Active Solder Joining Electrical Buss on Photovoltaic Cells

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Abstract

Active solders formulations activated with Ti, Ce, Mg and Ga have been developed for optimum joining to silicon and SiO2. These solders are finding application in the attachment of copper and/or aluminum buss strips to the back planes of photovoltaic cells to direct the current from the cells and create a solar panel. The paper describes a thermasonic bonding (ultrasonic energy and heating process)where these active solders are melted and disrupted to create a strong bond between the back contact, aluminized surface of polycrystalline Si photovoltaic cells and a copper buss strip. The paper will present the active soldering process and compare it to conventional soldering processes. It will also present and compare the joints' metallographic structure, comparative joint peel strength, and electrical resistance.

Introduction

Solar panels consist of three basic elements, top contact, base and rear contact, as shown in Fig. 1. Electrical contact needs to be made between these surfaces to close the circuit and provide an electron path to be able to conduct a current as photons emit electrons in the semiconductor polysilicon photovolatic (PV) cell.

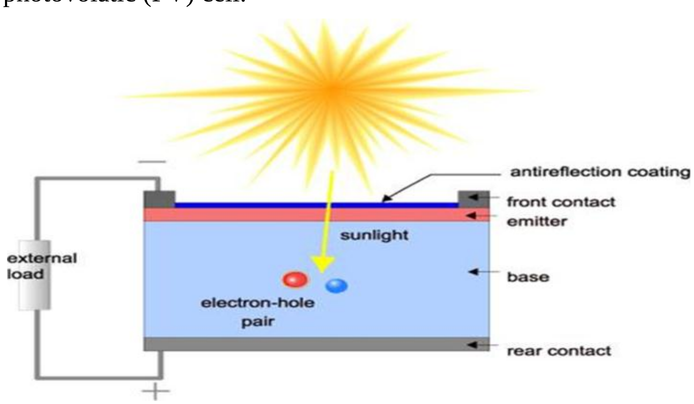

Figure 1. Illustration of solar cell.

Electrical current is carried by buss strips (copper or silver) deposited or soldered to the front and back contacts. In today's PV technology, the back plane is made via depositing and diffusing an aluminum powder suspension, shown in Fig. 2. The Al-layer is the darker gray layer made up of sintered aluminum powder particles that, during sintering, interdiffuse aluminum (Al) into silicon to create a conductive back contact that collects the electrons emitting from the Si-cells. For conventional soldering of the rear contact buss, silver strips for tab contact areas have been required to create a solderable interface to the Si back contact. Soldered busses connect one cell to create a string of electrically connected cells to form a solar power module, as shown in Figure 2b.

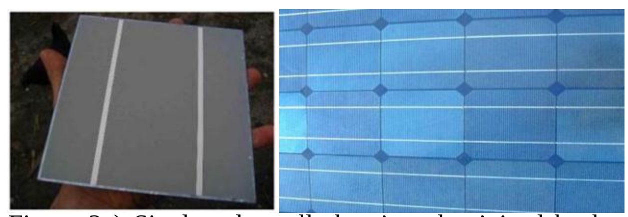

Figure 2a) Single solar cell showing aluminized back panel, 2b) String of solar cells connected via soldered copper strip.

It was proposed that active Sn-3Ag-2.5Ti-0.1Ce-0.1Ga solders (S-Bond ®) could bond direct to the PV cell aluminized rear contact to reduce cost and increase the performance and reliability of PV cells and modules. Active soldering would eliminate the need for the silver contact layer and flux, lowering cost and then with direct aluminum / silicon contact lower contact resistance to decrease electrical losses and thus increase cell/module power efficiency.

Figure 3 illustrates how the proposed active solders would bond the electrical buss directly to the PV cell using thermasonic bonding. Thermasonic bonding uses a heated soldering iron (probe) tip that is ultrasonically activated.

