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Comparison of the Solderability Performances of Inhibitor Containing and Inhibitor-Free Immersion Silver Coatings

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  - Motivation for a coupon study
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  - Solders and fluxes
  - Storage environments
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- Test Results & Discussion
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- Summary

Introduction

- Pb-bearing surface finishes for PCB's are being phased out.

- Potential alternative finishes include OSP's, ENIG, Ni/Pd with a Au flash over Pd, Immersion Sn and Immersion Ag.

- Attributes of ImAg
  - less expensive than Au or Pd,
  - has excellent wire bondability,
  - inherently solderable with Sn-based alloys,
  - and the intermetallic compound layer formed between Ag & Sn (Ag_3Sn) is not particularly brittle.

- Limitations of ImAg
  - Ag tarnishes by reacting with S in air,
  - reacts with airborne Cl to form a Ag-Cl layer,
  - Ag develops a native oxide layer on its surface (Ag_20),
  - these chemical reactions can have an impact on the solderabilty performance of ImAg.

Introduction

- Earlier studies have examined the performance of ImAg for PWB's.
  - high temp. aging indicates that Ag coatings can meet a minimum 6 month shelf life requirement unprotected and achieve a 7 year shelf life when wrapped in vapor phase corrosion (VPC) paper and moisture barrier bags.
  - the Ag finish exhibits excellent solderability retention after multiple reflow steps often required of double sided boards or more complex PWA's.
  - finally, longer-term investigations have not uncovered any reliability concerns with ImAg coatings.
- These studies have provided valuable information on the performance of ImAg in applications-related testing.

Introduction

- At the coupon level
  - we seek a science-based understanding to establish a baseline of laboratory solderability data.
- Benefits include:
  - an initial insight in the analysis of process failure,
  - and the studies are relatively inexpensive and the data can be rapidly assessed.
- Moreover, the solderability tests provide a “model system” that identifies factors that control the behavior of the coating.
  - determine the role of the flux type on solderability and whether the role is derived from surface tension effects or cleaning efficacy.
- Similarly, the tests provide the means to evaluate the effects of surface finish composition and\or surface degradation on solder wetting–and-spreading behavior.

- Therefore, a study was initiated to investigate the solderability performance of ImAg finishes.

Objective

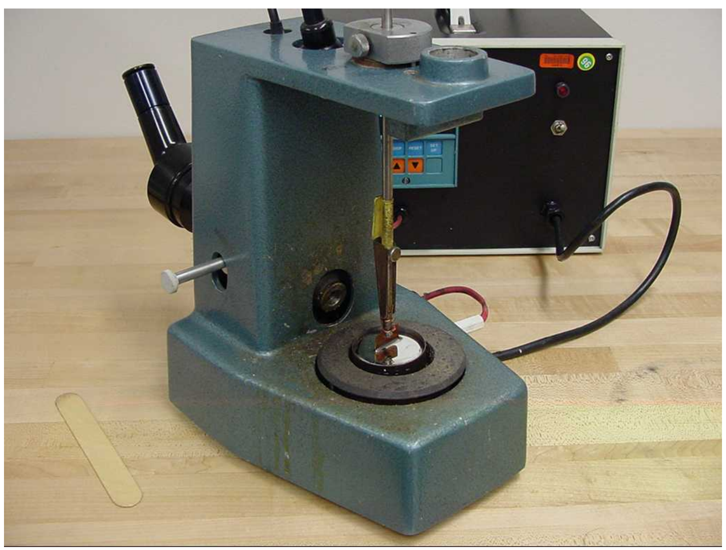
- Investigate the solderability of an immersion Ag (ImAg) finishes with and without an inhibitor coating, after accelerated aging treatments to simulate long-term exposure.
  - Battelle Class 2 (Industrial Environment) - Duplicated in Facility for Atmospheric Corrosion Test (FACT) at Sandia National Labs

- Determine the effects or pre-assembly heat treatments used to remove water and other volatiles from the printed circuit board.

