IPC Solder Products Value Council (SPVC) Lead-Free Technical Subcommittee Report: Take Action Limits (TAL) for SAC305 Lead Free Automated Soldering Processes

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At present there are a large number of materials that have been proposed as replacements for lead containing solder for reflow and wave and selective soldering.

Unlike solder paste in a reflow process, solder in automated processes changes in composition and impurities with time as the solder is utilized. There currently are no contamination limits for lead-free solder in J-STD-001D. The contamination limits listed in J-STD-001D only apply to tin/lead solders.

Given the limited amount of data available at present, the IPC SPVC members have undertaken a study to determine the "Take Action Limits" (TAL) of solder pot contamination for SAC305 lead free solder. (As the number of lead free alloys currently in use for automated soldering processes is too large for a comprehensive study in any reasonable time frame, the IPC SPVC members, after deliberation, decided to limit the initial work to the SAC 305 ***(96.5%Sn, 3.0% Ag, 0.5% Cu)*** alloy.)

The first action of the SPVC team was to poll suppliers for their current Take Action Limits (TAL) for SAC305. Once these results had been compiled and compared to one another and other published specifications for contamination limits, a proposed set of testing methodologies was drafted. Three action levels were than identified by the SPVC members:

- **Normal operation** defined as the level one would expect contamination levels to be based on running steady state
- **Increased Monitoring** defined as a level that is not a danger but a level that indicates an upward trend that should be monitored more closely
- **Adjust Pot** defined as the level at which pot should be adjusted to insure reliable performance of the solder joints.

Elements to test were based on what elements would normally buildup in an operating solder bath. Elements that could potentially be introduced into a solder bath included silver (Ag) from immersion silver boards, Nickel (Ni) and Gold (Au) from ENIG boards, Copper (Cu) from exposing the underlying copper on all boards, and Antimony (Sb), Bismuth (Bi), and Indium (In) since these elements are frequently contained in many commercially available solder pastes.

A total of eight alloys, with varying levels of elemental contamination, were prepared for the initial testing.

Wetting time and force were measured for all alloys. A ring dip test was also performed to determine if there was a correlation between bridging and the concentration of copper.

A statistical analysis of the wetting data, using Minitab software, was done on all the quantitative wetting data collected. Statistical analysis showed that, within the limits of the test scatter, no strong effect could be found at the levels of metallic contamination, i.e. scatter in wetting balance testing made it difficult to say that any clear trend exists. At most it can be surmised that, within the limits of the test procedures, there is no difference in alloy wetting performance.

To further investigate the effects of metallic contamination samples of all eight solders (A to H), the solders were sent to the Center for Characterization and Microscopy of Materials, (CM)2 in Montreal, Canada. Each one of them was cut, polished and characterized using backscattered electron micrographs and EDS analysis in a SEM. Three different regions per sample (#1 – tin, #2 – intermetallic and #3 – copper (substrate)) were examined.

In reviewing the micrographs the primary difference between them is the apparent structure in the tin region for all samples except one. Samples with a high copper content showed the greatest amount of "structure."

It is apparent that the metal levels in these samples do not have a significant effect on performance as measured by these tests. The differences found in the SEM showing significant structure in the bulk would need to be confirmed.

Based on the testing and analysis performed it is the recommendation of the SPVC that the proposed levels of contamination, shown in the table below, be presented to the IPC committees charged with J-STD-002C and J-STD-006B for inclusion into those documents.

The engineering judgment of the companies surveyed combined with the null results obtained in testing reported here indicate that the levels shown in the table are adequate for lead free alloys in a wave solder process ***and as such represent an advance over the confusion reigning at present.***

Proposed TAL Contamination Levels

Contaminant	Normal	Increase Pot Monitoring	Adjust Pot
Silver	< 3.2%	> 3.5%	> 4.25%
Aluminum	≤ 0.001%	> 0.002%	≥ 0.006%
Arsenic	< 0.02%	> 0.02%	> 0.03%
Gold	0 – 0.03%	0.08%	0.02%
Bismuth	≤ 0.03%	> 0.03%	0.25%
Cadmium	≤ 0.001%	> 0.002%	> 0.005%
Copper	< 0.6%	> 0.8%	1.2%
Iron	0.01%	> 0.01%	> 0.02%
Indium	< 0.01%	> 0.01%	> 0.1%
Nickel	< 0.01%	> 0.025%	> 0.05%
Lead			≥ 0.10%
Antimony	< 0.05%	> 0.05%	> 0.2%
Tin	Balance	> 97.25%	> 97.5%
Zinc	0.003%	< 0.003%	> 0.003%

For the future it is planned that SPVC will consider:

- Increasing the range of metal contamination to determine if there are still higher thresholds of the TAL.
- Examining bulk properties as a function of contamination e.g. creep or shear or pull strength.
- Examining changes in fluidity with increasing contamination: wave solder simulation.

IPC Solder Products Value Council

Lead-Free Technical Subcommittee Report

Take Action Limits (TAL) for SAC305 Lead Free Automated Soldering Processes

Howard Stevens

Metallic Resources Inc.

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IPC Solder Products Value Council

- **Mission: To identify and execute programs designed to enhance the competitive position of solder manufacturers and their customers.**

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- Avantec
- Cookson Electronics
- EFD, Inc.
- Harimatec
- Henkel Technologies
- Heraeus, Inc.
- Indium Corp.
- Kester
- Koki Company Ltd.
- Matsumura Metal Co., Ltd.
- Metallic Resources, Inc.
- Nihon Superior Co. Ltd.
- P. Kay Metals Supply
- Qualitek
- Redring Solder
- Redring Solder (M) SDN
- Senju Metal Industry
- Shenmao Technology, Inc.
- Sigma Ming GOA Electronics
- Yik Shing Tat industrial

Statement of Problem:

- Solder in automated processes changes in composition and impurities with time as the solder is utilized, unlike solder paste in reflow processes.
- No maximum contamination levels exist in IPC for machine soldering with lead free alloys .
- Contamination limits in IPC J-STD-001D only apply to tin/lead, and not lead free.

SPVC Goal:

- To be able to add value to our customers by providing consistent (one voice) recommendations for action levels on contaminant elements for machine soldering alloys.

SPVC Alloy Choice:

- Too many lead free alloys currently exist to study all of them.
- After deliberation, the SPVC selected SAC305 (Sn96.5/Ag3.0/Cu0.5) to study.

SPVC Test Subcommittee Members:

- Mr. Paul Lotosky (Cookson Electronics)
- Mr. Ross Berntson (Indium)
- Mr. Stanley Rothschild (Metallic Resources, Inc.)
- Mr. Karl Seelig (AIM)
- Dr. Greg Munie (IPC Secretary)

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Study Methodology:

- Solder Manufacturers polled for their current Take Action Limits for SAC305.
- SPVC committee compiled results and compared to one another as well as other published contamination specifications.
- SPVC proposed a set of testing methodology.

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Table 1:

- **Shows the collected input on pot contamination levels from four SPVC members, IPC J-STD-006B (Requirements for Electronic Grade Solder Alloys) and J-STD-001D (Requirements for Soldered Electrical and Electronic Assemblies).**

Table 1: Compiled Data

Element	J-STD-006B	J-STD-001D	Company A	Company B	Company C	Company D
Tin	96.5%	+/- 1.5% of alloy	Bal.	95.00-96.80%	95%	Bal.
Arsenic	0.03%	0.03%	0.03%	0.03%	0.03%	0.03%
Antimony	0.05%	0.50%	0.05%	0.05%	0.50%	0.20%
Gold	0.05%	0.20%	N/A	0.20%	0.20%	0.10%
Iron	0.02%	0.02%	0.02%	0.02%	0.02%	0.02%
Nickel	0.01%	0.01%	0.01%	0.01%	0.01%	0.05%
Bismuth	0.10%	0.25%	0.10%	0.25%	0.25%	0.02%
Aluminum	0.005%	0.006%	0.001%	0.006%	0.01%	0.002%
Copper	Alloy +/- .1%	0.4-.6%	0.5 +/-0.1	0.4-1.2%	1.00%	0.3-1.0%
Silver	Alloy +/- .2%	3% +/- .2%	3% +/- .2%	2.25-3.75%	2.75-4%	2.8-3.5%
Zinc	0.003%	0.005%	0.001%	0.005%	0.005%	0.003%
Cadmium	0.002%	0.005%	0.001%	0.005%		0.003%
Indium	0.10%		0.05%	0.10%	0.01%	
Lead	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%

Study Methodology:

- As opposed to one maximum contamination level (shown in IPC-J-STD-001D), the IPC SPVC sub committee opted to identify three action levels.

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Table 2:

- **After deliberation on the existing recommendations for contamination levels, the three levels in Table 2 were proposed.**

Three Levels of Limits:

- Normal Operation.
- Increased Pot Monitoring.
- Adjust Pot.

Table 2: Proposed TAL Contamination Levels

Contaminant	Normal	Increase Pot Monitoring	Adjust Pot
Tin	Balance	>97.25%	>97.50%
Arsenic	<0.02%	>0.02%	>0.03%
Antimony	<0.05%	>0.05%	>0.20%
Gold	0-0.03%	0.08%	0.2%
Iron	0.01%	>0.01%	>0.02%
Nickel	<0.01%	>0.025%	>0.05%
Bismuth	≤0.03%	>0.03%	>0.25%
Aluminum	≤0.001%	>0.002%	>0.006%
Copper	<0.6%	>0.8%	1.2%
Silver	<3.2%	>3.5%	>4.25%
Zinc	<0.003%	>0.003%	>0.005%
Cadmium	≤0.001%	>0.002%	>0.005%
Indium	<0.01%	>0.01%	>0.10%
Lead			>0.10%

Normal Level:

- **The purpose of the "Normal Level" is to identify that level, under steady usage, at which contaminant levels would be expected to not pose any problems.**

Increase Pot Monitoring:

- **The purpose of "Increase Pot Monitoring" is to alert the user of the possibility of a potential problem. Upon reaching a level in the second column, the user should:**
  - **1.) verify accuracy of the analysis,**
  - **2.) identify the source of the contamination, and**
  - **3.) increase monitoring activities.**

Adjust Pot :

- The purpose of the "Adjust Pot" column is to inform the user that corrective action should be taken when an element(s) reaches the designated level. That includes:
  – Replacing the solder bath.
  – Reducing the level of contamination by dilution or removal of contamination.

