

**The Effect of Test Voltage,  
Test Pattern and Board  
Finish on Surface  
Insulation Resistance (SIR)  
Measurements  
for Various Fluxes**

**Ling Zou & Christopher Hunt**

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Head, Centre for Materials Measurement and Technology

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# **The Effect of Test Voltage, Test Pattern and Board Finish on Surface Insulation Resistance (SIR) Measurements for Various Fluxes**

by

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## **ABSTRACT**

Existing SIR methods use a relatively coarse pitch test pattern and a high test voltage. This paper explores the SIR behaviour for five test field strengths, four test patterns and four board finishes with various fluxes. The field strengths include 10, 50, 100, 200 and 400 V/mm. The patterns vary from the existing IPC-B24 400 / 500  $\mu\text{m}$  track and gap down to a 100 / 100  $\mu\text{m}$  track and gap pattern. The work shows that both the test voltage and SIR test pattern are critical in influencing the SIR value. As the test voltage and pitch of the test pattern are reduced the SIR value drops. Hence using existing international standards test parameters the SIR value can be over estimated by 30 times. The work shows that fine pitch patterns and lower test voltages are more discriminating when determining reliability. A AuNi board finish and more frequent sampling have also been recommended.

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## 1. Introduction

Achieving high reliability is increasingly the key issue in today's electronics manufacture, now that very low defect levels in manufacture are obtainable. Residual contamination remaining on the board that may cause problems in service is a concern to high quality manufacturing. The Surface Insulation Resistance (SIR) technique has been widely used to assess the effect of contaminants on the reliability of assemblies. The SIR is a measure of an electrochemical process between two metallic conductors on a substrate surface. The SIR value is dependent on many test parameters: electrical field strength, the SIR test pattern, board or substrate finish and test environment. The current SIR method described in international standards is based on 30 year old technology. Instrumentation capability, assembly and flux technology, have significantly improved since then. The time is ripe to update the method and meet the needs of today's electronic industry.

The work presented here investigates how SIR is affected by field strength in combination with different SIR patterns, fluxes and board finishes. From this study recommendations for appropriate field strength, track and gap, board finish, sampling rate and test length for the SIR measurement are made.

## 2. Experimental

The scope of the experiment was defined to encompass five fluxes, five field strengths, four SIR patterns, and four board finishes. This gives a total of 400 individual experimental runs. To reduce this to a manageable number a design of experiment (DOE) approach was adopted. Hence an experimental matrix of 50 combinations of different field strengths, patterns, fluxes and board finishes was defined. Certain combinations of different fluxes and board finishes for the same board pattern under the same field strength condition, could be combined and tested in the same run. This provided ten test runs, which are shown in Table 1. There were five combinations in each test run, made from different fluxes and board finishes. Within each test run, two test boards and one control board for each combination of finish and flux were measured, consequently 15 boards were tested during each run. All the tests were carried out according to the SIR Test Board Preparation and Measuring Procedure. For these measurements the test temperature and humidity were 65°C and 85% respectively.

Table 1  
The experimental matrix for all test runs

| Number of test run | Field strength (V/mm) | Electric bias (V) | Track/gap ( $\mu\text{m}$ ) | The combinations of board finishes and fluxes |        |        |        |        |
|--------------------|-----------------------|-------------------|-----------------------------|-----------------------------------------------|--------|--------|--------|--------|
| 1                  | 10                    | 1                 | 100/100                     | HASL A                                        | Pd B   | Pd C   | HASL D | AuNi E |
| 2                  | 10                    | 3.5               | 350/350                     | HASL A                                        | Cu B   | Cu C   | HASL D | AuNi E |
| 3                  | 50                    | 5                 | 100/100                     | HASL A                                        | Cu B   | Pd C   | HASL D | AuNi E |
| 4                  | 50                    | 17.5              | 350/350                     | HASL A                                        | AuNi B | AuNi C | HASL D | AuNi E |
| 5                  | 100                   | 20                | 200/200                     | HASL A                                        | HASL B | HASL C | Cu D   | AuNi E |
| 6                  | 100                   | 50                | 400/500                     | Cu A                                          | Pd B   | Pd C   | HASL D | AuNi E |
| 7                  | 200                   | 40                | 200/200                     | HASL A                                        | Pd B   | Cu C   | AuNi D | AuNi E |
| 8                  | 200                   | 100               | 400/500                     | AuNi A                                        | Cu B   | Pd C   | HASL D | AuNi E |
| 9                  | 400                   | 80                | 200/200                     | Cu A                                          | AuNi B | Pd C   | AuNi D | HASL E |
| 10                 | 400                   | 200               | 400/500                     | Pd A                                          | AuNi B | Cu C   | AuNi D | HASL E |

The analysis of test results from the experiments listed in Table 1 can predict the influence these parameters have on the SIR value, but it is difficult to quantify the effect. Therefore, following the tests from Table 1 additional tests were carried out with a reduced number of variables. This second phase of testing concentrated on just using Flux B and the AuNi finished boards, but still using the same range of field strengths and SIR test patterns. Unfortunately a defect was discovered with the 100/100 and 200/200 boards and only the 350/350 and 400/500 boards were used in this second phase with AuNi finish. Consequently, a complete repeat of these tests was carried out using the Cu finished boards. It was established for this combination of flux and board that the test could be shortened to 48 hours, since the SIR value had stabilised by this time.

### 3. Test results and discussion

The results are presented as an average value from two boards. Each board has four SIR patterns and hence eight results are averaged for each condition. The standard deviation of the Log SIR is less than 0.2 decade ohms. The SIR responses with time for 10 test runs are shown in Figures 1-10 respectively. The SIR results for the control boards are included in each Figure as well. The fluxed boards are in solid lines, and the clean control boards are dotted. The data in Figure 2 and Figure 9 up to 24 hours were lost due to a brief mains spike stopping the data acquisition but not the test. All SIR values are those for the pattern and are not in ohm squares. A salient point to note from these Figures, was that the SIR values slowly increased with time, and stabilised within three days, and that any occurrence of dendrites had also initiated within this period for all test runs. This provides the fundamental evidence that the test period could be shortened from seven days to three days.