Test Methods

- Two test methods were used to calculate the contact angle, θ_C, as the “generalized” solderability metric.
  - Meniscometer test
  - Wetting balance test

Meniscometer



Wetting Balance

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Experimental Test Methods

- The "absolute" solderability metric is the **contact angle, θ_C**.
- The contact angle is determined by:
  - **Meniscometer Test Method** – measures the meniscus height by measuring the vertical movement of a solder meniscus up the face of a coupon using a traveling microscope.
  - **Wetting Balance Test Method** - measures the weight of the meniscus that forms on the sample as a function of time.

$$\theta c = \sin^{-1}\left[\frac{4w^2 - \left(\rho g P H^2\right)^2}{4w^2 + \left(\rho g P H^2\right)^2}\right]$$

where: ρ = solder density
g = acceleration due to gravity
P = sample perimeter
H = meniscus height
W = weight of solder within meniscus

Preferable solderability is accompanied by contact angles that are generally < 30°

Contact Angle (θ_C) Range	Relative Wettability
0º < 0 < 10º	Perfect
10º < 0 < 20º	Excellent
20º < 0 < 30º	Very Good
30º < 0 < 40º	Good
40º < 0 < 50º	Adequate
55º < 0 < 70º	Poor

Reference: Klein Wassink

Solderability Optimization

Solderability is **optimized** when the contact angle, θ_C is **minimized**

γ_{SF} = solid (substrate)-flux interfacial tension

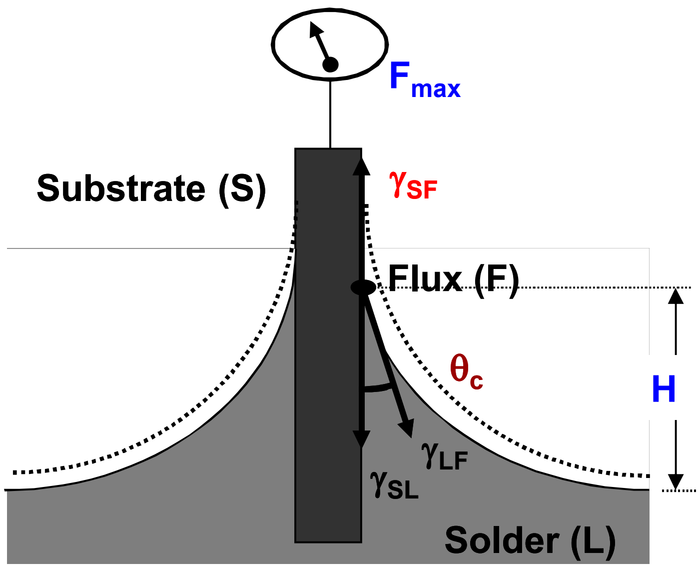
γ_{SL} = solid-liquid (solder) interfacial tension

γ_{SF} is maximized by:
- surface cleanliness
- surface oxide removal
- substrate material

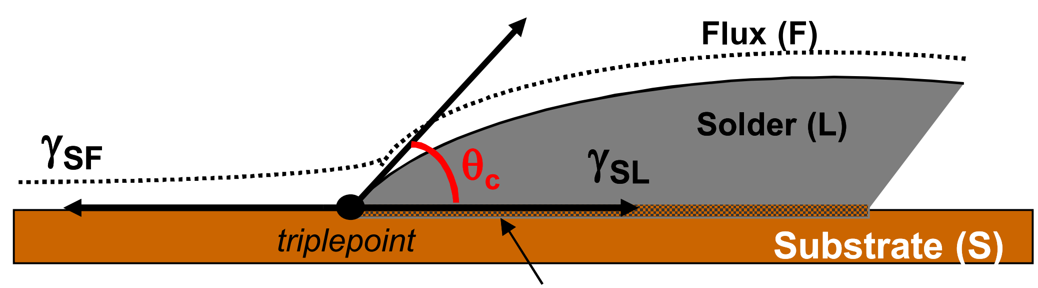
γ_{SL} is minimized by:
- solder alloy
- substrate material (interfacial reaction)

