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Tin Corrosion under QFN Packages at Elevated Temperature and Humidity

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Biography:

Karen Tellefsen has been with Cookson Electronics Assembly Materials for 16 years working on electrochemical reliability testing and the penetrability of post-process flux residues by ICT probes. She has been active in several IPC standards sub-committees. She received her Ph.D. in physical chemistry from the University of Ottawa.

Executive Summary

Using X-ray imaging, solder corrosion, resembling metal migration, had been observed under QFN (Quad Flat No-Lead package) devices and chip resistors on circuit boards that were processed with two SAC 305 alloy solder pastes after 500 hours of exposure to 85ºC and 85% R.H. with no applied voltage. Analysis of the material under QFN's by SEM (scanning electron microscopy) and energy-dispersive X-ray spectroscopy showed it was primarily a tin compound. This phenomenon was only observed for components that had a relatively large quantity of flux residue trapped underneath them.

Further investigation was made using six different SAC305 alloy solder pastes and solder paste test coupons with copper OSP and NiAu metal surface finishes. The test coupons were examined with X-ray imaging before exposure to 85ºC and 85% R.H. and then after 250, 500, 750 and 1000 hours of exposure. On the NiAu boards, tin corrosion was observed for five of the six pastes after 250 hours exposure, and after 750 hours exposure for the sixth paste. For OSP boards, three pastes showed corrosion after 250 hours, an additional paste after 750 hours, and two pastes showed no corrosion after 1000 hours exposure. The corrosion is dependent on solder paste flux chemistry, solder alloy and the board's metal finish.

The investigation discussed here concerns three solder paste flux chemistries, SAC305 and 63 Sn 37 Pb alloys and 3 reflow conditions. Flux chemistry had the greatest effect on tin corrosion under QFN components; however SAC305 corroded faster than 63 Sn 37 Pb. Reflow conditions had almost no effect.

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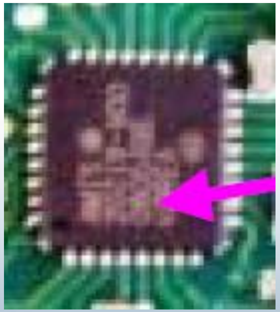
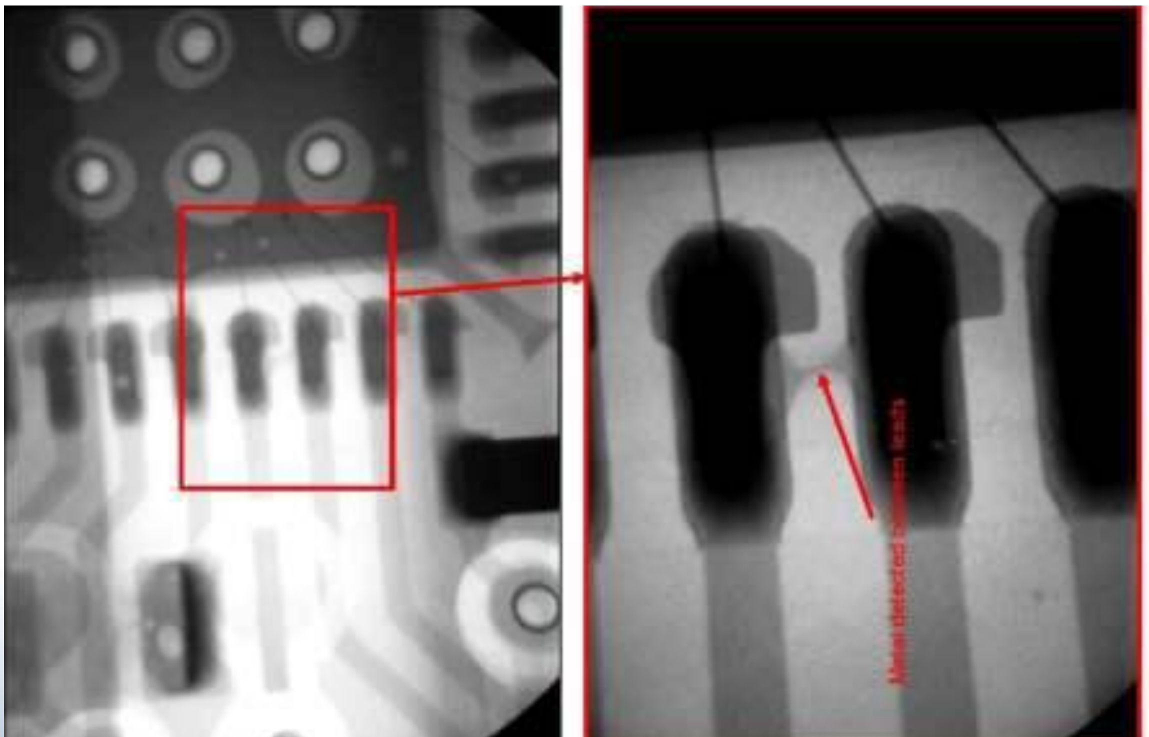
Introduction

- MSLCircuits (then Jabil) engineers had a failure on circuit processed with a lead-free solder paste after 820 hours of 85ºC 85% RH exposure.
- A short was found under a QFN component using special RX settings and suspected as potential root cause for failure..
- This type of failure was not observed for the 63/37 paste used.



