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ABSTRACT

Thin crystalline silicon solar cells cannot be interconnected with standard soldering techniques because of warping and breakage. Interconnection with conductive adhesives showed excellent behavior: warping can be avoided and 80µm thin cells do not break during and after interconnection. Contact resistances measured on glued interconnections are similar to soldered contacts. Damp/heat tests show no degradation after 2500 hours at 85°C/85% humidity. Temperature cycling –40/+80°C has shown no effects after 200 cycles. I-V measurements of interconnected thin back-contact cells in mini modules show no loss in fill factor. Test mini modules made with soldered back contacts and glued front contacts show excellent performance even after over 900 cycles. Interconnection with conductive adhesives is a promising technique combining excellent mechanical properties, good conductivity, durability, and low process temperatures thus reducing stress.

INTRODUCTION

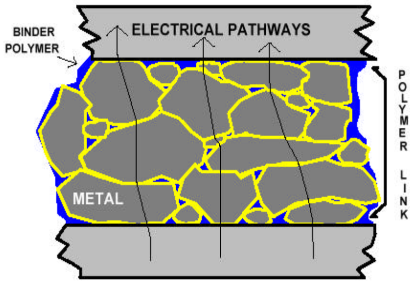
Thin solar cells are difficult to interconnect with standard soldering techniques. High temperature during soldering, between 250-400°C, introduces stress on the joints and cells. This can cause warping and possible breakage of cells and decreases yield. Traditional front side contacted cells suffer from extra stress caused by the tabs going from front to rear in series interconnection. Also, extra shadow losses occur due to front area 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. 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.

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

CONDUCTIVE ADHESIVE SYSTEMS

A wide variety of conductive adhesive systems for electronic packaging exists. They can be based on thermosetting or thermoplastic polymers and 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 to expensive. Epoxies are easy to tune, resistant to humidity, and without hazardous out-gassing. Silver particles usually vary in size from several µm to several tens of µm. 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.



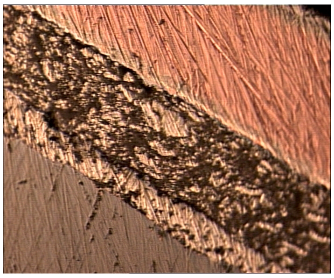


Fig. 1a: A symbolic representation of the conducting mechanism of conductive epoxy adhesives.
Fig. 1b: Microscopic picture showing silver plated copper tab glued on silver plated silicon solar cell (upper right to lower left). The silver particles in the adhesive are clearly distinguishable in the picture.

IDEAL LOW STRESS INTERCONNECTION FOR THIN BACK-CONTACTED CELLS

In the design of a module for ultra-thin cells, stress is the determining parameter. Stress can be reduced by adjusting 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 scores low, 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 based on for example polyurethane and new EVAs are available and they can be processed at even lower temperatures like 80°C. Combined with a conductive adhesive that cures at the same temperature, a process will be available that introduces as little mechanical stress as possible in the joints and cells.

A possible process sequence is:

- Make interconnection pattern on a full cover substrate, either a laminate of a metal foil and a polyester foil or screen-printed metal strips directly on glass.
- 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.
- Place cell on substrate, laminate module and cure adhesive in a single step process.

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 360ìm, 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 gluing, and 250°C and 400°C for soldering has been selected. For gluing, full surface adhesion with a copper foil of 50µm thickness and local gluing with a tab has been modeled. Results of full surface gluing are presented in figure 2, and gluing with a tab has been displayed in figure 3.

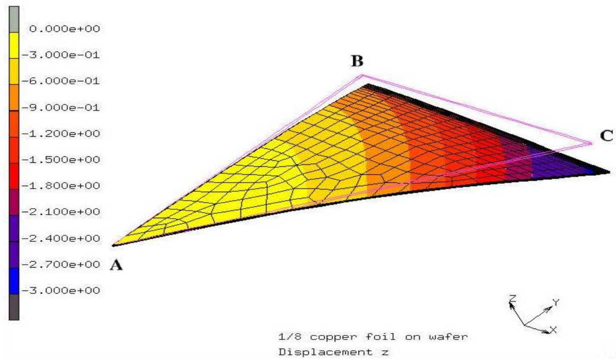


Fig. 2: FEM model calculation of the deformation of a cell glued to a full area substrate as a result of build-up of mechanical stress caused by differences in thermal expansion coefficients. A curing temperature step of 80°C has been used in this calculation.

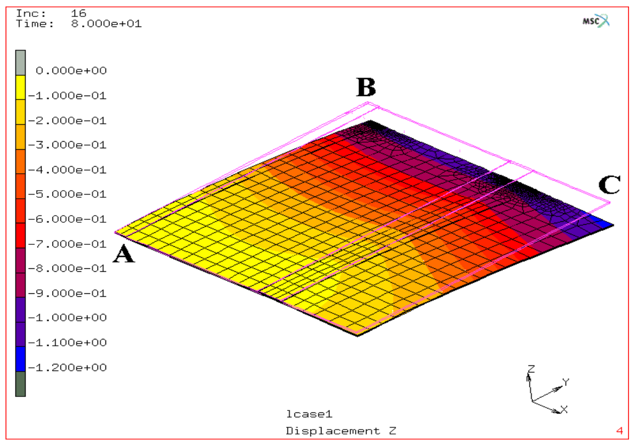


Fig. 3: Deformation in mm of a wafer due to stress resulting from a tab glued on and cured at 80°C.

