EXCELLENT RELIABILITY WITH HIGH THROUGHPUT TECHNIQUES AND MATERIALS FOR ALLOY ATTACHMENT

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ABSTRACT

Although device alloy attachment has received considerable study in recent years due to increasing requirements for high power performance, secondary and tertiary levels of attachment have received scant attention. Yet, their reliability is key to the performance of each microwave module, and critical to the reliability of the solder system as a whole. An evaluation is presented which comprehensively examines alloys which can be utilized for secondary attachment in microwave modules. After reflow, the evaluation cycle encompassed a 168 hour bake operation, thermal cycling and mechanical vibration and shock. The samples were x-rayed, examined visually for wetting anomalies, and microsectioned to analyze intermetallic formation. All alloys tested were reflowed without flux in a reducing atomosphere reflow furnace, a high throughput process clearly amenable to high volume production.

INTRODUCTION

The majority of microwave assemblies are gold-based modules with two to three levels of attachment requirements. Components to be attached might encompass GaAs devices, thin film or thick film ceramics, capacitors and other small components. Finally, the fully assembled carrier plates may be attached to the base of the housing. With low volume, prototype builds, it is sometimes feasible to eliminate one alloy level through the use of screw mounting of either carrier plates or ceramics. However, constraints in the module size, questionable reliability of the technique, and cost constraints related to throughput, limit the use of screws in any production environment. Moisture, contaminants and other reliability questions can limit their use in the assembly of military components. The single most reliable attachment technique over the long term has proven to be alloy attachment. Due to the increased application of higher power level components, alloy attachment of devices has received considerable attention. Unfortunately, secondary and tertiary levels of attachment are scarcely considered although their reliability is key to the performance of each microwave module. With volume production requirements, it is critical that we evaluate these with respect to long term performance, reliability and throughput. A thorough examination of various alloys for secondary attachment in gold-based assemblies is presented. This study has identified a number of alloys with excellent long-term performance potential. Additionally, it has identified special precautions which must be taken in order to utilize some of the more common indium-based systems. The results demonstrate attachment techniques which are easy to process in high throughput environments and which are highly reliable through rigorous environmental conditioning.

The alloy which is commonly utilized for device attachment is gold tin 80/20 with a liquidus of 280 degrees C. It has demonstrated good long term reliability performance and has proven to be a standard attachment material for device attach in the industry (1). In gold based assemblies, the choice for secondary and tertiary alloys to complete the module solder system typically falls to an indium alloy. PbIn 50/50 is one of the more commonly used solders for this role with a liquidus of 209 degrees C. Although it has generally provided good reliability, with more rigorous or more extended environmental conditioning, this alloy often falls short due, in particular, to intermetallic formation. The gold/indium intermetallic is formed subsequent to solid state diffusion which is exacerbated with increased temperature or increased time at temperature after the initial reflow.

An examination of the problem together with a solution to eliminate the intermetallic is presented as well as demonstrated reliability performance over the long term. Finally, evaluation of additional alloys over rigorous environmental conditioning is shown.

The reliability of PbIn solder attachment to gold surfaces was called into question as a result of intermittent failures in a variety of applications in which this alloy is used. The failures were usually experienced as carrier plates or pedestals lifting from attachment to a housing. Historically, failures which have been analyzed were caused by intermetallic formation of the indium with the gold surface, with delamination occurring in the gold depleted zone between the gold and the intermetallic.

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A study was undertaken to fully evaluate the intermetallic issue and to insure reliability of PbIn attachment for current and future programs. The study evaluated both thick and thin gold plated surfaces on kovar carrier plates to which GaAs MMIC's and ceramic thin film networks had been attached utilizing pbin 50/50 solder.

MATERIAL

Kovar carrier plates (of which 104 were utilized for the test) were received with representative gold plating thickesses in microinches as follows:

Thin plated gold samples		Thick plated gold samples	
mean	32.74	mean	122.5
std. dev.	2.71	std. dev.	6.7
lowest reading	29.31	lowest reading	114.7
highest reading	36.43	highest reading	136.7
no. of samples	15	no. of samples	15

Under the gold plating was one hundred microinches of electroless nickel. The carrier plates were 1 inch x 1 inch x .015 inch. Flatness check of a sample of 10 demonstrated flatness within 1.0 mil across the carrier plate. One hundred four of these carrier plates were utilized for the PbIn reliability evaluation as explained in the introduction.

