

EVALUATION OF SOLAR CELL WELDS BY SCANNING ACOUSTIC MICROSCOPY

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SUMMARY

Scanning laser acoustic microscopy was used to nondestructively evaluate solar cell interconnect bonds made by resistance welding. Both copper-silver and silver-silver welds were analyzed. The bonds were produced either by a conventional parallel-gap welding technique using rectangular electrodes or new annular gap design with a circular electrode cross section. With the scanning laser acoustic microscope, it was possible to produce a real time television image which reveals the weld configuration as it relates to electrode geometry. The effect of electrode misalignment with the surface of the cell was also determined. A preliminary metallographic analysis was performed on selected welds to establish the relationship between actual size and shape of the weld area and the information available from acoustic micrographs.

INTRODUCTION

Welding is becoming an increasingly attractive alternative to soldering as a means of joining interconnect tabs to solar cell contact surfaces. The potential advantages include reduced weight, ability to withstand higher peak operating temperatures, increased thermal fatigue resistance, and improved automation capability for fabricating large arrays. Although the idea of welded solar cell interconnects is not new (ref. 1), acceptance of the technology remains limited due to a lack of experience in space flight applications and the need for a reliable technique for nondestructively evaluating bond quality. Whereas visual examination is generally sufficient for evaluating solder joints, welded joints require more sophisticated procedures because the bond area is hidden from view. Therefore, welded solar cell interconnect joints can be nondestructively evaluated only by indirect methods. The scanning laser acoustic microscope, which combines laser technology with ultrasonic technology, appears to be a good choice for this application. The instrument is capable of operating at high ultrasonic frequencies with resultant high resolution and, at 100 MHz, can produce a real-time image of an area about 2.3 by 3 mm in size at a magnification of 75.

It has previously been shown (ref. 2) that acoustic images of welded solar cell interconnect joints can be produced with the scanning laser acoustic microscope. However, substantiating evidence relating weld geometry to the acoustic information was not presented. It was the purpose of this investigation, therefore, to show that a relationship does exist between actual weld area and the results obtained with the acoustic microscope. This was accomplished by generating acoustic micrographs of welds having various geometric configurations and using the acoustic images to map out areas to be sectioned for metallographic analysis. Correlations between acoustic results and bond area were thus obtained.

MATERIALS, APPARATUS, AND PROCEDURE

Welding

Two types of electric resistance weld electrodes (fig. 1) were used to make the welds that were analyzed in this program. Figure 1(a) shows a pair of conventional parallel-gap electrodes made of molybdenum. The tips were rectangular in cross section measuring 0.65 by 1.25 mm on a side, with a gap of 0.25 mm. Figure 1(b) shows a new annular-gap electrode design, also made of molybdenum, which consists of a center electrode surrounded by an annular electrode. (The annular gap design was developed at the Lewis Research Center by C. R. Baraona and A. F. Forestieri). The outside diameter of the annulus was 2.0 mm and the inside diameter was 1.5 mm. The gap width was 0.13 mm.

The interconnect materials were either copper or silver foil, 0.05 mm thick. Solar cells were 2 by 4 centimeters and had wraparound contacts. The cells were not encapsulated in or attached to a solar array substrate or blanket material such as Kapton or aluminum honeycomb. The parallel-gap welds were made on glass covered cells, 400 μm thick, while the annular-gap welds were made on uncovered cells, 225 μm thick. The interconnects were welded to both positive and negative contact surfaces. Voltage settings ranged from 0.6 to 1.0 V, applied for 50 to 100 ms. The electrode tips maintained a load of 9 to 36 N on the tab for the duration of the welding operation.

