

**NPL REPORT MAT 28**

**Test Method for  
Measurement of the  
Propensity for Conformal  
Coatings to Inhibit Tin  
Whiskering**

**M WICKHAM and C HUNT**

**NOT RESTRICTED**

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## Test Method for Measurement of the Propensity for Conformal Coatings to Inhibit Tin Whiskering

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### **ABSTRACT**

A technique using interdigitated, specially electroplated discs has been developed at the National Physical Laboratory for determining the relative ability of conformal coatings to mitigate against Sn whisker growth. All the control samples without conformal coatings developed whiskers of sufficient length ( $>250\mu\text{m}$ ) to cause electrical shorts between the discs. The electrical monitoring system was able to detect these shorts and the current flowing in the detection circuit was restricted to a level sufficient to prevent destruction of the whiskers. The control samples all exhibited electrical shorts within 14 days, some within as few as 3 days, allowing for a relatively rapid i.e. less than 12 week evaluation of the Sn whisker mitigation benefits of conformal coatings.

The test method was developed using three conformal coating types: acrylic, polyurethane and paraxylene. These were shown to suppress the formation of whiskers compared to uncoated samples. In over 150 days of testing, no evidence of whiskers penetrating out from under the acrylic or polyurethane coatings was found, except in areas of insufficient coverage. Of the three coatings tested, only the acrylic coating did not stop penetration of whiskers through the coating from an external whisker source. Both the acrylic and polyurethane samples did grow whiskers in areas of insufficient coating coverage, at the corners between the flat surfaces of the discs and the sides. The paraxylene coating suppressed and insulated whiskers successfully for at least 150 days of ageing, with no edge whiskers generated.

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Approved on behalf of the Managing Director, NPL,  
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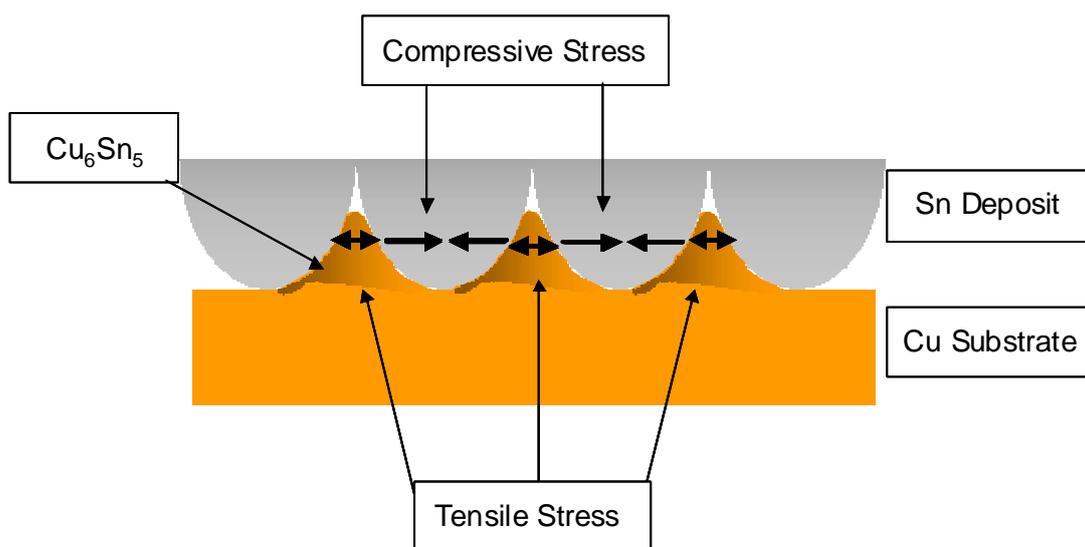


## 1 INTRODUCTION

The introduction of European legislation that bans the use of lead in electronics (reference 1), has led industry to embrace new finishes on components that are lead-free. The electronics industry prefers to use fusible tin alloy coatings, since they have superior solderability, and consequently are more tolerant of deficiencies in the assembly process. However, none of the possible replacement alloys for SnPb plated finishes are a clear favourite compared to pure tin. They all have significant disadvantages from a plating perspective, while offering no advantages in the soldering process. Hence, pure tin is now dominating lead-free component supply. The Achilles heel of pure tin is the phenomena of spontaneous single crystal growth, known as whiskers, which can occur under certain conditions. Whiskers can grow up to several millimetres in length and short out to adjacent contacts.

Although a widely known phenomena, it is not that common, and new chemistries have been developed that greatly reduce whisker propensity. However, a “whisker-free” finish has yet to found and many consider this an unachievable goal. For many high reliability users, this is a real problem. They cannot obtain SnPb component coatings for many components but require a whisker-free assembly. Well documented failures due to tin whiskers range from three communication satellites losses, missile and military radar failures, through heart pacemakers and medical monitors, to nuclear power station reactor shutdowns and poor reliability in watch oscillators. NASA has an excellent web-site with many details on the occurrence of Sn whiskers (reference 2).

The mechanisms for initiation and growth of Sn whiskers are still a matter of much research, but the most generally accepted mechanism is the generation of stress in the plating by intermetallic growth. The diffusion of the substrate material into the Sn plating (or vice versa) can lead to formation of intermetallic compounds, such as  $\text{Cu}_6\text{Sn}_5$ , and create compressive stresses on the adjacent Sn grains. The stresses may be relieved through the formation of whiskers (shown in Figure 1).



**Figure 1: Mechanism for generation of internal stress in Sn platings (Adapted from reference 3)**

The use of conformal coatings has been suggested as a means of controlling whisker growth, either by inhibiting the initiation of growth or by preventing whisker growths shorting between adjacent conductors (references 4 to 8). Work carried out by Boeing on commercially available coatings has shown suppression of tin whiskers when compared to the uncoated controls (references 6 and 7). However, all of the commercial coatings were eventually penetrated by whiskers, indicating that these coatings cannot be depended on as a foolproof mitigation strategy.

However, discussion between NPL and conformal coating suppliers has indicated that innovative conformal coatings could be formulated to improve whisker penetration characteristics and possible whisker suppression as well. But such coatings would require a suitable test methodology to determine the effects of chemistry variations on Sn whisker mitigation. Thus NPL has formed a group of coatings suppliers and end-users with the assistance of UK government funding, to develop a suitable methodology.

