Improved Condensation Testing to Evaluate Protection Performance of Conformal Coatings

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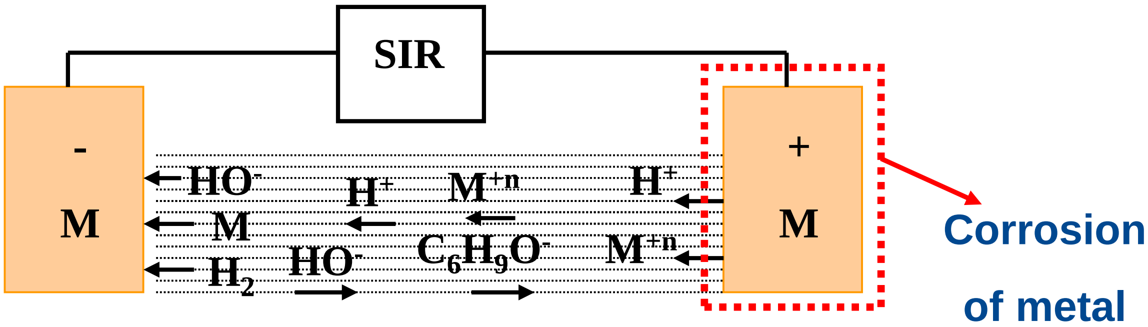
Introduction

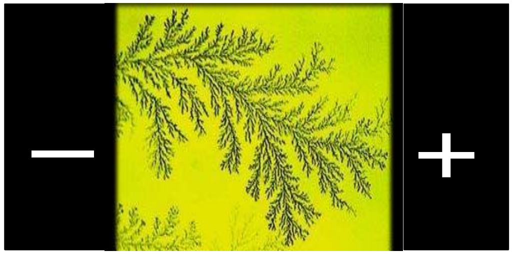
- Why the circuit reliability is important
- How to evaluate and predict circuit reliability using Surface Insulation Resistance (SIR) measurements
- How condensation affects the electrochemical reliability of circuits
- Issues with conventional condensation testing
- NPL’s new approach to condensation testing
- How to control different condensation levels using the new approach.
- Results for a protection performance evaluation of conformal coatings using condensation testing at three different levels.

Introduction

- Achieving high reliability in service is a key issue in today’s high-density electronic assemblies.
- As packaging densities increase, and electronic assemblies move to ever harsher environments (hotter/damper/ condensing), electrochemical reliability becomes more critical
- The combination of contaminants, moisture and electrical bias facilitate electrochemical corrosion processes that result in loss of continuity or short circuits (failures)
- Moisture plays an important role for circuit failures, and condensation can significantly accelerate failures.

Electrochemical failure and Surface Insulation Resistance (SIR) measurement





Dendrite short two conductors

Cathode

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

$H^+ + 2e \rightarrow H_2$

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

Anode

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

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

- SIR measurements are based on the measurement of an leakage current associated with this electrochemical corrosion process.
- This corrosion process is very sensitive to moisture. When moving from ~100 nm water films (85°C/85%RH) to visible liquid water layer (condensation), the metal corrosion on circuit board can be significantly accelerated. SIR will drop significantly, and failures can occur in a few minutes.

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Condensation formation on circuit boards in real world

- Electronic circuits can easily suffer from condensation in service
- Condensation normally occurs where there is a rapid temperature and/or humidity change of either for circuit assembly or the ambient conditions. Low circuit assembly temperatures (below dew point) will cause condensation onto components and substrates, e.g. aircraft landing from high altitude.
- These conditions generally only last for a few minutes until the assembly and/or environment equillibriate.
- Condensation is not a equilibrium and stable state. Due to the transient nature of condensation, it is difficult to control and repeat.

The dew points and condensation formation

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

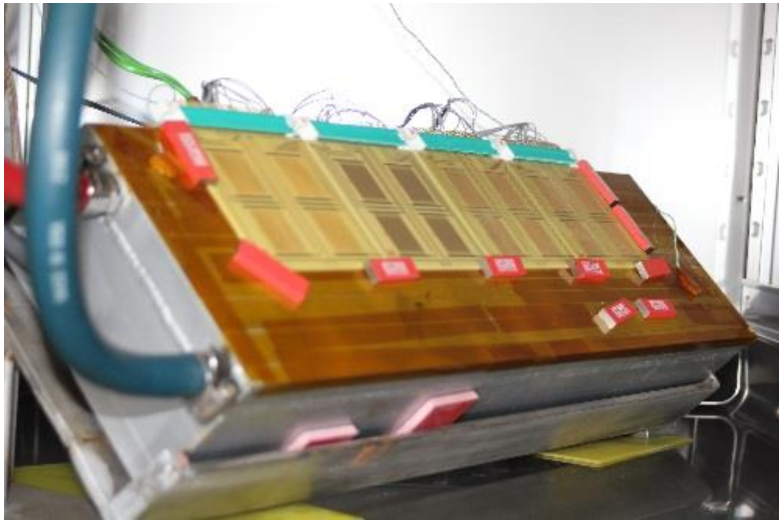
- For condensation testing, ideally, we need to control the sample temperature independently from the environment.
- Condensation levels can be controlled by the temperature difference between samples and the environment.

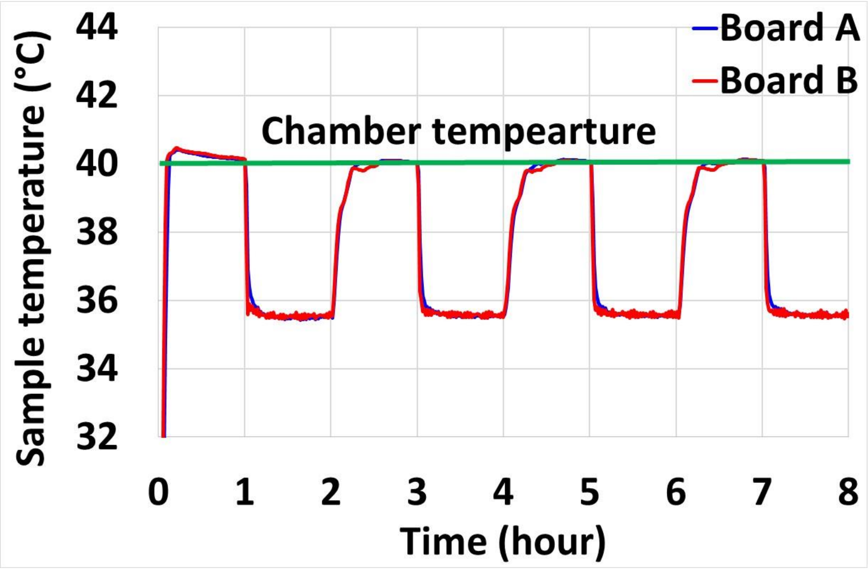
NPL new approach to create condensation

- We maintain a stable temperature / humidity condition within 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 only takes a few minutes
  - By depressing the temperature to any point, the condensation level can be set and controlled to the required level
  - A uniform condensation film can be formed across the whole sample
  - The condition can be cycled, taking the condensation film off and on to simulate the condensation in real world .

