

CONDUCTIVE ADHESIVES FOR LOW-STRESS INTERCONNECTION OF THIN BACK-CONTACT SOLAR CELLS

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ABSTRACT: Thin crystalline silicon solar cells interconnected with standard soldering techniques warp and have a high change of breaking. Therefore, thin cells should be interconnected with conductive adhesives: warping can be avoided and 80 μ m thin cells do not break during and after interconnection unlike soldered cells. Damp/heat tests and temperature cycling show no degradation. Tested mini modules made with soldered back contacts and glued front contacts show excellent performance even after over 900 cycles. Contact resistances measured on glued interconnections are similar to soldered contacts. I-V measurements of interconnected thin back-contact cells in mini modules show no loss in fill factor. Interconnection with conductive adhesives is a promising technique combining excellent mechanical properties, good conductivity, durability, and low process temperatures thus reducing stress.

1 INTRODUCTION

Thin solar cells are difficult to interconnect with standard soldering techniques. High temperature during soldering introduces stress on the joints and cells. This can cause warping and possible breakage of cells. Substituting soldering for a low temperature joining technique would avoid building up of mechanical stress, thus increasing process yield and reliability.

A promising alternative technique is interconnection with conductive adhesives. The process temperature is much lower, depending on the applied adhesive. These adhesives combine excellent mechanical properties with good electrical conductivity. Adhesives have already proven long-term stability in many industrial applications, and introduction in PV can be very beneficial for the industry. Of course, conductive adhesives should prove reliable in outdoor use for extended periods of time.

Traditional two-sided contact cells suffer from extra stress caused by the tabs going from front to rear in series interconnection. Also, extra shadow losses occur due to front surface covering. Back contact cells do not have these disadvantages and allow a simple interconnection through a prefabricated metal pattern on a glass substrate or a backside foil.

In this paper, the combination of rear-contacted solar cells interconnected with conductive adhesives is studied. We will compare stress on thin cells and joints between traditional soldering and conductive adhesives. Thermo-mechanical stress calculations will show the advantages of conductive adhesives. An overview of conductive adhesives systems will be presented with pros and cons for the use in PV modules. First results of stability tests performed with conductive adhesives are presented. The ideal low-stress process for interconnection of ultra-thin solar cells with the use of conductive adhesives will be introduced. Application for rear-contact cell designs will be presented.

2 CONDUCTIVE ADHESIVE SYSTEMS

A wide variety of conductive adhesive systems for electronic packaging exists. They can be based on thermosetting or thermoplastic polymers and are filled with flakes of silver, gold or other, less noble metals [1]. Adhesive systems are available as a tape or as a one- or two-component paste that can be dispensed or screen-printed. Conductive adhesives suited for contacting solar cells are generally silver-loaded epoxy resins. Silver has the advantage of being unaffected by oxidation and not too expensive. Epoxies are easy to adjust, resistant to humidity, and without hazardous out-gassing. Silver particles usually vary in size from several μ m to several tens of μ m. Particles are forced together by the epoxy matrix in which they are suspended. Electrical conductance is through side-to-side contact of the particles (see Fig. 1).

Solar cells generate high currents, requiring low resistances. Long-term stability in outdoor conditions requires excellent mechanical properties. High volume production demands screen printable adhesives.

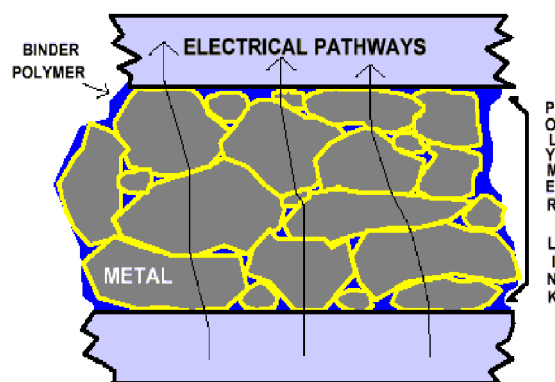


Figure 1a: A symbolic representation of the Conducting mechanism of conductive epoxy adhesives.



Figure 1b: Microscopic picture showing silver plated copper tab glued on silver plated silicon solar cell (upper right to lower left). The silver particles in the adhesive are clearly distinguishable in the picture.

3 IDEAL LOW STRESS INTERCONNECTION FOR THIN BACK-CONTACT CELLS

In the design of a module for ultra-thin cells, stress is the determining parameter. Stress can be reduced by equalizing the thermal expansion coefficients of the materials or by reducing the temperature range applied to the module. The only temperature that can be influenced is the processing temperature. In this respect soldering is poorly suited due to process temperatures of 250- 400°C. During lamination, the process temperature is 150°C. Some of the available adhesives can be cured at this temperature, which makes co-processing of lamination and interconnection possible. New lamination materials are available that can be processed at even lower temperatures like 80°C. Examples are polyurethane and new EVAs. Co-processing these materials with a conductive adhesive that cures at the same temperature introduces as little mechanical stress as possible in the joints and cells.

