Application Report
SZZA031 - December 2001

A Nickel-Palladium-Gold Integrated Circuit Lead Finish and Its Potential for Solder-Joint Embrittlement

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ABSTRACT

This gold (Au) embrittlement study evaluates TI's original four-layer nickel-palladium (NiPd) lead finish that was introduced in 1989 and TI's nickel-palladium-gold (NiPdAu) lead finish that replaced four-layer NiPd in 2001. Samples were prepared with three different Au thicknesses for the NiPdAu components. The printed wiring board (PWB) finishes used were organic solderability preservative (OSP) and electroless nickel-gold (NiAu). The latter were made with two different Au thicknesses. The goal was to understand the effect of Au from the component finish and the PWB pad finish on Au embrittlement in the solder joint. A matrix of samples was built from the components and boards described above and exposed to 1000 temperature cycles. Lead pull testing and metallurgical analysis of the solder joints were performed to determine if the variations in Au content, either from the lead or the board or both, led to Au embrittlement of the solder joints.

The theoretical calculations (Appendix A) showed that 3 weight % Au would not be exceeded in the solder-joint test. Based on the Au embrittlement literature, this predicts no solder-joint embrittlement would occur. The lead pull data showed no evidence of catastrophic drop in solder-joint strength that would be expected with Au embrittlement. The cross sections show no SnAu intermetallics in the bulk of the solder for the solder joints made with normal Au-thickness-range components and boards. Thin layers of SnAu intermetallics are seen at the solder/component and solder/PWB interfaces. This is expected because intermetallics form between Sn from the solder and Au from the PWB and component finishes. Only the solder joints made with artificially high Au-thickness components and PWBs have the acicular SnAu intermetallics that have been shown to cause Au embrittlement in some instances in the literature. The NiPdAu leadframe finished components investigated for this applicaton report showed no measurable Au embrittlement of the solder joint.

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Introduction

In 2001, TI converted from a nickel-palladium (NiPd) lead finish for components to a nickel-palladium-gold (NiPdAu) lead finish. The NiPd finish for IC leads was first introduced in the late 1980s.[1,2] By October 2001, more than 40-billion NiPd-finished IC packages were in the field. The four-layer NiPd structure is shown in Figure 1. The structure of the NiPdAu lead finish is shown in Figure 2. The introduction of Au on the top surface of the NiPdAu leadframe finish suggested an Au embrittlement study would be useful.

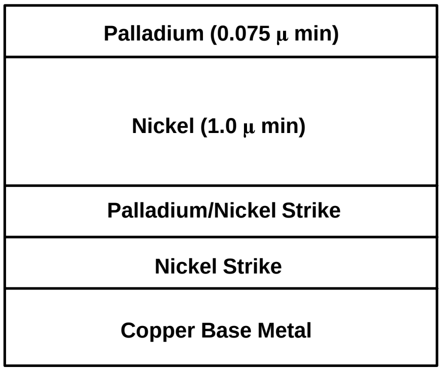

Figure 1. Structure for TI Four-Layer NiPd Finish

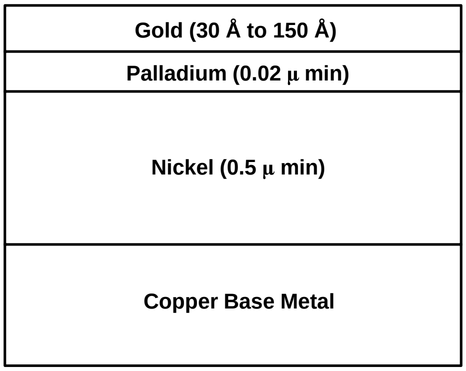

Figure 2. Structure for NiPdAu Finish

A very good description of Au embrittlement is provided by Glazer et al.: “Because Au has essentially no solubility in either Sn or Pb, when the solder joint solidifies, Au is dispersed through the joint in the form of brittle, elongated $AuSn_4$ or $Au(SnPb)_4$ intermetallic precipitates.” [3] (see Figures 20 and 24)

In the literature, the amount of Au that causes embrittlement of a solder joint has been suggested to cover a range of 4 weight % to 6 weight % Au in the joint.[4,5,6,7] Glazer et al. recommend that Au in the joint not exceed 3 weight %, based on the results of their study, “Effect of Au on the Reliability of Fine Pitch Surface Mount Solder Joints”.[3] This careful study considered only Au from the PWB as a contributor because the leads were SnPb finished. Recently, Zribi et al. have shown a failure mechanism due to a ternary Au solder alloy that occurs with Au concentrations as low as 0.1 weight %.[8] This work was done with ball grid arrays soldered to NiAu-plated PWBs. Zribi’s work raises a question about the use of NiAu-finished PWBs in general. However, it is not clear how the weight % Au is calculated in Zribi’s study.

Au in the solder joint can come from the component lead and the PWB pad finish. For this study, the thickness of Au on the component leads and on the PWB pads was varied from 0 to an extreme for different samples.

Components and PWBs Tested

For the PWB pad finish, 5-µ to 7-µ Ni and 0.09-µ to 0.1-µ Au were targeted for the standard NiAu PWB samples. The thick-Au samples had the same nickel thickness, but with an Au-thickness target of 0.4 µ to 0.65 µ (this is denoted as 5× NiAu PWB in this application report). The third (control) variation on PWB pad coating was an organic solderability preservative (OSP) applied directly to the copper (Cu) pad.

The IC component style used was a 20-pin, dual-inline, surface-mount, small-outline package (SOP), with lead pitch of 1.27 mm. TI package designator for the test component is NS. The components were plated with NiPdAu with the Ni and Pd being held constant and the Au targeted to 30 Å, 150 Å, and 3000 Å. These Au thicknesses are the minimum, 5× the minumum, and 100× the minimum thicknesses indicated in the TI NiPdAu specification for Au. Throughout this application report, we refer to the various component sample finishes as Std NiPdAu, 5× NiPdAu, and 100× NiPdAu. TI’s four-layer NiPd was used as the control, contributing no Au to the solder joint.

The Au actual thickness measurements for the components and PWBs used in the study are shown in Appendix A, part B.

Test Matrix for Au Embrittlement

Relative contribution of Au from components and PWB pads for each sample is shown in Table 1. The solder paste was 62Sn/36Pb/2Ag with a melting point of 179°C. The peak reflow target temperature was 225°C.

Table 1. Group Numbers for Each Variation Tested

Au CONTRIBUTION FROM COMPONENT	Au CONTRIBUTION FROM PWB PAD		
	OSP	Std NiAu PWB	5× Std NiAu PWB
NiPd (no Au)	1	5	9
NiPdAu (Std finish)	2	6	10
NiPdAu (5× Std finish)	3	7	11
NiPdAu (100× Std finish)	4	8	12

Reflow Profile

The reflow profile was based on inputs from the solder-paste vendor (see Figure 3). This profile reaches a preheat temperature of 120°C to 160°C for approximately 60 seconds before rising to a peak temperature of 225°C to 228°C.