## 2 METHODOLOGY

### 2.1 TEST VEHICLE DESIGN

A test vehicle structure utilising parallel copper sheets electroplated with Sn and resembling a capacitor has been designed. The plates were etched in Olin194 copper sheet as a series of 25mm diameter interconnected discs with mounting holes and electrical connection tags, as shown in Figure 2. The interconnecting arms were necked to enable easy folding at regular points.



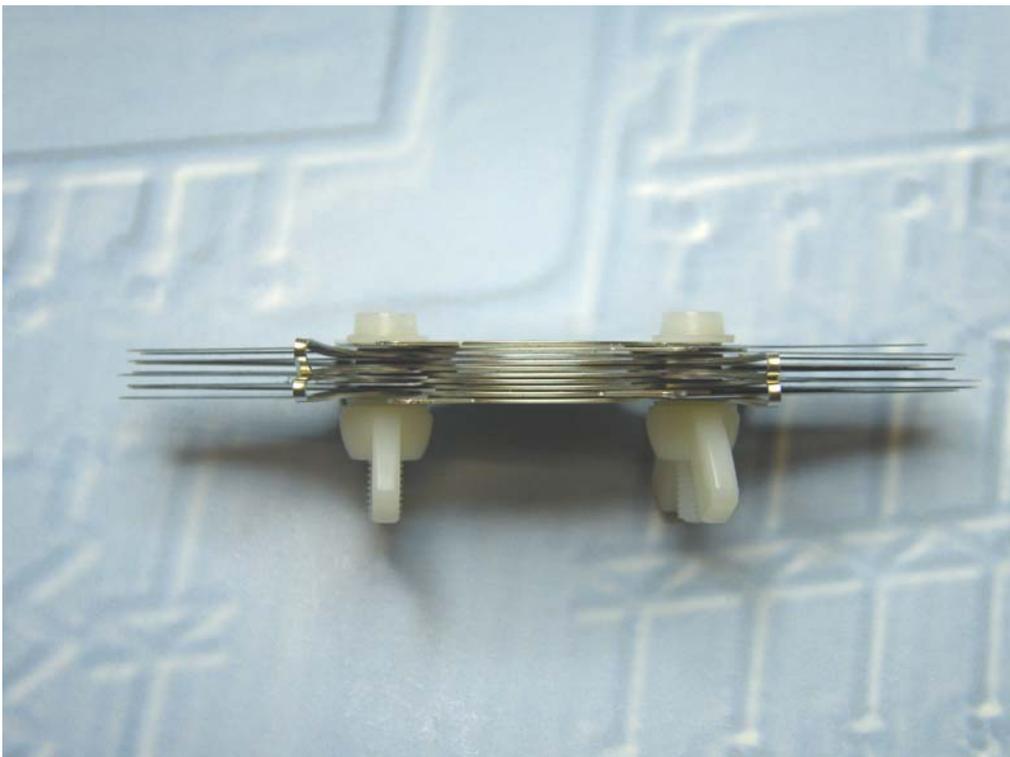
**Figure 2: Etched copper sheet before plating, coating and assembly**

After appropriate plating and conformal coating, the etched sheets are concertinaed so that the discs became parallel as shown in Figure 3. Two such sheets were then assembled together so that an arrangement of alternate interconnected parallel plates is achieved. The interconnecting arms for each set of plates were assembled on opposite sides to ensure that only the circular plates are overlapping.

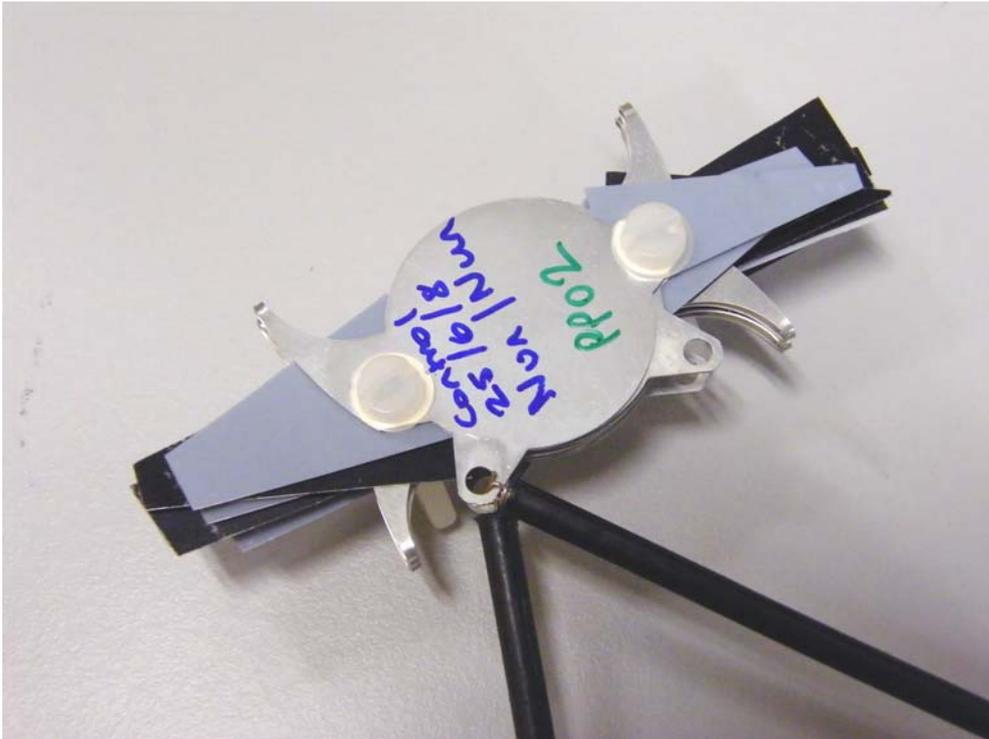


**Figure 3: Folded sheet**

The adjacent plates were separated by 0.25mm thick plastic spacers (elongated for ease of assembly), and the entire structure was then mounted on two nylon machine screws and secured with nylon wing nuts. The resultant structure is shown in Figure 4 and Figure 5.

