

Testing Interconnections using Conductive Adhesives for Application in PV Modules

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ABSTRACT

In current module production the electrical interconnections are soldered to the solar cells. For current modules with thin cells and new module concepts with back contact cells, the replacement of solder by conductive adhesives can be advantageous. However, the current IEC tests were developed for soldered interconnections, which have other failure mechanisms. Therefore, three additional tests have been developed for the testing of conductive adhesives to be used in solar modules. In combination with computer simulation techniques developed in the same project, the tests will contribute to a better understanding of failure mechanisms of PV modules with conductive adhesives.

Keywords: Reliability, Conductive Adhesive, PV Module

1 INTRODUCTION

Our aim is to develop specific durability tests for lifetime prediction of electrically conductive adhesives when applied in PV modules. The current IEC tests for solar panels are meant for panels with soldered interconnections. Since glued interconnections are subject to different failure mechanisms, it is difficult to extrapolate test results to normal outdoor conditions. For this reason, dedicated tests applicable to a module with interconnections using electrically conductive adhesives have to be developed.

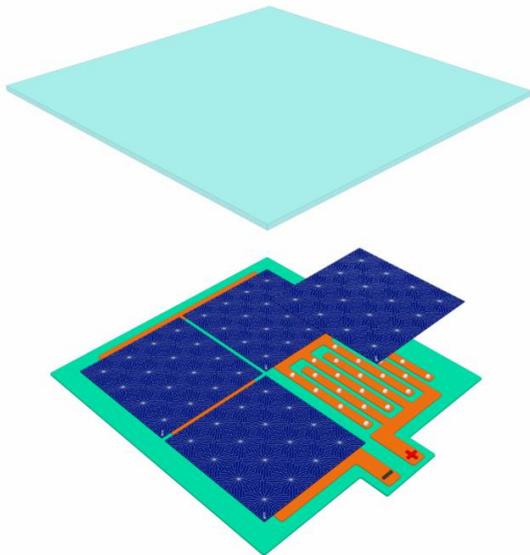


Figure 1: Schematic build-up of a back-contacted cell module with the front side glass, 4 PUM-cells and the rear side interconnection foil.

Conductive adhesives are especially suitable for the interconnection of back-contacted solar cells [1,2]. The cell layout and the back-sheet foil for back-contacted cells (Fig. 1) differ from modules as produced nowadays. Such changes in the module concept will lead to changes in the stress levels in the cell, foil and interconnections.

2 EXPERIMENTAL SET-UP

Three tests have been developed for research of adhesive interconnections, i.e. a rod-rod, a fatigue and a ShuntPUM test.

The **rod-rod test** was used for characterising the electrical and mechanical bulk properties of conductive adhesives and the interfaces between adhesive-to-cell or adhesive-to-back-sheet foil. The sample consists of two metal rods that are interconnected with conductive adhesive. In cases where the cell or foil interface required to be included, a small piece of silver metallised wafer or back-sheet foil was attached to one of the rods. The adhesive interconnection was made between a rod and cell or foil surface. A dedicated set-up enabled the manufacturing of test samples with a well-defined thickness of the adhesive layer. The simple sample design could be used in different test situations. In a tensile test bench the electrical resistance of adhesives was tested as a function of mechanical stress. Also, the adherence of adhesives to the back-sheet was tested. In a torsion test the shear stress of the glue was tested.

The **fatigue test** was developed for fast testing of conductive adhesives in an environment that contains some aspects of the application in solar modules. The reasoning behind the test is based on the differences in thermal expansion between silicon and a selected second material. Both materials were metallised in order to form an electrically conductive layer and to have a similar contact surface as in real modules. The two materials were mechanically interconnected by two dots of conductive adhesive, surrounded by EVA. Thermal shock chamber testing was carried out over a temperature range of -40 and $+85^{\circ}\text{C}$. The degradation was determined by measuring the electrical series resistance of the two adhesive spots.