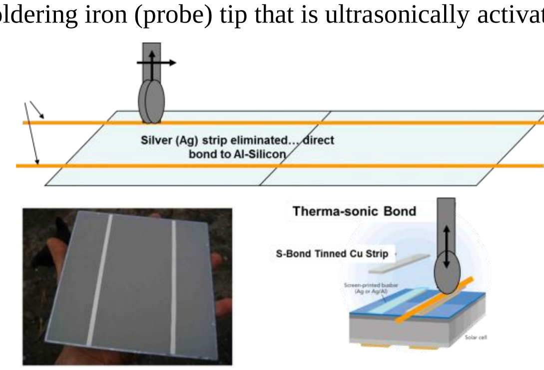

Figure 3. Illustration of active solder thermasonic bonding process.

In the thermasonic process, ultrasonic (acoustic) waves disrupt the oxides on the molten solder strips as the thermasonic (u/s soldering) tip heats the surrounding area to enable melted solder to wet the area. In the process used in these investigations, the bulk panel was heated to 180°C while the probe tip operated at 350°C to heat the surrounding back contact and buss. When the solder pre-coated buss was heated, the solder layer was remelted and flowed and wetted the surrounding contact area as the oxides on the surfaces were disrupted via ultrasonic energy. Figure 4 is a picture of a thermasonic tip bonding an active solder coated Cu-strip.

Figure 4. Thermasonic solder tip heating and bonding to Al-rear contact on PV cell.

In conventional soldering of the aluminized rear contact, a Sn-3.5Ag solder coated copper bus is heated with a soldering iron tip in the presence of RMA flux and pressed onto the preheated silver (Ag) pad on the PV cell rear contact. In this case, the flux reduces the oxides on the Sn-3.5Ag solder and the underlying silver layer and as the solder melts and flows as the solder wets the underlying Ag-layer.

Figure 5 shows and illustrates how active solders (e.g. S-Bond®) and regular solders can be coated onto the copper buss strips before they are soldered to the rear contact of the PV cell. The active solders are coated onto the copper buss strip using an ultrasonically activated solder bath, while conventional Sn-Ag solders would use a flux activated solder bath.

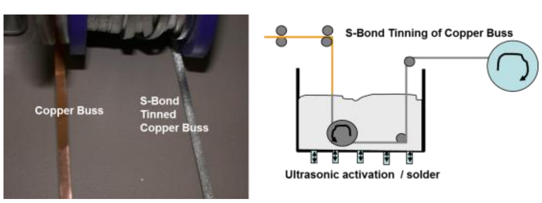

Figure 5. Picture and illustration of copper buss and the S-Bond solder coating process.

Procedures

Two types of PV cells were selected. One set for conventional soldering that had pre-deposited Ag pads and the other set with fully aluminum powder coated back contacts [no Ag pads]. For conventional soldering samples, Ag-padded PV cells were degreased and heated to 180°C as soldering iron operating at 350°C tip temperature was pressed onto a lightly RMA flux coated Sn-3.5Ag coated copper (2.5 mm wide x 0.12mm thick) strip. The soldering tip was then moved manually at a slow enough speed to heat and reflow the Sn-3.5 Ag solder onto to the underlying Ag-layers. Full cells (6 contacts along 2 parallel lines with 3 contacts each) and 25 x 25 mm samples cut from full panels with Ag-pads centered on the sample were made for metallography, resistivity tests and mechanical peel tests.