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 Fig. 4 and Fig. 5).

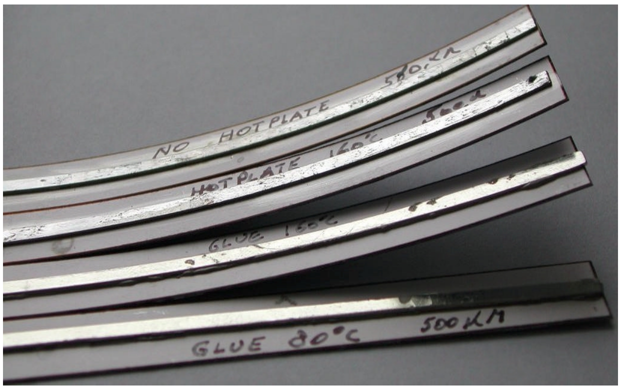


Fig. 4: Bending due to stress of 300µm thick silicon strips with 2mm wide tabs. From back to front: soldering at 400°C on cold surface, soldering on 160°C hotplate, conductive adhesive cured at 160°C, conductive adhesive cured at 80°C.

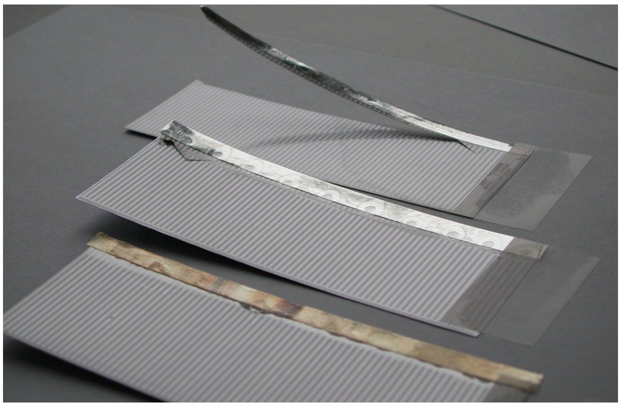


Fig. 5: Stress on 80µm thin Ebara IBC cells interconnected to 70µm thick copper tabs. From back to front: soldering with iron, soldering with thermode, glued at 80°C.

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 breaking, even for the very controlled soldering with thermode. Hardly any wafer bowing is apparent when these ultra-thin cells are glued to the tab material at 80°C.

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 –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.

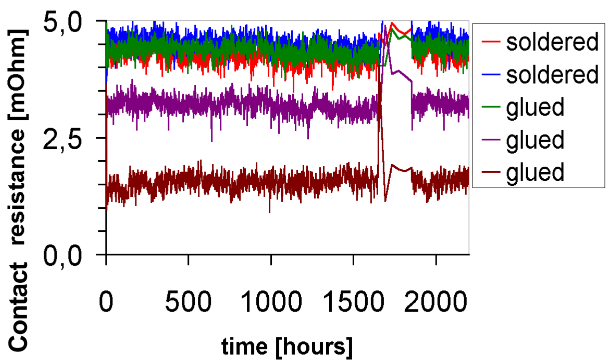


Fig. 6: Measured resistance of samples with a 1cm^2 contact area in 85°C/85% humidity damp/heat test.

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.

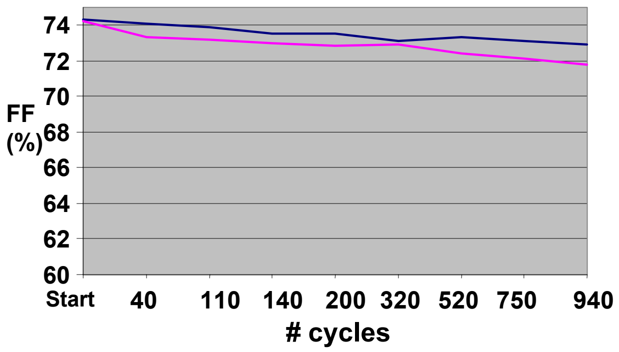


Fig. 7: Fill factor of single cell laminates after temperature cycling –40°C/+80°C [3]

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. I-V measurements of plain cells compared to interconnected cells in mini modules show no loss in fill factor.

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

CONCLUSION

The experiments show strong bending of soldered samples, whereas glued samples show less bending, or bending can be completely avoided for 80°C curing. For ultra-thin wafers, soldering is not suited at all due to wafer breaking. Interconnection with conductive adhesives is a reliable approach that gives much less stress and causes no cell breakage.

Extensive climate testing of interconnections made with conductive adhesives prove 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-contacted cells, an interconnection scheme with conductive adhesives and integrated curing of encapsulants and adhesives is a very attractive approach.

ACKNOWLEDGEMENT

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