

**A Method to Quantify the
Surface Insulation
Resistance Performance of
Glob Tops Exposed to
Different Temperature/
Humidity Combinations**

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Head of Centre for Materials Measurement & Technology

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SUMMARY

Often the only information that suppliers of encapsulant glop top and dam and fill materials provide for users of their materials is a single value of surface insulation resistance. This datum provides very little information about the performance of the encapsulant over the wide range of different humidity/temperature conditions that it may encounter in its service life.

This procedure describes a simple method for characterising the performance of encapsulant materials over a broad range of environmental conditions. The resultant data can be used to assess the performances of different manufacturers formulations or types of encapsulant dispensed on to different board finishes or on to different board materials.

1 INTRODUCTION

The long term reliability of electronic devices is a key issue in today's markets. This places additional burdens on device manufacturers to ensure that their products function in a range of often aggressive environments e.g. automobile engine compartments. Curable plastics (encapsulants) are often used to selectively coat sensitive electronic components that could be damaged as a result of being exposed to, for example, high humidity, salt spray or fuel fumes. Encapsulants are available either as relatively high viscosity materials (glob tops) that are directly dispensed onto the component and its immediate vicinity or as 'dam and fill' products. A dam and fill product is composed of a high viscosity formulation which is used to produce a ring of material around the component (the dam) that is then filled with a low viscosity fill. Dam and fill materials are particularly successful in underfilling components due to the low viscosity of the fill component.

Typically manufacturers give relatively little guidance on how these materials perform under wide ranging environmental conditions. This introduces some uncertainty in selecting not only the appropriate type of encapsulant for a particular application but also deciding which manufacturer's formulation is most appropriate.

1.1 THE MECHANISMS RESPONSIBLE FOR FAILURE OF CIRCUIT BOARD ASSEMBLIES

In service failure of chip scale packages or ball grid arrays can occur as a result of pad or wire bond corrosion or due to a breakdown in the surface insulation resistance (SIR) caused by current leakage. This current leakage consists of ions that flow between two conductors immersed in an electrolytic medium such as water. The driving force for the process is a difference in potential between the conductors. At its most severe the flow of positively charged metallic ions between two conductors can lead to the formation of dendrites on the cathode¹ that cause bridging. The amount of water within the board or glob top material immediately after manufacture is normally very little if the board has been suitably cleaned and dried. However this can change significantly with time especially if the board is exposed to damp atmospheres during service. The presence of hygroscopic organic residues such as flux or cleaning agent surfactants can exacerbate the problem. Organic residues by forming soluble complexes with metal ions also contribute to ion flow within solids. Circuit corrosion can also occur in the absence of an applied voltage leading to a loss of conductor and current leakage due to bridging by corrosion products.

Circuit board assemblies can also fail as a result of repeated thermal cycling. This can occur in service and be responsible for solder joints cracking because of differences in the thermal expansion coefficients of the board component material, conductor and solder. There is some evidence to suggest that this susceptibility to cracking can be marginally reduced by conformal coatings². However the efficacy of particular coatings or glob tops in this role will depend on their chemistry and how well they coat the soldered junction.

2 TEST METHOD

Measurements of the SIR of a simple PCB can be used to assess the performance of different glob tops on different finishes or different substrates exposed to a range of environments. Whilst in principle any environment can be used for the test e.g. fuel fumes, this procedure focuses on the materials response to a range of temperatures and humidities.

2.1 BOARD DESIGNS AND MATERIALS

2.1.1 Selection of board materials and test patterns

The simple board design shown in Figure 1 comprises of four double comb patterns i.e. two differently sized squares of length 25 mm and 13 mm respectively and two circles of diameter 7.2 mm. The circular double combs although the same size have different connection rails. The guard rails shield the double comb patterns from noise. Each double comb pattern comprises of a 0.7mm pitch gold over nickel track (350 μm track and 350 μm spacing). Note that alternative materials can be used for the track. This procedure is also independent of the pattern design shown in Figure 1, in principle any size or shape of double comb design can be substituted.