How it works: The Condensation System

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





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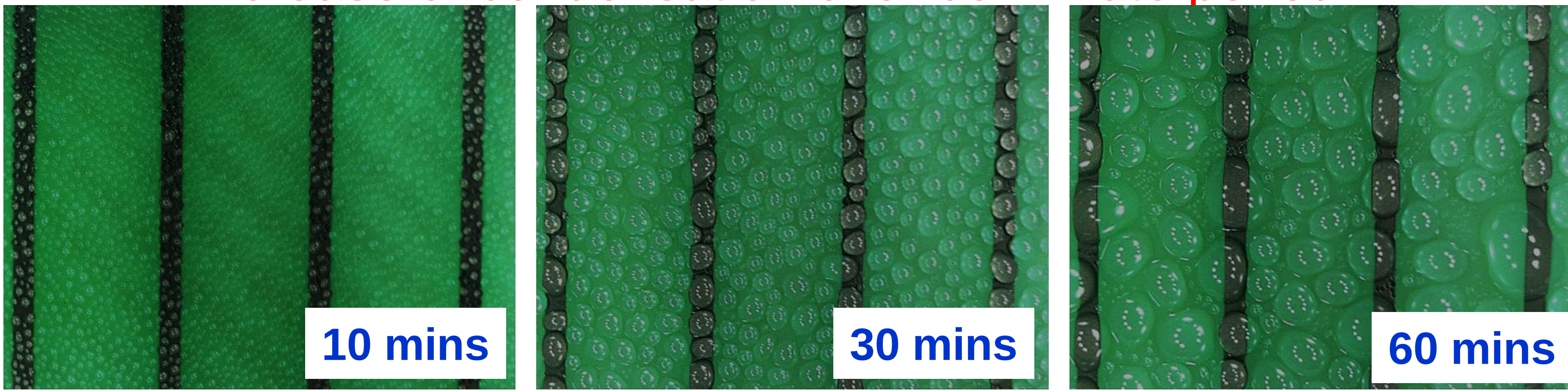
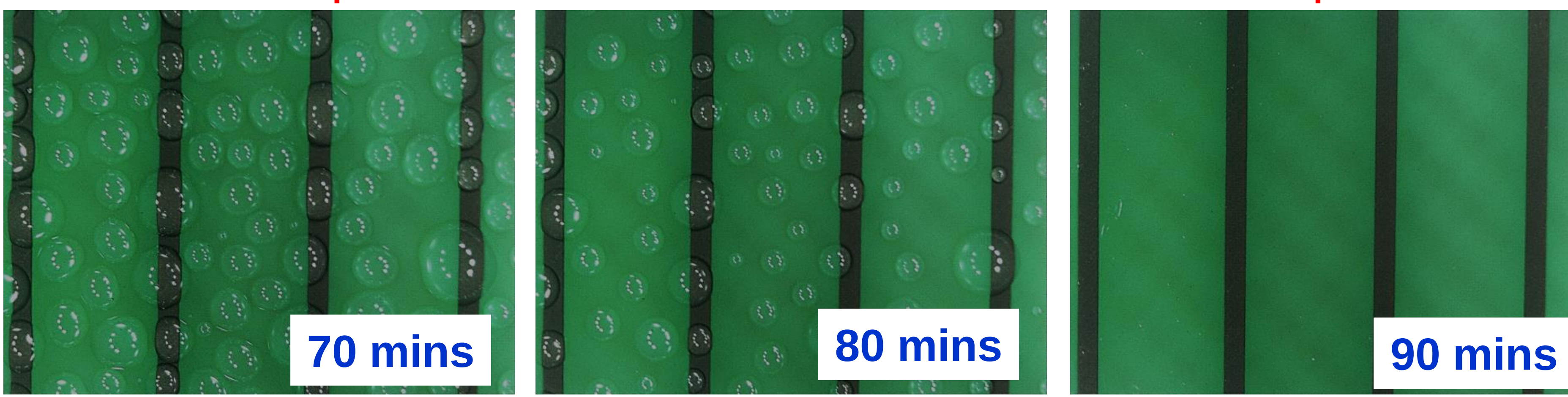
40°C/85%RH – 0.9°C below dewing point – PCB for 60 mins, then sample back to 40°C