The thermasonic active solder process was used to make similar full size PV cells and smaller 25 mm x 25 mm panels, without Ag pads. The process aimed to bond directly to the aluminum sintered powder to silicon back contact. The back contact aluminized layers consisted of loosely sintered “excess” aluminum powder particle layer diffused onto the silicon PV cell. In order to get the strongest bond, initial testing indicated the loosely sintered excess aluminum layer had either to be partially removed or densified. Two methods were used in this investigation to prepare the aluminum powder layer for active solder joining. One method used the thermasonic probe tip run back and forth over the contact area to burnish (polish) the loose particle layer, the other was using stainless steel wire brush to remove the loose aluminum powder layer down to the underlying aluminized silicon layer. Once the aluminum layer in the contact area was treated, an active solder coated (Fig. 5) copper strip (buss) of the same size in the conventional solder samples was placed, without the flux coating, onto the prepared contact area. The panel was also preheated to 180°C and the ultrasonically activated (12 W, 4 mm D tip, 60KHz) thermasonic probe was manually pressed to the contact area with the active solder pre-coated buss in order to heat the contact and copper strip, melt the active solder layer and with ultrasonic activation, spread the molten solder to directly wet the underlying aluminized contact area. The speed of the probe tip was manually/ visually adjusted to be able to sufficiently melt the active solder layer on the Cu-strip and to have the active solder wet and with ultrasonic activation adhere to the contact area.

Metallography & SEM

The preparation of the contact samples began with cutting a metallographic sample from the cell by holding the solar cell between pieces graphite and cutting the cell with a razor. The contact samples were then placed in an epoxy in such a way that the cross-sectional area was visible from the top. The sample then went through a series of grinding and polishing steps, first to bring the target area to the surface and then to clean the surface of debris. After metallographic optical micrograph images were taken, the polished sample were gold sputtered to make the surface conductive for SEM evaluation. Graphite tape was also used to ensure conductivity before placing the sample into the SEM.

Mechanical Strength / Peel Test

The peel test was performed using a MTS Bionix 100 test system applying the pulling force on the copper buss strip at a 180 degree angle to the solder contact. As shown in Figure 6.

The strip buss (lead) was bent using the blunt side of a razor as the pivot to ensure consistency in the bend for all the test samples, as shown in Fig. 6.

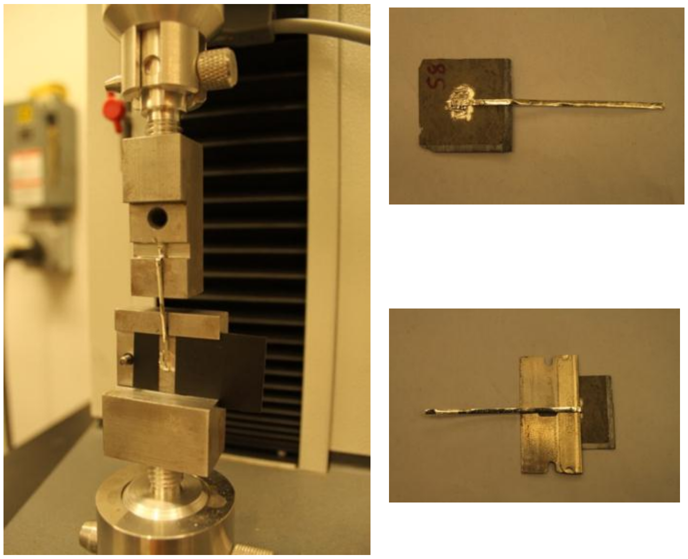

Figure 6. Picture or peel test set up and peel test sample

The conventionally soldered and the thermasonic bonded active solder peel test samples were placed in tensile/peel test slotted holders with plastic shims the slot. The shims were positioned to be in front of the sample and cover as much area as possible without touching the pull test area to minimize bending and Si-base fracture as the leads were pulled.

To apply the peel load, the top section of the holder was lowered until the buss strip (lead) fit into the clamp. The buss lead was positioned vertically and pushed into position while being supported above the contact area. The tensile machine cross head was then moved to pull the lead taut before the cross head was engaged for test and moved at 25mm / min until the lead was peeled completely from the PV cell surface.

The program Testworks 4 was used to control the tensile machine and record the load cell (1000N) output as a function of cross head displacement. The settings for force and distance were zeroed before the test was initiated. The results show the crosshead distance (mm) vs. force (N).

