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Evolution of Tin Whiskers on various Chip Components during Thermal Cycling

by

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1. SUMMARY OF WORK

The failure of spacecraft electrical systems that have been caused by the growth of tin whiskers is rare, but when they do occur their effect ranges from catastrophic (the complete loss of three Galaxy telecoms satellites) to extremely costly (Spacelab, Shuttle non-conformances, etc.). Pure tin platings can never be considered as being whisker-free and it is for this reason that such electroplatings are not permitted to be used on ESA spacecraft (ref space standards ECSS Q-60, ECSS Q-70-71, ECSS Q-70-08, etc).

This report details a short study in which common tin-terminated chip components have been evaluated. They were subjected to thermal cycling as is required for the Verification of Surface Mount Technology to ECSS Q-70-38 (previously ESA PSS 01-738). Chip components were either as-received from the manufacturer, soldered by vapour phase to a pcb substrate, hand-soldered, or processed by a technique stated to mitigate the growth of whiskers by the application of a second solder paste/vapour phase step developed by the company Spur (ref. Spur Doc. 197-00001/2 of 28 Feb 2006).

The results confirm that all the non-soldered tin terminations supported whisker growths after the 500 thermal cycles. Surfaces that had been alloyed with tin-lead solder did not grow whiskers, but they did show nodular surface disturbances. The addition of solder to the upper face if the terminations by hand-soldering, or by the Spur process, was seen to prevent the growth of whiskers.

More and more types of commercial chip components are now being supplied with pure-tin finishes. The findings of this small study show that accelerated tests can produce short whiskers. Long term in-service applications are known to cause growths to lengths greater than 100 microns and it is these that caused failures. The present findings confirm the need to pre-tin terminations by a process that ensures all pure-tin surfaces are transformed to an alloy of tin. This mandatory requirement is prescribed in ECSS Q-70-38.

2. SAMPLE DESCRIPTION

Three component groups and three assembly groups were supplied for tin whisker evaluation. The three assembly groups boards numbered EV1 to 3, EV4 to 6 and EV7 to 9. NPL analysed EV2, 5 and 8. Two components, a capacitor and resistor were received already mounted on a SEM stub. On a second stub NPL mounted three components: a Beyschlag mini-melf, a 1206 Murata capacitor, and a 2418 Murata capacitor. The code and details of components evaluated are listed in Table 1. Board EV2 was machine soldered, and board EV8 was hand soldered. Board EV5 was reworked by applying tin-lead paste to the top flat surface of the component.

Table 1: Details of evaluated components

Code	Type	Details, type of component
S1A	Resistor[1]	Unused component from Spur
S1B	Capacitor[2]	Unused component from Spur
S2A	Mini-melf	Unused component manufactured by Beyschlag (Germany)
S2B	Capacitor 1206	Unused component manufactured by Murata (Japan)
S2C	Capacitor 2418	Unused component manufactured by Murata (Japan)
EV2A	Resistor[1]	VP soldered once on EV2 board
EV2B	Capacitor[2]	VP soldered once on EV2 board
EV5A	Resistor[1]	VP soldered twice[3] on EV5 board
EV5B	Capacitor[2]	VP soldered twice[3] on EV5 board
EV8A	Resistor[1]	Hand soldered on EV8 board
EV8B	Capacitor[2]	Hand soldered on EV8 board

[1] Phycomp [2] AVX / SYFER

VP means vapour phase [3] is Spur company process

The board assemblies were manufactured by Spur Electron Ltd., and an example board is shown in Figure 1. The manufacturing routes for the pcb-assembled samples followed the processes outlined in Figure 2.

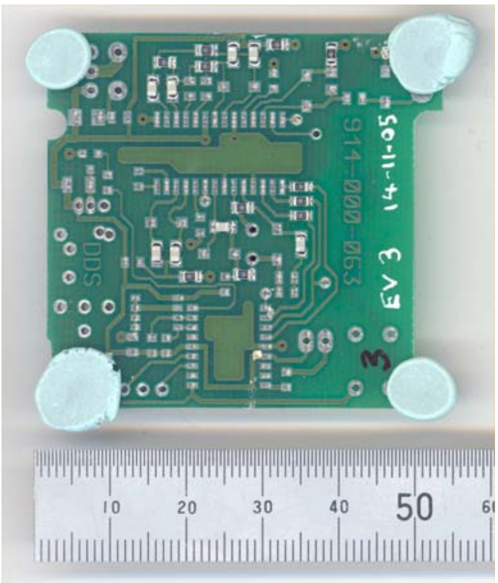


Figure 1: Spur manufactured board (EV3), after thermal cycling.
(The picture was taken with a scanner and the board is stood off on bluetack to protect the component surface finish)