Nondestructive Evaluation

The scanning laser acoustic microscope and its principles of operation are described in detail in reference 3. Figure 2 shows a sketch illustrating the application of the acoustic microscope for evaluation of solar cell welds. The solar cell is placed on the sample stage with the interconnect tab on top. A coverslip consisting of a clear plastic material and a film of gold a few angstroms thick on one surface is placed on top of the tab. The purpose of the coverslip is to provide a reflective surface for the laser beam in instances where the surface of the material being evaluated is not sufficiently reflective. The ultrasonic transducer, located at the bottom of a shallow well in the top surface of the sample stage, produces continuous waves at a frequency of 100 MHz and an incident angle of 10° to the cell surface. The ultrasonic waves are transmitted through the water couplant and into the solar cell. The energy is further transmitted into the interconnect tab wherever bonding exists. The interaction of sound waves at an angle to the top surface of the interconnect tab sets up a dynamic ripple which is then transmitted to the cover slip by a water coupling medium. A laser beam constantly scans the area in raster fashion. The intensity of the reflected laser light is modulated by the dynamic ripple and is proportional to the amplitude of sound waves at the reflective surface of the coverslip. These variations in light intensity are seen by the photodetector as an AC signal which is processed and used to produce a real-time TV image in black and white. The brightest regions on the screen represent areas of highest ultrasonic amplitude and black regions are indicative of little or no ultrasonic transmission. The real-time image covers an area 2.3 by 3 mm on a side at a magnification of 75. Acoustic micrographs at a magnification of 32 were made by photographing the TV screen using Polaroid film.

Metallography

To determine the ability of the acoustic microscope to provide visual evidence of the integrity of interconnect-cell bonds, it was necessary to perform a destructive analysis on selected welds. This was accomplished by selecting welded joints that produced unique or interesting patterns on the acoustic micrographs and sectioning the cell to permit a cross sectional view of the bond line between the interconnect tab and the solar cell contact. Sectioning was done with a dicing saw. The weld specimens thus removed were mounted on edge in an epoxy encapsulation that served as a specimen holder. The encapsulated specimens could then be ground in specified increments to obtain views of planes at predetermined locations within the weld joint. The extent of the bond or nonbond in each plane was determined metallographically. Standard techniques were used to polish the metallographic specimens. Since a complete microstructural study of the weld joint was not required, photo-micrographs were taken of the surfaces in the unetched condition only. Surfaces were considered to be bonded when no interfacial features indicative of disbond could be detected at a magnification of 750.

RESULTS AND DISCUSSION

Results obtained with the scanning laser acoustic microscope and the related metallographic analyses are presented in figures 3 to 5. Each figure shows a photograph of the surface of the interconnect tab after welding, an acoustic micrograph of the region of the weld, and a photomicrograph of a crosssection through the middle of the weld. The ability of the acoustic microscope to describe the size and shape of the bonded area is discussed.

Figure 3 shows the results obtained from an analysis of a joint made by welding a copper interconnect tab to a silver solar cell contact using the parallel-gap resistance welding technique. A partial imprint of the electrode pair was embossed in the surface of the relatively soft copper (fig. 3(a)). The partial imprint indicates that the electrodes applied nonuniform pressure to the tab, probably because of a minor misalignment relative to the solar cell surface. A complete imprint would consist of two parallel rectangles which resemble footprints. Figure 3(b) is an acoustic micrograph of the weld and surrounding area. On first observation it was not clear whether the weld zone was represented by the white region of the acoustic micrograph only or by the white area plus the smaller gray area immediately to the left. Thus, the actual size and shape of the weld had to be accurately determined by other means. This was accomplished in two ways. First, it was found that the unbonded part of the copper tab could be removed by folding it back over the bonded part and carefully tearing it at the perimeter of the weld nugget with tweezers, leaving the welded part of the tab in place. The result of this operation is shown in figure 3(c). The welded copper material is intact in the center of the picture, surrounded by the silver solar cell contact surface. The black residue on the contact surface is a material of unknown origin which was present beneath the unbonded part of the tab. Note the partial footprint of the right hand electrode which covers almost half of the welded copper tab. It is obvious that the weld nugget was not centered between the electrodes nor was it confined to the region beneath the electrodes. It is also apparent that, although the electrode footprints provide some information regarding the general location, they say little about either the size or the shape of the weld. Figures 3(b) and (c) show that the weld is represented only by the white area on

the acoustic micrograph, which closely approximates the size and shape of the weld nugget. Although not apparent in this series of photographs, it was further observed that the acoustic microscope can also reveal the location of the weld relative to a feature such as the edge of the tab, which is visible in the top of figure 3(a).