The **ShuntPUM test** was designed for testing the electrical properties of interconnections in PUM modules during accelerated lifetime testing with a comparable stress level to the interconnection as in real modules. For this purpose, dedicated back contact PUM cells were prepared, where the aluminium rear side layer forms a short-circuit connection with the emitter and base areas. The function of such a cell is reduced to a conductive substrate without changing the thermo-mechanical properties of the module. The electrical resistance of the interconnections was monitored by

exposing single cell modules to accelerated lifetime tests such as damp heat and thermal cycle tests. Meanwhile, a 10A current was fed through the module to simulate the current flows in the module and to be able to continuously measure the contact resistance of the glued interconnections.

The selected conductive adhesives are numbered from A to H. They could be divided into two families, namely mechanically rigid adhesives (A-E) and flexible adhesives (F-H).

3 ROD-ROD TEST

The rod-rod samples (Fig. 2) were used for measuring the bulk tensile and shear strength of the adhesive, the strength of the adhesive/back-sheet interface, and the electrical resistance under tensile stress. Four adhesives were tested, the three rigid types C-E and the flexible type G.

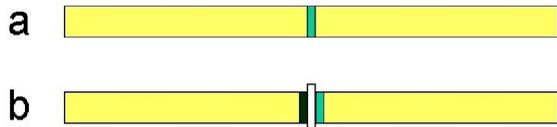


Figure 2: Bulk properties of the adhesive can be tested with sample (a), while interface properties require cell or foil pieces to be attached to one of the rods prior to interconnecting them with conductive adhesives (b).

The tensile strength of three rigid adhesives C, D and E was higher than the flexible type G. The results in figure 3 were based on 10 tests per type of adhesive. The adhesive was applied between two roughened, gold plated rods and all samples failed in the adhesive itself.

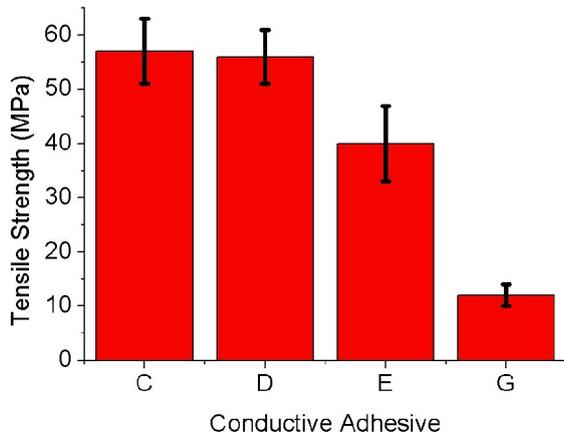


Figure 3: Tensile strength of 4 adhesives

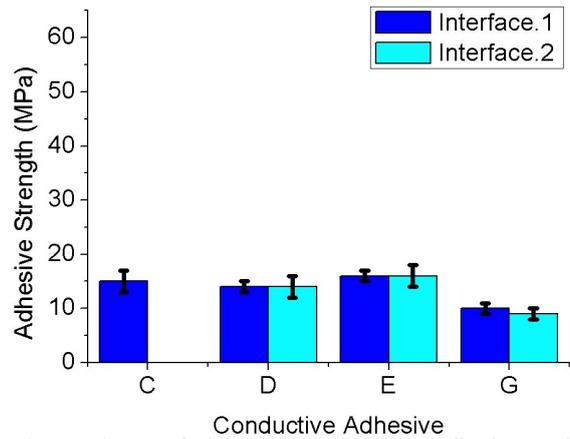


Figure 4: Interfacial strength between adhesive and silver plated foil.

The adhesive strength of the same types of conductive adhesive was tested, but connected to the back-sheet foil interface in the solar module. The measured strengths have reduced values (Fig. 4), because all connections failed at the interface of the silver-plated foil. The foils with interfaces 1 and 2 were produced identically, but were slightly different as two different storing conditions had been applied. Apparently, both conditions resulted in comparable results for the adhesive strength.

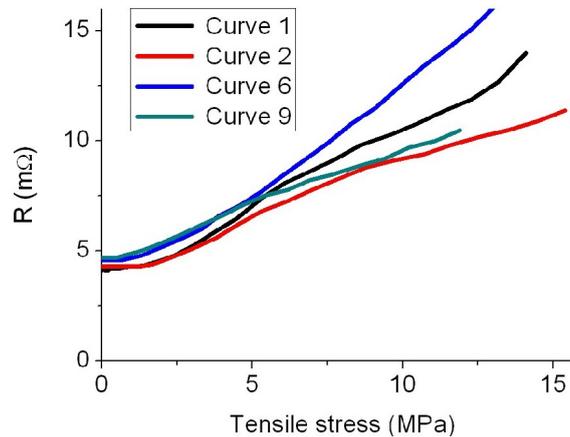


Figure 5: The electrical series resistance of the rod-rod sample in the tensile test for four samples of the flexible adhesive G.