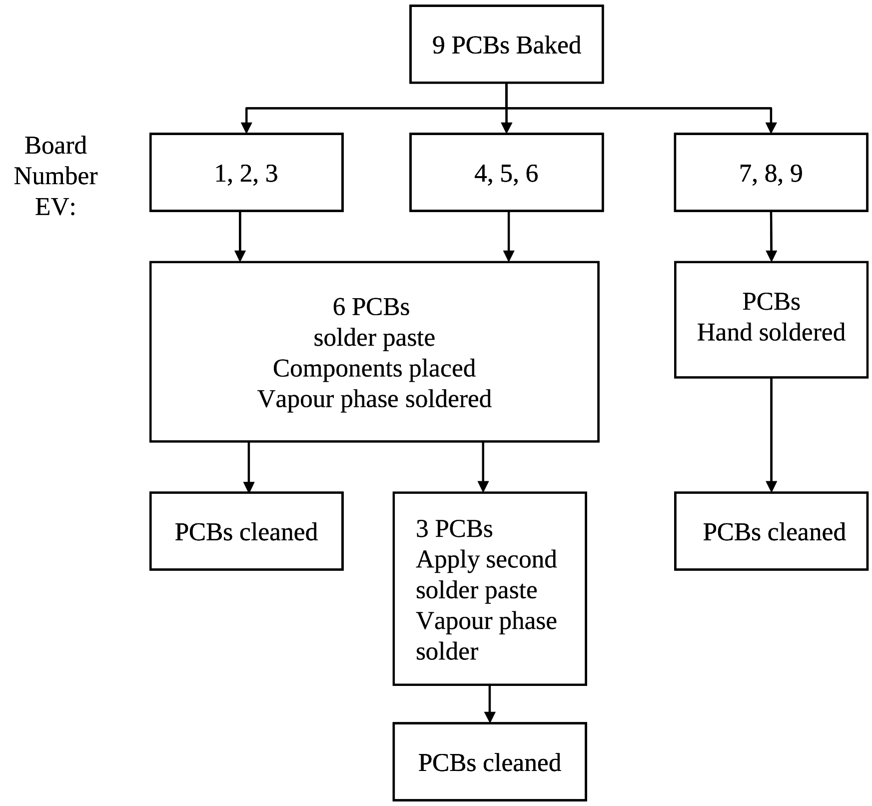


Figure 2: Manufacturing route followed by Spur for the EV boards

3. TEST PROCEDURE

The components listed in Table 1 were inspected in the SEM at zero cycles to reference the surface condition. Individual components were mounted on SEM stubs using double sided conductive pads. Individual boards were mounted on stubs, these boards were painted with a ~3mm strip of conductive ink from the back side to an area on the top side where there was tracking covered by resist. The ink was not close to the components. The components and boards were then thermally cycled. The temperature cycle followed ECSS-Q-70-08, and was from -55 to 100°C, with a temperature rise and fall of ~±10ºC/minute, and with nominal 10 minute dwell times. The actual recorded temperature profiles are presented in Figure 3 for thermocouples attached on different components and assemblies, and these are indicated in the legend. After completion of 500 cycles all components were inspected in the SEM for tin whiskers. Both secondary electron (SEI) and back scattered (BSC) images were recorded for the sample stub flat and tilted at 45°. Images were recorded at 100. 200, 1000 and 5500 magnifications, and the micron bars are 200, 80, 20 and 3µm respectively. All the images are attached as graphic files. The codes for the images are listed in Table 2. Components S2A, S2B and S2C were microsectioned and micrographed using an optical microscope to check for intermetallic growth, plating thickness and general construction.

Because a large number of Scanning Electron micrographs were made during the inspection of the many as-received chips and assembled chips (all having different magnifications and viewing angles) it was necessary to invent a code so that these pictures could be registered. The code is given in Table 2. It is made up as follows:

- The first three or four letters refer to the sample identifier
- The next letter indicates whether it is a resistor (A), or a capacitor (B)
- The "C1" refers to the samples being cycled 500 times. As received samples miss this code
- The next letter is either "F" or "T", indicating the sample was flat or tilted
- The next letter is either A, B, C, D, referring to the magnification, which was 100, 200, 1000 or 5500 times, respectively
- The final part of the file name was either "A-SEI" or "B-BSC" for the SEI or BSC image modes.

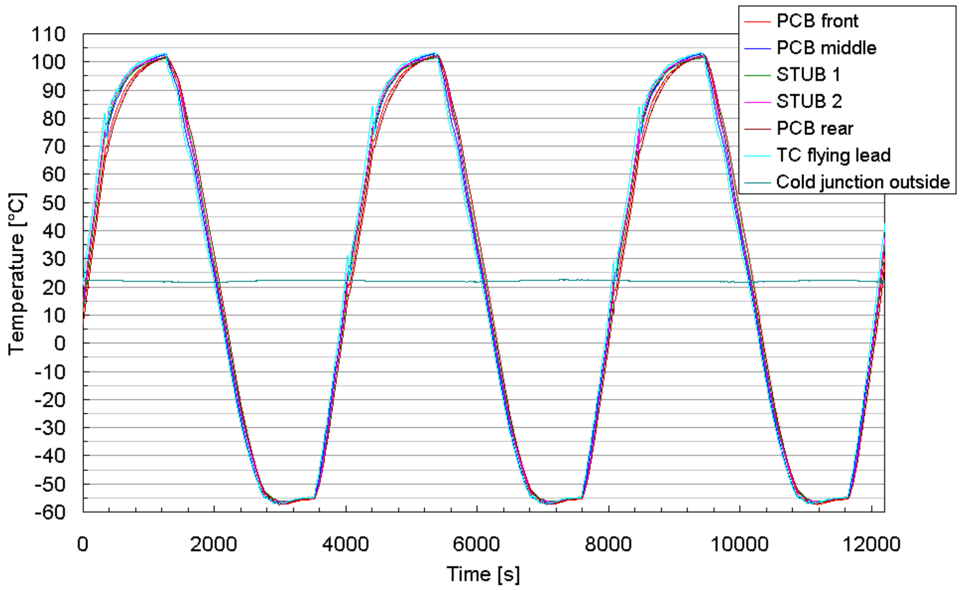


Figure 3: Temperature profiles on components and assemblies

Table 2: Details of file name for some of the samples

File code	Component	View	Magnification
S1AC1F(A-D)	S1A	Flat	A: 100 B: 200 C: 1000 D: 5500
S1BC1F(A-D)	S1B		
S1AC1T(A-D)	S1A	45°	
S1BC1T(A-D)	S1B		
S2AC1F(A-D)	S2A	Flat	
S2BC1F(A-D)	S2B		
S2CC1F(A-D)	S2C		
S2AC1T(A-D)	S2A	45°	
S2BC1T(A-D)	S2B		
S2CC1T(A-D)	S2C		
EV2AC1F(A-D)	EV2A	Flat	
EV2BC1F(A-D)	EV2B		
EV2AC1T(A-D)	EV2A	45°	
EV2BC1T(A-D)	EV2B		
EV5AC1F(A-D)	EV5A	Flat	
EV5BC1F(A-D)	EV5B		
EV5AC1T(A-D)	EV5A	45°	
EV5BC1T(A-D)	EV5B		
EV8AC1F(A-D)	EV8A	Flat	
EV8BC1F(A-D)	EV8B		
EV8AC1T(A-D)	EV8A	45°	
EV8BC1T(A-D)	EV8B		

4. RESULTS

A large number of images have been collected on a CD and are available at Estec. The most interesting images are included in this report. Thermal cycling generally ruptured the surface, giving it a more granular broken appearance. The majority of samples show some type of evolution from the surface, these varied from irregular shaped forms, and are called here nodules, to the more classically shaped whiskers. Nodules can be further classified as their diameter equalling their length, whereas whisker length exceeds the diameter. The maximum whisker length observed in this study was approximately 10µm. The nodule and whisker propensity has been broadly characterised in terms of frequency and length, and examples of this classification are given in Figures 4 and 5. Example images of nodules and whiskers are given below for each sample following 500 thermal cycles, these images are at 200 and 5500 magnification.

