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SIR, CAF and Condensation Testing for Electronic Assemblies

Ling Zou

17 July 2018

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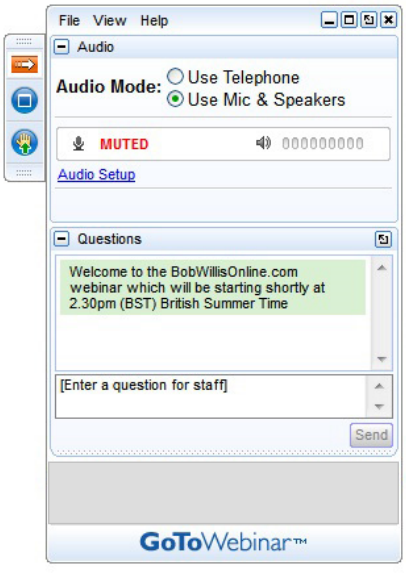

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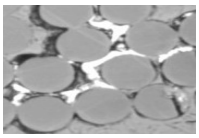
Electrochemical Reliability Testing for Electronic Assemblies

- Achieving high reliability in service is the key issue in today's high-density electronics assemblies.
- As assemblies move to increased packaging densities, and in many cases higher voltages, the field strengths driving electrochemical corrosion become greater
- In addition many assemblies are required to operate in harsher environments (hotter/damper/condensing).
- NPL undertakes metrological research and testing in three key areas
  - Surface Insulation Resistance Testing (SIR)
  - Conductive Anodic Filament Testing (CAF)
  - Condensation Testing

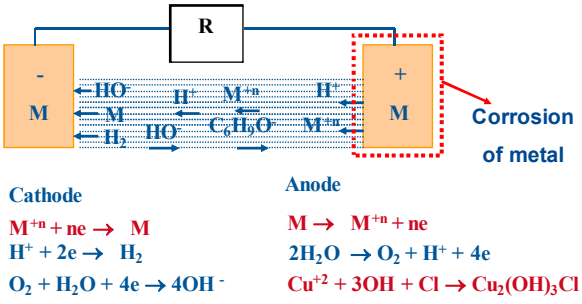
Electrochemical Corrosion

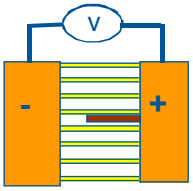
- For electrochemical corrosion to occur, the following must be present:
  - Bias, normally circuit operating voltages
  - Moisture, normally ambient humidity but can be condensation on or around the circuit assembly
  - Contamination
- Test methodology should reproduce these conditions using production processes to enable realistic determination of electronic assembly reliability
- For biased circuits the most important metal corrosion induced failures is dendrite formation and CAF (Conductive Anodic Filament) formation.

Dendrite short two conductors



Electrochemical reactions for biased circuit





Cathode

$M^{+n} + ne \rightarrow M$

$H^+ + 2e \rightarrow H_2$

$O_2 + H_2O + 4e \rightarrow 4OH^-$

Anode

$M \rightarrow M^{+n} + ne$

$2H_2O \rightarrow O_2 + H^+ + 4e$

$Cu^{+2} + 3OH + Cl \rightarrow Cu_2(OH)_3Cl$

- Corroded metal ion migrates from anode to cathode under electric field and deposited at the cathode to form dendrite on circuit board surface
- Corroded metal ion form insoluble metal compounds, and form CAF along glass fibre and resin interface inside circuit board.
- Both dendrite and CAF formation can cause circuit failure

7

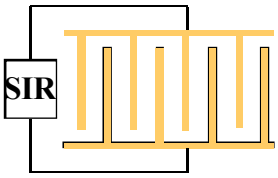
Surface Insulation Resistance (SIR)

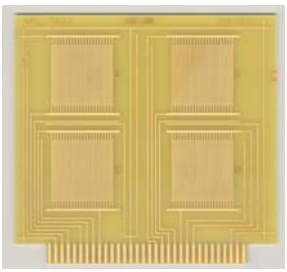
- These failures have been successfully identified and evaluated using Surface Insulation Resistance technique, this technique is based on the measurement of an leakage current (SIR) associated with this electrochemical corrosion process.
- SIR measurement is a direct measure on circuit reliability, and is the only method which attempts to link contamination and reliability.
- Any ionic contamination will lower the SIR and degrade electrical performance of the circuit, if the contamination is corrosive, and then dendrite can be formed and cause circuit failure.
- SIR technique can be used to qualify both materials and production processes.

8

SIR Measurement

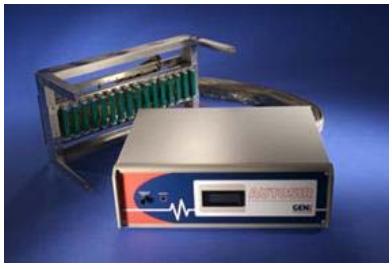
- How to measure the SIR
- A test board with a test pattern is exposed to an accelerating test environment of temperature and humidity under bias to measure Surface Insulation Resistance SIR (leakage current) between two metal electrodes on a insulated substrate surface.
- The SIR value is dependent on following test parameter
  - Test voltage (Field strength)
  - Test pattern (Overlap and spacing)
  - Test environment (Temperature and humidity)