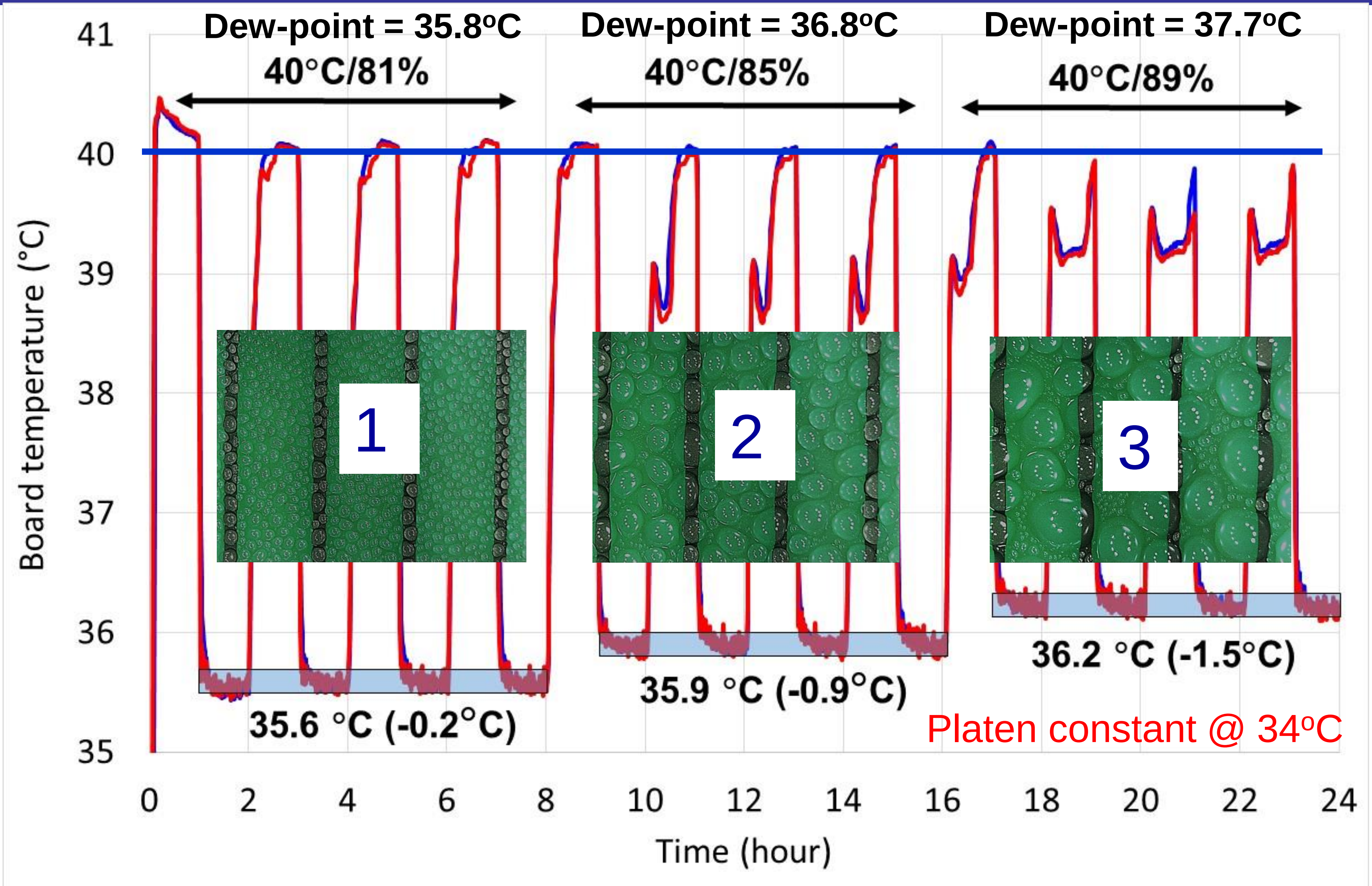
Increase of condensation over 60 minute period



Evaporation of condensation over 60 minute period

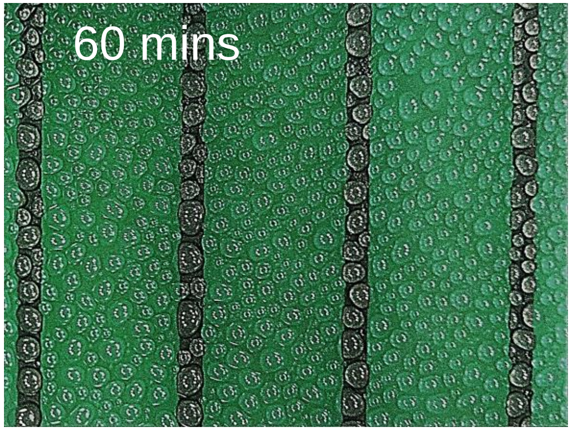


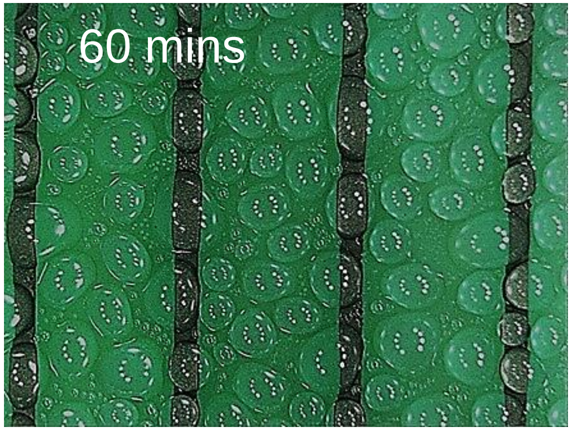
Three condensation levels used for 24 hours testing

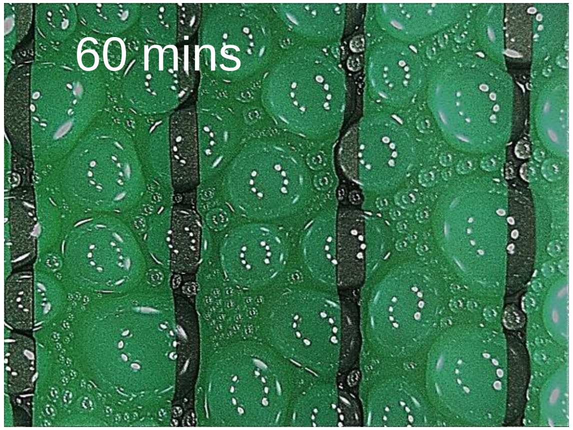


Three level condensations

Chamber condition	Dew point (°C)	Board temperature[1] (°C)	Below dew point (°C)	Condensation[2] (mg/cm^2)
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







- 24 hours condensation testing with three condensation levels, 4 cycles at each level.