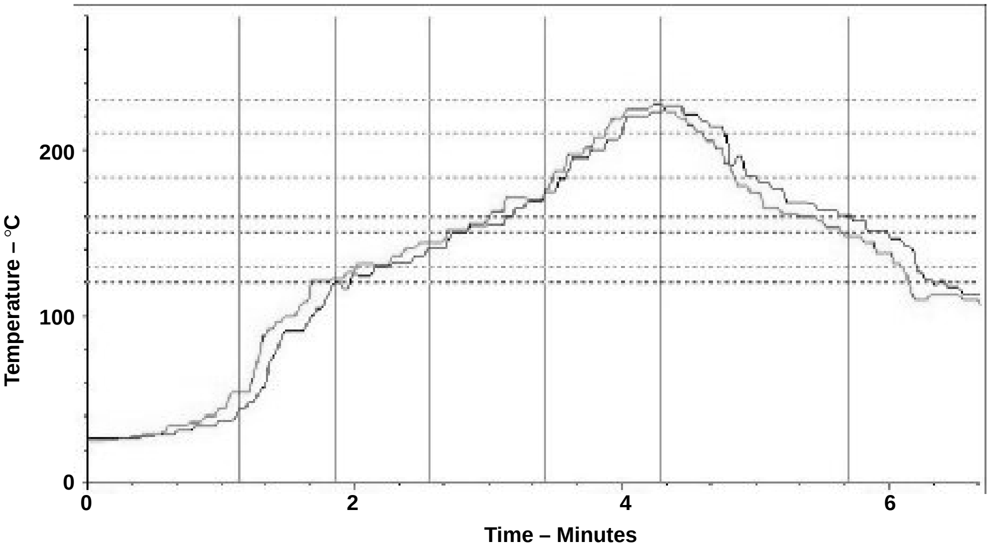

Figure 3. Reflow Profile for SnPbAg Solder Alloy

Board-Mount Equipment and Procedure

The solder paste stencil was laser-cut and polished 150-µm stainless steel. Printing of the solder paste was performed manually. Prior to component placement, optical inspection of the printed solder paste was performed to insure adequate paste height and complete printing. An optical alignment tool for manual component placement was used to position the leads to the solder-paste prints. For the reflow soldering process, a Rehm full-convection reflow oven with N_2 purge was used. Remaining O_2 was 500 ppm to 1000 ppm.

Theoretical Au Content Calculations

Appendix A, part A, shows that the Au thickness to achieve 3 weight % Au content for the solder joints made using the OSP boards and ICs under test would be 0.757 µ or 7570 Å–roughly 250 times the minimum thickness specified for Au on the component lead. This is ~50× the maximum thickness specified for the Au on the lead. The weight % Au calculated assumes that the layer of Au on the component dissolves entirely into the solder joint. The calculation assumes no Au comes from the PWB pad. Assumptions about the surface area of the lead and the characteristics of the solder paste also are in Appendix A, part A.

Predicted Au Content of Solder Joints Using Thickness Data for ICs and PWBs

Appendix A, part B, shows the measured Au thickness data for the PWBs and components in this study. This data was taken using energy-dispersive X-ray analysis (EDX) for the ICs and X-ray fluorescence (XRF) for the boards.

Appendix A, part C, shows the calculations for Au content in the solder joints for the embrittlement matrix in this study. The key conclusions about weight % Au in the joints are shown in Table 2. The simplistic approach taken for these calculations was that the Au layer dissolved completely and uniformly into the solder joint. The Au thickness was taken as the average. The other assumptions are noted in Appendix A.

Table 2. Calculated Weight % Au in the Solder Joints for the Test Matrix

Au CONTRIBUTION FROM COMPONENT	WEIGHT % Au IN THE JOINT (CALCULATED)		
	OSP	Std NiAu PWB	5× NiAu PWB
NiPd (no Au)	0	0.57	1.55
NiPdAu (Std finish)	0.01	0.59	1.57
NiPdAu (5× Std finish)	0.07	0.61	1.63
NiPdAu (100× Std finish)	1.13	1.70	2.66

The calculated contribution of the component lead finish to the percentage Au in the solder joint in the standard and 5× NiPdAu thickness range is 0.01 weight % Au to 0.07 weight % Au. The Au from the PWB, even at the standard level of Au on the board, overwhelms the contribution of Au on the lead to the weight % Au in the joint. The Au flash on component leads poses a negligible risk of contributing to Au embrittlement of the solder joints made with such components.

Performance Measures and Results

Visual Appearance

The solder wetting and fillet height of the solder joint is shown in Figure 4. This substantiates the assumption made in Appendix A, part A.2.d, that the fillet height of the solder joint is to the top of the lead. The fillet height was used in calculating the surface area of the lead that was soldered.

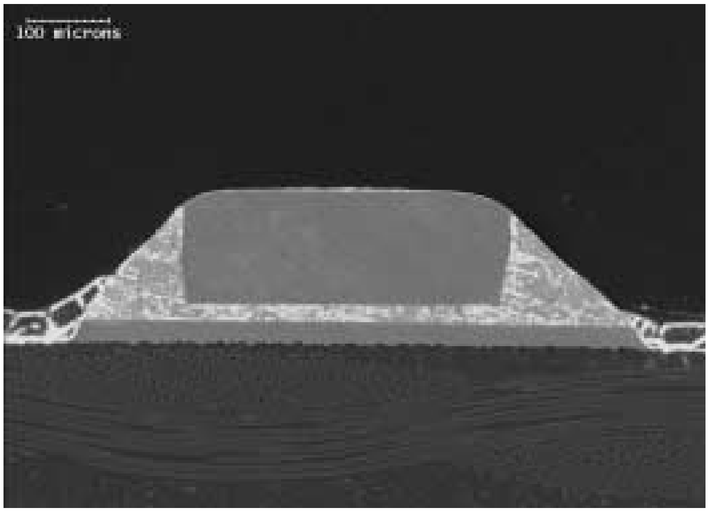

Figure 4. Cross Section of Solder Joint

Lead Pull Test

Lead pull testing determined the force needed to pull an individual IC lead from the PWB land pattern after soldering. First, to allow access to an individual lead on the PWB, the leads were cut near the package body. Next, with the leads separated from the package body, the PWB was fastened in a test fixture. Finally, the lead was pulled perpendicular to the PWB surface until it separated from the PWB. The rate of movement of the test device was 0.4 mm/sec vertically to the board surface. The force to pull the lead from the PWB was measured and recorded. Lead pull data was taken before and after temperature cycling.

Lead Pull Data

The temperature cycle excursion was –40°C to 125°C in 10-minute cycles. This is a thermal-shock test with the boards being moved from a –40°C chamber to a 125°C chamber. There was no ramp between the temperature extremes.

The minimum lead pull value specified by the SEMI standard for non-temperature-cycled samples (with the lead cross-sectional area of the units tested) is 10 N.[9] All lead pull values for temperature-cycled units are above the minimum requirement. The SEMI standard indicates that the average lead pull force of the temperature-cycled units shall be greater than half of the average lead pull force of the non-cycled units.[9] The lead pull values shown in Figure 5 for post-temperature-cycled units also meet this SEMI-standard requirement.

In Figure 5, the average lead pull value for the group prior to temperature cycle exposure is indicated with an X. A diamond shape indicates the average lead pull value for the group after exposure to 1000 cycles of the temperature-cycle excursion stated previously. A square and triangle denote the minimum and maximum lead pull values, respectively, for each group.