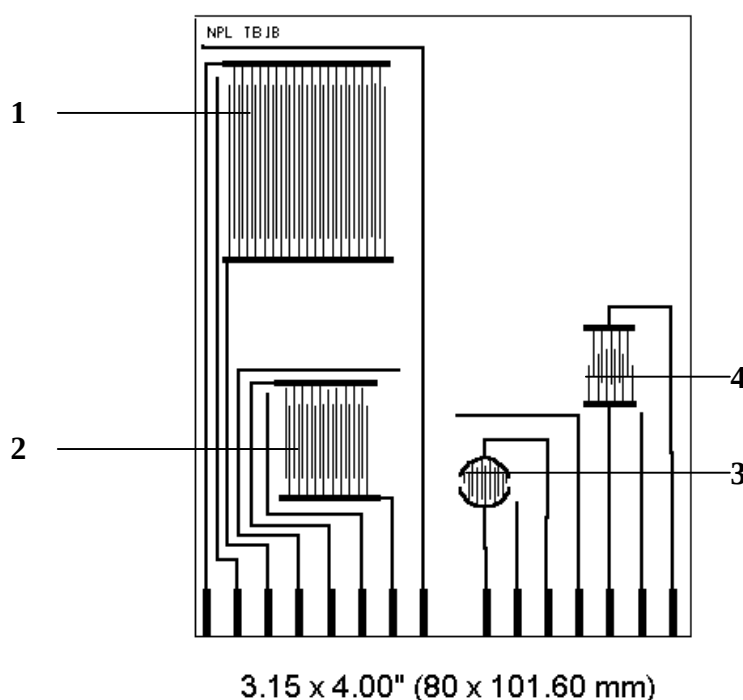


Figure 1: The test board comprises of four double comb patterns labelled 1 to 4.

Before dispensing the glob top material on to the boards e.g. FR-4, flex (polyimide) or ceramic boards should be cleaned using an IPA/deionised water mixture (75:25). (This although desirable is not necessary if the purpose of the investigation is to explore the performance of glob tops on 'dirty' boards). After cleaning the boards they should only be handled by personnel wearing gloves to minimize the risk of contamination.

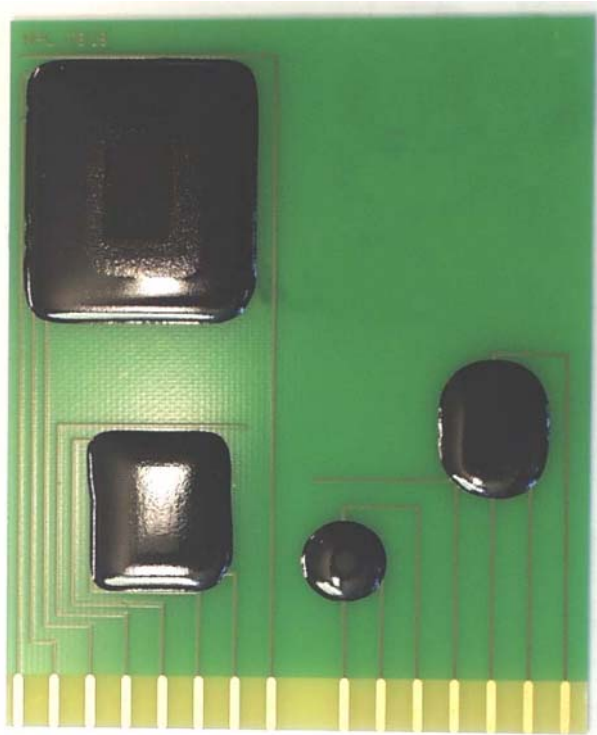


Figure 2 : An example of a urethane based glob top dispensed on to a ceramic board coated with solder resist. Note that the materials not only cover the double comb areas but also their immediate vicinity i.e. the solder resist coated ceramic.

2.1.2 Dispensing and cure of glob tops

An example of a glob top material being used to encapsulate double comb patterns deposited on a resist coated ceramic board is shown in Figure 2. Single phase glob top materials are most reliably dispensed using single head dispensers that can be programmed to repeatedly dispense the same volume of material at a prescribed rate over defined regions of the test boards. The dam and fill glob tops generally require a two stage head for dispensing although it is possible to dispense the dams first followed by the fill material for small test runs. The different sizes and shapes of the double comb patterns will automatically produce variations in the depth of the encapsulant material on a single board. Significant differences in the dimensions of the cured glob tops will occur in comparisons of different manufacturers products. This variation can be attributed to differences in the surface tension of the encapsulant on different substrates and in the solid content of different formulations. The manufacturers recommendations should be followed for curing the encapsulant.

