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Low cost semi automated assembly unit for small size back contact modules and low cost interconnection approach

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Abstract

We present our low cost assembly unit to manufacture back contact solar modules based on the conductive backsheet (CBS) approach. This in house developed apparatus was built to assemble test modules containing one up to four 6 inch back contact solar cells. The system is a retrofit of a commercially available CNC system which is equipped with a cell grabber and a manual dispensing system (by Nordson). The total cost of the setup was roughly 4000 € excluding the dispenser unit. Using this equipment we assembled several small size modules containing one and four Zebra cells, which are low cost 6 inch IBC solar cells developed at ISC Konstanz [1, 2]. The contact between copper backsheet and back contact cell of the one cell modules we present here is formed by low temperature solder paste (LTSP). First cell to module (CTM) loss evaluations and reliability results suggest that this material could be a viable alternative to electrically conductive adhesive (ECA) which is currently the most commonly used material for this purpose.

Peer-review under responsibility of the organizing committee of the Metallization Workshop 2016

Keywords: back contact module assembly unit; low temperature solder paste; conductive backsheet module

1. Introduction

Low cost back contact cells and modules gain more and more relevance for industrial production [3, 4, 5]. The module integration of back contact cells is still challenging; the conductive backsheet approach [6] is the most prominent solution apart of classical stringing. Module assembly with conductive backsheets is mostly realized using

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specialized production equipment. We developed a low cost solution to assemble prototype back contact modules. As means for cell contacting LTSP is evaluated since it is easy to handle and has the potential to be a cheap substitute for ECA in future back contact module applications.

Nomenclature

CAM	computer-aided manufacturing
CBS	conductive backsheet
ECA	electrical conductive adhesive
LTSP	low temperature solder paste
CTM	cell to module
CNC	computerized numerical control

2. Assembly unit

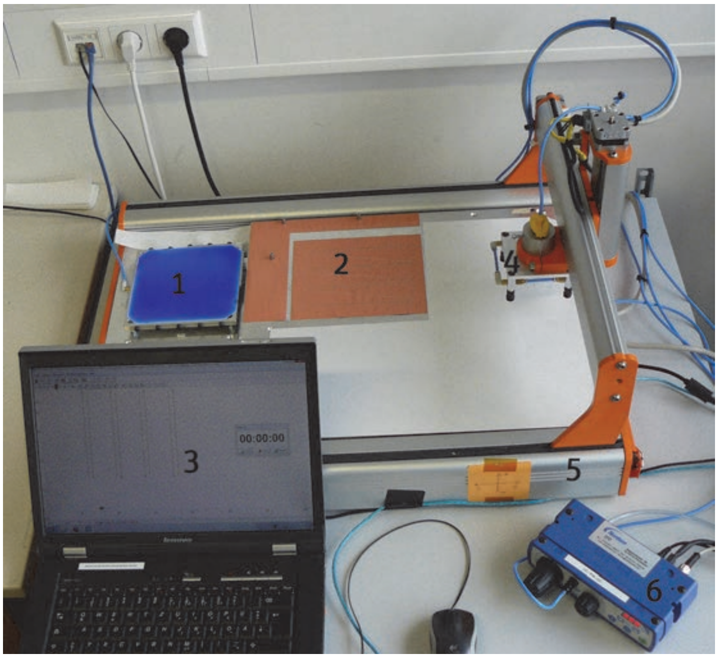

Figure 1: photo of the assembly unit; 1: Zebra cell on small vacuum chuck; 2: CBS for one-cell-module on big vacuum chuck; 3: Control Software; 4: Tool (dispenser or cell grabber); 5: CNC-System; 6: Dispensing unit