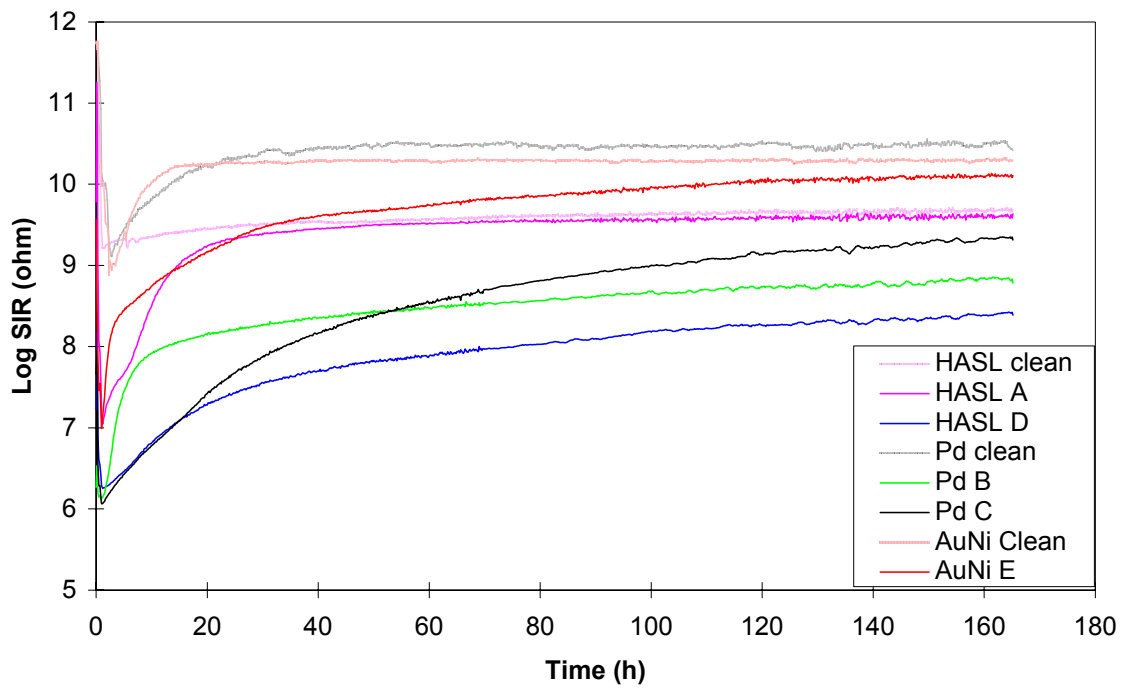


Figure 1. The variation of SIR with time for test run 1

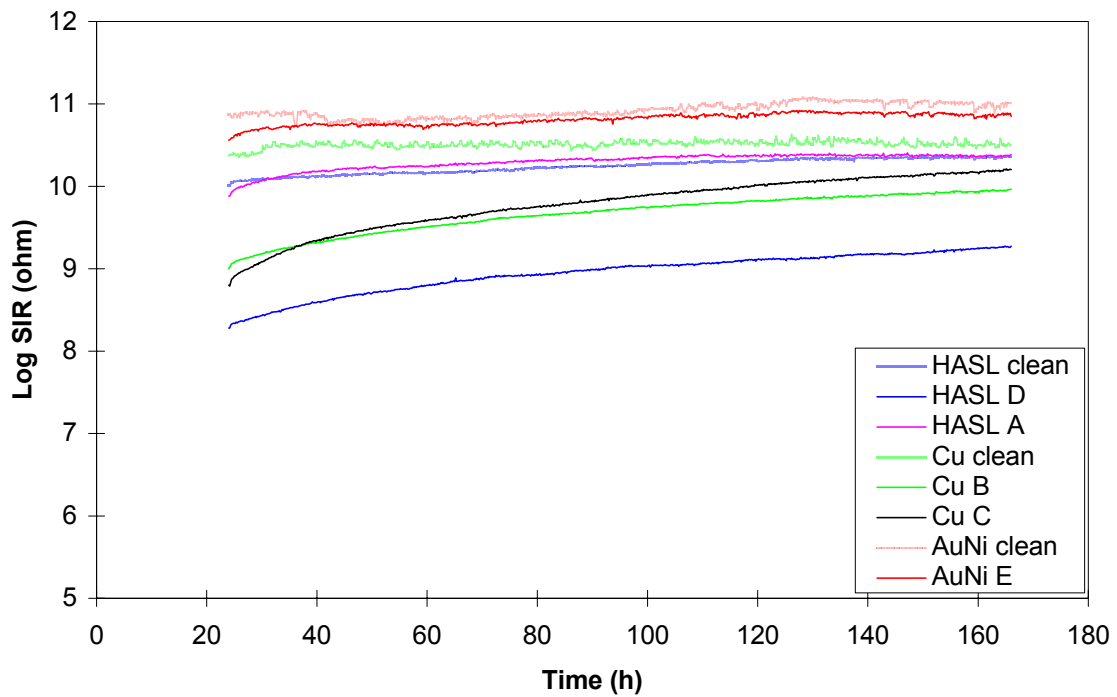


Figure 2. The variation of SIR with time for test run 2

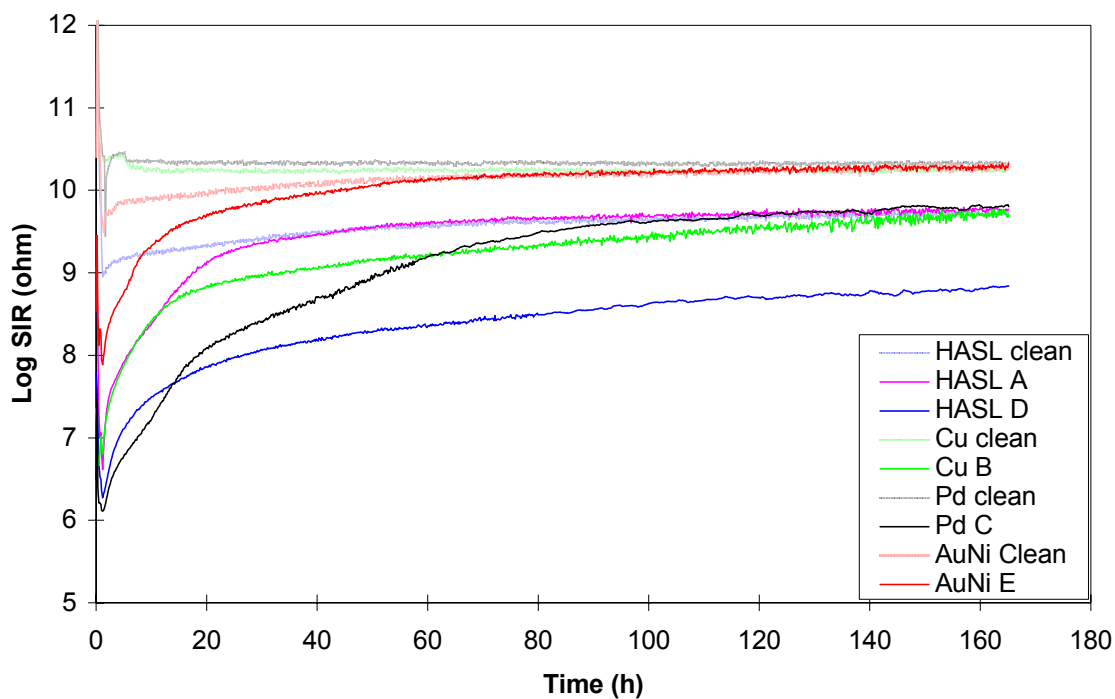


Figure 3. The variation of SIR with time for test run 3

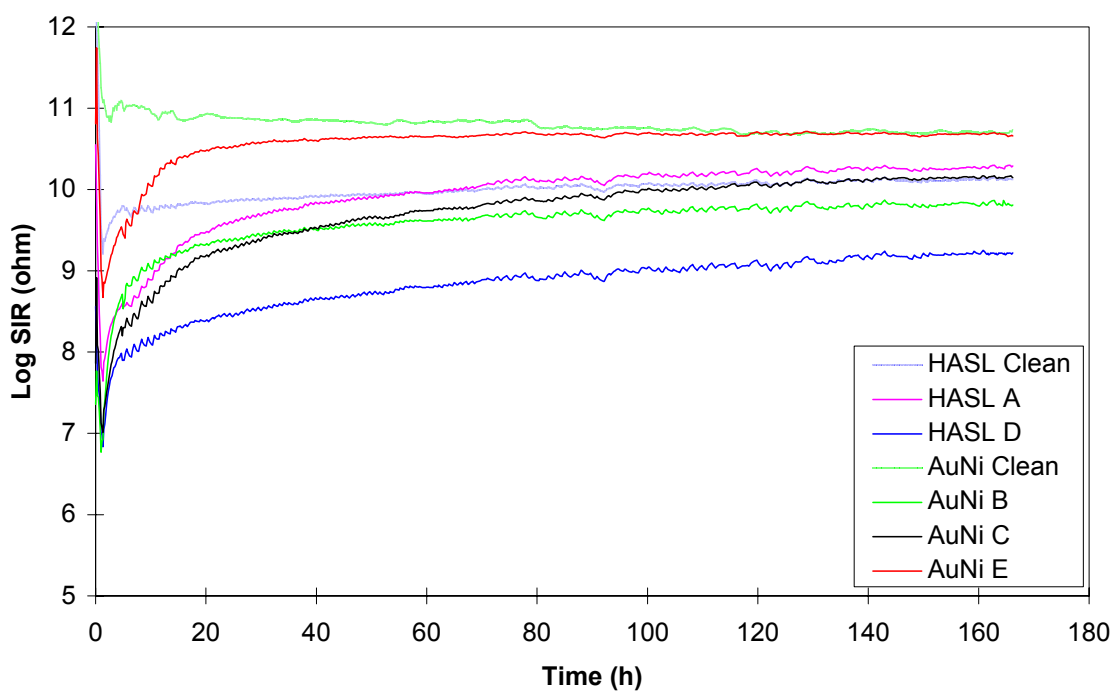


Figure 4. The variation of SIR with time for test run 4

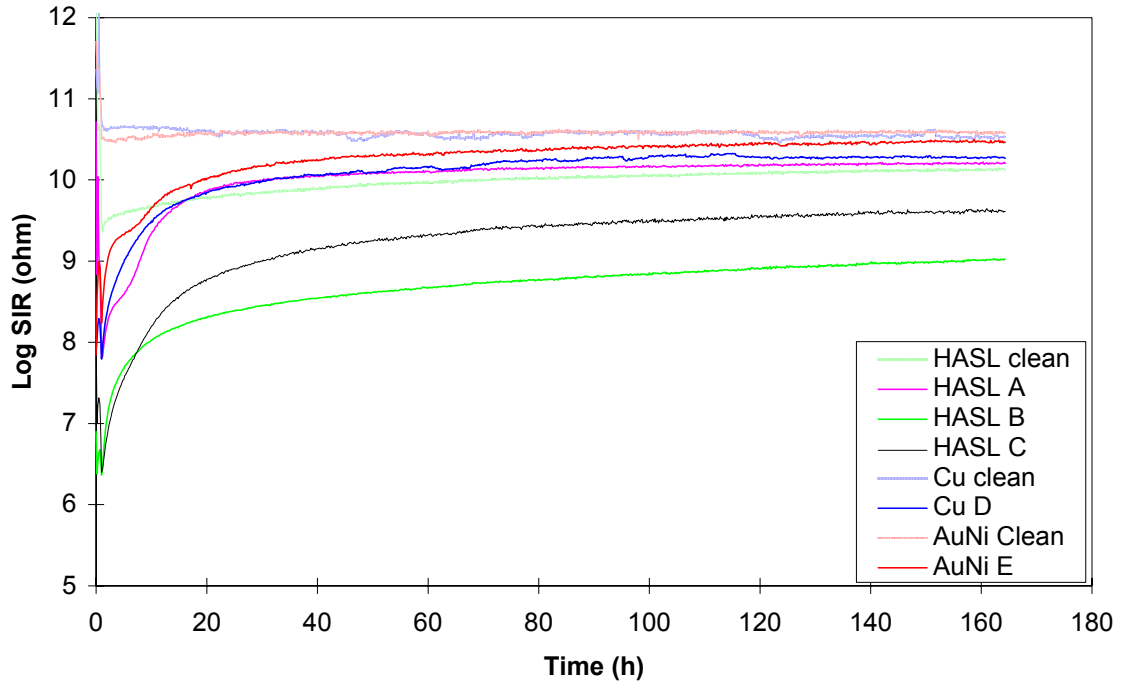


Figure 5. The variation of SIR with time for test run 5

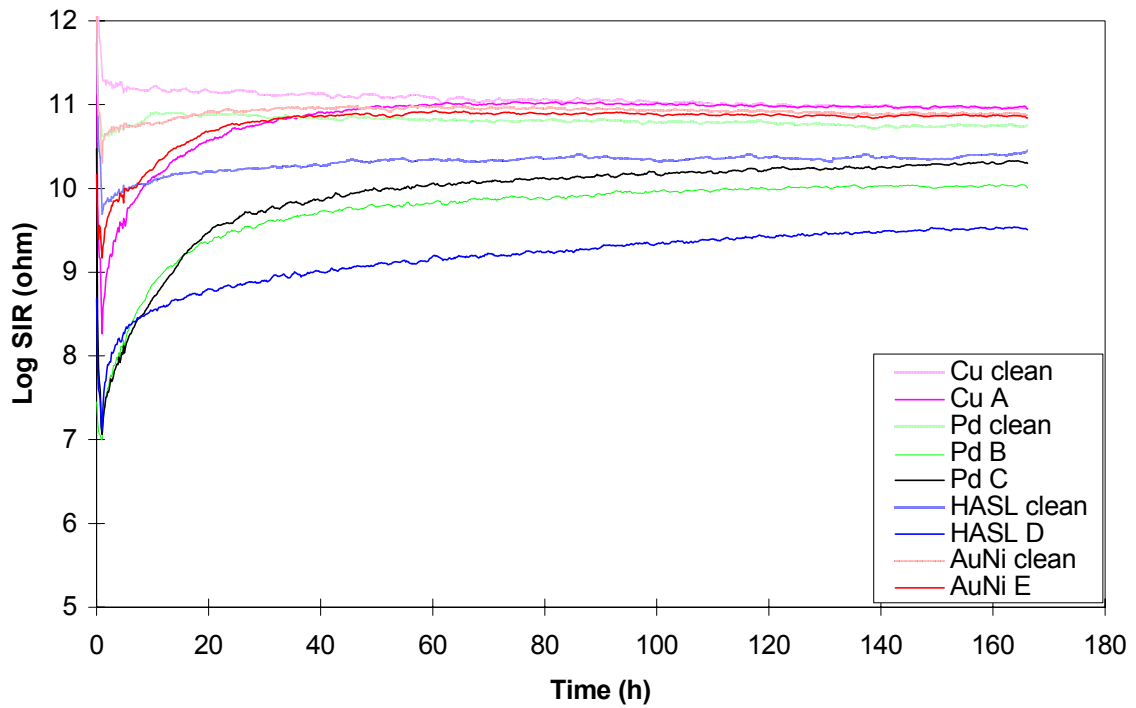


Figure 6. The variation of SIR with time for test run 6

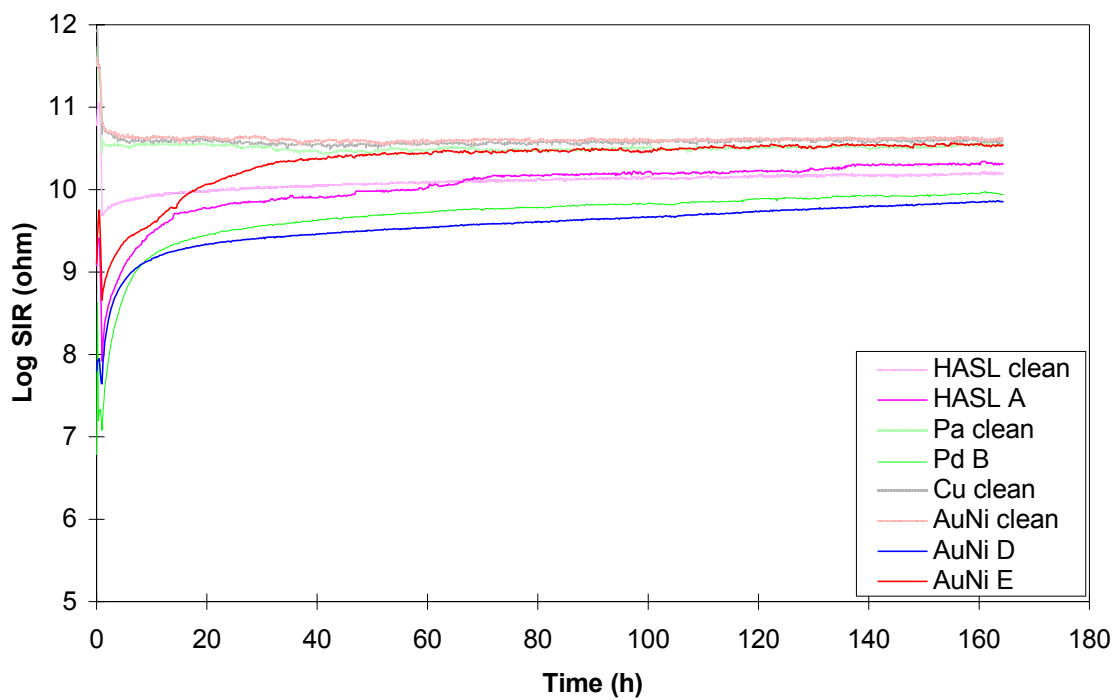


Figure 7. The variation of SIR with time for test run 7

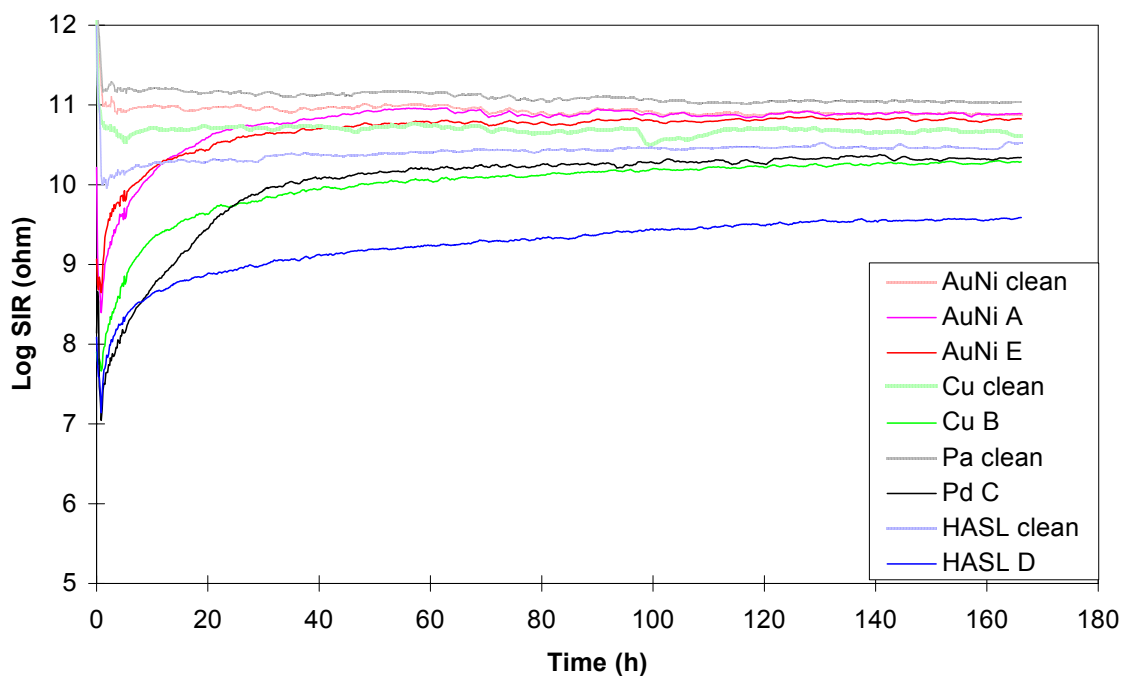


Figure 8. The variation of SIR with time for test run 8

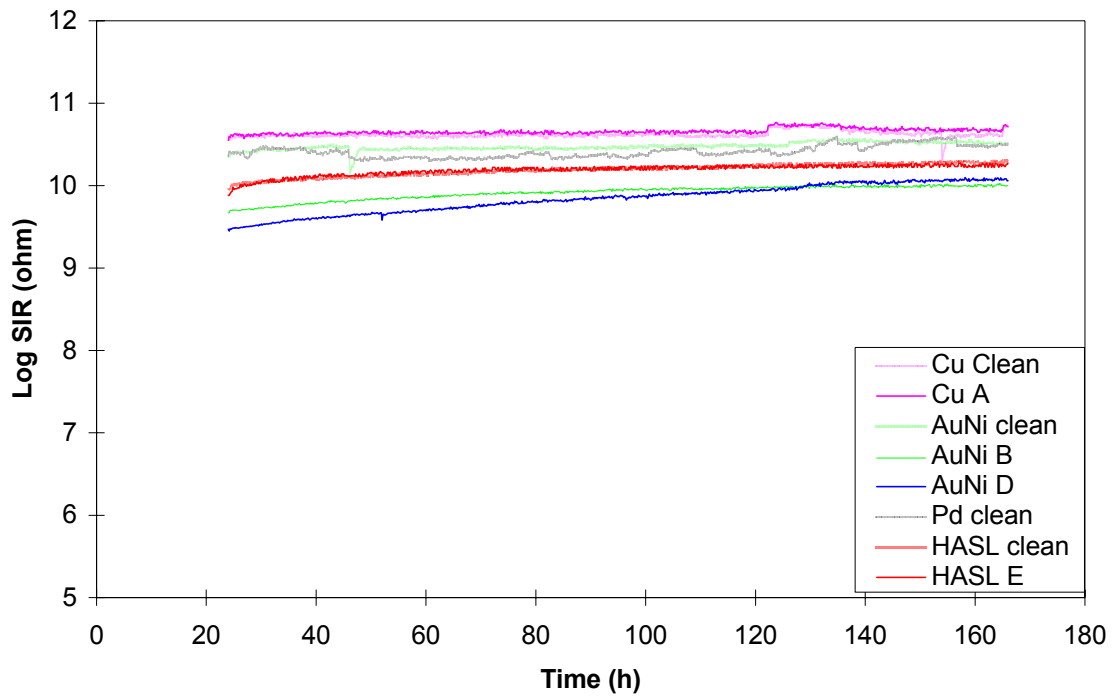


Figure 9. The variation of SIR with time for test run 9

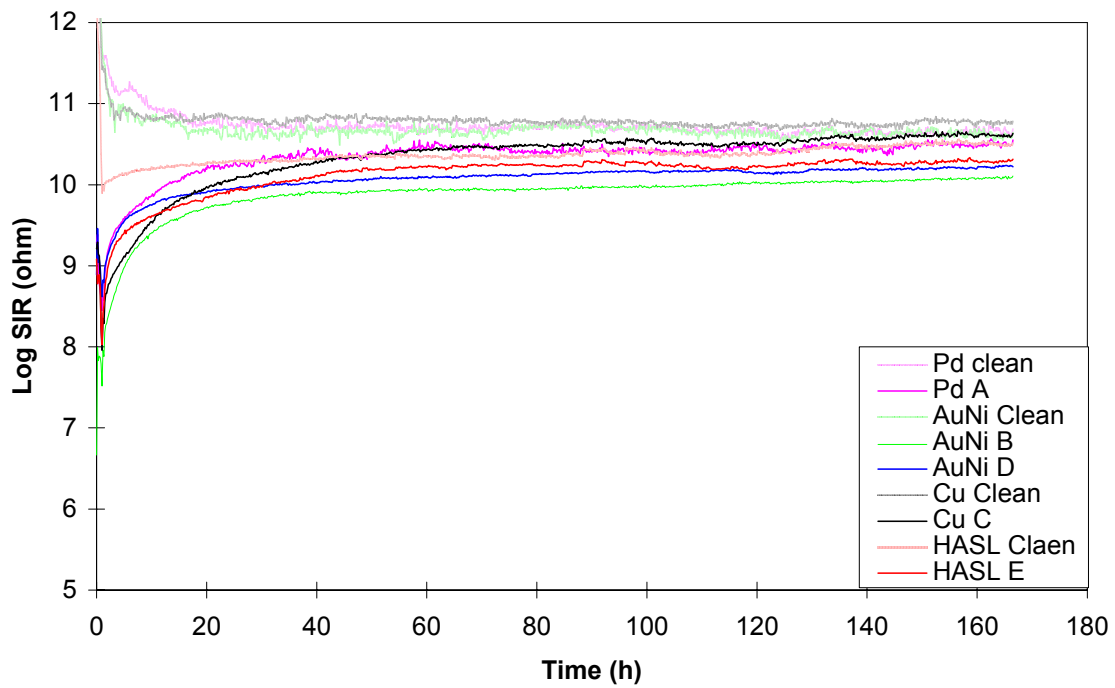


Figure 10. The variation of SIR with time for test run 10

The SIR values for test boards with flux C under 200 and 400 V/mm field strength from test runs 7 and 9 cannot be averaged, due to dendrite formation as seen in Figure 11. In Figure 11 the individual response from each SIR pattern, showing the impact on resistance of dendrite