X-ray picture of tin corrosion under QFN component



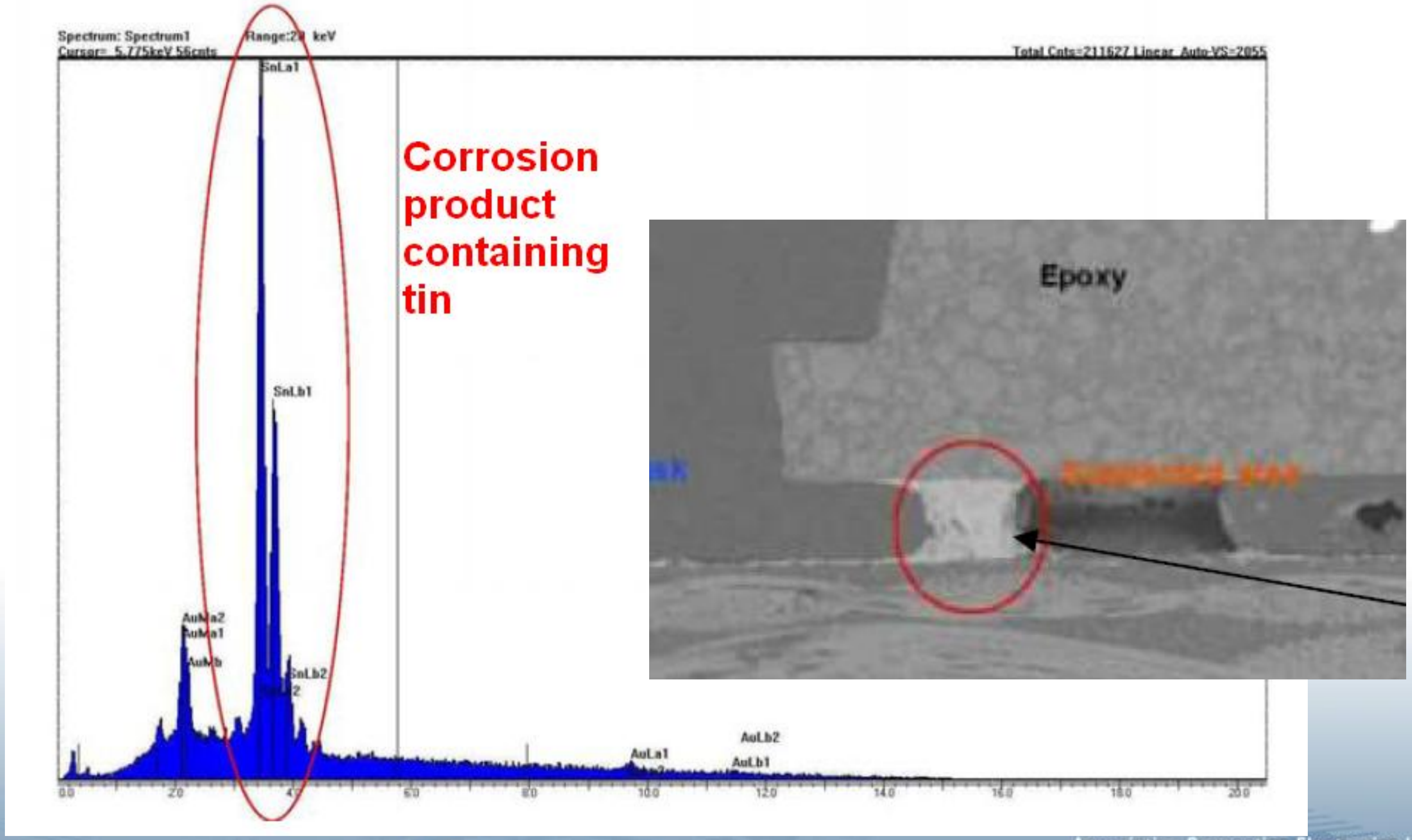
NiAu pad finish

Pin testable SAC305 paste

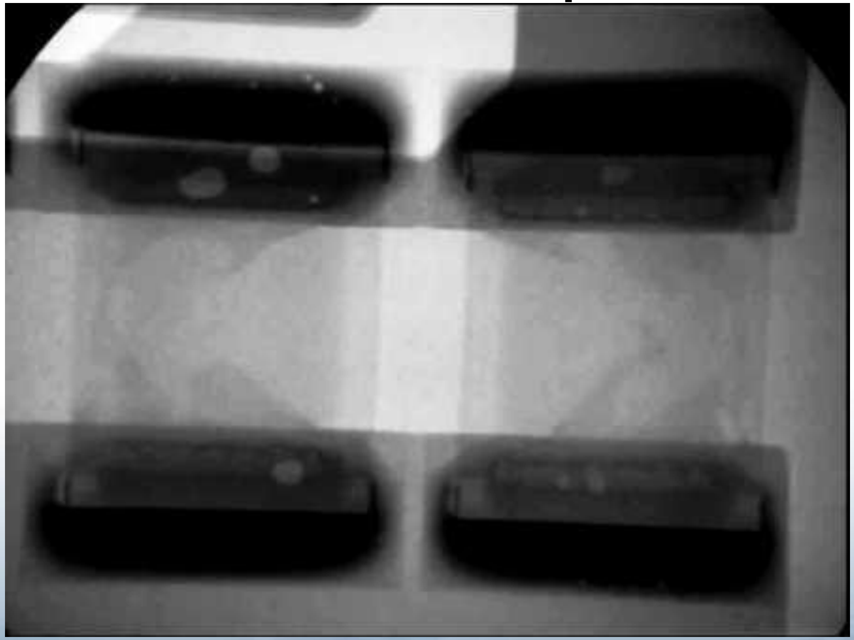
1000 hours at 85ºC 85% RH

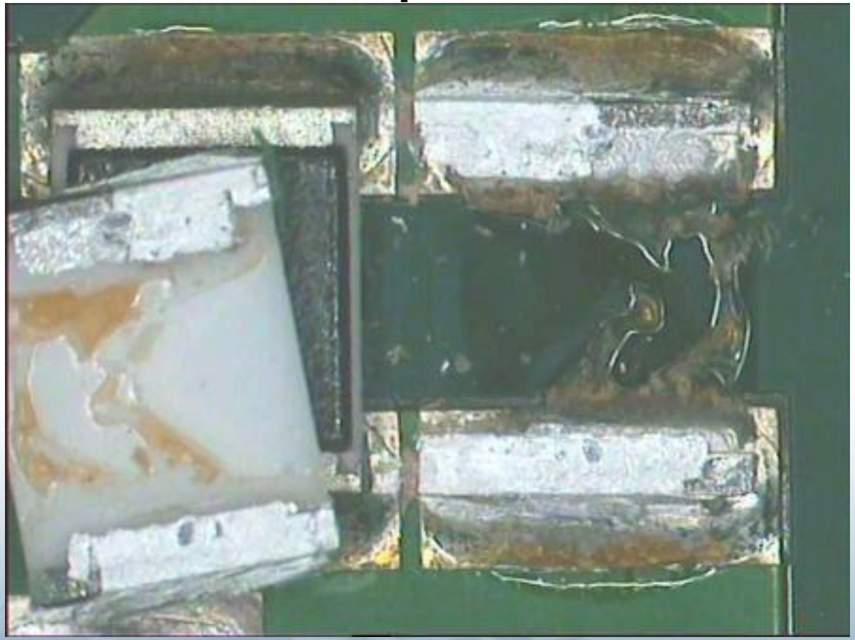
No voltage applied!

EDAX Spectrum of a short between two pad on QFN



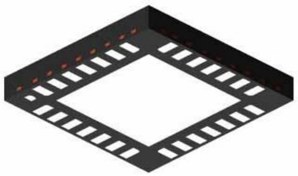
A similar phenomenon was found under large passive components. Note that the X-ray picture corrosion shadow matches the shape of the corrosion product under the component





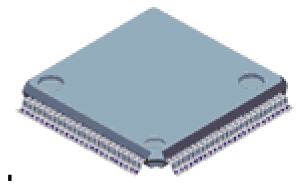
Summary of MSLCircuits' failure analysis

- Long exposure at 85ºC 85% RH, no voltage applied.
- Tin corrosion products found under QFN's and large (1206) passives only.
  - **Not** electrochemical migration!
  - Lots of flux residues trapped under these components.
  - Gold surface finish, possible galvanic corrosion mechanism, gold more noble than SAC305 or tin.
- I couldn't find a document describing a similar PCB failure in the technical literature.