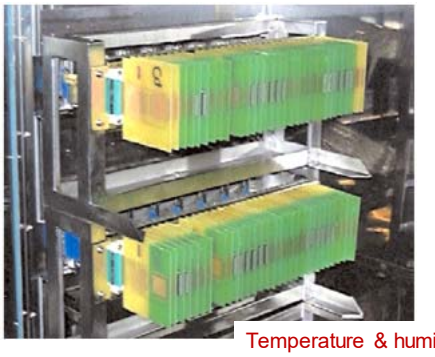




9

SIR Measurement



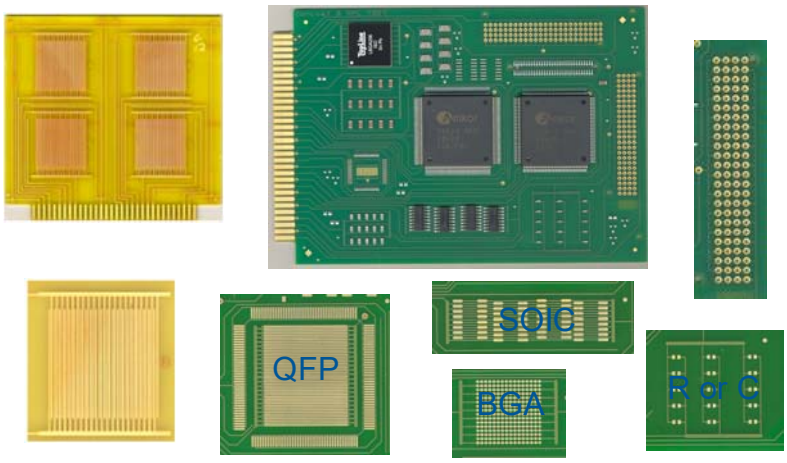


Temperature & humidity controlled chamber

- 256 measurement channels can be measured.
- How to design your test board, and set test condition (test temperature, humidity and test bias).

10

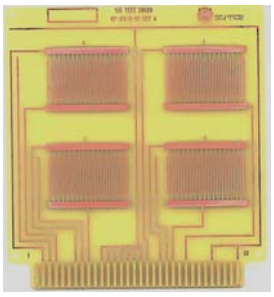
How to design test board



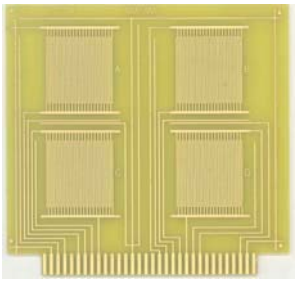
- SIR can be measured on simple comb pattern.
- SIR test pattern can be incorporated into the design

11

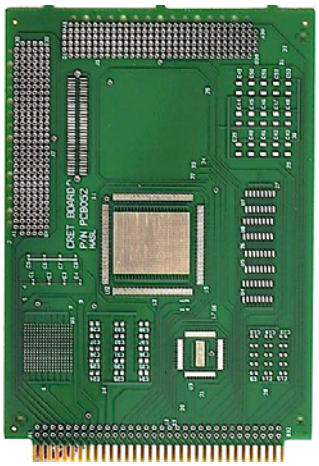
Standard Test Boards



IPC-B-24
500/400µm



NPL
(IPC-B-53)
200/400µm

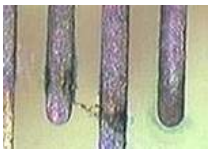


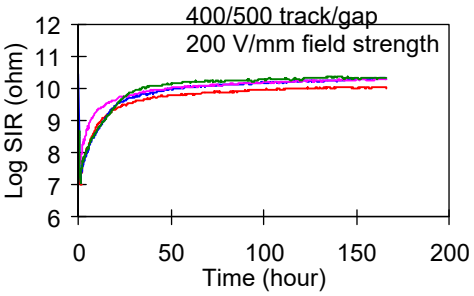
IPC-B-52
200 to1200µm

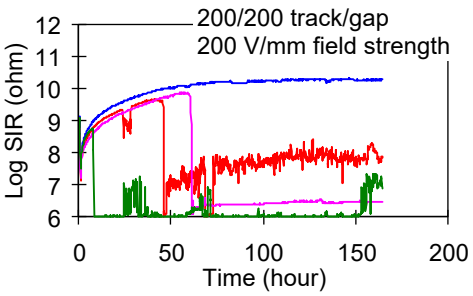
12

SIR Test Pattern

- Cu finish board
- 50µl flux on each pattern.
- The flux board was dried for 5 minutes at 100°
- Test condition: 65°C/85%RH for 168 hours







- Test pattern is critical in terms of the SIR response.
- With the same field strength, dendrite formed on fine pitch test board, but not on coarser pitch board.

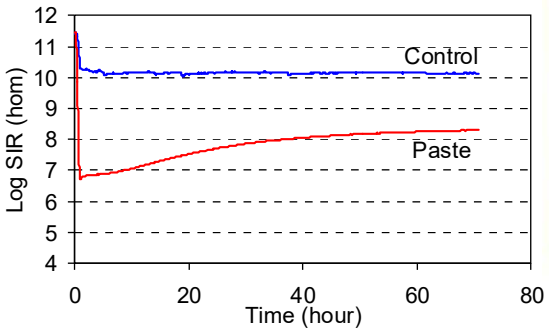
13

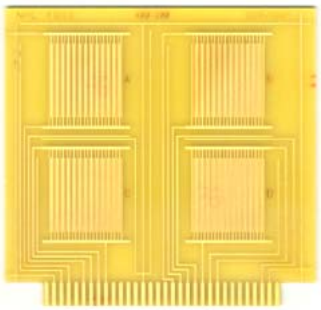
Materials Testing

- Simple comb pattern can be used to compare different materials.
  - Measure different fluxes
    - Test board can go through wave soldering process.
    - Disperse flux on test pattern, then test.
  - Different pastes.
    - Print paste on the board, and reflow
  - PCB materials, surface finishes, solder masks or conformal coatings, state of cure
    - Make test board with different materials or coated with different coating materials.

14

How to read SIR results





- Paste printed and reflow.
- Tested at 40°/93%RH with 5V.

- The paste after reflow left detectable residues lowing the SIR.
- SIR response can be different from different pastes.

