DEVELOPMENT OF A THIN FILM SOLAR CELL INTERCONNECT FOR THE POWERSPHERE CONCEPT

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Introduction

Dual junction amorphous silicon (a-Si) solar cells produced on polyimide substrate have been selected as the best candidate to produce a lightweight solar array for the PowerSphere program. The PowerSphere concept features a space-inflatable, geodetic solar array approximately 0.6 meters in diameter and capable of generating about 20W of electrical power. Trade studies of various wiring concepts and connection methods led to an interconnect design with a copper contact that wraps around the edge, to the back of the solar cell. Applying Plasma Vapor Deposited (PVD) copper film to both sides and the edge of the solar cell produces the wrap around contact. This procedure results in a contact pad on the back of the solar cell, which is then laser welded to a flex circuit material. The flex circuit is constructed of copper in a custom designed routing pattern, and then sandwiched in a Kapton® insulation layer. The flex circuit then serves as the primary power distribution system between the solar cells and the spacecraft[1,2,3]. Flex circuit material is the best candidate for the wiring harness because it allows for low force deployment of the solar cells by the inflatable hinges on the PowerSphere. An additional frame structure, fabricated and assembled by ILC Dover, will reinforce the wrap around contact-flex blanket connection, thus providing a mechanically robust solar cell interconnect for the PowerSphere multifunctional program[4,5]. The PowerSphere team will use the wraparound contact design approach as the primary solution for solar cell integration and the flex blanket for power distribution.

Use of the wrap around contact will yield three key benefits noted below.

1.) Utilizing the back of the solar cell for PVD copper electrical traces due to the insulation properties of polyimide. This multifunctional benefit reduces mass by removing what would otherwise be additional flex circuit material. Future advancements in this area could result in removal of the entire flex material from Powersphere solar array system creating an integral wiring harness.

2.) The use of the wrap around contact physically locates both the top and bottom contact on the same side of the solar cell. This provides fabrication process simplification by laser welding both contacts of the solar cell to the flex circuit at the same time thus reducing costs.

3.) After the wrap around contact PVD process is complete a protective Tefzel® film is applied over the solar cell and contact. The Tefzel® film is applied to the front of the solar cell to increase the thermal emissivity to 0.8, which limits the peak temperature of the cell from exceeding 80°C. It also improves the robustness of the solar cell and mitigates possible risk of damage from a handling aspect. By utilizing the back of the solar cell as the contact, the protective Tefzel® film will not impede on the laser welding process.

Requirements

Developments of a solar cell interconnect to be used for a Low Earth Orbit (LEO) application was driven by several specific requirements. It must be able to withstand the extreme environmental conditions that are present including Atomic Oxygen (AO), Ultraviolet light (UV) and rapid thermal cycling. Exposure to these conditions will cause degradation of the solar cell interconnect and possibly complete failure of the joint.

Additional requirements that were derived for the interconnect joint are described below.

1.) Mechanically robust in order to survive loads incurred during launch.

2.) Adequate sizing to support electrical loads.

3.) Ability to be scaled to support different sizes of solar cells.

4.) Easily repaired if interconnect is damaged.

Background

Several trade studies were undertaken to investigate the successful fabrication of solar cell interconnect architecture. Various methods of joining the a-Si solar cell to a flexible Kapton® blanket including joint architecture, materials and fabrication methodology were considered.

Prior to starting the trade studies a lap joint configuration was selected as the best candidate to verify all of the requirements to evaluate the robust solar cell interconnect. Also, methods that both electrically and mechanically joined the solar cell to the flex circuit material received the highest priority.

The architecture trade study parameters included the overall geometry, mechanical and electrical configuration of the interconnect joint. Several methods to electrically and mechanically join the materials were considered. Conventional methods such as conductive epoxies, solders and conductive tapes were quickly eliminated due to lack of confidence in the survivability at the temperature extremes. Additional methods that were considered to provide the electrical connection include drilled vias, welded wire or foil and PVD copper film.

Based on the trade studies, PVD copper film was selected as the leading candidate to provide the electrical interface. Pressure Sensitive Adhesive (PSA) was used to mechanically join the solar cell to the flex blanket. The PVD copper film was applied over the lap joint to produce the coupon shown in Figure 1.

