Hermetic Packaging for Microwave Modules

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D. L. Hollar

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AlliedSignal Inc.
Federal Manufacturing
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P. O. Box 419159
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HERMETIC PACKAGING FOR MICROWAVE MODULES

D. L. Hollar

Published October 1996

Final Report
D. L. Hollar, Project Leader

Project Team:
A. W. Robbins

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Abstract

Microwave assemblies, such as radar modules, require hermetically sealed packaging. Since most of these assemblies are used for airborne applications, the packages must be lightweight. The aluminum alloy A-40 provides the needed characteristics for these applications. This project developed packaging techniques using the A-40 alloy as a housing material and laser welding processes to install connectors, purge tube, and covers on the housings. The completed package successfully passed the hermetic leak requirements and environmental testing. Optimum laser welding parameters were established in addition to all of the related tooling for assembly.

Summary

New microwave assemblies, such as radars, require hermetically sealed packaging that is physically compatible with the electronic components inside and lightweight for airborne applications. A survey of available aluminum alloys revealed that the A-40 alloy (40% silicon-60% aluminum) possessed a good match for the compatibility and lightweight requirements. Welding was selected for hardware assembly, to provide package hermeticity. However, the general consensus of the industry is that A-40 is not rated as a weldable alloy. Technology developed on this project has established a laser welding process that will allow welding of the A-40 to the other hardware components and provide a hermetic seal. Weld joint geometries, laser welding parameters, and tooling were developed to produce prototype assemblies. The completed packages developed on this project were subjected to helium leak testing and environmental thermal cycling with successful results. Techniques were developed to eliminate weld cracking and improve weld penetration consistency by manipulation of the weld metal chemistry. Weld porosity was reduced by vacuum bake-out of the machined housing and careful control of the subsequent gold plating process. A preliminary study was conducted to develop an alternate housing material that could be cast to the housing near-net shape. The near-net shape could reduce the module machining costs. Future work on the module package should include developing methods for eliminating internal weld spatter and a more thorough evaluation of the MMC alternate housing material. An outside contract with the RF connector vendors should be considered to create an aluminum shell RF connector suitable for weld installation in the housing.

Discussion

Scope and Purpose

This project was initiated to develop a packaging method for an electronic microwave module. The module package must provide a hermetic environment as well as be compatible with the microelectronic components contained inside the module. The package must also be cost effective to produce and meet stringent environmental survival requirements.

The scope of the project included selection of compatible materials for the assembly, design of the package, and development of a laser welding process to install hardware components. Weld joint configuration, weld process parameters, and housing plating processes were required to finalize the package definition. Testing of the package to specific requirements was included to verify that the final assembly design requirements were met.

Prior Work

Previous work on this project explored various materials and material properties that would meet the requirements for the module housing. Metal chemistry and alloying effects of the A-40 alloy as well as preliminary welding results and weld joint geometries were discussed. All prior work results are documented in the report KCP-613-4385, *Microwave Module YAG Laser Weld Development,* published July 1991.[1]

Activity

Background

New microwave assemblies, such as radars, require hermetically sealed packaging. The packaging design must not only enclose the electronic components, but must be physically compatible with these components. Ceramic circuit boards are currently being used in microwave products and are bonded directly to the metal housings. In addition, most new microwave assemblies involve airborne applications. These two requirements suggest that the radar assembly housing material must be lightweight and have thermal coefficient of expansion (TCE) characteristics similar to ceramic.

Aluminum alloys come to mind as housing materials suitable for these microwave applications. A survey of available aluminum alloys revealed that the A-40 alloy (40% silicon-60% aluminum) possessed a good match for the two primary properties, namely lightweight and compatible TCE. Additional hardware required to complete the packaging included the housing covers, purge tube, and logic connector. This hardware must be welded in place to provide the hermetic seal. However, the general consensus of the industry is that A-40 is not rated as a weldable alloy. Technology developed on this project has established a laser welding process that will allow welding of the A-40 to the other hardware components and provide a hermetic seal.

Laser Welding

The housing covers must be welded in place after the electronics are installed, and this requirement places significant restrictions on the welding process selected. The Nd:YAG laser welding process was utilized for installing the covers and other hardware because it provides a very precisely controlled heat input. The welding process was developed and characterized using a 200-W pulsed Nd:YAG laser. The laser welding process successfully provided the hermetic seal welds without damage to the sensitive internal electronic components. Welding processes and tooling were developed for four specific joint configurations. The four weld configurations consisted of two covers (essentially identical), logic connector, purge tube, and purge tube sealing. The purge tube is used for the hermetic leak testing operation. Special tooling for the purge tube crimp seal, prior to the welding operation, was also developed. Figures 1 through 5 illustrate the housing and additional hardware components.

RF Connector Installation

Two RF connectors must also be installed into the housing. Aluminum shell RF connectors were not available, nor would the connector vendors consider a special run of aluminum shell connectors. Therefore existing commercial connectors were soldered in the gold-plated areas adjacent to the purge tube (see Figure 3).