Our assembly (shown in Figure 1) was redesigned from a commercially available CNC-System from Stepcraft. Instead of the milling tool we attached a cell grabber and a manual dispensing system from Nordson to the machine head. It is fit to execute different process sequences to fabricate modules utilizing CBS of different architecture and suppliers. The cost for the whole setup was 4000 € exclusive the dispensing unit. We replaced the mounting plate of the original device by a custom made Al plate housing two vacuum chucks. A small chuck to place a solar cell where it can be picked up by the cell grabber and a large chuck that holds a CBS in place during the assembly process. Both vacuum chucks are designed to facilitate precise alignment of the cell or the CBS on referenced initial positions. Cell alignment is realized with limit stops on the small chuck; the CBS is aligned with pins on the big chuck. The top plate of the big chuck is removable and also aligns on the same pins as the CBS which are bolted on the machines table. In that way the top plate can be easily lifted off with the readily assembled module in order to flip it prior to lamination. This is necessary since module lamination is generally done with glass facing down. A triaxial system can move a tool mounted on the machine head precisely within an operating range of 400 x 600 x 100 mm. Typically the machine head carries a milling tool. Instead, we installed a permanently mounted grabber tool which is equipped with 4 vacuum cups and an adapter that holds a removable syringe for dispensing. The grabber is needed to pick and place solar cells. The syringe is required to dispense ECA or similar conductive materials like LTSP on the CBS as a means for cell contacting. The repetitive positioning accuracy of the machine itself for cell placement and dispensing is ±50µm. We cannot reach this accuracy so far because we manually punch holes into the CBS on marked positions for alignment. In the near future it will be possible to punch those holes automatically which will lead to an accuracy that is closer to the machine's limit. The assembly unit is controlled with a software which works on general g-code programs. Using an open source CAM software any 2D CAD layout can be transformed into a g-code program. In this way we are able to design an individual routine for any arbitrary dispensing pattern. A dedicated software controls tool movements and sends signals to external devices e.g. to switch the magnetic valves of the vacuum chucks and the vacuum exhauster or the dispensing unit. The software also allows setting the amount of adhesive dispensed by controlling the duration of dispensing for points or the speed while dispensing lines. Additionally, the adhesive laydown can be influenced by setting the dispensing pressure or by choosing different needle diameters.

3. Module process

This section describes an assembly process with LTSP and a CBS (contacfoil by Eppstein Technologies) which consists of a structured copper layer and a dielectric layer for electrical isolation between copper and cells. The isolation layer is locally opened to facilitate the cell-backsheet contact. First, a g-code program is created which controls the dispensing process and another which controls the pick and place process. Next, the CBS is placed manually on the big vacuum chuck using the alignment pins and fixed by opening a manual vacuum valve. A syringe containing LTSP is mounted to the machine head and connected to the dispenser unit where the dispensing pressure is set manually. The dispensing routine is loaded into the CNC software. By running the routine with a closed dispenser valve the positioning of the dispenser needle in respect to the CBS is controlled and if needed adjusted in x-, y- and z-direction via the CNC control software. Next, the dispenser valve is opened, the routine is started again and the LTSP is applied onto the CBS as shown in Figure 2.

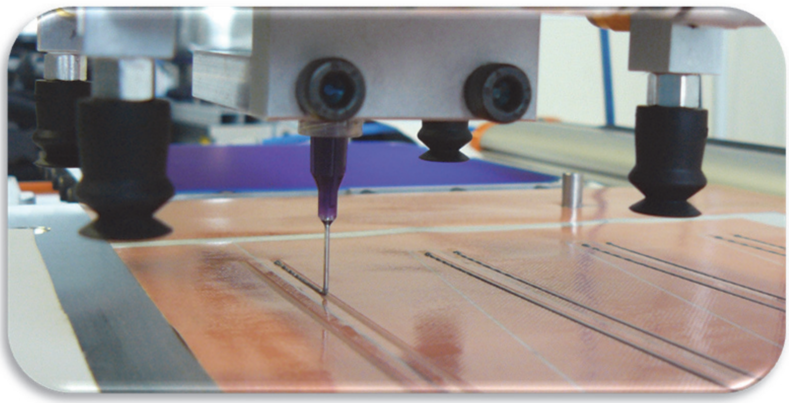

Figure 2: dispensing of conductive material onto conductive backsheet

After dispensing the LTSP on the locally opened areas on the CBS the syringe is dismounted from the machine head and the back contact solar cell is placed on the small chuck. Here, the cell is fixed on its referenced initial position and the vacuum is switched on. Now, the cell placing routine is loaded and the cell machine grabs the cell exactly on this position and places it precisely on the CBS (Figure 3).