γ_{LF} = liquid-flux interfacial tension

γ_{LF} is minimized by:
- substrate material & protective layer
- flux formation
- solder alloy



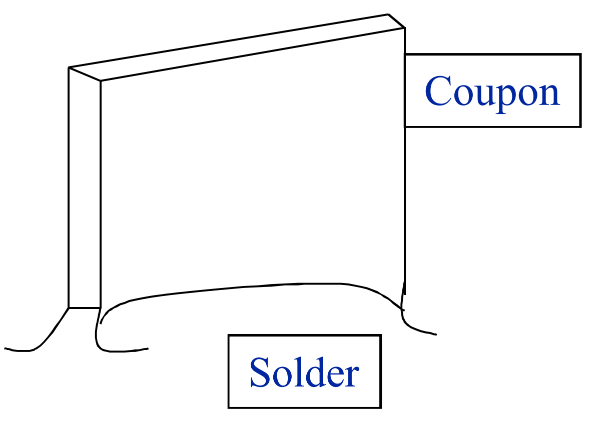
Solderability testing



intermetallic compound (reaction) layer

Experimental Procedures

- **Substrate Preparation**
  - **OFE Cu test coupons**
    - **2.54 cm ±0.013 cm square pieces sheared from 10 mil stock**
    - **degreased with TCE & IPOH**
    - **plated with ImAg**
    - **coated with a flux**
- **The function of the flux coating**
  - **removes <u>thin</u> tarnish from the substrate surface**
  - **prevents substrate re-oxidation during processing**
  - **reduces the solder surface tension**
- **Solder Fluxes**
  - **Rosin Based Mildly Activated (RMA)**
  - **Rosin (R)**
  - **Low-solids (LS)**
- **Solders**
  - **63Sn-37Pb**
  - **95.5Sn-3.9Ag-0.6Cu**
- **Test Temperatures**
  - **245ºC, 260ºC**



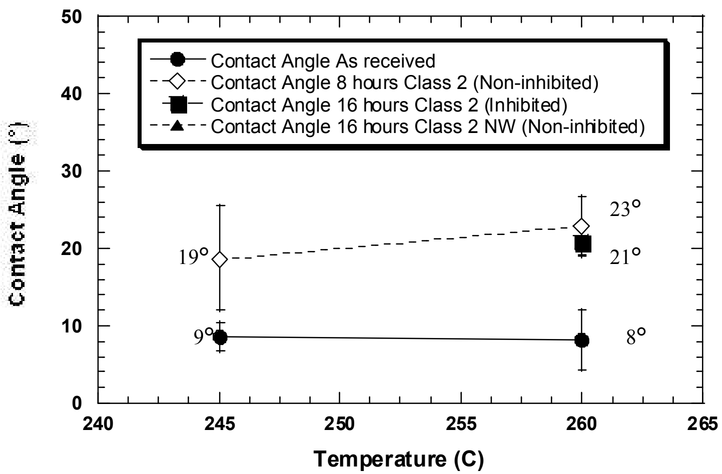
Exposure Environments

- **Battelle Class 2 (Industrial Environment)**
  - **The Facility For Atmospheric Corrosion Testing (FACT) at Sandia Labs was used to simulate the Battelle Class 2 environment.**
    - **target environment contains 10 ppb H_2S, 200 ppb NO_2, 10 ppb Cl_2, 70% RH, and 30ºC temperature.**
    - **coupons were exposed for time periods that are intended to simulate storage durations (i.e., shelf life) of 3 and 6 months, in a light industrial environment (acceleration factor for these conditions is assumed to be approximately 250). 8 hours exposure ~3 months storage life time and 16 hours exposure ~6 months storage life time.**

- **Pre-assembly circuit board pre-conditioning treatments**
  - **Expose coupons for 2 or 4 hours at 72°C in air.**
  - **Expose coupons for 2 or 4 hours at 93°C in air.**

Contact Angle – ImAg As A Function of Temp/Time Battelle Class 2 Environment

Contact angle as a function of temperature with and w/o inhibitor using 63Sn-37Pb solder and RMA flux.