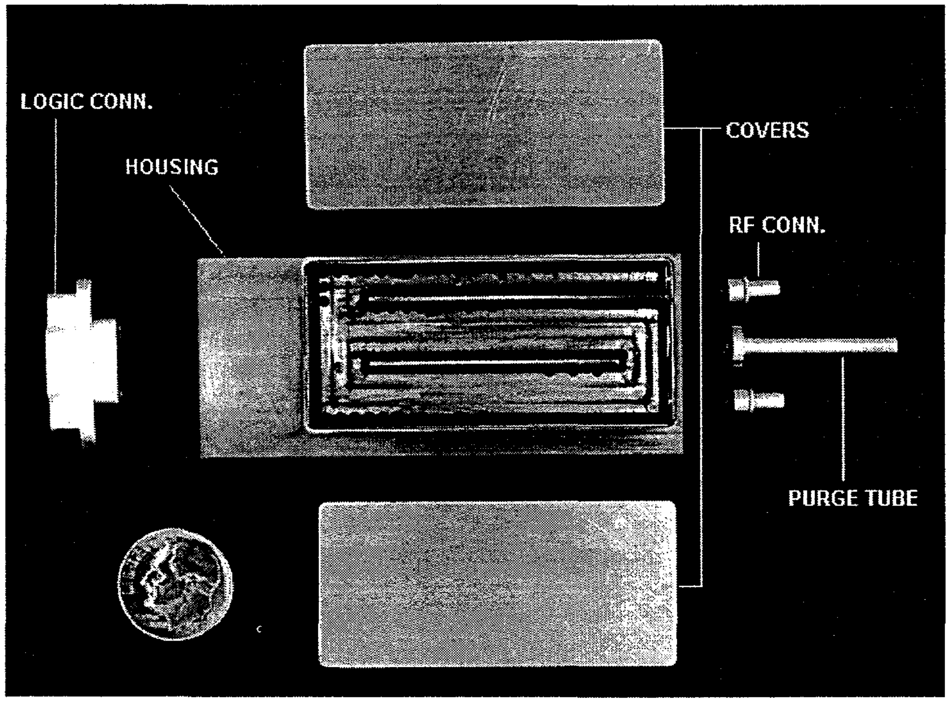

Figure 1. Exploded View of the A-40 Housing and Additional Hardware

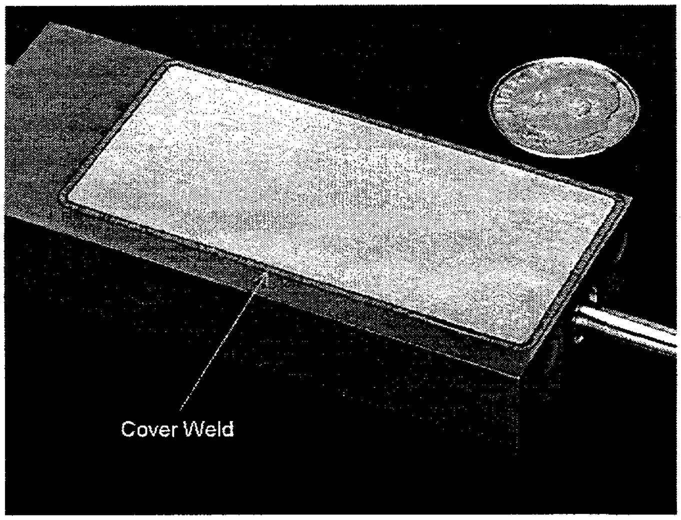

Figure 2. View of the Cover Welded into the Housing

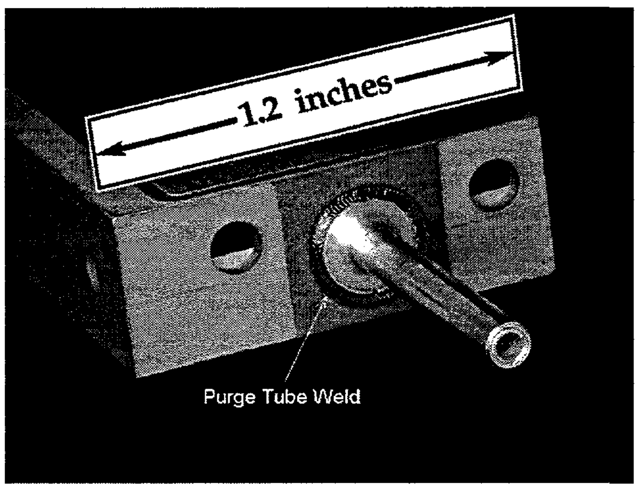

Figure 3. Purge Tube Welded into the Housing

An experiment was conducted to determine if the kovar shell connectors could be welded into the A-40 housing. Since the kovar connectors cannot be welded directly to the aluminum housing because of metallurgical incompatibility, an interface adapter would be required to join the aluminum and kovar. Some small adapters were machined from explosively clad aluminum/stainless steel stock. This would allow a metallurgically compatible weld between the kovar connector shell and stainless steel side of the adapter, as well as the A-40 housing and the aluminum side of the adapter. The experiment provided mixed results. It proved that there is potential for the clad metal adapter technique; however, more development effort would be required to prove-in the adapter and welding process.