In Figure 4 example images taken at 200 magnification of the frequency of whiskers are given:

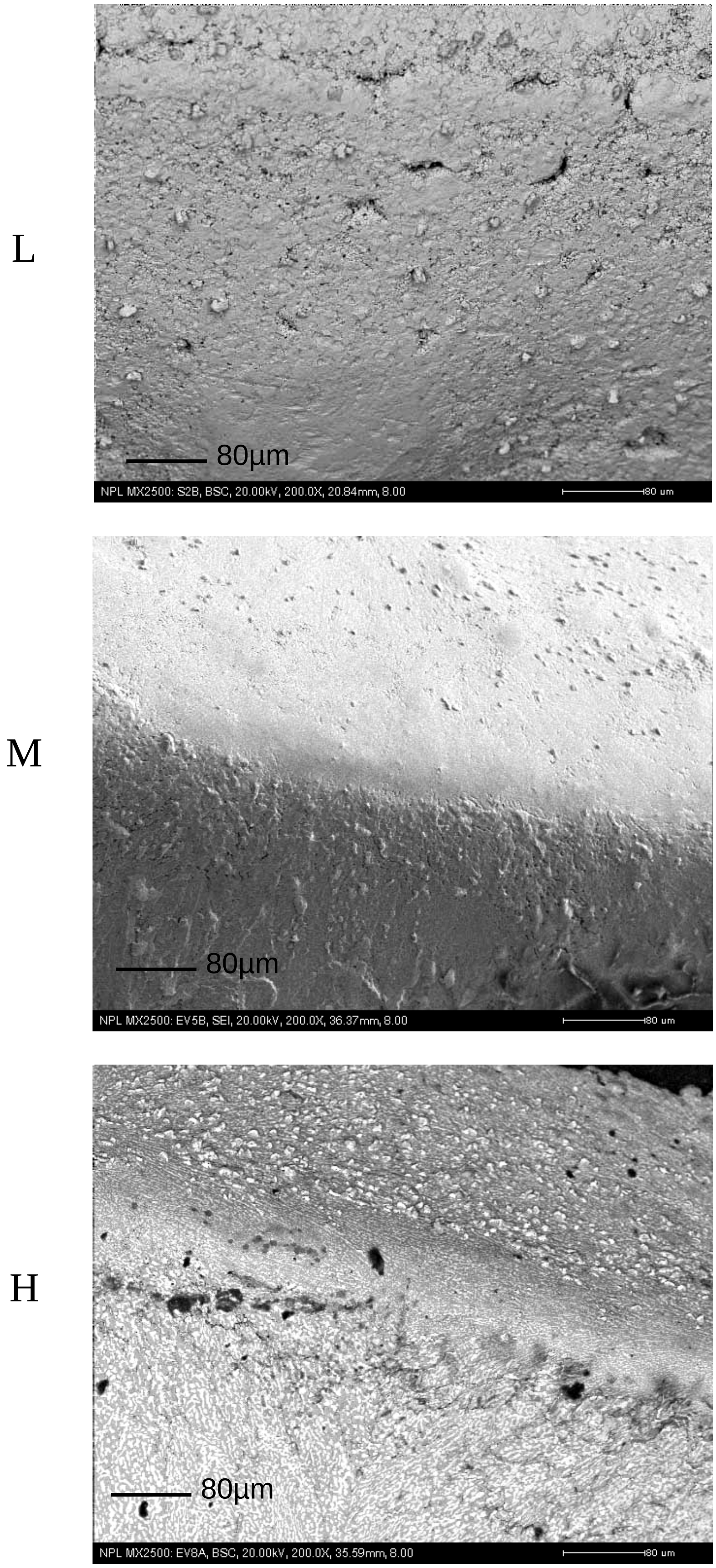
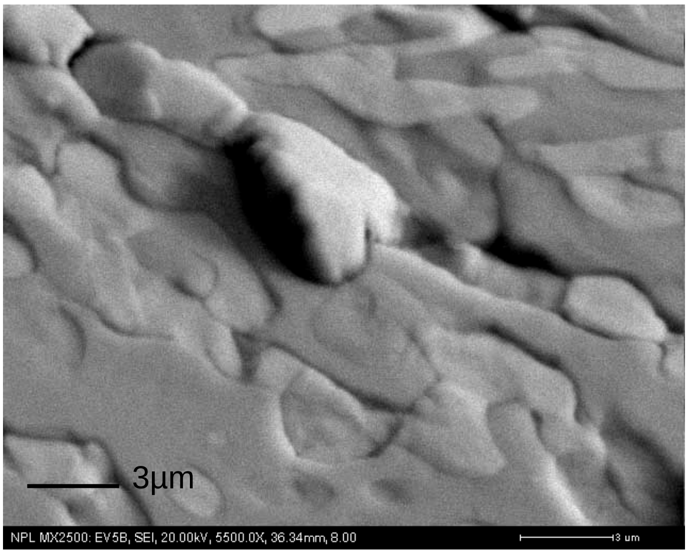
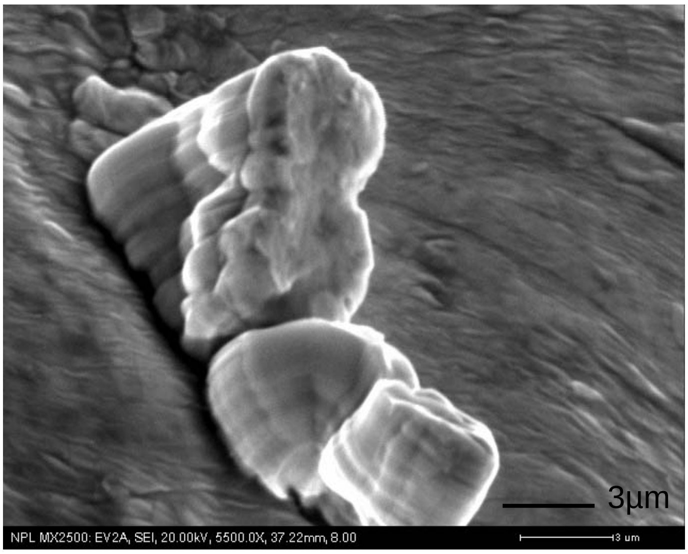