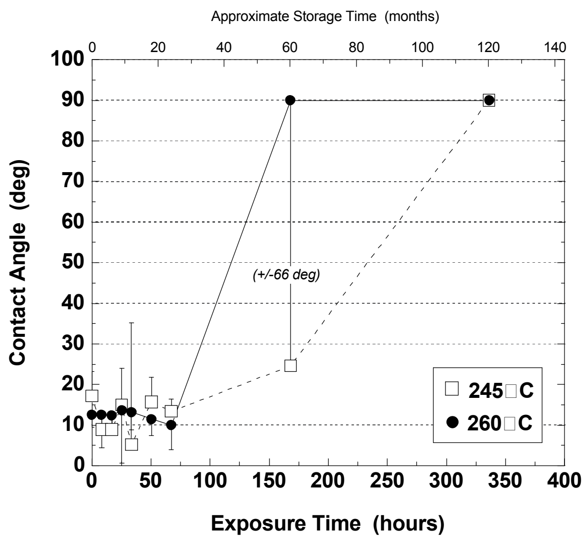


Non-inhibited As-received - Excellent solderability
Non-inhibited - Very good to excellent after 8 hrs.

Non inhibited - Non-wetting at both temperatures
For samples exposed for 16 hours.

On other hand, inhibited ImAg coupons
exposed for 16 hours, a reasonable CA was obtained.

Contact angle as a function of time with inhibitor using 63Sn-37Pb solder and RMA flux.



Prior work showed low CA's when inhibited
ImAg coupons were exposed for up to 66 hrs.
(approx. equivalent to 24 months storage).

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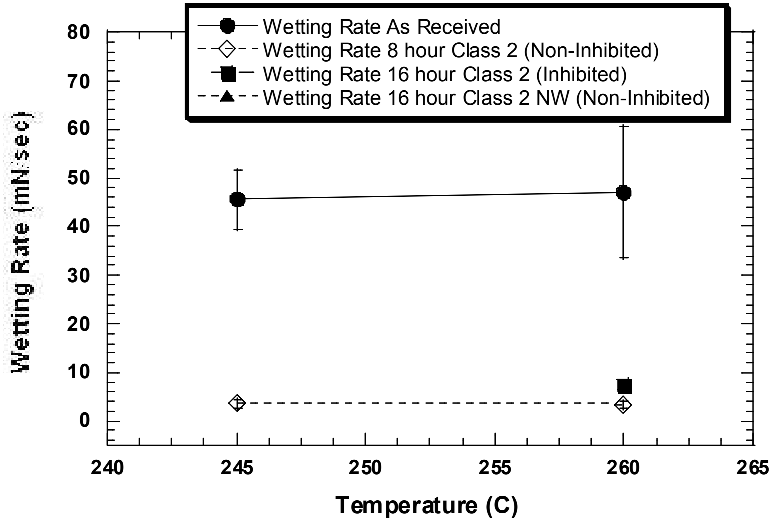
Wetting Rate - ImAg
As A Function of Temperature
Battelle Class 2 Environment

Wetting rate as a function of temperature with and w/o inhibitor using 63Sn-37Pb solder and RMA flux.