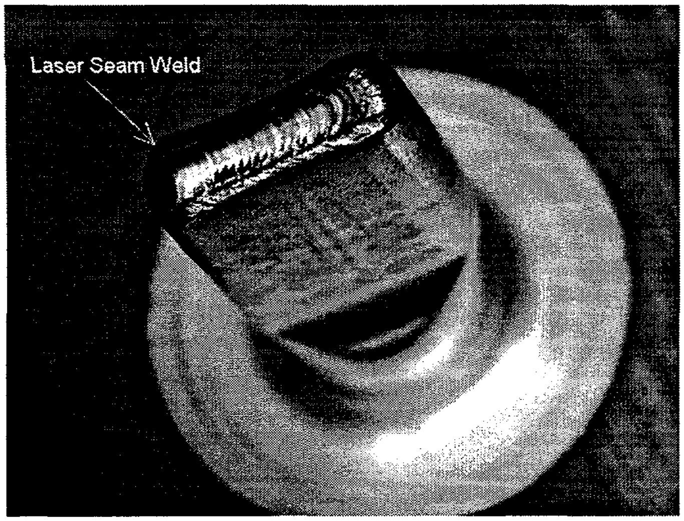

Figure 4. An Enlarged Photograph of the Purge Tube Sealing Weld, After Pinch-Off

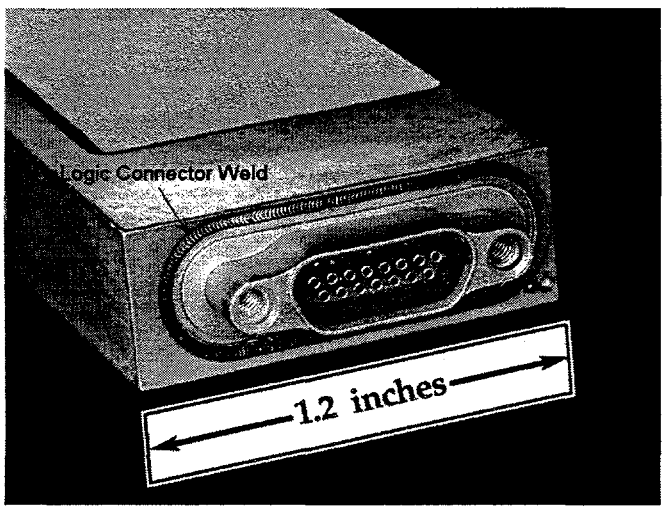

Figure 5. Logic Connector Welded into the Housing

Additional Hardware Material Selection

As noted in the previous project report, KCP-613-4385, 1100 and 6061 aluminum alloys were evaluated with respect to laser welding compatibility, while using the A-40 as the housing material.[1] It was found that both aluminum alloys provided a weldable, metallurgically compatible combination for the A-40. The 1100 alloy was chosen as the material for the covers and purge tube. The vendor for the logic connector rejected the 1100 alloy for use in the connector housing. As a result, the vendor selected 6061 and 2219 aluminum alloys to fabricate connectors used on this project. Welding results indicated that both connector housing alloys are compatible with A-40, when used in the current weld joint geometry. Some weld crack sensitivity might be expected when welding the 6061 alloy. The additional silicon from the silicon-rich A-40 housing is mixed in with the 6061 during the weld, thus minimizing weld crack sensitivity. The next topic provides additional insight into the metal chemistry.

Centerline Weld Cracking

An observation made during this welding evaluation illustrated the importance of the A-40 housing silicon enrichment effect. The laser welding process was originally developed to track the laser beam path on the weld joint centerline. During preliminary work, an occasional weld joint centerline crack would occur on the housing-to-cover weld. Standard aluminum welding practice suggested that the addition of more silicon to the weld joint could eliminate the cracking problem. To enrich the weld joint silicon content, the beam path was then offset 0.008" to the outside of the centerline, therefore favoring the housing side of the weld joint. Offsetting the beam to the housing side caused additional silicon from the A-40 to be mixed into the weld joint. Weld centerline cracking was eliminated using the offset beam path.

The cover-to-housing weld joint geometry also contributed somewhat to the centerline cracking problem. The cover weld is a highly restrained weld joint and doesn't provide any stress relief at the weld. The purge tube and logic connector weld configurations each have a stress relief groove adjacent to the weld. A stress relief feature is not an option for the cover weld because of the cover/housing layout. Figure 6 illustrates the weld joint geometry for each of the welds.

