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ASSESSMENT OF NiPd FINISHED COMPONENTS FOR SURFACE MOUNT ASSEMBLY APPLICATIONS

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ABSTRACT:

Recent trends towards finer pitch devices and assembly with lead free solders have resulted in increased interest in NiPd plated component leads by the electronics industry. This paper discusses the performance of NiPd fine pitch components as determined by wettability, assembly performance and solder joint reliability. Assembly evaluations were performed with a lead free solder as well as with eutectic SnPb solder. The compatibility of the NiPd component leads with different circuit board finishes (metallic and organic azole) will also be discussed.

1. Introduction

Availability of leaded electronic packages with Pb-free leadframe finishes is a key requirement for the development of truly Pb-free solder assembly technologies. Recently, thin Pd leadframe coatings have emerged as potential replacements for the traditional SnPb dipped or plated finishes. This trend is primarily driven by cost considerations. The use of preplated Pd leadframes would replace SnPb coating after the device encapsulation step or would replace hot SnPb dipping after the final leadframe trim and form operation. Moreover, wire bonding from the Si chip can be made directly to the Pd surface, thus eliminating the Ag spot application process. Overall, simplification of the integrated circuit (IC) packaging process results in significant cycle time reduction and cost savings in terms of both chemical usage and energy consumption. Coupled with the cost savings, there is a significant positive environmental impact due to the elimination of Pb based processes and their associated safety and waste treatment regulations.

Thin Pd leadframe finishes are also better suited to meet the demands of increasingly finer pitch devices. Packages with pitch counts of less than 50 mils that are hot solder dipped can have uneven coating thicknesses that cause the lead to deform, resulting in open or short solder joints.

In the early 1990's, Texas Instruments (TI) developed a preplating process for leadframes whereby a nickel plated leadframe is subsequently coated with a thin (3-4 μin) Pd layer.[1] The role of Pd is to protect the underlying Ni layer from oxidation caused by storage or incurred in the course of various thermal cycles during the assembly processes. During the soldering process, the Pd is expected to dissolve into the solder; while the underlying Ni coating provides the solderable surface.

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Although NiPd finished components have been available for the last four years, the use of these components has not been universally accepted. Solderability, storage, and post assembly inspection concerns are primary issues confronting the implementation of NiPd finishes.

As part of a collaborative research effort between AT&T Engineering Research Center, Sandia National Laboratories and Advanced Micro Devices (AMD), an evaluation was conducted which examined the performance and compatibility of NiPd coated preplated component leads with both SnPb and Pb-free solders in circuit board assembly. Component lead wettability, as well as solder joint microstructure were assessed using 32 I/O, 0.5mm pitch TSOP components. Solder fillet integrity was evaluated by metallographic analysis and mechanical pull testing. Reliability testing included thermal cycling over the 0 to 100°C range for 1000 and 2500 cycles. This report summarizes the results to date and provides a technology assessment for the use of NiPd components in current and future surface mount assembly processes using SnPb and Pb-free solders.

2. Experimental

2.1 Coating Thickness

32 I/O Thin Small Outline Package (TSOP) IC packages were obtained with NiPd coated Leadframes (TI process). The NiPd chemistry consisted of four layers, with nominal thicknesses described below:

- Ni strike over copper base metal, 0.1 μm (4 μinches) thick.
- NiPd alloy, 0.01 μm (0.4 μinches) thick
- Ni, 1.2 μm (48 μinches) thick
- Pd, 0.1 μm (4 μinches) thick.

2.2 Visual Analysis

Microscopic (10 - 50X) examination of the TSOP 0.5 mm pitch leads was undertaken to assess the quality and uniformity of the two finishes to be compared, SnPb and NiPd, with particular attention directed to the NiPd finish. As Ni tends to be brittle, there is concern about how well the NiPd coating would survive the component form and trim operation.

2.3 Solderability

Solderability testing was performed per ANSI/J-STD 002 Test E - Wetting Balance test (Leaded Components), using a Multicore Universal Solderability Tester (MUST). Generally 5 specimens were examined per condition tested. Testing was performed with a water white gum rosin flux (Alpha 100-25, 25% nonvolatiles) and an RMA (rosin mildly activated) flux (Alpha 611, 37% nonvolatiles).

2.4 Surface Analysis

Auger Electron Spectroscopy (AES) was performed on the TSOP samples to correlate the solderability measurements with surface composition. A Perkin-Elmer PHI Model 610 Scanning Auger Microprobe was used for all AES analysis. A 3.0KV 4.5μa electron beam was used for all survey scans and depth profile analyses. A 5.0KV 250na/mm^2 beam was used for all depth profiling analysis yielding a sputter rate of ~240Å per minute.

2.5 Assembly Performance

The assembly performance of the TSOP leads was assessed by the following experimental matrix:

- Component lead finish: (1) plated SnPb, (2) hot dipped 100% Sn and (3) plated NiPd
- Solder: (1) SnPb (63wt% Sn, 37wt% Pb) and (2) SnAg (96.5 wt% Sn, 3.5 wt% Ag)
- PWB finish: (1) SnPb HASL, (2) imidazole, (3) immersion tin and (4) electroless NiPd

Surface mount assembly was performed using specially designed circuit boards containing 4 TSOPs per board. For both solders, the solder paste was formulated with a no clean RMA flux. The reflow profile was adjusted for the SnAg and SnPb solders as described previously.[2]

Evaluation of the TSOP boards included visual inspection, microstructural joint evaluation and mechanical pull testing. Data were obtained for the as-assembled condition as well as following thermal cycling between 0°C to 100°C. The thermal cycle profile consisted of 5 minute dwells at each extreme temperature, and a 10°C/min ramp between the two temperatures.

3. Results and Discussion

3.1 Visual Analysis

The SnPb coated leads had a thick round layer. The NiPd leads were flat with square corners. The NiPd leads also had varied levels of microcracking, with some cracks as deep and wide as 10 μ, (400 μinches) exposing the copper under the NiPd surface finish. These occurred at the convex portion or the bottom side of the heel of the lead. Scanning electron micrographs are shown in Figures 1 (a) - (c) and elemental mapping of (c) in Figure 1 (d) shows the exposed copper base metal. This is probably a result of the component trim and form operation.

3.2 Solderability

Figure 2 (a) shows the wetting balance measurements of the "as received" TSOP components tested using both a water white gum rosin flux (Alpha 100-25) and an RMA

flux (Alpha 611). Also shown in Figure 2 (a) are the wetting balance measurements of components that have been exposed to stress aging of 168 hours at 85°C/85% RH, followed by 500 temperature cycles of -65°C to +150°C. This is an extreme stress condition typically used by component vendors for device qualification testing.

The NiPd coated leads from two separate shipments did not show positive wetting when tested with the water white gum rosin flux. "Acceptable" wetting curves were obtained with the use of the RMA flux. After stress aging, "acceptable" wetting curves were again generated with the use of the RMA flux. The WWR flux did not permit wetting.

Because the focus of this work was not component qualification, but rather to assess the performance of new, fine pitch NiPd finished component leads, testing with the more active RMA flux was deemed more appropriate to simulate conditions in a typical surface mount assembly process. Although wetting of the NiPd leads was inferior with WWR flux, it should be kept in mind that the solder pastes used in the surface mount assembly process are typically formulated with RMA based fluxes. The wettability of NiPd was shown to be "acceptable" with the use of these fluxes.

3.3 Surface Analysis

Figure 2 (b) shows a schematic representation of a lead of a typical TSOP package. The circles indicate the positions where surface composition was measured using AES. Typical areas of interest are: position 1 (top of the lead where exposed Cu was observed under visual examination as described in section 2.2), position 2 (middle of the lead, that tends to get "wiped" during the form and trim operations), position 3 (bottom end of the lead) and position 4 (underside of the lead, which is critical for the formation of a strong metallurgical bond).