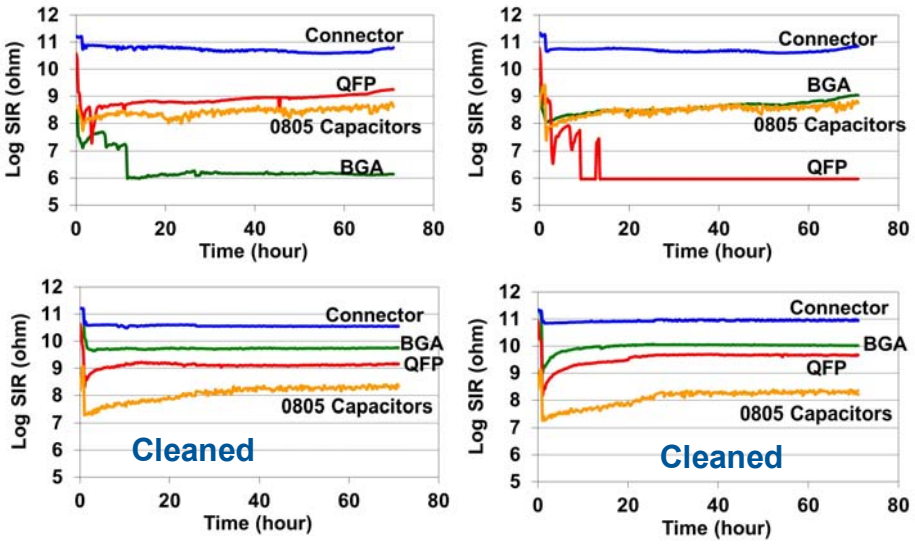
15

Process and Design Testing

- Complex board design with isolated components assembled can be used to qualify production process, particularly when cleaning processes involved.
- Test boards assembled, then re-worked on QFP and BGA with liquid flux, with and without cleaning.

16

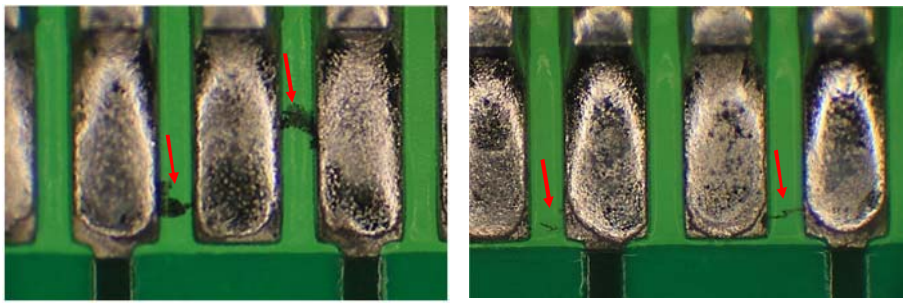
Typical Process SIR results



- Tested at 40°/93%RH with 5V.

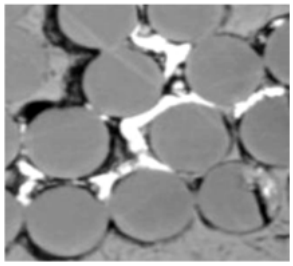
17

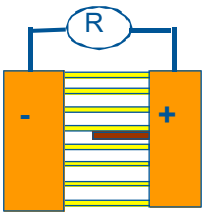
Dendrites on failed component



Conductive Anode Filament (CAF)

- CAF formation inside the PCB is an important failure mode for electronic circuit. It is a electrochemical process, and initially caused by anodic Cu corrosion.
- CAF is Cu corrosion products grow along the glass/resin interface from anode to cathode to bridge two opposite charged conducts.



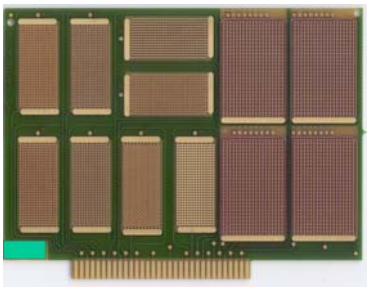


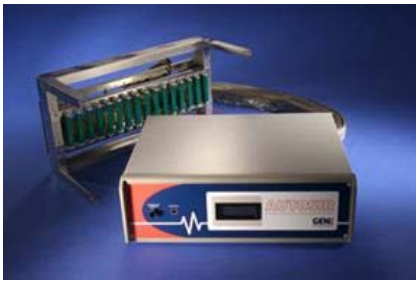
Increasing concerns about CAF

- CAF failure was first reported in the 1970's by Bell laboratory.
- Three main drivers of increasing concern:
  - The drive to increase circuit density with smaller printed wiring board geometries.
  - The rapid increase of the use of electronics in harsh environments and for high reliability and safety critical applications.
  - High temperature lead-free soldering process affect laminate stability and increase CAF failure.

20

CAF measurement



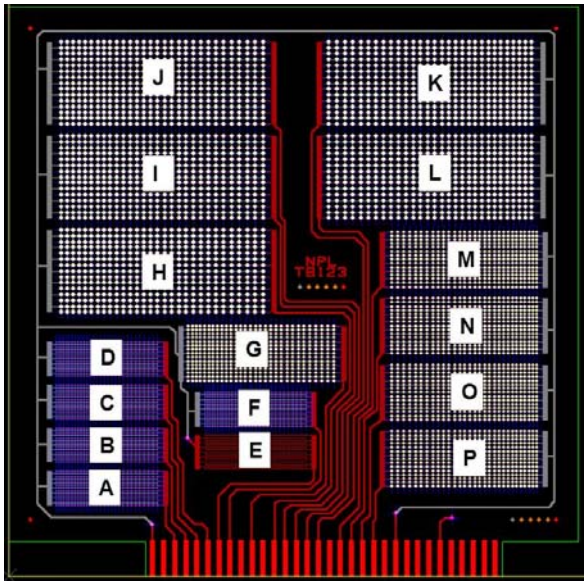


- Test PCBs at high temperature and humidity (85°C/85% RH) condition with bias (50V) for 500 -1000 hours.
- Monitor Insulation Resistance (IR) continually.