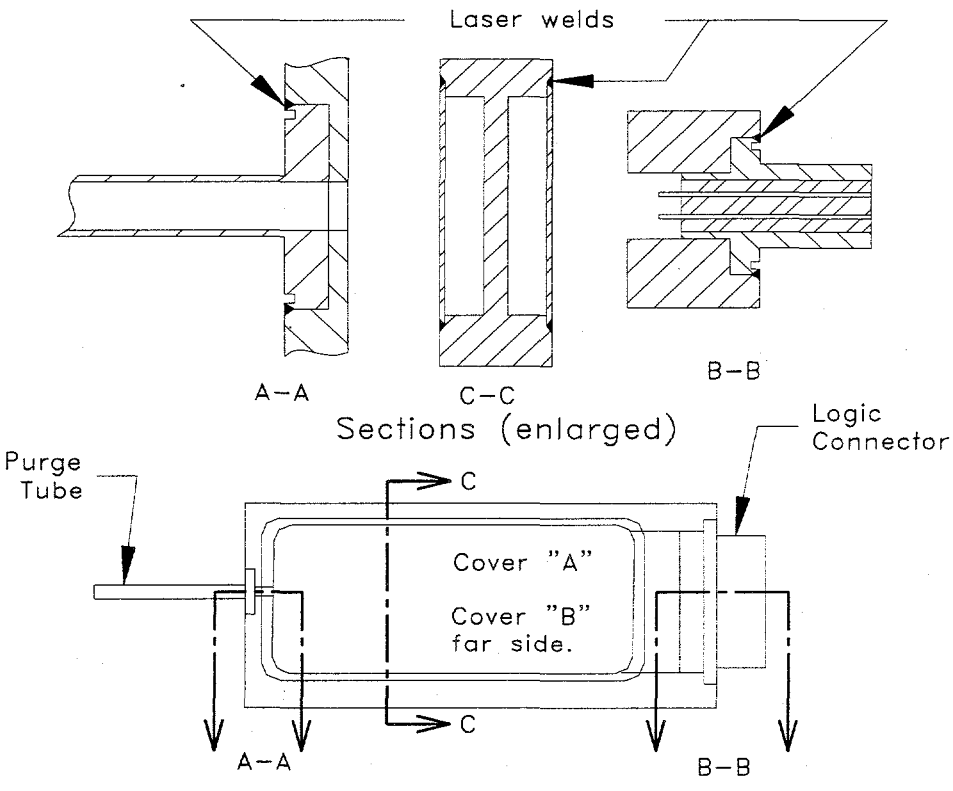

Figure 6. Weld Joint Geometry for Each of the Hardware Components

Initially centerline cracking was not observed on the purge tube or logic connector weld. These two welds were welded with the 0.008" offset process as defined for the cover weld, in an attempt to use consistent processing on all welds. The 0.008" offset caused an occasional leak in these welds; as a result, the process for the logic connector and purge tube welds was returned to centerline beam path tracking.

Weld Joint Penetration

Weld joint penetration inconsistency was observed from the metallurgical cross sections of the cover weld joints. Metallurgical cross sections shown in Figure 7 were prepared from two different areas of the same cover weld. Weld energy and the other weld parameters were monitored and found to be consistent. The cause of the inconsistent penetration was resolved in concert with the weld cracking problem noted above. It was found that the wrought aluminum cover was more reflective to the laser energy than the A-40 housing. As a result, a slight variation in beam location on either side of the centerline, typical of normal manufacturing tolerances, translated into more or less energy being absorbed by the weld joint. It is known that energy absorption is directly related to weld penetration. Moving the laser beam path onto the A-40 housing improved the weld joint penetration consistency as well as eliminating the centerline cracking previously described. Figure 8 illustrates the improved weld joint penetration consistency. It is thought that the very high silicon content of the A-40 alloy is the factor contributing to the greater laser energy absorption.

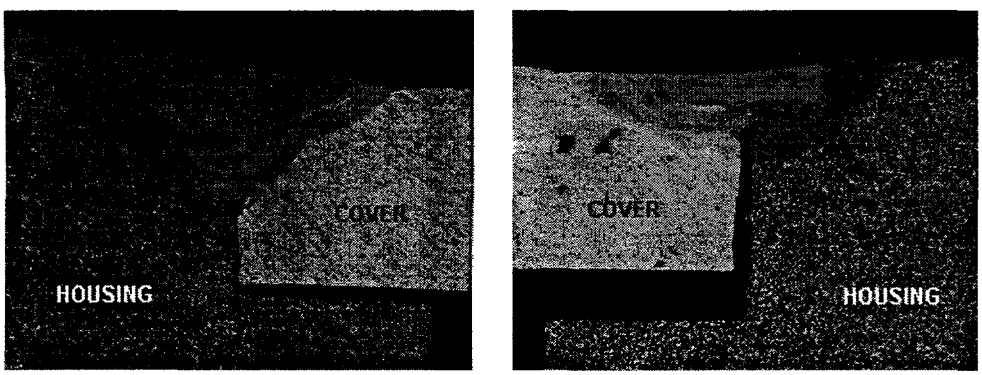

Figure 7. Photomicrographs of the Weld Penetration Results Using the Centerline Path Tracking. (Note the variation in penetration.)

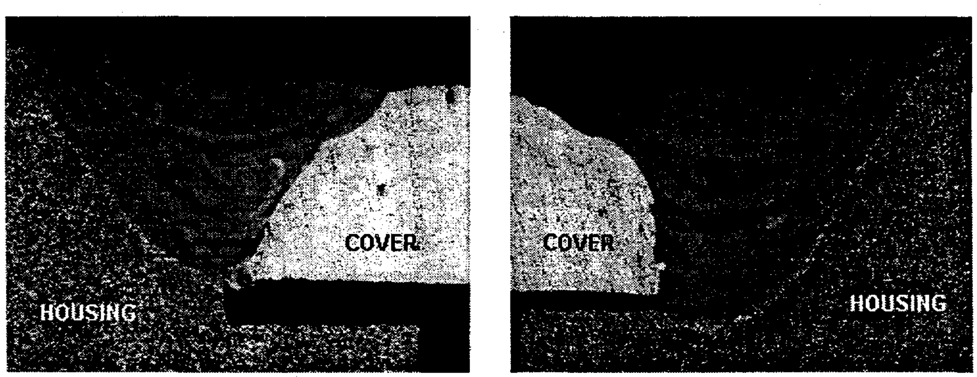

Figure 8. Photomicrographs of Weld Penetration Results Using the 0.008" Offset Path Tracking

Unfortunately, the weld penetration consistency improvement using the beam path offset was not discovered until late in the evaluation. As a result, all of the spatter and hermetic seal test data was accumulated using the centerline path tracking. It was expected that the hermetic test data would be improved by more consistent penetration; however, the potential for internal weld spatter probably increased with the improved penetration.

Weld Schedule Development

A weld process parameter evaluation was performed to determined optimum machine control and process settings for the laser welds. Weld penetration and consistency were used as the criteria. Weld spatter and porosity are usually considered as part of weld schedule development. However, these two items are addressed in the sections *Internal Weld Spatter* and *Housing Preparation and Plating.*

Three process parameters were varied, and metallurgical cross sections were made at each setting to establish penetration. Weld pulse length, Joules per pulse, and beam defocus (spot size) were considered. Weld pulses per second and travel speed were held constant at 8 pps and 3.6 in./min, respectively. These parameters were not varied since they will also affect the weld energy input. An effort was made to achieve 100% penetration on the cover weld. The setting that produced full penetration on the cover weld was considered as "nominal." The parameters were then varied about the nominal settings to predict process robustness.