Why are QFN's particularly prone to corrosion problems?

- A large volume of solder paste is printed compared to other SMT components.
  - Large ground connection in the center.
  - Components of fluxes, that usually volatilize during reflow, such as activators and low-boiling solvents, are more likely to be trapped under QFN's.
- Water from atmospheric humidity is more likely to be trapped under the QFN.

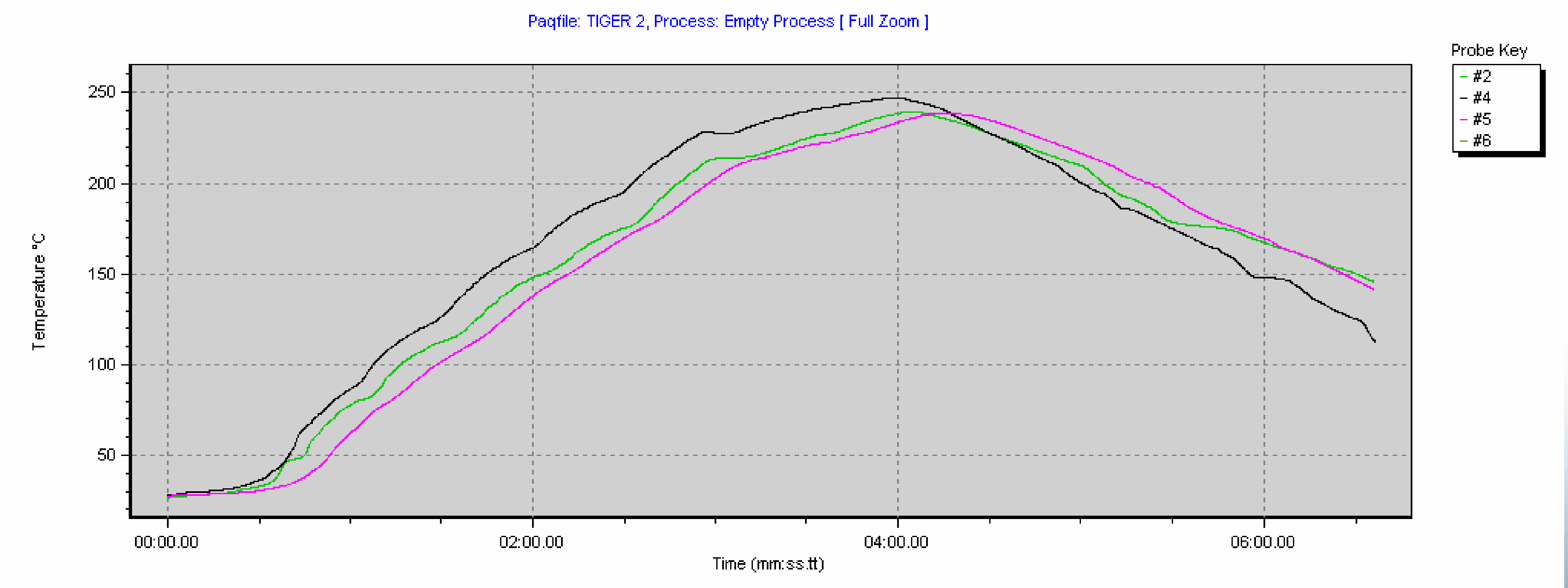


First Cookson Study

- Cookson Electronics CERF coupons with two metal surface finishes, OSP and NiAu.
  - 1.6 mm thick, LPI solder mask.
  - Populated with a variety of SMT components, including QFN's, passives, QFP's and BGA's.
- Six SAC305 solder pastes used.
  - Three different manufacturers.
- One coupon per paste/finish combination

Process conditions

- All coupons cleaned in an Ionograph with heated IPA/water solution
- 125 μm solder paste stencil



Exposure and X-ray Examination

- All coupons placed horizontally in a temperature/humidity test chamber for a total of 1000 hours at 85ºC 85%RH.
- QFN’s QFP’s and passive components were examined with a Phoenix Micromex X-ray inspection system:
  - Before 85ºC 85%RH exposure.
  - After 250, 500, 750 and 1000 hours exposure.

