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Susceptibility of Lead-Free Systems to Electrochemical Migration

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ABSTRACT

The corrosion and electrochemical migration behaviour on circuit boards will change with the move to lead-free soldering systems, and may affect both circuit performance and long-term reliability. One failure mechanism of particular concern is that of the formation of metal dendrites in the presence of contamination (e.g. flux residues), which can lead to catastrophic failure. The propensity of the eutectic SnAgCu (SAC) lead-free solder alloy to form dendrites has been assessed in terms of the required critical flux concentration to form dendrites, and benchmarked against the performance of conventional SnPb alloy. Two PCB finish materials (Cu and AuNi) have been also investigated for comparison. The major investigatory tool was Surface Insulation Resistance (SIR) measurements, although compositional data were gathered from individual dendrites using SEM-EDX equipment. The work has shown that dendrite formation occurs more readily with the SAC alloy than with the SnPb alloy due to silver migration. Hence contamination of lead-free assemblies must be lower than that associated with a conventional SnPb assembly processes. Dendrites are more easily generated with AuNi finishes than with copper finishes due to nickel migration. A copper finish is least likely to form dendrites due to its low corrosion rate and low solubility of $\text{Cu}(\text{OH})_2$.

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1	INTRODUCTION	1
2	EXPERIMENTAL.....	3
2.1	TEST BOARDS	3
2.2	TEST BOARD CLEANING.....	3
2.3	TEST FLUX	4
2.4	TEST BOARD CONTAMINATION.....	4
2.5	FLUX CONCENTRATION	4
2.6	SIR MEASUREMENT	5
2.7	EDX ANALYSIS OF DENDRITES	5
3	RESULTS	5
3.1	SIR RESULTS ON CLEANED TEST BOARDS.....	5
3.2	SIR RESULTS ON FLUXED BOARDS	6
3.3	SEM-EDX ANALYSIS OF DENDRITES	12
4	DISCUSSION.....	15
4.1	MINIMUM FLUX CONCENTRATION TO FORM DENDRITES	15
4.2	THE PROPENSITY OF METAL TO FORM DENDRITES.....	16
5	CONCLUSIONS	17
6	REFERENCES.....	18
7	ACKNOWLEDGEMENTS	19

1 INTRODUCTION

Achieving high reliability in service is the key issue in today's electronics assemblies. Reliability failures can be caused by contaminants facilitating electrochemical processes that result in a loss of continuity, or short circuits. These failures have been successfully studied using the surface insulation resistance (SIR) technique^{1,2}, which is based on the measurement of an electrical current associated with electrochemical processes, and measures oxidation reactions at the anode and reduction reactions at the cathode in a coupled system. Current leakage, or SIR, is of concern both for good to circuit performance and for long-term circuit reliability. Circuit requirements in terms of SIR differ significantly depending on application. For example, although for logic circuits it is satisfactory to achieve SIR of $10^6\Omega$, for high performance analogue circuitry the requirements may be above $10^9\Omega$. In addition to using SIR to qualify a manufactured board as fit for purpose after manufacture, it can also be combined with stress screening to provide a reliability indicator. Thus the two roles of SIR have become: measuring circuit isolation, and monitoring circuit reliability. An important failure mechanism that SIR can identify is electrochemical migration (ECM) of metal ions, and this is a long-term reliability issue. ECM is defined in IPC-TR-476 as dendritic growth³, a deposited metallic conductive path with a branched structure. A catastrophic circuit failure can occur when the deposited metallic features of a dendrite grow from the cathode to reach the anode.

The electrochemical process between two metallic conductors on a substrate surface, is shown in Figure 1. In order for electrochemical migration to occur between conductive electrodes across an insulating circuit board surface, three conditions must be met simultaneously:

- Electrical carriers (such as ionic contamination from flux residues, or harsh environments) must be present.
- Water must be present (typically an adsorbed layer from the atmosphere) to dissolve the ionic materials and sustain them in their mobile state. (Contaminants that are hydrophilic will enhance the water layer and hence facilitate further ionic conduction and lower the surface insulation resistance).
- An electrical potential between the electrodes is needed to establish an ionic current in the water layer.

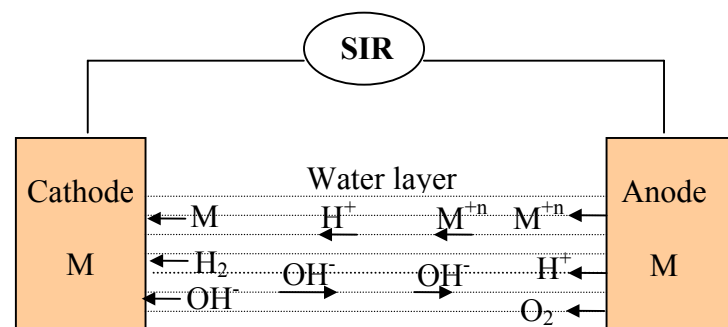
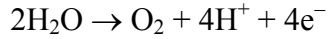
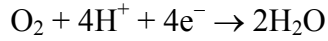


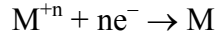
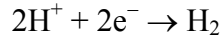
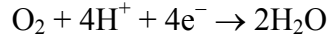
Figure 1. The electrochemical mechanism for SIR measurement

In this work, a 5V bias was applied between the two electrodes, and the SIR for each comb was measured in the controlled temperature and humidity chamber (40°C/93%). The following are some of the possible anode and cathode reactions.

At the anode



At the cathode



For dendrite growth, the metal oxidation at the anode and metal ion reduction at the cathode must occur, and be the dominate electrode reactions. This can be considered as a three-step process:

- *Metal oxidation:* Metal is oxidized to metal ions into solution at the anode.
- *Metal ion transportation:* Metal ions migrate from the anode to cathode under an electric field.
- *Metal deposition:* Metal ions reduced to metal and deposited at the cathode.

Clearly all these processes are necessary for dendrite formation, and there are many factors that can influence each process individually. *Metal oxidation at the anode:* each metal will have a different corrosion rate⁴, and a metal with a fast corrosion rate will clearly form higher metal ion concentrations in the thin water film, hence enhancing the formation of dendrites. *Metal ion transportation:* if the metal ion forms an insoluble compound, it will not migrate from the anode to cathode, and therefore solubility of the metal hydroxide is key to dendrite formation⁵. Finally, *metal deposition* at the cathode: Zamanzadeh⁶ found that there is limiting over-potential for dendrite formation, below which dendrite formation can never occur.

In classical electrochemical experiments that take place in the bulk solution the anodic and cathodic reactions are investigated separately. However, for this electronic system with dendrite formation, oxidation and reduction of the metal electrodes are coupled and can interfere with each other. The SIR measurement system cannot discriminate between the various processes. A fundamental study of the electrochemical process is not easy for this system as the adsorbed layer of atmospheric moisture is only approximately 100nm thick. The SIR measurement approach measures all the electrochemical processes simultaneously to predict circuit reliability. Work in the literature can be found that reports the effect of contamination, temperature and humidity, on dendrite formation using the SIR tool⁷⁻⁹, but the effect of solder alloy on SIR has not been previously studied in detail.

With the move to lead-free soldering, a new range of tin-rich alloys has been introduced to replace SnPb. The main alloy family of choice is based around the SnAgCu (SAC) eutectic, and this alloy can be expected to influence the SIR properties and dendrite growth, and subsequently the reliability of the circuit. The purpose of this work was to use the SIR technique to investigate the propensity of a SAC solder alloy used as a board finish to form dendrites after contact with different fluxes. For comparison purposes, the work also included a similar study of SnPb and two commonly used PCB surface finishes. The results from this work are used as the basis for discussion of the likely impact of lead-free board finishes on the reliability of electronic assemblies.