Thin film ceramics were received with backside metallization of gold/Ni/gold with thin and thick gold plated samples. The thin gold plate ranged from 25 to 50 microinches of gold. The thick gold plate ranged from 150 to 200 microinches of gold. This plating was placed over 75 microinches minimum nickel. Under the nickel layer was plated a standard RF ground of 100 microinches minimum gold. Ceramics reflowed on one carrier plate included 2 large area thin films (.500 inch x .200 inch x .010 inch), and small die shear thin film networks (TFN) of the dimensions specified above.

One GaAs MMIC was reflowed on each sample carrier plate (dim. .100 inch x .150 inch x .004 inch). Gold plating thickness on the backside of the device was 300 microinches thick. A 0.002 inch thick PbIn 50/50 preform with dimensions the size of each carrier plate was utilized for the attachment of thin film ceramics and GaAs MMIC's to the carrier plate.

DISCUSSION AND RESULTS

The samples were reflowed in a reducing atmosphere belt furnace at a peak temperature between 250 and 255 degrees C. Thin film networks with thin plating were mounted on carrier plates with thin plating and those with thick plating were mounted on thick plated carrier plates. Also die shear plated TFN's were mounted on both thick and thin plated carrier plates. All samples were then subjected to the following test cycle:

* 3 hour bake at 150 degrees C
* 168 hour bake at 125 degrees C
* thermal cycling -55 to +125 degrees C
* mechanical shock, 1500 G's, 5 shocks at 0.5 ms per shock in the Y1 direction.

The 3 hour initial bake is representative of the assembly flow temperatures and typical epoxy repairs to which the reflowed module would be subjected. It includes wirebonding on a 150 degrees C stage and a number of epoxy cures at 1 hour each. The bake and thermal cycling conditions were representative of planned module flow at the time. As expected, there was no visual change in the appearance of the samples after 3 hours of bake at 150 degrees C or after subsequent bakes of 12, 24, 48, 84, or 168 hours at 125 degrees C. Die shear samples of 10 thick plated and 10 thin plated TFN's were also completed at each of these time levels. The die shear results were as follows:

HOURS BAKED	THICK GOLD (kg.)		THIN GOLD (kg.)
No bake	1.16	mean	1.36
	.23	std. dev.	.33
3 hours	.75	mean	1.20
	.20	std. dev.	.19
12 hours	.57	mean	1.17
	.24	std. dev.	.10
24 hours	.48	mean	.88
	.18	std. dev.	.26
48 hours	.97	mean	1.20
	.24	std. dev.	.40
84 hours	.65	mean	1.13
	.22	std. dev.	.35
168 hours	.33	mean	.91
	.15	std. dev.	.32

A significant reduction of shear strength was seen in the thick gold plated samples at 3 hours. This significant strength reduction was not present in the thin gold plated die shear samples, although some slight reduction in strength was seen with these samples as well. The thick plated samples continued to decrease in shear strength during the successive hours of bake at 125 degrees C. After 168 hours shear strength was approximately 30 percent of the original strength after reflow. In the thin plated samples, the shear strength after 168 hours of bake was approximately 70 percent of the original strength after reflow.

Microsections and x-ray diffraction were also completed after each of these bake levels. All thick gold plated microsections had fractures along the intermetallic/gold interface, (Figure 1). Fractures were seen at the 3 hour level. None of the thin gold samples evidenced any fractures. In the thick plated samples, there was evidence of heavy intermetallic growth. When analyzed with x-ray diffraction and line scans, both $AuIn_2$ and Au_4In_9 were found.

The units were subjected to 10 thermal cycles at -55 to +125 degrees C after the 168 hour bake operation. Although the thick and thin plated samples were visually no different prior to the thermal cycling, after only 10 cycles, the solder spontaneously separated in many areas on