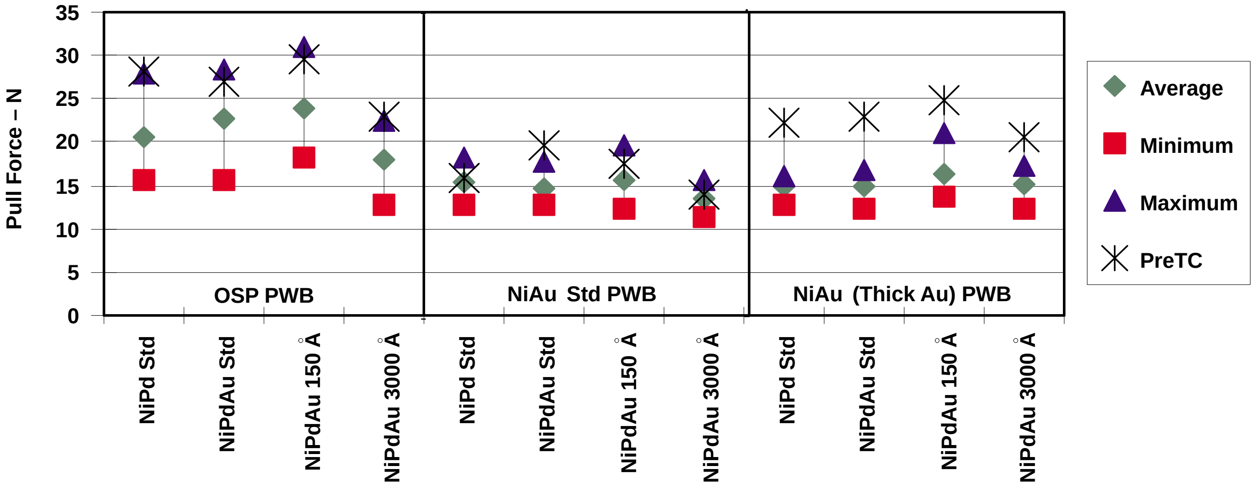

Figure 5. Lead Pull Results

Observations From Lead Pull Results

For the combinations of OSP PWB pad finish and NiPdAu, component finishes with standard Au thickness and 5× Au show slightly higher lead pull values compared to NiPd component finish (no Au). Lead pull values for NiPdAu finish with 100× Au are slightly less compared to the other three samples. For the standard NiAu pad finish, lead pull values with NiPd, standard NiPdAu, and 5× Au are all essentially equivalent. The NiPdAu component finish with 100× Au is only slightly lower than the other three. These results are about 25% lower than the OSP results. For the 5× Std NiAu PWB finish, the four lead pull values (post-temperature cycle) are essentially the same as those of the standard NiAu-pad-finish board.

The most significant drop between pre-temperature-cycled and post-temperature-cycled lead pull averages is noted for all four groups in the 5× NiAu PWB finish. The eight samples mounted on NiAu PWB finish (both standard PWB Au thickness and 5× PWB Au thickness) appear to be, as a group, lower than the four samples mounted on an OSP pad finish. The difference is about 25%.

Statistical Analysis of Lead Pull Data

Analysis of Variance (ANOVA)

To analyze the lead pull results from the various groups, statistical techniques were employed. First, a multifactor ANOVA was used for the response of the lead pull (see Table 3). The ANOVA results in Table 3 decompose the variability of the response (lead pull) into contributions due to the inputs. In this experiment, the inputs analyzed were Au thickness on the component lead (Lead), Au thickness on the PWB pad (PWB), and the interaction between the two (A×B).

Table 3. ANOVA Results

SOURCE	SUM OF SQUARES	MEAN SQUARES	CONTRIBUTION
Main Effects			
A: Lead	593.0	197.667	8.4 %
B: PWB	4180.29	2090.15	59.3 %
Interactions			
A×B	380.02	63.3367	5.4 %
Residual	1892.81	4.04447	26.9 %
Total	7046.13		100 %

The ANOVA results indicate that the Au on the PWB had the strongest contribution (59.3%) to the variance seen in lead pull results between all test groups. The contribution of the Au on the component lead accounted for 8.4% of the total variance, which is less than the contribution of the residual error (26.9%). The interaction of the Au content in the component lead, with Au content in PWB finish, accounted for 5.4% of the variance, which is also less than the contribution of the residual error. ANOVA results indicate that the Au content of the PWB pad had the strongest effect on lead pull performance, with the Au content on the component lead being overwhelmed by the residual error of the experiment.

Graphical data analysis was used to understand the variation between the test groups. Figure 6 shows the lead pull results broken down into each factor-level setting. The graph shows Au thickness on the component lead across the X-axis, lead pull values on the Y-axis, and Au thickness on the PWB pad by line color (or shading).

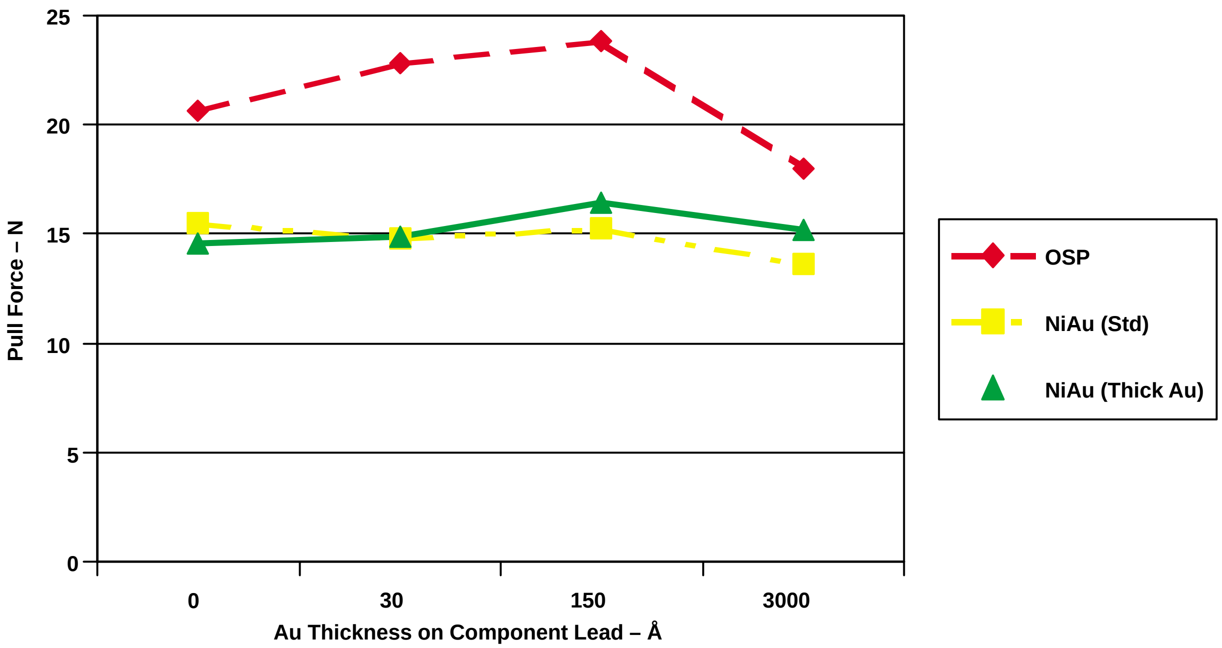

Figure 6. Lead Pull Results by Factor-Level Setting

Figure 6 indicates that the addition of NiAu to the PWB significantly lowers the lead pull strength results when compared to OSP-coated boards. However, the pull strength on standard NiAu PWBs or 5× Std PWBs were similar to one another. Pull tests of component samples with 100× Au were lower than those components with lesser Au thicknesses. For the line indicating zero Au thickness on the PWB (OSP line) the data points for the Au thickness on the component lead of 0, 0.30 Å, and 5× Au are similar, while the data point for 100× Au is different. For the lines indicating average values of PWB Au thickness of either Std or 5× Std Au (bottom two lines), the results are similar within each group, as well as being similar to one another. Even with the difference in results between components mounted on OSP PWBs (no Au) and components mounted on NiAu PWBs (various levels of Au thickness), all data points are above the minimum required by the SEMI standard for noncycled and temperature-cycled components.[9]

Box-and-Whisker Plots

Box-and-whisker plots were used to analyze the scatter of the data for each group. In this data-presentation method, the box covers the middle half of the data. The middle line within each box is the middle data point (median). The whiskers extend to the extreme data points of each group. Outliers are indicated as small boxes beyond the whisker points. For our data set, the shift in the pull-strength average is significantly different where the shift is large compared to the variation in the data (distance between the whisker tips). If the mean of one box falls outside the range of another box, a significant difference is present.