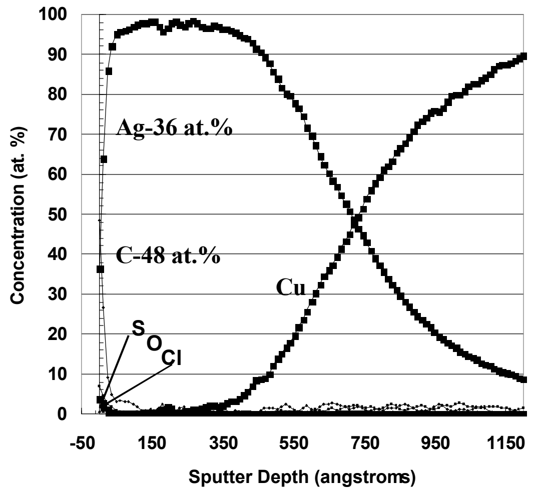


The W_R was much slower for both coupon types after exposure to the Class 2 conditions.

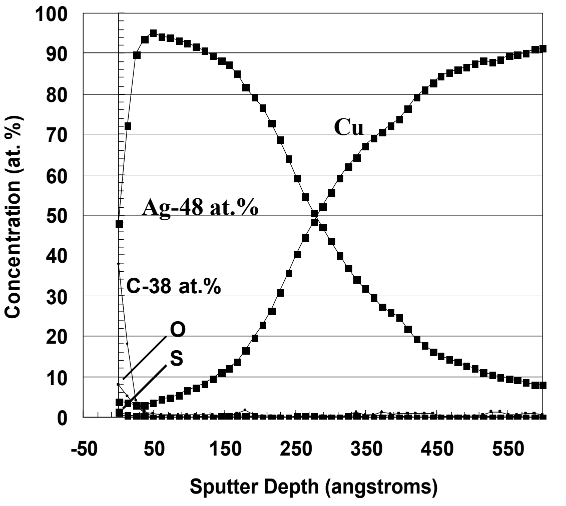
In the case of the inhibitor containing finish, the trend of the W_R extended beyond the 16 hour treatment in a manner similar to the CA's observed up to 66 hrs.

Auger Electron Spectroscopy – ImAg Depth Profile As-fabricated

Auger depth profile (with inhibitor) in as-fabricated condition.



Auger depth profile (w/o inhibitor) in as-fabricated condition.



The inhibited ImAg coupon has higher C concentration and lower Ag concentration at the surface than uninhibited coupon.

The higher C content reflects the inhibitor material plus C from the natural environment.

On the other hand, the 38 at.% C surface concentration on the non-inhibited coupon was a result of natural sources.

Furthermore, the non-inhibited coupon exhibited a greater degree of Cu diffusion towards the surface but not to the extent to affect solderability.

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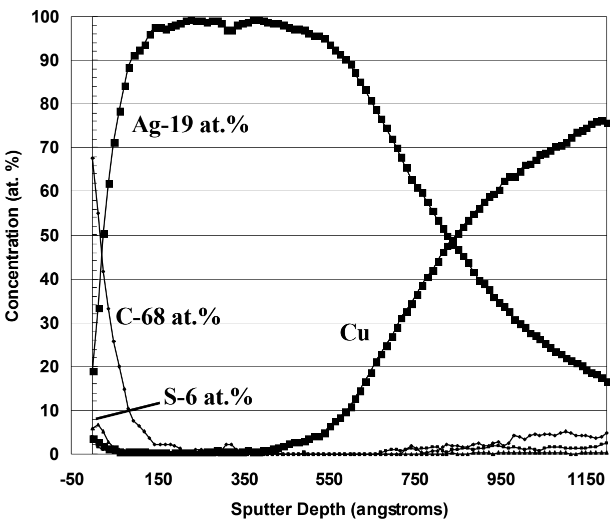
Auger Electron Spectroscopy – ImAg Depth Profile Battelle Class 2 Environment

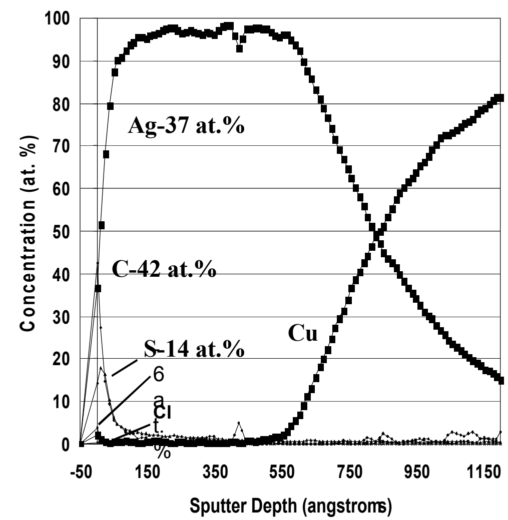
ImAg Auger depth profile (without inhibitor) after 3 month simulated storage.