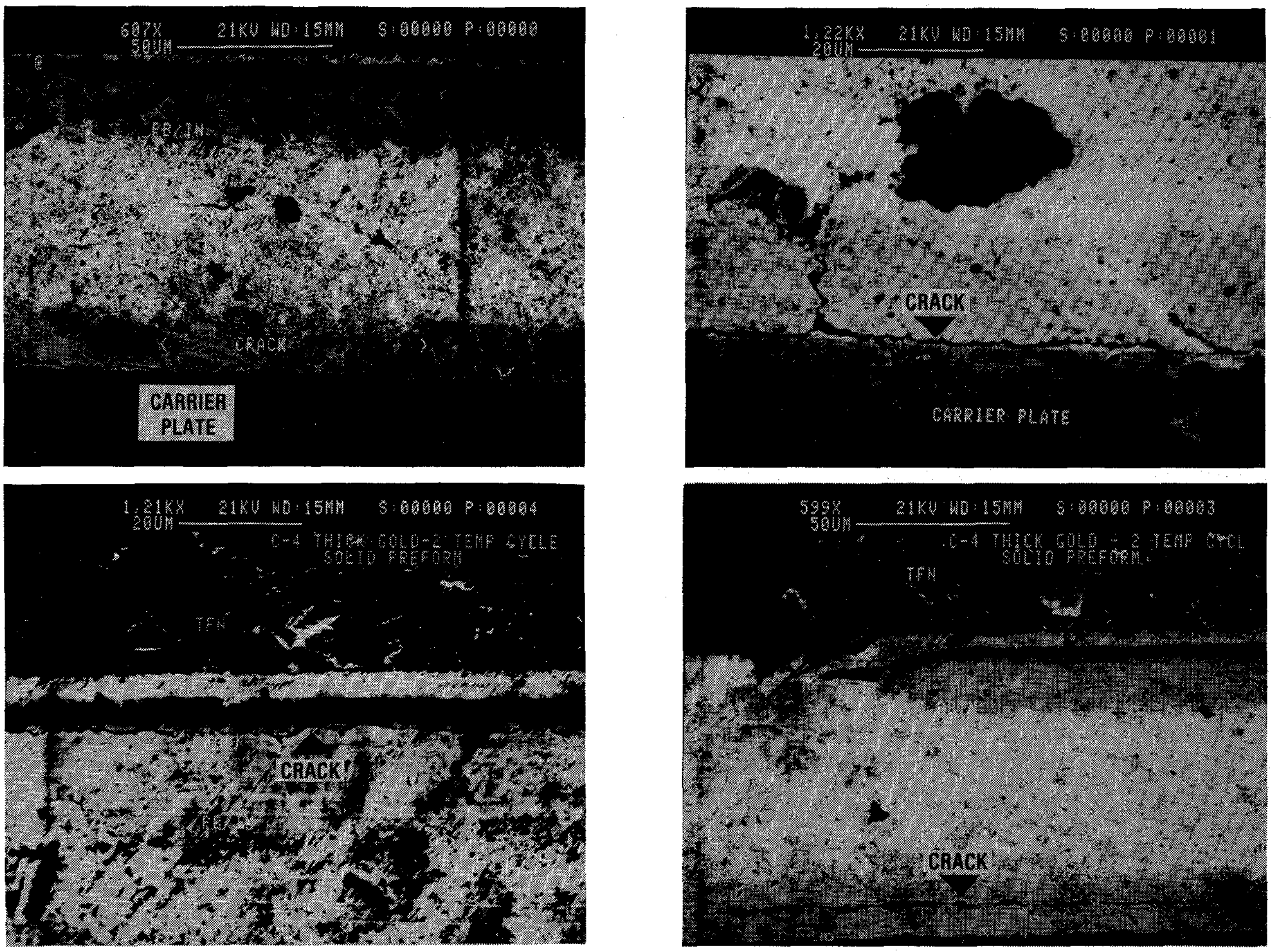

Figure 1. Examples of Fractures in Verification Samples.

100 percent of the thick plated samples, (Figure 2). Also 40 percent of the large area thin film networks separated from the solder. There were no failures in the thin plated samples. All of the thin plated samples were subjected to sinusoidal and random vibration and to 1500 G's of mechanical shock in the Y direction. None of the samples failed. Attempts were then made to forcibly remove the large area TFN's from the carrier plates on all samples using tweezers. They could not be removed.

Repair testing was also completed on 10 samples with thin plating. One, two, three, four and five repairs were completed on separate carrier plates. The samples were then subjected to 168 hours at 125 degrees C, to 10 temp cycles at -55 to +125 degrees, and to mechanical shock and vibe. Microsections were performed after the combined tests of bake and thermal cycle. The microsections showed no dewetting and there were no fractures on these samples. The remaining samples were submitted to mechanical shock at the level described above. No failures occurred.