Figure 4: Frequency of nodules and whiskers (Low, Medium, High)

L
small
nodule



M
large
nodule



H
whisker

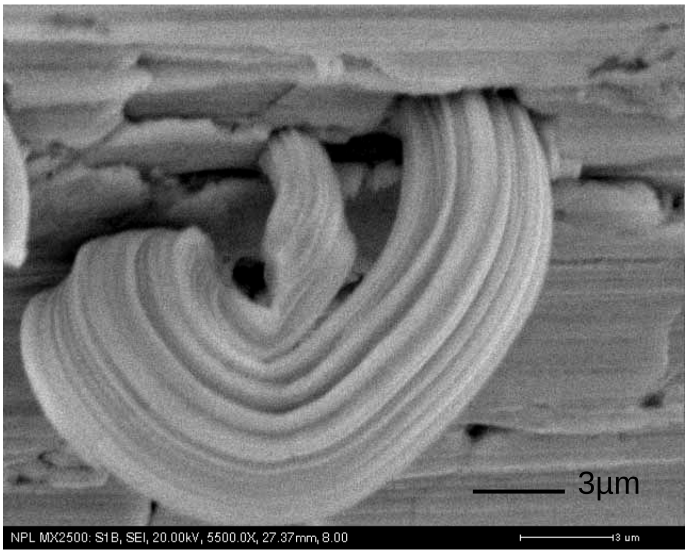


Figure 5: Length of nodules and whiskers

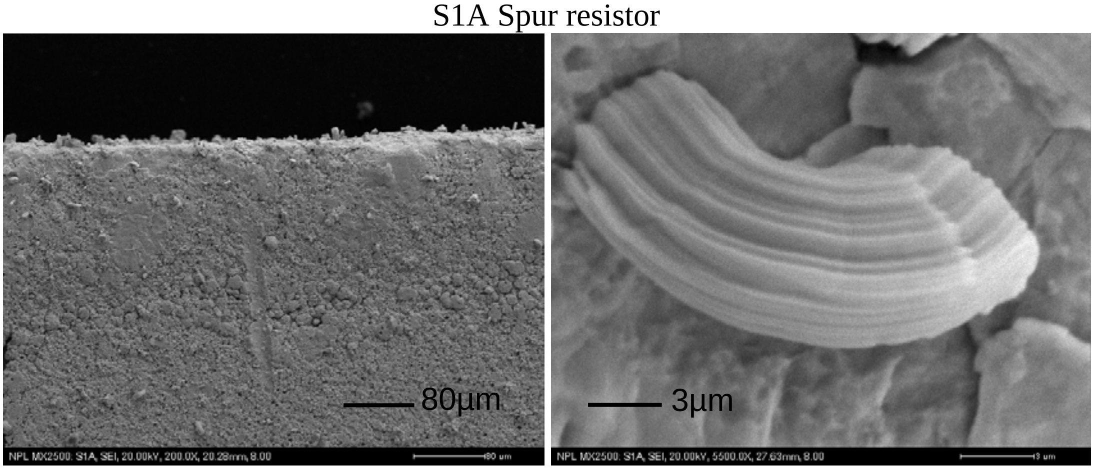
The nodule and whisker propensity results after 500 cycles are presented in the various Figure 6 images, and are summarised in Table 3. The longest whisker found was taken as categorising the sample.

Table 3: Nodule and whisker occurrence after 500 thermal cycles

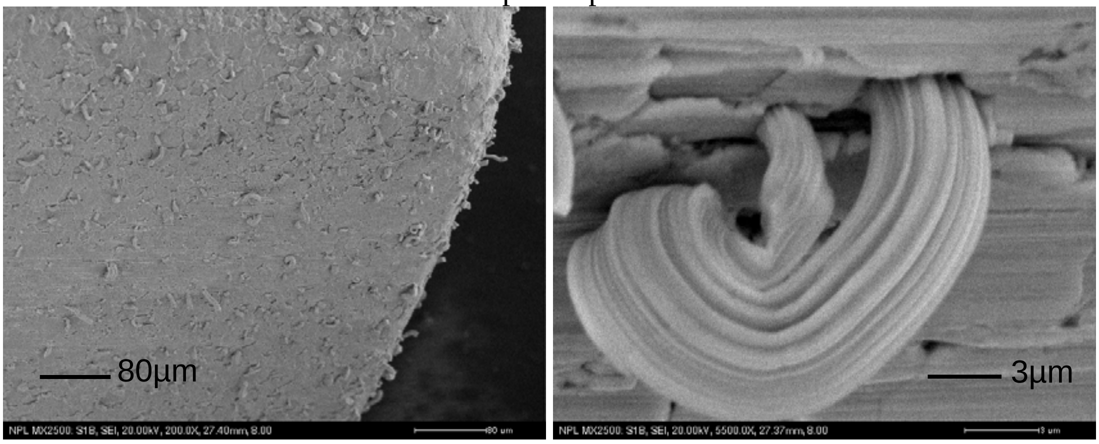
Code	Component	Nodule & Whisker Frequency	Nodule & Whisker Length	Note
S1A	Spur resistor	L	H	
S1B	Spur capacitor	H	H	
S2A	Beyschlag mini-melf	H	H	
S2B	Murata 1206 capacitor	L	M	
S2C	Murata 2418 capacitor	M	H	
EV2A	Resistor	H	M	On top surface (pure tin area)
EV2B	Capacitor	L	H	
EV5A	Resistor	H	L	On top surface (tin/lead area)
EV5B	Capacitor	M	L	
EV8A	Resistor	H	M	
EV8B	Capacitor	L	L	