formation. The results are for Flux C, and the 200/200 board with 200 and 400 V/mm. Figure 12 shows dendrites formed on the boards. Dendrites only formed with the water-based flux, flux C. Although the test board with flux C did not give the lowest SIR value compared with the other four fluxes, these results confirm that with strong water soluble fluxes it is comparatively easy to form dendrites. With flux C dendrite formation was observed at 200 V/mm with the 200/200 track and gap boards. But with the 400/500 at the same field strength (and hence a high bias), no dendrites were observed.

**This very important result indicates that the track and gap of the SIR pattern are critical in terms of the measurement response.** The implication of this is that the SIR pattern should be representative of the manufactured circuit, and using coarser pitch patterns may fail to identify potential problems. Dendrite formation is a very important failure mechanism and can lead to catastrophic failure of circuits.

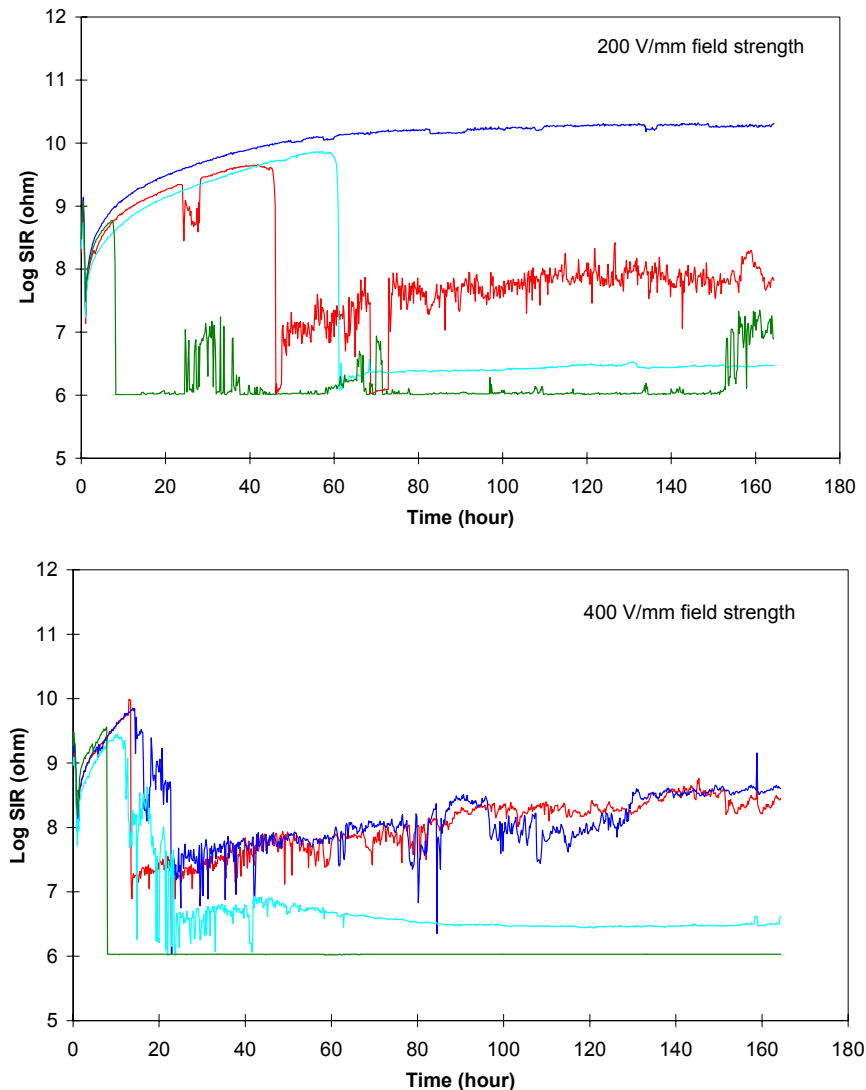
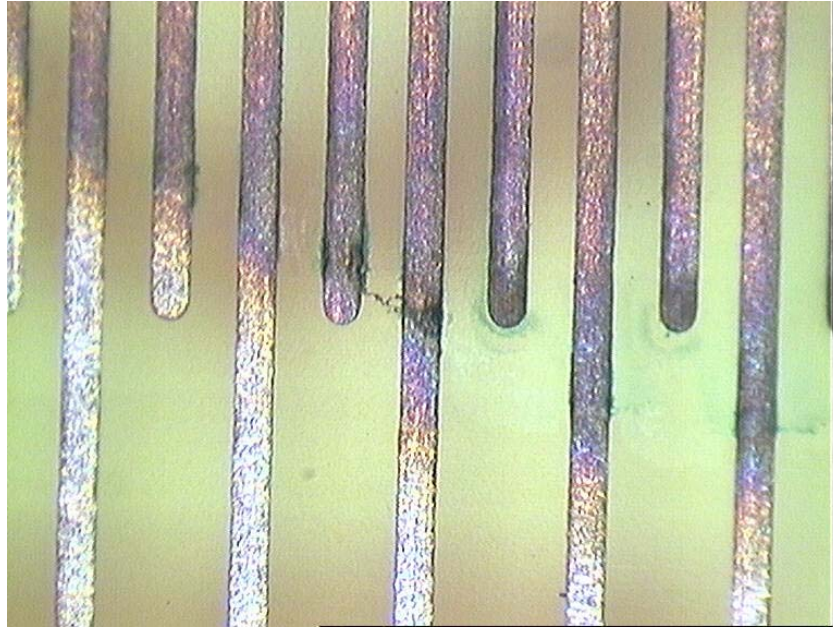
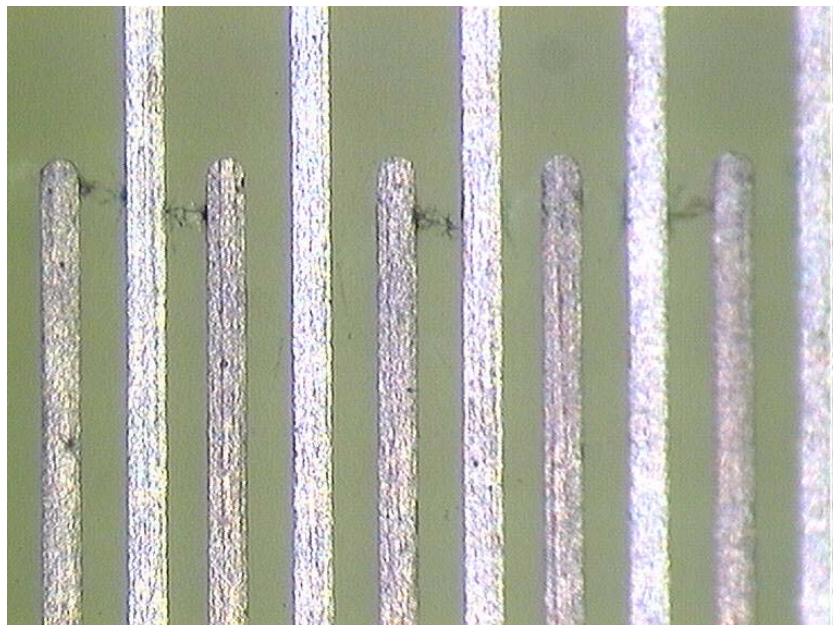


Figure 11. The SIR response with time for dendrite formation



200/200 Cu board with flux C under 200 V/mm field strength



200/200 Pd board with flux C under 400 V/mm field strength

Figure 12. The dendrites formed on 200/200 Cu boards with flux C under 200 and 400V/mm field strength

### 3.1. Discussion of the DOE results

The final SIR values from each test in the experimental matrix in Table 1 were used in the “design of experiment” (DOE) programme. Figure 13 shows an analysis of the means and medians for the final SIR values. Although the analysis of the results cannot be used to give an exact prediction for each parameter, it provides a very useful indication of the functional dependence of each parameter on SIR. It is immediately clear from Figure 13 that all the parameters influence the SIR measurement.

The left hand graph in Figure 13 shows the grand mean of the SIR values, together with the mean at each level of each factor. Generally, for normally-distributed data, the mean is a more powerful estimator of location than the median. However, if the data are not normally-distributed, the median is more reliable. So, in the right hand graph the median values are plotted for completeness, and it is clear that there are differences between the two plots. Hence, the data are not normally distributed. It will become clear that this is principally due to the occurrence of dendrites in some of the tests.