2.2 SURFACE INSULATION RESISTANCE MEASUREMENTS

2.2.1 Test conditions

Exposing the test boards to alternating wet and dry environments over a range of different temperatures enables the performance of different glob tops to be assessed and compared.

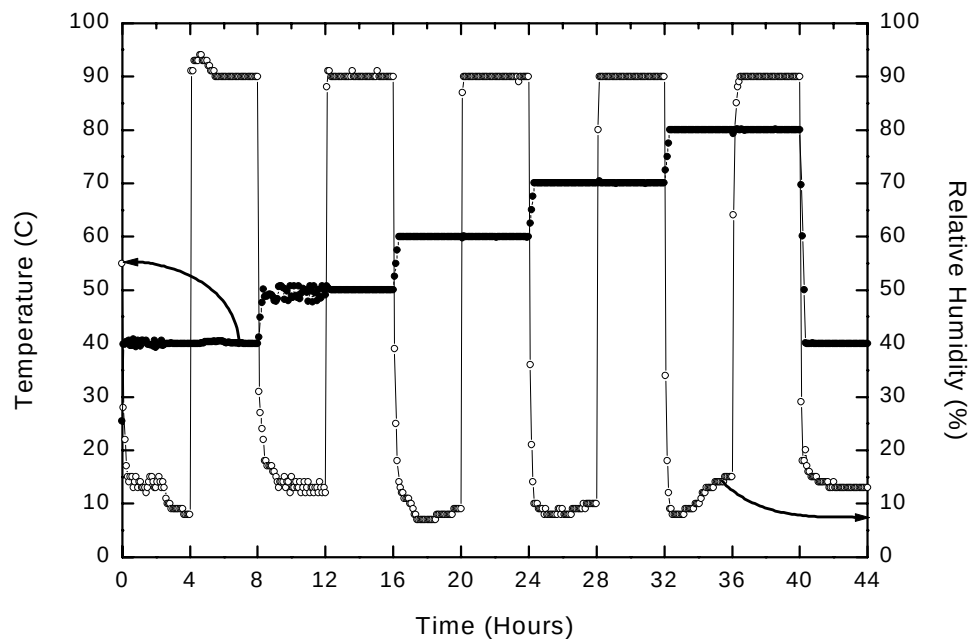


Figure 3 : The temperature/humidity profile.

A typical measured profile for humidity and temperature during a test is shown in Figure 3. From this figure it is evident that the humidity is cycled over a two hour period from 10% RH to 90% RH. This humidity cycle is superimposed on to a stepped temperature profile where each step is maintained for a period of four hours. The temperature and humidity conditions within the environmental chamber should be monitored by wet and dry platinum resistance thermometers.

During the test period a +50 V biased voltage is continuously applied across the double comb patterns. A $10^6 \Omega$ limiting resistor is present in each measurement channel to preserve dendrites.

2.2.2 Data collection

The apparatus used to measure SIR should have a current sensitivity of approximately 1×10^{-11} A. A sampling interval of 5 to 10 minutes enables changes in SIR to be closely monitored under different environmental conditions during the 44 hour period of the test.

3 DATA ANALYSIS

3.1 VISUAL APPEARANCE

It is not possible to examine the boards for direct evidence of corrosion or dendritic growth as most encapsulant materials are opaque. However visual inspection can be used to check the boards for signs for encapsulant delamination, particularly at the edges. Delamination of the encapsulant even if incomplete could provide an easy route for moisture ingress and an explanation for poor SIR performance.

3.2 THE SIR OF CONTROL BOARDS

Figure 4 shows the time dependence of log SIR for double combs deposited on a bare ceramic board. Clearly the behaviour of log SIR mirrors the change in humidity of the test environment. Recovery of log SIR occurs over a very short timescale to values in excess of the measurement capability of the test equipment (approximately $10^{13.4}$ Ohms). The ability of the board SIR to recover during exposure to low humidity decreases with increasing temperature. This result is not unexpected due to the additional quantity of water contained in the atmosphere at these temperatures is presumably reflected as an increase in the moisture content of the encapsulated boards. The variation in log SIR between different patterns is a reflection of the different comb areas (difference in squares) and a measure of noise in the measurement system.