The Effect of Metals Contamination on Wetting.

- The SPVC first agreed on what elements to test by determining what elements would normally be built up in an operating solder bath.
- They then agreed on what levels of element impurities to test for.

These elements can best be described as:

- Approximating buildup from immersion silver boards (Ag).
- Approximating buildup from ENIG boards (Ni, Au).
- Approximating buildup of copper exposed to the soldering process (Cu).
- Approximating buildup of elements that are commonly encountered (Sb, Bi, In).

The Effects of Metals Contamination on Wetting

- A total of eight alloys were prepared for initial testing. Table 3 shows the analysis of those alloys for metal contamination levels.

These alloys can be described as:

- **Alloy A: SAC305 meeting J-STD-006B (with high Cu).**
- **Alloy B: SAC305 meeting J-STD-006B with Fe at max level.**
- **Alloy C: SAC305 meeting J-STD-006B with Cu, Ag, Ni, Au at max level.**
- **Alloy D: SAC305 meeting J-STD-006B with Al, Sb, Bi, Zn at max level.**

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These alloys can be described as:

- **Alloy E: SAC305 meeting J-STD-006B with all elements (except Cd) at max level.**
- **Alloy F: Control SAC305 per J-STD-006B.**
- **Alloy G: SAC305 (has high Cu 1.2%).**
- **Alloy H: SAC305 (has high Cu 1.4%).**

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Table 3: Alloys Prepared

Contaminant	A	B	C	D	E	F	G	H
Silver	3.05	3.1	4.2	3.09	4.33	3.09	2.83	2.85
Aluminum	< 0.001	< 0.001	< 0.001	0.003	< 0.002	< 0.002	0.0005	0.0005
Arsenic	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	< 0.007	0.0025	0.0025
Gold	< 0.001	< 0.001	0.183	< 0.001	0.141	< 0.001	0.0016	0.0016
Bismuth	< 0.002	< 0.002	< 0.002	0.292	0.306	< 0.002	0.01	0.01
Cadmium	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.0007	0.0008
Copper	1.02	0.503	0.974	0.487	0.964	0.508	1.13	1.44
Iron	< 0.002	0.002	< 0.002	< 0.002	< 0.002	0.003	0.011	0.028
Indium	< 0.007	< 0.007	< 0.007	0.099	0.095	< 0.007	0.004	0.0038
Nickel	< 0.002	< 0.002	0.052	< 0.002	0.058	< 0.002	0.0037	0.0038
Lead	<0.005	<0.035	<0.005	<0.005	<0.006	< 0.005	0.07	0.07
Antimony	< 0.003	< 0.003	< 0.003	0.191	0.193	< 0.003	0.047	0.047
Tin	Balance	Balance	Balance	Balance	Balance	Balance	Balance	Balance
Zinc	< 0.001	< 0.001	< 0.001	0.001	0.001	< 0.001	0.0003	0.0004

Effects of Metals Contamination on Wetting

- Samples A through F were prepared by AIM.
- Samples G and H prepared by Metallic Resources.
- Only third party test facilities used.

Effects of Metals Contamination on Wetting

- Wetting time and force measured for all alloys.
- A ring dip test was also performed to determine if a correlation between bridging and the concentration of copper existed.

Effects of Metals Contamination on Wetting

- All test coupons prepared individually just prior to testing.
- Copper foil of 35 microns (1 oz. copper) used for test.
- Copper foil shall have no surface treatment and is expected to have an oxidized appearance.

Effects of Metals Contamination on Wetting

- If the copper foil was bright and shiny, it was not used (indicative of surface anti-tarnish treatments). Surface treatments can interfere with the ability to make a consistent "good coupon" for testing.

Effects of Metals Contamination on Wetting

- The copper foil coupons shall be die cut to ensure repeatability of tested samples.
- The copper foil coupons shall be 2 mm in width.
- Create a file for each width and person involved performing the Gage Repeatability & Reproducibility.

Test parameters shall be:

- **Solder temp shall be "as recommended" for the alloy and the spec being used (i.e. for Sn63 J-STD-003 235° C, and J-STD-002C, 245° C, and 255° C for SAC305 regardless of the spec.**
- **Immersion depth shall be 0.4mm.**

Test parameters shall be:

- Immersion speed shall be 2 mm/sec.
- Dwell time in the solder shall be 10 seconds.
- Immersion angle shall be 90° incident to the solder.
- No pre-heat shall be used.

Sample Preparation for the "Known Good Coupon":

- Use tweezers to immerse a foil sample into a beaker of Acetone and gently agitate for 20 seconds.
- Remove sample and blot dry both sides with lab tissue.

Sample Preparation for the "Known Good Coupon":

- Again, with tweezers, immerse the sample into a 20% v/v Nitric acid solution and gently agitate for 20 seconds.
- Immerse the sample in DI water and gently agitate for 20 seconds. Then blot dry.

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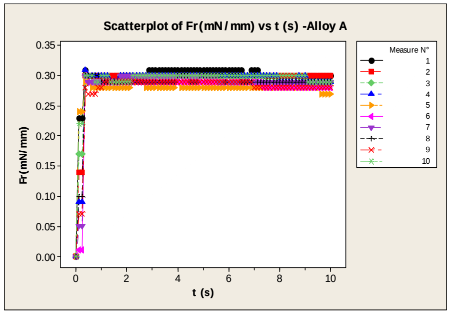
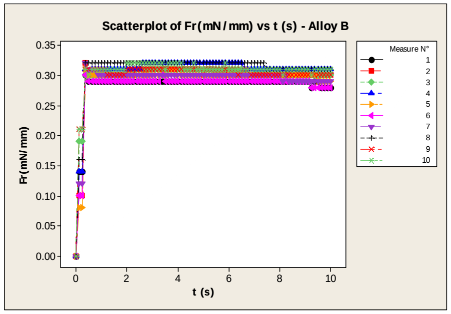
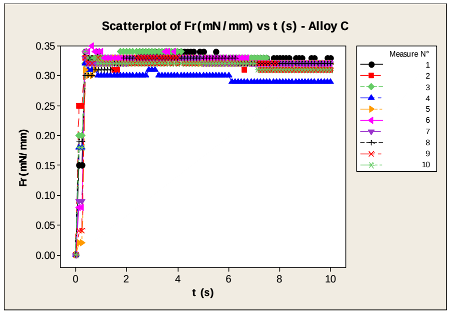
Effects of Metals Contamination on Wetting

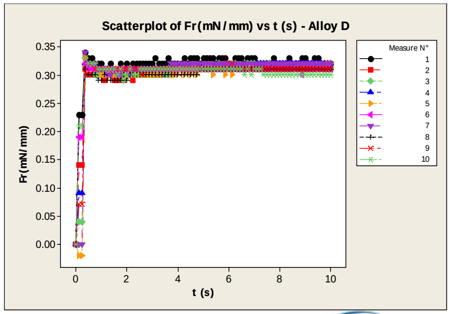
- **Dip the sample into the "standard activated flux" normally used for solderability testing for 5 seconds.**
- **Holding the samples vertically, blot to remove excess flux.**
- **Place sample into tool holder.**
- **Run the test.**

Wetting Test Results
Alloys A - D









Time = 0 – 10 sec.

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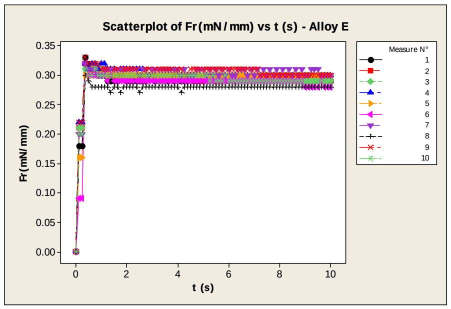
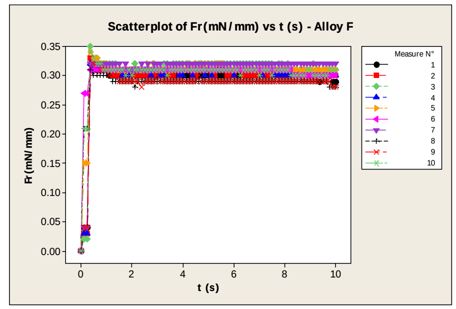
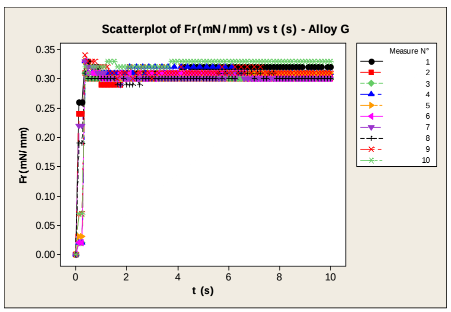
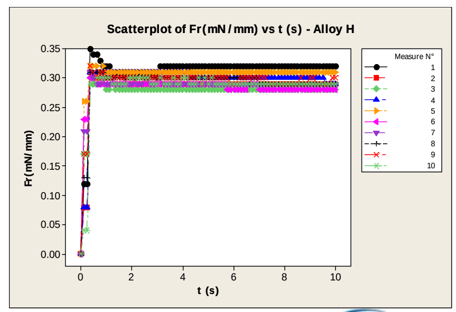
Wetting Test Results
Alloys E - H







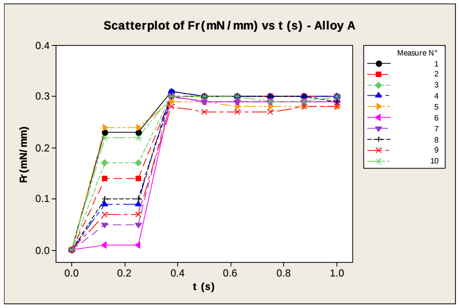


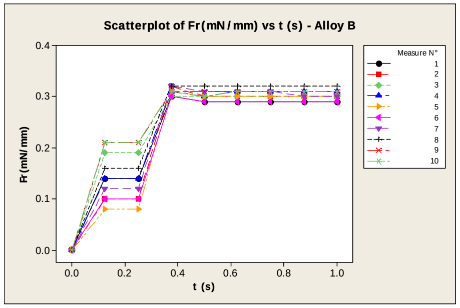
Time = 0 – 10 sec.