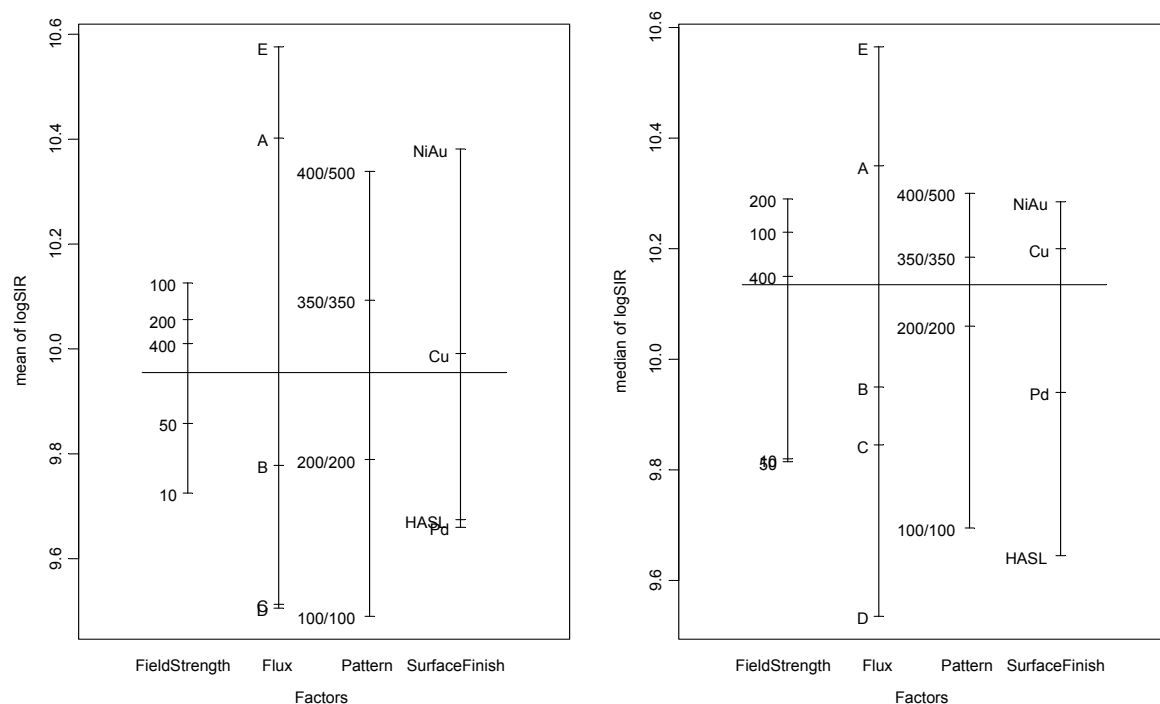


Figure 13. Analysis of Means and of Medians for the final Log SIR values

We will consider the field strength data first. For a pure ohmic resistance the SIR value should be constant for increasing voltage. It is clearly not, as can be seen with the increasing SIR value with field strength. For example with a field strength of 100 V/mm there is a higher SIR value than for a field strength of 10 V/mm. Note also that the relationship between SIR and field strength is not linear. The mean SIR values increase to a maximum at 100 V/mm, and then fall off as the field strength is increased further. This is due to dendrite formation lowering the final SIR value. This trend is noted for both the mean and median

data in Figure 13, however the median data are not as heavily weighted by the results with the dendrites and hence we observe the highest SIR with the 200 V/mm.

The data are plotted in a fuller manner in Figure 14 for all the factors. Figure 14 is a box and whisker plot. The shaded box contains the data within one standard deviation of the mean. The white bar is the median value. The vertical dotted line to the curly bracket encompasses the 5% confidence interval limits. Additional lines represent data out-liers. The field strength data in Figure 14 clearly show the trend to higher SIR with field strength and increasing pattern track and gap. It is also apparent that the upper 5% confidence limit is approximately constant for all conditions, but the lower limit quite markedly tends to lower values with reducing field strength.

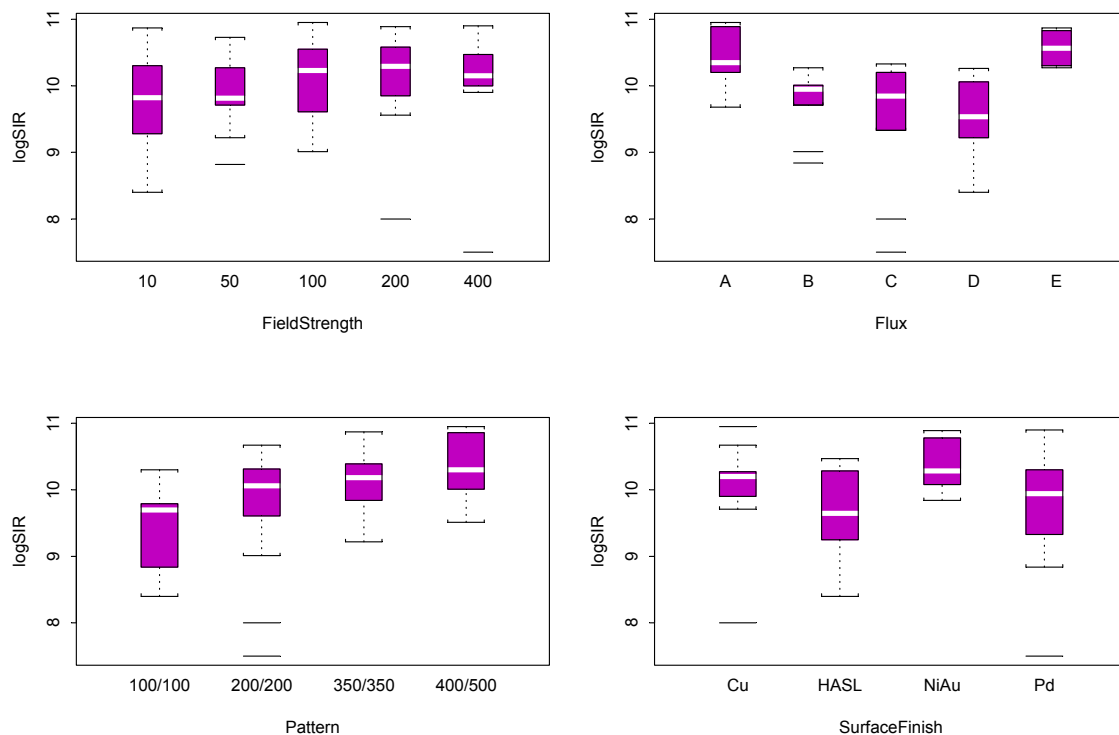


Figure 14. The distribution of the Log SIR values at each level of each factor

We now consider the track and gap, or pattern, data in Figure 13. The results clearly show that as the track and gap increase this leads to higher SIR values. This trend is clearly expected, since the SIR values are those for the whole pattern and are not ohm squares<sup>(1)</sup>. The number of squares in each of the four test patterns, and the SIR value for the whole pattern, based on the median values, and the SIR in ohm squares are given in Table 2. The ohm squares value is got by simply adding the log SIR value and the log of the number of squares. If the SIR measurement is simple surface conductivity measurement, then the SIR ohm squares values for different patterns should be constant. However the SIR ohm squares values in Table 4 vary from pattern to pattern. This implies that the measured SIR value is not simply resistive, following the geometric shape of the SIR pattern. This implies that the resistance is strongly influenced by electrochemical processes occurring at electrode interface.

In Figure 15 the SIR data are plotted as a function of SIR pattern. The trend line has a gradient of -0.47, which we will call “K”. If the SIR followed an ohm square behaviour the gradient would be -1. If the log of the number of squares is multiplied by -0.47, and this is then added to the median SIR value we get the bottom row in Table 2. These values are far more consistent than the row above, not surprisingly. It is possible that the K value could be useful in characterising the impact on SIR of the pattern and flux chemistry, and that the same approach could be used to look at field strength.

Table 2  
An analysis of SIR values and the SIR pattern geometry

| Patterns                                           | 100/100 | 200/200 | 350/350 | 400/500 |
|----------------------------------------------------|---------|---------|---------|---------|
| Number of squares                                  | 31250   | 7750    | 2571    | 1400    |
| Log (Number of squares)                            | 4.50    | 3.89    | 3.41    | 3.15    |
| Log SIR from medians<br>(ohm)                      | 9.68    | 10.06   | 10.19   | 10.34   |
| Log SIR<br>(ohm.squares)                           | 14.18   | 13.95   | 13.60   | 13.49   |
| Log SIR calibrated by<br>K (0.47)<br>(ohm.squares) | 11.80   | 11.88   | 11.80   | 11.82   |