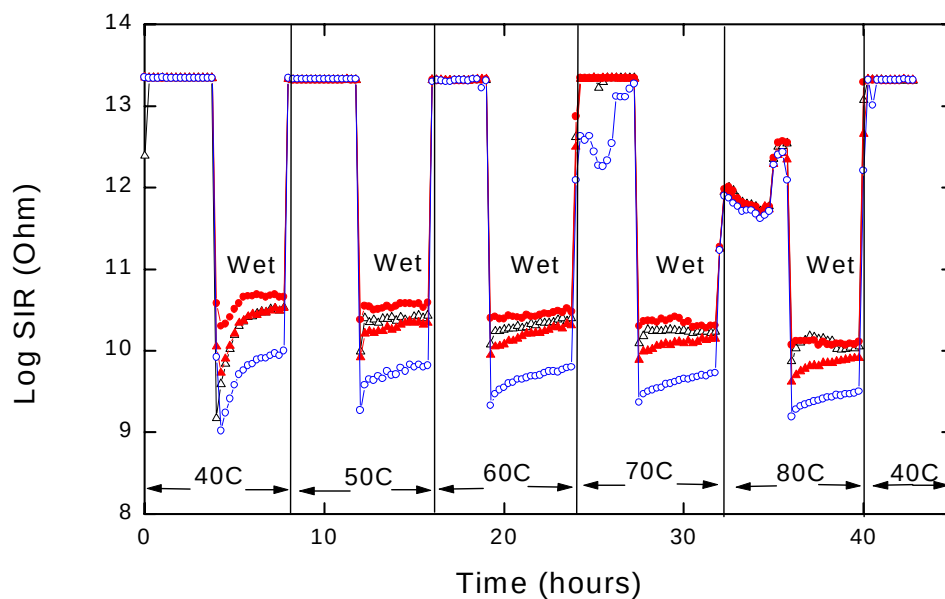


Figure 4 : Log SIR for bare double combs deposited on to a ceramic substrate reflects the changes in humidity that occur with each temperature increment. The magnitude of log SIR depends on the area of the double comb ($\circ$ = pattern 1, $\triangle$ = pattern 2, $\square$ = pattern 3, $\bullet$ = pattern 4).

A plot of log SIR versus time for encapsulated double comb patterns is shown in Figure 5. The peaks and troughs seen in the plot correspond to the damp and dry phases of the humidity cycle analogous to the control board shown in Figure 4. The SIR rapidly falls during the damp phase of the humidity cycle indicating that this material is not acting as a moisture barrier for temperatures in excess of 40°C . However the cyclic changes of SIR with humidity are less for the encapsulated patterns than for those deposited on to bare board. This shows that the encapsulant is providing some degree of moisture protection especially at 40°C where there is no change in the SIR of the encapsulated double combs despite an 80% increase in relative humidity. This behaviour is common to a number of urethanes, silicones and acrylic materials.

3.3 DERIVATION OF SIR MEASURES

The SIR temperature indices are derived from measurements made during exposure of the board to damp conditions at temperatures in excess of 40°C. SIR values measured at high humidity and at low temperatures (<50°C) are typically in excess of $10^{13} \Omega$ and therefore beyond the measurement capabilities of most commercially available test equipment.