Electrical Contact Resistance

The set-up for the resistivity test consisted of a current source, multimeter, test module, biaxial and triaxial cables, and a connector box. The devices were connected in such a way that the current source and multimeter were pressed onto one contact, while the opposite contact was connected to ground. Full solar cell panels, either conventional (flux) soldering or thermasonic bonded active solder (S-Bond®), was prepared by cutting and trimming the leads between the contact points, with some of the lead left to make connections. Tests were conducted for each half, top and bottom, of the sample, as shown in Figure 7.

The test for contact resistance was performed by measuring the voltage while performing a current sweep across contacts at varying lengths. Each solar cell has three contacts linearly aligned on the top and bottom of the back of the cell

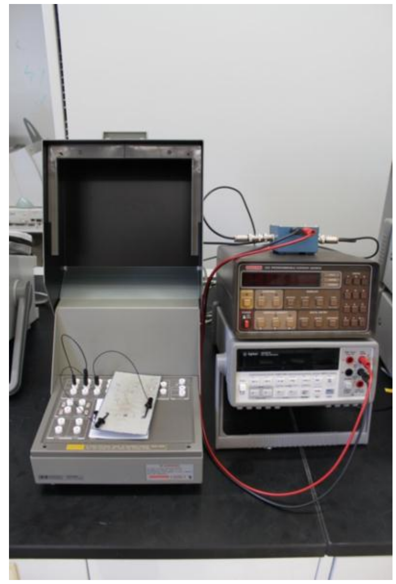

Figure 7. Multimeter test set up for measuring contact resistance and resistivity of soldered bus on PV cells.

By performing a current sweep across two adjacent contacts and then performing the same current sweep across the two outside contacts the contact resistance, assumed the distances between contacts were the same and that the contacts had the same contact resistance. Since the process for making these contacts was manual hand, they are not identical, but for a comparative study the average values were used.

The equivalent circuits for the adjacent and outside contacts are both a series resistance. (Fig. 8 and Fig. 9) The equations derived from the equivalent circuits are used to calculate the values for R_C and R_L. The two R_{TOTAL} values are the values that were measured.

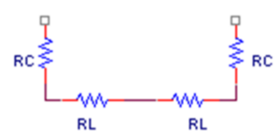

Figure. 8 Equivalent Circuit for Adjacent Contacts

$$R_{1TOTAL} = 2R_C + 2R_L$$

Equation1

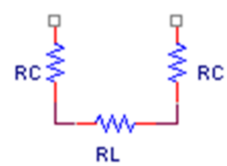

Figure 9. Equivalent Circuit for Outside Contacts

$$R_{2TOTAL} = 2R_C + R_L$$

Equation 2

Results & Discussion

Metallography & SEM

Metallographic results are shown in Figures 9 – 14 showing the structure of the joints made by conventional soldering (Figs. 9 – 11) and via thermasonic active soldering (Figs. 12-14). The photomicrographs show the overall solder joint-with copper buss-solder joint-silicon interfaces.

The conventional solders joints were dense and well adhered to the Ag layer on the Si surfaces. There was no apparent direct bond of the Sn-Ag solder layer of the Si-cell materials. The thermasonic active solder joints are shown in Figs. 12-14 and indicate a direct bond of the active solder to the Si-cell base materials, in this location bonding with no intermediate aluminum particulate layer. The active solder joints are also dense and appear well adhered.

