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QUANTIFYING THE SOLDERABILITY OF LEAD FREE SOLDER ALLOYS ON SOLAR CELLS USING WETTING BALANCE ANALYZER

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ABSTRACT: Solderability is a major aspect to be considered in module manufacturing. To understand the effects governing the soldering process it is necessary to understand the solderability as a system. It is composed of the suitability of the materials, the feasibility of the process and the reliability of the interconnection [1]. For determining the suitability of involved materials, we recommend using a wetting balance analyzer. In the first part of the paper, we show how the analyzer works. We explain the experimental setup and which boundary conditions affect the results. The size of the test samples should be defined and identical. The number of measurements with one piece of solder should not be too large. Generously fluxing both cell and solder is very important to achieve trustable results. An exemplary series of measurements is given to explain how to handle them. To prove the suitability of the system, we show the differences in wetting of three different alloys. A standard SnPbAg and two lead free alloys: SnAgCu and SnBi. Additionally we show how different kinds of flux influence the wetting behaviour of SnAgCu alloy.

1 INTRODUCTION

A common method for characterizing soldered contacts is a mechanical pull test. Soldered ribbons are pulled off a solar cell while the applied force is measured. The result of this test is whether the feasibility of the soldering process is given. Quantifying the suitability of involved materials such as solder, flux and cell is not possible. However it is necessary to understand the solderability as a system like it is shown in Figure 1.

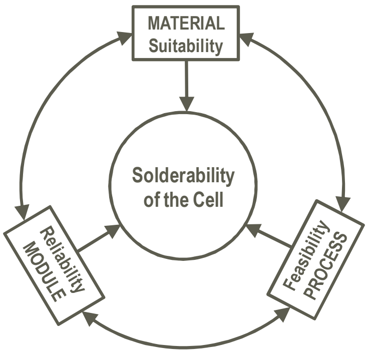

Figure 1 The system of solderability is influenced by suitability of the materials, feasibility of the process and reliability of the interconnection inside the product [1].

The ribbon pull test is qualifying the feasibility, climate chamber tests the reliability. For determining the suitability of included materials, we recommend to use a wetting balance analyzer.

In manufacturing electronic devices, testing the ability of molten solder to wet a substrate is common [2]. How the wetability can be measured is described in the standard EN 60060-2-44. Two main ways are described. The first is to apply molten solder onto the substrate and visually assess the wetting behavior. The second and recommended way is to use a quantifiable method, namely the wetting balance analyzer.

In solar cell manufacturing, a dip test is useful to check whether the general solderability is homogeneously given over the cell. The main advantages of the wetting balance analyzer is to quantify the differences in solderability between different solder alloys, flux and metallization pastes, or more precisely, how fast the cell is wetted by the solder, how far it spreads and whether dewetting effects appear. The influence of the soldering equipment can be excluded.

2 BACKROUND

The wetting balance as a measuring tool is well known (e.g. [2], [3]). First results using solar cells were published by Moyer in 2009 [4]. A suitable method is the so called micro wetting balance test (Figure 2) [5]. A globule of molten solder is elevated to a diced cell piece until the immersion depth is reached. Recording of the wetting force starts immediately when the solder touches the cell. First the wetting force drops because of the cell is swimming on top of the solder. The curve is rising when the solder starts to wet the surface. In the next step solder starts to spread over the surface caused by a difference in surface tension between substrate and solder. The result is a declining of wetting angle. Since the solder tries to take its form as a ball it pulls the cell down. A force occurs which rises to positive values and remains until the end of measurement.

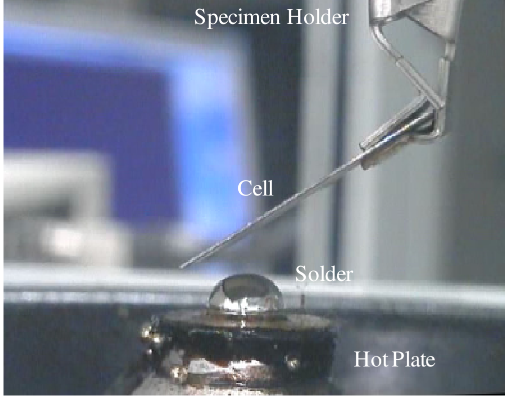

Figure 2 A diced solar cell is fixed on a measuring unit. A globule of molten solder on a hot plate is elevated to the cell.

A different approach to assess the solderability should be to directly measure the contact angle. Nevertheless it is difficult to achieve trustable results. We tested several experimental setups with different ways of applying both flux and solder to the cell under inert gas atmosphere. However it was not clearly distinguishable whether the angle between solder and cell or between a ring of solid flux content and cell was measured. In addition a time resolved quantifying of the wetting angle was not possible.

3 EXPERIMENTAL SETUP

Since solderability should be understood as a system of many variables, boundary conditions have to be considered.

Test piece

In contrast to a standard soldering process of solar cells, the test piece is not placed on a hot plate. Nevertheless the soldering temperature has to be reached before soldering starts. Therefore the cell is heated by the drop itself. Consequently the size of a single specimen should be identical in all experiments. We diced solar cells into pieces of 15x25mm by laser cutting.