In Figure 6 the left hand image is at 200 magnification and the right hand image is at 5500 magnification. Some images are in the SEI mode and some are in the BSC mode

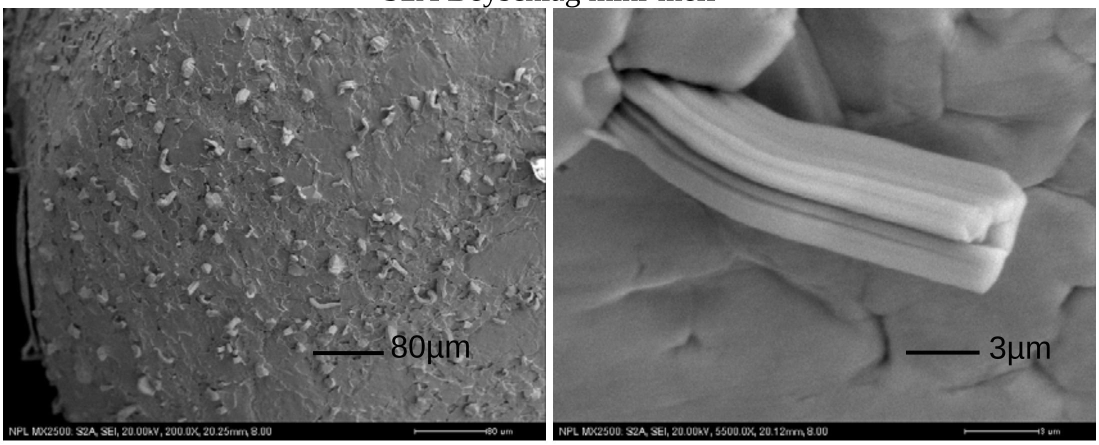
S1A Spur resistor



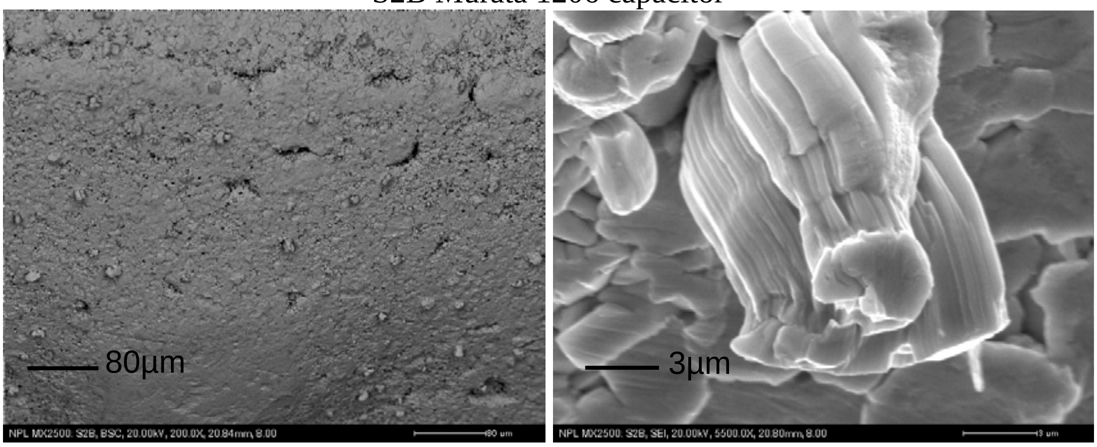
S1B Spur Capacitor



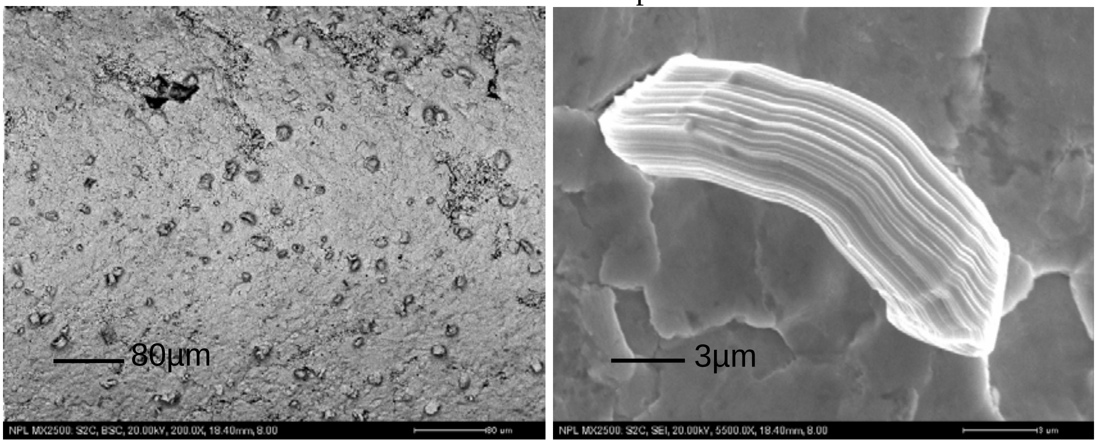