The surface composition of an unformed leadframe, from two different lots of TSOP components fabricated at AMD and that of a 50 mil SOIC component obtained from another vendor were measured at the different locations on the lead and summarized in Table 1.

The AES data shows the effects of the leadframe form and trim process. In the case of the unformed leadframes, the surface composition consists of primarily Pd (>90%) with 1-2% Ni and very low amounts of oxygen. There is no evidence of the Cu base metal. In the case of the formed leads, there is a significant difference in elemental composition, as one moves up the lead from the bottom to the top. Both the underside and the top surface were composed of Pd, Ni and O. However, the middle and top positions showed a significant concentration of Cu (30-40%), the source of which has been identified by both AES and SEM and X-ray elemental mapping to be a result of extensive *microcracking* of the "heel" of the NiPd coating. Microcracking of the NiPd coating exposed the underlying Cu layer, which became oxidized to cause degradation of the solderability of the leads. Component vendors are actively investigating new equipment options. Clearly, the NiPd finish is susceptible to cracking during the leadframe forming process.

Table 1: Surface Composition of NiPd Lead Finishes by AES
Percent Atomic Concentration (Major Elements)

	Position	Pd	Ni	Cu	O
AMD Leadframe	side 1	92.8	1.3		5.7
(unformed)	side 2	91.6	3.2		5.0
AMD Lot 1	top (1)	22.0	22.5	32.7	22.6
	middle (2)	17.0	7.8	47.1	27.9
TSOP 32	toe (3)	67.8	2.0		30.0
	underside (4)	53.3	13.1		33.4
AMD Lot 2	top (1)	54.8	8.4	18.0	18.6
	middle (2)	60.9	4.7	17.3	17.1
TSOP 32	toe (3)	70.1	2.8		26.9
	underside (4)	78.7	1.2		20.0
	top (1)	42.5	6.2	26.3	24.8
SOIC	middle (2)	37.2	5.5	26.6	26.6
	toe (3)	85.9	1.4		12.5
	underside (4)	74.9	2.8	7.4	14.7

3.4 Assembly Performance

3.4.1 Joint Evaluation

Visual inspection was performed using magnifications of 6X - 50X. Of primary interest was examination of the solder fillet characteristics with respect to wetting and spreading. A numerical ranking of 1 (poor) to 5 (excellent) was given to all solder fillets associated with each of the experimental conditions evaluated. The numerical ranking takes into consideration the extent of solder spreading on the PWB pad and wicking up the component lead. *No cracks were observed in any of the joints.* The results of the visual examination are shown in Table 2.

The NiPd surface finish had no appreciable effect on fillet quality because the qualitative rating figure was found to be largely insensitive to the component lead finish per PWB finish/ solder alloy combination. A significant reduction in wettability was observed with the lead-free SnAg solder. However, an intrinsically lower wettability by SnAg as compared to SnPb solder has been reported in previous assembly studies.[2] The PWB surface finish produced a secondary effect, suggesting a degradation of solderability with the imidazole and electroless NiPd circuit board finishes versus the SnPb finish.

It can be concluded that the NiPd components exhibit acceptable solder wetting performance when incorporated

Table 2: NiPd Component Lead Assembly Performance Evaluation

TSOP Lead Finish	Paste	PWB Finish	Visual Rating*
NiPd	Sn/Pb	Sn/Pb	5
SnPb	Sn/Pb	Sn/Pb	5
NiPd	Sn/Pb	Ni/Pd	4
NiPd	Sn/Ag	Ni/Pd	3
Sn	Sn/Ag	Sn	3
NiPd	Sn/Ag	Sn	3
SnPb	Sn/Pb	Imidazole	4
NiPd	Sn/Pb	Imidazole	4
* 1 = poor			
5 = excellent			

in the conventional surface mount assembly process (i.e., using RMA solder paste flux chemistry). Assembly performance by the lead-free SnAg solder was not significantly different with the use of the NiPd components. This compared with earlier reported trends. Assembly with the lead-free SnAg solder is not affected by the use of the NiPd components.

3.4.2 Microstructural Joint Analysis

The TSOP packages were cross-sectioned before and after thermal cycling. Figure 3 shows the light microscope photographs of TSOPs assembled with SnPb solder before aging (TSOPs with SnPb and NiPd finishes on PWBs finished with SnPb and NiPd). The joints have smooth, concave fillets and excellent spreading. A close look at the photographs shows the occurrence of what appears to be "dark spots", whose frequency increases with the increase in Pd concentration, as introduced from lead and/or pad finish. For example, in Figure 3 (a), which has no Pd, the spots are hardly noticeable. The number of spots steadily increases from Figure 3 (a) → 3(b) → 3 (c) : No Pd →, Pd (on lead) → Pd (on lead and on PWB). A similar trend was observed with the SnPb-SnPb-Cu vs NiPd-SnPb-Cu.

To investigate the origin of these spots, the cross-sections were analyzed by SEM/EDX elemental mapping. The SEM micrographs for NiPd-SnPb-NiPd are shown in Figures 4 (a)-(d). Figure 4 (b) is a magnified (1800X) image of the spots. The elemental maps of Figure 4 (c) and (d) shows that the "spots" are predominantly Pb-rich, Sn free areas. No such spots were apparent with the SnAg series. The effect of these Pb-rich areas on joint integrity is not clear.

Shown in Figure 5 is the x-ray dot map of the Pd trace for the (a) heel fillet region labeled "A" in the cross-sectional micrograph and (b) gap region of the joint (labeled "B") formed in the NiPd-SnPb-NiPd system following 1,068 thermal cycles. Areas of Pd and Sn concentrations are clearly visible in the gap region and indicated the formation of the PdSn intermetallic compound ($PdSn_4$). Intermetallic compound structures were not observed in similar x-ray dot map analyses of the NiPd-SnPb-Cu samples (not shown). In the heel fillet region, the Pd concentration is less than in the gap region. As a result, the Pd is more diluted in the fillet region, thereby decreasing the development of $PdSn_4$ intermetallic particles and increasing the Pb-rich areas.

After 1,068 cycles, the solder joints were cross sectioned and evaluated for each of the following attributes:

1. Voids in the joint
2. The presence of cracks in the solder or at the interfaces
3. Damage to the fillet such as grain boundary sliding, microcracks etc, and
4. Wetting of the leads as determined by fillet progression.

The extent of each attribute was assessed quantitatively on a scale of 0 to 5, 0 being poor quality, 5 being excellent joint quality.

Table 3: NiPd Component Lead Assembly Performance Evaluation after 1,068 TC

TSOP Lead Finish	Solder Paste	PWB Finish	Voids	Cracks	Fillets	Wetting
NiPd	Sn/Pb	SnPb	4.75	4.13	5.00	5.00
SnPb	Sn/Pb	SnPb	4.63	4.50	4.38	5.00
NiPd	Sn/Pb	NiPd	4.38	5.00	4.63	4.38
NiPd	Sn/Ag	NiPd	3.50	5.00	5.00	4.38
Sn	Sn/Ag	Sn	4.88	5.00	5.00	5.00
NiPd	Sn/Ag	Sn	4.25	5.00	5.00	3.38
SnPb	Sn/Pb	Cu	4.88	4.25	3.13	5.00
NiPd	Sn/Pb	Cu	4.75	4.50	4.68	3.00

Void formation and wetting are actually attributes of the assembly process. Cracks and fillet quality reflect the effects of thermal cycling.

The following general observations can be made from the data in Table 3.

- The extent of microcracks and fillet damage was generally minor. Their occurrences were primarily a function of the solder alloy, being most prevalent with the SnPb solder and absent from the SnAg solder joints.