The monitoring of the electrical resistance of samples during tensile testing gives insight in the sensitivity of the adhesives for mechanical stresses. No relation was found between tensile stress and resistance of the rigid types C-E. However, figure 5 reveals that the resistance of flexible type G was strongly influenced by the tensile stress.

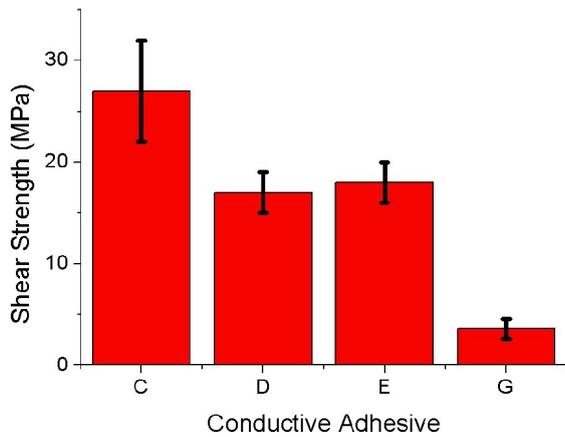


Figure 6: The shear strength of four adhesives

Another parameter of interest is the shear strength of the adhesives which was measured with a torsion test. Several gold-plated rod-rod samples were used per test and all adhesives failed at the rough interface of the rod. Figure 6 shows again that rigid adhesives C-E performed better than the flexible type G. The latter did not only show a low shear strength but it appeared to creep as well. The flexibility level of the adhesives became visible in the torsion angles that were in the range of 0.3-0.8 degrees for C-E and 4-10 degrees for G.

4 FATIGUE TEST

The fatigue test was conducted on two of the rigid adhesives used in the rod-rod test, D and E, and the flexible type G. A new flexible adhesive H was added to the test.

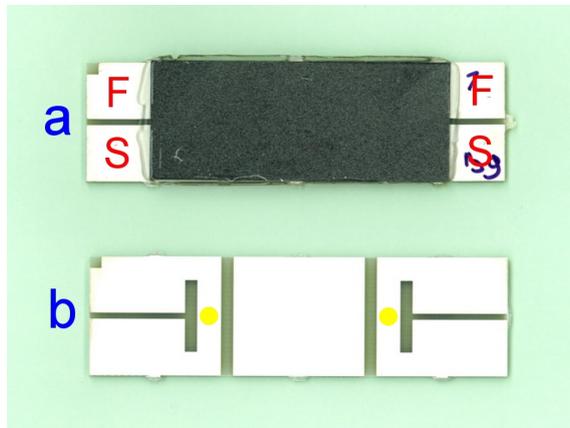


Figure 7: The fatigue test sample (a) with pads for Force and Sense contacts and the patterned substrate (b) with in yellow the locations for the adhesive spots.

The bottom layer of the sample (Fig. 7) consists of 0.5 mm thick FR4, a glass-fibre reinforced polymer substrate that is well known as electronic printed-circuit board material. The metallisation is patterned to electrically isolate the two adhesive spots. The distance between the adhesive spots is 30 mm. Around these spots a layer of EVA has been applied. On top, a piece of silver metallised silicon with a thickness of 0.3 mm was placed and then the package was laminated. It was possible to accurately monitor the series resistance of the samples during the experiment using the four-wire measuring technique. The F-terminals are the current feeding

terminals, while the S-terminals sense the voltage at the conductive adhesive joint.

The thin samples with their low heat capacity made it possible to use a fast 30 minutes cycle in which the samples stayed 15 minutes at -40°C and 15 minutes at 85°C. The samples went through 500 cycles. The results are shown in figure 8. The flexible adhesive G did not perform very well. The increase in resistance is relatively high and so are the fluctuations in the measurements. This effect might be due to the sensitivity of this adhesive for mechanical stresses as was observed before in the rod-rod test (Fig. 5). The flexible adhesive H also showed some increase of the series resistance. The best performing adhesives in this test were the two rigid types D and E.