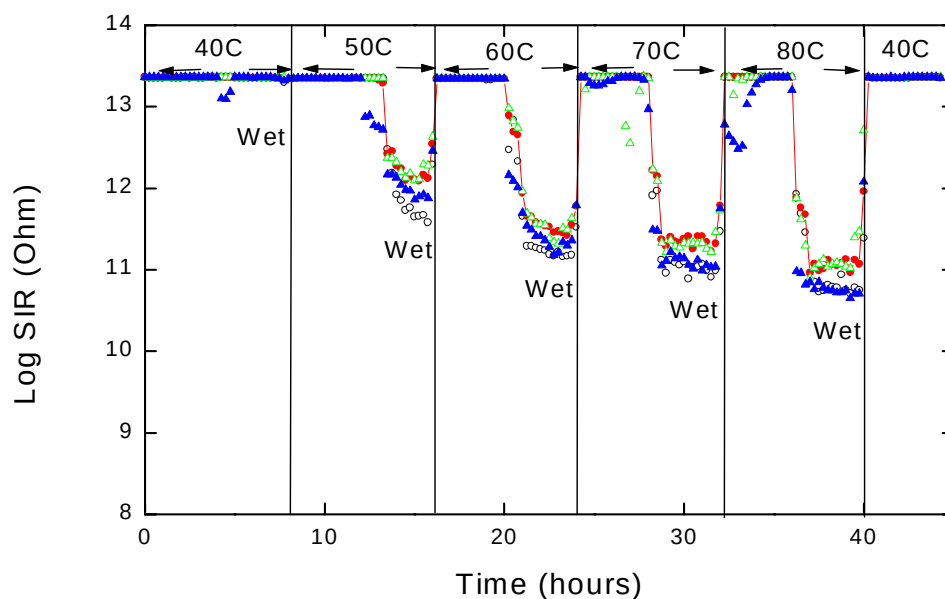


Figure 5: A typical plot of log SIR versus time obtained for a glob top (epoxy based) deposited on to a ceramic board. The environmental conditions are indicated on the figure. The humidity cycles between 10% RH (the first two hours at each temperature) and 90% RH (shown as 'wet'). ($\circ$ = pattern 1, $\blacktriangle$ = pattern 2, $\triangle$ = pattern 3, $\bullet$ = pattern 4).

The average value for each SIR measurement made under damp (wet) conditions when plotted versus time typically shows a linear relationship as shown in Figure 6. Linear least squares fits to these data are used to generate a predicted value for log SIR at 50°C and a slope that describes the temperature dependence of log SIR. The departure of the data at 40°C from the linearity shown in figure 6 is commonly seen and is the reason for only using SIR measurements made at 50°C above. The midpoint value of the SIR during exposure to high humidity although arbitrarily chosen does circumvent potential problems arising from temperature or humidity instability at the start of each cycle.

4 USING THE INDICES

Currently decisions regarding the suitability of a particular manufacturers coating for a given application are based on a single SIR value. However a single measurement of SIR measured at a fixed humidity and temperature gives little information about the performance of the coating under a range of different combinations of environmental conditions. The SIR

temperature indices are able to offer a profile of the coatings SIR behaviour as a function of temperature and humidity. This information can be used to compare different chemical compositions of the coatings and different manufacturer's formulations as shown in Table 1. Glob top materials with high predicted SIR values at 50°C coupled with low slopes will give high SIR over a wide range of different temperatures and humidities for a particular board, finish combination as shown in Figure 7. Conversely glob top materials that have high values of predicted SIR at 50°C coupled with a strong temperature dependence suggest that the SIR will fall substantially under high temperature, humidity conditions. Table 1 also shows that the material performance also depends on the type of board which could reveal compatability issues with different finishes or sensitivity to flux residues.