- The NiPd finish appeared to reduce the extent of wetting on the leads for both solders, but the effect of reduced wetting was greater for the SnAg solder. This is not unexpected, given the reduced wettability of high temperature solders.[2]
- Void formation was clearly increased with the presence of NiPd finish on both component lead and PWB.

3.4.3 Mechanical Pull Testing

Ninety degree pull testing was performed on individual leads of the TSOP devices, using a cross head speed of ~ 9 mm/min. Between five and ten leads were pulled for each device. The average load as well as the standard deviation are reported in Table 4 below.

Table 4: Lead Pull Tests

Lead Coating	Paste	PWB Coating	As Received	1,068 T/Cs	2,417 T/Cs
NiPd	SnPb	SnPb	1.7 ± 0.33	1.9 ± 0.11	2.0 ± 0.02
SnPb	SnPb	SnPb	1.8 ± 0.16	1.9 ± 0.05	2.0 ± 0.19
NiPd	SnPb	NiPd	2.0 ± 0.27	1.5 ± 0.13	1.2 ± 0.14
NiPd	SnAg	NiPd	2.4 ± 0.12	2.0 ± 0.09	2.2 ± 0.22
Sn	SnAg	Sn	2.1 ± 0.22	2.1 ± 0.24	2.2 ± 0.12
NiPd	SnAg	Sn	1.8 ± 0.20	2.2 ± 0.26	2.2 ± 0.22
SnPb	SnPb	Imidazole	1.8 ± 0.22	1.9 ± 0.19	1.8 ± 0.12
NiPd	SnPb	Imidazole	1.5 ± 0.22	1.5 ± 0.17	1.8 ± 0.09

Given the scatter in the data, the maximum load values for all eight assembly conditions were considered to be nearly equivalent in the as-assembled condition, with the exception of NiPd-SnPb-Imidazole which shows lower strength due to poor fillet geometry.

After thermal cycling (1,068 and 2,417 cycles), nearly all of the assembly combinations yielded very slight changes in the maximum load values. However, the assembly combination consisting of NiPd finishes on both the PWB and component leads showed a distinct decrease (40%) in the mechanical strength of the SnPb solder joints. This result presents some concern about the effect of Pd finishes on solder joint integrity. The remaining data shown in Table 4 indicates potential joint strengthening at low Pd concentrations (when the source of Pd is the component lead only). These phenomena will be discussed in more detail in the next section.

3.5 Palladium Metallurgy

Although ample information is available on the effects of Au contamination on SnPb and SnAg solder joints, very little work has been done on the role of Pd on solder joint properties. The purpose of the Pd component of the NiPd finish is to protect the Ni layer surface from excessive oxidation that can potentially inhibit wetting by the solder during joint formation. In the course of the reflow process, the Pd layer is dissolved into the solder as the molten metal spreads on the Ni coating surface. Nickel, having a much lower dissolution rate into solder (i.e., SnPb alloys), deposits only a limited amount of Ni into the solder joint. The extent to which the solder composition is affected by the surface finishes on the package leads (or terminations) and the circuit board feature coatings, is determined by: (1) the nature of the dissolving species; (2) the "localized" volume of solder in the joint area; and (3) the thickness of the surface finishes.

3.5.1 Pd Concentration in the Solder Joint

Calculations have shown that the contamination of the solder by the seemingly "thin" surfaces finishes can be quite substantial, particularly for surface mount joints of fine pitch and ultra-fine pitch leaded packages for which the amount of solder volume in the joint is very limited. A calculation was performed in order to predict the Pd content of solder joints made with 32 I/O TSOP package leads. It was assumed that the lead had a 1.02×10^{-5} cm (4 µin.) thick Pd coating. The computation was extended to include the presence of a NiPd coating on the PWB pad as well. That layer thickness was typically between 5.08×10^{-5} cm (20 µin.) and 15.24×10^{-5} cm (60 µin.); therefore, computations were performed that included the nominal thicknesses: 5.08×10^{-5} cm (20µin.), 10.16×10^{-5} cm (40µin.), and 15.24×10^{-5} cm (60 µin.).

A significant factor in the precious metal contamination of solder joints is that the concentration levels exhibited localized variations. That is, upon dissolution in the solder, the Pd does NOT dissipate throughout the entire solder volume; rather, it can remain quite localized. Studies performed on the dissolution of Pd coatings [3] clearly showed that, in addition to being localized in a particular volume of solder, Pd tends to remain near the interface from which it dissolved, more so than does either Au or Ag, for example. A computation was performed in which the Pd concentration was determined at two locations in the solder joint: (1) in the gap between the bottom of the TSOP gull wing lead and the PWB bonding pad and (2) in the heel fillet of the solder joint. The sources of Pd were assumed to be the lead and/or pad surfaces directly in contact with those regions. Pertaining to the gap region (1), two gap thicknesses were assumed, based upon cross-sectional observations of typical joints. Those values were 0.0019 and 0.0051 cm.

Shown in Table 5 are the calculated Pd concentrations for a number of contamination scenarios such as Pd-coated leads only; pad with 5.08×10^{-5} cm (20 µin.) only; as well as a combination lead and/or pads; the latter having different Pd coverage.

Table 5. Pd Contamination (%) in Gap and Fillet of 32 I/O TSOP 63 Sn-37Pb Solder Joint

	Gap thick, cm	Lead only	Pad (20μin) only	Pad (20μin) + lead	Pad (40μin) only	Pad (40μin) + lead	Pad (60μin) only	Pad (60μin) + lead
Small Gap	0.0019	0.75	3.6	4.3	7.0	7.7	10.0	11.0
Large Gap	0.0051	0.28	1.4	1.7	2.7	3.0	4.0	4.3
Fillet		0.10	0.27	0.37	0.54	0.64	0.81	0.91

As part of the exercise, it was necessary to determine the levels of Pd which might embrittle the solder. A considerable amount of data has been accumulated for the Au-63Sn-37Pb system in which a nominal 4 wt% Au content has been considered as the minimum level at which solder embrittlement occurs.[4] [5] [6] The study described by Reference [4] included the performance of shear tests and fracture toughness tests on 63Sn-37Pb solder joints fabricated from Pd-electroplated copper test bars. It was observed that an equivalent Pd content of 1.0% (resulting from incomplete dissolution of the Pd electroplated coating), dropped the fracture toughness by nearly 50%; similar decreases were observed with 1.5 and 2.0 wt% Pd contents. The authors noted that the Pd dissolved and subsequently formed the intermetallic compound, $PdSn_4$. The Pd contamination of the solder caused a minimal effect of the shear strength, it impacted only the ductility.

Data pertaining to the embrittling effect of precious metals on the non-traditional solders, such as SnAg, is not as extensive as is the case of the tin-lead solders. Mechanical tests conducted by Jacobson and Humpston [7] indicated a significant loss of ductility at the 8 to 10 wt% Au content of the 96.5Sn-3.5Ag base solder, which is approximately twice the amount of Au tolerated by the 63Sn-37Pb solder. If these results are to be interpolated to the case of Pd, then it would appear that the 96.5Sn-3.5Ag solder would face embrittlement with a Pd content in excess of 2 wt%.

The data in Table 5 indicates that the Pd (intermetallic) content of both gap regions would exceed the 1 wt% limit for 63Sn-37Pb solder under every circumstance except for the lead-only case. The larger solder volume contained within the fillet region suppressed the Pd concentration below the 1 wt% limit for the 63Sn-37Pb joints under all circumstances. This analysis demonstrates that the Pd finish of the lead and/or PWB features has the potential to alter the mechanical properties of the solder joints.