2 EXPERIMENTAL

2.1 TEST BOARDS

A test board was designed consisting of four identical SIR comb patterns, as shown in Figure 2. The size of each comb pattern was 25 x 25mm with 0.60mm pitch and 0.20mm gap. Boards were prepared with four finish materials; SAC, SnPb, AuNi and copper. AuNi and copper finished boards were obtained from the PCB supplier directly. SAC and SnPb finish boards were manufactured from AuNi boards printed with proprietary no-clean solder pastes. The pastes used were Sn63Pb37 for the SnPb-finished boards, and Sn96.5Ag3.0Cu0.5 for the SAC-finished boards.

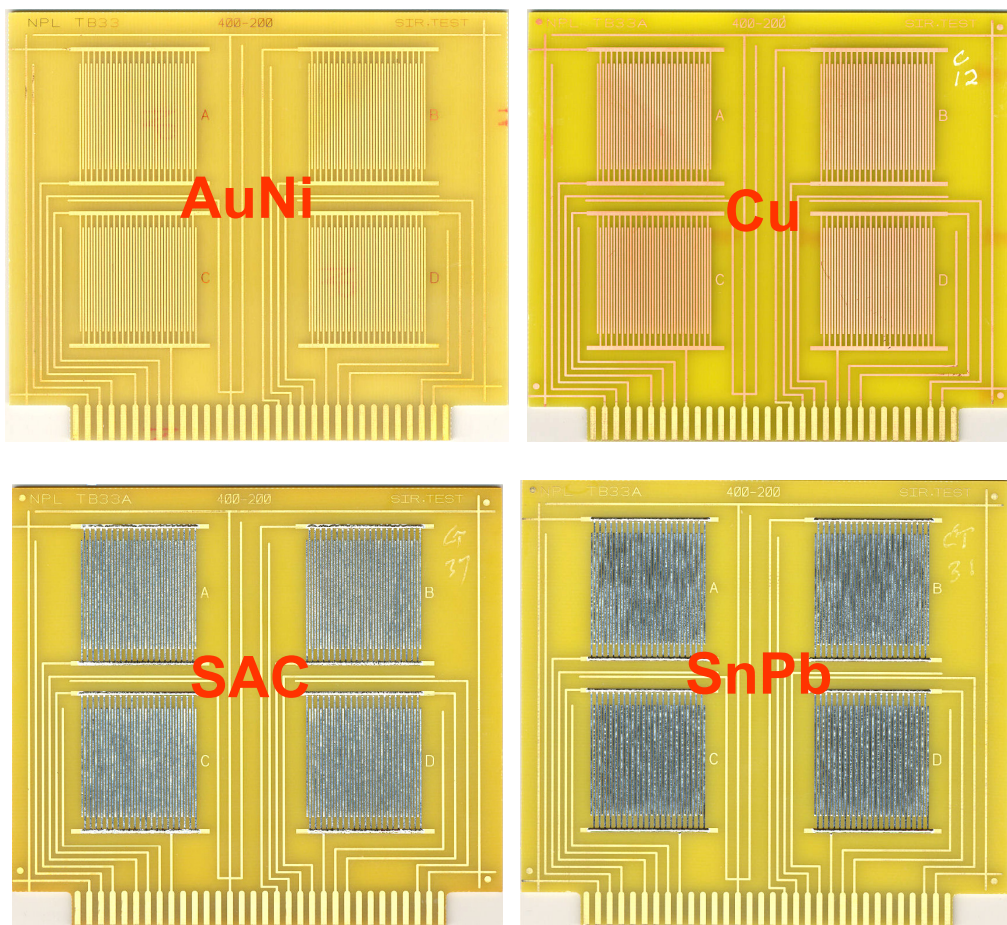


Figure 2. Test board with four finishes

2.2 TEST BOARD CLEANING

The aim of this work was to investigate the effect of solder alloy and PCB finish material on the SIR behaviour and dendrite formation. In order to eliminate any effects of contamination associated with the manufacture processes, the cleanliness of test

boards with different finishes had not only to be assured but also to achieve similar high levels of SIR. The cleaning procedures were:

For the AuNi- and copper-finished boards:

- Ionograph cleaning in 75% IPA + 25% DI water mixture at 45°C for 15 minutes

For SAC- and SnPb-finished boards:

- Ultrasonic cleaning in 100% Zestron FA+ at 50°C for 5 minutes
- DI water rinsing at 50°C for 5 min
- Ionograph cleaning in 75% IPA + 25% DI water mixture at 45°C for 15 minutes

2.3 TEST FLUX

Three commercial fluxes A, B and C were used for the study, all recommended by a single flux supplier, and all were no-clean fluxes suitable for lead-free soldering. Flux A was a 35% resin RMA flux. Flux B was a low resin content, halide-free solvent-based flux. Flux C is a resin-free and halide-free solvent-based flux.

2.4 TEST BOARD CONTAMINATION

The cleaned boards were fluxed using 50 µl of the test fluxes to cover each comb pattern. Fluxed boards were dried in a 100°C dry oven for 5 minutes.

2.5 FLUX CONCENTRATION

For this work it was necessary to determine the minimum flux concentrations that caused dendrite formation on the four board finishes. While this appears to be an artificial manipulation, it does allow the characterisation of the flux residues in the critical regime for each flux chemistry, and is relevant since process residues vary over a wide range. Therefore the flux concentrations were reduced as necessary from the as-received flux concentration by dilution with IPA. For Flux A it was found that 100% concentration of the as-received flux had to be used, and even at this concentration Flux A could not promote dendrites on all board finishes. For flux B and C, three different concentrations (low, middle and high) were found for the different metal finishes from preliminary testing, and these are listed in Table 1.

Table 1. Test flux concentration for different finish board

Board finish Flux	AuNi	Cu	SnPb	SAC
	Flux concentration (% in IPA)			
Flux A	100	100	100	100
Flux B	5	50	10	5
	10	65	15	10
	15	80	20	15
Flux C	5	40	8	8
	8	50	12	10
	10	60	16	12

2.6 SIR MEASUREMENT

A single board (four identical test patterns) for each combination of board finish and flux concentration was SIR tested. The SIR measurements were performed under conditions of constant temperature and humidity, 40°C/93%RH. A bias voltage of 5V DC was applied during the test period of 72 hours, and the SIR was measured every 15 minutes. The test equipment had a $10^6 \Omega$ resistor incorporated into each test channel to preserve dendrite formation, so the minimum SIR measurement value of each channel was $10^6 \Omega$.

2.7 EDX ANALYSIS OF DENDRITES

The dendrites formed during the SIR measurement on different board finish were identified and located using a optical microscope with back lights and an SEM, and the dendrite composition was assessed using an energy-dispersive X-ray (EDX) analyser attached to the SEM

3 RESULTS

3.1 SIR RESULTS ON CLEANED TEST BOARDS

The average SIR values from two cleaned test boards (eight comb patterns) with time for different board finishes after cleaning are presented in Figure 3. The results clearly show that the SIR values were all similar and significantly above $10^6 \Omega$. The results confirm that the cleaning procedures proposed for the different board finishes effectively removed contaminants from the PCB manufacturing and solder paste reflow processes, and achieved a high cleanliness level.