21

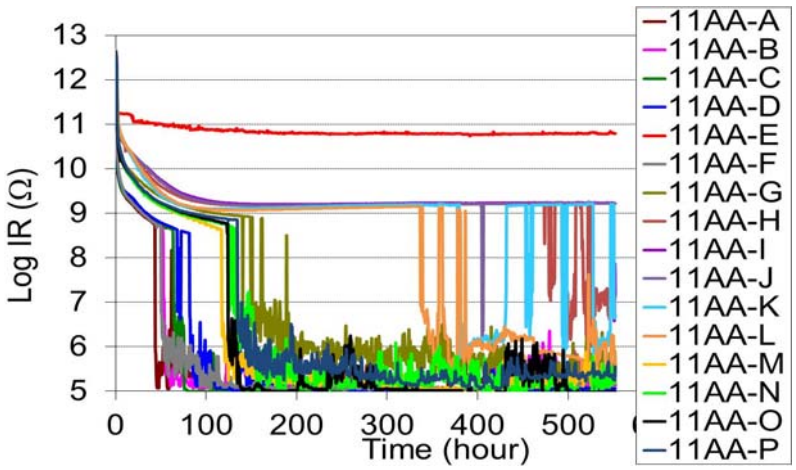
CAF TB123

- 16 Patterns:
  - 5 x 250μm Ø 300 μm wall to wall
  - 5 x 500μm Ø 400 μm wall to wall
  - 5 x 800μm Ø 550 μm wall to wall
  - 1x SIR control
- Each Pattern has 450 holes & 420 CAF opportunities
- 30 holes in staggered in x Pitch varied by 0.541 mm corresponds to 1080 Fabric fill pitch
- 6 boards per panel (Horizontal or vertical)



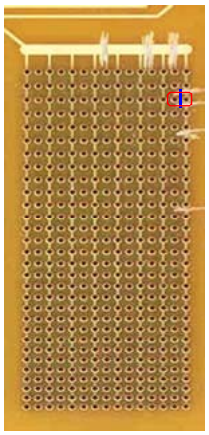
22

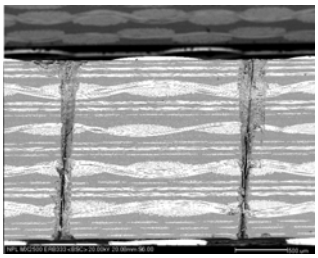
How to read IR (CAF) results

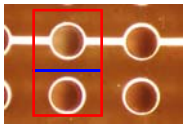


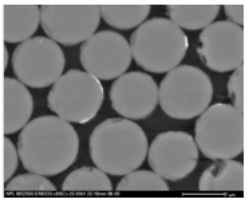
- Time to Failure (TTF): Time at IR first drop below $10^8\Omega$

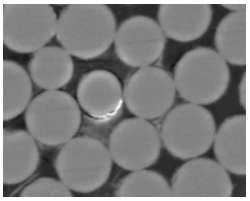
Locating CAF between two via

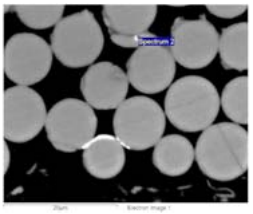








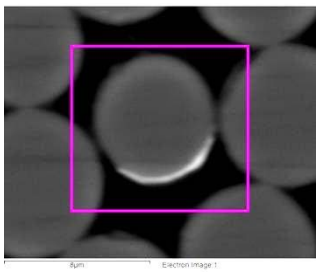


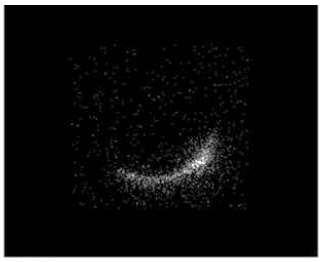


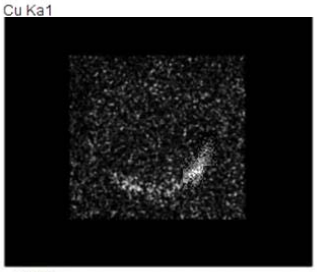
- Each Pattern has 450 holes & 420 CAF opportunities.

24

Element map for CAF

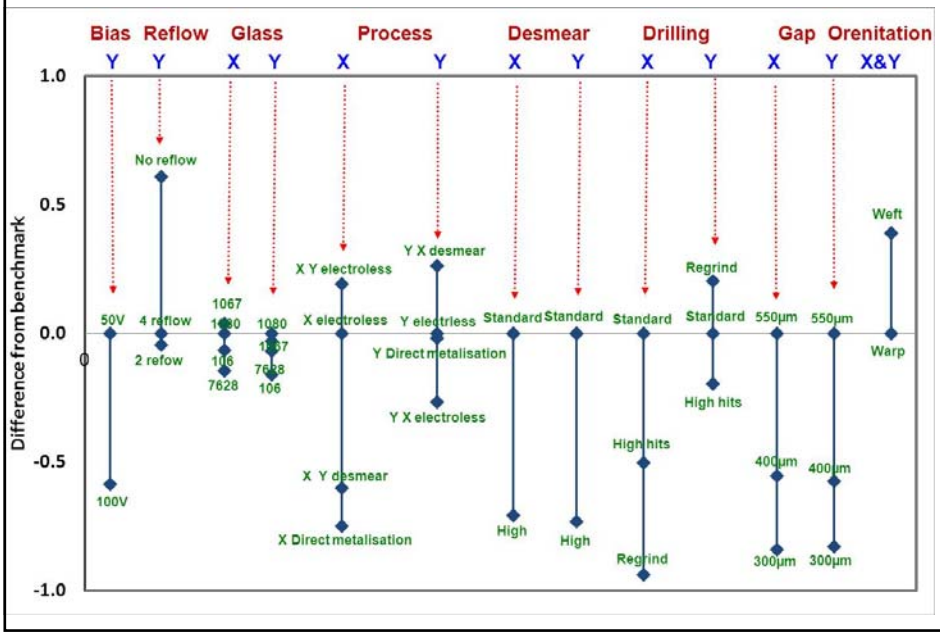






25

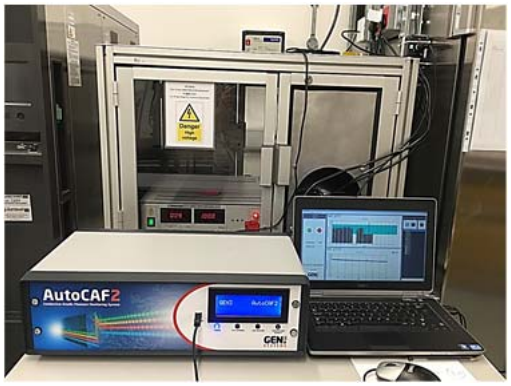
Summary



1000V SIR Test Capability

- Test voltage play a very important role for circuit reliability.
- The test voltages for existing measurements are only up to 300V. Trends for more electric vehicles mean that these measurements need to be conducted at significantly increased voltages to understand potential new failure mechanisms when using voltages up to 1000V.
- Some testing in Asia reported at 2000 and 3000V (over stressing)
- NPL has commissioned a 1000V SIR test facility

1000V SIR Testing



- First 1000V testing for 1000 hours has been successfully completed.
- The cables used for the testing is capable for 1000V.