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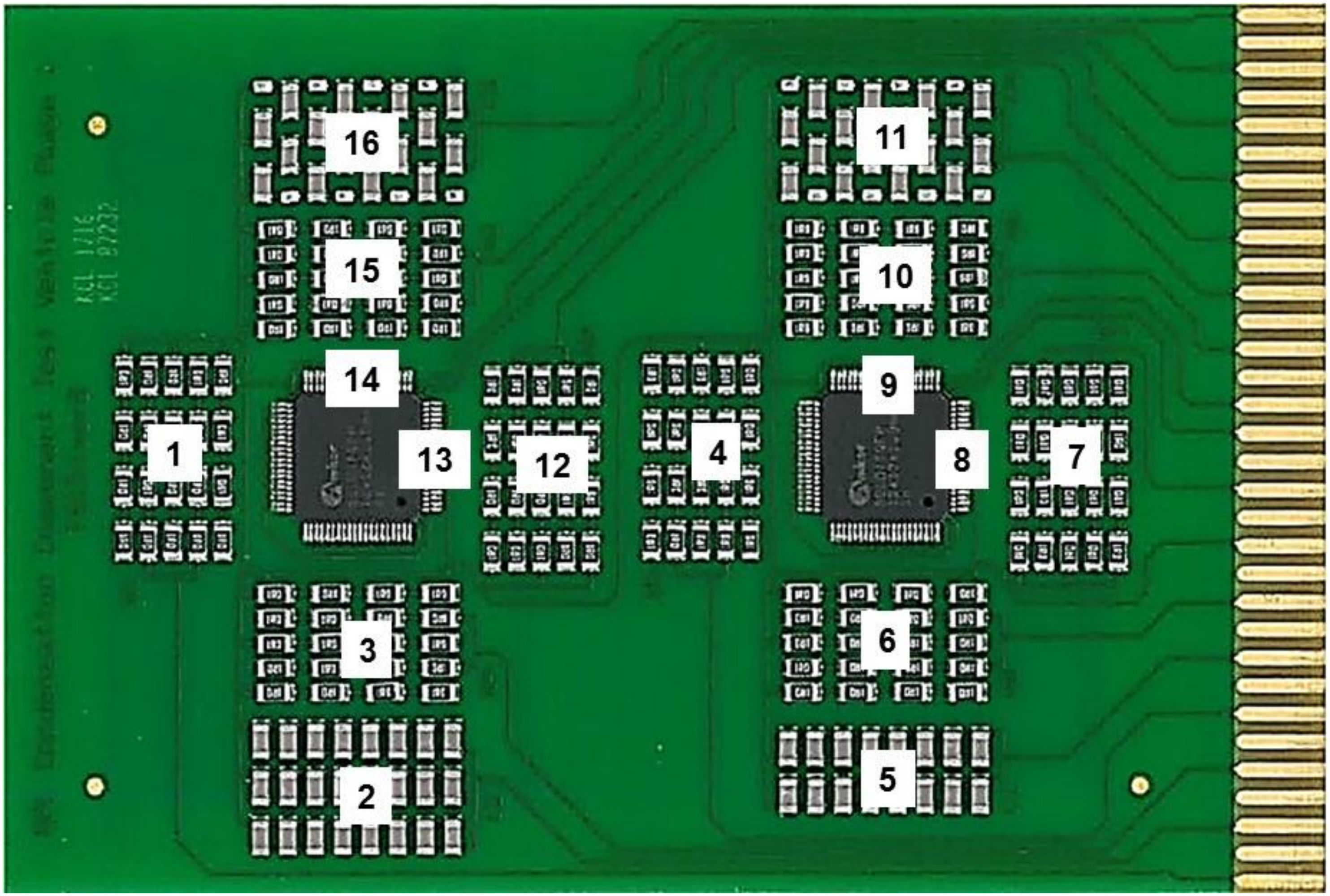
Industry partners joint project

- Alpha Assembly Solutions
- Continental Automotive Systems, Inc.
- GEN3 Systems Limited
- Henkel Ltd
- H K Wentworth Ltd
- HumiSeal Europe Ltd
- MBDA UK Limited
- Momentive
- Robert Bosch Gmbh
- Rolls-Royce Controls & Data Services Ltd
- TRW Electronics Engineering
- The partners were coded as A, B, C, D, E, F, G, H, I, J and K

TB151 assembly and SIR pattern codes



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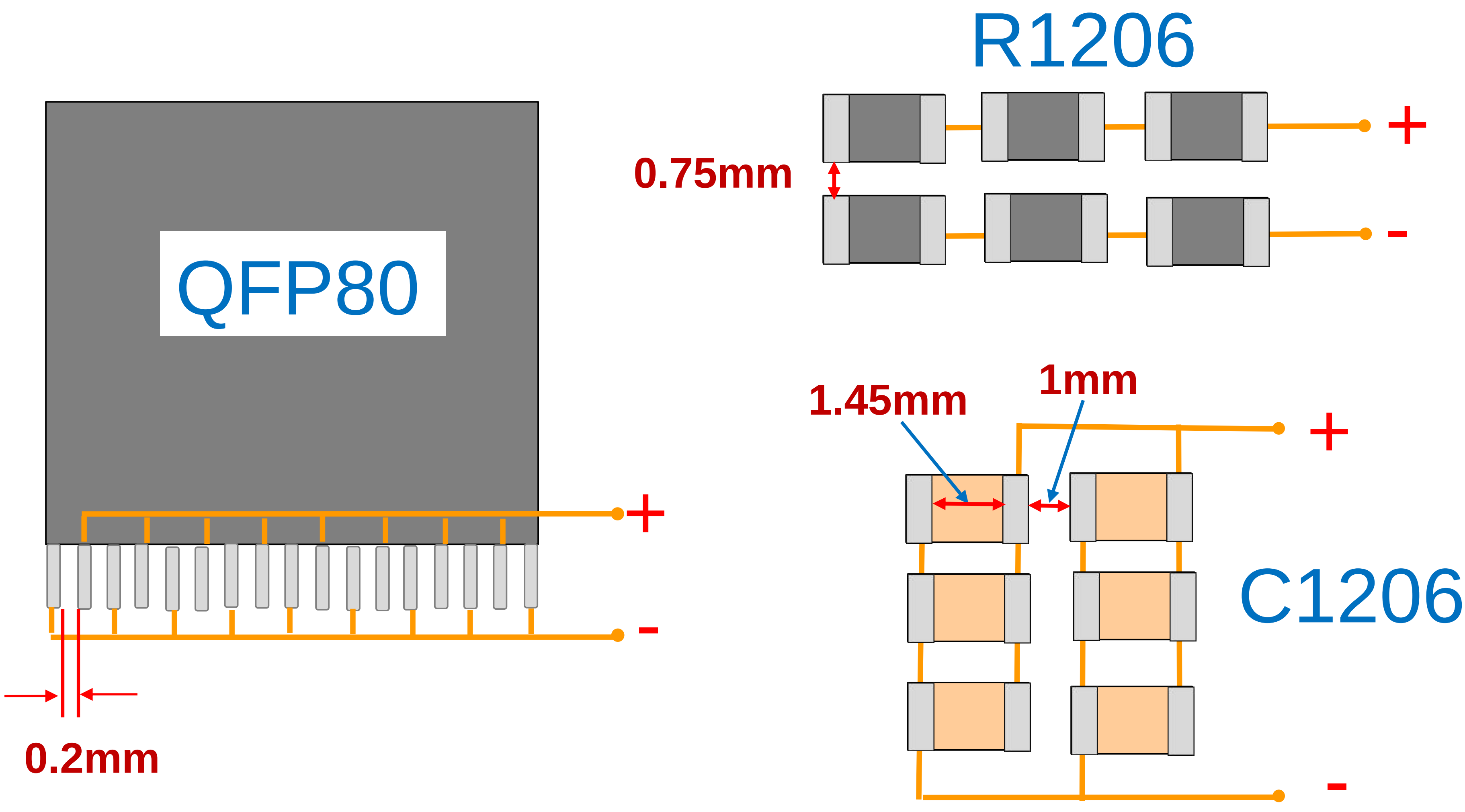
SIR pattern codes