S2A Beyschlag mini-melf



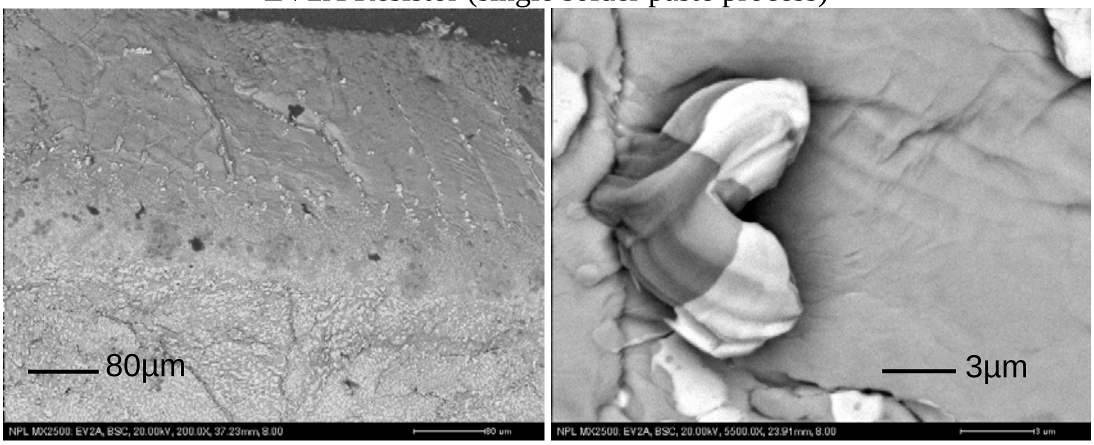
S2B Murata 1206 capacitor



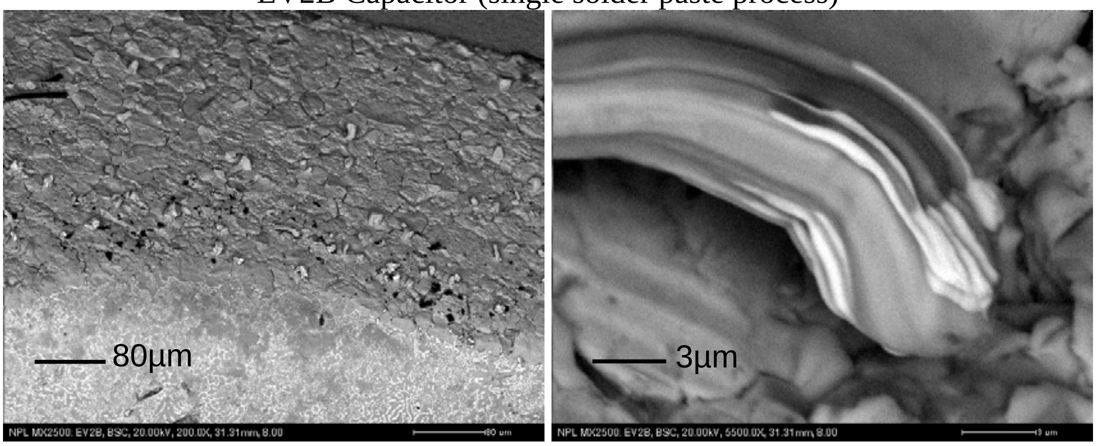
S2C Murata 2418 capacitor



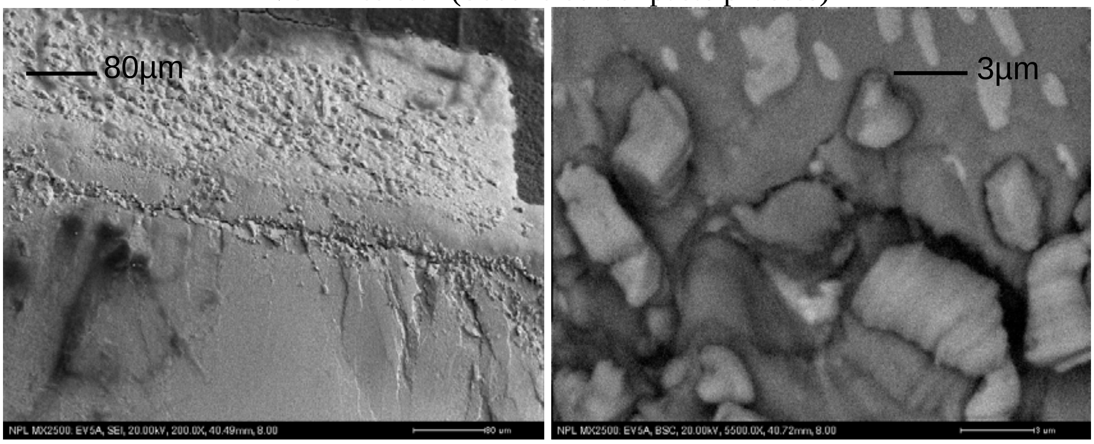
EV2A Resistor (single solder paste process)



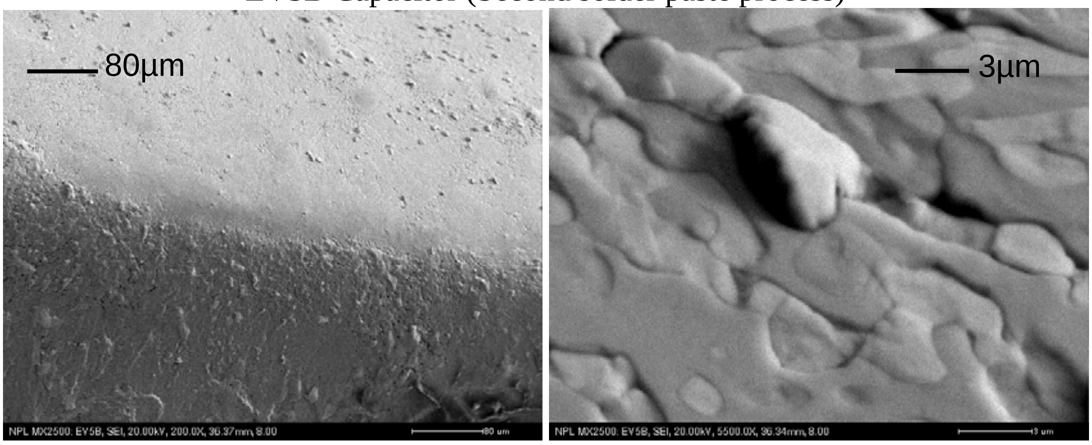
EV2B Capacitor (single solder paste process)