All welding was performed in the beam-defocused mode with sharp focus located above the work surface. The defocus mode provides a larger beam spot size and reduces the potential for drilling. A six-inch focal length lens was used and, because of its longer beam waist, reduces the effect of beam focus position.

Finally, the nominal setting of 8.5 Joules per pulse, 3 ms pulse width, and 0.16-inch defocus was selected for the cover weld. Using this setting for the purge tube and logic connector installation also provided satisfactory results. It was found that the purge tube sealing weld required a slightly greater energy of 9.0 Joules with two passes, each offset 0.01" from the tube seam centerline.

Along with weld schedule development, thermocouple temperature data is routinely collected on welded assemblies containing thermally sensitive components. The thermocouples are usually placed on the housing adjacent to the welds to determine if damaging temperatures are produced. Even though the laser welding process provides a very precisely controlled heat source, the thermal sensitivity of the internal microelectronics was of paramount concern in establishing the optimum welding process. No housing thermocouple temperature data was accumulated in this evaluation since the housing was only warm to the touch immediately after welding the covers in-place.

Environmental Testing

Two complete housings were welded using the nominal weld parameters and process. These housings were leak tested and then temperature cycled. Both assemblies indicated <2 X 10^{-8} cm^3/s He leak rates prior to the thermal cycle. The thermal cycle schedule is noted below:

- Initial soak: 230°C for 30 minutes
- Cycled 50 times, -20°C to 85°C in 1-hr cycles

The assemblies were leak tested after the thermal cycling, and test results indicated that there was no change in the hemeticity of the welds.

Internal Weld Spatter

As with most welding processes, including laser welding, some weld spatter is generated during the welding process. The laser beam not only melts the weld metal but causes a micro-eruption as some of the metal is vaporized. The micro-eruption produces spatter which usually takes the form of very small particles of solidified metal. Generally the spatter from a weld is expelled outside of the assembly. Since this assembly contains unsealed microelectronics, there has been a concern that even very small spatter particles could be a problem if they migrated inside the package.

An evaluation was performed to determine if spatter did enter the internal cavity of the package during welding. Since the covers are the last items to be welded, this weld has the greatest potential to create an internal weld spatter problem. The logic connector and purge tube are welded into the housing first, before any of the electronics are installed. The housing can then be cleaned prior to installation of the electronic components. The purge tube seal weld is on the outside of the crimp seal area, thus preventing any particle migration into the assembly for that weld.

The spatter evaluation test part was designed to simulate the cover weld. Noting Figure 9 illustrating test part, the ceramic plate was located such that any internal weld spatter would most likely be trapped on the surface of the plate and where it could be observed. Next, samples were welded at the established weld schedule using the test part setup. The weld schedule parameters were varied and samples were also welded at several different weld parameter settings. The parameter variation was selected to simulate production "worst case" parameter drift. After welding, the ceramic plates from each sample were carefully removed and examined under a microscope at 70X for evidence of weld spatter. The weld samples were leak tested to determine if the weld produced a hermetic seal. The samples were then metallurgically cross sectioned to determine how much weld penetration was achieved. The results of this evaluation are tabulated in Table 1.

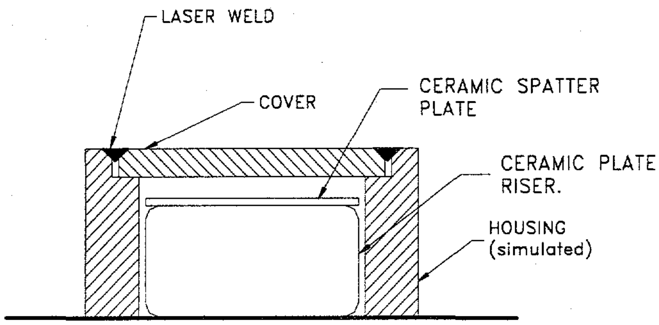

Figure 9. Weld Spatter Test Specimen and Setup

Table 1. Preliminary Weld Spatter Evaluation

Sample No.	Weld Schedule	Spatter Y/N	Leak Rate[4]	Weld Penetration[1,2]	Weld Parameter Changes
2	A	N	5×10^{-9}		Nominal
44		N	1×10^{-8}	0.013-0.014-0.013	
47		N	3×10^{-9}		
30	B	Y	3×10^{-9}		Reservoir
29		Y	3×10^{-9}		voltage
28		Y	3×10^{-9}	0.010-0.021-0.021	increase[3]
27	C	N	1×10^{-4}	0.014-0.007-0.004	Pulse width
26		Y	3×10^{-9}		increase[3]
24		Y	2×10^{-9}		
10	D	N	1×10^{-4}	0.006-0.007-0.002	Pulse width
7		Y	1×10^{-5}		and voltage
5		N	1×10^{-3}		increase
25	E	N	2×10^{-9}		Increase
8		N	1×10^{-4}	0.007-0.021-0.015	spot size
9		Y	8×10^{-9}		
41	F	N	1×10^{-5}	0.017-0.014-0.018	Increase
4		N	1×10^{-7}		voltage and
6		N	1×10^{-2}		spot size
21	G	Y	1×10^{-4}	0.006-0.005-0.007	Increase
23		N	1×10^{-2}		pulse width
39		N	1×10^{-4}		and spot size
54	H	N	2×10^{-2}		Increase voltage,
40		Y	5×10^{-9}	0.007-0.017-0.010	pulse, width,
58		N	3×10^{-9}		and spot size

(1) One sample was randomly selected from the group of three, and penetration cross sections were performed for three different locations on this sample.
(2) All settings at 8 pulses/second, 3.6 inches/minute travel speed.
(3) Increasing these parameters increases weld energy.
(4) cm^3/s Helium

The tabulated results were used to establish the probability for internal weld spatter as a function of the laser weld parameters. As expected, the higher energy levels increased the probability of producing spatter.