QFN100, Paste B, NiAu

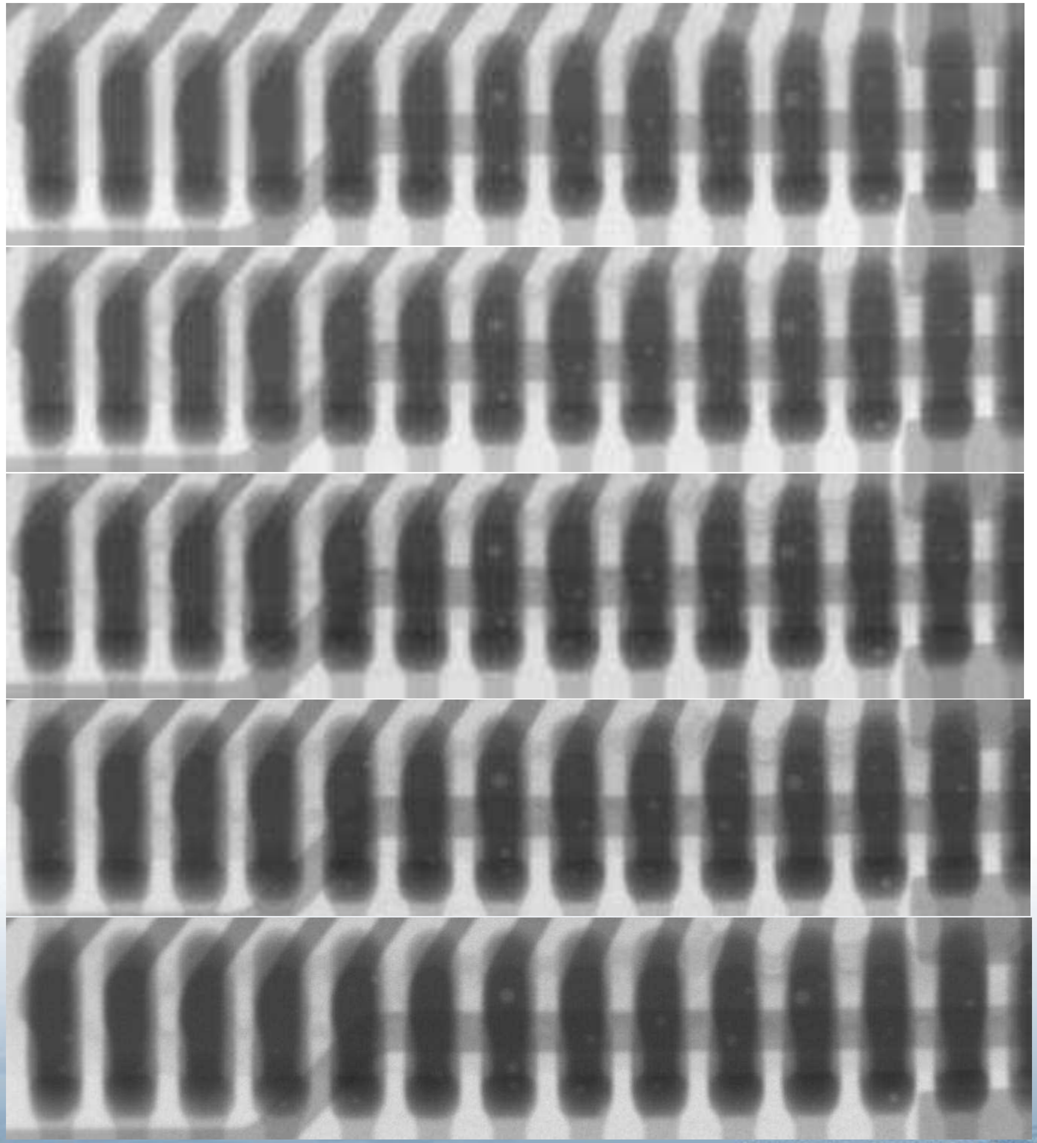
Before exposure

250 hours

500 hours

750 hours

1000 hours



1206, Paste B, NiAu

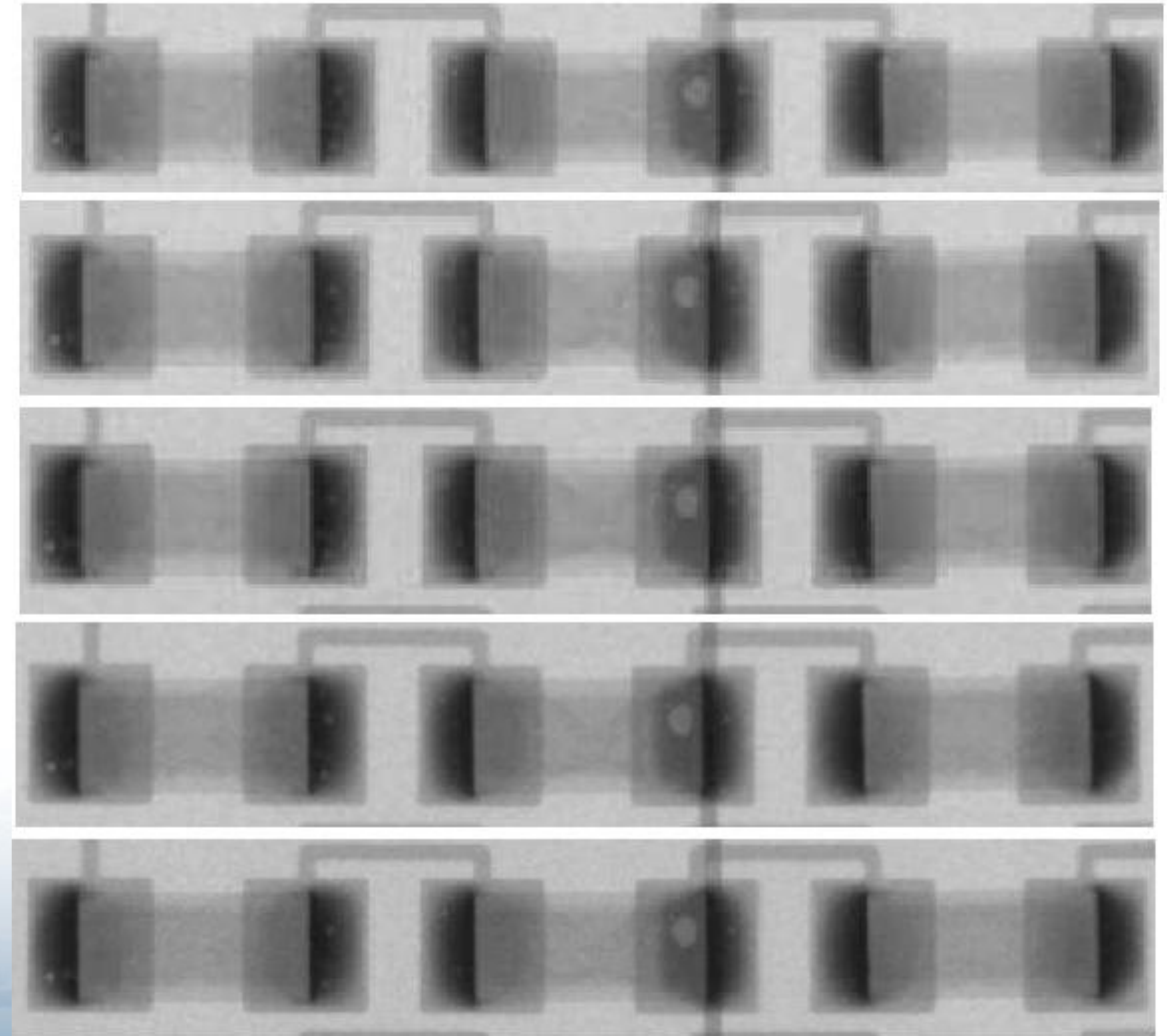
Before exposure