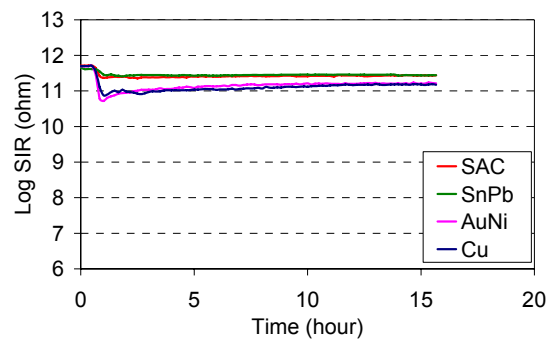


Figure 3. SIR results for different board finishes after cleaning

3.2 SIR RESULTS ON FLUXED BOARDS

The average SIR values for different board finishes with 100% flux A are plotted in Figure 4, where one test board (four comb patterns) was used for each finish. It can be noted from Figure 4 that there is no significant difference in the SIR results from boards with different finishes using flux A. The SIR values were slightly lower than those obtained from clean boards (compare with Figure 3) suggesting that if the contamination level were not high enough to lower the SIR, (and thus cause significant corrosion to initiate metal ion electrochemical migration), the metal material will not affect circuit reliability. *Hence, there should be no reliability issues using flux A and any of the four board finishes.*

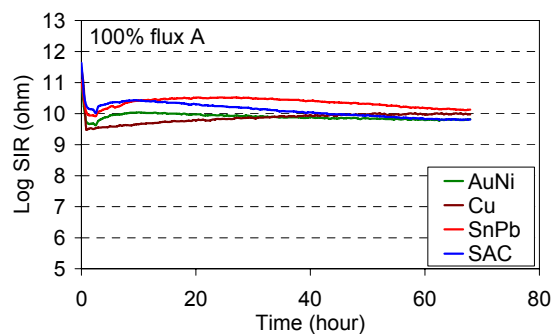


Figure 4. SIR results from different board finishes using flux A

The SIR values from four test patterns contaminated with three concentrations of flux B for AuNi-finished boards are presented in Figure 5, and those for Cu-, SAC- and SnPb-finished boards in Figures 6, 7 and 8 respectively. Similarly the results for four board finishes with flux C are presented in Figures 9, 10, 11 and 12 respectively.

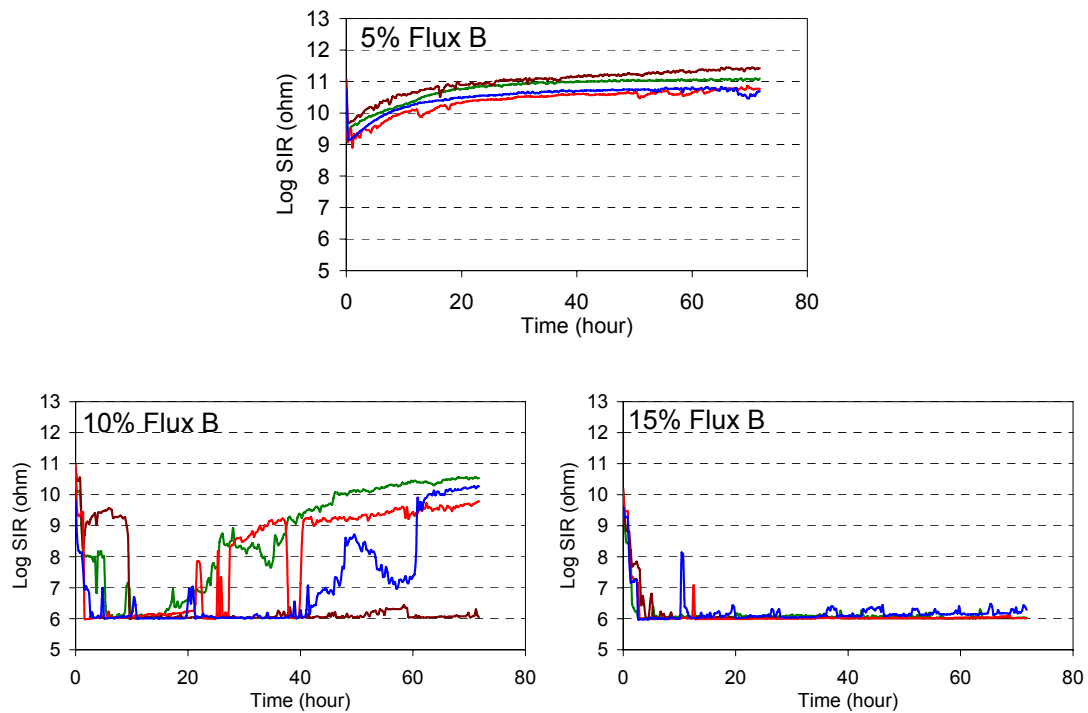


Figure 5. SIR results from AuNi-finished boards with three concentrations of flux B

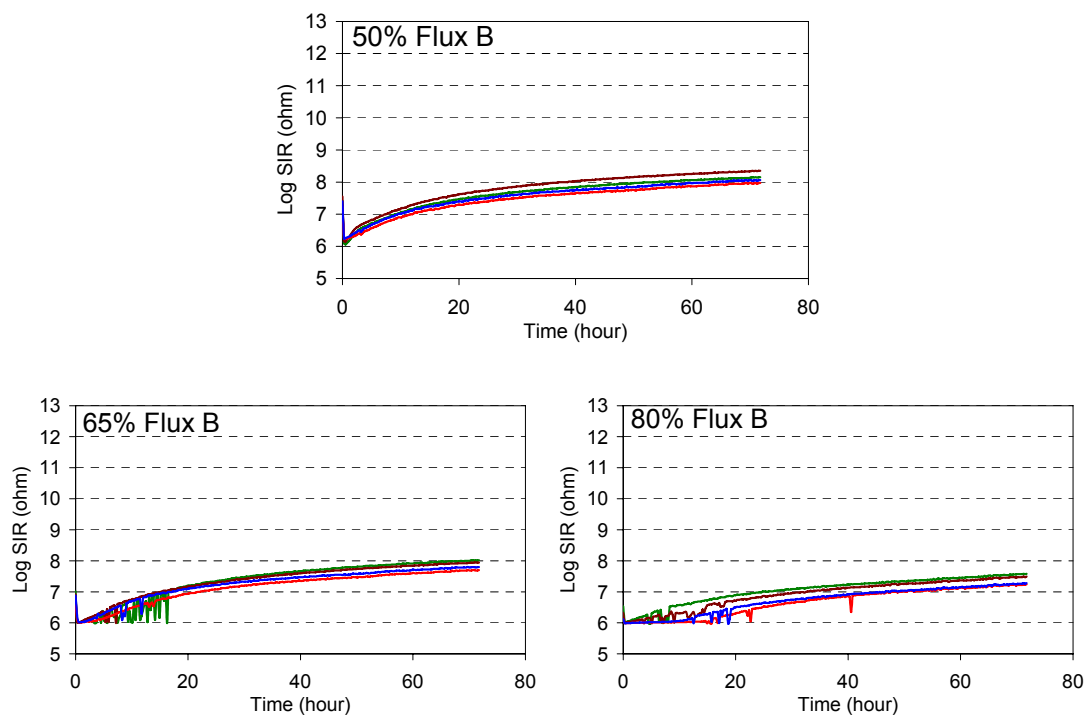


Figure 6. SIR results from Cu-finished boards with three concentrations of flux B