A possible process sequence for co-processing a module with conductive adhesives is:

1. Make interconnection pattern on a full cover substrate, which can either be a laminate of a metal foil and a polyester foil or screen-printed metal strips directly on glass.
2. Apply conductive adhesive on back contact solar cell. Apply non-conductive adhesive on substrate to prevent air-filled voids in the module and to give added strength to the mechanical bond between cell and interconnection substrate.
3. Place cells on substrate.
4. Laminate module and cure adhesive in a single step process.

4 MODELLING AND EXPERIMENTS ON STRESS

To show the reduction of stress on cells and connecting joints, thermo-mechanical stress has been calculated with Finite Element Methods (FEM). The following parameters were chosen: wafer thickness of 360µm, copper tabs of 100µm thick, and an adhesive epoxy layer thickness of 50µm. Other important input parameters were moduli of elasticity and thermal expansion coefficients. A uniform 'process' temperature of 80°C

and 150°C for glueing, and 250°C and 400°C for soldering has been selected. For glueing, full surface adhesion with a copper foil of 50µm thickness and local glueing with a tab has been modeled. Results of full surface glueing are presented in figure 2, and glueing with a tab has been displayed in figure 3.

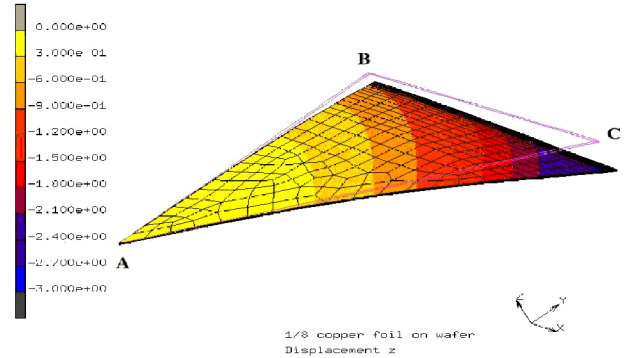


Figure 2: FEM model calculation of the deformation of a cell glued to a full area substrate as a result of build-up of mechanical stress caused by differences in thermal expansion coefficients. A curing temperature step of 80°C has been used in this calculation.

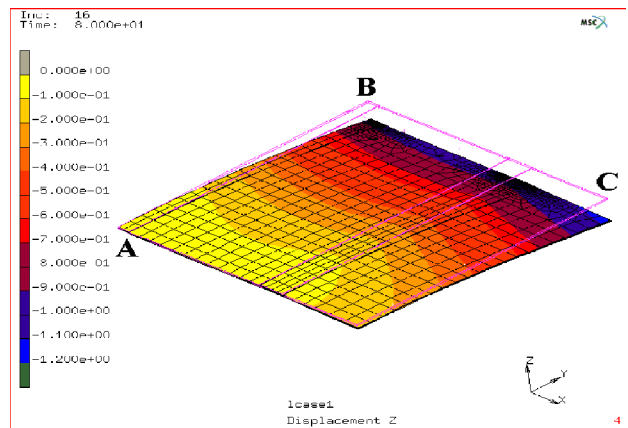


Figure 3: Deformation in mm of a wafer due to stress resulting from a tab glued on and cured at 80°C.

These calculations show a much larger deformation for full surface adhesion. Calculations for soldering have not been performed yet. The model will have to be refined further to be able to compare the calculated deformation with experiments, especially for soldering where non-uniform heating of wafer and tab has large effects on build-up of stress.

Experiments have been done on slices of standard wafers with 2mm wide tabs of different thicknesses soldered at 400°C. As a wafer support either a hotplate of 160°C or a surface at room temperature has been used. In comparison the same tabs have been glued with conductive adhesives cured at either 160°C or 80°C (see Figure 4 and Figure 5).

For standard wafer thickness, wafer bow is much larger for the soldered samples. At 80°C, all wafer bending is avoided. For ultra-thin cells, soldering leads to wafer breakage, even for the very controlled soldering with a thermode. Hardly any wafer bowing is apparent when these ultra-thin cells are glued to the tab material at 80°C.



Figure 4: Bending due to stress of 300µm thick silicon strips with 2mm wide tabs. From back to front: soldering at 400°C on cold surface, soldering on 160°C hotplate, conductive adhesive cured at 160°C, conductive adhesive cured at 80°C.