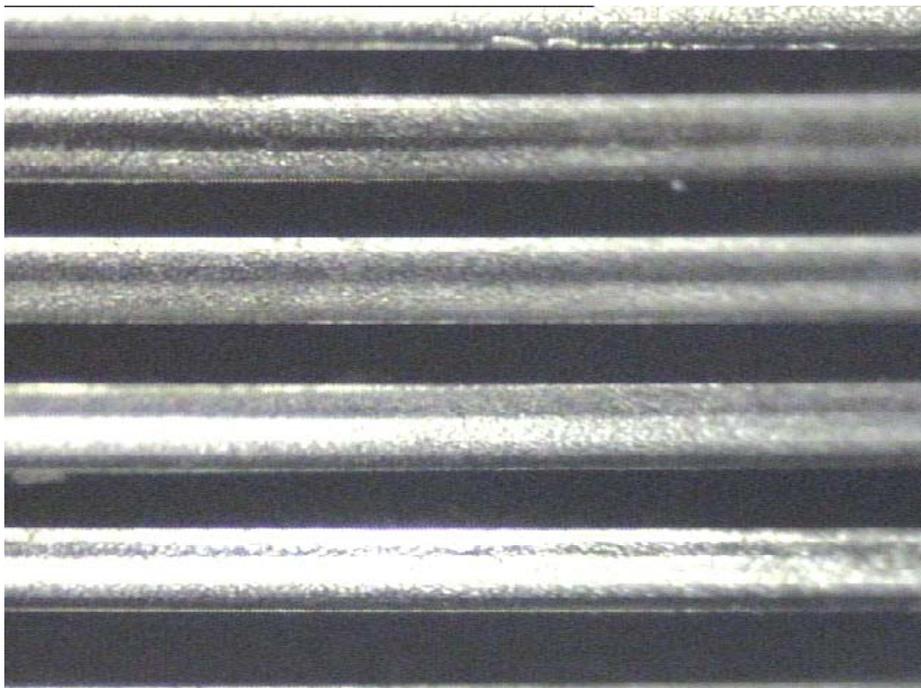


**Figure 4: Two interlinked etched sheets with plastic spacers and mounting bolts**



**Figure 5: Parallel plate test vehicle with electrical test probes.**

The resultant structure consisted ten plates in two interconnected sets, each set insulated from the other with 0.25mm thick insulating spacers, resulting in 4500mm<sup>2</sup> of overlapping plate area. The gap between the plates is shown in detail in Figure 6. By monitoring for an electrical short between the two sets of plates, any Sn whiskers that grow from a plate with sufficient length to reach an adjacent plate, can thus be detected.



**Figure 6: Detail of test vehicle showing 0.25mm gaps**

## 2.2 PLATING

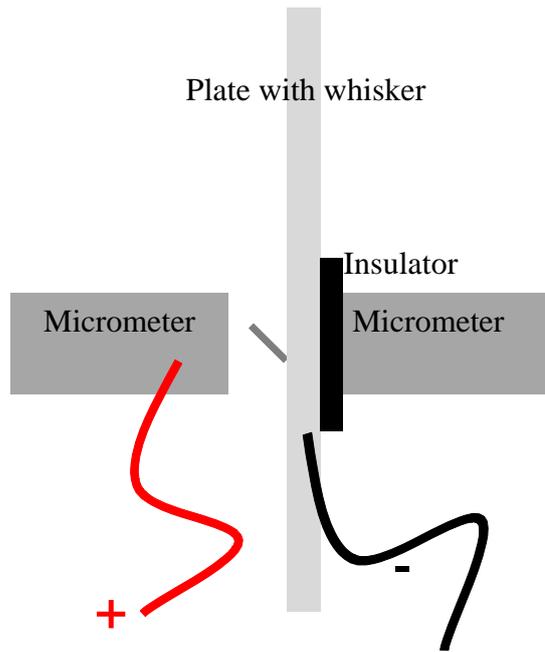
All samples were electroplated in our in-house facility. A custom bright tin electroplating process was used, based on a stannous sulphate bath. This chemistry was developed in a previous NPL project (reference 9) and has been shown to be prone to developing Sn whiskers. To further increase the propensity to whisker, the Sn was electroplated to a thickness considerably less than normal for electronic components ( $<2\mu\text{m}$ ) to enable the intermetallic growth at the Sn/Cu interface to rapidly increase the internal stress in the plating. For plates intended only for detection of whiskers, the Sn was electroplated to at least  $10\mu\text{m}$ , to inhibit the growth of whiskers.

## 2.3 ELECTRICAL TEST

Trials were conducted to determine the current carrying capacity of a single whisker. This was necessary to ensure that the electrical test parameters used were insufficient to destroy a whisker if all the current used to detect the short were to flow down a single whisker. Excessive current would cause such a whisker to melt and thus not be detected. A micrometer was adapted to allow precision positioning of a conductor into contact with a single whisker. The apparatus is shown in Figure 7 and schematically in Figure 8. A detailed image of whiskers bridging the precision gap in the test rig is shown in Figure 9. These trials indicated that currents in excess of  $50\mu\text{A}$  destroyed whiskers and that  $3\text{V}$  was sufficient to cause conduction.



**Figure 7: Whisker current carrying capacity test rig**



**Figure 8: Schematic of whisker current carrying capacity test rig**



**Figure 9: Detail of whiskers bridging current carrying capacity test rig**

For whisker detection in the coated and plated parallel plate samples, a test voltage of 4V was used from a constant current power supply. The current flowing through any short circuit was limited to  $2\mu\text{A}$  by using  $1.8\text{M}\Omega$  resistor in series. An ammeter of suitable sensitivity was used to detect if an electrical short were present. Initially, samples were tested immediately after assembly and then at weekly intervals for the first month and then at monthly intervals.