3.5.2 Mechanical Performance of Pd Containing Joints

At this point, we re-examine the pull strength data for the 63Sn-37Pb joints (Table 4). In the order of increasing Pd content in the joint, the lead finish/solder paste/PWB finish systems would be: (1) SnPb-SnPb-SnPb and SnPb-SnPb-Cu; (2) NiPd-SnPb-SnPb; (3) NiPd-SnPb-Cu (which has less solder than the previous case, hence a higher expected Pd concentration); and (4) NiPd-SnPb-NiPd. The possible effects which the temperature cycling would have on the joints was two-fold: (1) Temperature cycling may introduce thermal fatigue damage to the joints and/or (2) provide thermal energy that relaxes the solder microstructure as well as assists in diffusion processes related to solute atoms such as Pd. Fatigue damage and structural relaxation traditionally weaken the strength of the solder.

The strengths of the different joints in the as-assembled condition indicates that the Pd had a minor effect on the joint mechanical properties. It was hypothesized that, although the Pd had dissolved into the solder, it remained in super-saturated solid solution after solidification of the solder. In solution, the Pd content did not limit solder ductility.[7] Rather, it would be the form of larger $PdSn_4$ platelets that would impact joint ductility for the worse.

The effect of thermal cycling on the mechanical pull test data for the SnPb and SnAg solders can be summarized as follows:

- The sample joints which did not contain a NiPd finish on any of the structures did not exhibit significant strength changes from the as-fabricated condition after 1,068 and 2,417 thermal cycles.
- In the case of maximum Pd additions arising from NiPd finishes on both the lead and PWB features, both solders exhibited strength decreases after thermal cycling. Clearly, the SnPb solder was more sensitive to the higher Pd contents than the SnAg alloy.
- *The most significant effect was seen with the NiPd/Sn-Pb/NiPd joints, which with the highest Pd content exhibited strength decreases of 25% and 40% after 1,068 and 2,417 thermal cycles, respectively.*

3.5.3 Microstructural Effects

The solder joint pull strength data cited above can be interpreted with respect to the following scenario of microstructural development of the joints resulting from

thermal aging. First, it must be noted that the test procedure administered primarily a tensile load between the lead and the solder in the joint. Therefore, this test was sensitive to both the strength and ductility of the solder. The relatively quick loading rate of the test was also expected to further increase the sensitivity of the joint strength to the solder ductility. Lastly, although failure would likely commence in the heel fillet, both the heel fillet and gap regions would have a significant role in the solder joint mechanical properties.

It was noted that without the presence of Pd, both SnPb and SnAg solder joints exhibited no significant strength change with the progression of thermal cycling. Nevertheless, the overall stable behavior of the solder joints provided an optimum baseline from which to examine the role of Pd.

The introduction of small Pd additions into the SnPb solders from solely the lead finishes caused the joint strength to increase slightly. This trend resulted from either a solid solution strengthening mechanism generated by elemental Pd in the solder, or through a precipitation strengthening process resulting from the formation of small $PdSn_4$ particulates (which may have been coherent or incoherent). The SnAg solder exhibited no significant strength increase. Solid state diffusion of Pd was likely responsible for these microstructural changes and subsequent strength magnitudes. The anticipated Pd concentration levels computed in Table 5 were less than the minimum 1 wt% level observed to cause a significant decrease in SnPb joint ductility [Reference 5]. This point was certainly true for the SnAg solder which is less sensitive to precious metal embrittlement, as predicted from Au contamination experiments.

The strengthening of SnPb solder by the small additions of Au has been observed by other investigators. Bester [8] noted higher ultimate strengths, good ductility, and impact strength for Au contents of less than 3-4wt%. However, at Au contents in excess of 3-4wt%, a significant drop in ductility and impact strength were noted. The ultimate strength, which is determined at slower loading rates than impact tests, remained unchanged. Similar trends were recorded by Jacobson and Humpston.[7] However, the strength of the SnAg solder rose steadily with the increased Au content in the work of Reference 7.

The significantly greater Pd additions arising from the PWB NiPd surface finishes in the NiPd-SnPb-NiPd and NiPd-SnAg-NiPd samples caused a decrease to the joint strengths. The deterioration of the strength likely reflected a drop in solder ductility since strength data from other investigators showed an insensitivity to Pd (or Au) content as noted above. A deterioration was clearly suggested by the Pd contents computed in Table 5. The effect was less pronounced with the SnAg joints as compared with the SnPb samples, confirming the apparently lower sensitivity of the former solder to the embrittling effects of Au, a trend that appears to extend to the case of Pd as well. Mechanistically, the "process" of embrittlement was as follows: After joint solidification, the dissolved Pd remained in solution in the solder. Hence, the as-fabricated joints did not show embrittlement when compared with the non-Pd containing, as fabricated samples. Under the elevated temperatures of thermal cycling, solid state diffusion caused the formation of increasingly larger $PdSn_4$ particles. It was the large particles of the intermetallic compound which ultimately caused embrittlement of the joints (See Figure 5).

Finally, it should be noted that microscopic examination of the solder joints revealed no significant localized damage, such as micro-cracks in the joints.

4. Conclusions

The NiPd electroplated coating was examined as an alternative finish for electronic package leads and PWB surface finishes. Visual and surface analysis performed on the TSOP package indicated the integrity of the NiPd coating was sensitive to the form and trim process. NiPd lead wettability tested with SnPb solder and RMA flux was comparable to SnPb finishes. However, wetting was unacceptable when a water white rosin (or R) flux was used. Surface mount solder joint assembly performance with an RMA, "no clean" flux based paste having either SnPb or SnAg metals, was comparable to the SnPb surface coating.

The dissolved Pd from the lead coating caused minimal change to the SnPb solder joint microstructure. Pb-rich areas were observed within the SnPb solder matrix; these Pb-rich areas did not occur with the SnAg solder. The introduction of an additional NiPd coating on the PWB pads increased the propensity of the Pb-rich area formation, but did not cause a significant change to the strength of the TSOP solder joints. However, lead wettability was slightly decreased.

Exposure of the TSOP solder joints to thermal cycling tests caused no change to the strength or microstructure when NiPd was present only on the lead surface, for both SnPb and SnAg alloys. In the case of maximum Pd additions arising from NiPd finishes on both the lead and PWB features, both solders exhibited strength decreases after thermal cycling. The SnPb solder was more sensitive to the higher Pd contents. A hypothesis based upon Pd-embrittlement of the solder joint was developed. The mechanism of joint embrittlement at higher Pd concentrations was identified to be the $PdSn_4$ intermetallic particles that are formed at elevated temperatures due to solid state diffusion.

This work shows that NiPd is a viable substitute for SnPb as component surface finish. Pd concentration calculations show that there is no appreciable danger in solder joint embrittlement from the amount of Pd present on the component leads only. However, the Pd finish on both leads and the PWB has the potential of degrading the mechanical properties of solder joints.