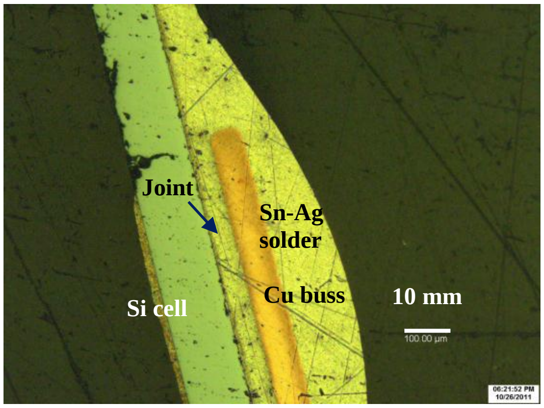

Figure 9. Low magnification image of conventional soldered joint cross section

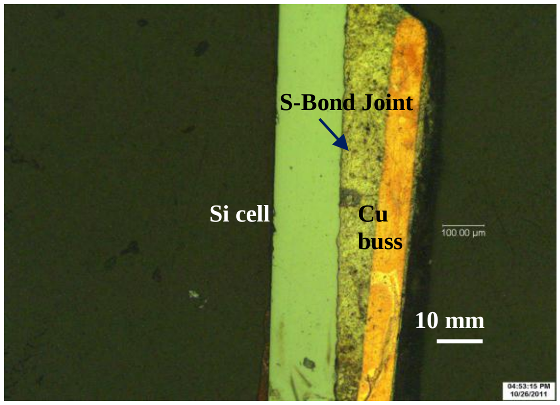

Figure 12. Low magnification image of active soldered joint cross section

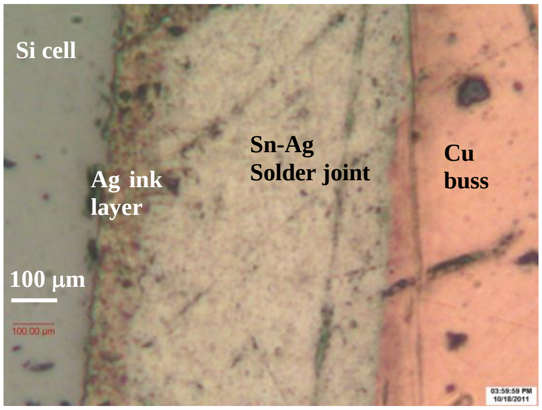

Figure 10. Photomicrograph of conventional soldered joint cross section, close up of joint area.

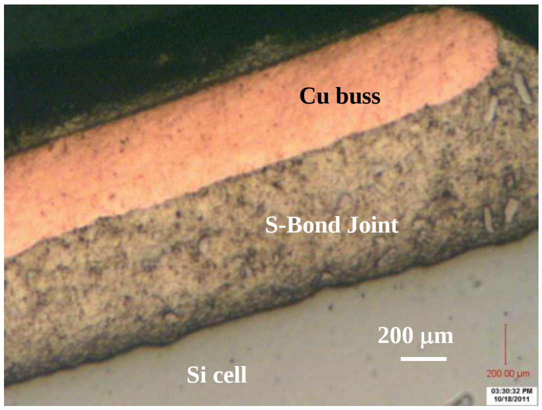

Figure 13. Photomicrograph of active thermasonic soldered joint cross section, close up of joint area.

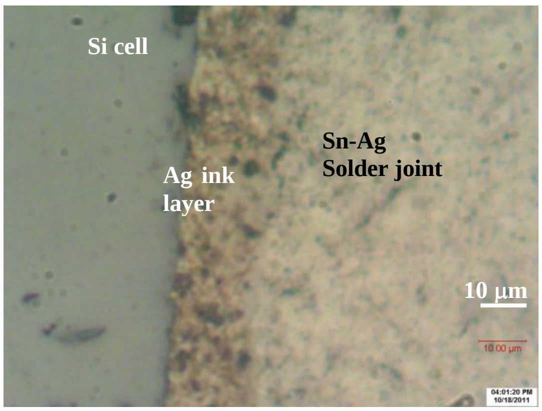

Figure 11. Photomicrograph of conventional soldered joint cross section at Si/solder interface.