Code	SIR pattern	Code	SIR pattern
1	R1206 resistor, X orientation	9	QFP80 Y orientation
2	C1206 capacitor	10	R1206 resistor, Y orientation
3	R1206 resistor, Y orientation	11	C1206 capacitor, staggered
4	R1206 resistor, X orientation	12	R1206 resistor, X orientation
5	C1206 capacitor	13	QFP80 X orientation
6	R1206 capacitor, Y orientation	14	QFP80 Y orientation
7	R1206 resistor, X orientation	15	R1206 resistor, Y orientation
8	QFP80 X orientation	16	C1206 capacitor, staggered

Components incorporated into SIR patterns



Test matrix

- NPL built and supplied each partner with 36 assemblies to coat.
- The assemblies were fabricated using two solder pastes A and B:
  - Paste A: Halogen-free ROL0 no-clean solder paste
  - Paste B: Traditional rosin based ROM1 material and contains halide.
- 36 assemblies were coated by partners using their selected coatings and processes.
- Coated samples were sent back to NPL for condensation testing.

Evaluation of coatings

- Five partners provided coated assemblies (130 assemblies) with a total of 16 different coatings or coating parameters for evaluation with 2 different solder pastes
  - Silicones 8
  - Synthetic rubbers 3
  - Acrylics 2
  - Urethanes 1
  - Urethane/Acrylics 1
  - Polyurethanes 1
- Some coatings with different thicknesses.
- Some coatings were aged by thermal cycling.
- 2-4 repeat samples for each coating.

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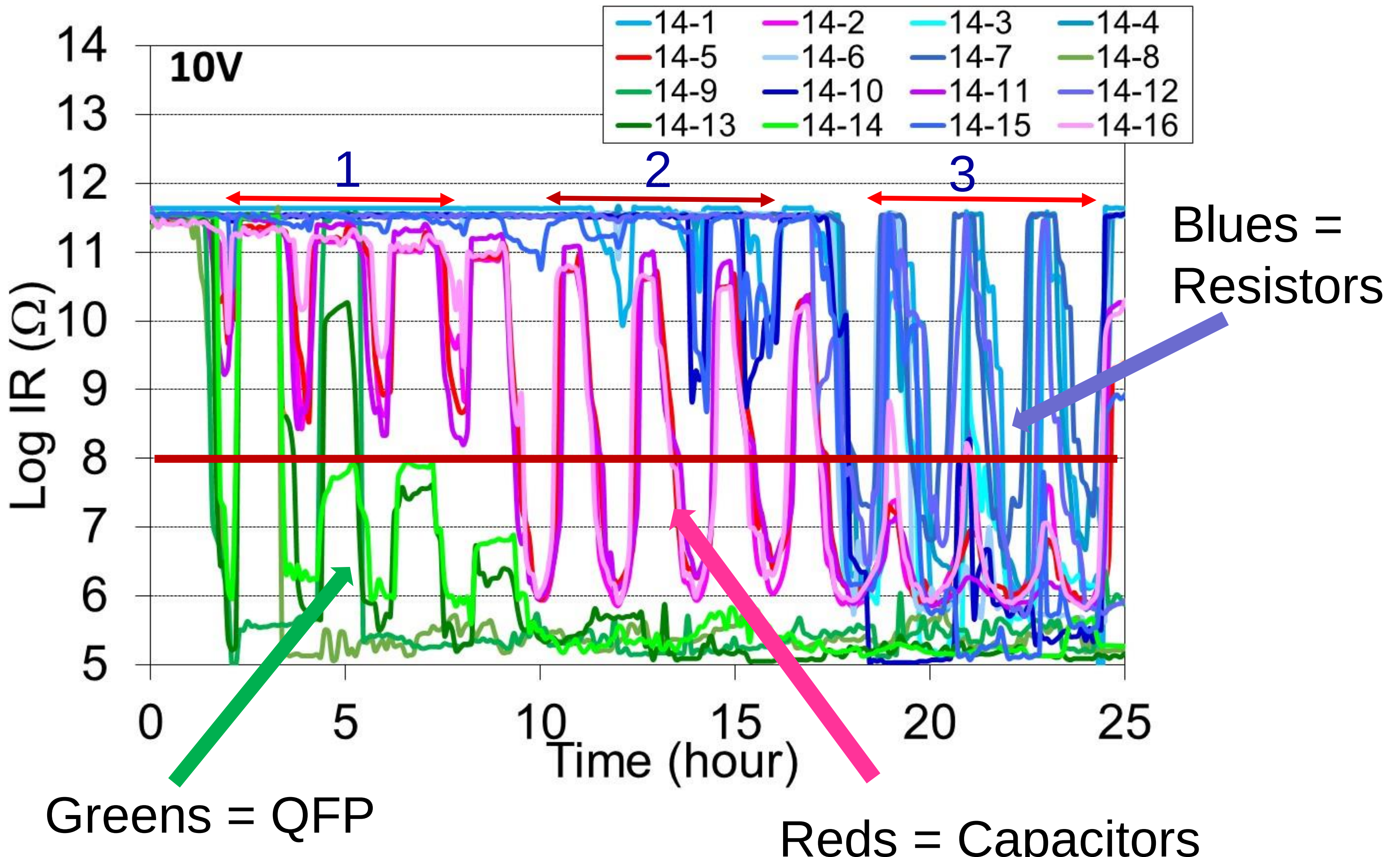
24 hours condensation cycle