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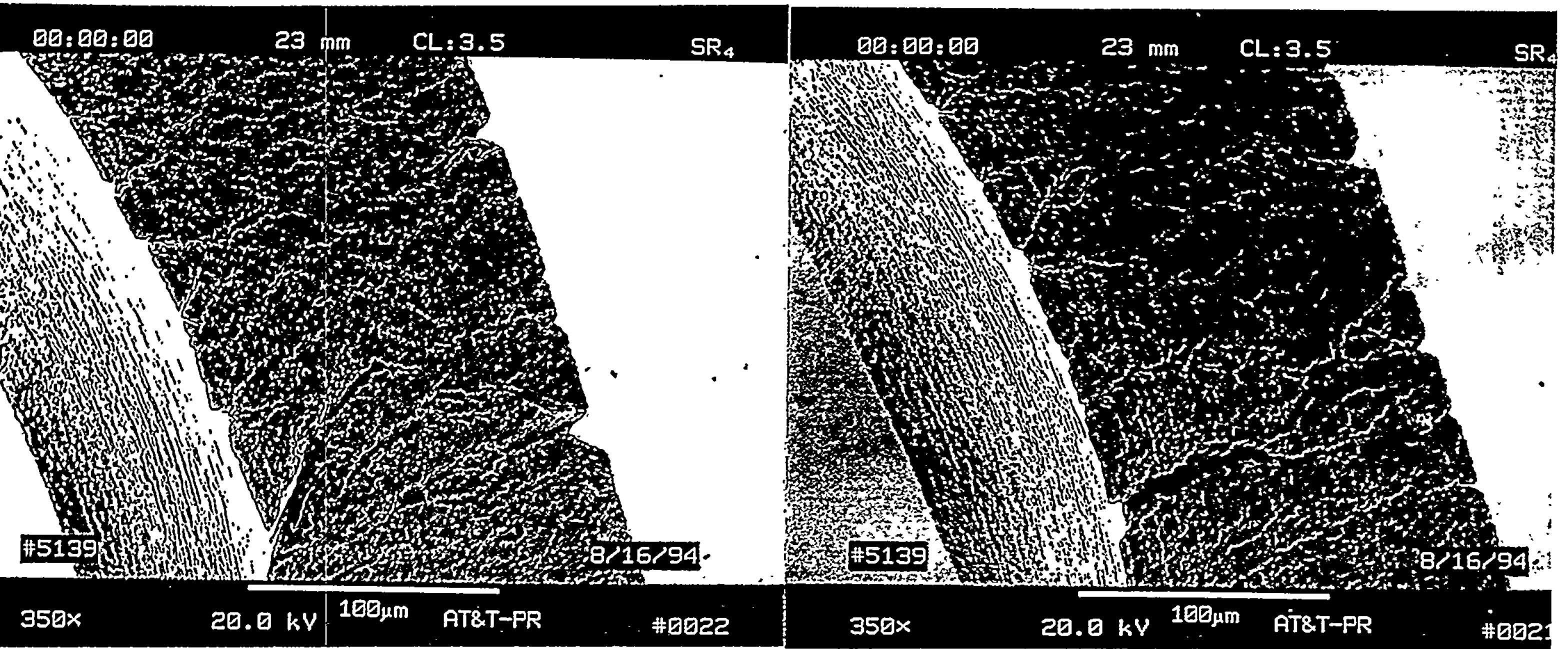
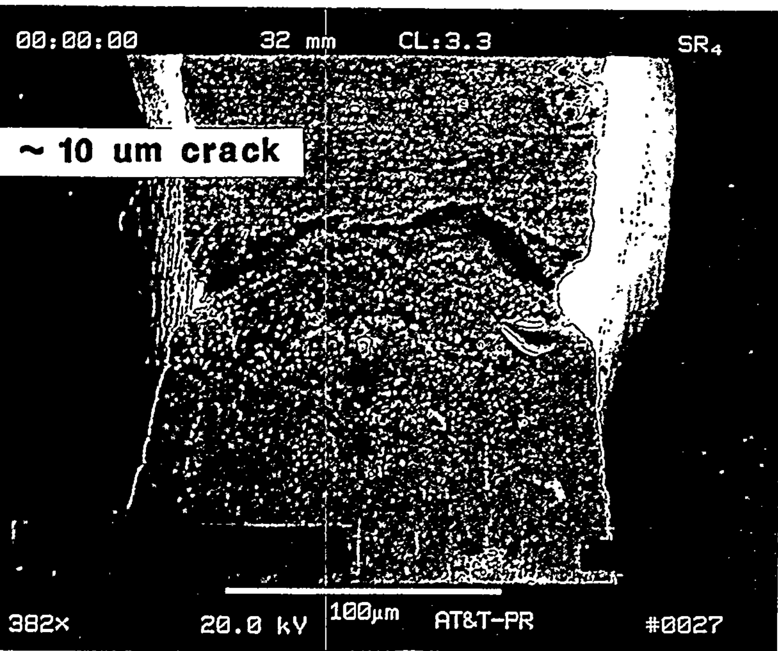
Figure 1



(a) Surface Microcracking (b)



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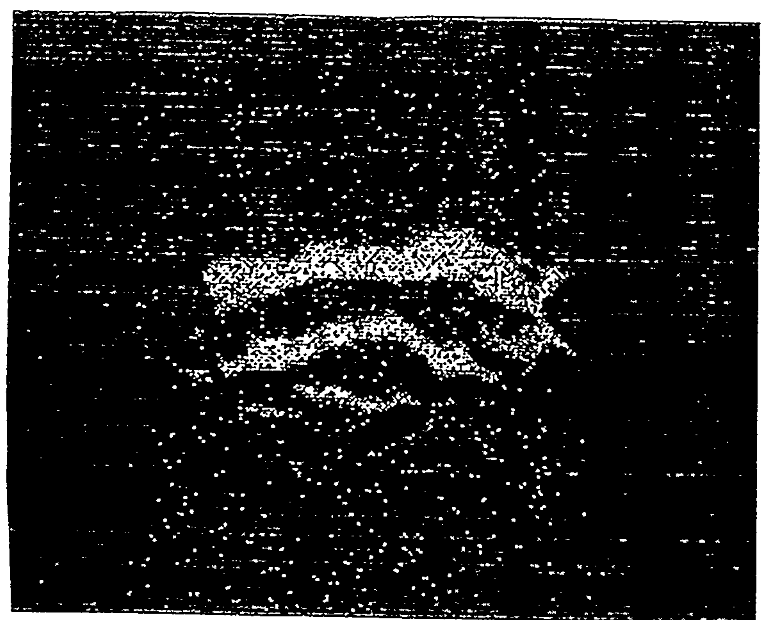
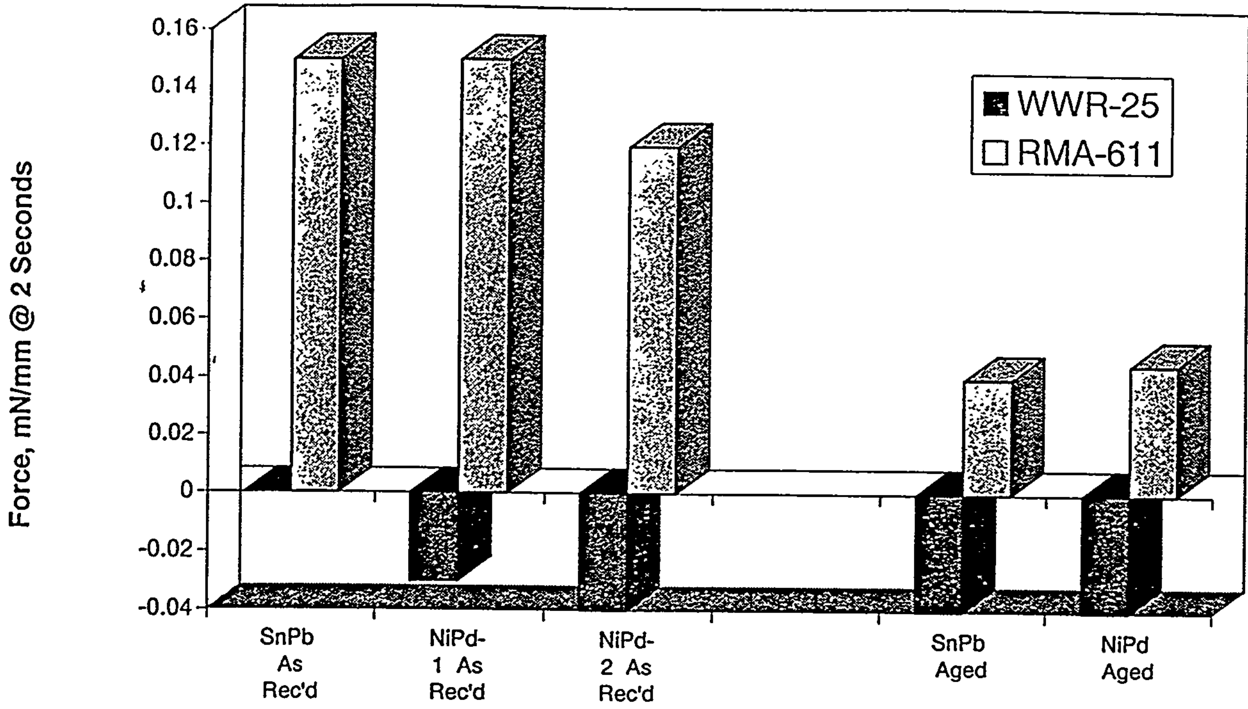