## 2.4 TEST VEHICLE ARRANGEMENTS

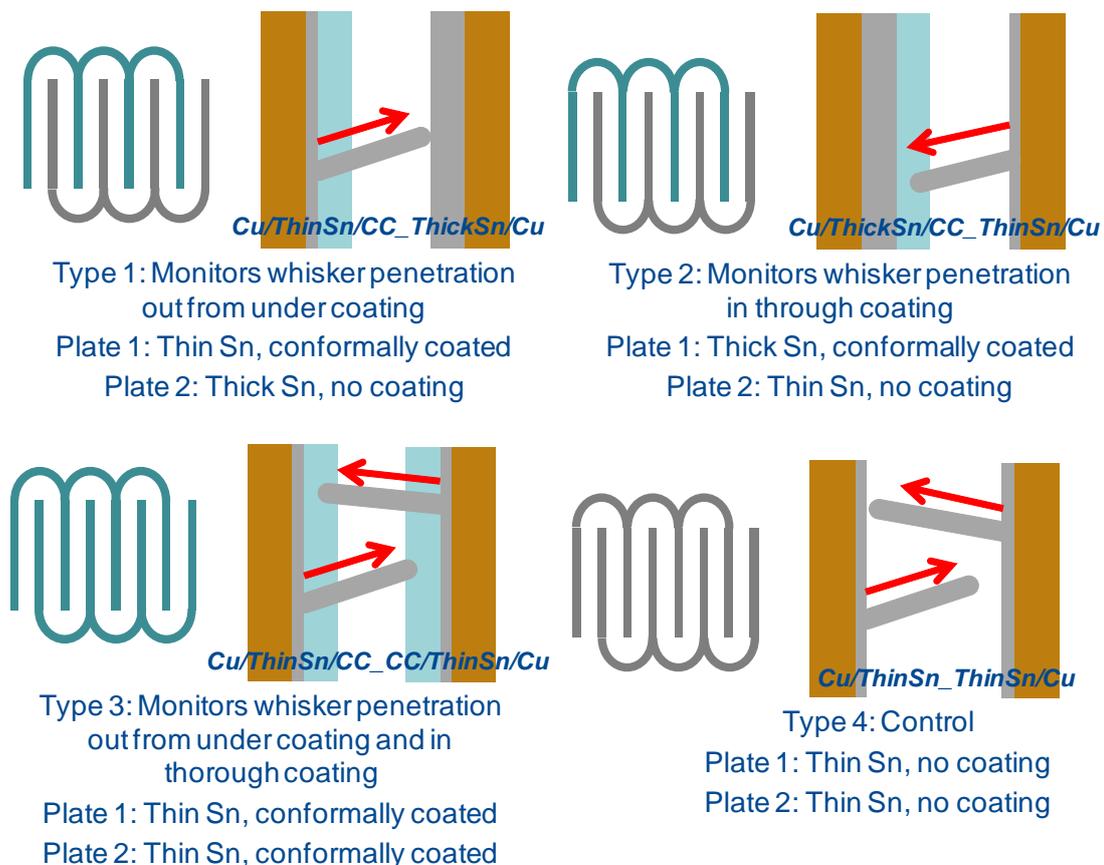
Four different styles of test vehicle can be fabricated as detailed below and shown in Figure 10, to investigate whisker growth in different areas.

Type 1 (whisker out) vehicles were designed to monitor for whisker growth from beneath a conformal coating. The plates to be coated were electroplated with thin Sn ( $<2\mu\text{m}$ ) to generate whiskers. The uncoated plates were electroplated with thick Sn ( $>10\mu\text{m}$ ) to act as a detector plate.

Type 2 (whisker in) vehicles were designed to monitor for whisker growth through a conformal coating from an external uncoated source. The plates to be coated were electroplated with thick Sn ( $>10\mu\text{m}$ ) to act as a detector plate. The uncoated plates were electroplated with thin Sn ( $<2\mu\text{m}$ ) to generate whiskers.

Type 3 (whisker in/out) were designed to monitor for whisker growth out from under a conformal coating and then back through an adjacent coating. Both plates to be coated were electroplated with thin Sn ( $<2\mu\text{m}$ ) to generate whiskers.

Type 4, designed as control samples. The plates are left uncoated and electroplated with thin Sn ( $<2\mu\text{m}$ ) to generate whiskers.



**Figure 10: Schematics of the four types of test vehicle arrangement**

To overcome the shorts caused by whiskers growing out from under insufficiently coated areas or shorting back through similar areas, a change to the design of the discs is proposed. If the size of one of the sets of discs were reduced in size, this would extend the distance between the whisker source and the insufficiently coated areas, or extend the distance between the whisker source and the gaps in the coating. In either case, the uncoated detection discs should use the smaller sized discs. Examples of the redesigned discs sets are shown in Figure 11, where the smaller set has been plated, and the larger one is still unplated.



**Figure 11: Redesigned plates showing smaller discs in comparison to larger uncoated discs**

### 3 CONCLUSIONS

The technique devised using interdigitated electroplated discs has been proven to successfully determine the relative ability of conformal coatings to mitigate against Sn whisker growth. All the control samples without conformal coatings developed whiskers of sufficient length ( $>250\mu\text{m}$ ) to cause electrical shorts. The electrical monitoring system was able to detect these shorts and the current following in the detection circuit was restricted to a level sufficient to prevent destruction of the whiskers. The control samples all exhibited electrical shorts within 14 days, some within as few as 3 days, allowing for a relatively rapid i.e. less than 12 week evaluation of the Sn whisker mitigation benefits of conformal coatings. Longer term testing would be required to ensure the coated samples remained whisker free.

## 4 ACKNOWLEDGEMENTS

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 MBDA (UK) Ltd  
 Rolls Royce Marine  
 Schloetter Compny Ltd.  
 Selex S&AS UK  
 Thales Missile Electronics Ltd.  
 H K Wentworth Ltd

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## 6 APPENDIX A: TEST RESULTS

### 6.1 METHODOLOGY

Two samples of each type of test vehicle were fabricated for three different conformal coatings as described above.