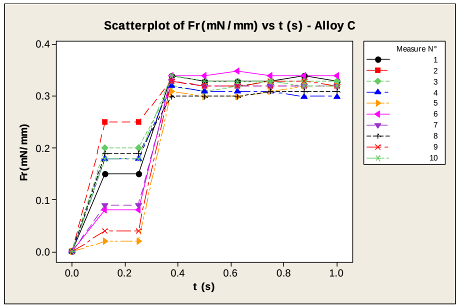
Effects of Metals Contamination on Wetting: The Results

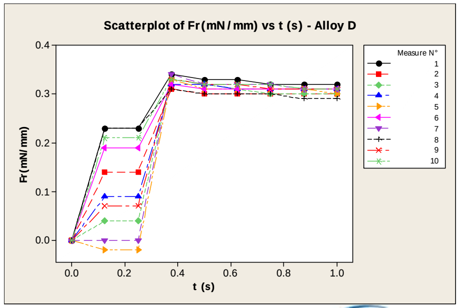
- Initial analysis suggests all alloys performed the same in the 0 to 10 second range.
- A closer look at wetting in the 0 to 1 second range is shown below.

Wetting Test Results
Alloys A - D









Time = 0 – 1 sec.

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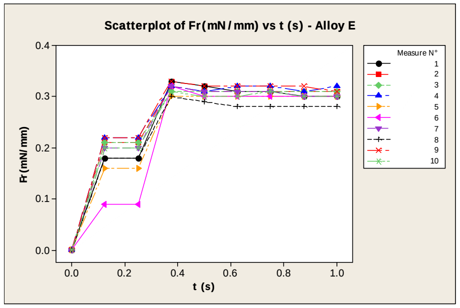
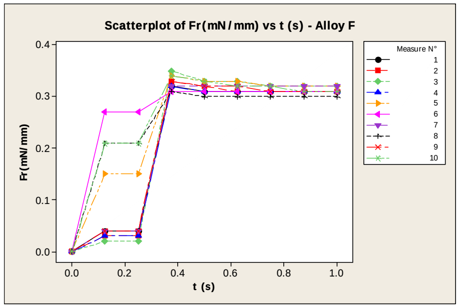
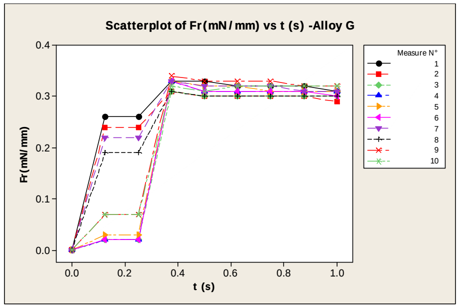
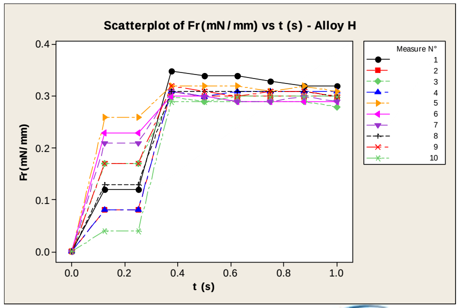
Wetting Test Results
Alloys E - H









Time = 0 – 1 sec.

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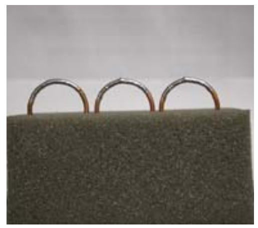
Effects of Metals Contamination on Wetting: The Results

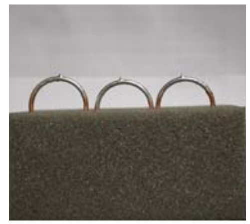
- Initial analysis also suggests that all the alloys perform the same in the 0-1 second range.

Ring Test Results

A



B



C

D

E

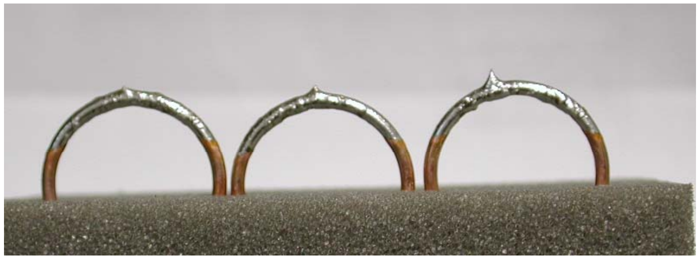
F

G

H

Ring Test Results

Alloy A



Alloy Code	Silver	Aluminum	Arsenic	Gold	Bismuth	Cadmium	Copper	Iron	Indium	Nickel	Lead	Antimony	Tin	Zinc
A	3.05	<0.001	<0.007	<0.001	<0.002	<0.001	1.02	<0.002	<0.007	<0.002	<0.005	<0.003	Bal	<0.001
H	2.85	0.0005	0.0025	0.0016	0.01	0.0008	1.44	0.028	0.0038	0.0036	0.07	0.047	Bal	0.0004

Alloy H

Effects of Metals Contamination on Wetting: The Results

- **Qualitatively, the wetting on Alloy A is a little less smooth than that of Alloy H.**

Cross Sections and SEM Analysis

- **All eight samples (A through H) sent to the Center for Characterization and Microscopy of Materials.**
- **Samples, cut, polished and characterized using backscattered electron micrographs and EDS analysis in a SEM.**

Cross Sections and SEM Analysis

- **Three different regions per sample (#1 tin, #2 intermetallic, #3 Copper substrate) were examined.**

SOLDER A:

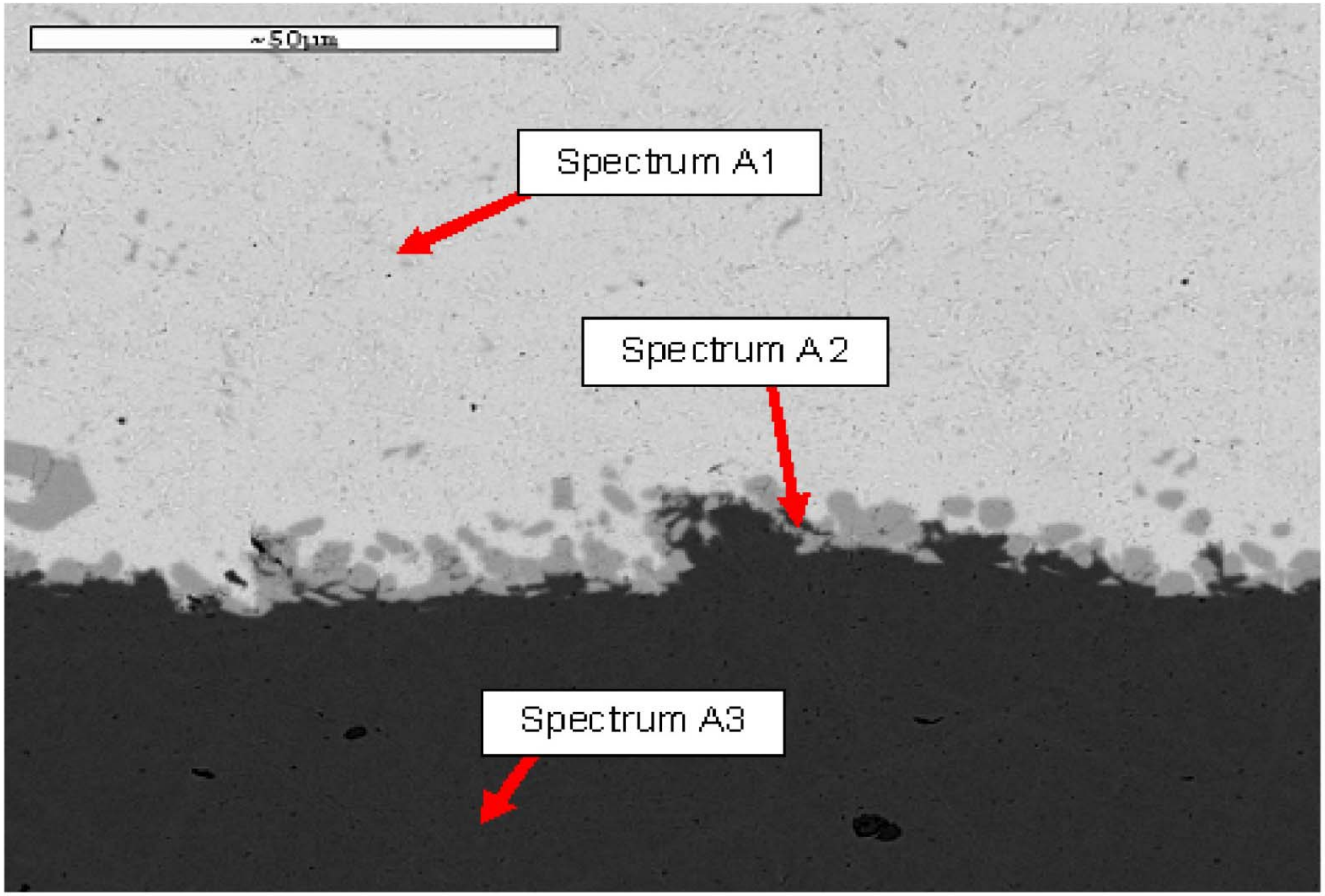


Figure 15: Backscatter electron micrograph of solder A (1000X)