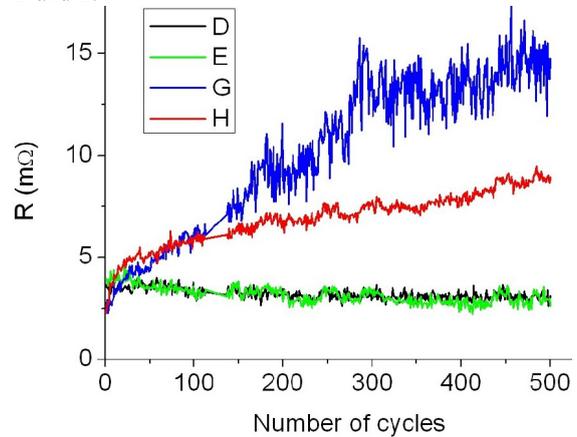


Figure 8: The electrical resistance of fatigue samples during thermal shock testing at -40/85°C, measured at -40°C. Adhesives D and E are rigid, G and H are flexible types.

Unfortunately, rigid adhesives can lead to mechanical failure of the silicon part in the sample. Several samples with rigid adhesives came out of the climate chamber with cracks in the silicon across the adhesive spots. Despite the cracks, the contacts were still functioning. Another type of crack that sometimes occurred was a small crater in the silicon directly above the adhesive spot (Fig. 9). Naturally, the mechanical stress in this sample build-up is different from a solar module where glass and EVA are included.



Figure 9: Detail of the break-out crater in the simple sample design above a spot with conductive adhesive.

A modified sample was build-up with a 3 mm piece of glass sheet laminated with EVA onto the silicon. This sample did not show any visible fractures in the silicon after 500 thermal shock cycles, probably because of the more representative thermo-mechanical stress conditions in and around the adhesive spot.

5 SHUNTPUM TEST

To test the interconnections during accelerated lifetime testing, a modified back-contacted cell was prepared, the so-called ShuntPUM cell, where the aluminium rear side metallisation forms a short-circuit between the emitter and base contacts. Hence, the function of such a cell has been reduced to a conductive substrate while maintaining the thermo-mechanical properties of the solar cell. Several modules have been made using such shorted cells. The resistance of the shunted contacts was monitored during damp heat and thermal cycle testing, while a 10A current was fed through the module.

The damp-heat test was performed under IEC61215 conditions (85°C; 85%RH) but with an extended exposure time of almost 3000 hours instead of 1000 hours. Two conductive adhesives were used, namely the rigid type A in eight single cell modules and the flexible type H in six modules. Figure 10 shows typical curves of a continuously increasing series resistance as a function of exposure time for both adhesives.

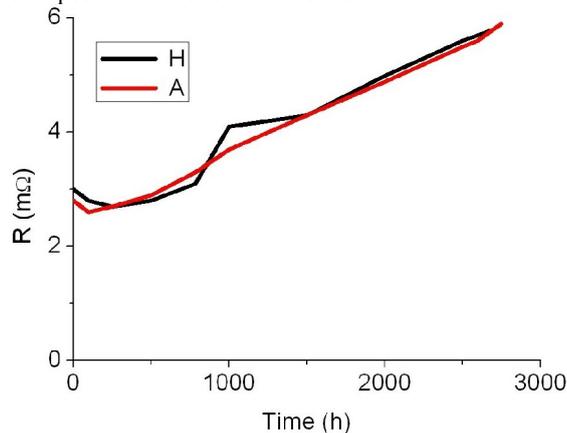


Figure 10: The electrical resistance of ShuntPUM modules with a rigid and a flexible conductive adhesive during damp heat testing, all values at 85°C.

The thermal cycle test was also performed conform the IEC standard but to an extended amount of cycles, namely about 550 or 750 instead of 200. In this experiment four types of adhesives were tested, namely the rigid types A and B, and the flexible types F and H. Figure 11 shows the results of a typical curve per adhesive. In this experiment the resistance at 20°C was obtained out of the log data and that resulted in two values per cycle. In most cases the data for the cooling and heating part of the cycle appeared to be identical, but the flexible adhesive H showed differences.