Time (hour)	Cycle	Chamber condition	Platen temperature	Sample temperature	Condensation Level
0-8	1-4	40°C/81%	34.0°C	35.6°C	1
9-16	5-8	40°C/85%		35.9°C	2
17-24	9-12	40°C/89%		36.2°C	3

- 24 hours condensation testing with three condensation levels, and 8 hours (4 cycles) for each level.
- Each cycle took 2 hours,
    - One hour: Condensation formation and build up
    - One hour: Condensation evaporation.
- Test voltage: 10V

SIR results for uncoated sample – paste A at 3 condensation levels



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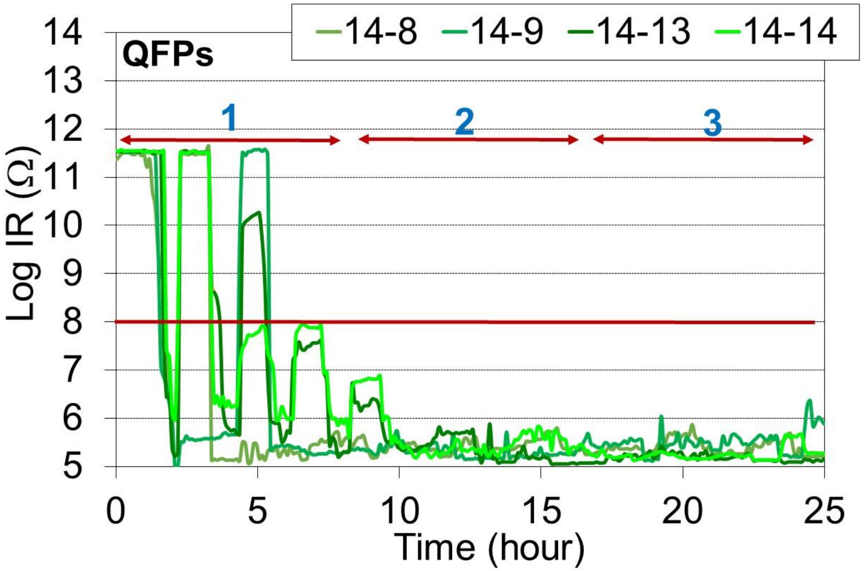
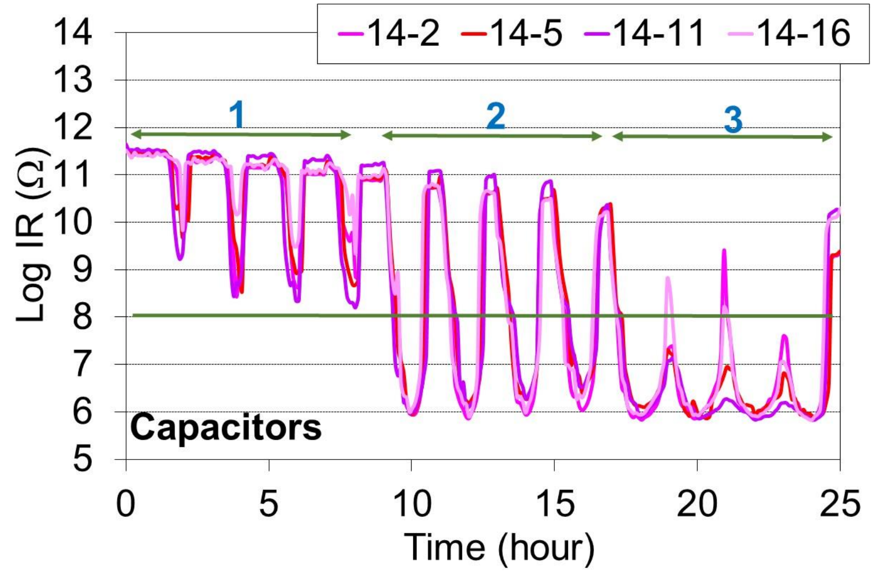
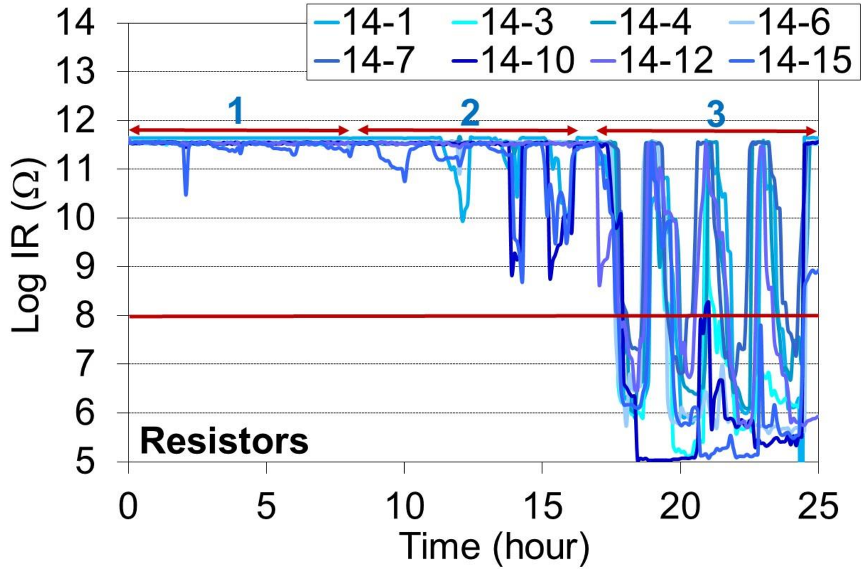
Uncoated components start to fail at different condensation levels