Figure 7 shows a box-and-whisker plot for the data set, with OSP coating on the PWB (no Au). Au on the component lead for each group is indicated on the horizontal axis and the lead pull values are indicated on the vertical axis.

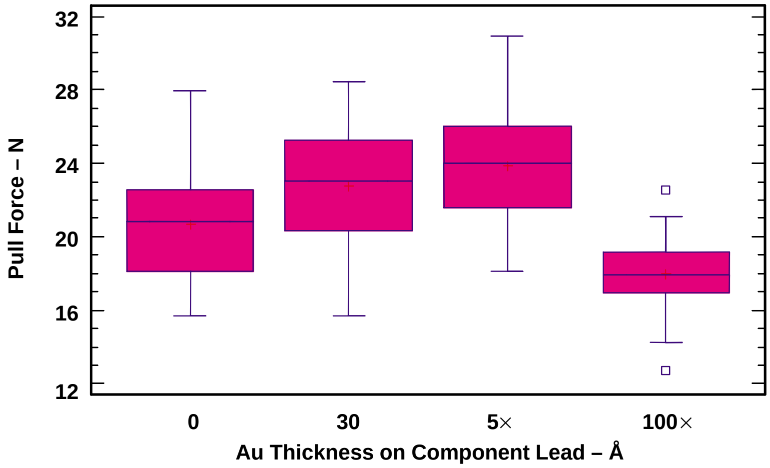

Figure 7. Box-and-Whisker Plot for OSP Coating on PWB (No Au)

The box-and-whisker plot for PWB Au thickness of zero shows that where the component-lead Au thickness is 0, 30 Å, or 5× Au the data is similar. This is indicated by the overlap of the boxes representing the middle half of the data. For the data set with component-lead Au thickness of 100×, the box is much lower and does not show much overlap, thus, a distinguishable difference exists. Overall, there is a lot of scatter in the data, indicating other factors that have not been accounted for in the experiment.

Figure 8 shows a box-and-whisker plot for the data set with standard Au (0.09 μ to 0.1 μ) on the PWB. In Figure 8, results are similar between data sets with 0 and 30 Å of Au on the component leads. Results are also similar for data sets with 0 and 5× Au on the component leads. The data set with component-lead Au thickness of 100× is lower than data for the other data sets.

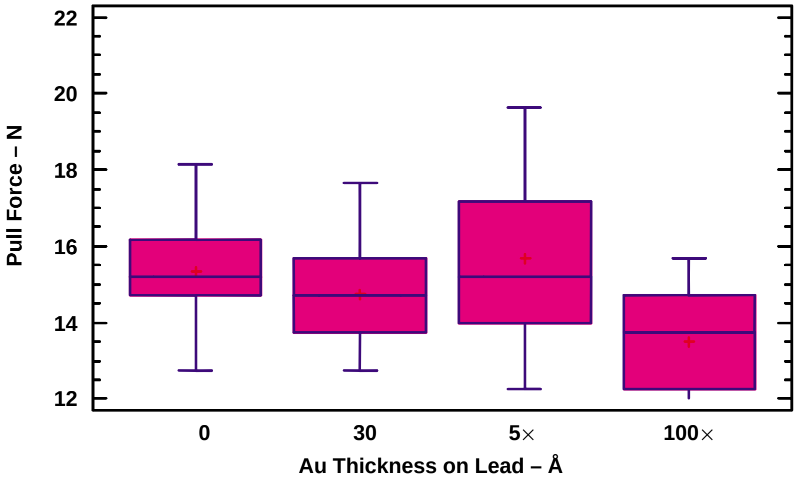

Figure 8. Box-and-Whisker Plot for Standard NiAu PWB

Figure 9 shows a box-and-whisker plot for the data set with 5× Au (0.4 μ to 0.65 μ) on the PWB. In this figure results are similar, except where the Au thickness on the component lead is 5×.

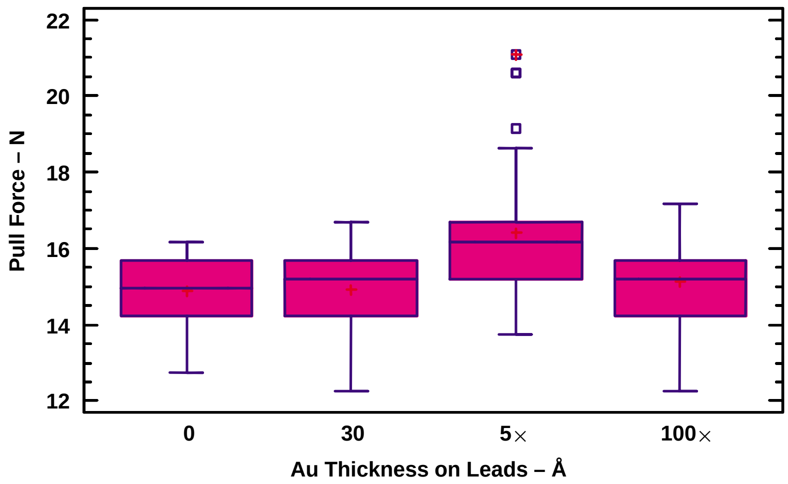

Figure 9. Box-and-Whisker Plot for PWB With 5× Au (0.4 µ to 0.65 µ)

Summary of Statistical Analysis

Statistical analysis indicates that addition of Au to the PWB dramatically lowers the pull strength values. This result is reflected in the multifactor ANOVA, which showed that the Au on the PWB had the highest percentage contribution to lead pull variance. While the presence of Au on the PWB lowered the pull strength, the amount of Au (above zero) did not make a difference. A lowering of the pull strength is noted when the component lead has 3000 Å of Au. There is not much difference in the results when the Au on the component lead is 0 to 150 Å. Even in the worst-case conditions of thick Au on the PWB and thick Au on the component lead, there was no catastrophic drop in lead pull values after temperature cycling. All values are above the minimum industry standard requirement for the lead pull test method.

Cross Sections of Solder Joints

Cross sections were done on the joints made from the sets of components (samples) discussed in the following paragraphs. All of the sections were done on joints that had been through 1000 thermal cycles, except as noted for sample 10.

Sample 6: NiPdAu Standard Finish, PWB Standard NiAu Finish

The 1000× image shows a fairly uniform appearing solder joint with a Sn-rich phase in which Pb-rich phases are embedded (see Figure 10). On the board side at 4000×, the Ni/Sn intermetallic at the Ni/solder interface is visible (see Figure 11). Some small, Sn/Au/Ag, intermetallic-phase areas also are present. The bulk Sn-rich phase does show some Au in the EDX spectra, but not a distinct Au-rich phase. The Pb-rich phase shows no Au. The 4000× image of the lead side shows the relatively thick Ni/Sn intermetallic and some Au/Sn intermetallics scattered along the Ni interface (see Figure 12). In Figure 13, the percentage of Cu, Ni, Au, and Sn is shown along the line marked 1–2 in Figure 12. Note the change from pure Cu through an Ni-rich region to the SnAu intermetallic region to bulk Sn.