The 8 hour exposed surface exhibited more carbon at the surface than the 6 month exposed surface.

The surface carbon concentrations did not correlate with the contact angles.

ImAg Auger depth profile (without inhibitor) after 6 month simulated storage.



The change in solderability could not be correlated to Cu diffusion.

An significant increase in S (tarnish) likely contributed to non-wetting after 16 hrs. exposure.

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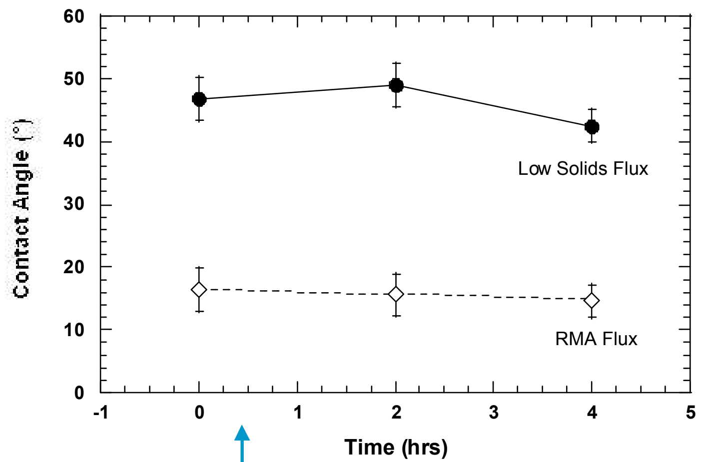
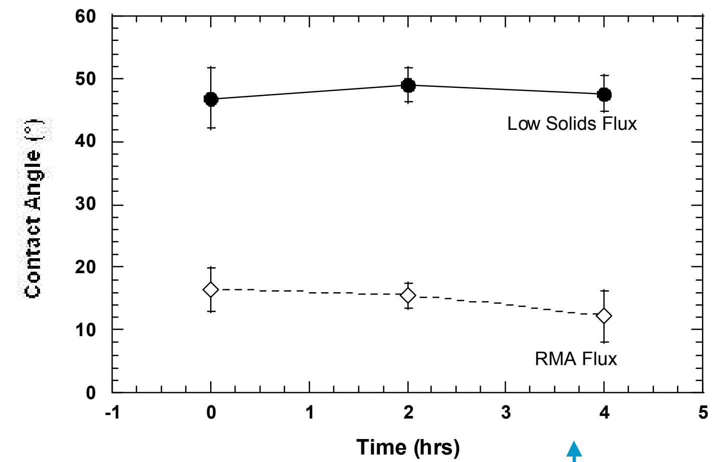
Contact Angle/Wetting Rate 2 and 4 hours Exposures (In Air) at 72°C and 93°C Using 63Sn-37Pb

Contact Angle at 72°C



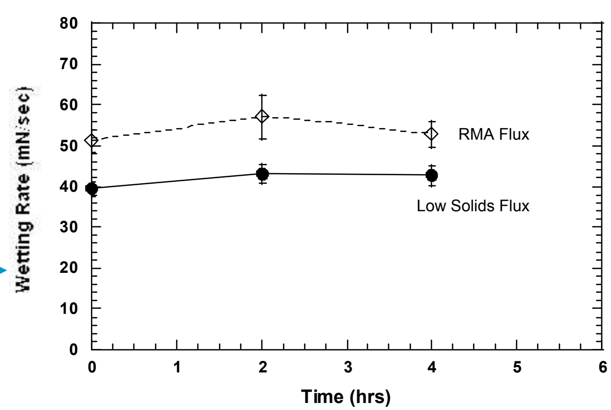
Contact Angle at 93°C



As expected, the LS flux had higher CA's than those Exhibited by the RMA flux.