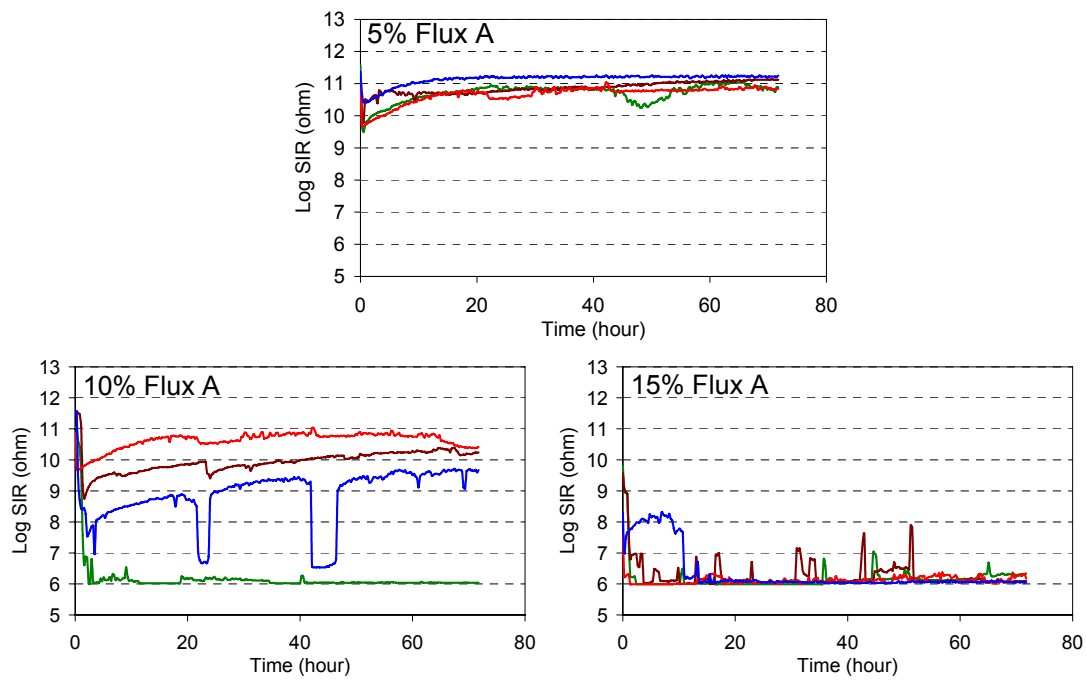


Figure 7. SIR results from SAC-finished boards with three concentrations of flux B

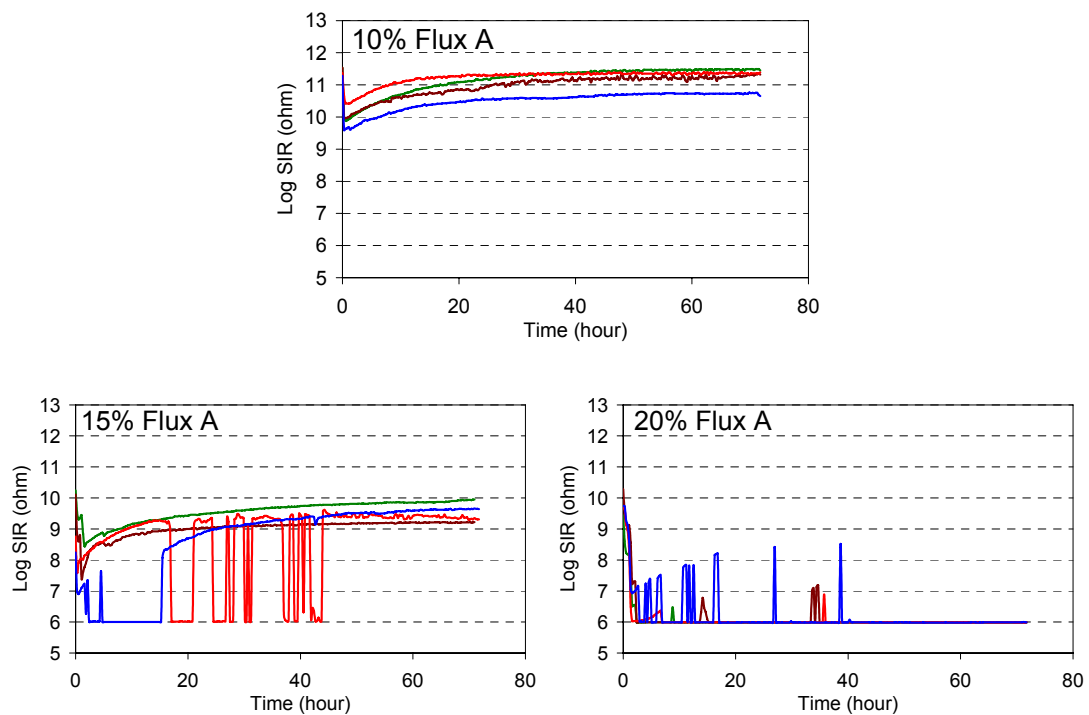


Figure 8. SIR results from SnPb-finished boards with three concentrations of flux B

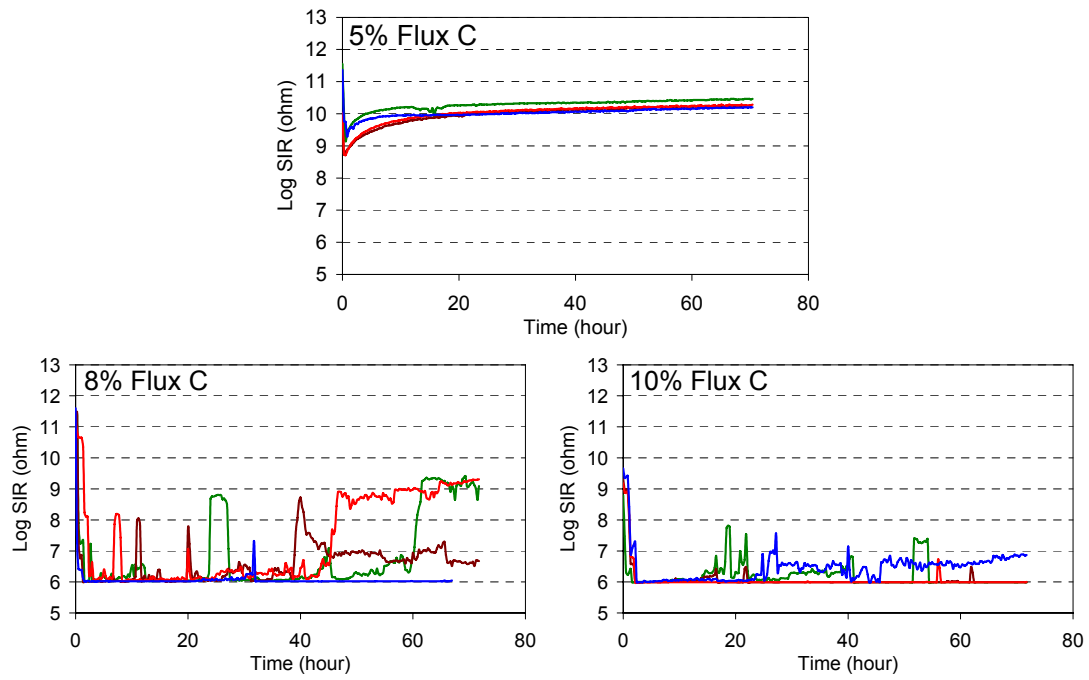


Figure 9. SIR results from AuNi-finished boards with three concentrations of flux C