Cu Elemental Map showing copper

(d)

Figure 2



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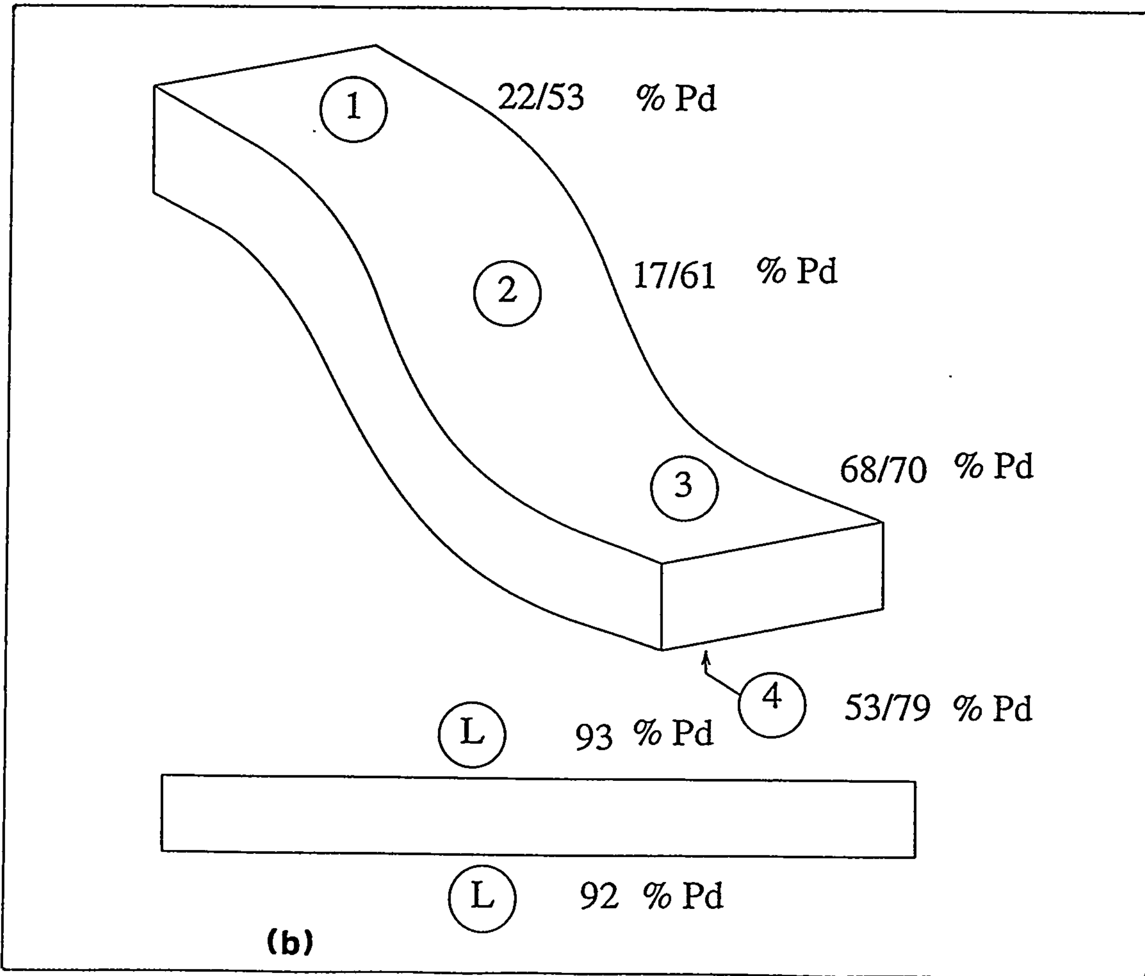


(b)

Figure 3

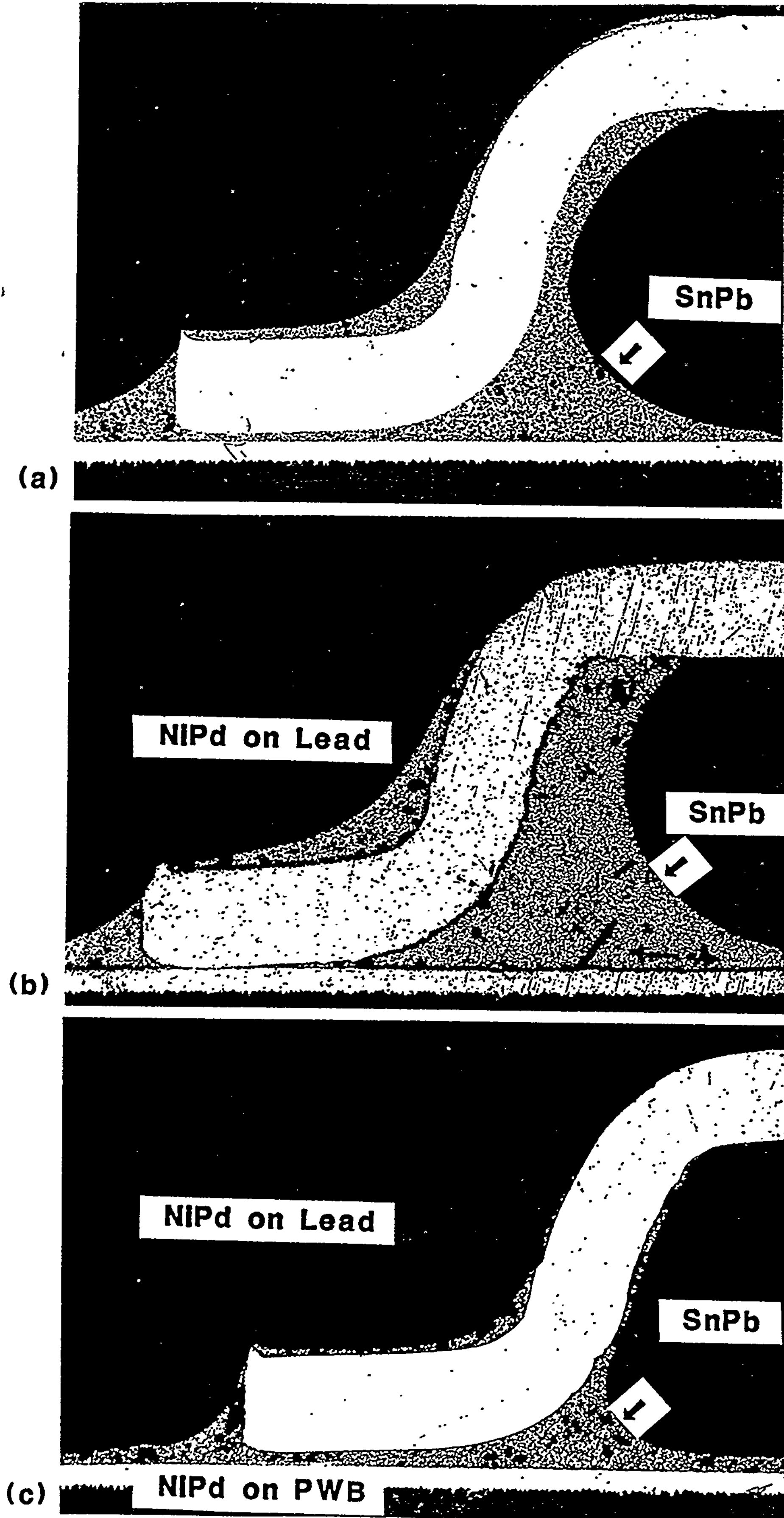
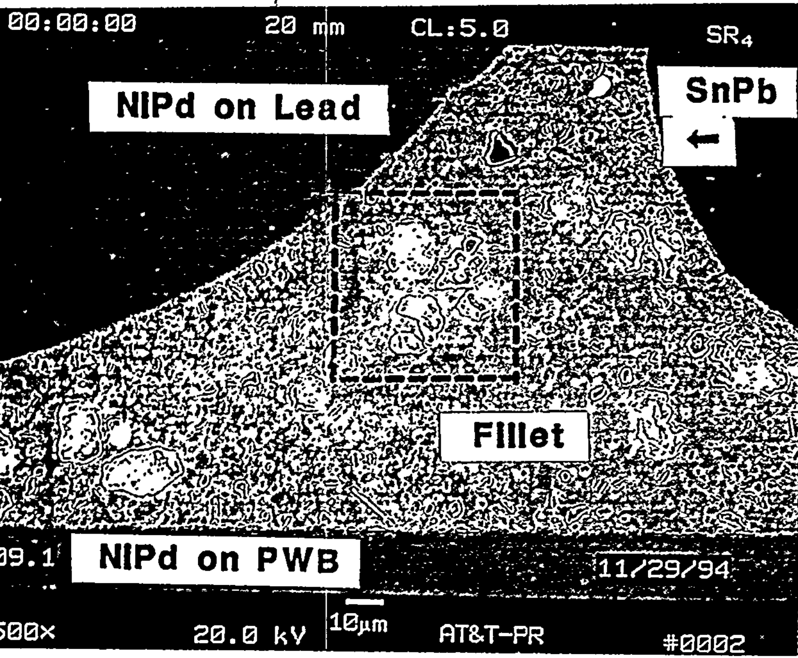