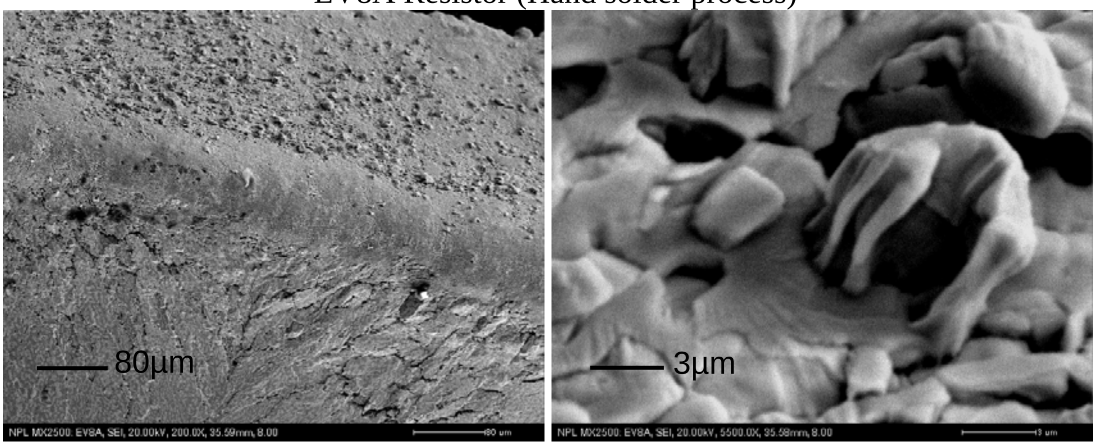
EV5A Resistor (Second solder paste process)



EV5B Capacitor (Second solder paste process)



EV8A Resistor (Hand solder process)



EV8B Capacitor (Hand solder process)

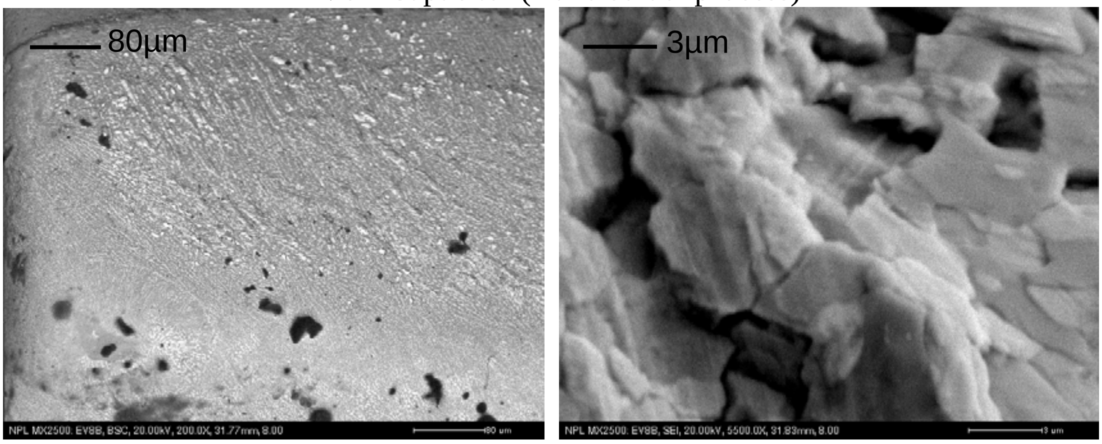
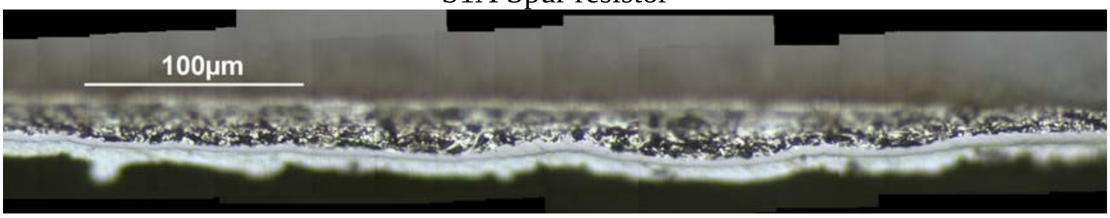


Figure 6: Tin nodule and whisker results for all components after 500 cycles

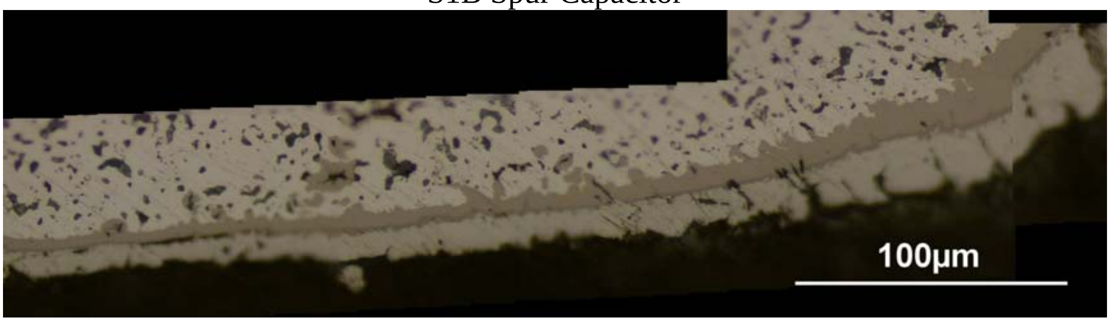
Examples of the unsoldered samples were sectioned after thermal cycling, and these are presented in Figure 7. Samples were analysed in the SEM, and analyses of the metallisation through the surface were taken. A general comment applicable to all the samples is that there appear to be nodules and whiskers along the surface of the tin.