250 hours

500 hours

750 hours

1000 hours



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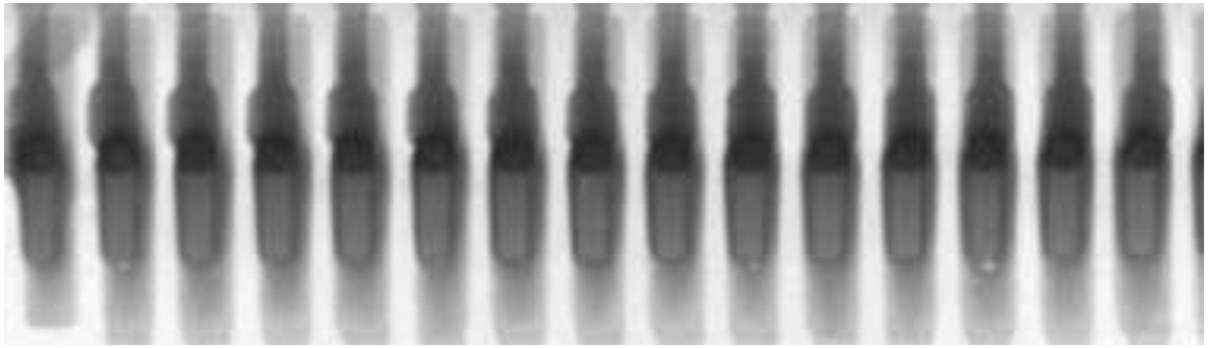
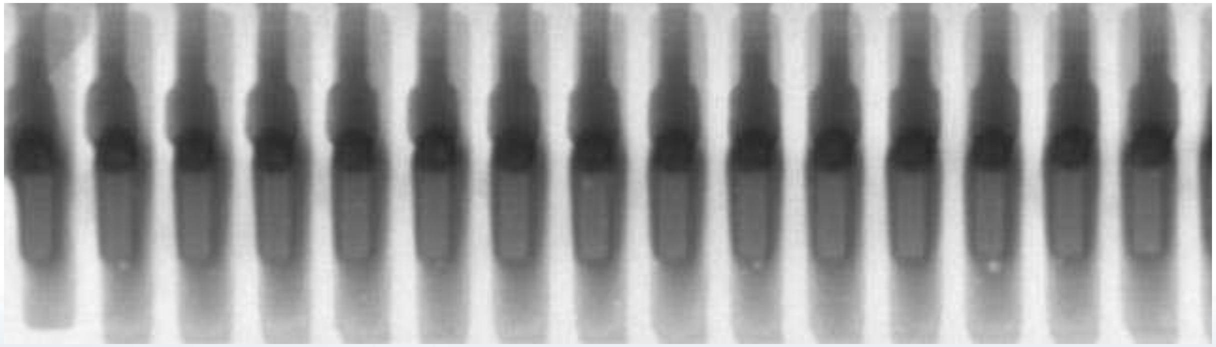
QFP120, Paste B, NiAu