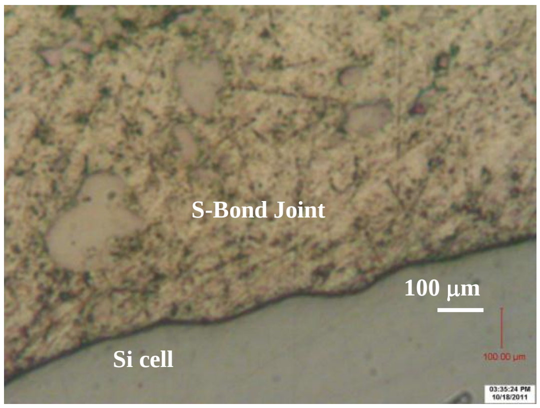

Figure 14. Photomicrograph of active thermasonic soldered joint cross section at Si/solder interface.

SEM analysis of the standard solder showed a flat interface between the solder/silver pad and the silicon, see Figure 15. The solder bonded very well with the silver layer (Ag-pad) but did not give any extra adhesion to the silicon. The image shows that the Sn-3.5 Ag solder, silver and silicon form distinct layers and do not migrate into each other. There was bonding between the solder and silver pad but the solder bond did not mix and dissolve the underlying Ag-layer. Figure 16 the conventional solder joint SEM/linescan illustrates this point further.

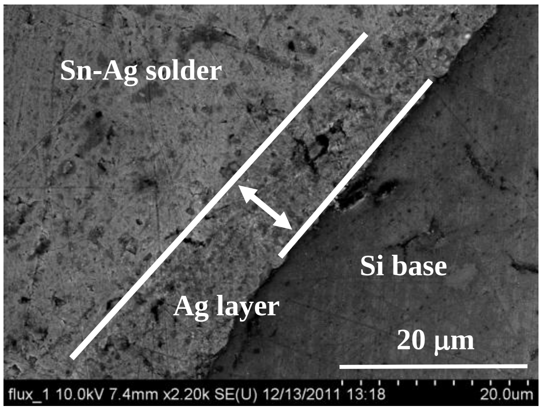

Figure 15 SEM back scatter image of conventionally soldered joint.

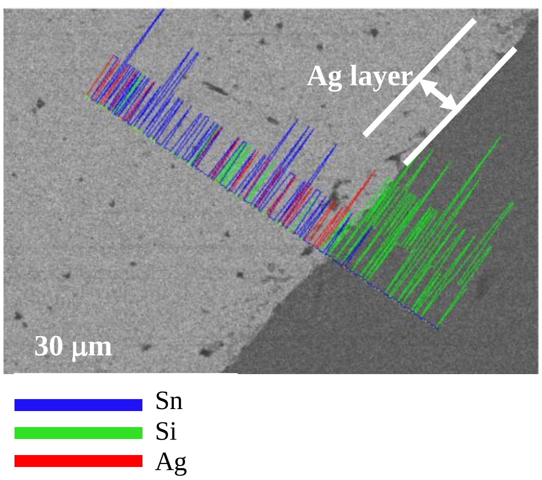

Figure 16. SEM and line scan image of conventionally soldered joint.

The SEM image in Figure 17, shows the thermasonic active solder bonded joint (S-Bond) indicating an irregular curvy interface compared to the conventional solder interface which exhibited a flat interface. The interface also has a remnant intermediate aluminum particulate layer between the silicon and the solder. The linescan image superimposed on the photomicrograph, in Fig. 18, shows the extent of the different element distribution in the layers near the Si cell interface.

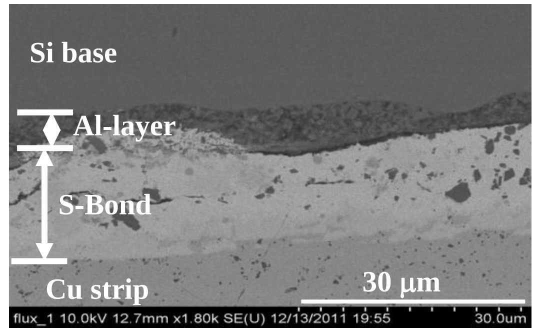

Figure 17. SEM image of image of thermasonic active soldered joint.