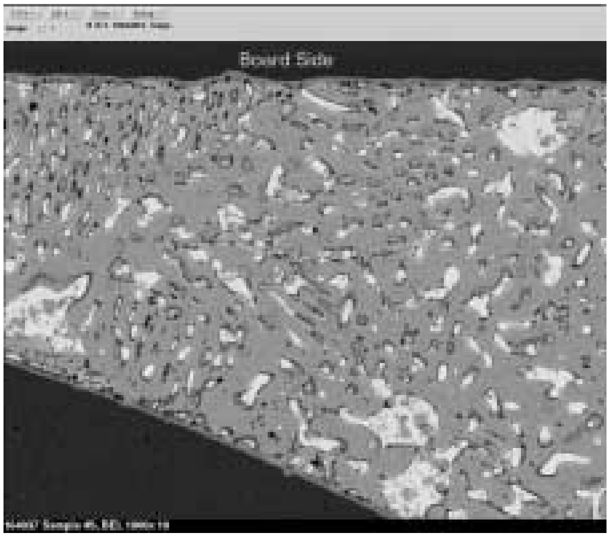

Figure 10. Sample 6 After Thermal Cycling (The Dark Gray Matrix Is the Tin-Rich Phase, While the Bright Phase Is the Lead-Rich Phase)

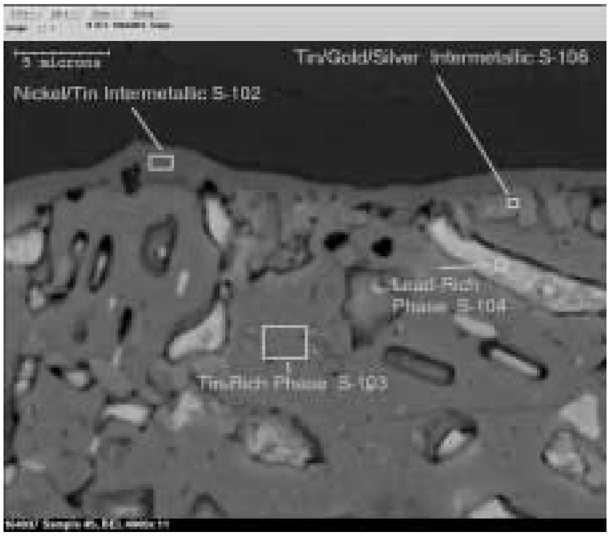

Figure 11. Board Side of Sample 6 at 4000× After Thermal Cycling

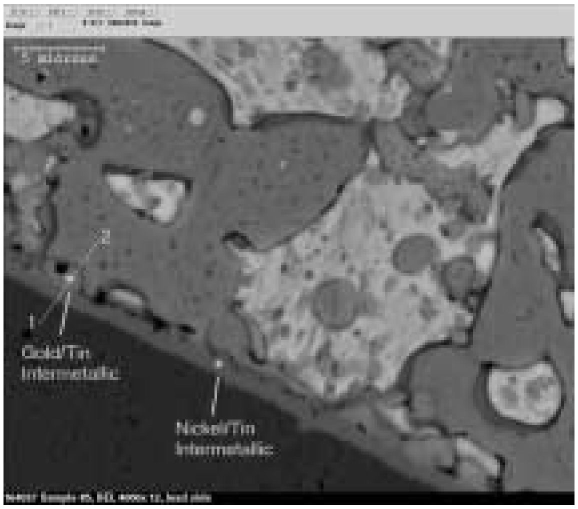

Figure 12. Lead Side of Sample 6 at 4000× After Thermal Cycling

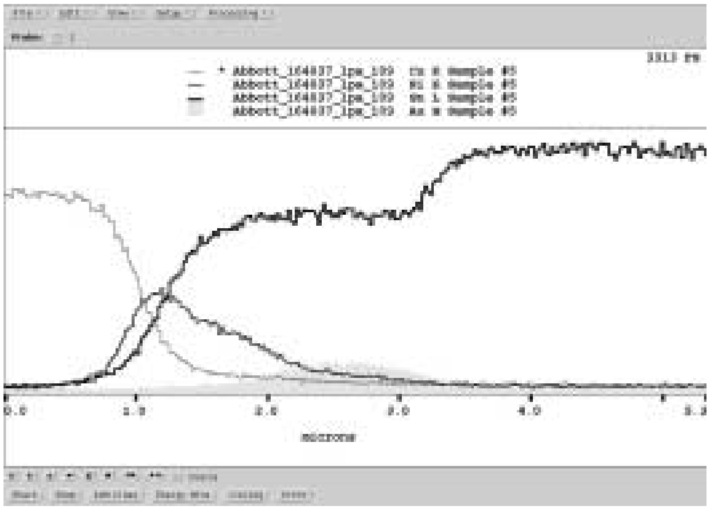

Figure 13. Spectra of Cu, Ni, Au, and Sn Taken Along Line 1–2 in Figure 12 (See Comments in Text)

Sample 5: NiPd Lead Finish, PWB Standard NiAu Finish After Thermal Cycling

The 1000× image of this section shows a predominantly Sn-rich area in which Pb-rich phases and some rod shaped Sn/Ag phases are embedded (see Figure 14). These phases have been seen before with SnPbAg solder paste. The 4000× image on the board side also shows a Sn/Ni intermetallic phase on the electroless Ni plating and some scattered Sn/Au/Ni intermetallics of a different form than the Sn/Au/Pd intermetallics on the lead side (see Figure 15).

On the lead-side phase at 4000×, there is an Ni/Sn intermetallic layer at the Ni surface (see Figure 16). Over this are some rods or plates of Sn/Au/Pd. The presence of Au at the lead interface indicates that Au has migrated from the board side to the lead side because there is no Au on the NiPd lead surface. In Figure 17 the scan along the line 1–2 indicated in Figure 16, shows a distinct Ni region between the Cu and Sn regions. It also shows a lower Sn percentage attributable to an SnAg intermetallic, which is the rod-shaped region in Figure 16 (the Ag is not shown in the scan).

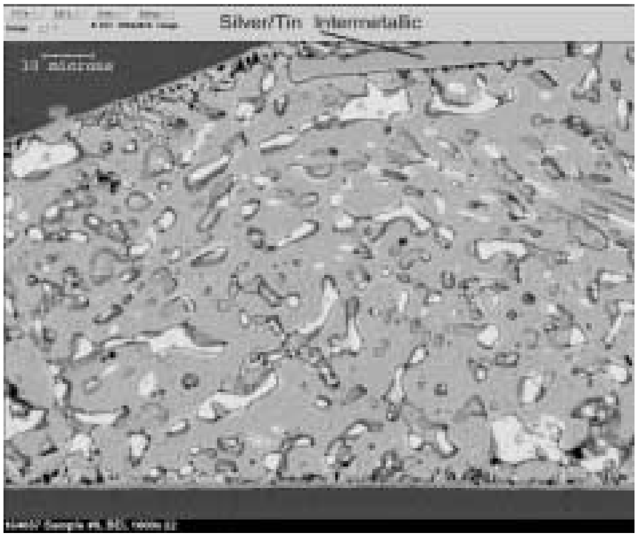

Figure 14. 1000× Image of Sample 5 After Thermal Cycling

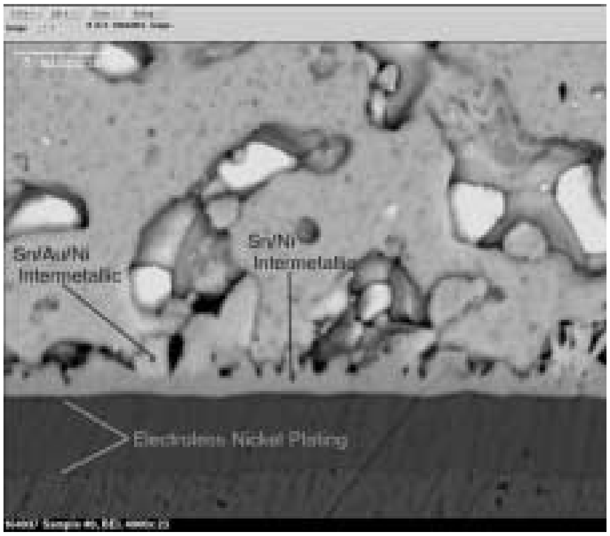

Figure 15. Board Side of Sample 5 at 4000× After Thermal Cycling

Figure 16. 4000× Image on the Lead Side of Sample 5 After Thermal Cycling

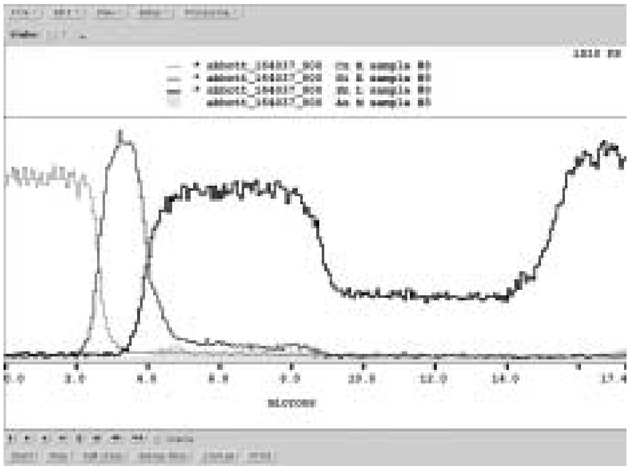

Figure 17. Line Scan Along Line 1–2 in Figure 16 (See Comments in Text)