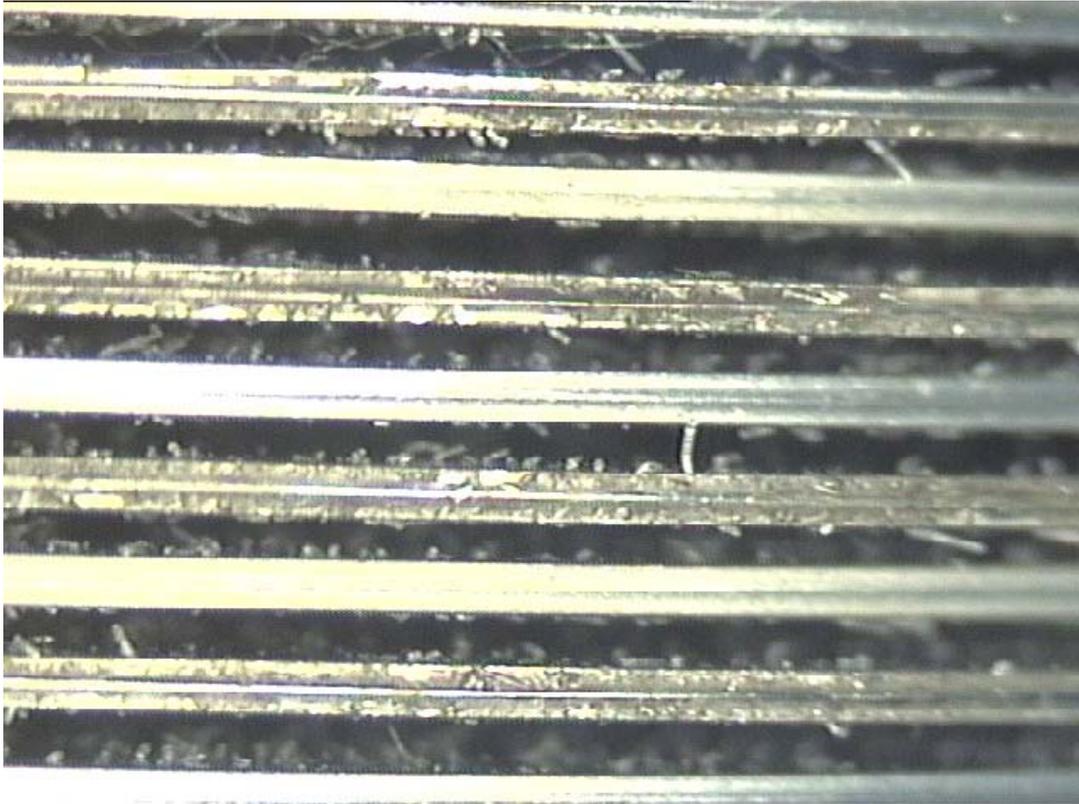
### 6.2 SAMPLE COATING

After electroplating with the correct thickness of Sn, samples were coated with three commercial conformal coatings, an acrylic (A1), a polyurethane (P1) and a paraxylene (X1). All coating thicknesses and application methods were as per manufacturers guidelines. Two examples of each test vehicle type were assembled for each of the three coatings.

In the case of the paraxylene samples with thin electroplated Sn, some whisker growth had already started prior to coating of the samples. However, the coating completely encapsulated these whiskers (Figure 12) and when the samples were assembled, the plates were all electrically isolated, even though some whiskers present were of sufficient length to bridge the gap (Figure 13).



**Figure 12: Surface of paraxylene sample after coating showing completely encapsulated whiskers**



**Figure 13: Assembled paraxylene open circuit sample showing bridging whiskers**

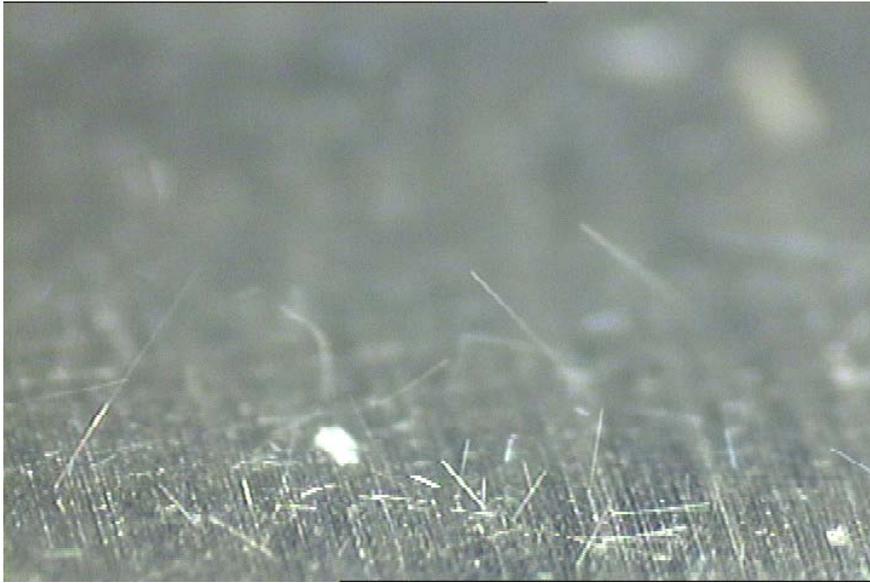
### 6.3 SAMPLE AGEING

All samples were aged at ambient temperature ( $22^{\circ}\text{C} \pm 1^{\circ}\text{C}$ ) and humidity (40% +5%, -10%) for 150 days.

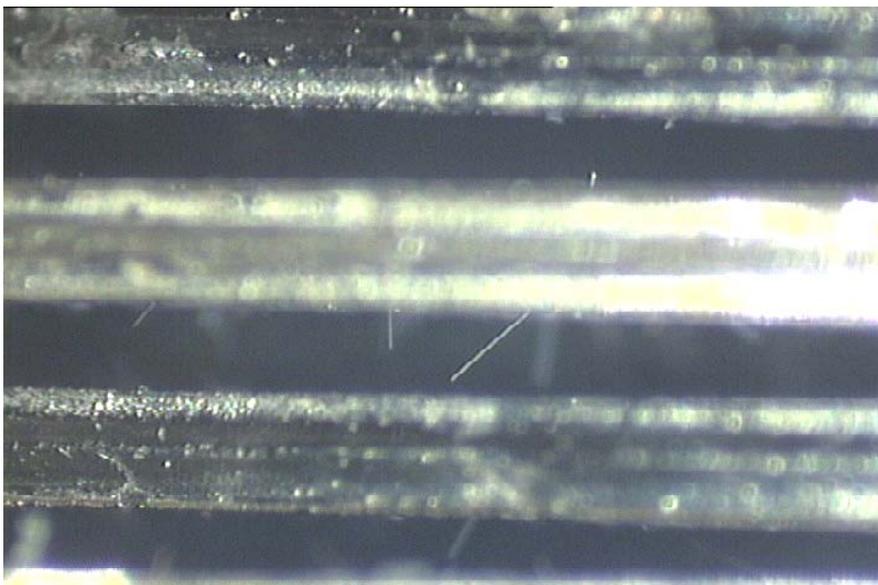
## 7 RESULTS

### 7.1 CONTROL SAMPLES

All control samples exhibited electrical shorts within 14 days of electroplating. Visual examination of control samples showed a high density of whiskers across all plated surfaces with whiskers in excess of 1mm in length after 4 weeks. Examples of typical control samples are shown in Figure 14 and Figure 15.