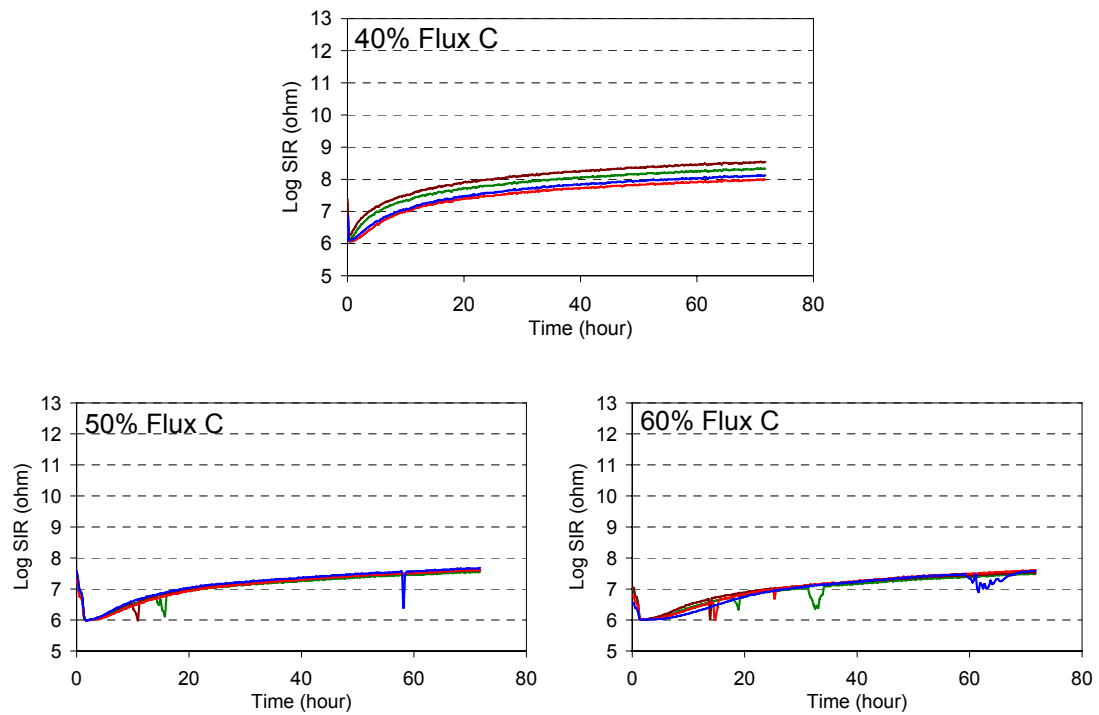


Figure 10. SIR results from Cu-finished boards with three concentrations of flux C

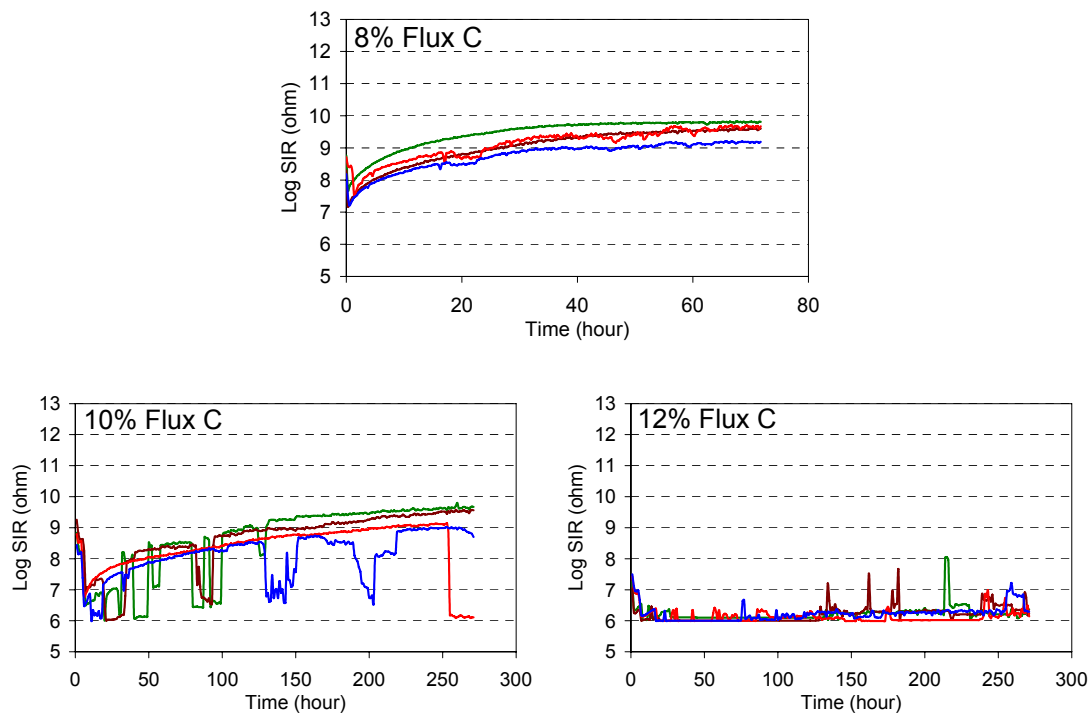


Figure 11. SIR results from SAC-finished boards with three concentrations of flux C

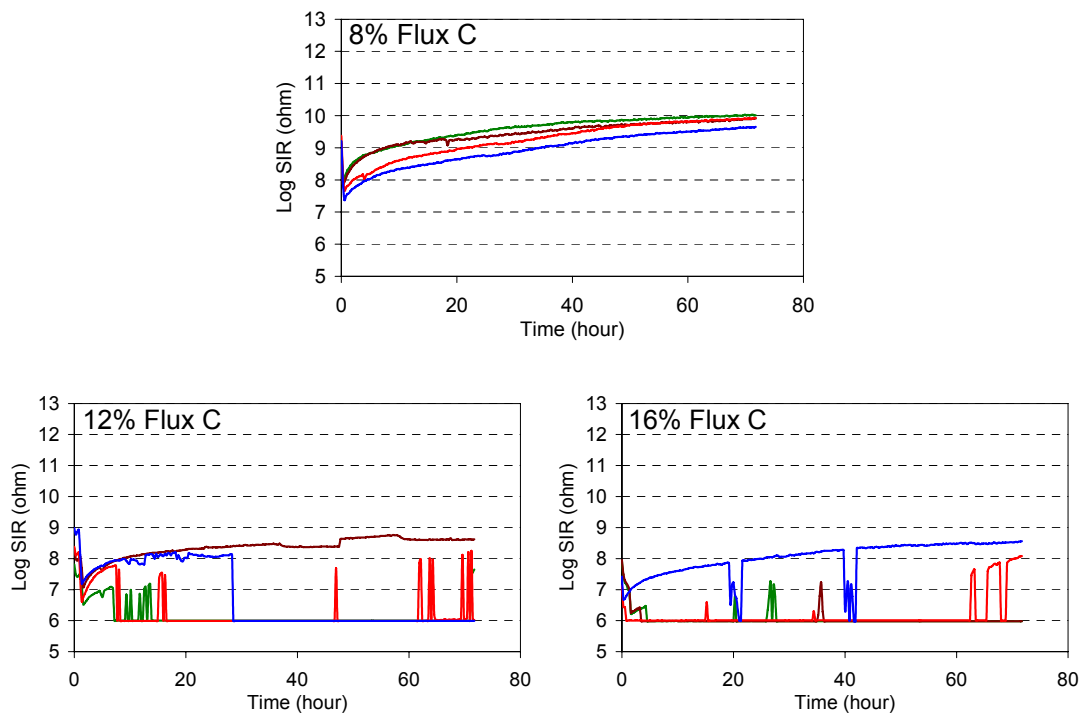


Figure 12. SIR results from SnPb-finished boards with three concentrations of flux C

Some important findings should be noted from these results. For all board finishes combined with the low flux concentrations, the SIR values slowly increased with time, and stabilised within the test period. This increasing SIR was typical of the situation in which the ionic contaminants were depleted from the insulating surface due to mobile ions migrating toward the electrodes and then undergoing reduction and oxidation processes at both electrodes, thus no longer contributing to the conduction process. In the case of the intermediate flux concentration levels, the SIR values started to show some rapid changes, the result of dendrite formation on the test boards. Hence a flux level was defined as the minimum flux concentration to promote dendrite (FCPD) growth. When the flux concentration was increased still further, dendrite formation was more prevalent, as shown by the third plot in each Figure.