Figure 4



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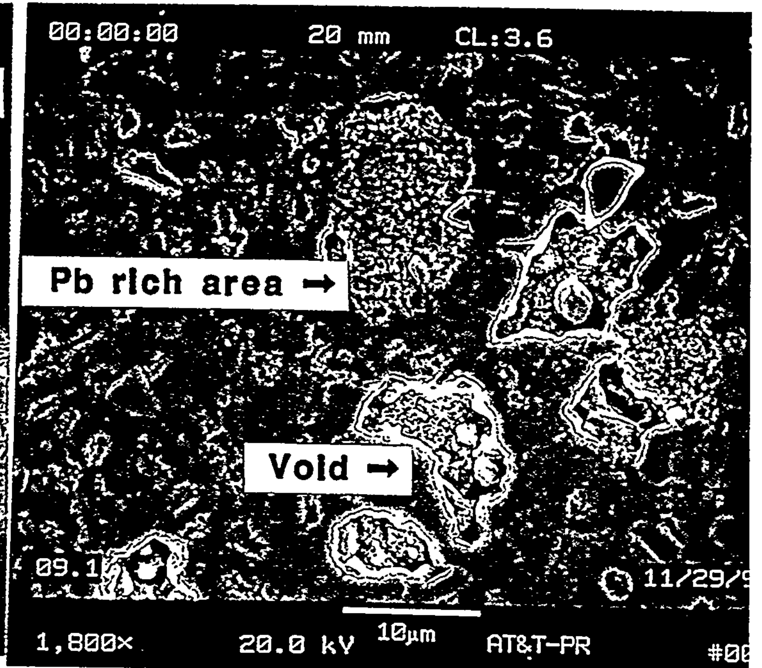

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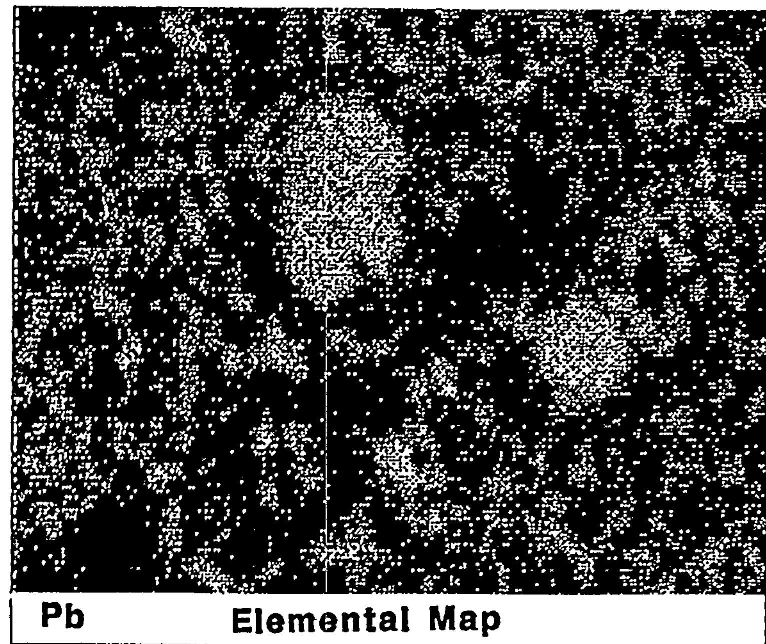

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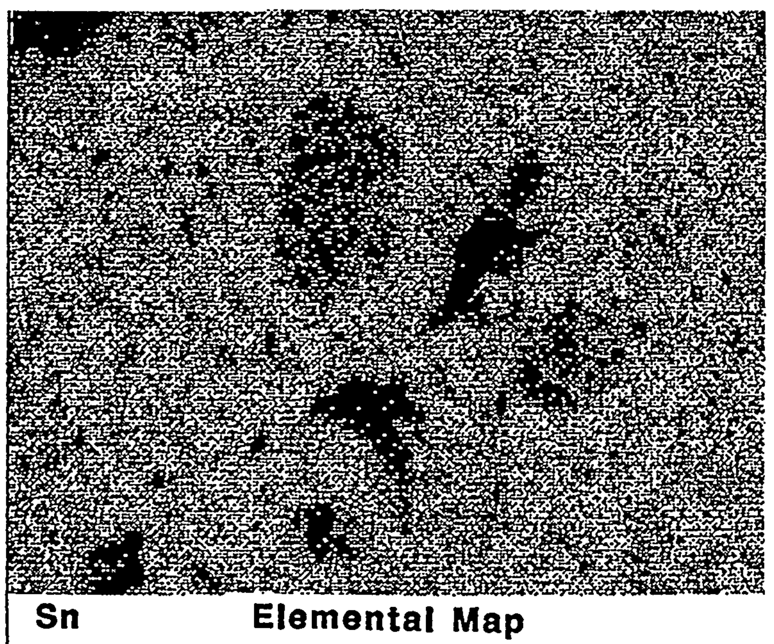