Sample 7: NiPdAu 5× Au, PWB Standard NiAu Finish After Thermal Cycling

Sample 7 should be similar to samples 5 and 6 because the Au thickness on the board surface overwhelms the Au effect from the lead (see Figure 18). In fact, there appears to be a slightly more uniform layer of Sn/Au intermetallic at the board side. This may be caused by the roughly 7× thicker Au on the lead side migrating to the board side. It also could be caused by local variation in the Au thickness on the PWB.

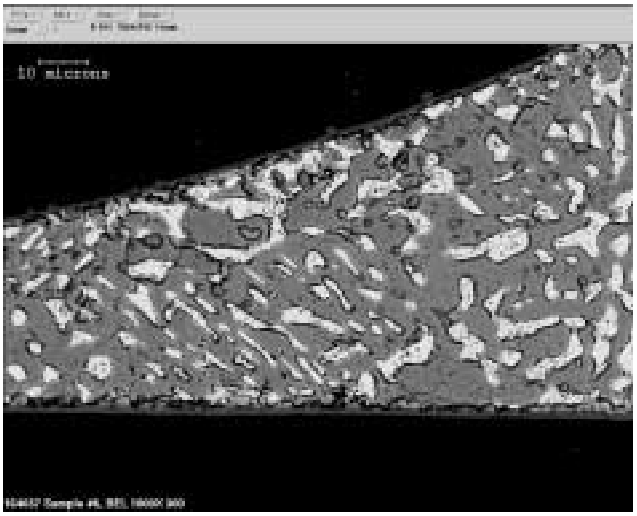

Figure 18. Sample 7 at 1000× After Thermal Cycling

Sample 2: NiPdAu Standard Finish, PWB OSP Finish After Thermal Cycling

The low-magnification image shows a solder joint with features similar to samples 5 and 6 (see Figure 19). SnAg rod-shaped intermetallics are present. On the lead side, there is the expected Sn/Ni intermetallic at the Ni interface and, on the board side, there is the Sn/Cu intermetallic, which is thicker than the Sn/Ni intermetallic layer. *No Au is seen in any of the images for this system,* which supports the idea that the Au from the board finish overwhelms any effect of the Au from the lead finish.

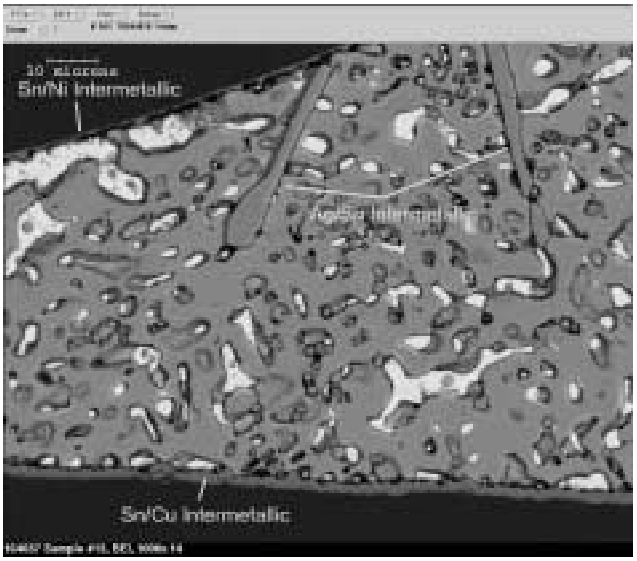

Figure 19. 1000× Image of Sample 2 After Thermal Cycling

Sample 10: NiPdAu Standard Finish, 5× NiAu PWB With No Thermal Cycling

This sample was *not* thermal cycled. Figure 20 shows large numbers of Sn/Au acicular intermetallics dispersed in the bulk of the solder joint. The Sn/Ni intermetallics at both the board (see Figure 21) and lead (see Figure 22) surfaces are thinner than for the thermally cycled samples, which is expected. On the lead side there are Sn/Au regions that are detached from the Sn/Ni and Sn/Au intermetallics on the surface. The Sn/Au intermetallic layer appears to overlie the Sn/Ni layer that is on the Ni layer. The line scan, clearly shows that the SnAu intermetallics at that location form because of the high Au content of the PWB and these intermetallics are showing up at the *lead side* of the joint (see Figure 23). This shows the mobility of Au in molten solder.