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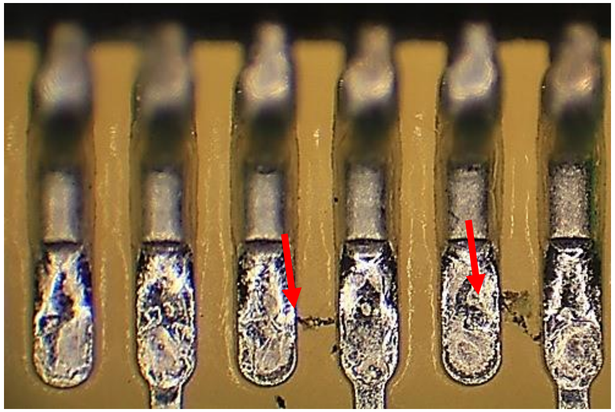
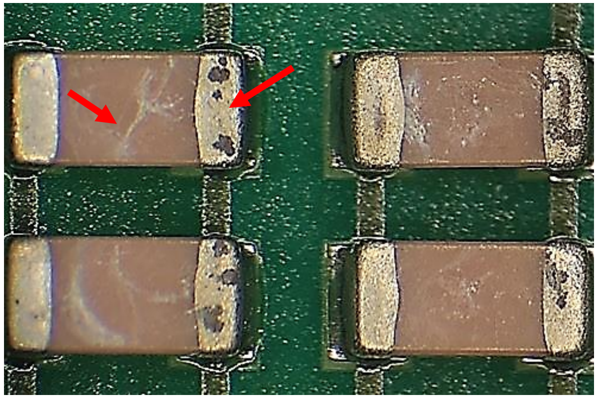
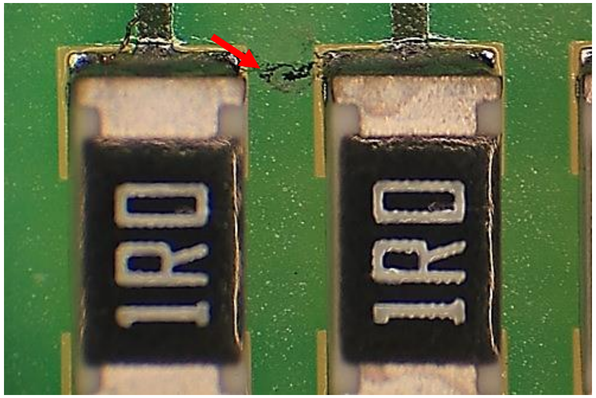
Uncoated component failures







- For QFPs, dendrites were formed mainly between the ends of the soldered PCB lands, where flux residues may be more concentrated.
- For capacitors, corrosion (discolouration) at anode was found on every capacitor.
- For resistors, corrosion and dendrites were observed on some resistor patterns.

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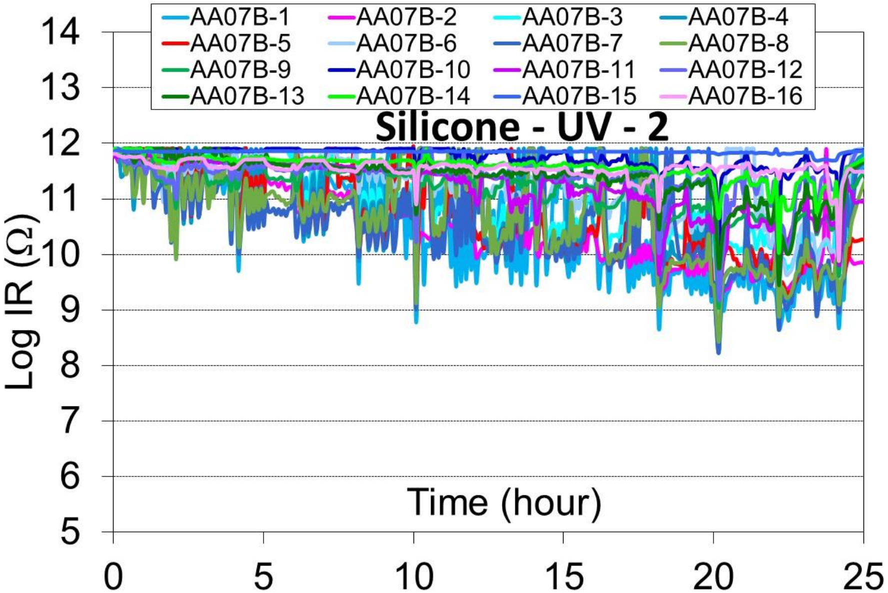
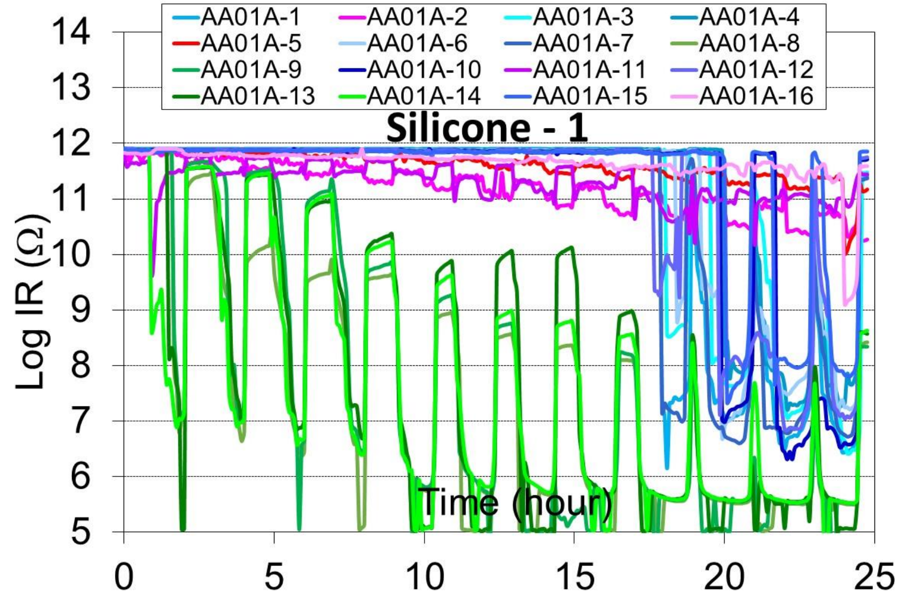
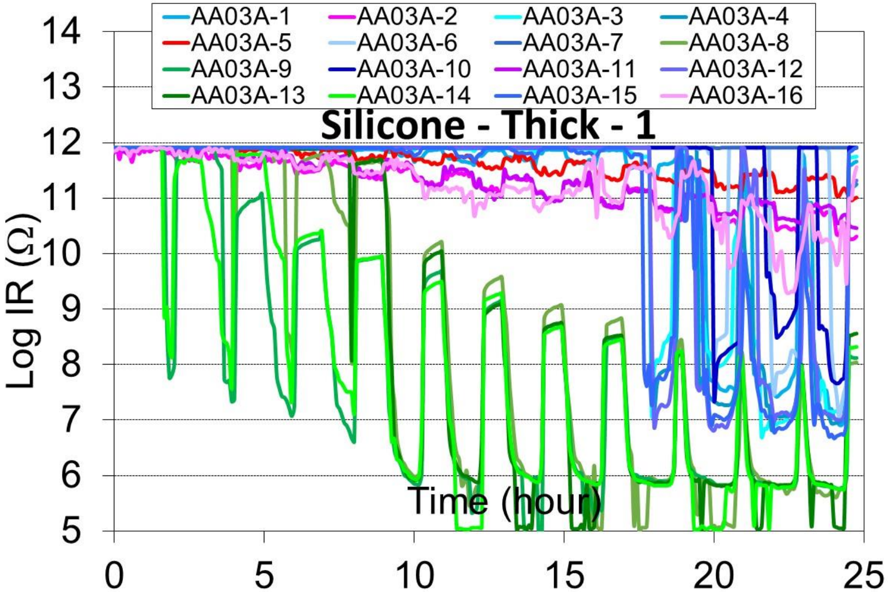
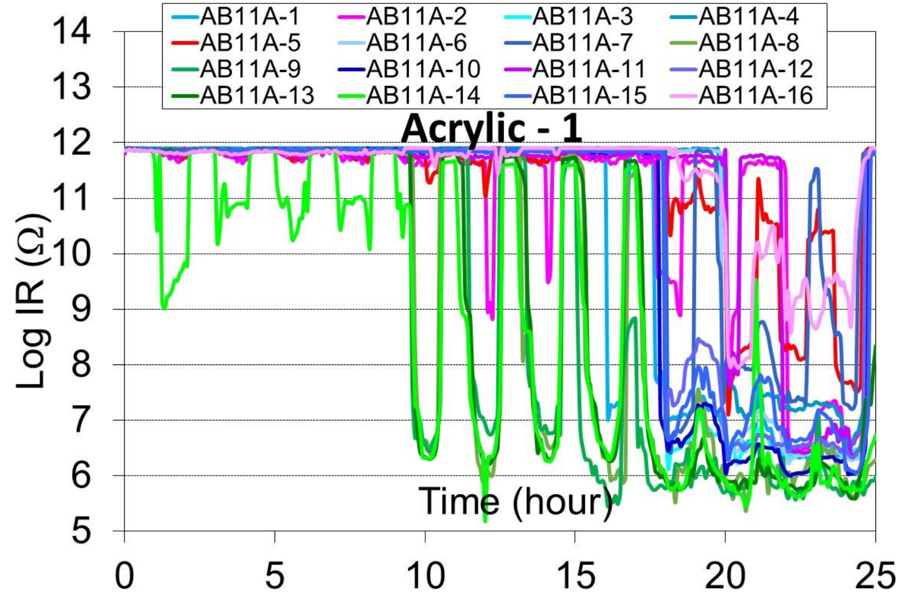
Typical SIR results for different coatings