Figures 5-12 demonstrate that although dendrite formation strongly depends on flux concentration, the FCPD is different for different board finishes using different flux types. The FCPD on different finished boards with two types of flux are listed in Table 2 and plotted in Figure 13. The latter clearly shows that although the flux concentrations to form the dendrites for different fluxes were unsurprisingly not the same, the order for both fluxes on different board finishes was the same. Therefore the propensity of these metals to form dendrite (from high to low) can be assessed from the minimum FCPD as:

$$\text{AuNi} > \text{SAC} > \text{SnPb} > \text{Cu}.$$

Table 2. The FCPD flux concentration to promote dendrite on different finish boards

Board finish	Flux Concentration (% in IPA)	
	Flux A	Flux B
AuNi	10	8
Cu	65	50
SAC	10	10
SnPb	15	12

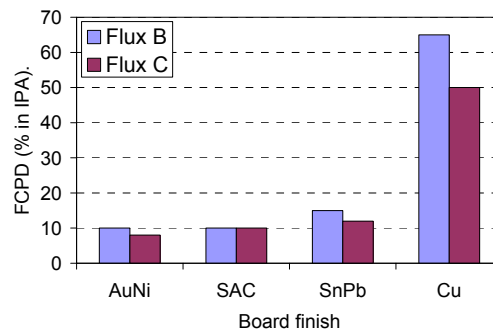


Figure 13. The flux concentration to promote dendrite growth on different board finishes

3.3 SEM-EDX ANALYSIS OF DENDRITES

The dendrites formed on different board finishes during the SIR measurement were photographed using an optical microscope, as shown in Figure 14, and analysed using SEM-EDX equipment. The results are listed in Tables 3-6, and are normalised and given in weight percent. They revealed that for the AuNi-finished boards the composition of the dendrites was mainly nickel, consistent (from an electrochemical point of view) with preferential dissolution of the nickel, compared with the noble metal gold.

On the copper-finished boards the dendrites' composition was, as expected, 100% copper. However, for the SAC board finish the situation was more complex. The dendrites were a mixture of silver and nickel, with a small amount of tin and a trace amount of copper. The nickel in the dendrite probably came from the AuNi-finish on the PCB.

The analysis on the SAC board finish revealed that the wall of AuNi-finish track was not completely covered by the SAC solder, with 7% nickel detected at the track board interface, as listed in Table 7. This probably reflects a wetting problem in the lead-free soldering process. The dendrites on the SnPb board finish were composed of a mixture of tin and lead, and there was no evidence of nickel as the SnPb solder had completely wetted the track surface.

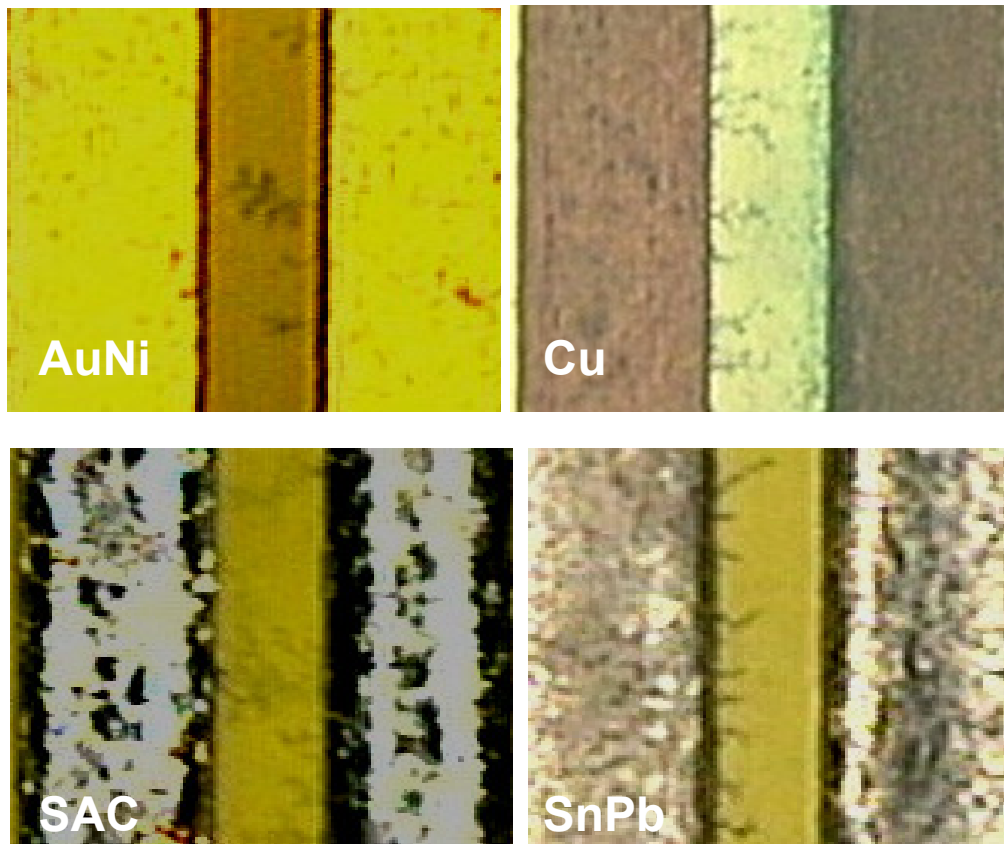
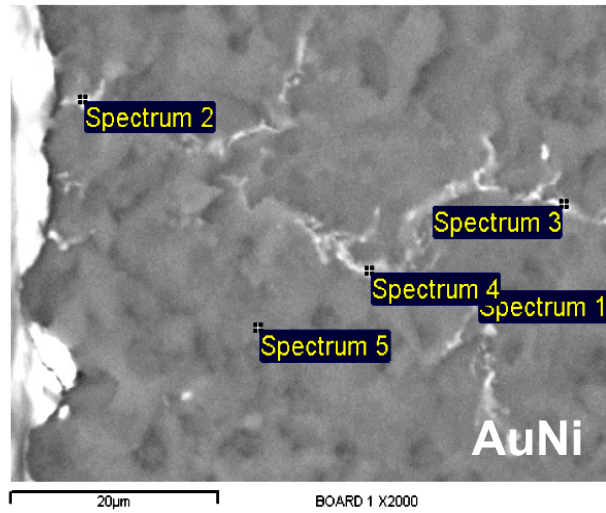
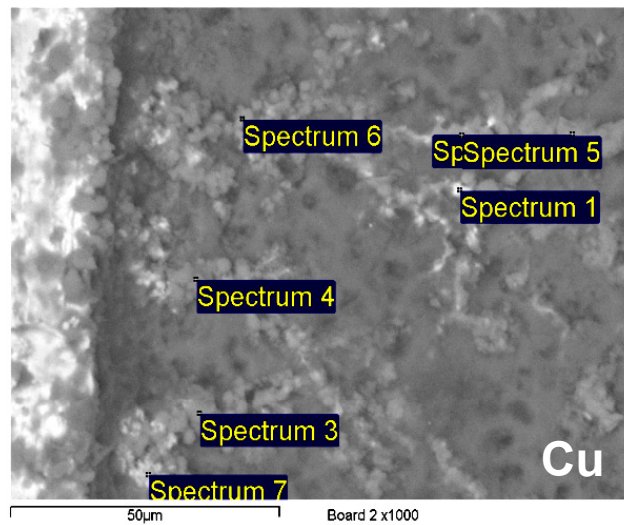