**Figure 14: Outer surface of typical control sample after 43 days showing whiskers over 1mm in length**



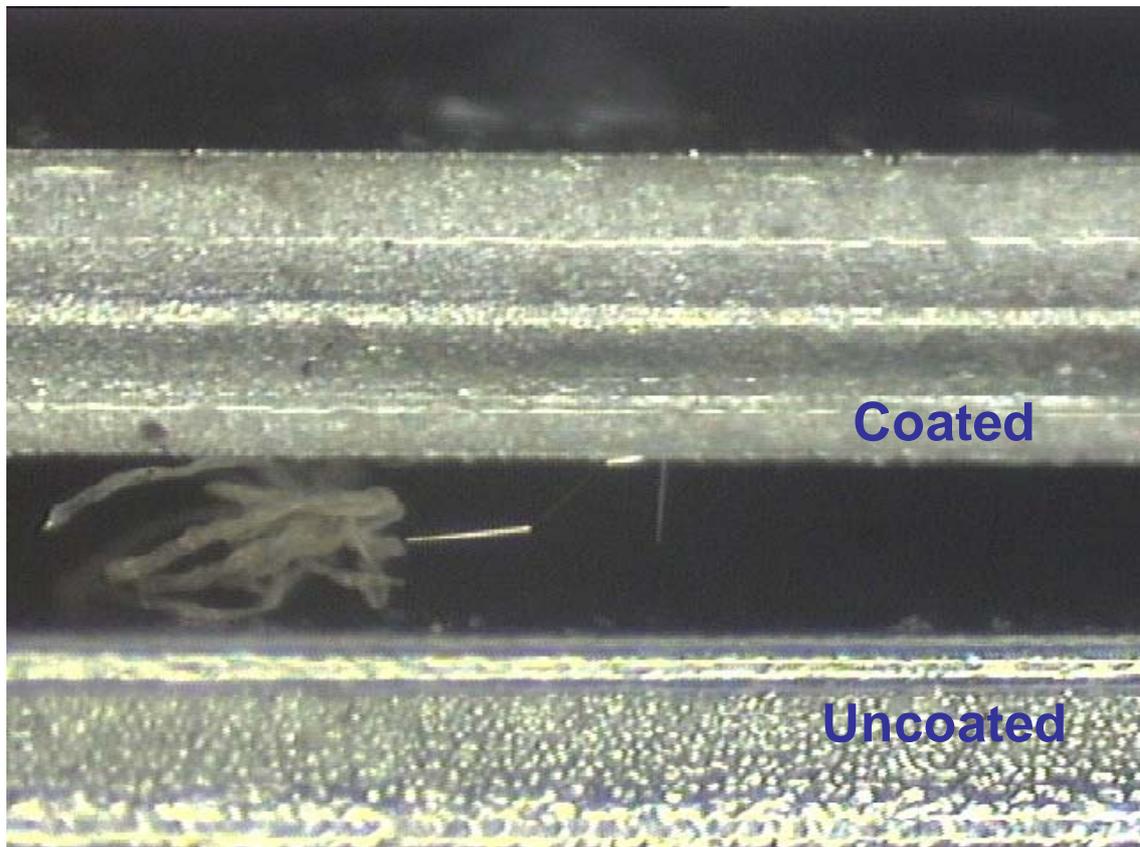
**Figure 15: Detail of typical control sample gap showing bridging whisker after 3 days**

## 7.2 A1 ACRYLIC SAMPLES

### 7.2.1 Acrylic Type 1 (Whisker Out)

One sample shorted after 80+ days at room temperature, but on visual examination, no whiskers were noted on the outer coated plates (with thin electroplated Sn) of either sample. Nor were any whiskers noted on the outer uncoated plates (with thick electroplated Sn) of either sample. However, whiskers were observed on the edges of both samples in the vicinity of the corner between the face and the edge of the plate (see Figure 16). This is an area that is generally less well covered during the conformal coating process. When the edges of the sample were brushed with a soft brush with

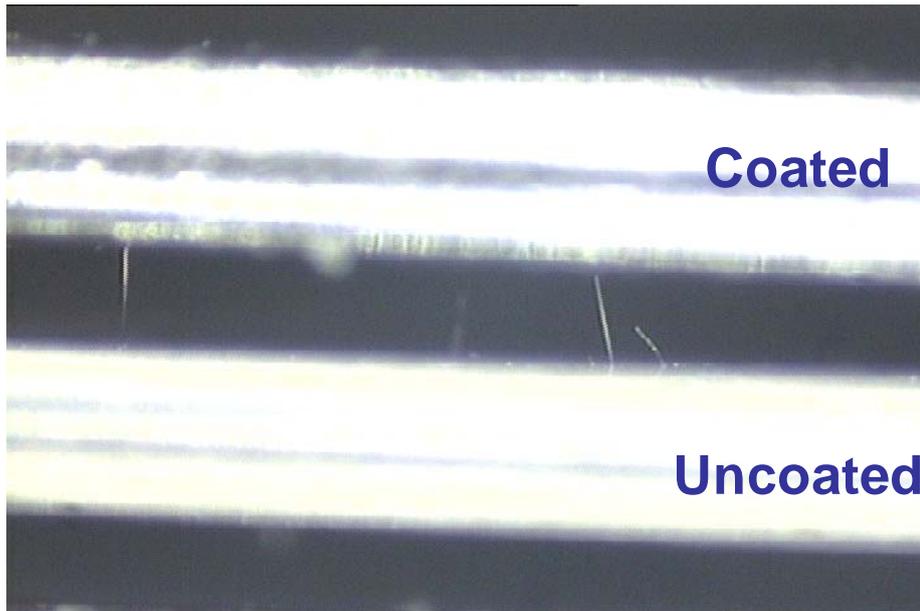
short bristles that only penetrated a limited distance between the plates, the sample returned to being open circuit.