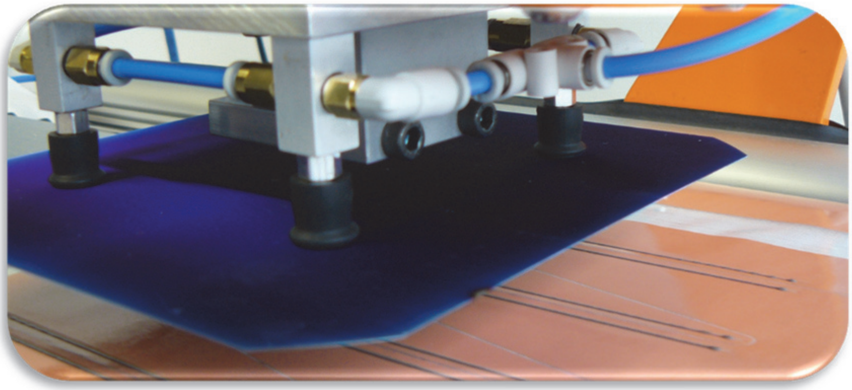

Figure 3: placing a cell on CBS

Before the module sandwich is ready for lamination, few final steps are performed manually. The front encapsulation layer and the glass are placed onto the cell with the vacuum of the chuck still running. Then, the vacuum valve is closed and the semi-finished module is removed with the top plate of the big chuck. Now, top plate and semi-finished module are flipped and the rear side of the module sandwich – encapsulation and backsheet – are placed. Finally, the module is ready for lamination.

4. Results on modules assembled with LTSP

We set up and run our assembly unit at ISC Konstanz and successfully built first modules with conductive backsheet containing 1 and 4 Zebra IBC cells. After validating the function of our assembly unit and confirming that we can generate repeatable module results we tested LTSP as alternative material to ECA for establishing the contact between solar cell and conductive backsheet. LTSP is widely employed in electronic industry to solder connect metal components. Its melting point depends on the composition of the solder alloy and starts as low as 96°C. Special formulations suited for the temperature range reached during module lamination are commercially available. LTSP is screen printable or dispensable and it promises cost savings up to a factor of 10 compared to ECA. This is an estimated value only since we could not get real quotations for realistic volume purchases for both products. The absence of a polymeric compound in the LTSP compared to ECA gives rise to some advantages and a drawback compared to ECA. On the one hand it can be stored at higher temperatures compared to ready to use ECA (in our case 5°C vs. -40°C) and promises a low series resistance interconnection due to a full metal joint, on the other hand the missing rigidity provided by the polymer matrix and the formation of unwanted intermetallic compounds over time could lead to lower mechanical stability of the bond.

4.1. Cell to module losses

Using the before described methods and materials we assembled one cell modules with commercially available copper backsheet (contacfoil connect by Eppstein Technologies) and LTSP. The solder we applied here is composed of Bi, Sn, Ag and solvents while 80% are solid metal content. Figure 4 shows the cell to module power and fill factor losses for three different groups. Two were assembled with LTSP and one with ECA as a reference. Different lamination conditions and thus curing conditions were applied. Comparing the median relative power drop for modules laminated with recipe 2 (4 modules) and recipe 1 (6 modules) we find a 1.2 % better result for recipe 1 modules which originates from a lower series resistance contact as can be concluded by the 2 % lower fill factor loss. The median FF drop for the modules assembled with LTSP and laminated with recipe 1 is comparable to the one of the ECA modules and recipe 3 (2 modules). The spread though in fill factor drop is higher which leaves room for process optimization but also promises achieving a relative fill factor drop of 0.3 % relatively only.