Additional information about the dimensions of the weld zone as well as the nature of the bond was obtained through a metallographic analysis. Figure 3(b) shows two dark spots within the white region of the acoustic micrograph, indicating the presence of defects which blocked ultrasonic transmission. A cross section through the larger of these defects is shown in figure 3(d). The photomicrograph reveals a bonded section measuring 0.78 mm long with a nonbonded portion in the middle. The nonbond, which corresponds to the dark spot on the acoustic micrograph, is 225 μm long and only 4 μm wide. Other bondline pores less than 30 μm in diameter are visible in the photomicrograph but were not resolved individually in the acoustic micrograph.

Figure 4 presents the results of an analysis of a joint made by welding a silver interconnect tab to a silver solar cell contact using the annular-gap electrodes. The electrode imprint on the tab surface is shown in figure 4(a). The circular feature was made by the annular electrode, and the spot in the middle is the result of pressure applied by the center electrode. The imprint on the tab is closely approximated in size and shape in the acoustic micrograph (fig. 4(b)), indicating that welding occurred beneath a major portion of the circumference of the annular electrode and the middle part of the center electrode. Supporting evidence is shown in the photomicrograph of a cross section through the middle of the weld (fig. 4(c)). Two bonded sections, one in the middle of the photomicrograph and one on the right side, correspond to white areas of ultrasonic transmission in the acoustic micrograph. Little or no bonding is evident on the left side of the photomicrograph, which agrees with the information in the acoustic micrograph.

Figure 5 shows the results obtained from another silver-silver weld made with annular-gap electrodes. The imprint embossed in the tab surface (fig. 5(a)) looks similar to the one in figure 4(a). However, the acoustic micrograph (fig. 5(b)) indicates that the weld geometry is quite different from that in figure 4. Bonding appears to have taken place primarily under one side of the annular-gap electrode, completely spanning the gap. Little bonding appears to have taken place under the other half. The photomicrograph (fig. 5(c)) of the cross section through the middle of the weld confirms the information obtained from the acoustic micrograph. With the exception of some bondline porosity, the bond between the tab and the metallized contact is continuous under the right hand side of the electrodes. On the left, little or no bonding exists, again confirming the evidence presented in the acoustic micrograph.

CONCLUDING REMARKS

The scanning laser acoustic microscope appears to be a viable tool for non-destructive evaluation of solar cell interconnect bonds made by welding. Metallographic analyses of selected welds showed that acoustic microscopy can accurately determine the size and shape of welded areas in both uncovered cells and cells with a protective glass cover adhesively bonded to the front surface. Although the glass cover and adhesive increase scatter and decrease

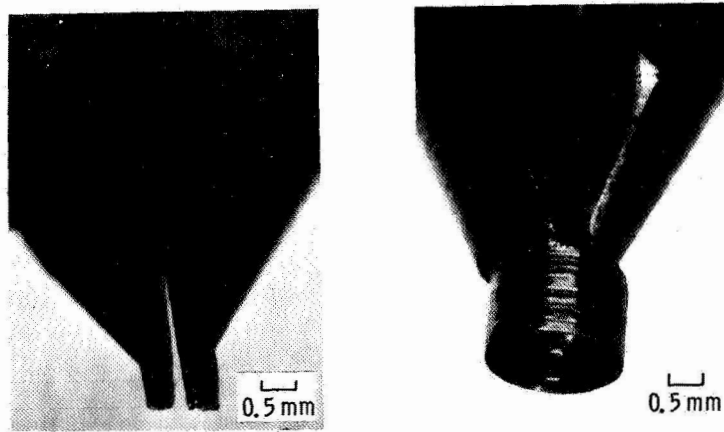
resolution, the adverse effects appear to be small, and the final result is acceptable for cells in the thickness range evaluated in this investigation.

In addition to generally describing the size and shape of weld areas, the acoustic microscope demonstrated a capability for detecting small nonbonded areas of the order of 200 μm diameter within an otherwise continuous weld zone. Conversely, it is expected that welded areas 200 μm diameter and larger could be detected against a background of unwelded material.