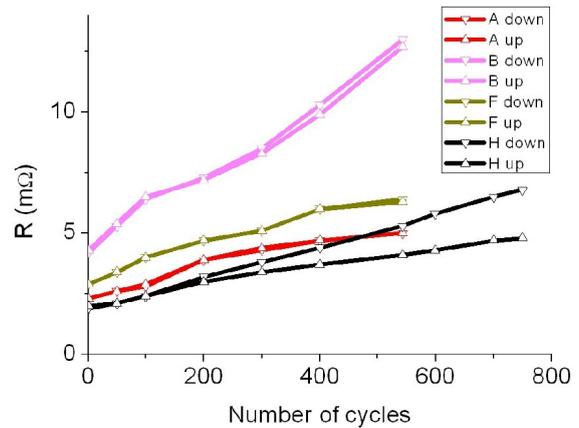


Figure 11: The electrical resistance of four ShuntPUM modules with different adhesives during Thermal Cycle (TC) testing. The measurements were obtained at 20°C, both in down and upwards direction of the temperature cycle.

A remarkable effect was observed when monitoring the temperature cycle. Initially, the module resistance followed the temperature coefficient of bulk silver, as is shown in figure 12 for the flexible adhesive H. As temperature cycling proceeds, other effects become apparent as shown in figure 13 for six identical modules using the same adhesive. The most remarkable effect was measured in the high temperature regime of the thermal cycle. Here the resistance dropped to a lower value when reaching a temperature of 54-60°C and went back to 'normal' after cooling down to 38°C. The same phenomenon occurred also in another module with the same adhesive, but in another temperature regime. This indicates that it has to do with mechanical stresses in the module, rather than being a material property of the adhesive.

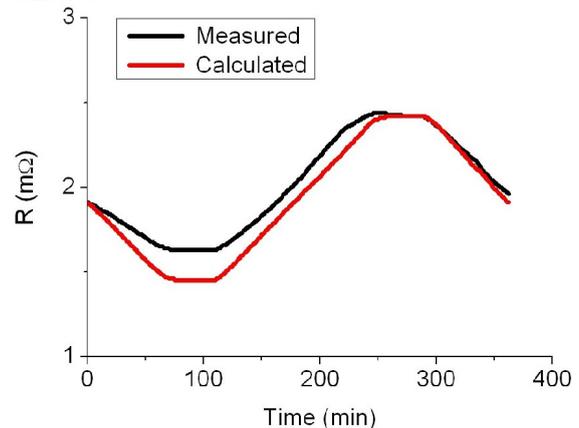


Figure 12: The electrical resistance of a ShuntPUM module with flexible adhesive H during the first cycle in thermal cycle testing (black curve). The red curve is the calculated temperature related resistance, based upon the initial resistance at $t=0$ and the temperature coefficient of bulk silver ($0.0041 \text{ } ^\circ\text{C}^{-1}$).

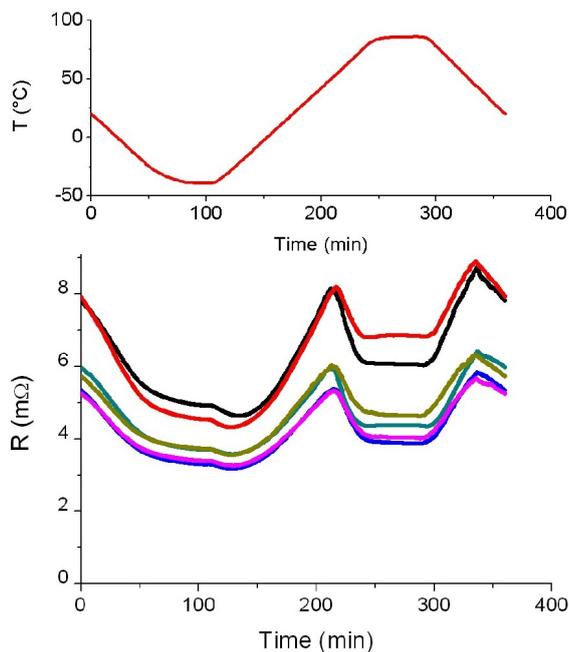


Figure 13: The electrical resistance of six ShuntPUM modules with adhesive H during cycle number 543.