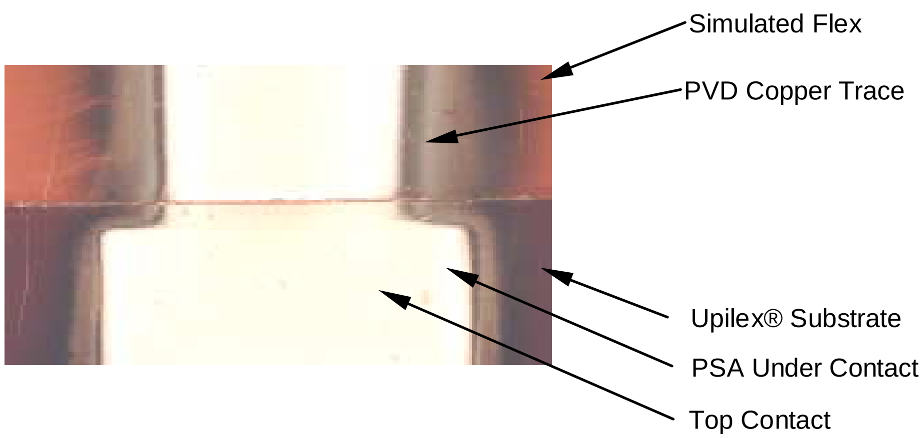

Figure 1- PVD Copper/PSA Coupon

This concept proved to be challenging due to the high out gassing of the adhesive during the vacuum deposition process and relatively large step between the cell and flex circuit. Thermal mismatch between the materials was also a concern and this concept was abandoned.

As a result of the previous coupon preparation an alternate PVD process was considered. This concept utilized the PVD copper film applied to the solar cell contact that was laser welded to the flex circuit. The copper film was applied to the top, edge and bottom of the solar cell thus routing the generated electrical load to the back of the solar cell. This wrap around contact is achievable by sputtering the copper film unlike other deposition processes that provide line of site application only. Having both contact located on the back of the solar cell provides many benefits that are previously noted. A cross section of wrap around concept is shown in Figure 2. Several coupons were produced using the wrap around design.

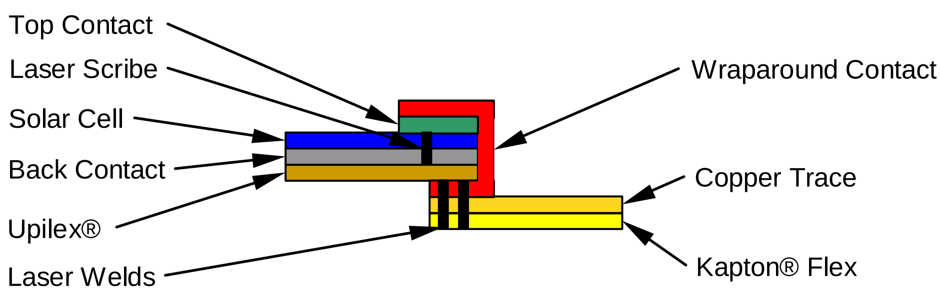

Figure 2- Cross Section of Wrap Around Contact

Figure 3 shows a magnified view of the initial laser welds that were produced indicating a good laser weld between the back contact and the PVD copper film. The picture shows the Kapton® side of the flex circuit where the laser makes first contact.

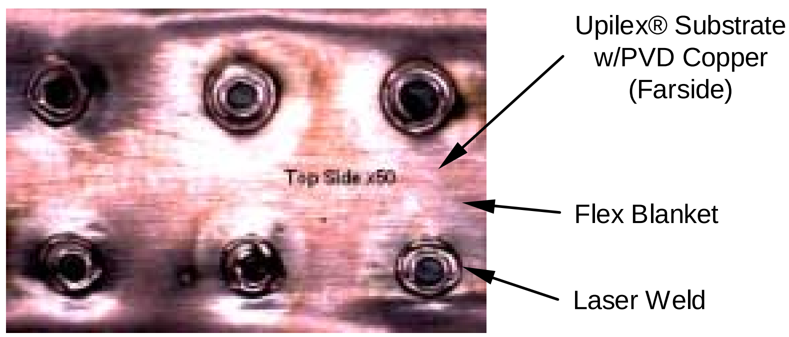

Figure 3- Laser Weld Coupon

Once the fabrication process was established, four coupons were produced using representative materials. Two of the coupons had an additional ILC Dover mock frame installed to simulate actual conditions. The coupons were subjected to rapid thermal cycling at NASA Glenn Research Center to simulate a LEO environment. Pretest and posttest resistance measurements between the simulated flex circuit and solar cell were documented to evaluate the electrical continuity and integrity of the welded coupons. During the thermal cycle testing all but one of the coupons survived with the one failure attributed to material handling. The posttest resistance measurements showed that there was little degradation of the laser-welded solar cell interconnect. Figure 4 shows both types of coupons, with and without the simulated frame.