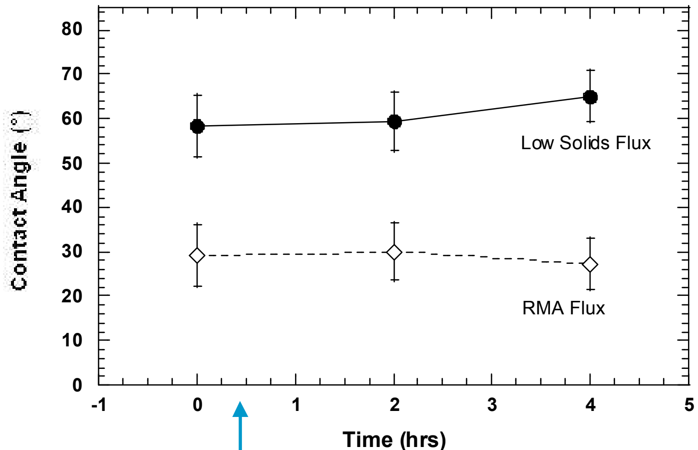
The pre-conditioning treatments can be performed in air on circuit boards having an ImAg coating plus inhibitor without loss of solderability.

W_R at 72°C were slower for LS flux

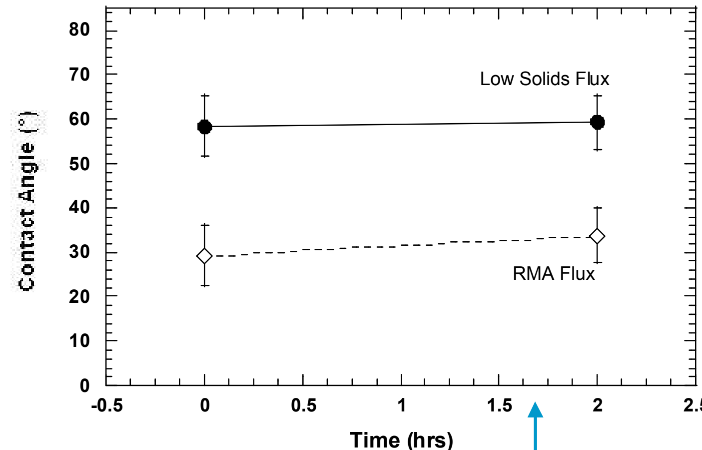


Contact Angle/Wetting Rate 2 or 4 hours Exposures (In Air) at 72°C and 93°C Using 95.5Sn-3.9Ag-0.6Cu

Contact Angles at 72°C



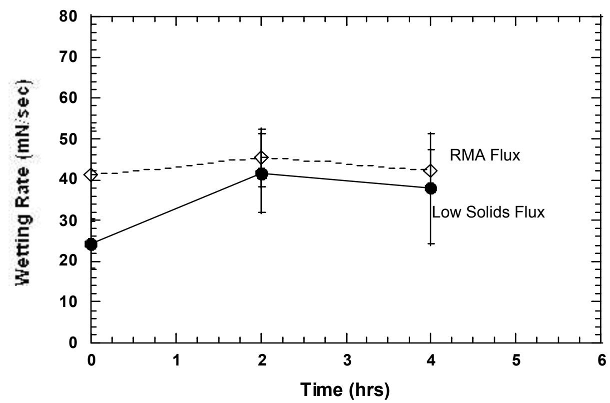
Contact Angles at 93°C



Same trend, the LS flux had higher CA's than were exhibited by the RMA flux.