To estimate the influence of broken contacts to the series resistance, a simple model was made. Each single cell ShuntPUM module contained 16 spots of conductive adhesive at emitter locations and 15 spots at base locations. The adhesive spots were considered to act as parallel resistors of 5 mΩ each and be connected in parallel in two groups. The shorted cell with aluminium metallisation was considered to have a compensating resistance of 2.5 mΩ that increased linearly up to 7.5 mΩ when the distance between the remaining operating spots increased. This resulted in an almost linearly increase in resistance in the first part of the curve (Fig. 14).

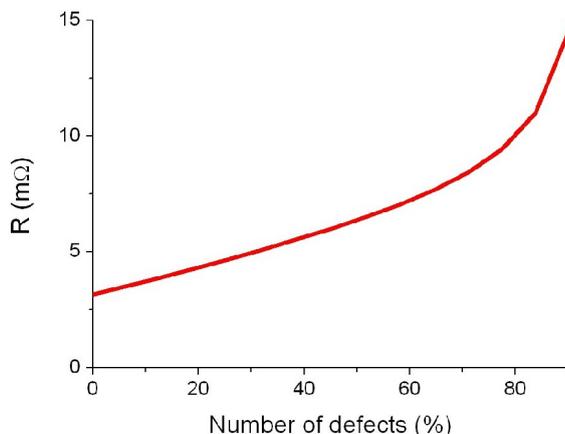


Figure 14: The influence of failing adhesive spots on the series resistance of a ShuntPUM module.

Some modules were inspected by infrared thermography while a current was fed through. This resulted in clear spots at locations where an electrical connection was in full operation and in dark places where the connections were broken (Fig. 15).

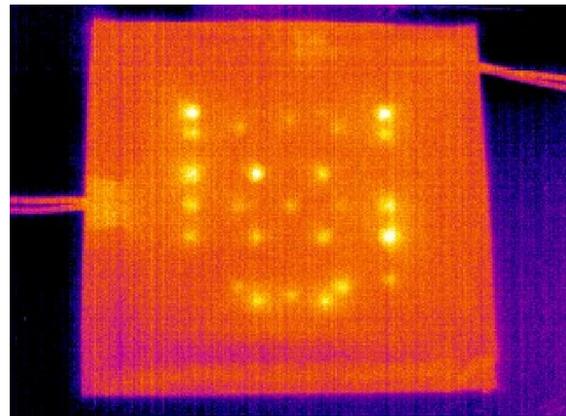


Figure 15: Infra Red (IR) Thermography was one of the methods used to search for broken contacts in the ShuntPUM modules.

6 DISCUSSION

The **rod-rod test** needs a careful sample manufacturing to obtain the desired thickness of the adhesive layer. The test offers several possibilities for testing conductive adhesives on the level of the interconnection. Next to the reported tests at room temperature, it is possible to measure the properties at other temperatures or to measure the influence of damp heat testing on the adhesives. The **fatigue test** succeeded in getting fast results within weeks. This test needs a careful sample manufacturing too to realise a good layer thickness of adhesive and EVA. In case of rigid adhesives the silicon layer often cracked due to an unrealistic stress situation. The use of a modified sample build-up with EVA and glass sheet should be considered to make the stress conditions more comparable with real modules. The **ShuntPUM test** gave interesting results in a setting with comparable thermo-mechanical stresses as in real PUM modules. A drawback is that the extended accelerated life-time testing takes a lot of time.

The three tests gave interesting results for the behaviour of conductive adhesives in the temperature range relevant for solar modules. In general, the rigid types performed better than the flexible types. The results will be used as input for the conductive adhesive developers to improve their products and for module makers to improve their module design and surface treatment procedures for the contact areas. Also, the results are important as input for the simulation assisted design of PV modules in the same project [3].

7 CONCLUSIONS

Three new tests were designed beyond the current IEC tests. The new tests give insight in the mechanical and electrical properties of interconnections using conductive adhesives during accelerated lifetime test procedures. In combination with computer simulation techniques developed in the same project, the tests will contribute to a better understanding of failure mechanisms of PV modules with conductive adhesives.

8 ACKNOWLEDGEMENT

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