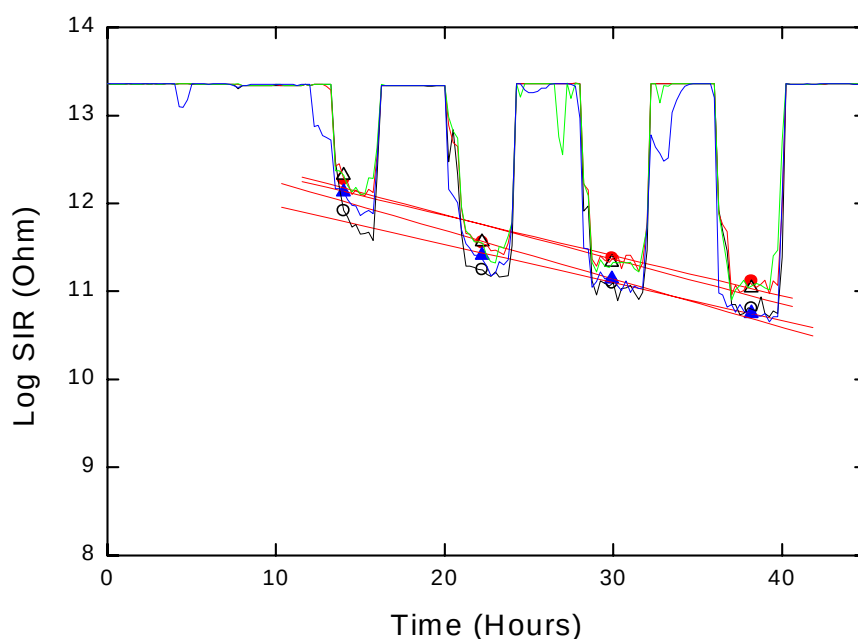


Figure 6 : Linear least squares fits to a plot of the average values of log SIR measured during each damp cycle as a function of temperature for the data shown in Figure 5. Note that the data at 40°C measured under damp conditions falls outside the linear relationship characteristic of data at higher temperatures.

The gradient of plots of log SIR versus temperature may be used to indicate the operational temperature range of encapsulated electronic devices, i.e. high gradients are indicative of low SIR values at elevated temperatures which may induce current leakage.

5 MEASUREMENT ISSUES

The small circular double combs offer a significantly higher SIR than the larger rectangular patterns because of their different size. This disparity can lead to problems of measuring very small currents, particularly since the resistance of any cable connections in the path between the double comb and the ammeter could be significant. To some extent this problem can be reduced by increasing the applied voltage from 50 V although there is evidence to suggest that the results will not be representative of the boards performance under lower operating voltage conditions³.

		Predicted Log SIR at 50°C (Ohm)				Temperature dependence Log (Ohm)/°C			
	Coating	Comb 4	Comb 3	Comb 1	Comb 1	Comb 4	Comb 3	Comb 2	Comb 1
Ceramic Board	Epoxy 1	11.87	11.87	11.5	10.97	-0.065	-0.065	-0.069	-0.069
	Epoxy 2	13.27	13.14	12.64	12.37	-0.063	-0.074	-0.042	-0.053
FR4 Board	Epoxy 1	12.11	12.19	11.9	11.73	-0.057	-0.057	-0.065	-0.067
	Epoxy 2	12.47	12.33	12.09	12.06	-0.048	-0.055	-0.051	-0.049

Table 1: Typical values of the SIR temperature indices for each of the double comb patterns 1 to 4 shown in figure 1.

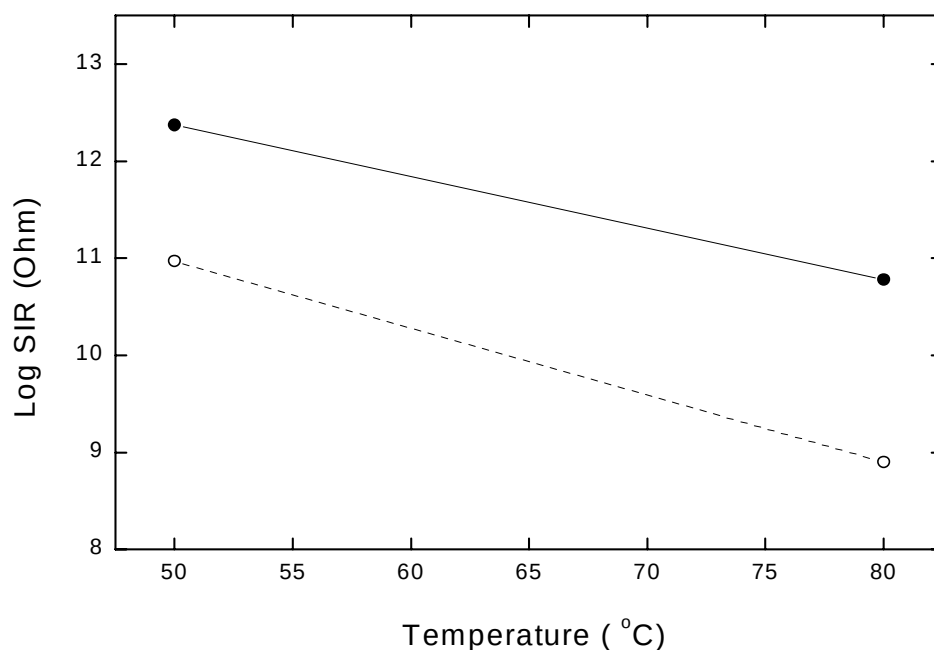


Figure 7: A comparison of the predicted SIR behaviour of epoxy formulations ER1 (○) and ER2 (●) for comb 1 deposited on a ceramic substrate as a function of temperature at 90 %R.H..