S1A Spur resistor



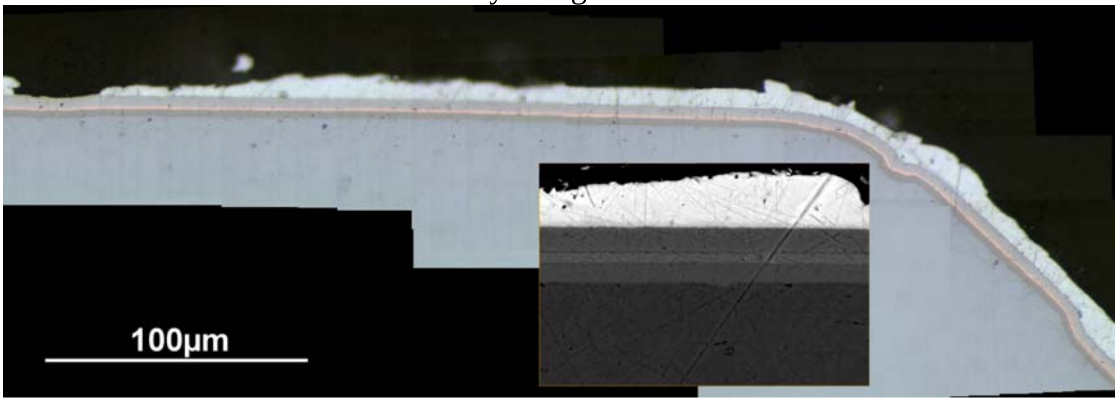
The Spur resistor shows a typical coating system, with a tin layer on a nickel barrier, which in turn is on a silver ink.

S1B Spur Capacitor



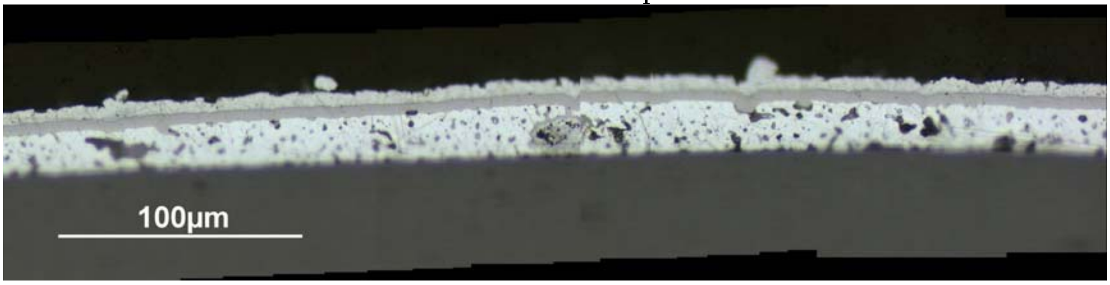
A similar structure is observed for the Spur capacitor.

S2A Beyschlag mini-melf



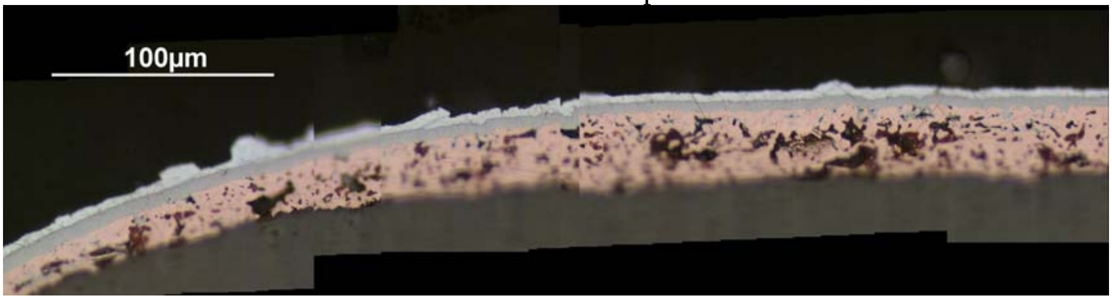
The Beyschlag component clearly shows a multilayered finish layer. Below the tin there is a Ni, Cu, Ni layer system on a iron matrix. The insert back scattered SEM image shows this structure clearly.

S2B Murata 1206 capacitor



The Murata 1206 capacitor reveals a typical tin coating on a nickel barrier, which in turn is on silver ink.

S2C Murata 2418 capacitor



The Murata 2418 capacitor shows the tin layer again on nickel, but then there is a copper material, and then the ceramic.

5. DISCUSSION

A general remark is that all the coatings, except the Murata components, exhibit irregular broken surfaces, and are not typical of standard plating finishes. All the component surfaces suffered eruptions from the surface following thermal cycling, EV8B having the lowest occurrence of nodules.

The tin-lead reworked board, EV5, did not show any whiskers, although there were some small nodules appearing from the surface, and these nodules were relatively numerous. There was clear evidence that there was lead on the top of the component. On EV8A, resistors, there were numerous nodules. The EV8B capacitors produced the lowest level of nodules. The EV2 boards were similar to the EV8, although on EV2B whiskers were observed, though still less than 10µm. On EV2A an unusual whisker is observed, splitting in two, and with lead at the top and a tin root.

The Beyschlag component, S2A, produced the worse whiskering, the next was the S1B (Spur Capacitor), then with similar appearance was S1A (Spur Resistor) and then S2C (Murata 1206 capacitor), and finally the S2B (Murata 2418 capacitor). The overall finish of the Murata components was superior to the other components, but similar whiskers were still observed.

6. CONCLUSIONS

All the non-soldered components produced short whiskers. With automatic vapour phase machine soldering, using solder paste only applied to the pcb land areas, whiskering also occurred. However, with the additional step of applying solder paste to the top of the component terminations it was seen that nodules did occur, but that the growth of actual whiskers was suppressed. The hand soldered components also produced nodules, but no whiskers, due to the fact that the application of solder wire, during hand soldering, causes the liquid solder to flow over and alloy with all the tin-terminated surfaces.