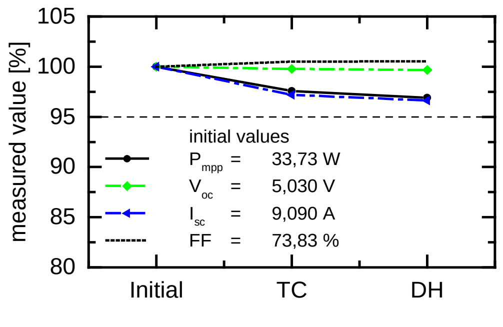

Figure 10: IV characteristics of module B before after reliability testing sequences

4. CONCLUSIONS

The transfer of established microelectronic packaging technology is an innovative approach for PV module integration to obtain easy-to-handle module assemblies with low electrical losses. It is a robust and reliable process which can be used for highly efficient back-contact solar cells with complex contact structures and is therefore considered an enabling technology for a wider introduction of back-contact solar cells into PV market.

We present such an interconnector adapter in the form of a TPU-copper laminate which is connected to the MWT cells rear side by an electrically conductive adhesive. These materials offer advantages over traditional PV module materials as they are lead-free and flexible. Moreover, the concept facilitates the module manufacturing as the cells only need to be contacted at the edges from submodule to submodule. The concept is transferable to other back contact cell structures.
After 3 development cycles we achieve a Cell to Adapter loss in efficiency of 1.2%$_{rel.}$
We demonstrate the successful fabrication of eight-cell PV modules using the adapter concept. The achieved Cell to module losses in power are of 0.6%$_{rel}$. fulfilling our goal of a maximum tolerable power loss of 1%rel.
A second module is exposed first to a thermal cycling test and subsequently to a damp heat test, both according to IEC 61215. The relative module power loss after testing is of 3.1%

REFERENCES

[1] SEMI EUROPE, 2014 “International Technology Roadmap for Photovoltaic (ITRPV)”, 2013 Results Revision 1, 24 March 2014
[2] R.Woehl et al. 2011, “20% efficient screen-printed and aluminum-alloyed back-contact back-junction cells and interconnection schemeof point-shaped metalized cells”, Proc 37th IEEE PVSEC, Seattle, 2011
[3] Van Kerschaver, E. et al. 1998, “A novel silicon solar cell structure with both external polarity contacts on the back surface”, Proc. 2nd WCPEC, Vienna, Austria, pp. 1479–1482.
[4] Eitner, U. et al. 2012, “Interconnector based module technology for thin MWT cells”, Proc. 27th EU PVSEC, Frankfurt, Germany.
[5] Schmidt, J. et al. 2001, “Impact of light-induced recombination centres on the current-voltage characteristic of Czochralski silicon solar cells”, Prog. Photovolt.: Res. Appl., Vol. 9, No. 4, pp. 249–255.
[6] Foerster, Philipp, et al. NCA flip-chip bonding with thermoplastic elastomer adhesives-Fundamental failure mechanisms and opportunities of polyurethane bonded NCA-interconnects. In: Electronics Packaging Technology Conference (EPTC), 2011 IEEE 13th. IEEE, 2011. S. 223-230