The results of this investigation suggest that application of scanning laser acoustic microscopy can be extended from individual solar cells to solar cell arrays, providing the cells are not encapsulated or attached to a substrate or blanket material in such a way as to block the transmission of acoustic energy. Any air gap between the substrate and the cell in the region to be nondestructively evaluated would preclude evaluation by ultrasonic transmission. It is therefore recommended that array manufacturers consider the requirements for successful nondestructive evaluation in the design stage to insure that accommodations for adequate inspection are made.

REFERENCES

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2. Stella, P. M.; Vorres, C. L.; and Yuhas, D. E.; SLAM Examination of Solar Cells and Solar Cell Welds. Presented at the Fifteenth IEEE Photovoltaic Specialists Conference, May 12-15, 1981.
3. Kessler, L. W.; and Yuhas, D. E.: Acoustic Microscopy - 1979. Proceedings of the IEEE, Vol. 67, No. 4, April 1979.



(a) Conventional parallel-gap electrodes.
 (b) Annular-gap electrodes.

Figure 1. - Resistance weld electrodes used for joining solar cell interconnects.

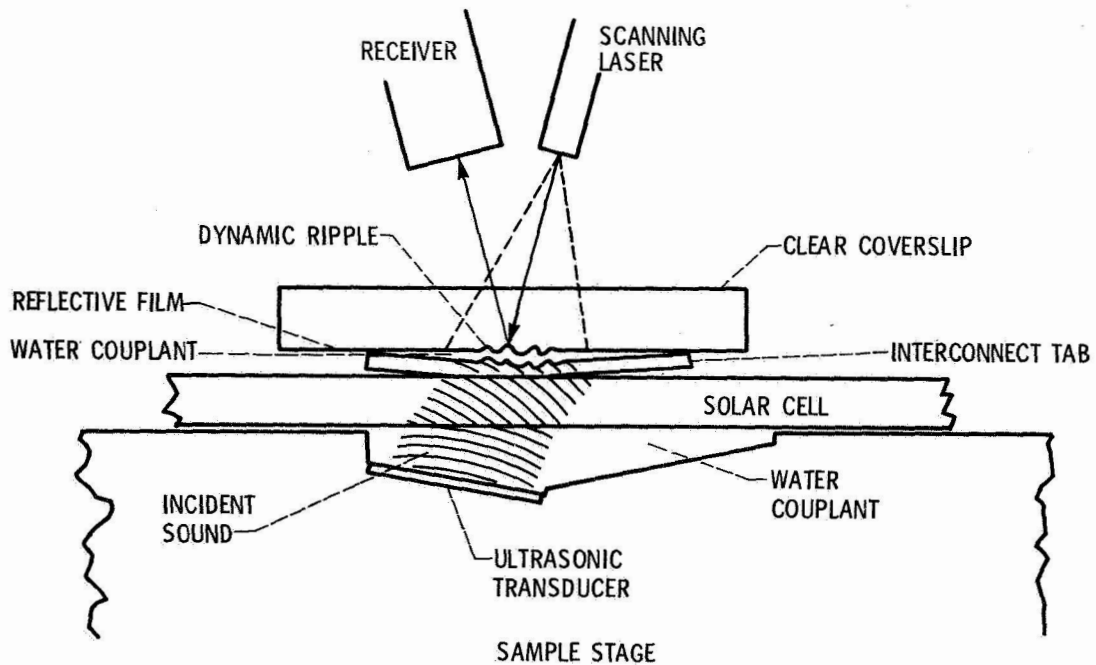
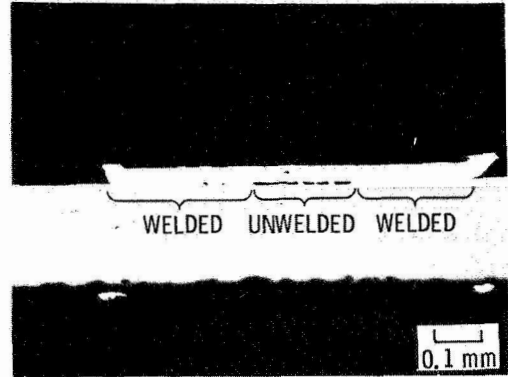
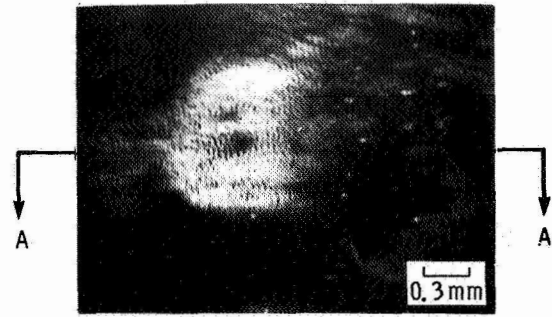
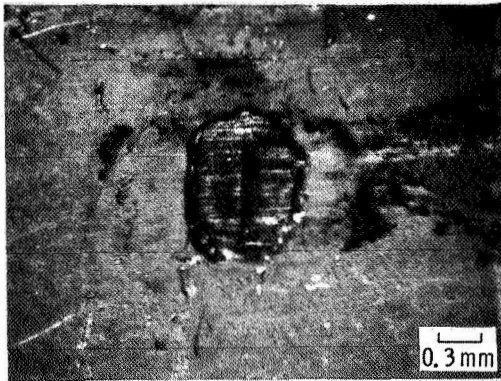
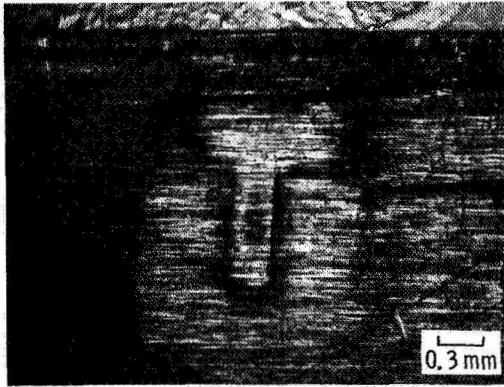
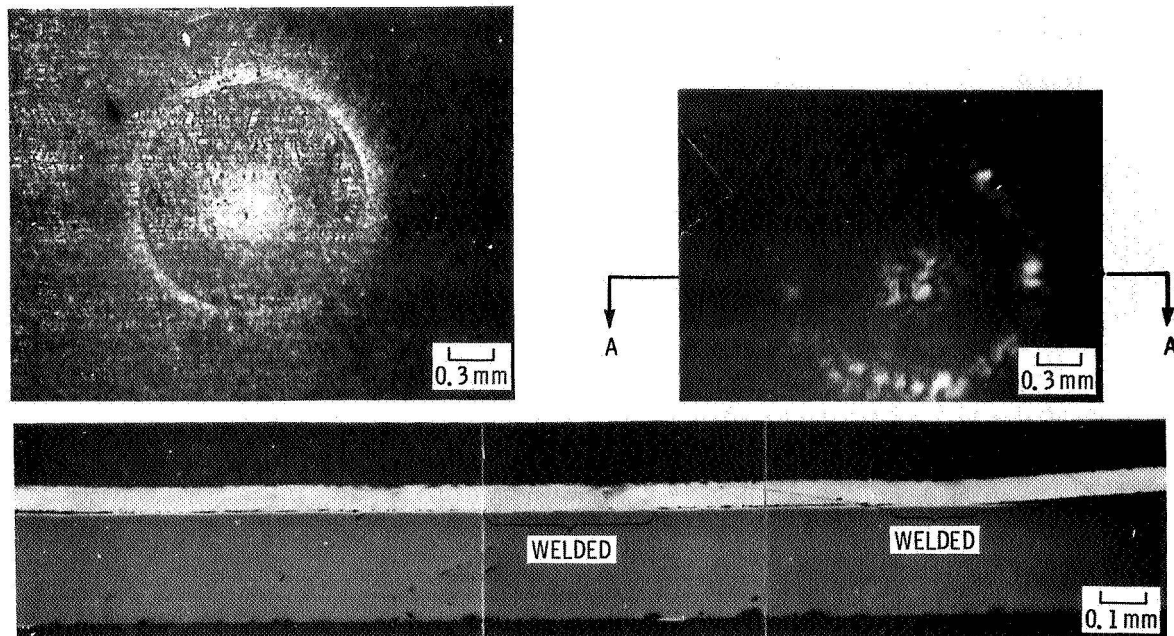