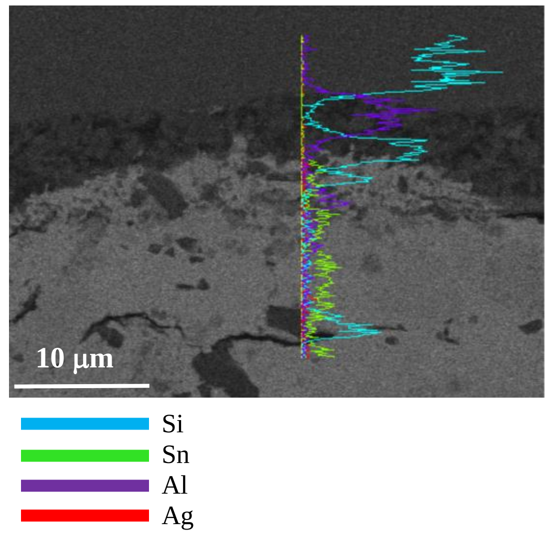

Figure 18. SEM and line scan image of thermasonic active soldered joint.

Mechanical Strength / Peel Test

Figure 19 is a plot of the peel load vs. cross heat displacement values as the soldered Cu strips were pulled at 180° angle to peel the Cu-buss strips from the silicon cell back contact. The chart shows that the active solder samples began to peel at an average load of 7.2 N where the conventionally flux soldered samples began to peel at an average load of 5 N. One can also see the initial starting peel load failure is higher and as the peel propagates, the load drops and has an irregular pattern as the peel failure progresses to final failure. Both solder joints exhibit the same post initial peel irregular load behavior.

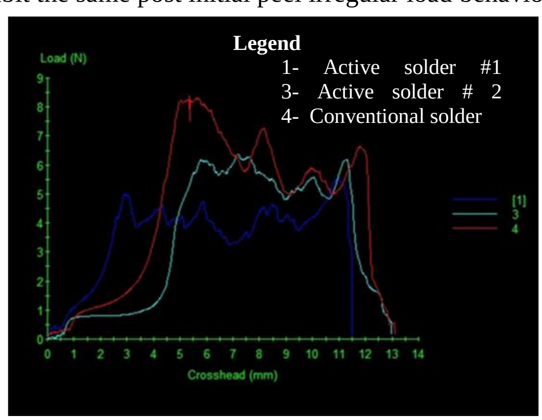

Figure 19. Plot of peel load vs. crosshead displacement in peel tests on solder joints.

After the peel tests were completed the fracture surfaces were examined under a stereoscope to evaluate the fracture modes, their extent and their distribution.

The fracture images in Figures 20-21 indicate that the active solder technique had more complete solder bonding than that of conventional soldering. Figure 20 shows the fracture surface of the conventionally soldered joint that exhibited mixed failure modes where the dark areas are areas are where bonding was not complete, maybe due to flux entrapment voids. The other lighter area is likely where the underlying silver pad was pulled off the Si-surface and then some areas are where the solder joint fractured, leaving remnant fractured solder area. There was not a consistent bonding over the contact area with good adhesion in some places and bad adhesion in others. The active, thermasonically soldered (S-Bond) samples, Fig. 21, showed much more consistency over the entire contact area. Active solder (S-Bond) fractures layers are seen in the image as indicated by the more uniformly light grey surface and this fractured solder area is much larger than with the standard solder. The areas of voiding were also much smaller and more distributed in the active solder boned joint (darker areas). This indicated that the active solder joint had very good adhesion to the surface since the fracture was mostly in the solder joint itself and not at a bond/layer interface.