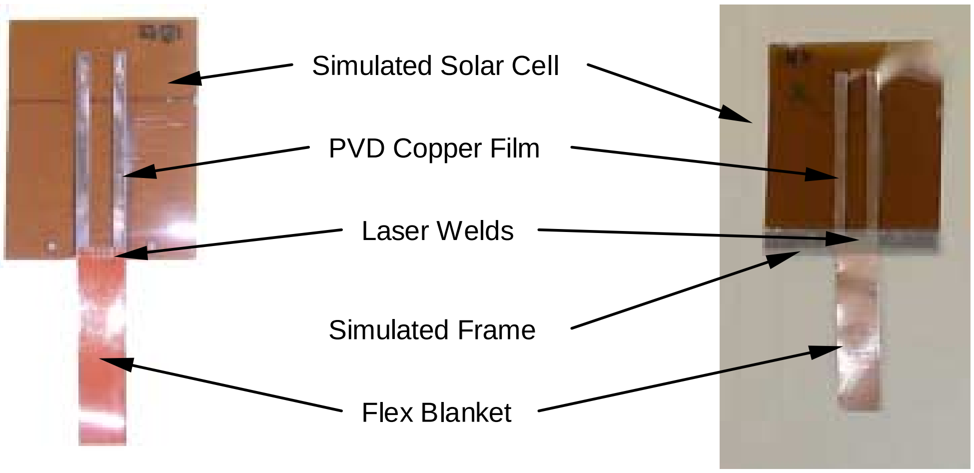

Figure 4- Unframed and Framed Weld Coupons

A thermograph inspection was also performed to verify adequate electrical sizing of the laser welds when subjected to 1 amp of current. The white areas around the laser welds in Figure 5 represent the coolest area and confirmed that the weld sizing was done correctly.

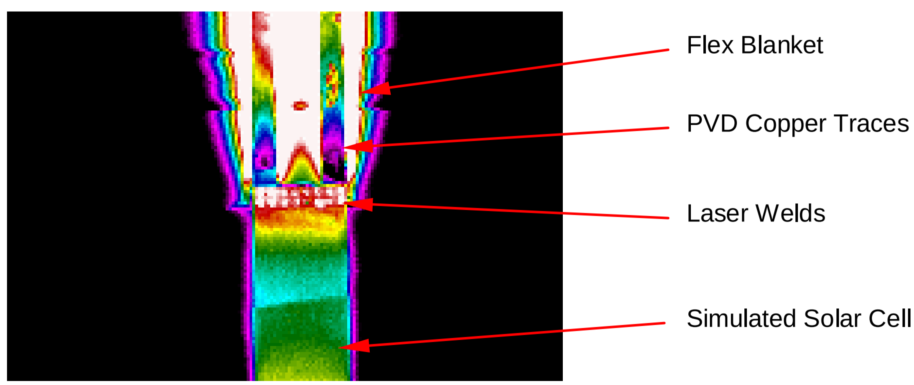

Figure 5-Laser Weld Thermograph

<u>Design Improvements</u>

Once the wrap around concept proved to be a viable approach for fabricating a robust interconnect, five improvements in the weld approach were investigated. The first improvement attempted was to laser weld completely through the flex circuit and solar cell. Visual observation of the plasma exiting the weld was used as initial verification of a successful weld. This can only be accomplished on the edge of the solar cell where the contact pad was isolated from the active solar cell area and eliminate possible shorting of the cell. Testing has shown that this change has significantly improved the quality of the weld.

A second improvement to the design was to decrease the PVD copper thickness on the wrap around contact. This was attempted to reduce the residual stresses in the copper film, which caused the substrate to curl and can potentially cause possible delaminations. However, sufficient copper thickness must be present to provide adequate material for the weld. The PVD copper thickness was optimized to meet all of the previously noted requirements. An analysis of the electrical sizing was also accomplished to verify that the reduction in film thickness was still adequate to carry solar cell power.

The third improvement was to apply a titanium thin film binder layer prior to the PVD copper film. This helped to reduce the delaminations of the copper from the solar cell substrate during the welding process. The delaminations occurred due to localized shrinkage of the weld material. The future binder material will use chromium at the base layer that has previously demonstrated superior properties to that of titanium.

The laser welding process provides both the mechanical and electrical joint, however the mechanical strength of the weld is weak suggesting the need for a adequate structural support such as Kapton® tape. Tape was used to provide the clamping force during the laser welding process. The tape also helped to reinforce the solar cell interconnect to minimize failures due to material handling during the solar cell frame installation. One additional benefit of the tape is that it provides more intimate contact of the copper during the welding process, which produces better welds.