Condensation Testing Introduction

- Electrochemical failure is very sensitive with moisture. When move from ~100 nm (85°C/85%RH) to visible liquid water layer (condensation), the metal corrosion on circuit board can be significantly accelerated. Failures can be happened in a few minutes. Condensation is very dangerous for circuit board.
- Condensation only happened where there is rapid temperature and humidity change either for objects or for surrounding environment.

29

Condensation on circuit boards in real world

- When there is rapid temperature change for circuit board or ambient condition. Low temperature on board (below dew point) will cause condensation, eg aircraft descending from high altitude. These conditions can last for minutes, may be half an hour.
- If the board sit in this environment long enough, board temperature will reach ambient temperature slowly, then condensation will be evaporated and disappeared.
- If temperature difference between board and ambient can be maintained, condensation will build up continually.
- Condensation is not a equilibrium and stable state, due to the transient nature of condensation it is difficult to control and repeat.

30

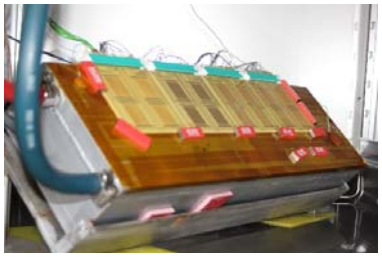
NPL approach to create condensation

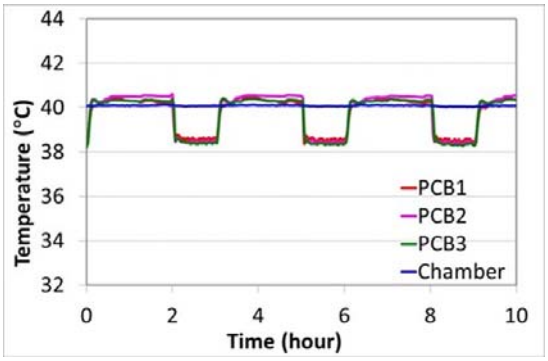
- We do not disturb the stable temperature / humidity condition of the chamber
  - With high humidity any chamber temperature above room temperature can be used
- We directly depress the temperature of the test board to any required specific temperature
  - This transition takes a few minutes
  - By depressing the temperature to any point, the condensation level can be set and controlled to the required level
  - Can be maintained indefinitely, hence the condensation film can be maintained indefinitely
  - A uniform condensation film is formed across the whole sample
  - The condition can be cycled, taking the condensation film off and on.

31

How it works: The Condensation System

- The test boards are mounted on a platen.
- The platen temperature is independently controlled, and can be lowered to required temperature to control condensation level.





32

The dew point

Ambient Condition	Dewing point	Below ambient
40°C/80%RH	35.6°C	4.4°C
40°C/85%RH	36.8°C	3.2°C
40°C/93%RH	38.6°C	1.4°C
50°C/80%RH	45.0°C	5.0°C

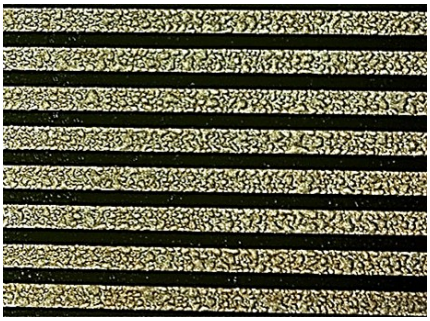
- At different ambient condition, condensation levels on the sample can be controlled by the platen temperature (test sample temperature).

33

40°C/93%RH – 0.1°C below dewing point – PCB for 60 mins, then sample back to 40°C

34

Condensation build up in 60 minutes

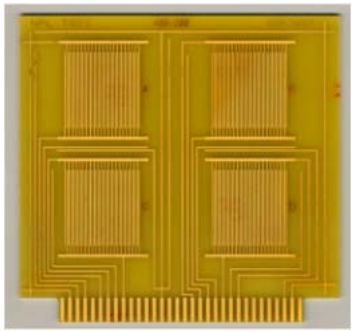


At 30 minute

At 60 minute

35

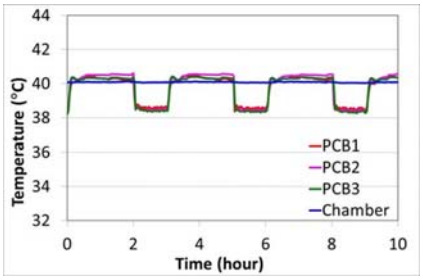
Using condensation system to evaluate circuit board reliability



- Simple comb SIR test board
- Condensation on and off
- SIR measurement

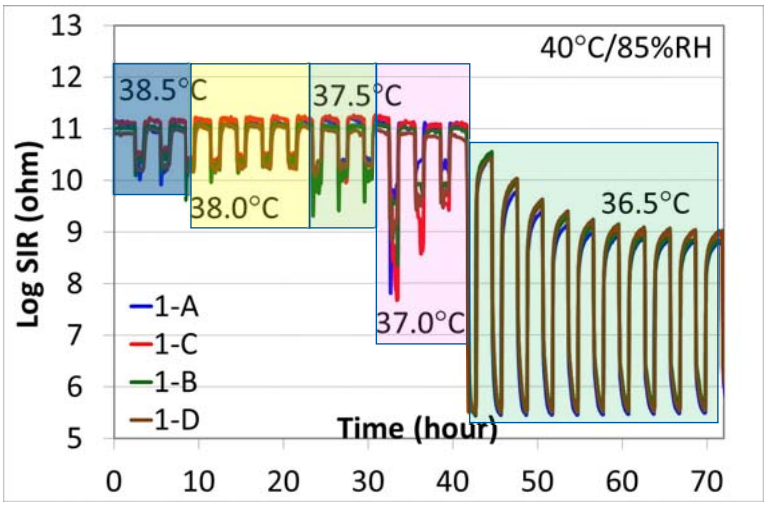
Tested at
40ºC/93%RH, 5V

400/200
track/gap



36

Bare PCB SIR results – 40°C/85%RH 5V – (dewpoint = 36.8°C)