This spatter evaluation should be considered a coarse screening process. Because of the uncertainty of the experiment, this screening could not reliably guarantee that spatter was not produced for a given weld schedule. The evaluation only confirmed that spatter was being generated. Even though spatter was not observed on some samples at the higher energy levels, speculation suggests that spatter may have been produced and not observed. Spatter particulate could have been small enough to be overlooked or not firmly attached to the ceramic and lost.

In conclusion, internal weld spatter should be considered a potential problem for future product development. Additional development work will be required to eliminate internal weld spatter. This evaluation indicates that spatter mitigation must be achieved by means other than weld schedule optimization. A redesign of the weld joint could possibly provide a mechanical barrier to prevent spatter from entering the module cavity.

Purge Tube Sealing and Leak Testing

Welds on the final assembly are helium leak tested prior to sealing the purge tube. Effort to date has incorporated leak testing at the final assembly level. However, it is recommended that the assembly be leak tested after the purge tube and logic connector are installed and prior to the installation of the electronic components. At this point the risk of rework to the assembly and cost of the hardware are minimized. It would even be prudent to leak test the logic connectors prior to installation, considering the cost of scrapping the machined housing. Replacement of the logic connector is not possible once it is welded into the housing. Some of the logic connectors purchased initially exhibited leaks. In general, few leaks were detected in assembly welds when using the optimum welding process. In some cases, repairs were accomplished with a rework welding operation on leaks due to defective welds.

The leak testing procedure requires that the purge tube be pinched off, creating a hermetic seal before removing the leak testing apparatus. See Figure 10 for an illustration of the sealing procedure. Tooling was developed for the purge tube pinch-off operation that would maintain the hermetic seal until the laser weld sealing operation could be performed.

Figure 11 illustrates the pinch-off tooling. With the pinch-off tool in place, the purge tube is cut off flush with the upper surface of the pinch-off tool. The pinch-off tool and the completed assembly are placed in the laser work station. A laser seam weld is completed along the end of the pinched tube. The pinch-off tool is removed after the weld is completed. Although not incorporated in development parts, standard leak testing protocol suggests back filling the assembly with a slight over pressure of a tracer gas (e.g., helium) and performing a leak test on the purge tube seal weld also. See Figure 12 for an example of the purge tube seam weld and a metallurgical cross section of the weld.