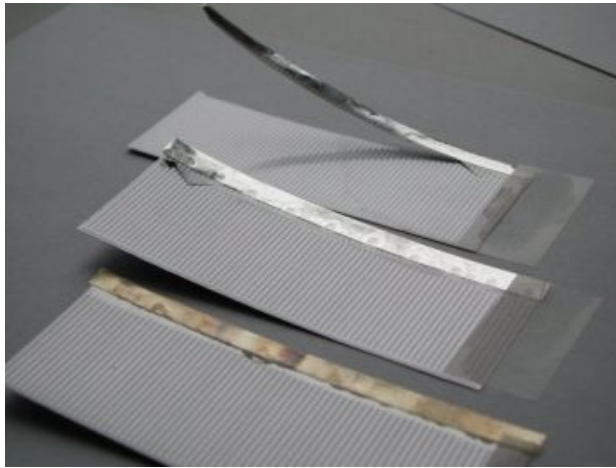


Figure 5: Stress on 80µm thin Ebara IBC cells interconnected to 70µm thick copper tabs. From back to front: soldering with iron, soldering with thermode, glued at 80°C.

5 EXPERIMENTAL RESULTS OF CELLS INTERCONNECTED WITH CONDUCTIVE ADHESIVES

Contacts made on silver plated substrates with silver plated tabs show excellent electrical properties. Contact resistances are in the mΩ range like soldered contacts. Samples have been damp/heat tested along with soldered references. After 2500 hours at 85°C/85% humidity, no degradation occurred (see Fig. 6). Also temperature cycling, between -40°C/+80°C, on the same samples has shown no effects after 200 cycles. No differences are measured between samples that have been encapsulated between glass, EVA and Al/Tedlar foil and plain samples without encapsulation.

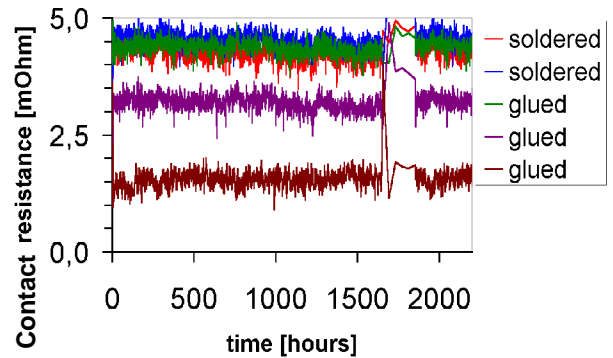


Figure 6: Measured resistance of samples with a 1cm² contact area in 85°C/85% humidity damp/heat test.

Cycle tests done on single, traditional cell laminates with soldered back contacts and glued front contacts show excellent performance after over 900 cycles. The IEC 61215 qualification test allows a 5% power decrease after 200 cycles (see Fig. 7) [3].

Adhesives applied to plain copper tabs or applied to screen-printed and fired aluminum BSF give low resistances directly after curing, but show rapid degradation after ageing tests due to oxidation and breaking of the adhesive-to-metal bond. Porous screen-printed aluminum also soaks up the adhesive component from the paste giving poor bonding. Tests are being done with special surface treatment to stop the soaking up of the adhesive and to prevent oxidation after curing.

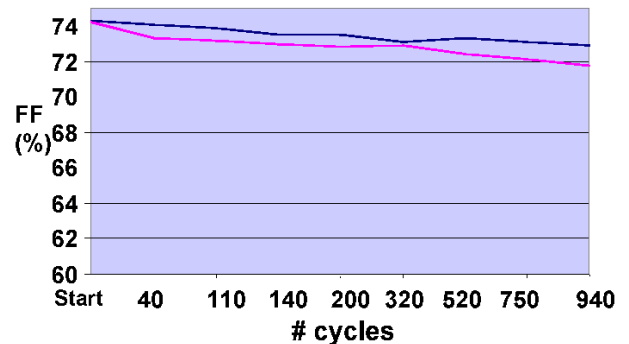


Figure 7: Fill factor of single cell laminates after temperature cycling -40°C/+80°C [3]

Several mini modules have been made to demonstrate the different interconnection schemes for some different back contact cell concepts. Figure 8 shows an example of a 9-cell busbarless EWT module [4]. I-V measurements of plain cells compared to interconnected cells in mini modules show no loss in fill factor.



Figure 8: Busbarless EWT mini module. Active cell area is increased due to omission of the busbars compared to standard EWT cells. Current collection function of the busbars is taken over by rear-side interconnection foil.

8 REFERENCES

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6 CONCLUSIONS

Experiments with soldering show strong bending of soldered samples. For ultra-thin wafers, soldering is not suited at all due to wafer breaking. On the other hand, glued samples show little bending, or bending can be completely avoided for 80°C curing, even for ultra-thin cells of 80 μm thickness. Interconnection with conductive adhesives gives little stress and causes no cell breakage.

Extensive climate testing of interconnections made with conductive adhesives proves them to be reliable. Damp/heat tests have been successfully conducted for 2000 hours and thermal cycling shows degradation within the limits of the appropriate IEC norm, even after 1000 cycles.

For back-contact cells, an interconnection scheme with conductive adhesives and integrated curing of encapsulants and adhesives is a simple and efficient approach.

7 ACKNOWLEDGEMENT

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