Some glob top materials appear to be relatively water resistant. The SIR of the material shown in Figure 8 remains almost independent of changes in humidity but shows an expected progressive decrease with increasing test temperature. It could be argued that this apparent insensitivity to moisture is due to the relatively short exposure times to high and low humidities. However the data shown in Figure 9 clearly shows that the SIR reaches a stable values after exposure to 85 % R.H. at 85°C within a period of approximately 30 minutes.

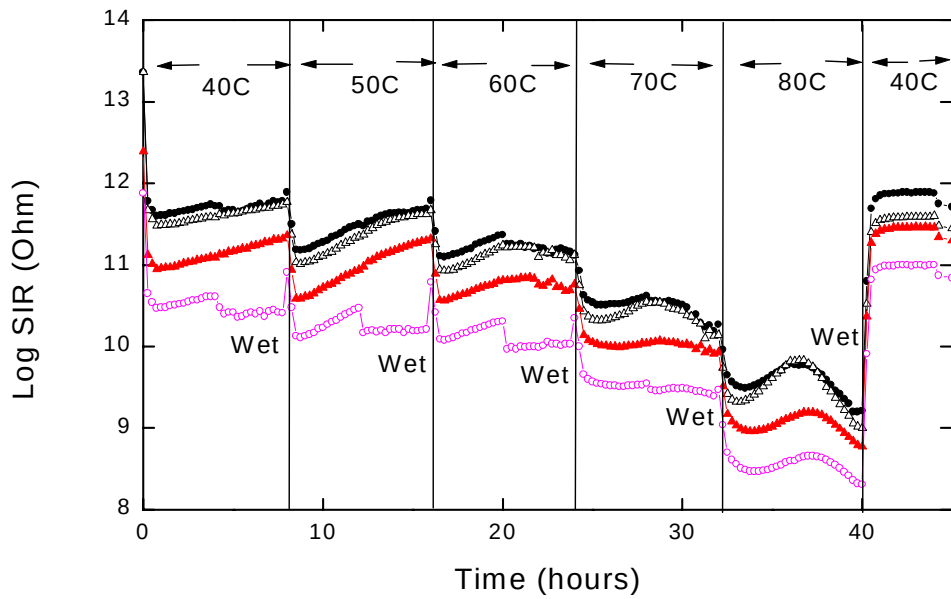


Figure 8 : An example of the temperature and humidity dependence of the SIR of a 'moisture resistant' epoxy based glob top material deposited on to a ceramic board. ($\circ$ = pattern 1, $\blacktriangle$ = pattern 2, $\triangle$ = pattern 3, $\bullet$ = pattern 4).