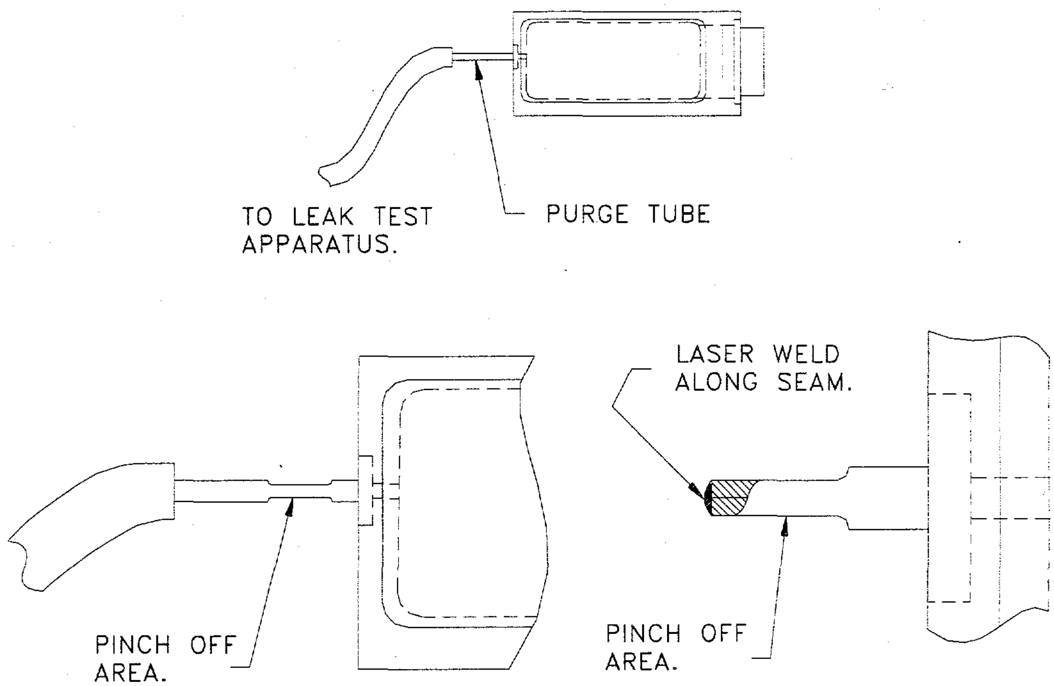

Figure 10. Purge Tube Pinch-Off and Laser Weld Sealing

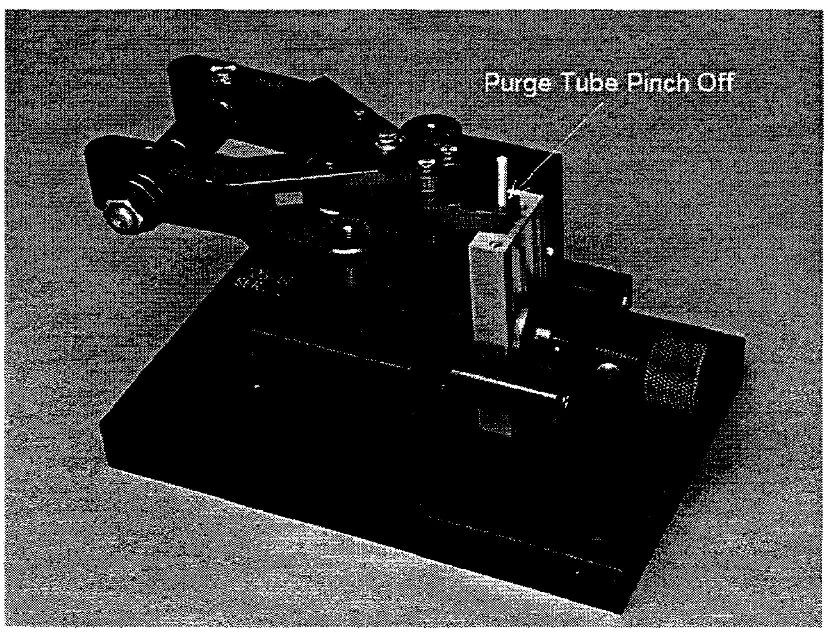

Figure 11. Purge Tube Pinch-Off Fixture in Preparation for the Pinch-Off Operation

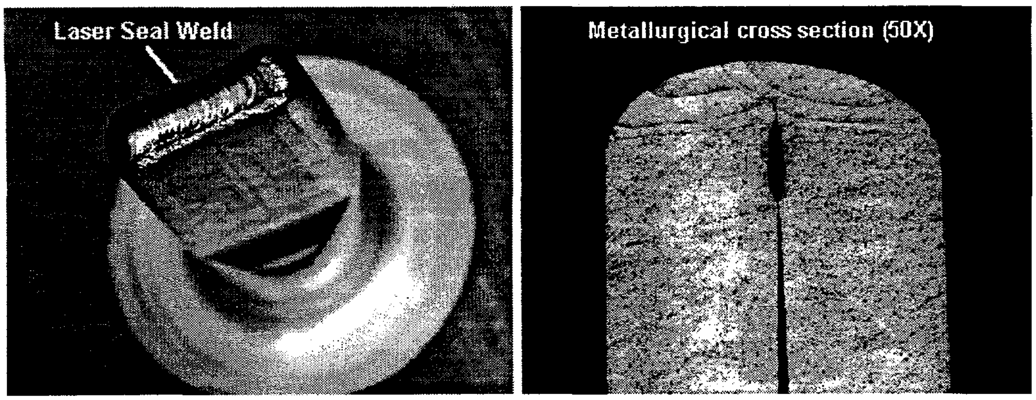

Figure 12. Purge Tube Seal Weld and Metallurgical Cross Section of the Weld

Alternate Housing Material Study

As previously noted, the A-40 aluminum alloy was chosen for the housing material. The A-40 provided a good compromise for weight, thermal coefficient of expansion (TCE), thermal conductivity, and weldability. The A-40 housings were machined from wrought bar stock. However, it was found that substantial machining time was required to complete the housing. Two reasons were identified for the lengthy machining time. First, the A-40 is difficult to machine and close tolerances were needed to meet the design requirements. To compound the machining difficulty, a significant volume of metal was removed from the bar stock to complete the housing. A-40 castings to near-net shape were not an option, and standard aluminum casting alloys have an unacceptable TCE as noted in the earlier report.[1] The cost of the machined housing was a very important factor in the potential success of the module because a quantity of approximately 80 modules would be required per weapon.

Later in the project, it was discovered that another lightweight material with an acceptable TCE would provide the capability for a close near-net shape casting. The near-net shape casting will substantially reduced the amount of machining required. The new material is a metal matrix composite (MMC) which is a mixture of aluminum and silicon carbide. The MMC material also provided a slight improvement in the TCE (over the A-40). All of the other noted physical properties are very similar to the A-40. One important negative feature of the MMC is that it is unweldable by any means. Therefore, a method was needed to assemble the hardware components into the housing.

The MMC vendors indicated that is was possible to braze other materials to the MMC. A proposal was made to braze a weldable aluminum insert in the areas requiring laser welding for hardware installation. *See Figure 13 for an illustration of the concept.* The weldable insert provided two improvements in the housing fabrication process. First, the insert was made out of 1100 aluminum, which is easy to machine and maintain close tolerances. Second, the insert was designed to allow removal and re-installation of the covers for reworking the internal electronic components. There was a strong desire for reworkability because of the cost of the final assembly.