In summary, after a series of comprehensive evaluations, it was determined that components with plating thicknesses of 120 microinches or more of gold present a degradation risk when soldered with PbIn 50/50 solder. The degradation is due to the formation of a gold-rich intermetallic layer during subsequent bake operations. Failure, specifically separation of the solder from the carrier plate at the solder to carrier plate interface, is induced after thermal cycling. The test cycle utilized in this study adequately screens this failure mode. The test cycle encompassed a 168 hour bake operation, thermal cycling and mechanical vibration and shock at the levels indicated.

Long-term reliability of the PbIn 50/50 solder process is constrained by control of the component plating process. In a controlled situation with plating thicknesses of 30-70 microinches, the stability of the PbIn to Au attachment poses no long-term risk even at elevated temperature conditioning. If the plating process cannot be adequately controlled or monitored however, then the recommendation is to utilize a different alloy system when soldering to Au plated components and assemblies.

120 MICROINCHES GOLD PLATING | 30 MICROINCHES GOLD PLATING

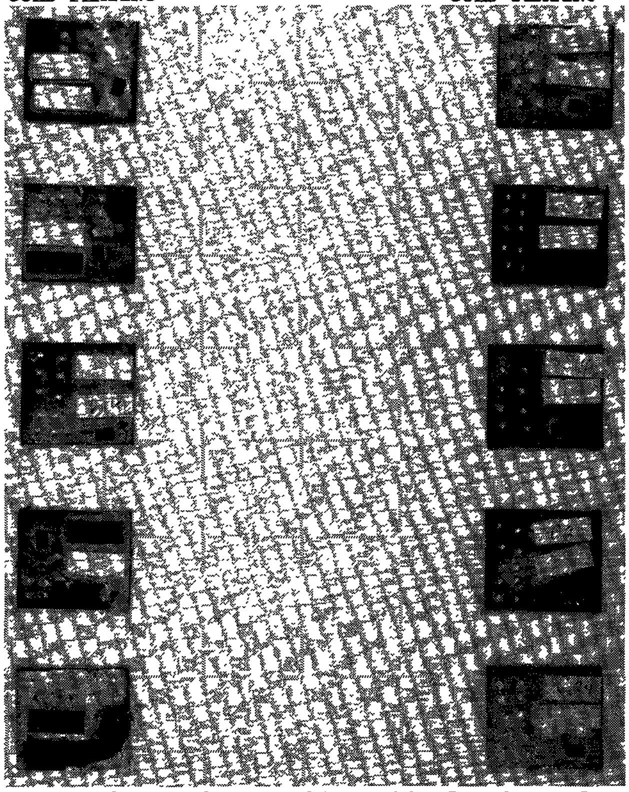

Figure 2. Thick and Thin Gold Plated Samples after Exposure to Environmental Cycling.

ALTERNATIVE ALLOYS

The Alternative alloy study was initiated in an effort to define solder systems which can be utilized with gold based assemblies without incurring reliability risks. The evaluation examined 5 preform alloys with PbIn 50/50 used as a control. Carrier plates with gold plating thicknesses of 30 microinches and 120 microinches were reflow mounted with thin film ceramics of matched thin and thick plating, and with GaAs MMIC's of backside plating thickness of .3 mil. The samples were then subjected to a 168 hour bake at 150 degrees C. and to 100 thermal cycles at -55 to +125 degrees C. The samples were x-rayed, examined visually for wetting anomalies, and microsectioned to analyze intermetallic formation. Finally, samples were mechanically shocked at 1500 G's in the Y1 direction at 0.5 ms for 5 shocks. Alloys tested included: SnPb 63/37, SnAg 96.5/3.5, PbSnSb 58/40/2, PbSnAg 60/37/3, PbSn 70/30.

Results demonstrated that 3 of the 5 alloys performed reliably through rigorous environmental conditioning without any level of degradation exhibited. These alloys were: PbSnSb 58/40/2, PbSnAg 60/37/3, and PbSn 70/30. The higher tin alloys exhibited significant AuSn intermetallic formation occurring during the reflow operation primarily rather than through subsequent solid state diffusion as with PbIn alloys.

CONCLUSIONS

An evaluation is presented which comprehensively examines alloys which can be utilized for secondary attachment in microwave modules. Although PbIn 50/50 has been shown to form intermetallics with time and temperature, the problem can be controlled with control of the Au plating process. In situations where such monitoring would be difficult, alloys have been identified which perform reliably under extended conditioning. All alloys tested were reflowed without flux in a reducing atmosphere reflow furnace, which is a high throughput process clearly amenable to high volume production.

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