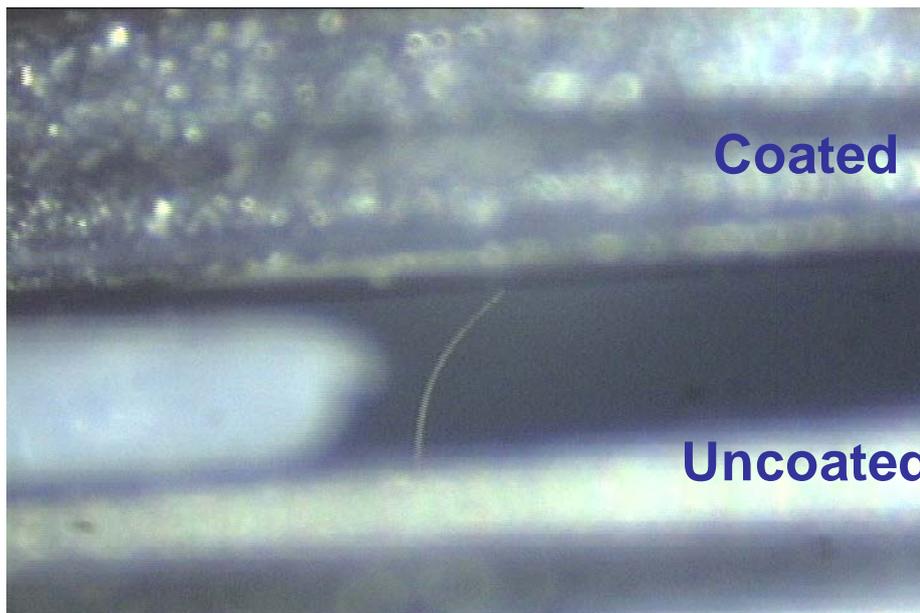
**Figure 16: Typical edge whisker on type 1 acrylic sample**

### 7.2.2 Acrylic Type 2 (Whisker In)

Both samples exhibited electrical shorts after 14 to 26 days of ageing, although the electrical short on one sample was intermittent. No whiskers were observed on coated plates (with thick electroplated Sn). However, multiple whiskers were observed up to 0.75mm in length on uncoated plates (with thin electroplated Sn) as shown in Figure 17. Many whiskers were of sufficient length to touch the opposite plate and showed evidence of bending or springing as a result of the whisker continuing to grow after touching the opposite coated surface (see Figure 18). When the edges of these samples were brushed the short circuit remained.



**Figure 17: Acrylic type 2 sample after 14 days showing possible bridging whiskers**



**Figure 18: Acrylic type 2 sample after 26 days showing springing of bridging whisker**

### 7.2.3 Acrylic Type 3 (Whisker In/Out)

Neither sample exhibited electrical shorts after 150 days of ageing. Visual examination of the samples showed no whiskers on either plate (both coated with thin electroplated Sn), but again some whiskers were evident at the edges of the plates as for type 1 samples. Clearly the coating inhibited the growth of whiskers over this 150 day period compared to the control samples.

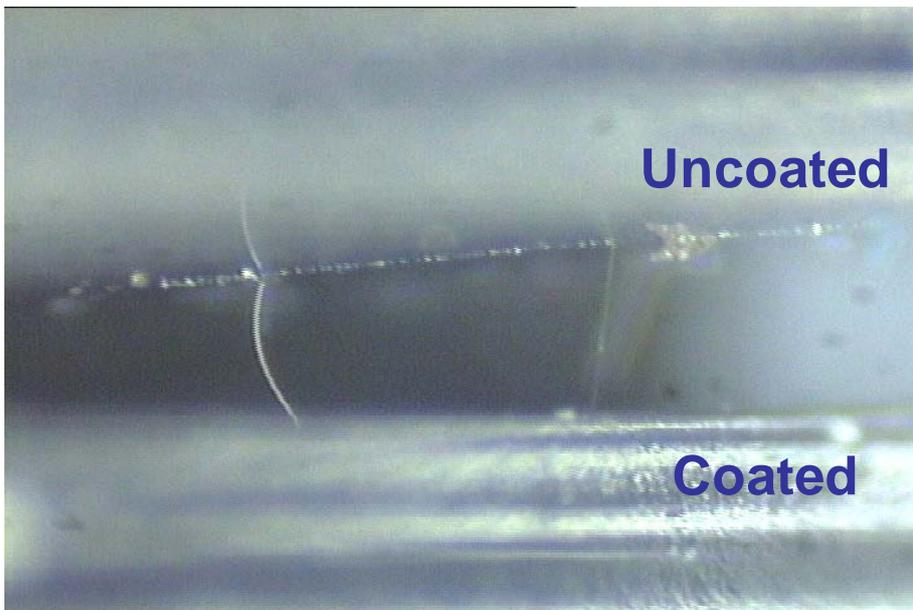
### 7.3 P1 POLYURETHANE SAMPLES

#### 7.3.1 Polyurethane Type 1 (Whisker Out)

Neither sample exhibited electrical shorts after 150 days of ageing. Visual examination of the samples showed no whiskers on the outer coated plates (with thin electroplated Sn) of either sample. Nor were any whiskers noted on the outer uncoated plates (with thick electroplated Sn).

#### 7.3.2 Polyurethane Type 2 (Whisker In)

One sample exhibited an electrical short after 72 days of ageing. No whiskers were observed on coated plates (with thick electroplated Sn). However, multiple whiskers were noted up to 0.75mm in length on uncoated plates (with thin electroplated Sn). Again, whiskers that touched the opposite plate showed evidence of bending or springing (see Figure 19). When the edges of these samples were brushed the sample returned to being open circuit.



**Figure 19: Polyurethane Type 2 sample after 36 days showing springing of bridging whisker**

#### 7.3.4 Polyurethane Type 3 (Whisker In/Out)

Neither sample exhibited electrical shorts after 150 days of ageing. Visual examination of the samples showed no whiskers on either plate (both coated with thin electroplated Sn).