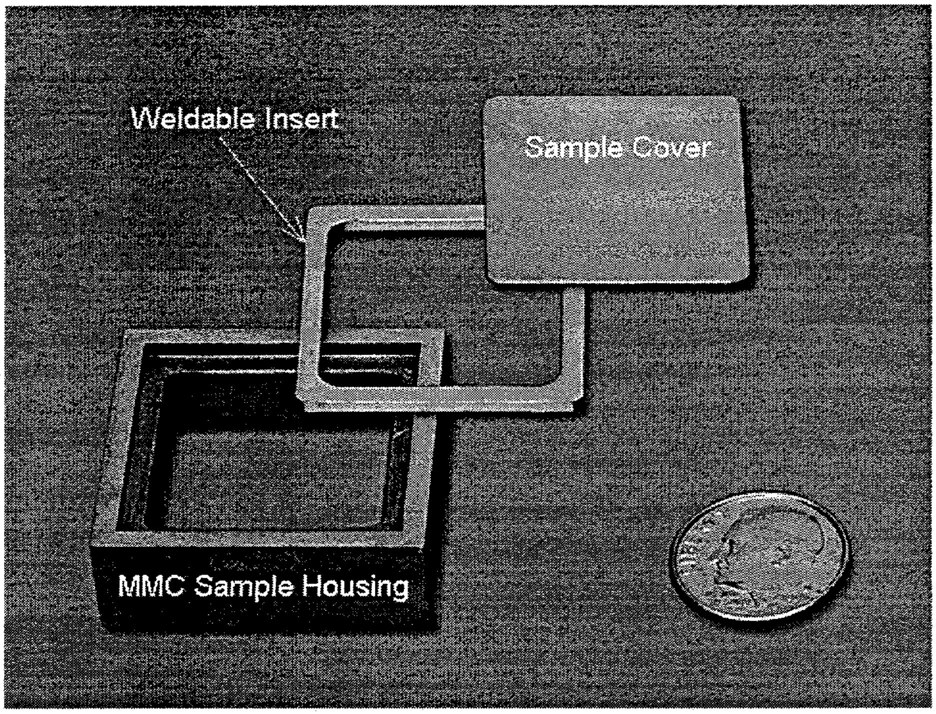

Figure 13. The MMC Sample Housing, 1100 Aluminum Weldable Insert (Before Being Brazed into the Housing), and the Sample Cover

Near-net shape sample MMC housings were purchased. A suitable brazing process was developed by the MMC vendor, and 1100 alloy inserts were brazed into the housings by the MMC vendor. The welding evaluation was not performed because the project objectives were changed by the time the material was received. MMC housing gold plating was also not evaluated but will be an important issue since the module housing will require gold plating in specific areas. The MMC sample material will be maintained in the event that there is renewed interest in the MMC housing concept.

Housing Preparation and Plating

Some weld porosity was observed during initial welding development of the A-40 alloy housing material. An evaluation was launched to explore potential causes of the weld porosity and also define any housing processing steps that may affect the welding. Because of the nature of a powdered metal product like the A-40 material, wrought metal porosity was suspected as a cause for the weld porosity. Laboratory evaluations revealed that the A-40 wrought material did, in fact, contain some porosity. Density calculations quantified the porosity at 3.7%. It was thought that moisture trapped in the base metal porosity caused the weld porosity. A 500°C vacuum bake-out for 1 hour after machining but prior to plating was implemented. The bake-out substantially reduced the weld porosity.

The housing must be selectively plated for solderability in specific areas. Again, the plating processing was carefully evaluated for its impact on the welding. The selective plating was accomplished by masking the areas that would later be welded. A plating process was developed with minimal impact on laser welding. It consisted of electroless nickel, followed by electroplated nickel, and a final gold plate. A deoxidizer cleaning step was also used as required.

Accomplishments

A microwave module packing concept was developed and prototype parts were produced. The package met the product requirements for the application by providing a hermetically sealed environment compatible with the microelectronic components contained in the assembly. The package design included the development of compatible aluminum alloy hardware, weld joint design, and a proven laser welding process. Testing of the completed package indicated that a leak rate of 2×10^{-9} cm^3/s He was achieved while successfully surviving severe environmental requirements. The laser welding process was optimized and produced crack-free, low-porosity welds with consistent weld penetration. Tooling was developed for the hardware assembly welds and the purge tube pinch-off. A gold plating process for the housing was developed which would allow soldering to the housing in selected places and have minimum impact on the welding process.

Internal weld spatter was identified as an area of concern for the cover welds. A test concluded that even using the optimum laser weld schedule, there is the potential for internal weld spatter to be present. It is believed that the spatter problem can be resolved, but additional work will be required.

An alternate housing material was investigated which would allow near-net shape casting of the housing. The near-net shape casting would substantially reduce the machining costs associated with the module. The new material is a metal matrix composite (MMC) containing aluminum and silicon carbide. Additional work will be required to determine if the new material meets all of the expected requirements.

Future Work

Several items surfaced during this project that should be investigated further to better define the requirements and processes needed to bring the subject module into production. Control and/or elimination of internal weld spatter will be required to successfully manufacture the radar module. Weld joint design and weld processing are areas that hold potential for elimination of this problem. Preliminary work was completed using clad metal adapters to weld the kovar shell RF connectors into the A-40 housing. This technique must be fully developed to allow weld installation of the connectors, unless aluminum shell RF connectors can be procured. Ideally, though, use of aluminum shell connectors would be the first choice to allow welding the connectors into the housing. Connector vendors may be interested in developing the aluminum shell connectors given the proper economic incentive. The experimental MMC housing material has a potential economic benefit for production of the module. All of the processing complexities of using this material need to be completely characterized to demonstrate the degree of economic benefit.

Reference

[1]J. P. Dereskiewicz, *Microwave Module YAG Laser Weld Development* (Topical Report). AlliedSignal Federal Manufacturing & Technologies: KCP-613-4385, July 1991 (Available from NTIS).