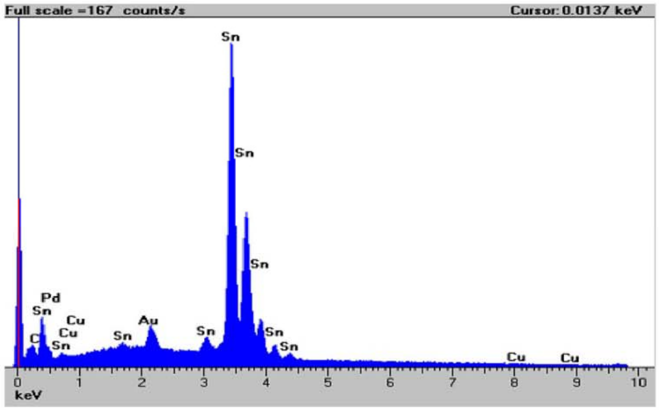


Figure 16: Spectrum A1: EDS spectrum of solder A, tin region

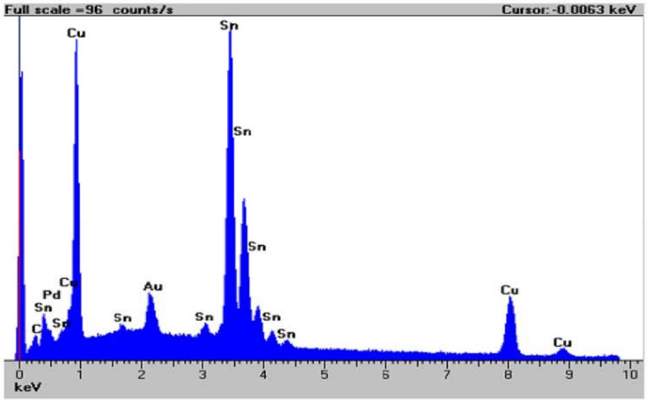


Figure 17: Spectrum A2: EDS spectrum of solder A, intermetallic region

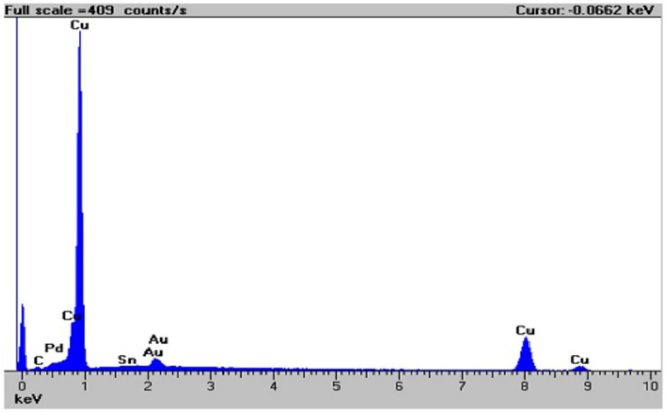


Figure 18: Spectrum A3: EDS spectrum of solder A, copper region

SOLDER B:

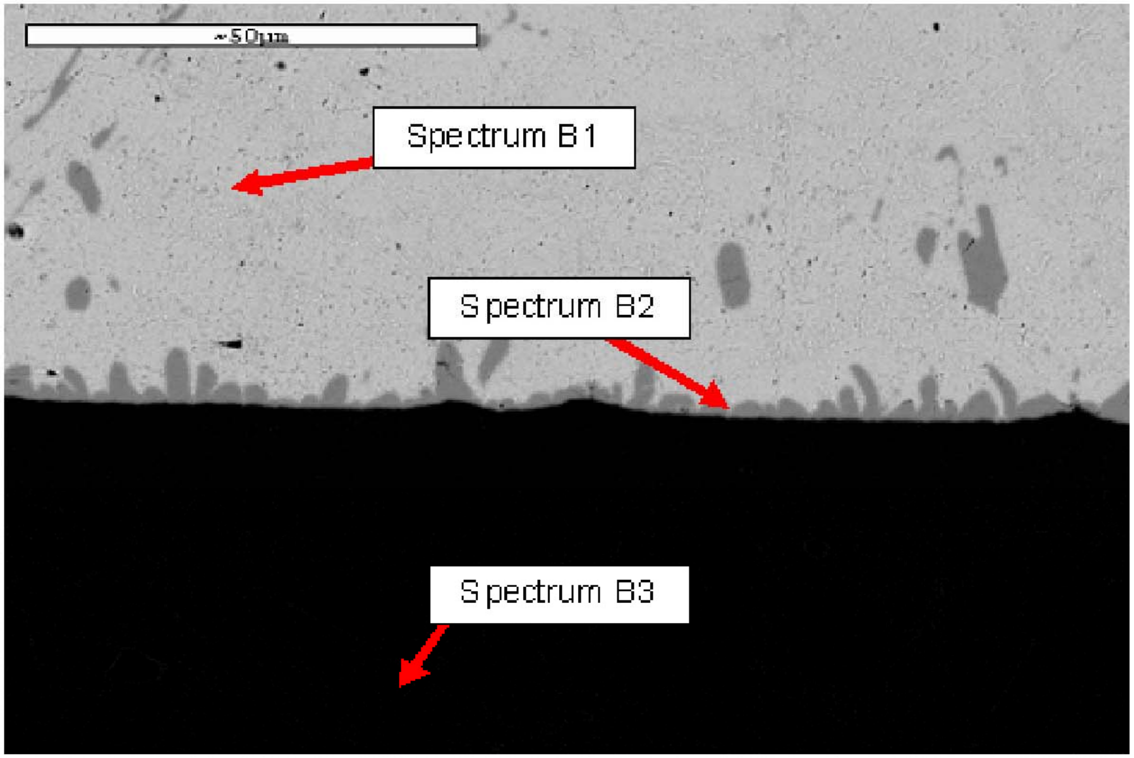


Figure 19: Backscatter electron micrograph of solder B (1000X)

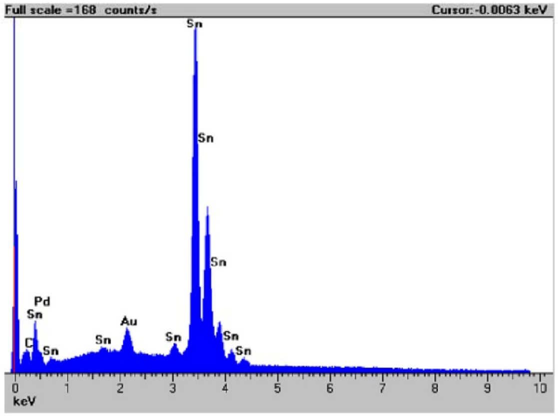


Figure 20: Spectrum B1:
EDS spectrum of solder B, tin region

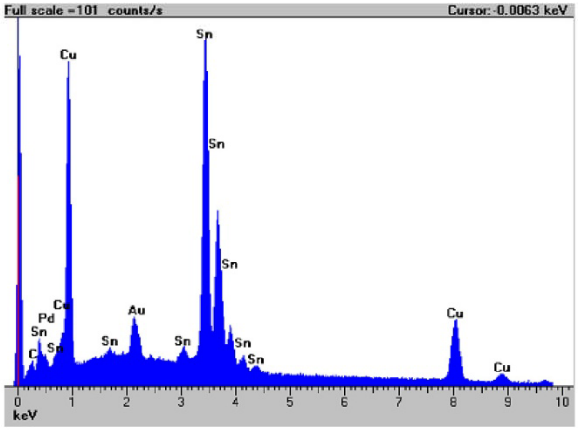


Figure 21: Spectrum B2: EDS spectrum
of solder B, intermetallic region

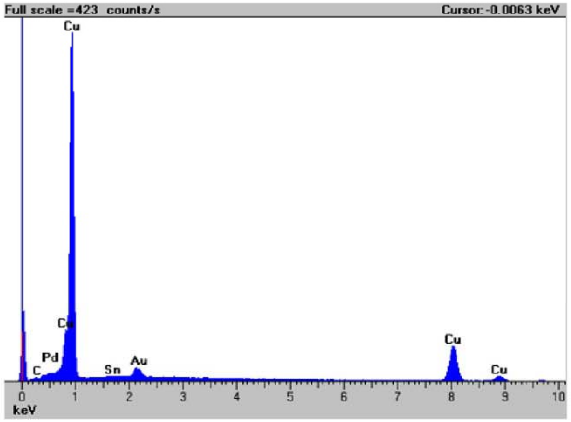


Figure 22: Spectrum B3: EDS spectrum of solder B, copper region

SOLDER C:

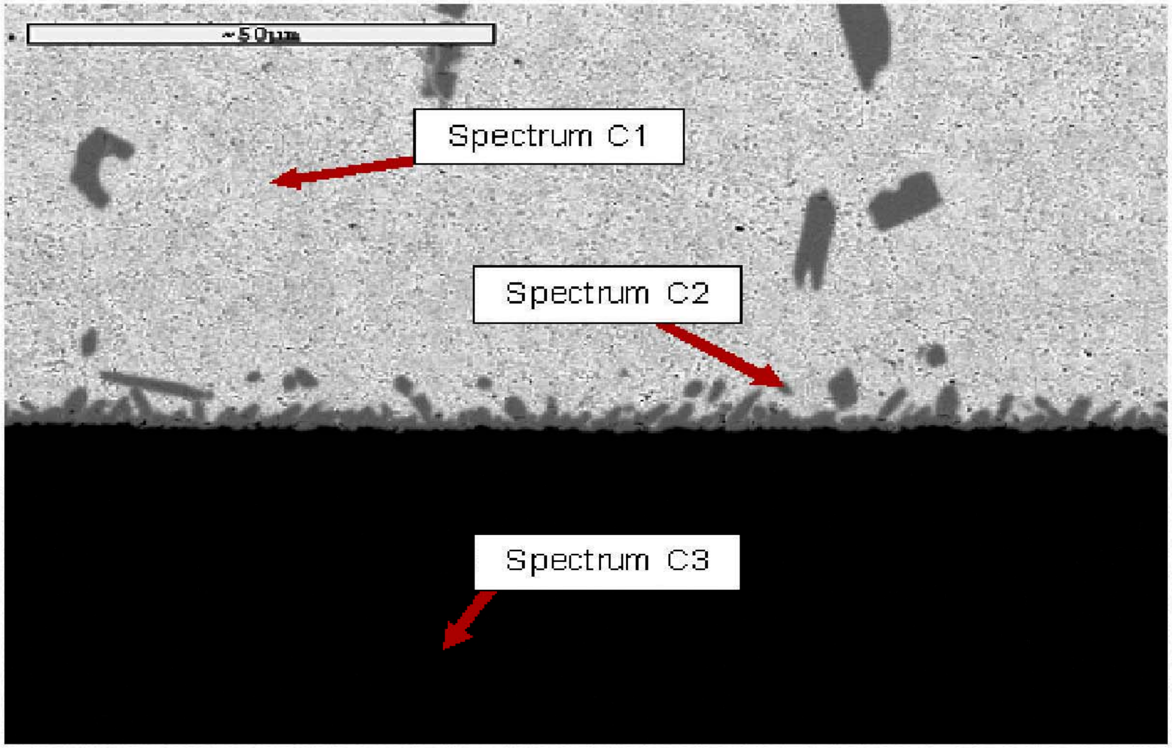


Figure 23: Backscatter electron micrograph of solder C (1000X)

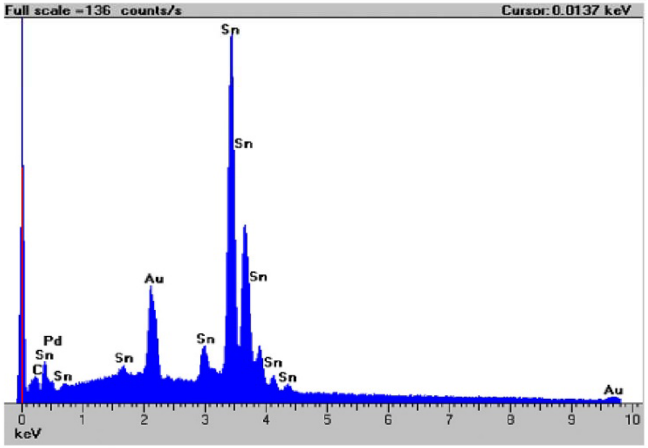


Figure 24: Spectrum C1: EDS spectrum of solder C, tin region

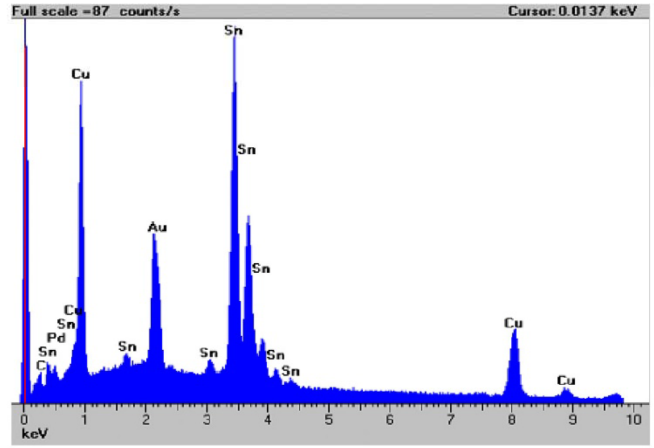


Figure 25: Spectrum C2: EDS spectrum of solder C, intermetallic region

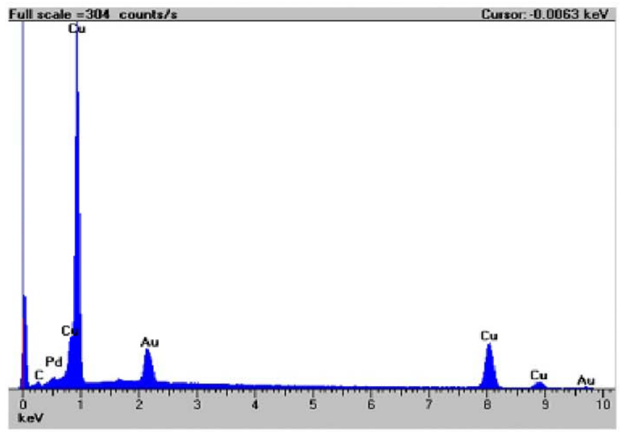


Figure 26: Spectrum C3: EDS spectrum of solder C, copper region

SOLDER D

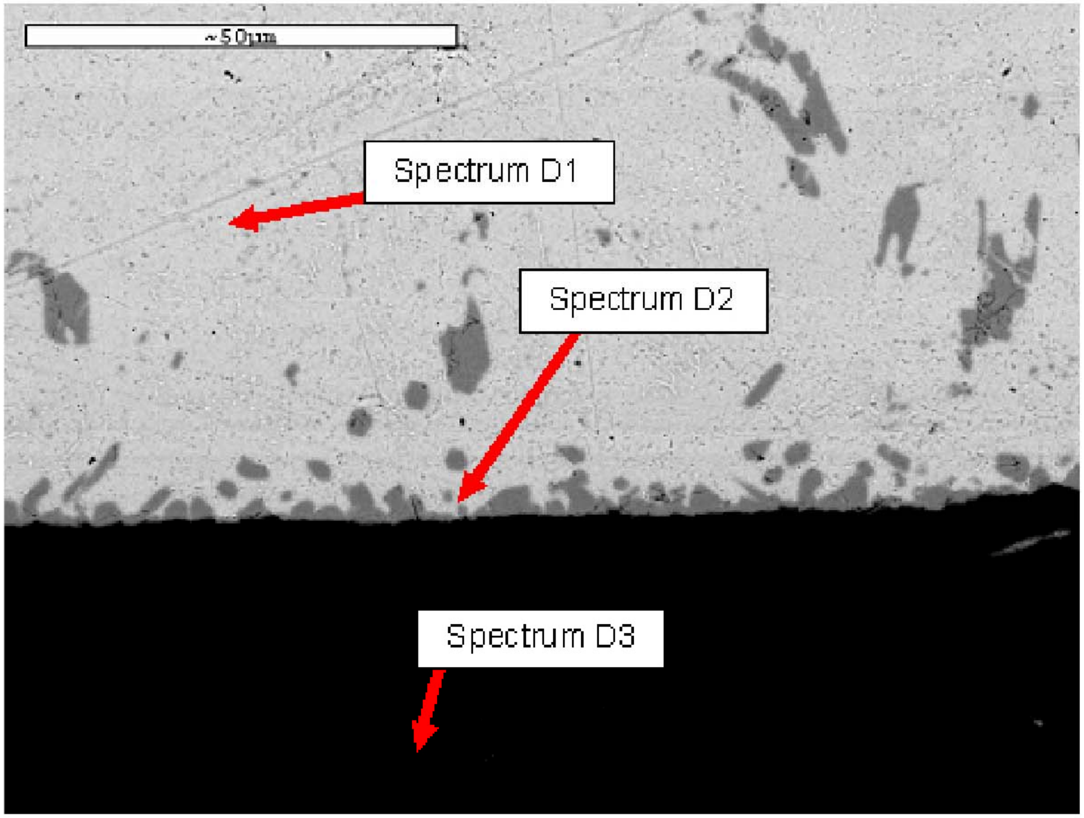


Figure 27: Backscatter electron micrograph of solder D (1000X)

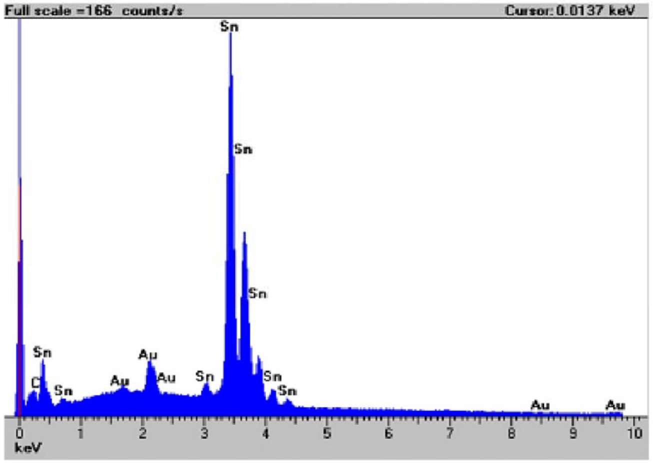


Figure 28, Spectrum D1: EDS spectrum of solder D, tin region

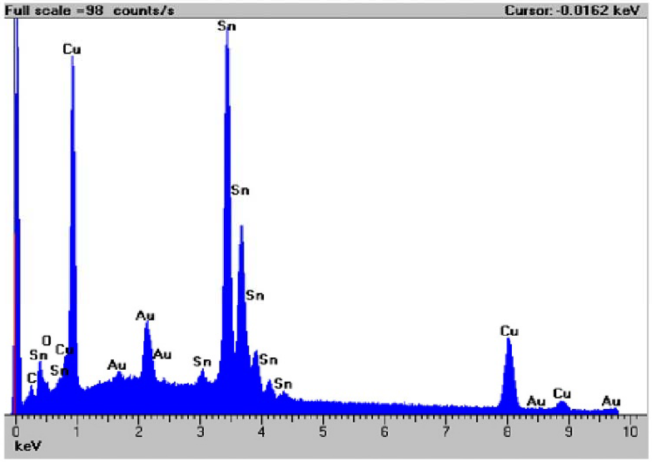


Figure 29: Spectrum D2: EDS spectrum of solder D, intermetallic region

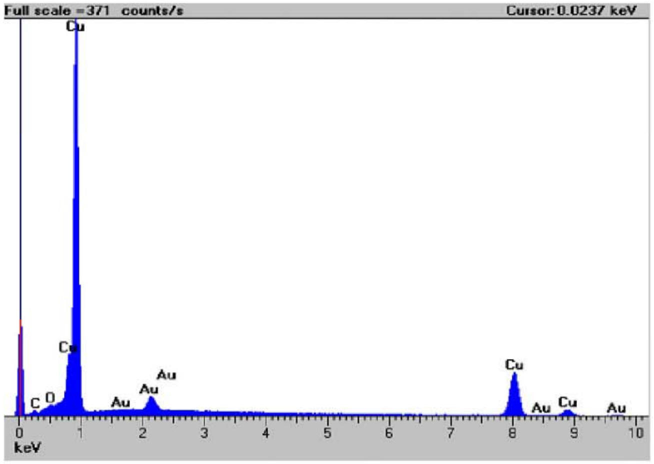


Figure 30: Spectrum D3: EDS spectrum of solder D, copper region

SOLDER E:

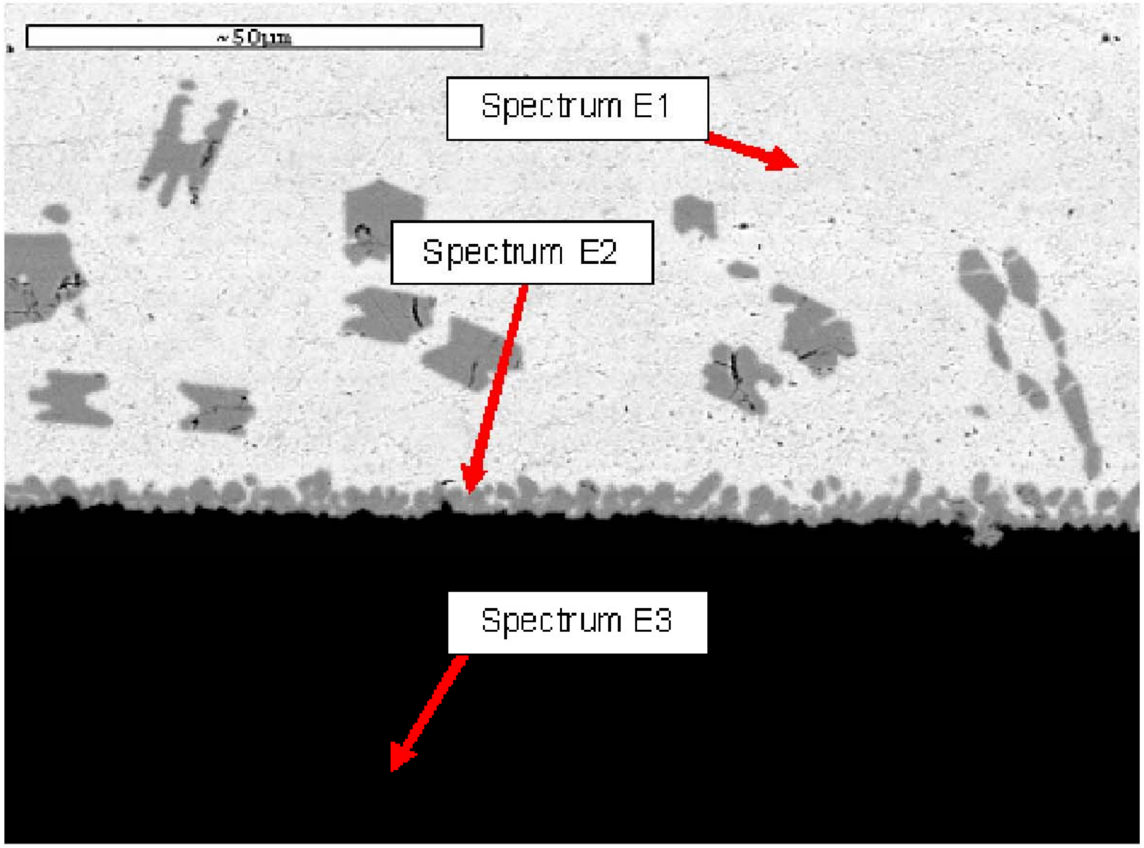


Figure 31: Backscatter electron micrograph of solder E (1000X)

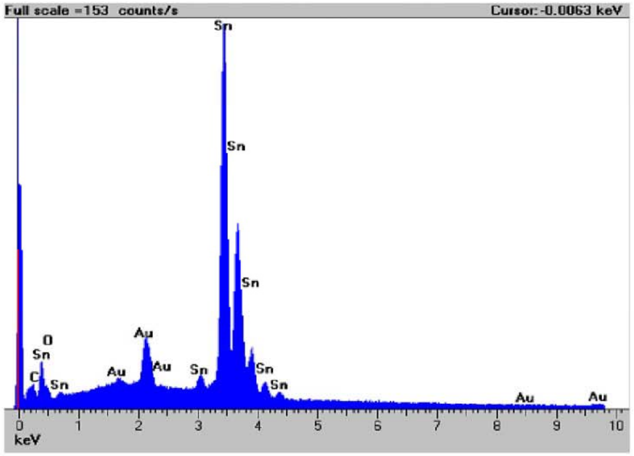


Figure 32: Spectrum E1: EDS spectrum of solder E, tin region

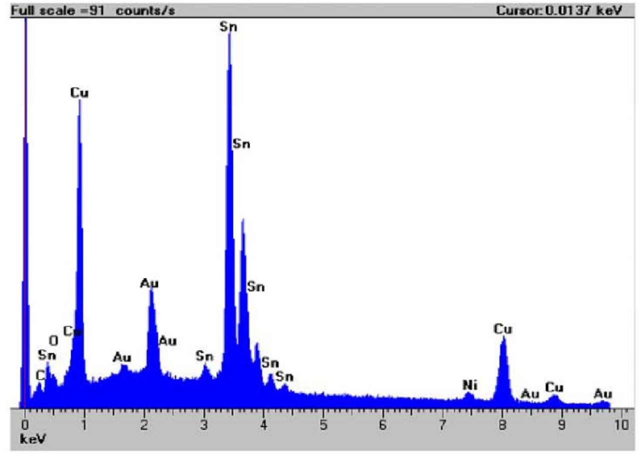


Figure 33: Spectrum E2: EDS spectrum of solder E, intermetallic region

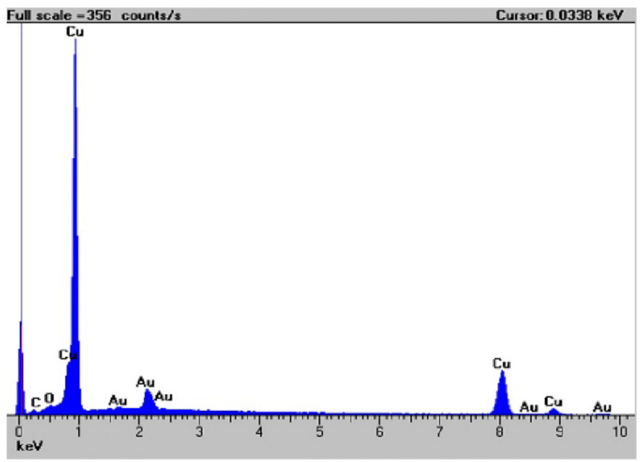


Figure 34: Spectrum E3: EDS spectrum of solder E, copper region

SOLDER F:

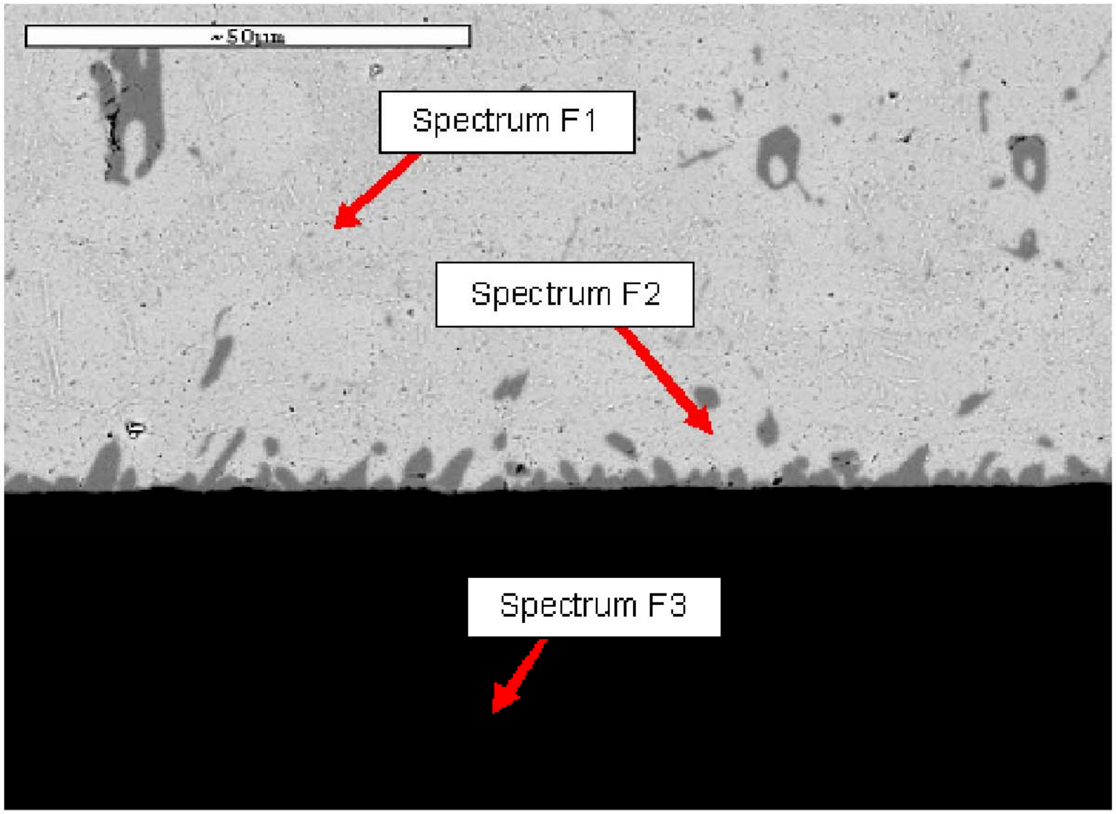


Figure 35: Backscatter electron micrograph of solder F (1000X)