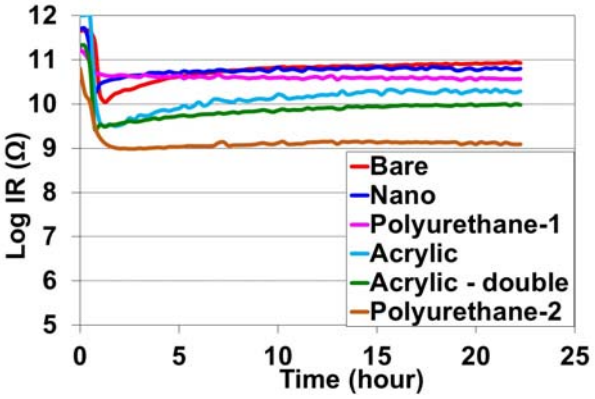
37

Evaluate conformal coating protection from condensation

- Conformal coatings are applied to protect electronic assemblies
- Conformal coatings are not a moisture barrier, SIR drops as coatings are applied. But they are a liquid barrier.
- The issue with CC is that perfect coverage over all terminations can be problematic.
- Any exposed termination can act as an electrode
- Condensing conditions will seek out these exposed areas and cause failures.

38

SIR results for coated PCB - 40ºC/93%RH



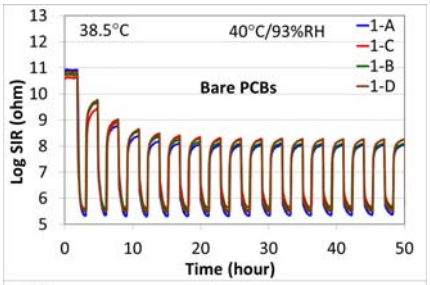
400/200 track/gap

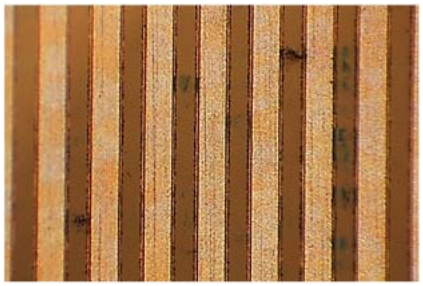
Tested at 40ºC/93%RH, 5V

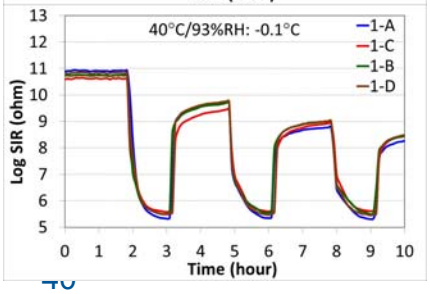
- The presence of conformal coatings lower SIR in high humidity environments.
- Conformal coatings have been proved are not a moisture barrier.
- Are coatings liquid water barrier?