One solar cell of 156x156mm² can be sliced in approximately 30 pieces. Each allows two tests on both sides. In order to compensate inhomogeneous solderability over the cell, the test pieces should be chosen randomly.

Solder

We used pre formed test pieces with a weight of 200mg. Due to leaching of silver into molten solder, the composition of the drop changes with every measurement. Furthermore there is a small piece of solder remaining at the sample sometimes. In best case, every single test should be carried out with new soldering material. On the other hand previous experiments showed that at least 20 single measurements can be done with the same piece without additional uncertainties. However we recommend changing the solder ball after every 10th measurement.

Flux

The most important factor for trustable measurement results is the way of fluxing. It is important that both cell and solder have to be fluxed adequate. The flux solves the surface oxide of the joining partners and enables wetting and spreading of the solder. A cotton bud was used to apply flux; on the cell just before mounting the specimen holder. The globule should be fluxed intensively just before the measurement starts. While fluxing, the skin of oxide which has to be removed is clearly observable. It is important, that the solder appears metallic bright at the beginning of the test. Therefore we recommend using rather more flux than too little. In all experiments we used standard no clean flux with low content of solids.

On the contrary in module production, flux is applied either on the cell or the solder ribbon. Before soldering, the flux is activated by evaporating the solvent in a separate step. Furthermore the capillarity between ribbon and cell supports spreading. The conditions during wetting balance tests are slightly different. Nevertheless it is to be considered as an advantage that the solderability can be investigated with a wetting balance excluding the influence of soldering equipment.

4 DATA ANALYSIS

In this part we give an example, how a typical series of measurements may look like. We made 40 single tests under equal conditions. Four cells of our standard production (Q6LTT3) have been sliced, 10 samples of each cell were tested on the back side. As solder metal we used Sn62Pb36Ag2 with a no clean flux. The immersion depth was 0,3mm, immersion speed 1,2mm/s, test time 10s and temperature 250°C.

Figure 3 shows a wide range of results. The zero crossing to positive values varies between 0.5 and 5s. The maximum force comprises between 0.5 and 1.5mN. One reason for the wide range might be an inhomogeneous soldering behavior over the four cells. Other reasons might be the way of applying flux or varying boundary conditions.

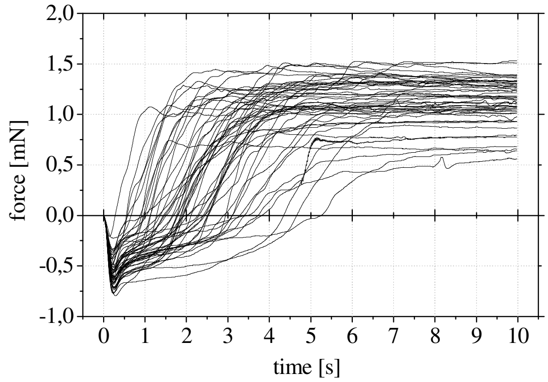

Figure 3 Series of 50 measurements with a wide spreading

However the shape of most curves is quite similar. In order to achieve useable results, we calculate median and standard deviation at each time.

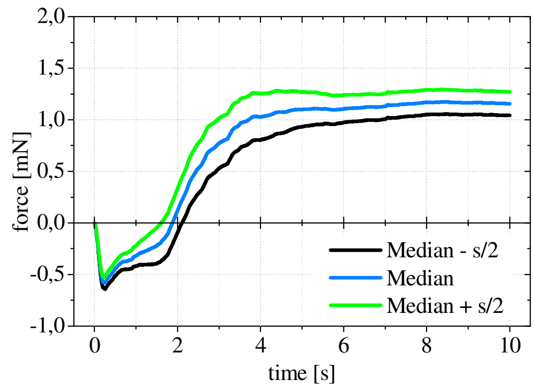

Figure 4 Median curve and standard deviation (s) calculated from 50 measurements. The majority of the curves are almost parallel and close together.

The curve in Figure 4 shows the median of the series of measurements shown in Figure 3. The flanking envelop includes the standard deviation, calculated at every point. It can be seen, that most of the single measurements are parallel and close together. As an example, the distribution of force after 10 seconds is shown in Figure 5. Most of all measurements were between 1.1mN and 1.3mN. The standard deviation was 0.22mN.

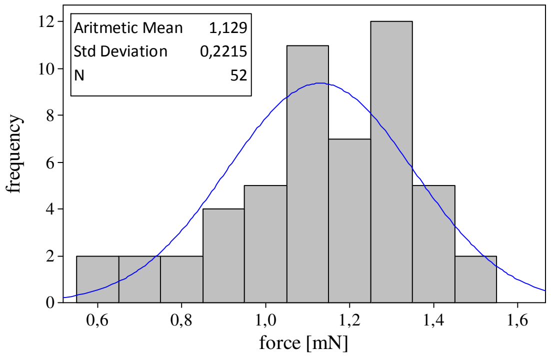

Figure 5 Histogram of force after 10 seconds follows a Gauss distribution

In summary some rules have to be considered:

1. The number of samples needs to be high enough. We recommend at least 20 single measurements chosen randomly.
2. The environmental conditions need to be very stable.
3. Each curve must be checked critically whether there is a uncertainty in measuring procedure (e.g. time between fluxing and testing)

In case of appropriate measurement conditions, the feasibility of the system is given. Of course it is not possible to determine the homogeneity of solderability over one cell. Therefore we recommend using a dip test. To quantify the mean solderability of one cell, the wetting balance is a powerful instrument.