Figure 14. Dendrites formed on different board finishes

**Table 3:** Dendrite formed on a AuNi-finished board

Spectrum	Ni	Au
1	100.0	
2	92.8	7.1
3	100.0	
4	100.0	
5	100.0	

**Table 4:** Dendrite formed on a copper-finished board

Spectrum	Cu
1	100.0
2	100.0
3	100.0
4	100.0
5	100.0
6	100.0
7	100.0

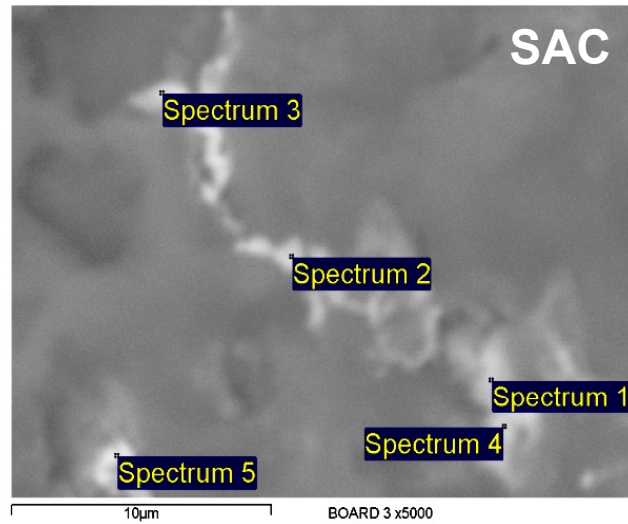


Table 5: Dendrite formed on a SAC-finished board

Spectrum	Ni	Cu	Ag	Sn
1	81.2		4.1	14.6
2	82.3		7.0	10.6
3	16.0		70.4	13.4
4	87.3	0.3	4.2	8.0
5	12.6	2.5	72.0	12.7

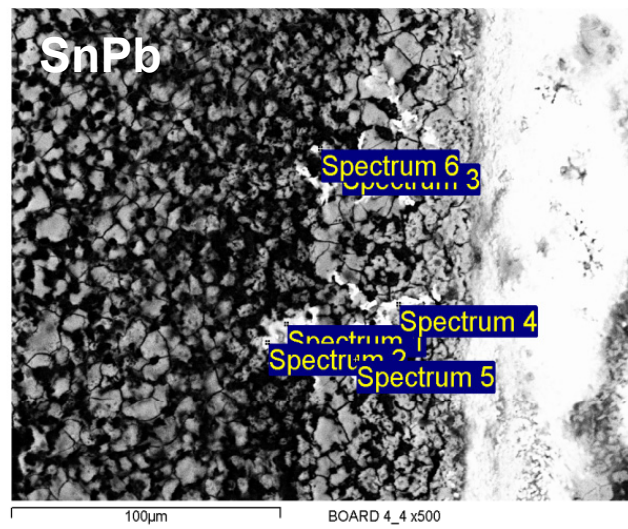
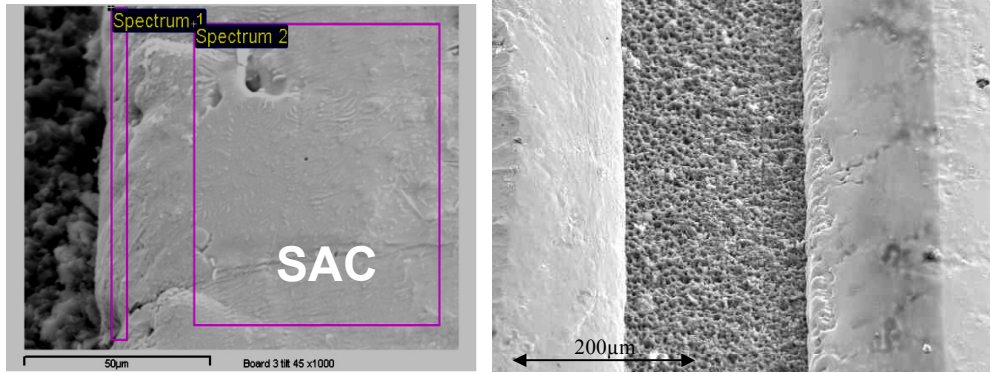


Table 6: Dendrite formed on a SnPb-finished board

Spectrum	Sn	Pb
1	29.6	70.4
2	61.8	38.2
3	41.0	59.0
4	56.9	43.0
5	18.8	81.1

**Table 7:** AuNi-finished board

Spectrum	Ni	Au	Sn	Ag	Cu
1	7.6		88.8	1.5	2.1
2	0.5	2.1	91.8	4.8	0.6

4 DISCUSSION

4.1 Minimum Flux Concentration To Form Dendrites

As described in the Introduction, if metal cations are continually deposited at the cathode, eventually a dendrite will be formed. However, metal deposition at the cathode is not the only possible cathodic reaction; O_2 and H^+ reductions are competing reactions. Which reaction takes place depends on the polarization of the electrode and on the standard potentials for each reaction. There is a minimum over-potential required for the appearance and propagation of a dendrite⁶. Hence, for dendrite formation, the cathode must be polarised to reach the over-potential of metal ion reduction. Under controlled temperature and humidity, this over-potential depends on the test voltage and contamination on the test board, and for the testing reported here a 5V DC was applied on the comb.

This voltage value, between the anode and cathode, is very high by comparison with typical electrochemical processes in bulk solutions. However, the electrolyte on the test comb under test temperature and humidity conditions is a thin water film, typically only $\sim 100\text{nm}$ thick, with dissolved flux residues. Hence the ohmic resistance of the ionic path is high, and a significant part of the test voltage is dropped across the inter-electrode gap, and only in part at the metal-electrolyte interfaces. Therefore the polarization of metal electrodes is very low, and the over-potential for metal ion deposition cannot be reached, so dendrite formation does not occur in most situations.

In this work the flux concentration was gradually increased until a minimum concentration, known to form dendrites, was approached. At this flux concentration, the polarization at the cathode metal-electrolyte interface exceeded the over-potential for metal ion reduction to form dendrite. Furthermore, at this flux concentration the polarisation at the anode would also be increased, accelerating metal dissolution, and

producing higher levels of metal ions for migration to the cathode, which in turn further reduces the over-potential required for metal ion reduction to form dendrite. This interrelationship between flux concentration and the metal cation over-potential for deposition, leads to the concept of a minimum FCPD, as listed in Table 2.

4.2 The Propensity Of Metal To Form Dendrites

In the previous Section the effect of flux concentration, which will affect the polarization and the corrosion of electrodes, was considered. In this Section, the effect of the electrode material is considered with three principle processes: corrosion rate of the anode, solubility of the metal ion compounds, and deposition of metal ion.