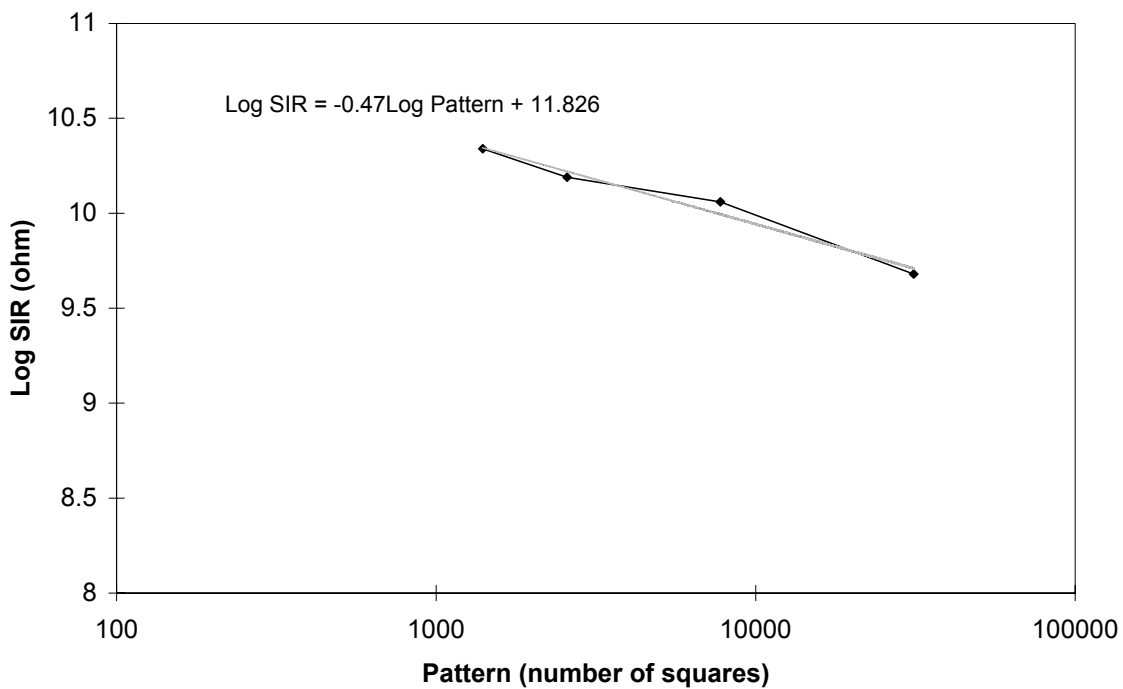


Figure15. The median SIR value with patterns for experimental matrix in Table 1

Returning to Figure 13, it is clear that the board finish also impacts on the SIR. The SIR values were much lower for the HASL boards than for the other finishes, even though all the finishes went through the same cleaning process prior to fluxing. This is consistent with the flux residues from hot air solder process being absorbed into the board. The impact of any subsequent cleaning processes may only partially remove these residues. This makes the use of HASL boards unsuitable for flux qualification processes. Their use may be considered when a specific production process needs to be assessed. The AuNi and copper finished boards had similar performances, and hence either would be suitable from this consideration. The flux behaviour in Figure 13 shows the widest response in the SIR, and reflects the range of activities in the selected fluxes. Figure 13 also shows how relatively strong the influence of the different fluxes are on SIR. In this set of experiments dendrites were only ever observed with Flux C, and the test where this happened are the out-lines marked around  $10^8$  ohm.

### 3.2. *Summary of the DOE results.*

***This work has shown that in the absence of dendrites the SIR is not simply resistive. It behaves in a complex way which is dependent on the field strength and the SIR pattern itself.*** Certain fluxes are more likely than others to cause dendrites and corrosion, and this is reflected in the SIR response. The choice of board finish is important, and copper and AuNi are the preferred choices. In terms of the robustness of the finish during the flux preparation procedure, the AuNi is superior to the copper.

The main issue to come out of this phase of the work is that the pattern and the field strength should be studied in more detail, so that the response can be more clearly identified. For this next phase the complete range of SIR patterns and field strengths were studied using the AuNi and Cu boards and Flux B.

### 3.3. *SIR response with field strength and pattern*

The SIR response with time for different field strengths with the 350/350 and 400/500 AuNi boards are shown in Figure 16 and 17. Since the SIR response was generally a smooth function, and with no marked variation of the SIR value after 30 hours, the final SIR value at 48 hours was taken for each test and plotted against the field strength. The results are presented in Figure 18, which also shows the trendline and equation for each pattern. The effects of field strength and test pattern on the SIR are clearly shown in this Figure. The SIR increase with field strength increase is very similar for both the 350/350 and 400/500 patterns. The gradient would be zero if the SIR were simply resistive and unaffected by changes in field strength, which is the This type of response seen with the control boards.

As mentioned before a problem was encountered with the finer pitch AuNi boards, so the experiment proceeded with copper finished boards.

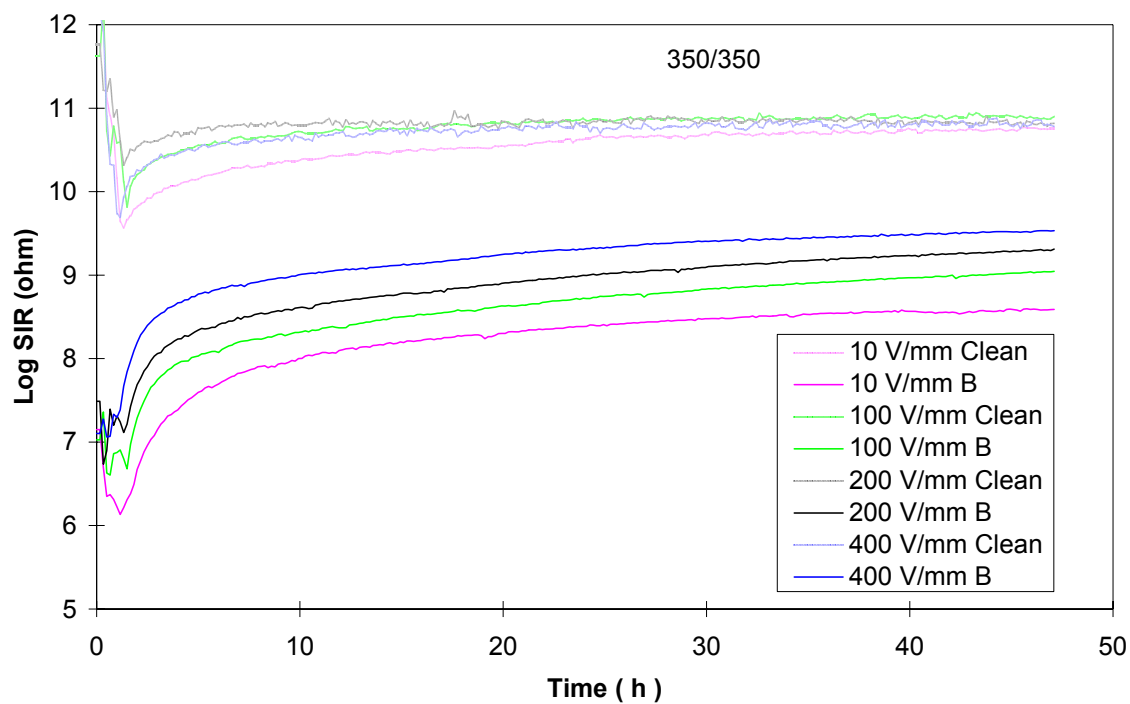


Figure 16. The variation of SIR with time from different field strength for 350/350 AuNi boards

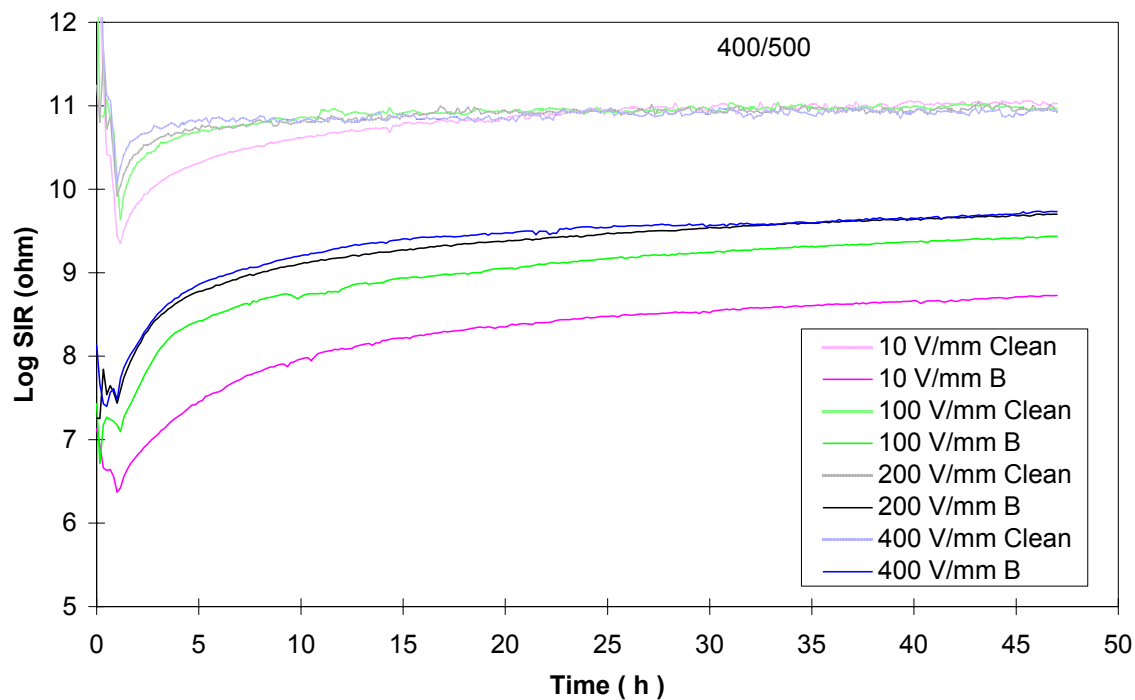


Figure 17. The variation of SIR with time from different field strength for 400/500 AuNi boards

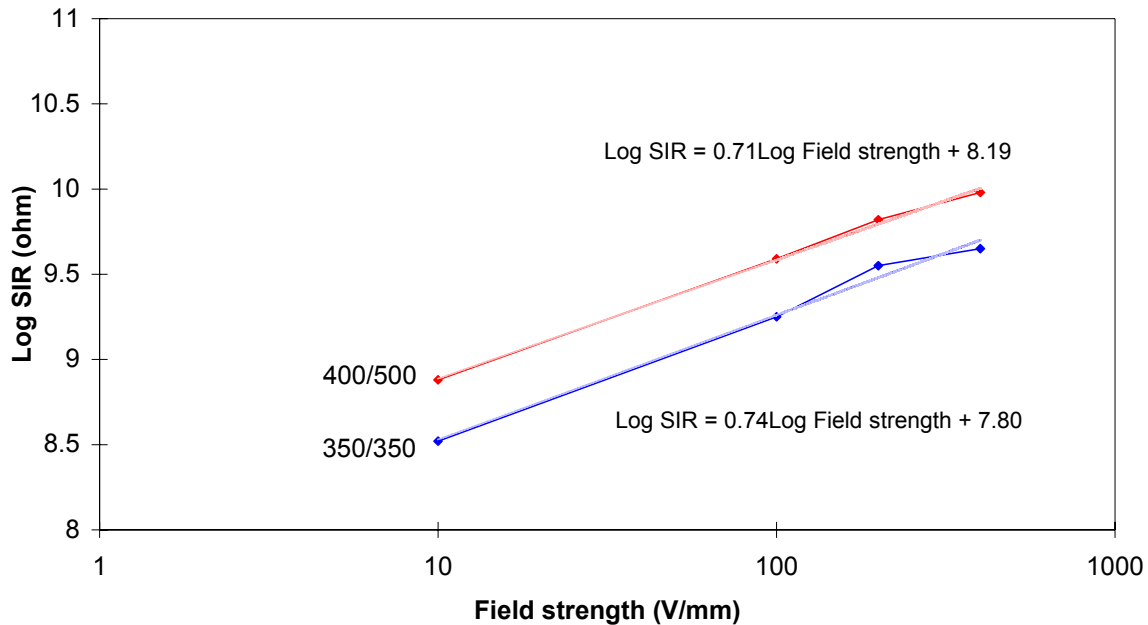


Figure 18. The variation of SIR with different field strength for 350/350 and 400/500 AuNi boards

The SIR responses with time for Cu boards with different field strength and patterns are shown in Figures 19-22. The final SIR values at 48 hours against field strength for different patterns are shown in Figure 23, which included the trendline and equation for each pattern. It is interesting in Figure 23 to note that the SIR values and the slope of the lines are different to those of the AuNi boards in Figure 18. The SIR values being higher and the slope less with the copper finish. Hence any conclusion can only be about trends, since specific values are clearly going to be sensitive to finish and flux (as seen here, the difference between AuNi and Cu finish).