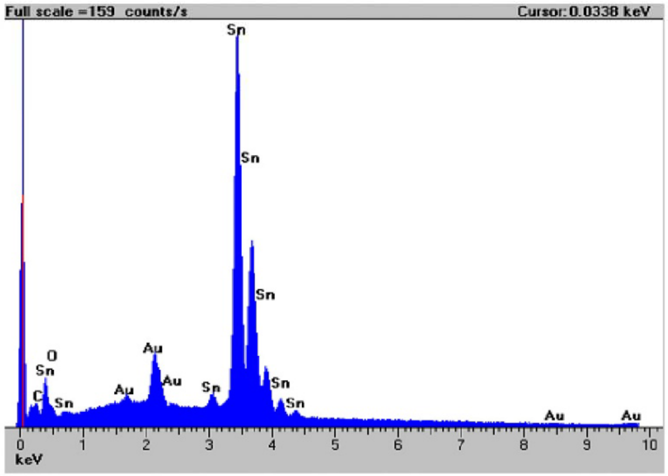


Figure 36: Spectrum F1: EDS spectrum of solder F, tin region

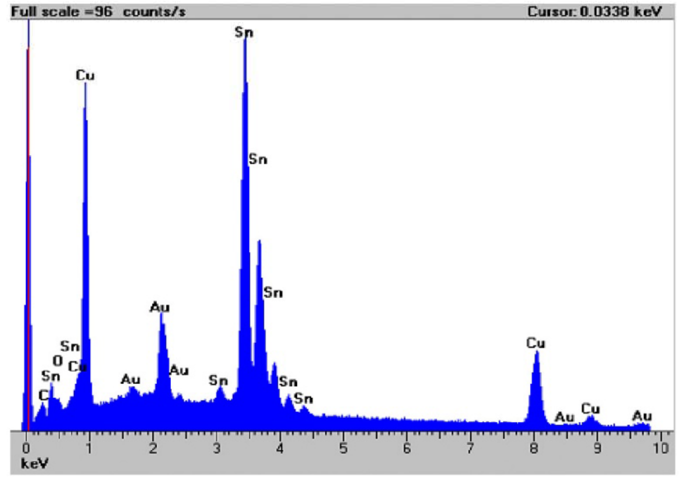


Figure 37: Spectrum F2: EDS spectrum of solder F, intermetallic region

e

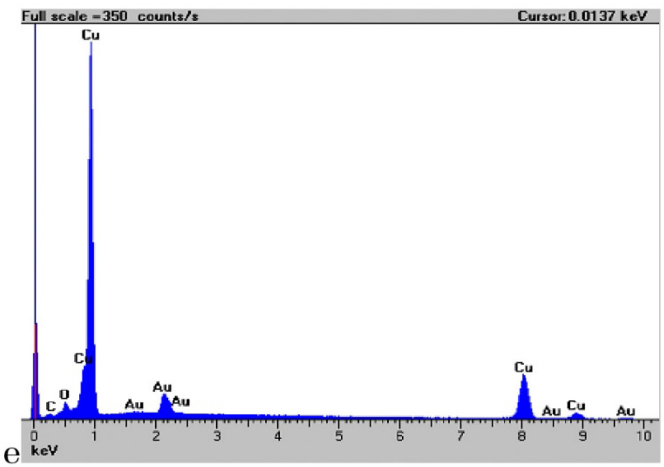


Figure 38: Spectrum F3: EDS spectrum of solder F, copper region

SOLDER G:

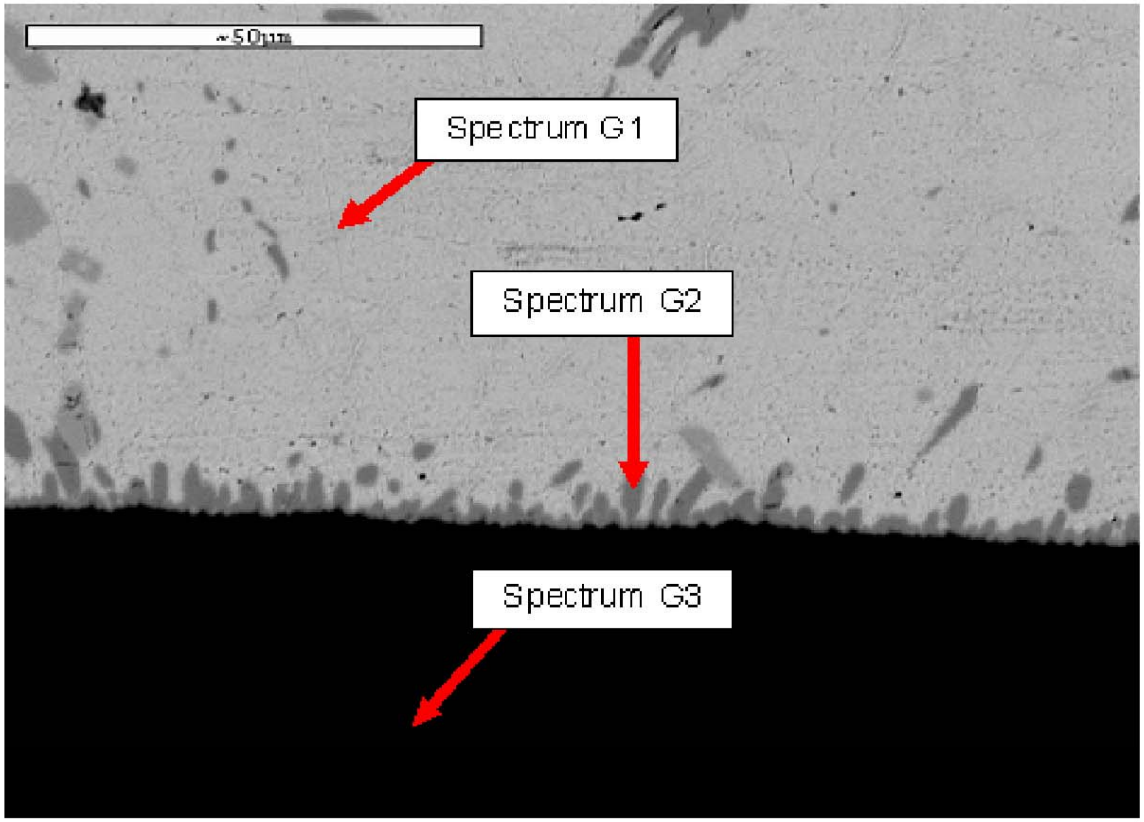


Figure 39: Backscatter electron micrograph of solder G (1000X)

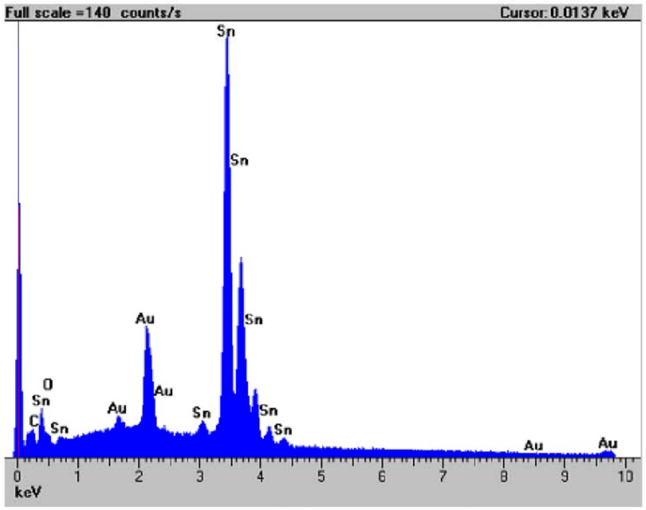


Figure 40: Spectrum G1: EDS spectrum of solder G, tin region

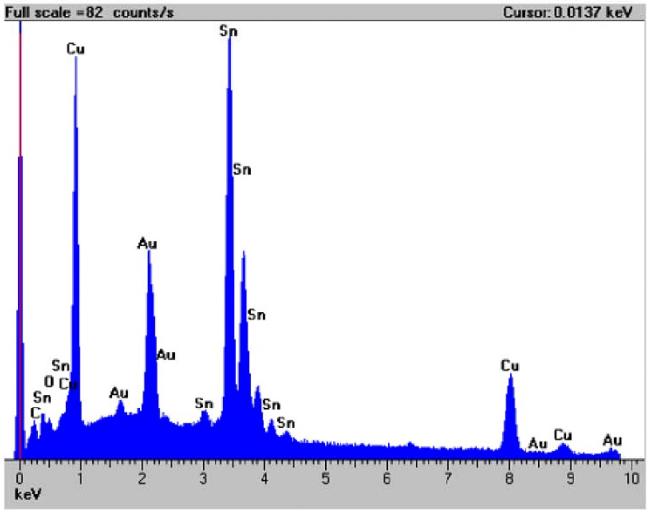


Figure 41: Spectrum G2: EDS spectrum of solder G, intermetallic region

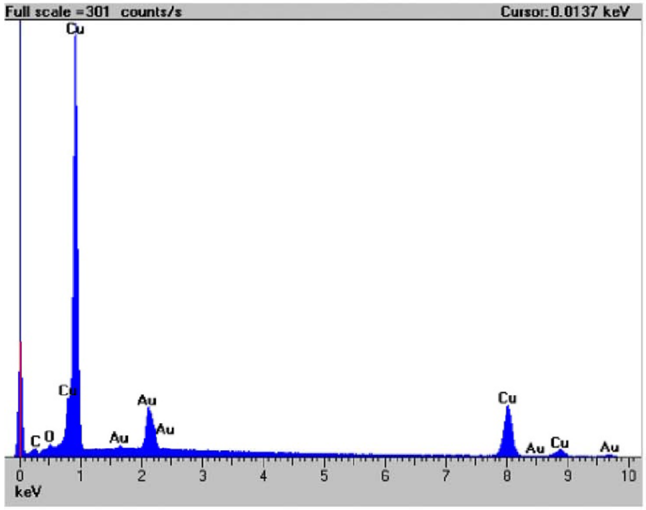


Figure 42: Spectrum G3: EDS spectrum of solder G, copper region

SOLDER H:

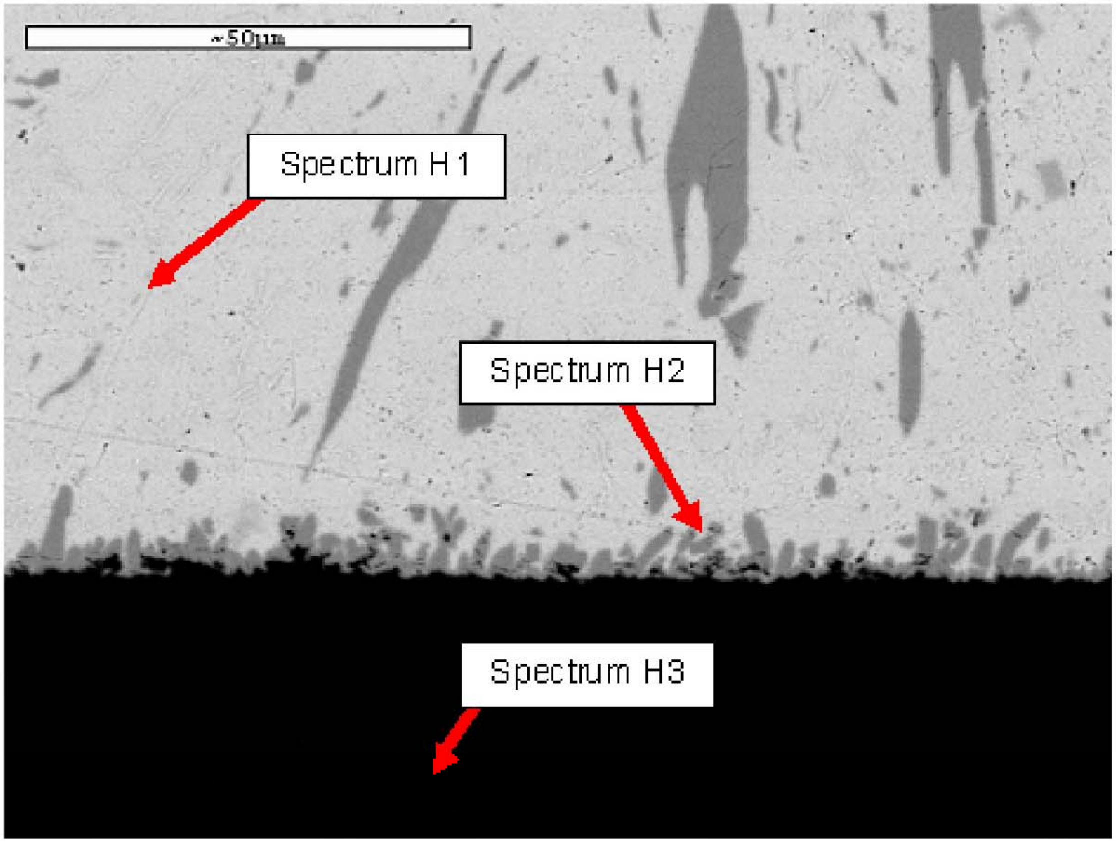


Figure 43: Backscatter electron micrograph of solder H (1000X)

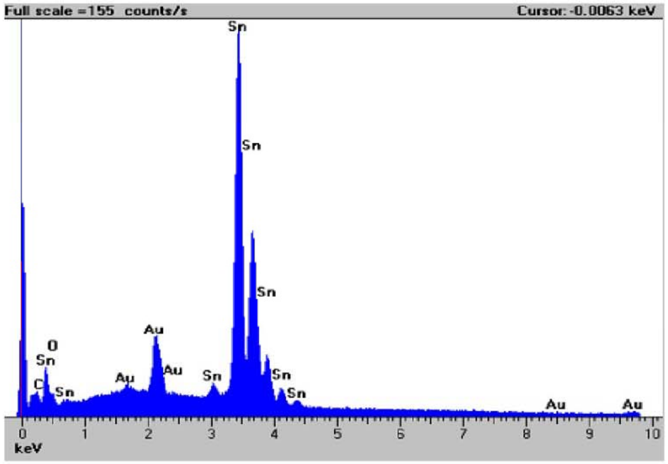


Figure 44: Spectrum H1: EDS spectrum of solder H, tin region

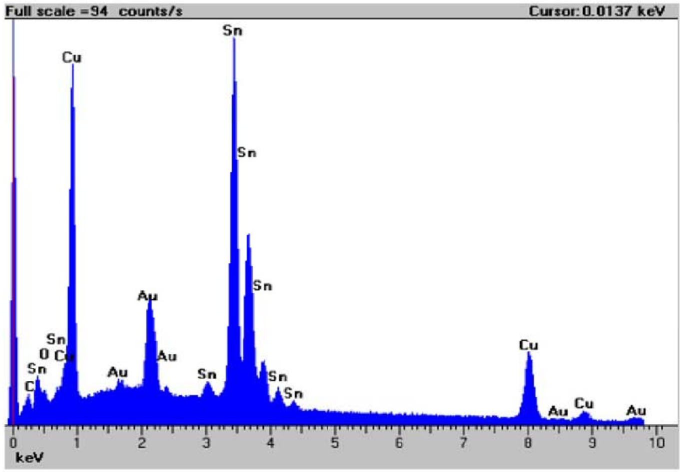


Figure 45: Spectrum H2: EDS spectrum of solder H, intermetallic region

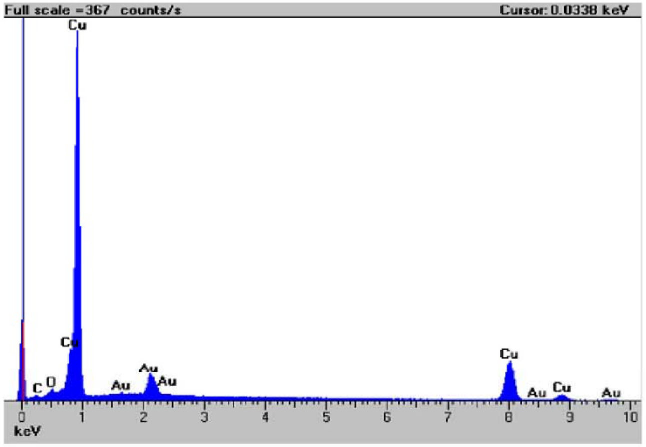


Figure 46: Spectrum H3: EDS spectrum of solder H, copper region

Cross Sections and SEM Analysis: The Results

- **The primary difference between all micrographs and samples is the structure of Region #1 (except for sample A).**
- **This structure is most apparent in samples E and H.**

Cross Sections and SEM Analysis: The Results and The Spectrum

- **Region #1: Some differences in the Gold peak but differences are small.**
- **Region #2: Some differences in the Gold peak can be seen. All other features are the same.**

Cross Sections and SEM Analysis: The Results and The Spectrum

- **Region #3: No significant differences can be seen as would be expected for such an examination of the substrate alone.**

Conclusion:

- The metal levels in these samples do not have a significant effect on performance as measured by these tests.
- Differences found in the SEM showing significant structure in the bulk solder would need to be confirmed.

Conclusion:

- **The Solder Product Value Council recommends that the proposed levels of contamination, as listed in Table 2, be presented to the IPC J-STD-001D, 002C, 003B, and JEDC No 22 B102D committees for inclusion.**

Table 2: Proposed TAL Contamination Levels

Contaminant	Normal	Increase Pot Monitoring	Adjust Pot
Tin	Balance	>97.25%	>97.50%
Arsenic	<0.02%	>0.02%	>0.03%
Antimony	<0.05%	>0.05%	>0.20%
Gold	0-0.03%	0.08%	0.2%
Iron	0.01%	>0.01%	>0.02%
Nickel	<0.01%	>0.025%	>0.05%
Bismuth	≤0.03%	>0.03%	>0.25%
Aluminum	≤0.001%	>0.002%	>0.006%
Copper	<0.6%	>0.8%	1.2%
Silver	<3.2%	>3.5%	>4.25%
Zinc	<0.003%	>0.003%	>0.005%
Cadmium	≤0.001%	>0.002%	>0.005%
Indium	<0.01%	>0.01%	>0.10%
Lead			>0.10%

Future Work:

- The engineering judgment of the companies surveyed, with the null results obtained, indicate that the levels shown in Table 2 are adequate for SAC305 lead free alloy in automated soldering processes.
- Confusion is eliminated.

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Future Work:

- Consider increasing the range of metal contamination to determine if there are higher thresholds of the Take Action Limits.

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Conclusion and Future Work:

- Examine bulk properties as a function of contamination (e.g. creep or shear or pull strength).
- Examine changes in fluidity with increasing contamination.

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