Figure 20. 1000× Image of Sample 10, No Thermal Cycling

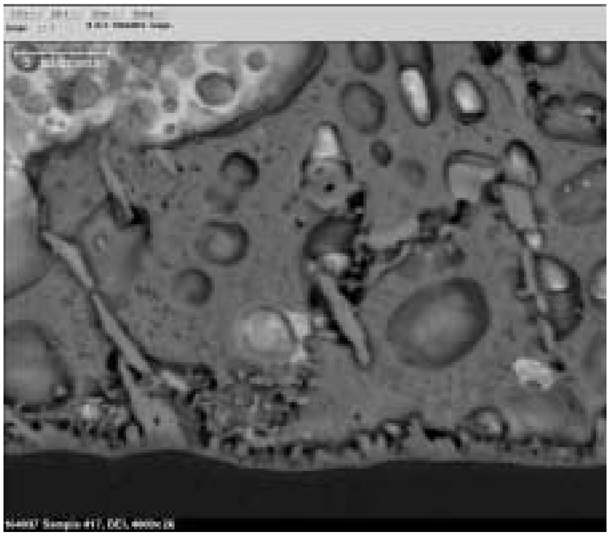

Figure 21. Sample 10 at 4000× Board Side, No Thermal Cycling

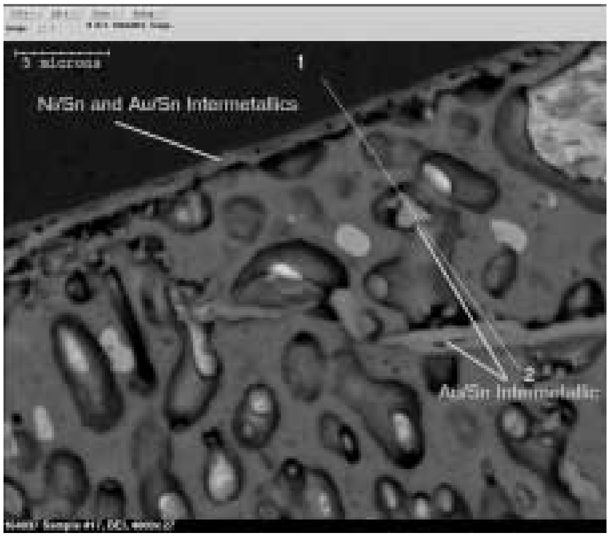

Figure 22. Sample 10 Lead Side at 4000×, No Thermal Cycling

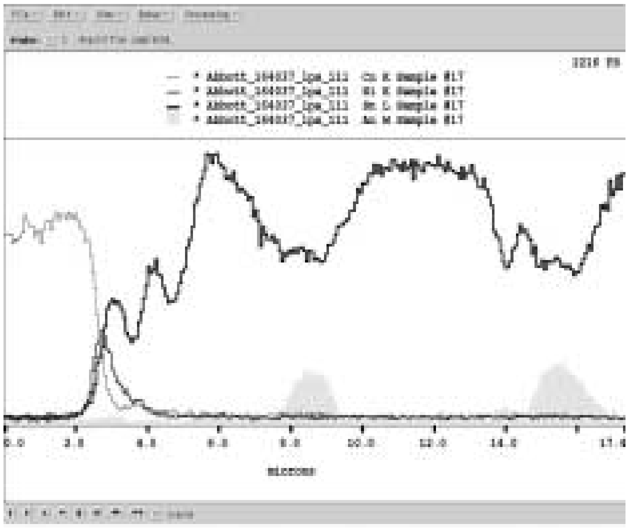

Figure 23. Line Scan Along Line 1–2 in Figure 22 (See Comments in Text)

Sample 12: NiPdAu 100× Au, PWB 5× Au Thickness After Thermal Cycling

With thick Au on both the board and the lead, Au/Sn intermetallics are expected in the bulk of the solder. This is shown in the 1000× image in Figure 24. On the pad side, there is a thin Sn/Ni intermetallic layer and thick Au/Sn intermetallic layers (see Figure 25). Similarly, on the lead side, there is a thin Sn/Ni intermetallic layer over which is a thicker Au/Sn intermetallic layer (see Figure 26). In Figure 26, there is also one of the acicular Au/Sn intermetallics. The line scan shows that with the highest level of Au in the solder joint of any sample in this study, there are two large SnAu intermetallics present along this scan line (see Figure 27).

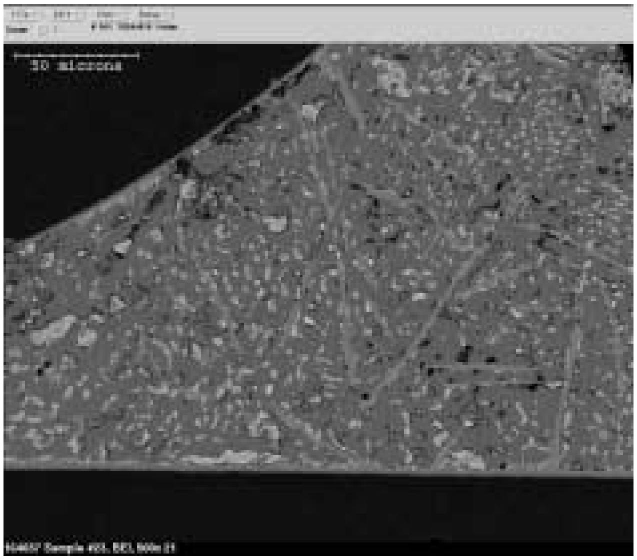

Figure 24. Sample 12 at 1000× After Thermal Cycling

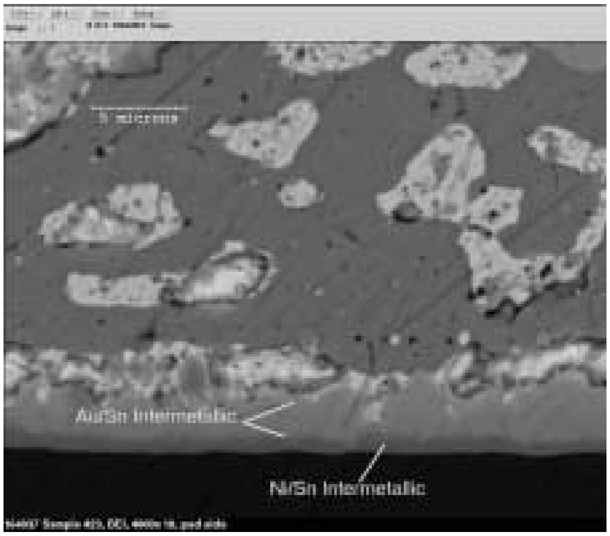

Figure 25. Sample 12 Pad Side at 4000× After Thermal Cycling

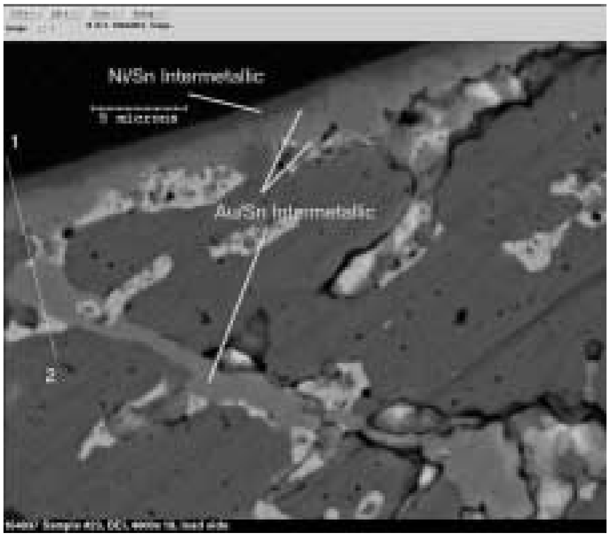

Figure 26. Sample 12 Lead Side at 4000× After Thermal Cycling

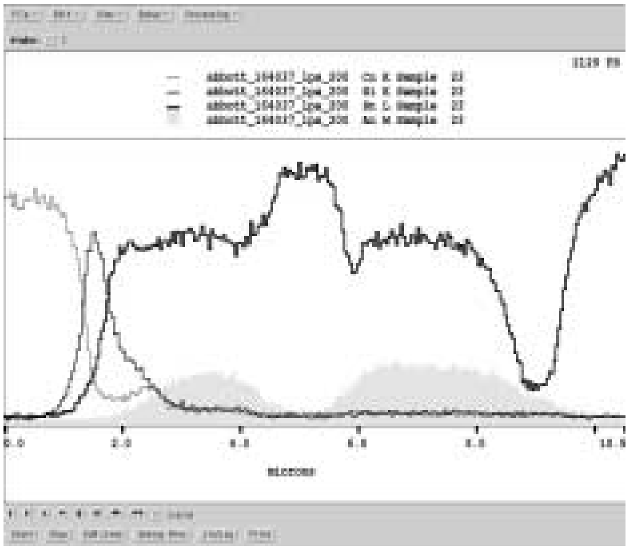

Figure 27. Line Scan Along Line 1–2 in Figure 26 (See Comments in Text)

Summary of Cross-Section Analysis

Both samples made with the PWBs at 5× Au showed large numbers of free-floating, acicular AuSn in the bulk solder joint (Figures 20 through 27). None of the other samples examined showed this phenomena. For the samples made with the standard PWB (Au at 0.2 μ), there were Sn/Au intermetallics at the solder interfaces, especially on the board side. There were a few free-floating, nonacicular intermetallics in the 0.2-μ PWB samples.

For the OSP board samples, no Au intermetallics were found for Au at any thickness from 0 to 100× Std NiPdAu. Any present may have been below the limit of detection. As expected, large amounts of Sn/Cu intermetallics were on the OSP board.

The cross-section results support the notion that Au embrittlement of solder joints will not occur because the Au coating on the surface of the component lead is very thin.