**Figure 23, as did Figure 18, shows that the response to varying field strength is also dependent on the SIR pattern. The coefficient “k” for field strength gradient increases as the pattern pitch diminishes. This indicates as the testing moves to finer pitch the SIR dependency on field strength becomes more acute.** This is very significant in terms of today’s circuitry where fine pitch and low voltages are becoming more prevalent. The current international standards for SIR testing use the 400/500 pattern and 100 V/mm field gradient, which would over estimate the SIR by 1.5 log ohm decade (30 times), when comparing with the 10 V/mm and the 100/100 pattern. This is a very large margin and would be extremely significant in predicting reliability.

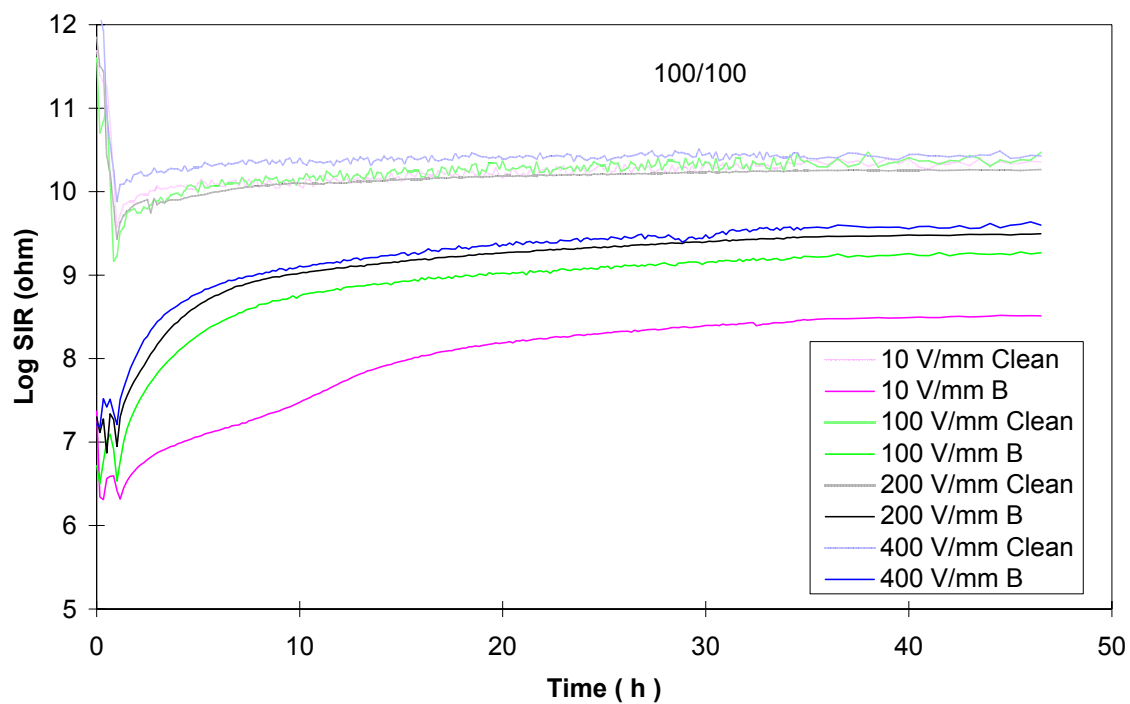


Figure 19. The variation of SIR with time from different field strength for 100/100 Cu boards

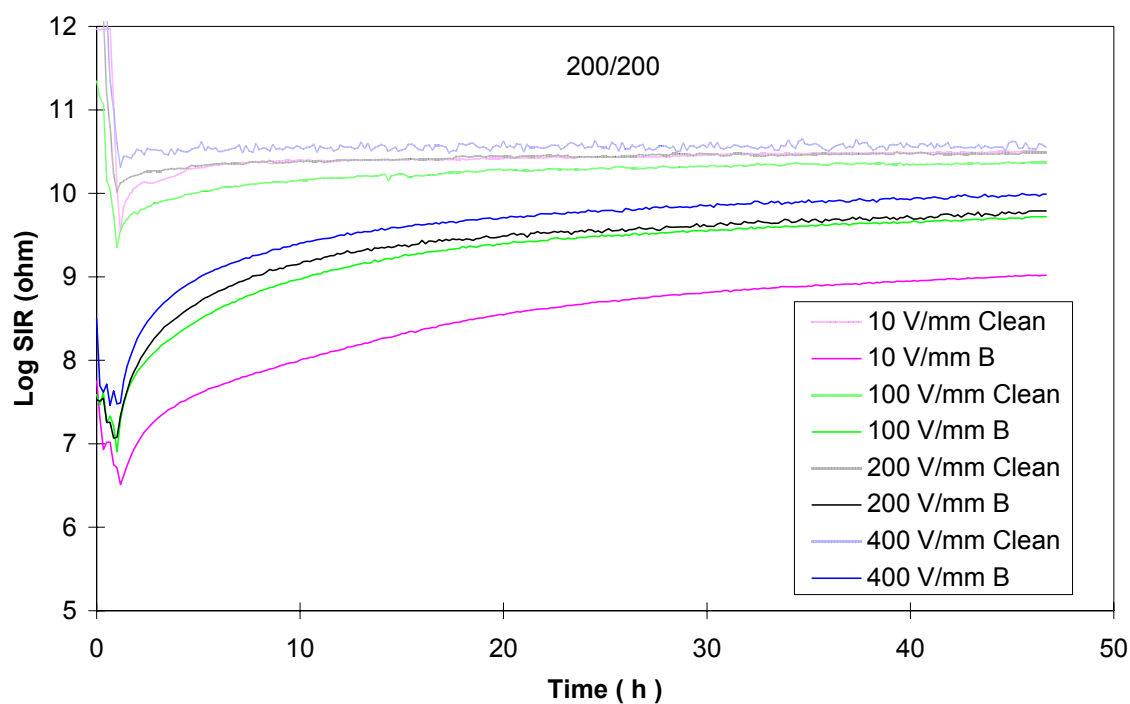


Figure 20. The variation of SIR with time from different field strength for 200/200 Cu boards

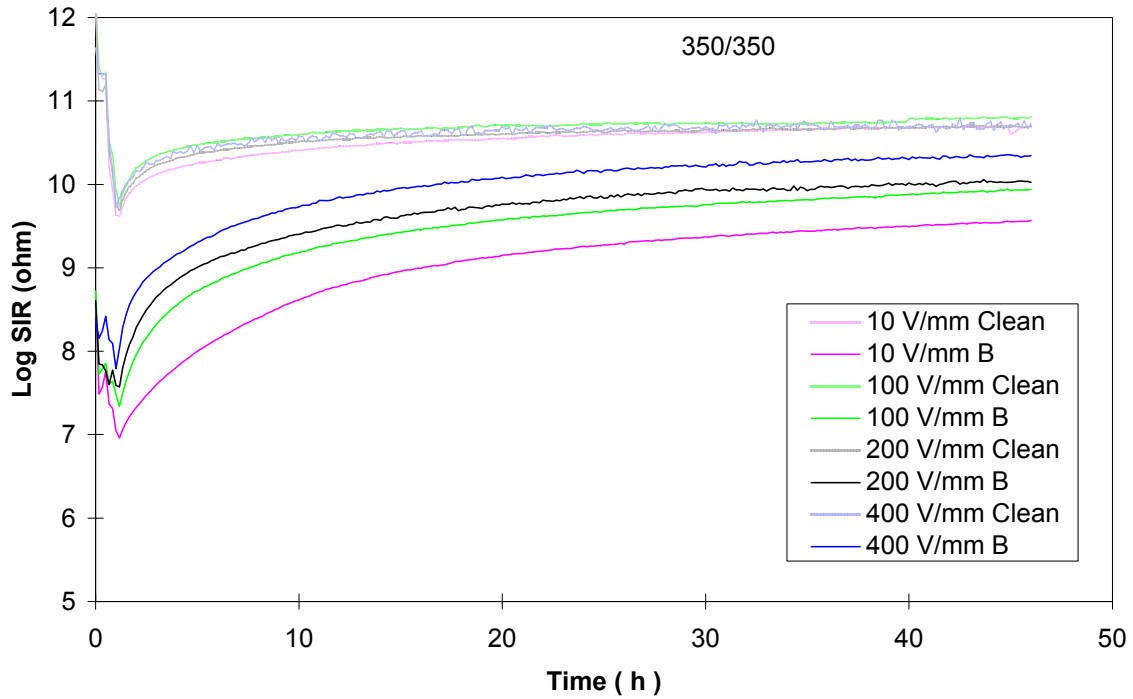


Figure 21. The variation of SIR with time from different field strength for 350/350 Cu boards