Before exposure



1000 hours



Summary
Corrosion under QFN100

Paste	PCB Coating	250 h	500 h	750 h	1000 h
A	OSP	Yes	Yes	Yes	Yes
	NiAu	Yes	Yes	Yes	Yes
B	OSP	Yes	Yes	Yes	Yes
	NiAu	Yes	Yes	Yes	Yes
C	OSP	No	No	No	Yes
	NiAu	Yes	Yes	Yes	Yes
D	OSP	No	No	No	No
	NiAu	Yes	Yes	Yes	Yes
E	OSP	No	No	No	No
	NiAu	No	No	Yes	Yes
F	OSP	Yes	Yes	Yes	Yes
	NiAu	Yes	Yes	Yes	Yes

1st Study Conclusions

- Corrosion was found under QFN 100’s and 1206 passives, but not under 402’s or QFP’s
- Pastes A, B and F had more corrosion under QFN’s than the less activated C & D pastes or the high rosin content E paste.
- More corrosion was found under QFN’s on coupons with Gold finish than those with OSP finish.
  - Exposed gold exacerbates the corrosion.

Second Cookson Study

- Only NiAu finish CERF boards used.
- SAC305 and 63/37 solder pastes used.
- Three different solder paste fluxes used.
- Three different reflow conditions used.
- Two coupons for every condition studied.
  1000 hours
- X-ray examination before exposure and after 250, 500, 750 and 1000 hours exposure.

Study Flux/Alloy/Reflow Matrix

Flux	Alloy	Reflow
Pin-testable Sn/Pb paste flux (G)	63/37	Typical Sn/Pb
	63/37	Typical SAC
	SAC305	Typical SAC
Pin-testable SAC paste flux (B)	63/37	Typical Sn/Pb
	63/37	Typical SAC
	SAC305	Typical SAC
	SAC305	Hot SAC
High rosin content paste flux (H)	SAC305	Typical SAC

Reflow Conditions

Reflow Type	Reflow Details
Typical SAC305	160ºC / 60s soak 240ºC peak 45-60s TAL
Typical 63 Sn/37 Pb	145ºC soak 220ºC peak 40s TAL
Hot SAC305	170ºC-190ºC 90S soak 245ºC PK 65s TAL