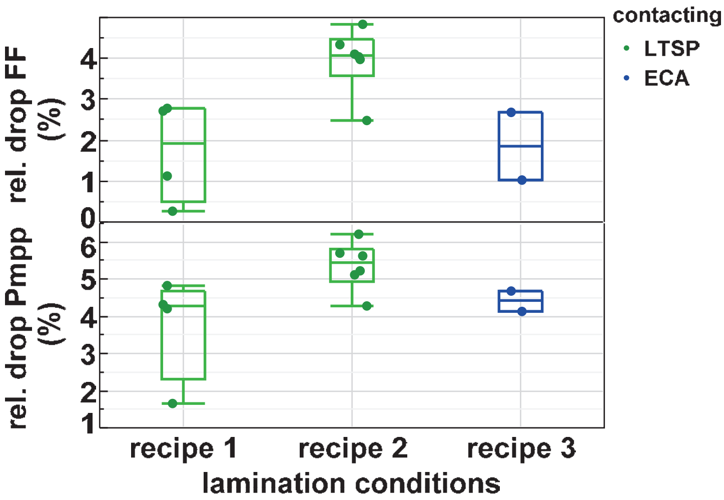

Figure 4: relative CTM power and FF drop for minimodules assembled with LTSP (green) and ECA (blue) for different lamination condition

4.2. Reliability tests

Low CTM losses are desirable to reach high module power output but reliability issues are very important to address since module vendors have to guarantee stable performance in the field for 25 years or longer. In order to assess the durability of modules assembled using LTSP against environmental influences we performed extended climate chamber tests, namely 400 cycles of thermal cycling (TC) test and 20 cycles of humidity-freeze test (HF).

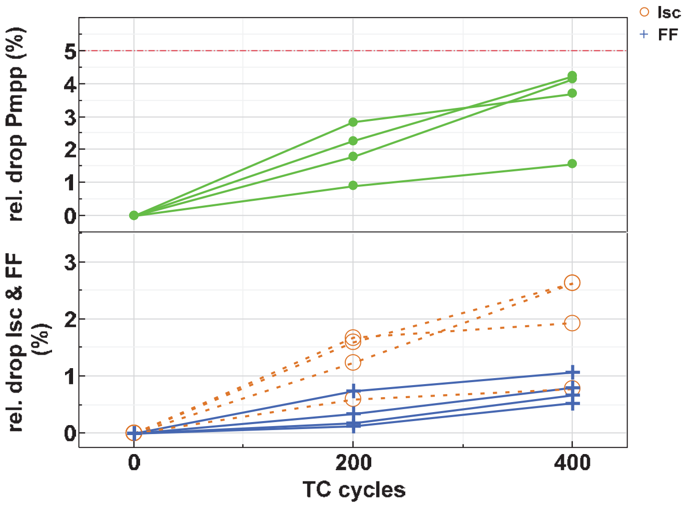

Figure 5 : relative drop of power, ISC and FF versus TC cycles for minimodules assembled with LTSP; the red bar in the power graph shows the IEC restriction of <5% relative power drop after TC200

Thermal cycling tests in a climate chamber are a fast way to probe robustness of a module against thermal expansions and contractions. At ISC Konstanz we perform these tests in a climate chamber (supplier: Voetsch) varying the temperature between +85°C and -40°C without current injection above 25°C. We tested 4 mini-modules by subjecting them to 200 thermal cycles, then removed the modules from the chamber to probe IV characteristics; the results are marked as TC200 in Figure 5. Subsequently we placed the mini-modules again in the climate chamber and run an additional 200 thermal cycles; results are labeled with TC400. Figure 5 reveals that even after TC 400 the power degradation of the modules is lower than the IEC restriction of <5% relative loss after TC200. The bottom part of Figure 5 shows that the main reason for the power drop is a drop of module short circuit current. The current drop is owed to a degradation of the anti reflective coating (ARC) of the module glass similar to the one depicted in Figure 6. The fill factor losses though stay between 0.5 and 1.1% relative indicating the mechanical stability of the electrical contact.