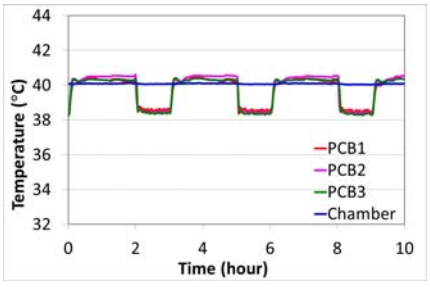
39

Bare PCB Condensation Results – 40°C/93%RH 5V



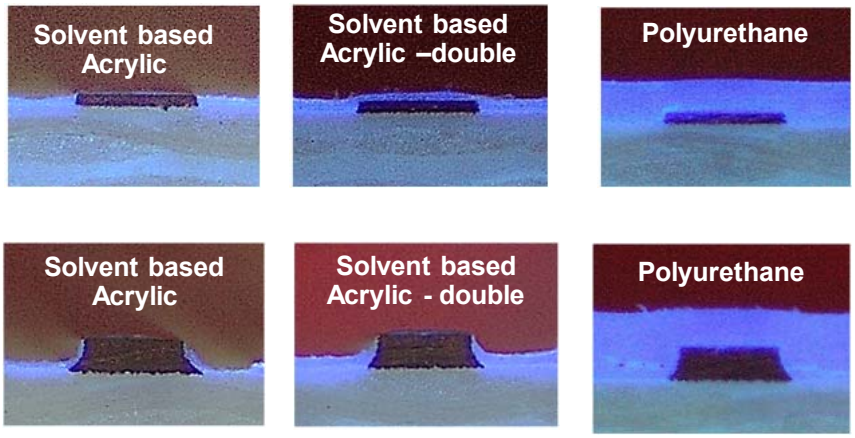






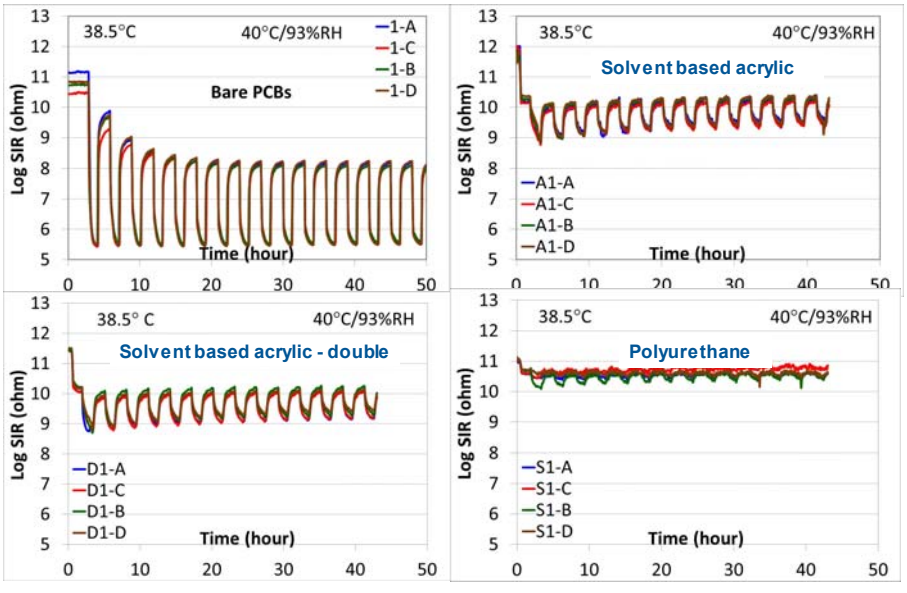
40

Coating coverage – 1oz. & 3oz. Cu track

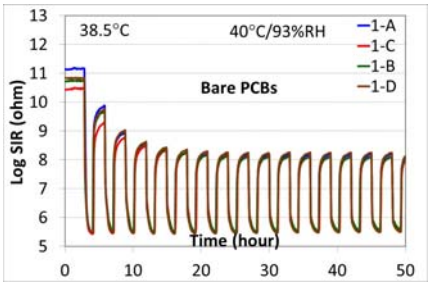


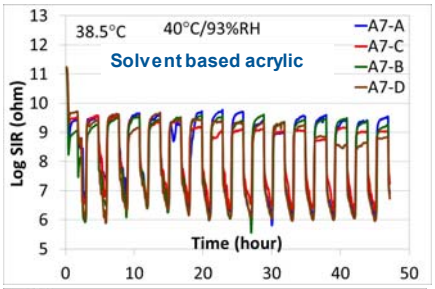
41

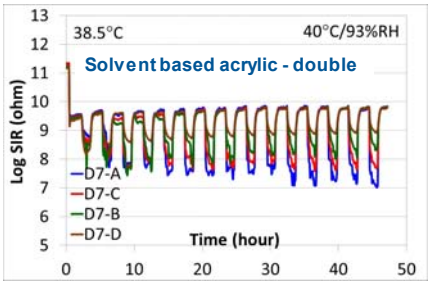
Coated PCB SIR results – 1oz Cu tracks

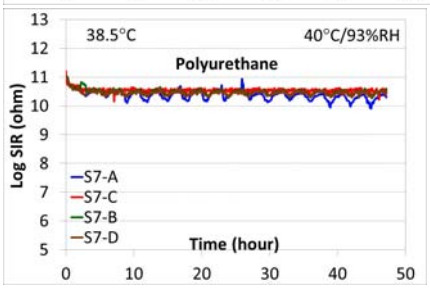


Coated PCB results – 3oz Cu tracks

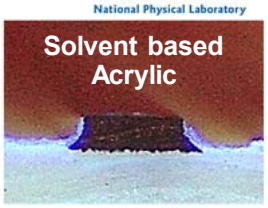


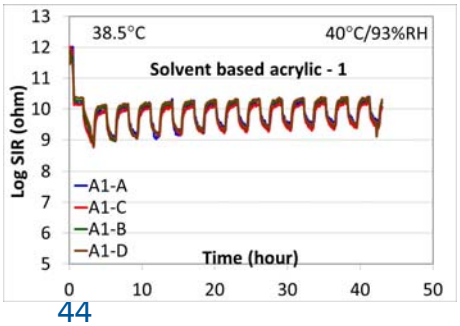


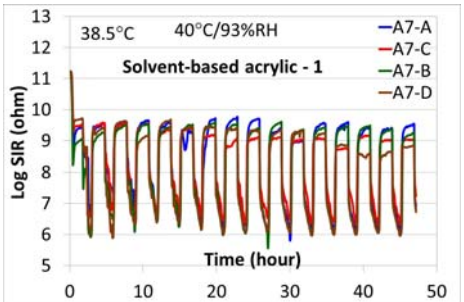




Corrosion and dendrite formed

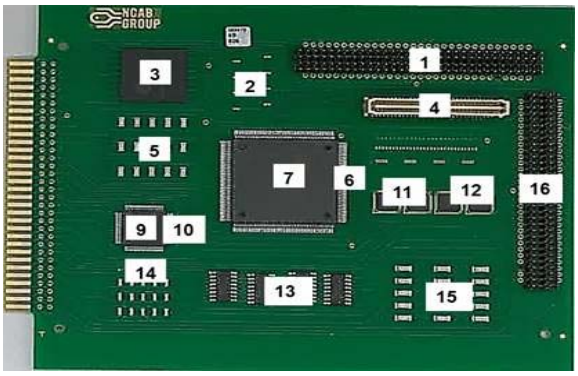






44

Test assembly – SIR pattern code

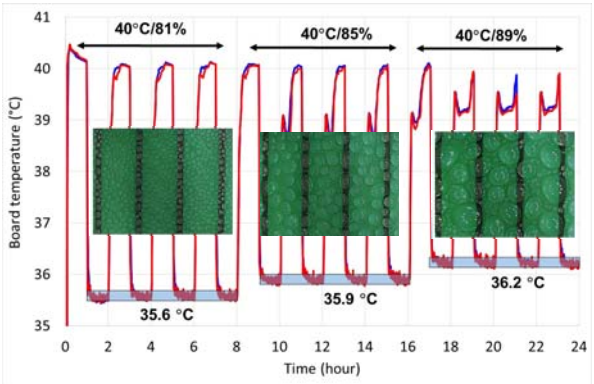


SIR pattern	Component
1	TH connector
2	0402 capacitor
3	BGA256
4	SMT connector
5	0805 capacitor
6	QFP160
7	Comb
8	none
9	Comb
10	QFP80
11	QFN40
12	QFN40
13	SOIC16
14	0603 capacitor
15	1206 capacitor
16	TH connector