The last improvement that was investigated was to increase the spacing or pitch of the laser welds. This was attempted to reduce some of the localized delaminations of the PVD copper from the substrate in the heat-affected zone of the weld area. By increasing the pitch of the welds the issue of delaminations was eliminated. Decreasing the amount of welds also decreases the amount of current carrying capacity. The electrical load analysis was reevaluated to verify that the amount of welds was adequate to support the electrical loads.

Flight Experiment

Building upon the successful development of the solar cell interconnect a flight experiment will be used to validate the wrap around contact and associated PowerSphere technologies. All of the design improvements were incorporated into the Material International Space Station Experiment 5 (MISSE 5) flight experiment. The experiment consisted of three a-Si solar cells laser welded to a flex circuit and embedded in a composite frame as shown in Figure 6.

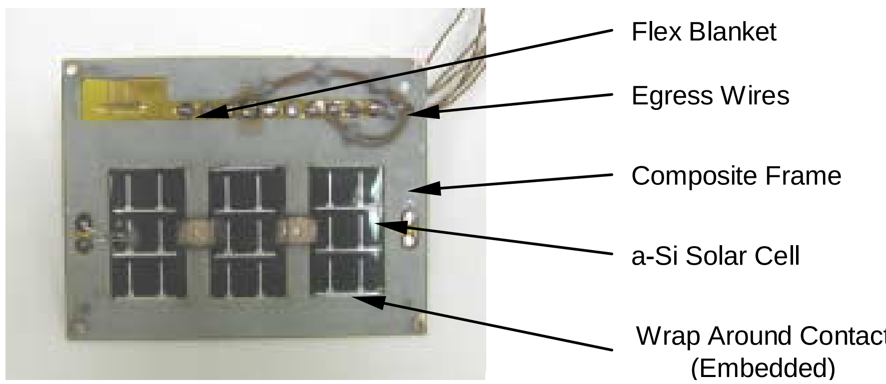

Figure 6- MISSE 5 Flight Experiment

The MISSE 5 experimental coupon will be mounted to the exterior of the International Space Station for an approximately one-year exposure. On orbit IV curves will be generated from the experiment to better understand the overall exposure to a LEO environment. The ability to demonstrate new technologies operating in the actual environmental conditions will prove to be an invaluable tool for future designs. Once the experiment is returned the materials will be evaluated and the effects of the LEO environmental exposure will be documented.

Significant improvements have helped to create a successful design and fabrication process for the PowerSphere solar cell interconnect. Fabrication of the MISSE 5 flight experiment helped to improve upon the initial concept and create an optimized design as shown in Figure 7.

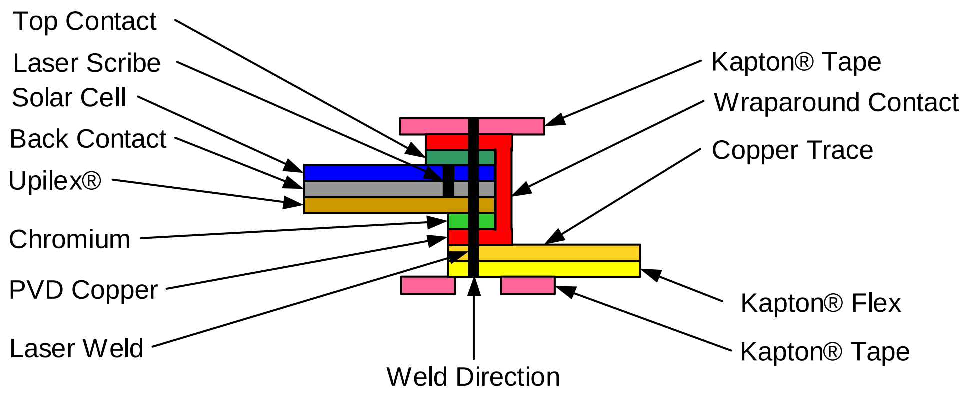

Figure 7- Optimized Interconnect Design Cross Section

In the optimized design the laser first makes contact with the Kapton® and then fully penetrates all layers with the plasma exiting the Kapton® tape on the opposite side. Once the solar cell interconnect has been welded, a frame will encapsulate the weld area and further reinforce the joint. A patent application has been filed with the United States patent office for the solar cell contact design co-developed by Aerospace Corp. and Lockheed Martin Corp.

Summary and Conclusions

The significant advancements in solar cell interconnect design and fabrication has provided a valuable building block for the PowerSphere program. Lessons learned from preliminary concepts, MISSE 5 flight experiment and thermally cycled coupons have provided a robust design. Future testing of the complete engineering design unit assembly will verify that the wrap around design is an effective concept for both electrically and mechanically joining a-Si solar cells to flex circuit.

Acknowledgment

This work was supported by NASA contract NAS3-01115.

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