To give an example, how the wetting balance can be used, we show some results concerning lead free soldering in chapter 5.

5 LEAD FREE SOLDERING

First experiments with the analyzer where related to lead free solder alloys. Two promising alloys are SnAg3.5Cu0.5 with a melting temperature of 220°C and SnBi43 with a melting temperature of around 150°C. As reference we used SnPb36Ag2 with a melting temperature of 183°C. Standard multi crystalline Q6LTT3 cells where cut into small pieces of 15x25mm². We have tested the front side with a no clean flux according to our standard soldering conditions. The testing temperature was set to melting point +50K. The immersion depth was 0.2mm and the immersion speed 1.2mm/min. After 20 measurements we calculated median curves which are shown in Figure 6.

The SnPbAg alloy shows good wetting behaviour. The force turns to positive values within the first two seconds and remains stable after 4 seconds.

The SnAgCu alloy wets the cell as fast as the SnPbAg. However the force is not crossing zero. On the one hand the specimen is not longer swimming on top of the molten solder. On the other hand, a force caused by declining of wetting angle not occurs. That means that the solder is not wetting the cell actively and the wetting angle remains around 90°. After 4 seconds the force starts to decrease what is an indicator for leaching.

The SnBi alloy wets the cell imidiatelly even before the immersion depth is reached, followed by a slow spreading. However the force does not reach the same level as the SnPbAg alloy.

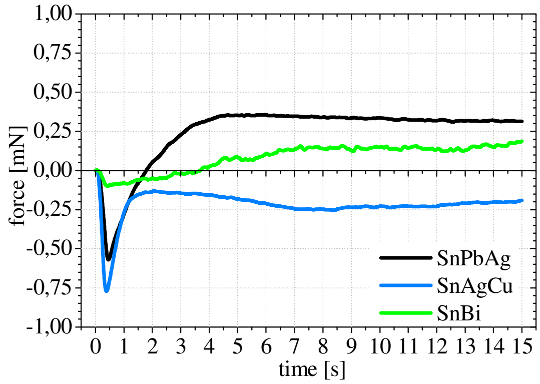

Figure 6 median curves of different alloys. Best wetting behavior of SnPbAg, followed by SnBi. SnAgCu is wetting but not spreading.

It is well known that spreading behaviour of SnAgCu is reduced due to the absence of lead [6]. The surface tension is higher and the surface oxides are very stable. The solderability of SnBi alloy is not limited by the wetting behaviour [7].

One way to improve the solderability of SnAgCu is to solder with more aggressive flux which reduces both surface tension and oxides [8]. The goal is to force the solder to spread over the cell what can be seen at a wetting curve which crosses zero.

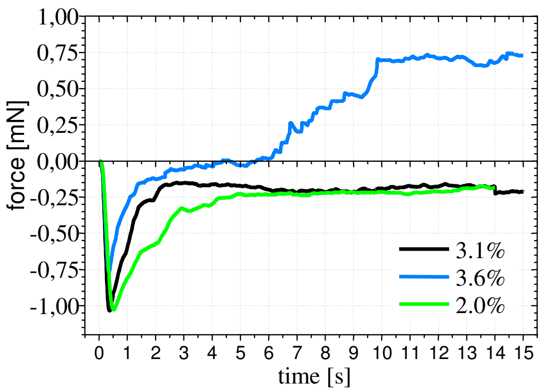

Figure 7: Wetting balance of SnAgCu solder with different flux. The wetting behavior increases with content of solids.

In Figure 7 we show wetting curves, recorded with three different kinds of flux. It is clearly observable that the content of solids influences the wetting behavior. The 2% flux reaches the 90° wetting angle after 4 seconds; the 3.1% after 1,5s and the 3.6% after 1s. The 3.6% was the only flux, which was able to force the solder to spread over the cell. In fact, the velocity of spreading is much lower than for leaded solder. However solderability is not limited by the spreading of solder necessarily. In areas where the ribbon is slightly pressed on the cell, a contact can be established, even with SnAgCu.

6 CONCLUSIONS

The wetting balance analyzer is a suitable tool to investigate the wetting behaviour of solar cells. It has to be considered that the measuring conditions have to be appropriate. Due to a wide scatter of single records, there are some rules to be adhered to. The array of curves can be summarized by calculating a median curve. Diagrams thus obtained can be used to characterize the solderability of a system from solder, cell and flux.

We compared a standard leaded alloy with two lead free alloys. We found that wetability of SnBi is better than of SnAgCu. To improve the wetability of the latter one, we tested alternative fluxes with different contents of solids. We found, that differences in the wetability can be quantified. Only the flux with a content of solids of 3,6% was able to force the solder to wet the cell actively.

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