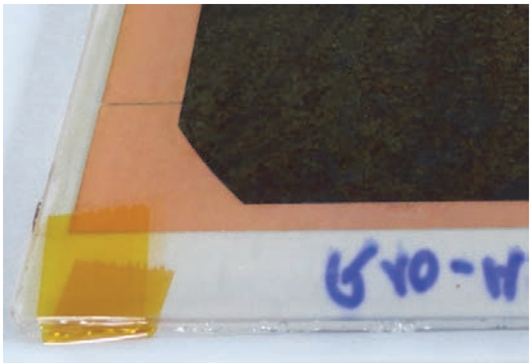

Figure 6: photo of a mini-module after HF 20 test revealing a deterioration of the ARC coating on the glass

During humidity-freeze testing in a climate chamber modules are subjected to temperature cycling between -40° and 85°C while relative humidity is at 85% for temperatures above 25°C. One cycle lasts 24 hours with approximately 4 hours at -40°C. The purpose of this test is to determine the ability of the module to withstand moisture ingress specifically if this moisture is brought to freezing temperatures. We tested five modules assembled using LTSP in our climate chamber with HF 10 and subsequent HF 20. Figure 7 depicts the relative change of power output, short circuit current and fill factor versus the HF cycles. The dashed red line in the power graph marks the 5% relative degradation limit permitted by IEC. After HF 10, all modules stay within the 5% limit, after HF 20 though all modules show a higher power drop. The origin of the power drop is divided in two parts as can be seen in the second half of the graph. While the fill factor drop ranges from 1.8 to 3.5% relative, the short circuit current drops between 4.2 and 5.7% relative, which is the biggest influence on the power drop and not expected. As for the TC tests, this drop does not relate to a deterioration of the electrical contact but is attributed to a degradation of the anti reflective coating (ARC) of the module glass which was observed by eye but not quantified yet (see Figure 6).

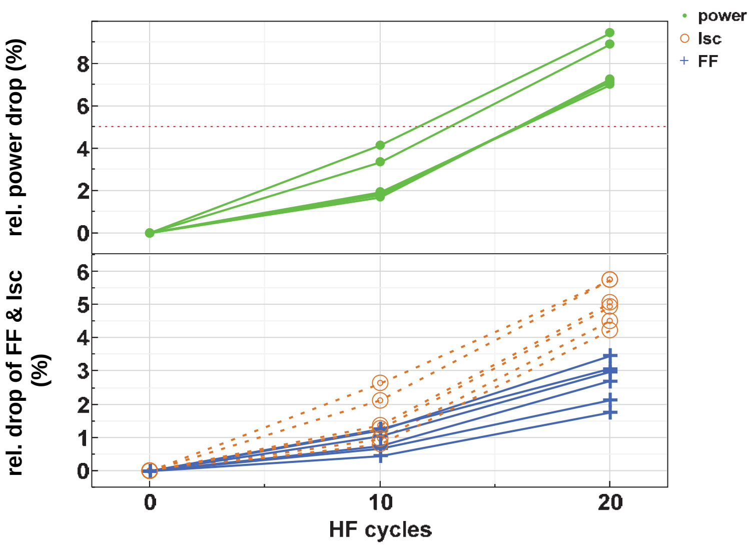

Figure 7: relative drop of power, ISC and FF versus HF cycles for minimodules assembled with LTSP; the red bar in the power graph shows the IEC restriction of <5% relative power drop after HF 10

5. Summary

In this work we present our in-house developed, low cost semi-automated assembly unit for back contact modules with up to four 6 inch back contact solar cells based on the CBS approach. These small size R&D modules are suitable for various tests to characterize module performance and reliability as well as for the evaluation of different consumables for module assembly or module process variations.

After validation of the module process we assembled mini-modules with LTSP as alternative to ECA for cell contacting. The modules revealed low CTM fill factor losses (2% relative in average) which are in the same range as for sister modules contacted with ECA. Reliability tests in the climate chamber (TC 400 and HF 20) reveal sufficient durability against mechanical stress and moisture ingress for the LTSP modules. An observed deterioration of the module glass ARC coating after climate chamber tests though biases the results negatively. Further studies and longer test periods should be performed to confirm our findings.

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