Metal has a high corrosion rate which would be expected to increase dendrite formation, and from these results using the same flux media the propensity to form dendrites decreases from: AuNi > SAC > SnPb > Cu. Interestingly, comparing the results from the SnPb finish with those from the SAC finish, it is SAC that has the higher propensity to form dendrites, but this is not consistent with the results of an earlier electrochemical study⁴. In that previous study the SAC alloy exhibited excellent passivation behaviour in diluted flux solutions, resulting in a much lower corrosion rate when compared with SnPb. In concentrated flux solution the corrosion rates are very similar for both alloys, but the corrosion rate of SAC never exceeded that of SnPb. This implies that the corrosion rate at the anode is not the only factor influencing dendrite formation for a specific metal ion.

For dendrites to form, the metal ions produced at the anode must be able to migrate to the cathode without being precipitated as insoluble compounds. The higher propensity of SAC to form dendrites is probably⁵ a function of the high solubility of AgOH. The solubility product constants (K_{sp}) and standard potential (E^0) of the studied metals are listed in Table 8. The latter also shows that although silver has more positive potential and should be difficult to corrode in most conditions, the external bias in the SIR system helps silver oxidation from the anode, and the high solubility of AgOH supports Ag⁺ migration from anode to cathode. Furthermore, positive electrode potential makes the possibility of silver deposition at the cathode easier than for other materials. The analysis of dendrites confirmed that these are mainly silver and nickel although there is only 3% silver in the solder alloy. (As mentioned earlier the nickel is assumed to come from the exposed track). ***This high propensity for silver to form dendrites from the SAC alloy is an issue of great concern for circuit reliability when using lead-free solders.***

When the soldering process switches from SnPb to SAC the higher temperature soldering process and different metallurgy require more active fluxes. There is, therefore, the potential of leaving more active flux residues on the circuit board, and hence circuit reliability is likely to be more sensitive for lead-free alloys. Therefore, the control of contamination from both the assembly process and harsh environments, should be much stricter to avoid dendrite formation on lead-free assemblies.

Table 8: Solubility product constants K_{sp} and standard potential E^0 of studied metals

Metal ion	$M(OH)_n$ K_{sp}	E^0 (Volts)
Ag^+	2.0×10^{-8}	0.80
Ni^{++}	5.5×10^{-16}	-0.23
Cu^+	2.2×10^{-20}	0.16
Pb^+	1.4×10^{-20}	-0.12
Sn^{++}	1.4×10^{-28}	-0.13
Au^+	--	1.68

Considering the two PCB finish materials, the propensity to form dendrites was significantly higher for AuNi than for copper. This does not necessarily mean that the reliability of a circuit will be ensured by selecting a copper finish, since, although the copper ion has low solubility, and thus the susceptibility for dendrite formation is reduced, its SIR will be lowered and may cause a reliability problem. The low propensity of copper to form dendrites can be attributed to the low corrosion rate and low solubility of $Cu(OH)_2$ of the studied metals⁵. The low corrosion rate of copper results in a low metal ion concentration at the anode, and consequently a low metal ion concentration at the cathode. The over-potential required for dendrite formation increases as metal ion concentration decreases⁶. Steppan et al⁵ reviewed dendrite growth and concluded that this phenomenon only occurs above a critical over-potential⁵. Therefore, a metal with a low corrosion rate will have low propensity to form dendrites. Furthermore the very low solubility of $Cu(OH)_2$ reduces the number of migrating copper ions to the cathode. Evidence that the copper ions are precipitated as an insoluble compound, is provided in Figure 14, where some green corrosion products can be observed around the anode.

5 CONCLUSIONS

- Contamination is a prime factor in influencing both circuit performance and long-term circuit reliability. It facilitates electrochemical migration processes that can result in leakage currents, loss of continuity, or short circuits via the growth of dendrites. The SIR technique is a very sensitive method for measuring leakage currents and has become a widely used test for monitoring surface currents associated with electrochemical processes. Hence the SIR value can be used as a direct measure of circuit reliability.
- In this work the SIR technique has been used to investigate the effect of solder alloy and PCB finish material on leakage current and dendrite growth. Three fluxes, each at various concentrations, have been used as contamination sources to provide the leakage currents and subsequent dendrite generation.
- Below a critical contamination level (flux content), the polarisation on both electrodes will be low. Hence at the anode there will be a low metal dissolution rate, and a resultant low metal ion migration. At the cathode the critical over-

potential for metal ion deposition will not be reached, and dendrite formation will not occur.

- With high contamination levels a significant metal ion migration will occur leading to dendrite formation and probable short circuit.
- There is a minimum contamination (i.e. flux contamination) to promote dendrite growth (FCPD) for each metal and each flux. The value of the FCPD provides a convenient parameter for assessing the propensity of a metal to form dendrites.
- In this work the relative propensity for dendrite formation was found to decrease from **AuNi** > **SAC** > **SnPb** >> **Cu**. But this does not mean that the reliability of a circuit will be assured by selecting a copper finish, since, although the copper ion has low solubility (and thus lower susceptibility to form dendrites) the SIR may be lowered (and pose a reliability issue).
- EDX analysis was used to ascertain the composition of some dendrites, and thus study the dendrite formation process. The propensity of SAC alloy to promote dendrite formation was found to be caused by silver migration from the alloy. (The high solubility of AgOH supports silver migration).
- Under similar environmental conditions the use of SAC is more likely to be associated with dendrite growth than is the use of SnPb, which is important for users (or potential users) of lead-free soldering. It emphasises that in order to avoid electrical reliability issues, ***the contamination of the lead-free assemblies*** (from either production or the environment) ***must be much lower than that associated with a conventional SnPb assembly process.***
- Dendrites are more easily generated with AuNi-finished boards than with copper-finished boards, due to nickel migration.

6 REFERENCES

1. Chan, H. A. (1996) “*Surface insulation resistance methodology for today’s manufacturing technology*” IEEE Transactions on Components, Packaging, and manufacturing Technology, Part C, Vol.19, NO.4 October, pp 300-307
2. Hunt, C. and Zou, C. L. (1999), “*The impact of temperature and humidity condition on surface insulation resistance values for various fluxes*”, Soldering and Surface Mount Technology, Vol.11 No 1, pp. 21-24
3. IPC-TR-476A (1997) “*Electrochemical migration: Electrically induced failures in printed wiring assemblies*”, May
4. Zou, C. L. and Hunt C. (2006) “*Electrochemical behaviour of solder alloy*” NPL Report DEPC-MPR (PAPER) 040 September

5. Steppan, J. J. Roth, J.A, Hall, L. C. Jeanotte, D. A and Carbone, S. P. (1987) "*A review of corrosion failure mechanisms during accelerated test*", J. Electrochemical Soc., Vol.134 pp. 175-190
6. Zamanzadeh, M. (1990) "*Electrochemical examination of dendrite growth on electronic devices in HCl electrolytes*" Corrosion, Vol. 46, No. 8 August pp 665-671
7. Ellis B. N. (1994) "*The determination of flux residue safety: the state of the art*" Circuit World, Vol.20, No.4, pp 26-32
8. Sohn, J. E (1993) "*Evaluation of no-clean fluxes using surface insulation resistance testing*" Proc of NEPCON West 93 pp 1325-1331
9. Zou, C. L. and Hunt, C. (1999) "*The effect of test voltage, test pattern and board finish on surface insulation resistance (SIR) measurements for various fluxes*" NPL report CMMT(A)222

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