Summary and Conclusions

- The theoretical Au content of the solder joints that would result from using the components and PWBs in this study is less than the 3 weight % level cited by Glazer as the maximum Au content for fine-pitch, surface-mount devices.
- The theoretical calculations of Au content demonstrate that the contribution of the Au from the lead is dwarfed by the contribution from the PWB.
- The lead pull data shows that Au embrittlement did not occur, even after 1000 thermal cycles.
- The statistical analysis of the lead pull data indicates that in this study, Au on the PWB is the prime contributor to lowering lead pull force (although results are still acceptable by industry standards).

- The metallographic data shows that:
  - The solder joint is made to the Ni surface of the component lead.
  - There is no Cu migration through the Ni barrier layer of the lead.
  - In a system with no Au on the PWB and with a standard Au thickness on the lead, there is no Au detectable in the bulk of the solder joint.
  - The Au from the PWB can migrate across the solder joint and appear at the lead/solder interface in the case of the NiPd-finished lead.
  - At very high Au thicknesses on PWB and leads but give Au concentrations of less than 3 weight %, acicular SnAu intermetallics do form. These do not appear to be sufficient to affect pull strength.
- The risk of Au embrittlement caused by TI's NiPdAu component lead finish is essentially nil.

Acknowledgments

The authors wish to recognize the following individuals for their professional assistance:

- Kay Haulick and Martin Pauli for their board mounts, visual documentation, and lead pull testing
- Dr. Al Hopkins of the Texas Instruments Attleboro S&C Group for the cross sections and SEM/EDX work
- Bill Russell of Raytheon Technologies for support with statistical analysis of lead pull data

The authors wish to recognize Multicore for supplying the SnPbAg solder paste used in this study.

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Appendix A Calculations for Au Embrittlement Study

Part A. Theoretical

1. Sn mass per pad
    a. Pad size is 0.7 mm × 1.4 mm = 0.98 mm^2.
    b. Stencil thickness is 150 μ or 150×10^{-3} mm.
    c. For a reflowed board, the solder thickness is 80 μ or 80×10^{-3} mm.
    d. Solder volume is 0.98 mm^2 or 80×10^{-3} mm = 0.0784 mm^3.
    e. SnPbAg solder has a density of ~8.4 g/cm^3.
    f. 0.0784 mm^3 × 8.4 g/cm^3 × 1 cm^3/1000 mm^3 = 6.59×10^{-4} g of solder per pad
2. Area of lead
    a. Foot length is 1.05 mm maximum; multiply by 1.5 to allow for heel filet = 1.575 mm.
    b. Foot width is 0.51 mm.
    c. Foot thickness is 0.15 mm.
    d. Surface area
    Foot area is 1.575 × 0.51 = 0.8033 mm^2.
    Edge area is (assuming fillet goes to top) [(1.575 × 2) + 0.51] × 0.15 = 0.549 mm^2.
    e. Total soldered surface area per lead is 1.3523 mm^2 per lead.
3. Calculated thickness of Au for >3 weight % Au in joint
    a. 6.59×10^{-4} g Sn per pad × 0.03 = 1.3523 mm^2 per lead × 19.32 g/cm^3 (Au density) × 1 cm^3/1000 mm^3 × Au thickness in mm
    b. Solve for Au thickness in mm = 7.57×10^{-4} mm or 0.757 μ or 7570 Å
    c. Nominal thickness in production does not exceed 50 Å. To get to the 3 weight % Au level, Au thickness would exceed the minimum by >150×, *if there were no Au on the PWB pad.*

Part B. Thickness Data on PWBs and Components Used in Study

The XRD/EDX data are for the PWBs and the components evaluated in this study. Ten leads per component were evaluated, except as noted.

- PWB pads (see Table A–1)

Table A–1. XRD/EDX Data

PWB PADS (Au μ)	THICKNESS OF Au (μ)			
	AVERAGE	MAX	MIN	SD
5× NiAu	0.55	0.67	0.48	0.04
Std NiAu	0.20	0.28	0.09	0.05

- Devices (see Table A–2)

Table A–2. XRF/EDX Data

COMPONENTS	THICKNESS OF Au (Å)			
	AVERAGE	MAX	MIN	SD
3000 Å	2893	4325	2225	722
150 Å	180	250	125	42
×1835[†]	33	37	30	3

[†] Sub-50-Å data obtained by EDX

NOTE 1: 1 μ = 10,000 Å = 10 × 10^{-3} mm

Part C. Calculations of Au Concentration in Parts Used in the Study

This part gives calculations of the percentage of Au in the joints we made, accounting for the Au on the PWB pads. The averages of measured Au values are used in the calculations.

4. Boards (see Table A–3)
   a. Pad size is 0.7 mm × 1.4 mm = 0.98 mm^2.
   b. Au thickness on board 38a is 0.55 μ or 5.5 × 10^{-4} mm.
   c. Au thickness on board 39a is 0.20 μ or 2.0 × 10^{-4} mm.
   d. Mass of Au on 38a is
      0.98 mm^2 × 5.5 × 10^{-4} mm × 1 cm^3/1000 mm^3 × 19.32 g/cm^3 = 1.04 × 10^{-5} g Au/pad.
   e. Mass of Au on 39a is
      0.98 mm^2 × 2.0 × 10^{-4} mm × 1 cm^3/1000 mm^3 × 19.32 g/cm^3 = 3.79 × 10^{-6} g Au/pad.
5. Components (see Table A–4)
   a. Total soldered surface area per lead is 1.3523 mm^2.
   b. For the nominal 3000-Å leads:
      1.3523 mm^2 × 2.893 × 10^{-4} mm × 1 cm^3/1000 mm^3 × 19.32 = 7.56 × 10^{-6} g Au/lead
   c. For the nominal 150-Å leads:
      1.3523 mm^2 × 1.80 × 10^{-5} mm × 1 cm^3/1000 mm^3 × 19.32 = 4.70 ×10^{-7} g Au/lead
   d. For nominal 30-Å leads:
      1.3523 mm^2 × 3.3 × 10^{-6} mm × 1 cm^3/1000 mm^3 × 19.32 = 8.62 × 10^{-8} g Au/lead
6. Percentage of Au in solder joints (general formula) (see Table A–5)
   a. Percentage of Au = [(mass Au on lead + mass Au on pad)/(mass of Sn + mass Au on lead + mass Au on pad)] × 100
   b. Mass of solder joint = 6.59 × 10^{-4} g

Table A–3. Calculations for Boards

FOR BOARDS	MASS OF Au (g)	THICKNESS USED IN CALCULATION (μ)
38a	1.04 × 10^{-5}	0.55
39a	3.79 × 10^{-6}	0.20

Table A–4. Calculations for Components

NOMINAL LEAD THICKNESS (Å)	MASS OF Au (g)	THICKNESS USED IN CALCULATION (Å)
3000	7.56×10^{-5}	2893
150	4.70×10^{-7}	180
30	8.62×10^{-8}	33

Table A–5. Calculated Percentage of Au in the Solder Joints

Au CONTRIBUTION FROM COMPONENT	CALCULATED WEIGHT % Au IN THE JOINT		
	OSP	Std NiAu PWB (0.28 µ)	5× NiAu PWB (0.67 µ)
NiPd (no Au)	0	0.57	1.55
NiPdAu (Std finish 30-Å Au)	0.01	0.59	1.57
NiPdAu (150-Å Au)	0.07	0.61	1.63
NiPdAu (3000-Å Au)	1.13	1.70	2.66

NOTES: 2. The contribution of the lead finish to the percentage Au in the solder joint in the 50-Å to 150-Å thickness range is 0.01 weight % and 0.07 weight %. The Au from the PWB, even at the level of 0.2-µ Au on the board overwhelms the contribution of the Au on the lead.

3. The percentage of Au in a joint can be estimated from EDX data or, possibly, from a wet chemical analysis for the percentage of Au in the joint.

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