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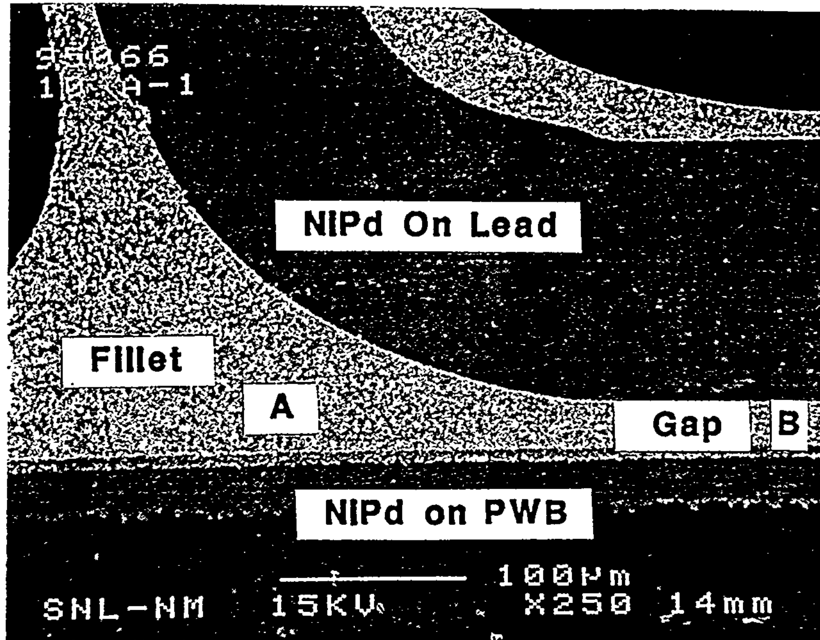
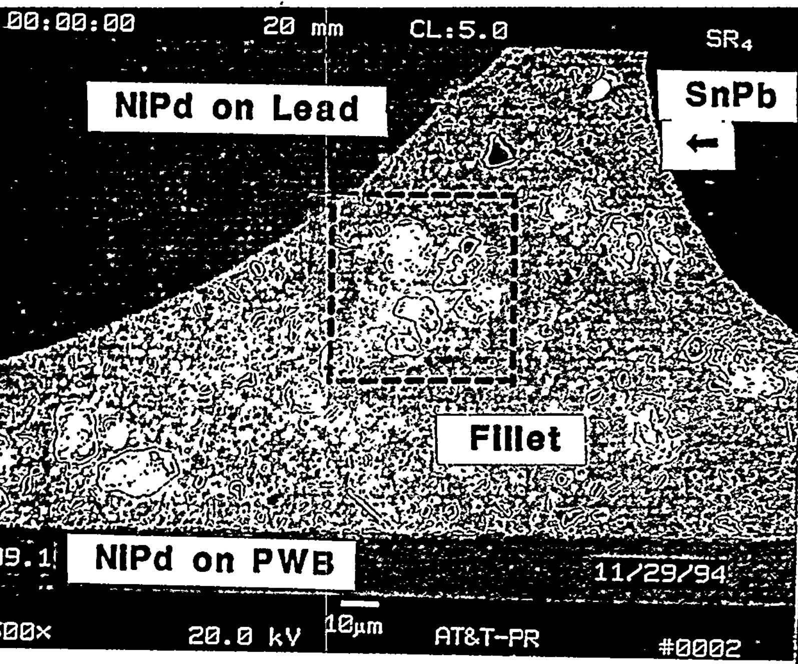


Fillet | Pb Fillet | Pd Fillet

Gap | Pb Gap | Pd Gap

Elemental Map

Figure 4



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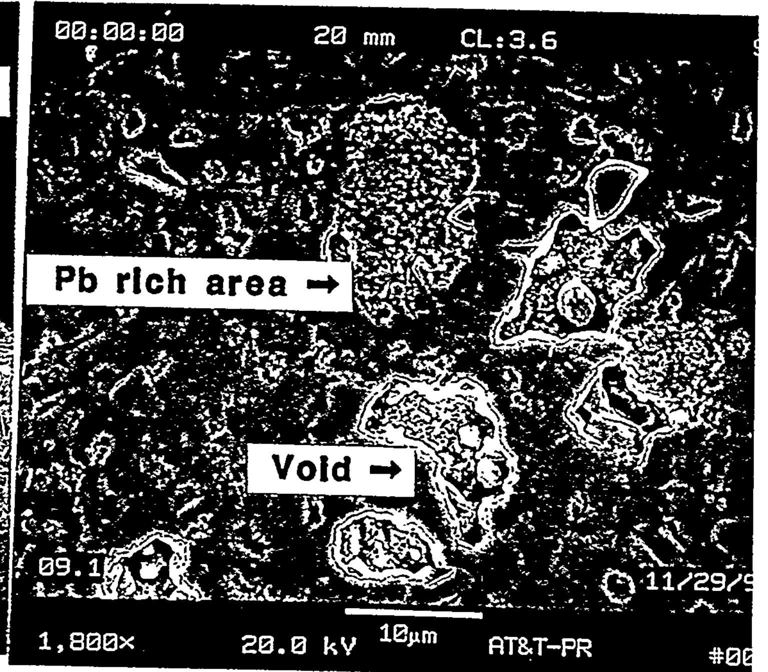

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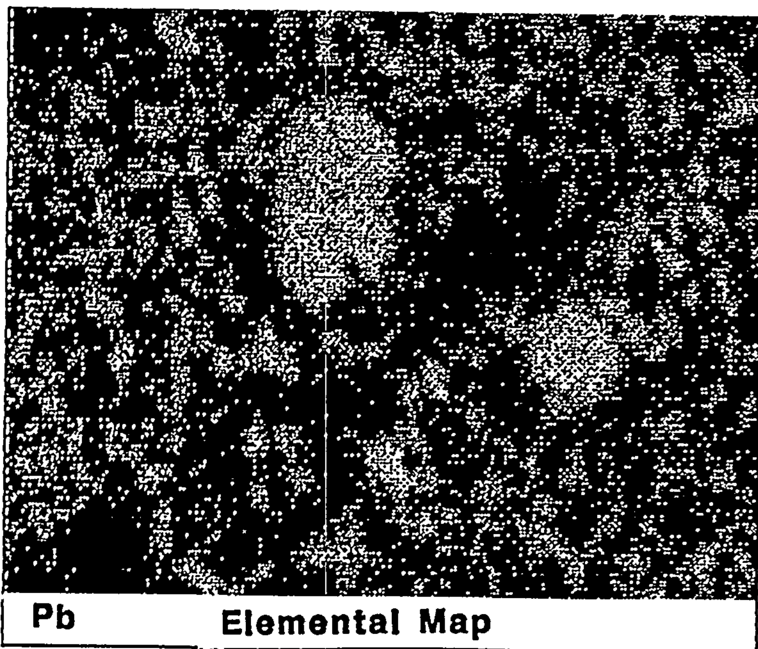

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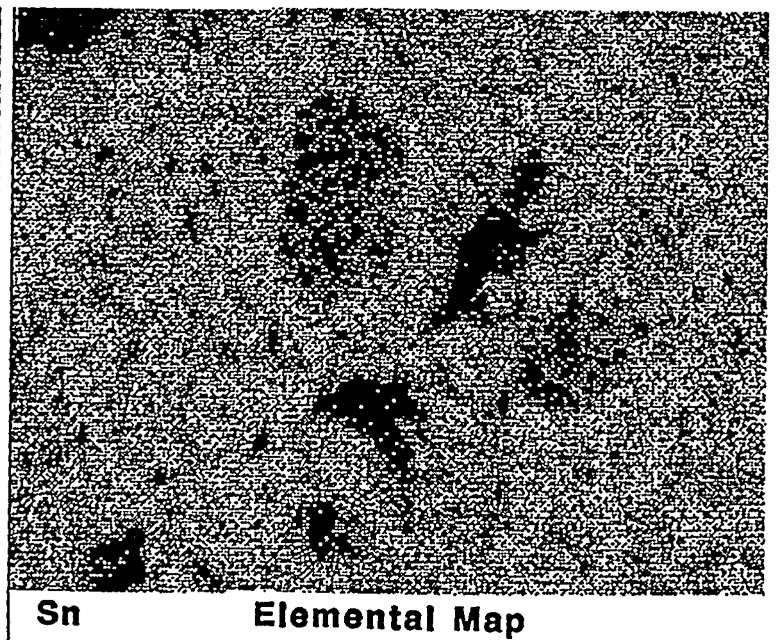

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