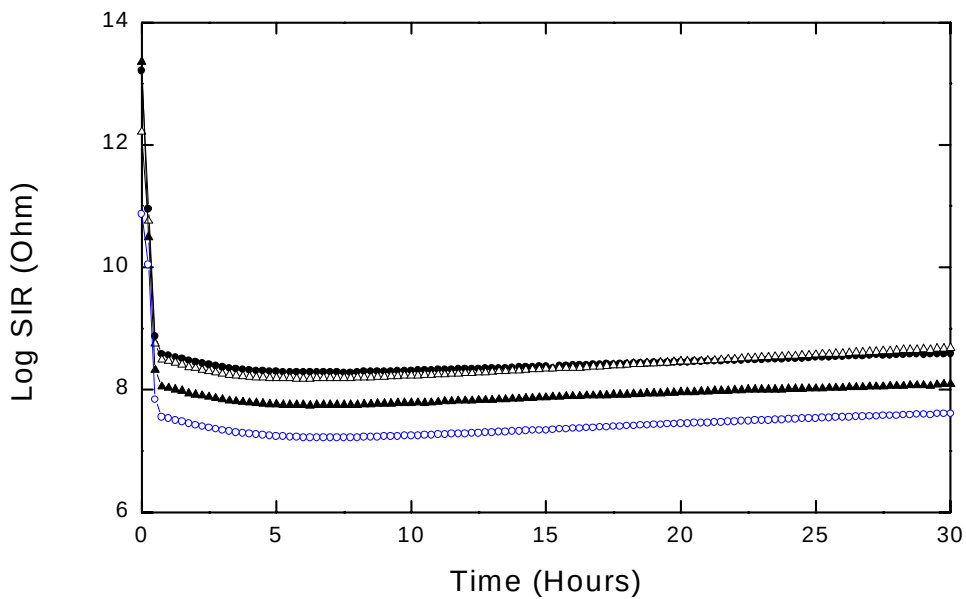


Figure 9 : The SIR of the epoxy based glob top material shown in Figure 8 rapidly reaches a stable value within approximately 30 minutes after exposure to 85 %R.H. and 85°C. ($\circ$ = pattern 1, $\blacktriangle$ = pattern 2, $\triangle$ = pattern 3, $\bullet$ = pattern 4).

Figure 10 shows an example of a glob top material that appears to be 'semipermeable' to water at higher temperatures. At 40°C the large rectangular combs are insensitive to increasing the humidity from 10 to 90 %R.H.. At higher temperatures the change in log SIR during exposure to dry or damp environments becomes increasingly more apparent. However the rate

at which log SIR changes after a change in the atmospheric humidity is much slower than that for the material shown in figure 5.

The procedure described in section 3.3 can be applied to materials that show similar behaviour to the examples shown in figures 8 and 10. However the temperature gradient may be non-linear.

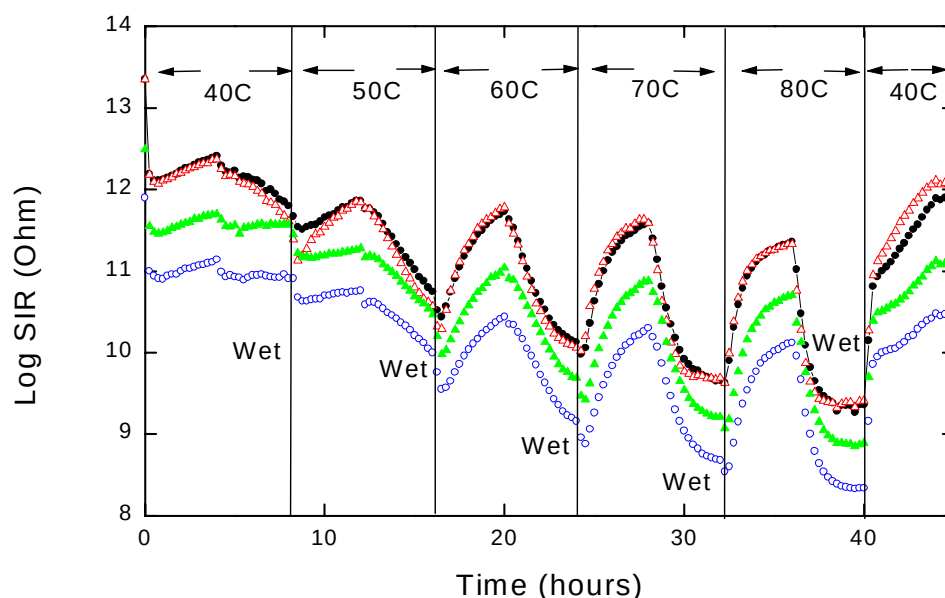


Figure 10 : An example of a 'semipermeable' urethane based glob top material deposited on to a ceramic board. (○ = pattern 1, ▲ = pattern 2, △ = pattern 3, ● = pattern 4).

6 ACKNOWLEDGEMENTS

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7 REFERENCES

Details of the study that lead to the derivation of the SIR temperature indices can be found in the National Physical Laboratory Report entitled ' Surface Insulation Resistance and the Properties of Encapsulants', P Tomlins and L.Zou, CMMT (A) 292, 2000.

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