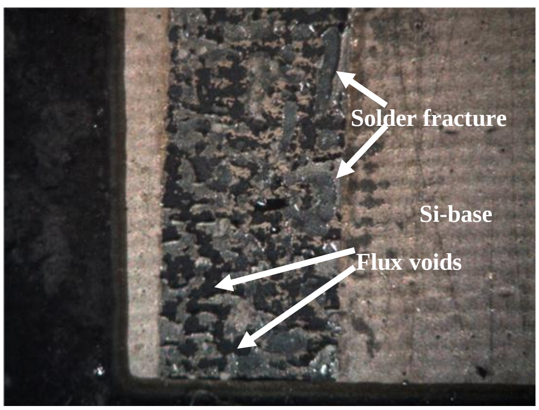

Figure 20. Stereoscope image of conventionally soldered peel test fracture surface.

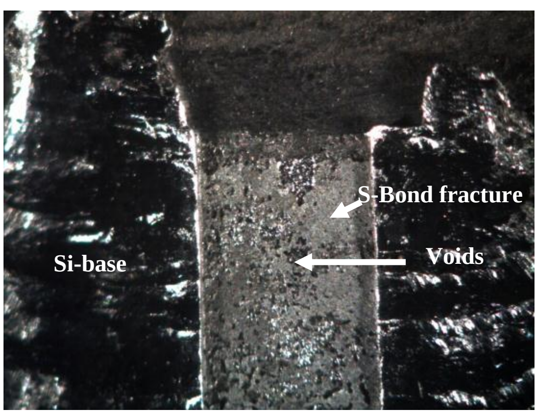

Figure 21. Stereoscope image of thermasonic active solder joined peel test fracture surface.

Electrical Contact Resistance

The electrical contact resistant tests measured contact resistance values of 1.5mΩ for the active solder bonded samples and 4.5mΩ for the conventionally soldered samples. The calculated RL values for the tests were 2.8mΩ for the active soldered samples and 2.7mΩ for the conventionally soldered samples. These values were expected to be the same and had a variance of 0.1mΩ. The test results are consistent with the joint structures (microphotograph/SEM), their peel strengths and their fracture modes, showing the active solder bonded joints to be superior to the conventionally soldered joints.

Conclusions

The investigations completed to date have shown that the thermasonic active solder bonded buss to rear solar panel contact is superior to conventionally soldered joints. Active soldered joints consistently showed more direct contact to the aluminized silicon, higher peel strengths and lower contact resistance than conventionally soldered joints. All these data indicate that active solder bonding is a technically superior joint for aluminized back contact buss attachment. The lower contact resistances of the active solder bonded joints and their higher strengths can be attributed to the direct silicon bond enabled by the “active” nature of these solders. Ti, Ce and Ga alloy additions in the active solders permit them, without flux, to adhere to oxides present on bond aluminum and silicon and thus create a direct metallurgical bond to the Si-base and thus eliminate an intermediate Ag-Si interface present in conventionally soldered joints. One should note that the direct bonding of the thermasonic active solders did have an aluminum “mechanical” powder layer removal step and in the bonding process, the ultrasonic soldering also added mechanical energy at the bonding interface. These “mechanical activation” steps have likely combined with the increased chemical activity, due to Ti and Ce additions, to make a very effective directly bonded metal: silicon interface.

Active solder bonded joints were made without the use of flux or reliance on a deposited silver (Ag) layer. These attributes have the potential to make a more cost effective solar panel manufacturing process, eliminating Ag, eliminating an Ag plating step, and eliminating the need to clean and/or ventilate flux fumes. Solar power performance has not yet been measured, but with lower electrical contact resistance, it is expected to see some degree of improved solar efficiency. Thermasonically active solder bonded joining shows promise as an improved method for making back contact electrical buss attachment and continued improvement of the process and further evaluation of it replacing conventional soldering will continue.

Acknowledgments

The investigators would like to acknowledge the financial support from the Ben Franklin Technology Partnership of Southeastern Pennsylvania and the US Department of Energy.