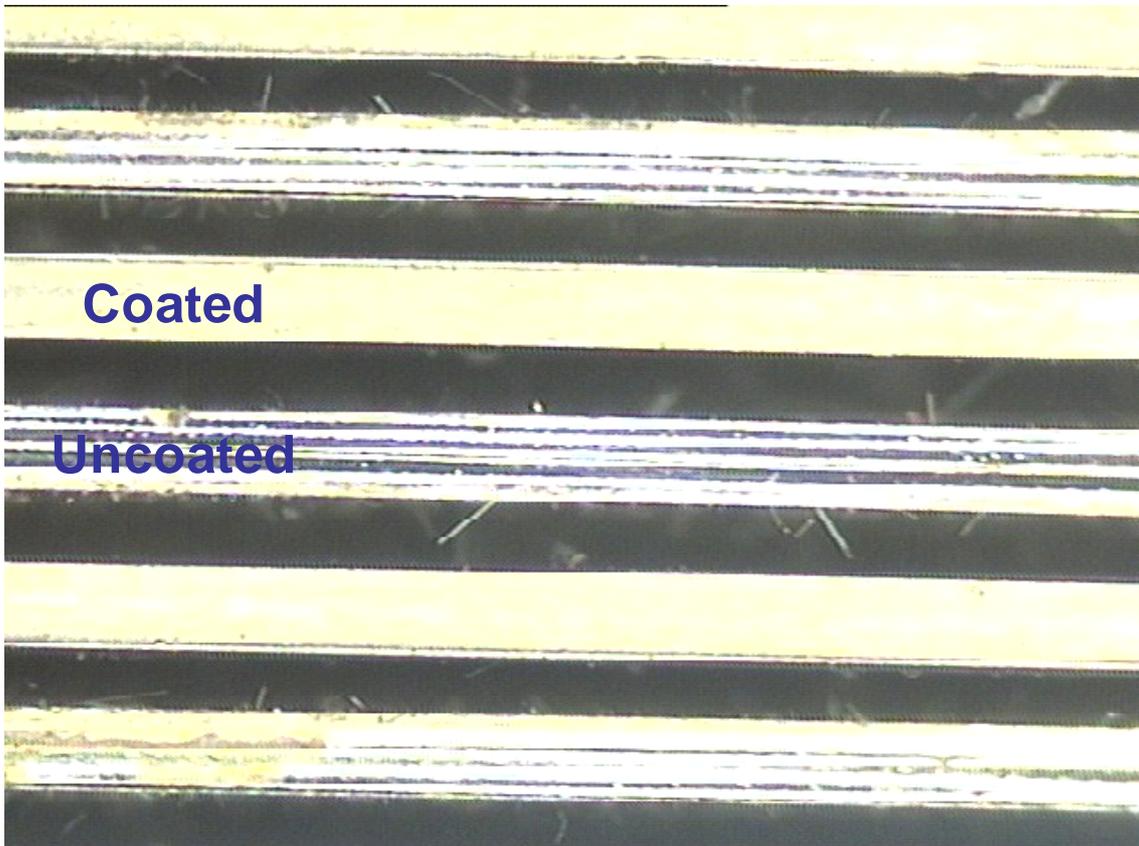
## 7.4 X1 PARAXYLENE SAMPLES

### 7.4.1 Paraxylene Type 1 (Whisker Out)

Neither sample exhibited electrical shorts after 150 days of ageing. Visual examination of the samples showed no further whiskers or extension of existing whiskers on either of the coated plates (with thin electroplated Sn). No whiskers were noted on the uncoated plates (with thick electroplated Sn).

### 7.4.2 Paraxylene Type 2 (Whisker In)

Neither sample exhibited electrical shorts after 150 days of ageing. Visual examination of the samples showed no whiskers on the coated plate (with thick electroplated Sn). On the uncoated plate (with thin electroplated Sn), many whiskers were observed of sufficient length to bridge the gap between the plates (see Figure 20).



**Figure 20: Paraxylene Type 2 sample showing bridging whiskers**

### 7.4.3 Paraxylene Type 3 (Whisker In/Out)

Neither sample exhibited electrical shorts after 150 days of ageing. Visual examination of the samples showed no further whiskers or extension of existing whiskers on either of the coated plates (with thin electroplated Sn).

## 8 DISCUSSION

Samples coated with an acrylic coating were partially successful in inhibiting electrical shorts due to Sn whisker. When all plates were coated, no electrical shorts occurred during 150 days of testing. Both the other types of samples (whisker in and whisker out) did develop electrical shorts during this period. On the samples designed to test for whiskers growing out from under the coating, whiskers shorted out through coating on one sample. When the edges of this sample were brushed with a soft brush with short bristles that only penetrated a limited distance between the plates, the sample returned to being open circuit. In this case, whiskers had grown out through areas where the coating had been insufficiently applied at the corner between the surface and edge of the disc. Whiskers in these areas were removed by the brushing action. This indicates that there were no shorting whiskers growing out from under the coating on the surface of the disc where adequate coating had been applied. Thus the acrylic coating has been shown to inhibit the growth of Sn whiskers except in the areas where there was poor coating coverage.

On the acrylic samples designed to test for whiskers growing back through the coating from an external source, electrical shorts were again generated on one sample. However, in this case, when the edges of these samples were brushed with a soft brush, the sample remained short circuited. This indicates that any whiskers penetrating the coating in areas around the edges, where the coating was insufficiently applied, were not the primary cause of the electrical short. Thus the acrylic coating was shown not to prevent Sn whiskers from an adjacent uncoated source penetrating the coating and causing an electrical short.

For the polyurethane coated samples, the results were better in terms of degree of mitigation achieved. With the samples coated on both sets of plates and where the thinly electroplated discs were coated, no electrical shorts were detected. Clearly the coating inhibited the growth of whiskers over a 150 day test period compared to the control samples.

Whiskers did develop and cause electrical shorts in through coating on one sample. However, when the edges of the sample were brushed with a soft brush with short bristles that only penetrated a limited distance between the plates, the sample returned to being open circuit. In contrast to the similar acrylic samples, whiskers had grown in through areas where the coating had be insufficiently applied at the corner between the surface and edge of the disc, which were removed by the brushing action. This indicated that there were no shorting whiskers growing in through the coating on the surface of the disc where adequate coating had been applied. Thus the polyurethane coating has been shown to inhibit the growth of Sn whiskers through the coating from an adjacent uncoated source, except in the areas where there was insufficient coating coverage.

The paraxylene samples performed well in all the tests. Despite the electroplated samples beginning to whisker prior to conformal coating, the coating insulated the whiskers and prevented further growth. None of the samples exhibited electrical shorts during over 150 days of electrical testing. Clearly the coating inhibited the further growth of whiskers compared to the control samples.

## **9 CONCLUSIONS**

All three types of coatings tested, acrylic, polyurethane and paraxylene have been shown to suppress the formation of whiskers compared to uncoated samples in up to 150 days of testing, even though the uncoated control samples all developed electrical shorts due to Sn whiskers within 14 days. No evidence of whiskers penetrating out from under any coating was found except in areas where the coating was thinner, or there were other coverage issues. A number of coatings do have problem coating edges, and hence edges will be a susceptible area from which whisker growth can occur. Of the three coatings tested, only the acrylic coating did not stop penetration of whiskers back through the coating from an external whisker source during the test period. Both the acrylic and polyurethane samples did grow whiskers in areas of insufficient coverage, at the corners between the flat surfaces of the discs and the sides. The paraxylene coating suppressed and insulated whiskers successfully up to 150 days of ageing, with no edge whiskers generated.