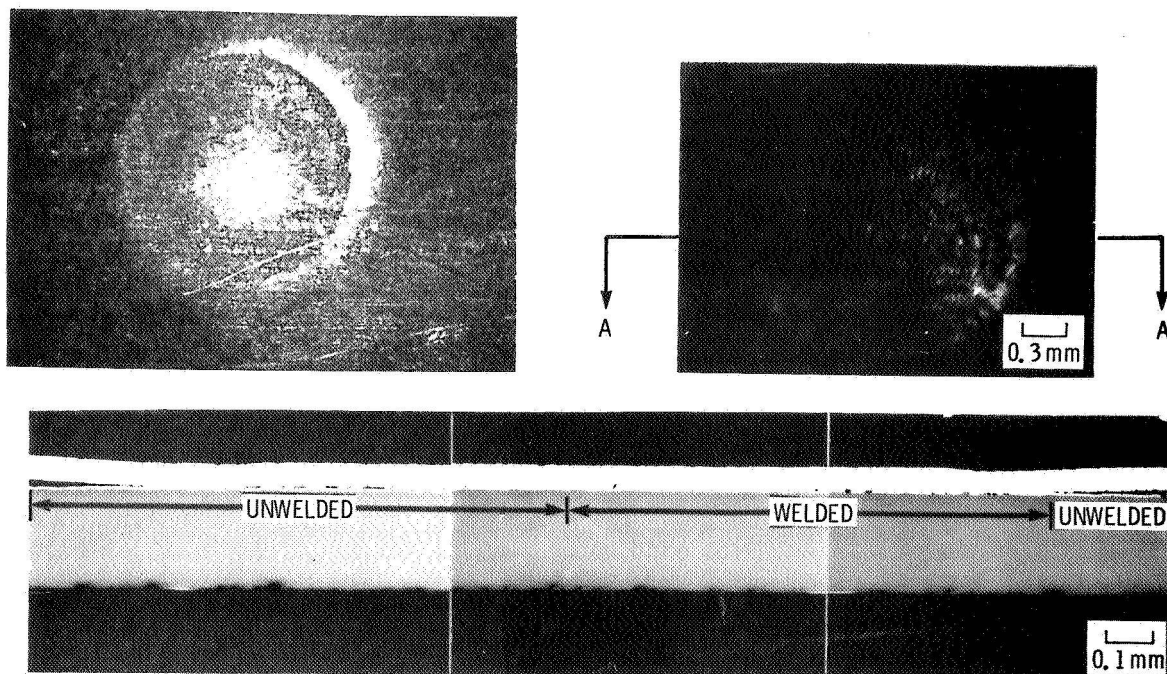
Figure 2. - Application of the scanning laser acoustic microscope for nondestructive evaluation of solar interconnect welds.



(a) Partial imprint on tab surface.
(b) Acoustic micrograph of weld zone.
(c) Nugget size revealed by removal of unwelded portion of tab.
(d) Photomicrograph of cross section A-A through middle of weld zone.
Figure 3. - Results of destructive and nondestructive analysis of Cu-Ag parallel-gap weld.



(a) Complete electrode imprint of tab surface.
 (b) Acoustic micrograph on nearly complete weld.
 (c) Photomicrograph of cross section A-A through middle of weld zone.
 Figure 4. - Results of destructive and nondestructive analysis of Ag-Ag annular-gap weld zone.



(a) Complete electrode imprint of tab surface.
 (b) Acoustic micrograph on nearly complete weld.
 (c) Photomicrograph of cross section A-A through middle of weld zone.
 Figure 5. - Results of destructive and nondestructive analysis of Ag-Ag annular-gap weld zone.