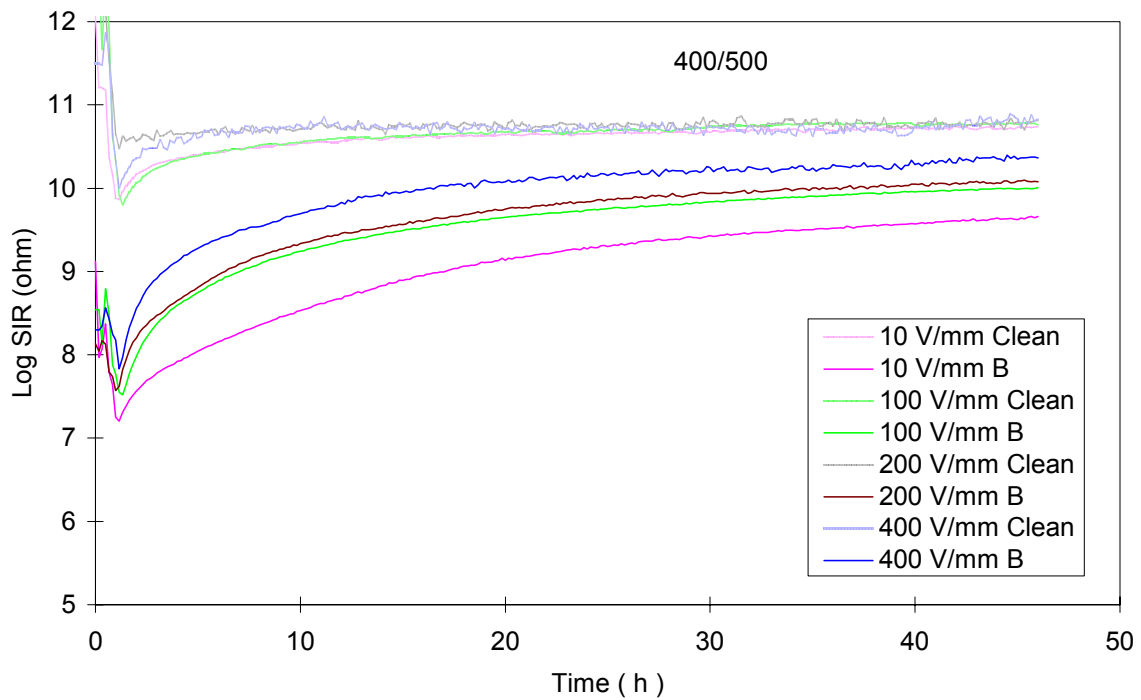


Figure 22. The variation of SIR with time from different field strength for 400/500 Cu boards

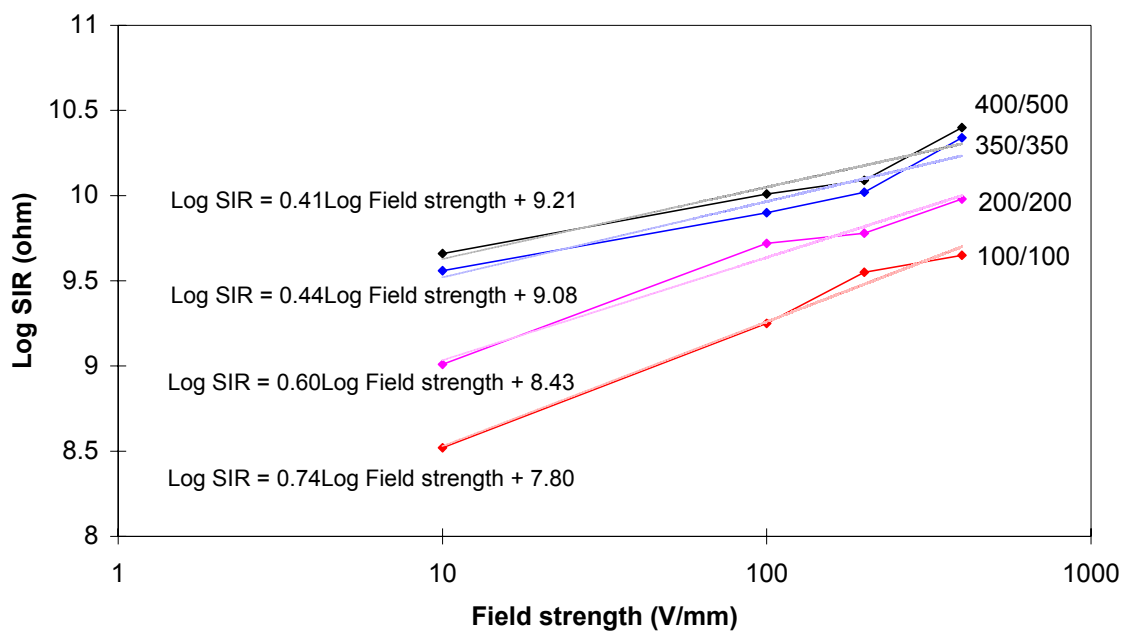


Figure 23. The variation of SIR with field strength for different patterns of Cu boards

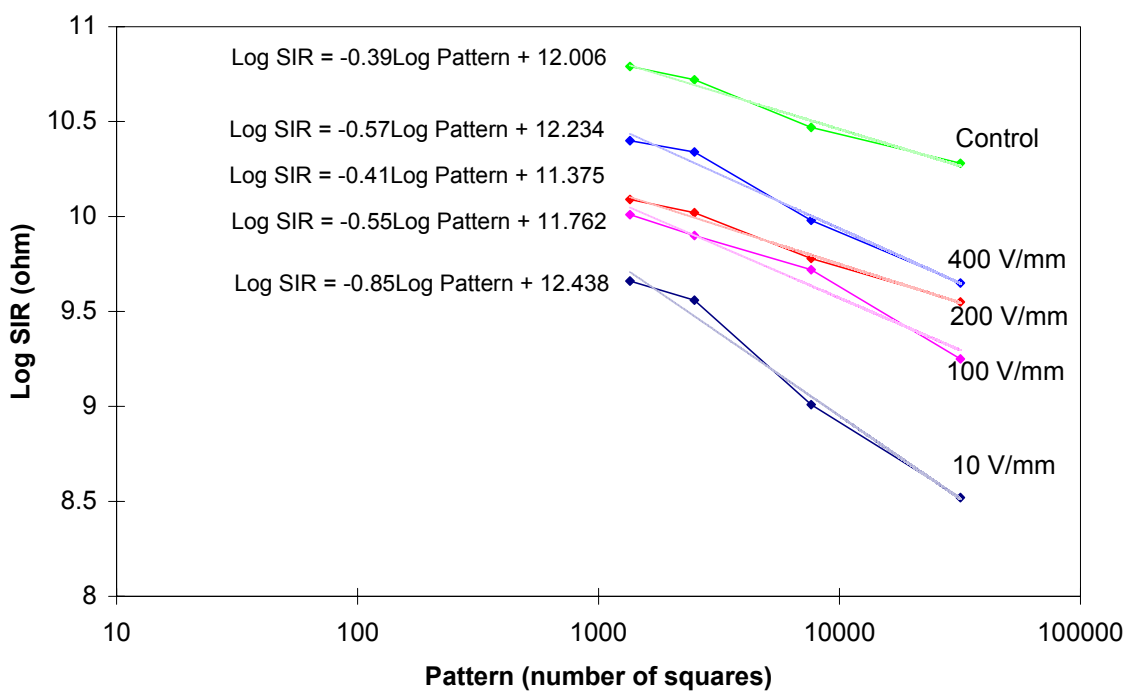


Figure 24. The variation of SIR with patterns for different field strength of Cu boards

In Figure 24 the SIR values are replotted as a function of test pattern. As was noted earlier the SIR values for the control boards are not affected by the field strength, and hence all the final values have been averaged and plotted here. As discussed earlier the slope of this line would be -1 if the SIR were simply ohmic in its resistance resistive. It is clear from this Figure that as the field strength decreases the SIR value is indeed becoming more ohmic, and it is at the higher field strengths that we are led to consider electrochemical barriers at the electrode interfaces. At 100 V/mm and above the gradient is typically around 0.5. At this value we can assume that changes in the gap does not have any real effect, and the change in SIR is due only to the change in available length of the electrodes in the SIR pattern. Again this conjecture is consistent with a highly resistive barrier being created at the electrodes, and dominating the resistance across the central part of the gap between two elements of the comb pattern. The 10 V/mm data is different, and this maybe due to the absence, or only partial forming, of a barrier. Hence, at this field strength the resistance is more appropriately correlated with the gap value.

## **4. Conclusions and recommendations for draft SIR method**

### **4.1. *Field strength***

Surface insulation resistance (SIR) is strongly dependent on the test field strength. Generally, the SIR increases with field strength. Increasing the field strength also increases the risk of dendrite formation. Hence, high field strengths are bad, and usually unrealistic. Therefore, in using SIR measurements to assess the reliability of electronic circuitry, the test field strength should be close to the realistic working field strength.

### **4.2. *Test pattern***

The test board pattern affects the SIR. The concept of ohm squares cannot be used, it does not permit a useful comparison of SIR patterns. The SIR response to various patterns can be useful in qualifying behaviour, and hence reliability of the circuit board. However, in formulating a test method the test pattern should be fixed. This pattern should be representative of fine pitch. We recommend that a pattern with a 400µm track and a 200µm gap be used. This is a fine pitch pattern and hence will reflect today's industry, but is not as challenging as the 100µm gap boards to manufacture. The track is 400µm to facilitate printing onto the pattern; a finer track maybe too demanding. The fine pitch or small gap will also be more efficient in capturing potential problems with dendrite formation.

### **4.3. *Board finish***

The SIR values are dramatically affected by the board finish. The HASL finished boards always gave the lower SIR value due to the residual contamination from the manufacturing process. This was in spite of all the different board finishes going through the same cleaning process prior to fluxing. Hence, the HASL board should not be used in SIR flux qualification.

The AuNi or copper finish is recommended for the SIR flux qualification. (AuNi is preferred since it is more robust during flux preparation).

#### **4.4. *Test time and sampling frequency***

All the test results show that the SIR values for all the combinations of different field strengths, track/gaps, fluxes and board finishes, become stable after 72 hours. When dendrite formation did occur, it was always within 72 hours. The data after 72 hours did not provide any further useful information. The 72 hours test period is recommended, but this is conditional on frequent monitoring of the data, say at every 10 minutes. Frequent monitoring should be mandatory.

### **5. Acknowledgements**

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### **6. Reference**

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