QFN100, Flux B, SAC305, typical SAC reflow

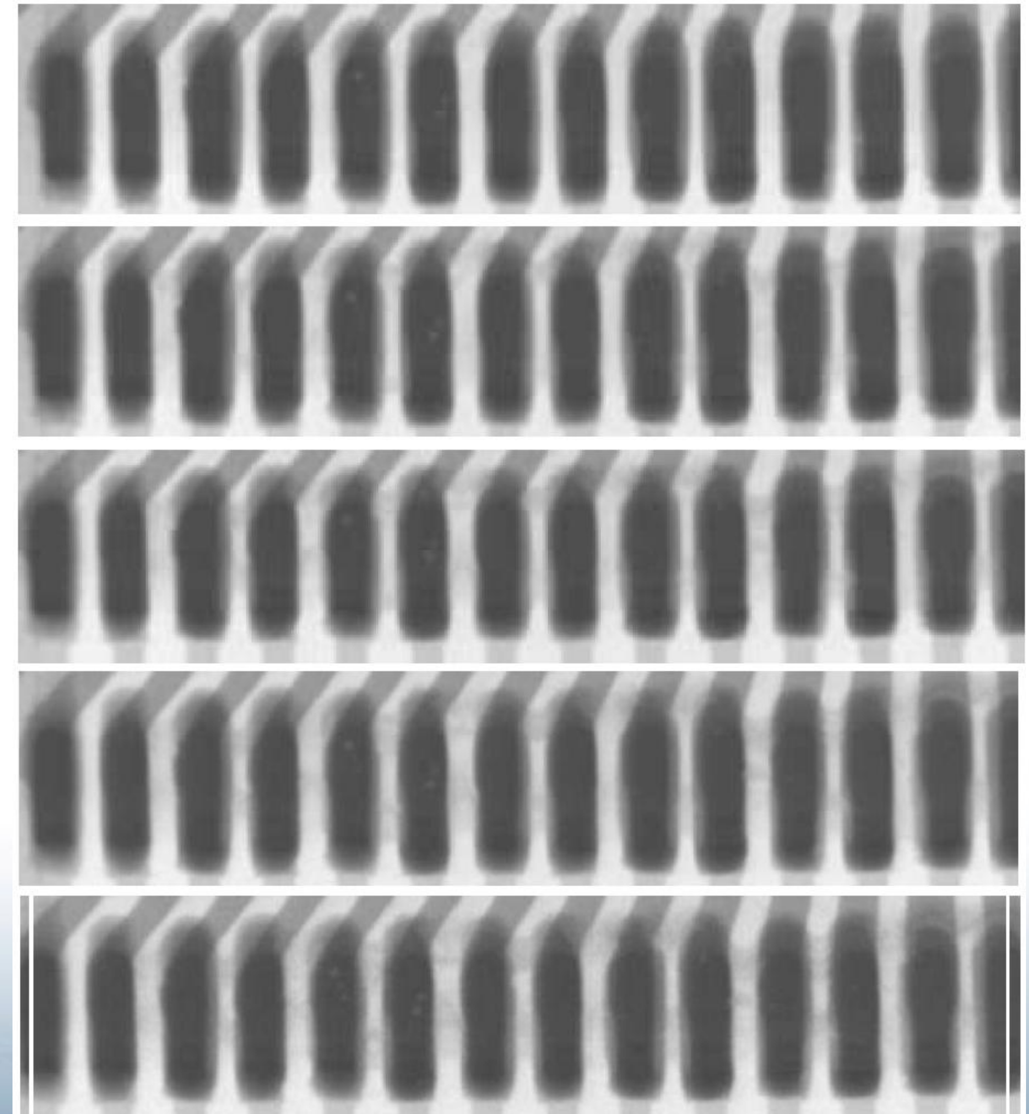
Before exposure

250 hours

500 hours

750 hours

1000 hours



Summary
Corrosion under QFN100

Reflow	Flux	Alloy	Initial	250 h	500 h	750 h	1000 h
Typical Sn/Pb	G	63Sn/37Pb	No	No	No	No	No
Typical SAC	G	63Sn/37Pb	No	No	No	No	No
Typical SAC	G	SAC305	No	No	No	V Little	Little
Typical Sn/Pb	B	63Sn/37Pb	No	V Little	Yes	Yes	Yes
Typical SAC	B	63Sn/37Pb	No	Little	Yes	Yes	Yes
Typical SAC	B	SAC305	No	Yes	Yes	Yes	Yes
Hot SAC	B	SAC305	No	Yes	Yes	Yes	Yes
Typical SAC	H	SAC305	No	No	No	No	No

2nd Study Conclusions

- Corrosion was found under QFN 100's, only slight corrosion was observed for 1206 passives, but no corrosion was found under 402's or QFP's
- The more active SAC no-clean flux B, had more corrosion under QFN's than the milder 63/37 flux G. Flux H, with a very high rosin content, allowed no observable corrosion.
- 63 Sn/37 Pb corrodes only slightly less than SAC305 solder alloy under similar conditions.
- Reflow conditions had no significant effect on corrosion under QFN's.

Questions still unanswered

- What is the corrosion product under the QFN?
  - Tin oxide or hydroxide?
  - Stannate cation?
  - Tin - activator acid salt?
- There's not enough corrosion product to allow analysis.
- What is the corrosion mechanism?

Speculative Mechanisms

- Dissimilar metals – Gold is more noble on the EMF scale than tin or SAC305 solder.
  - The gold surface of the pad is not completely wet by the solder, and may act as the cathode in the corrosion process.
- However:
  - The exposed gold surface is small compared to the corroding solder surface.
  - This phenomenon still occurs on OSP copper coupons, if not to the same extent.

Speculative Mechanisms

- Oxygen concentration gradient that decreases with distance under the QFN component.
  - Solder further under the component will corrode preferentially compared to solder at the outer edges where a where more oxygen supports the cathodic oxygen reduction reaction.

Thanks for your attention