Pre-conditioning treatments can be performed on circuit boards having an ImAg coating-plus-inhibitor without loss of solderability.

W_R at 72°C using were slower with LS flux.



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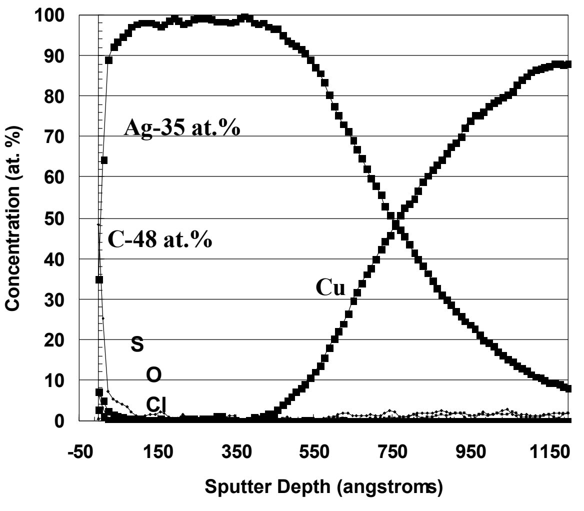
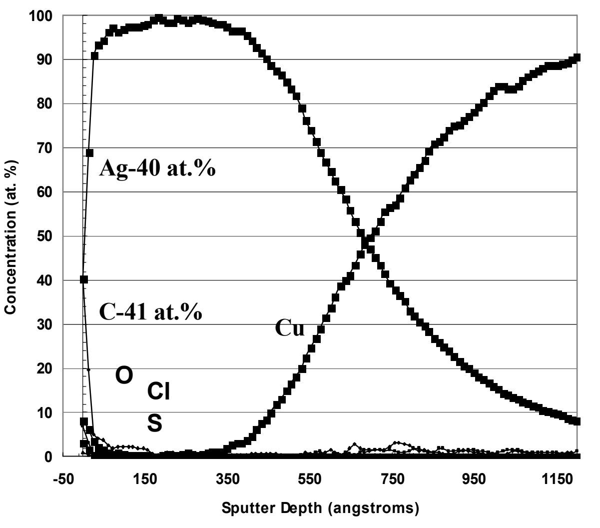
Auger Depth Profile Pre-assembly

72ºC – 2 hr. exposure – Inhibited



93ºC – 4 hr. exposure – Inhibited



There is no significant difference between surface C, O, S, or Cl concentrations.

The absence of a substantial change to the C signal suggests that the preconditioning did not degrade the inhibitor material.

Summary

- Solderability tests were performed on Cu coupons coated with an ImAg finish (inhibited and non-inhibited).

- Exposure to Battelle Class 2 Environment
  - The contact angle and wetting rate demonstrated the requirement to have an inhibitor to realize an adequate shelf life performance.
  - The loss of solderability by the non-inhibitor containing finish was due to a combination of oxidation and sulfidation (tarnish) of the Ag surface.
  - Longer exposures times (~24 hrs.) are required to generate sufficient Cu diffusion thereby degrading solderability.
  - Weaker fluxes are more sensitive to even modest changes in the solderability of ImAg finishes, as expected.

Summary

- Solderability tests were performed on Cu coupons coated with an ImAg finish (inhibited).

- Exposure to pre-assembly circuit board pre-conditioning treatments (2 or 4 hrs exposure at 72°C and 93°C).
  - For both the 63Sn-37Pb alloy and 95.5Sn-3.9Ag-0.6Cu solder, the contact angles and wetting rates were not degraded by the pre-conditioning treatments.
  - Similar trends were observed for both the RMA and low-solids fluxes.
  - These results suggested that the driving force for Cu diffusion could be narrowed down to the Cl and S contents of the environment rather than simply oxidation.

Acknowledgements

- Sandia Labs Support
  - Sam Lucero – FACT Operation
  - Wayne Buttry – AES Analysis
  - Carly George – Compilation of the data

- MAHALO!

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