SIR code	Paste	Solvent based acrylic Coating
1	A	None
2	A	Double
3	A	Single
4	B	None
5	B	Double
6	B	Single

45

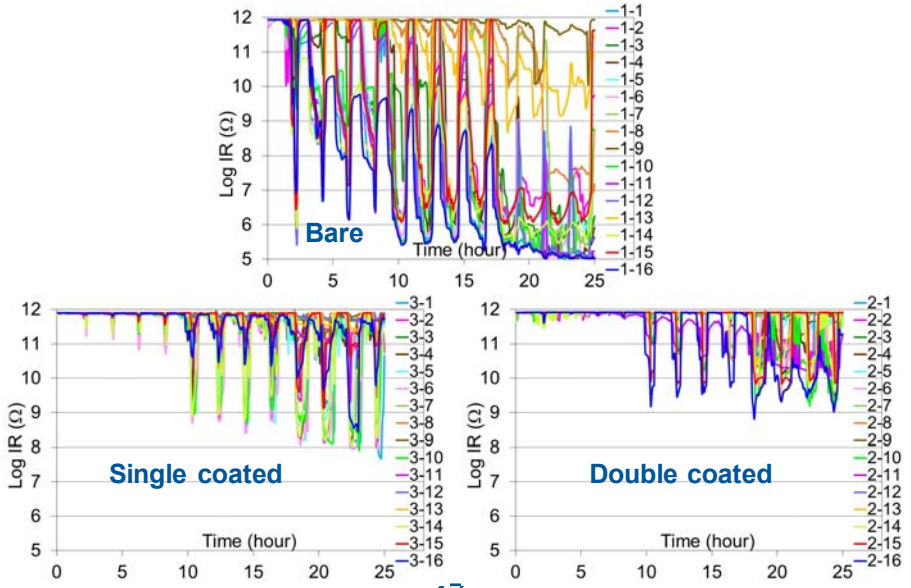
Temperature recorded on test sample for three condensation levels



Chamber condition	Dew point (°C)	Board temperature[1] (°C)	Below dew point (°C)	Condensation[2] (mg/cm²)
40°C/81%	35.8	35.6	0.2	2.2
40°C/85%	36.8	35.9	0.9	9.2
40°C/89%	37.7	36.2	1.5	15.0

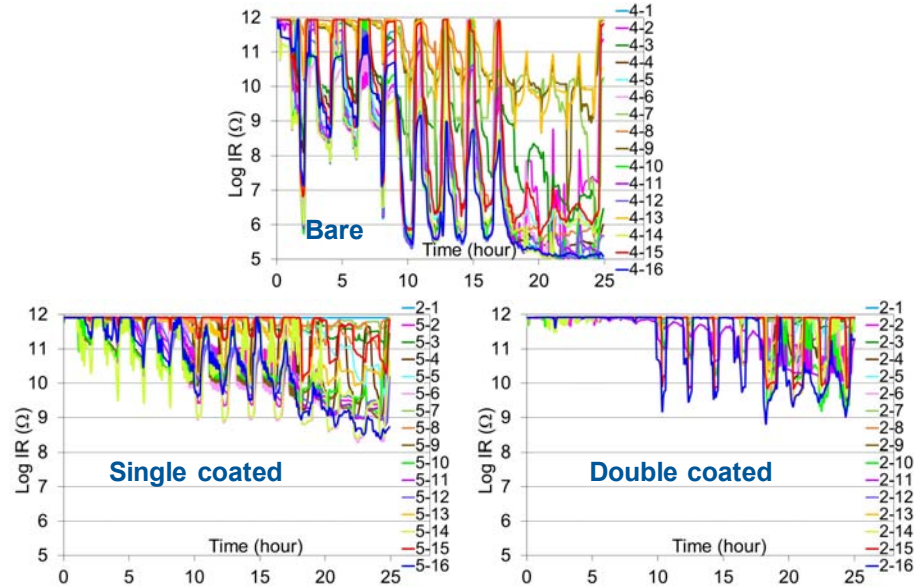
46

SIR results – paste A

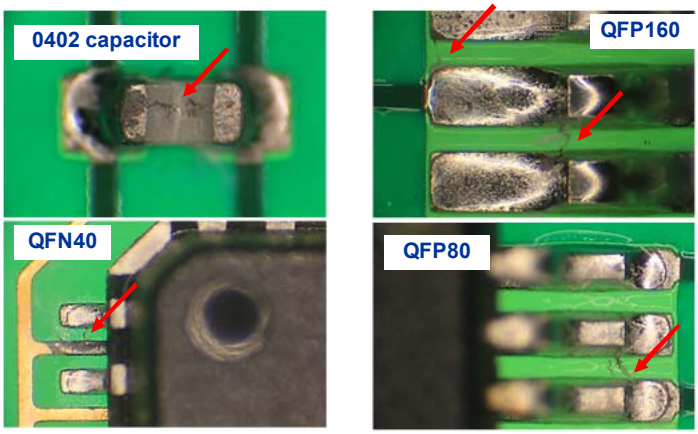


47

SIR results – paste B



Dendrites formed on un-coated assembly



- Corrosion and dendrite weren't found on coated assemblies

49

Summary

- SIR testing can be used to evaluate and discriminate between PCB fabrication and assembly materials and processes
- CAF testing can be used to evaluate and discriminate between PCB fabrication materials and processes, and also assembly processes
- Condensation testing can be used to evaluate coating protection performance for PCBs and assemblies.

50

SIR, CAF, Condensation measurement service

- SIR and CAF measurement service.
  - Up to 1000V
  - Controlled temperature and humidity
  - Controlled condensation level
  - 256 channels can be measured.
- Please contact us

  For advise on the techniques.

  SIR measurements.
- Contact detail

  Ling Zou (ling.zou@npl.co.uk), Tel: 0208 943 6065

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Characterisation and Testing of Hydrophobic and Water Resistant Coatings – The Next Generation in Coating Technology?

Tuesday 20th November:
Condensation Testing – Initial Results from a Round Robin Project

All webinars are at 2.30pm UK Time

Book your place on line www.npl.co.uk/ei