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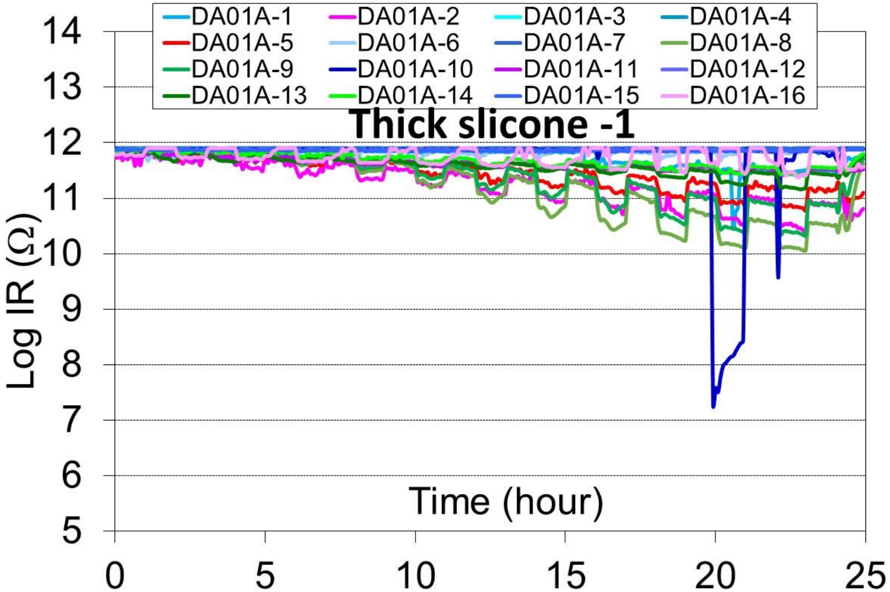

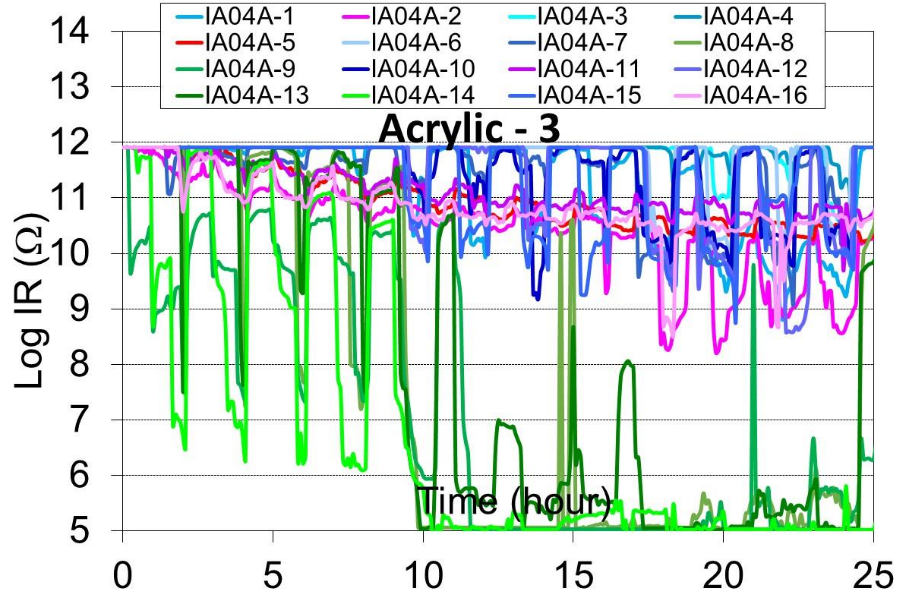

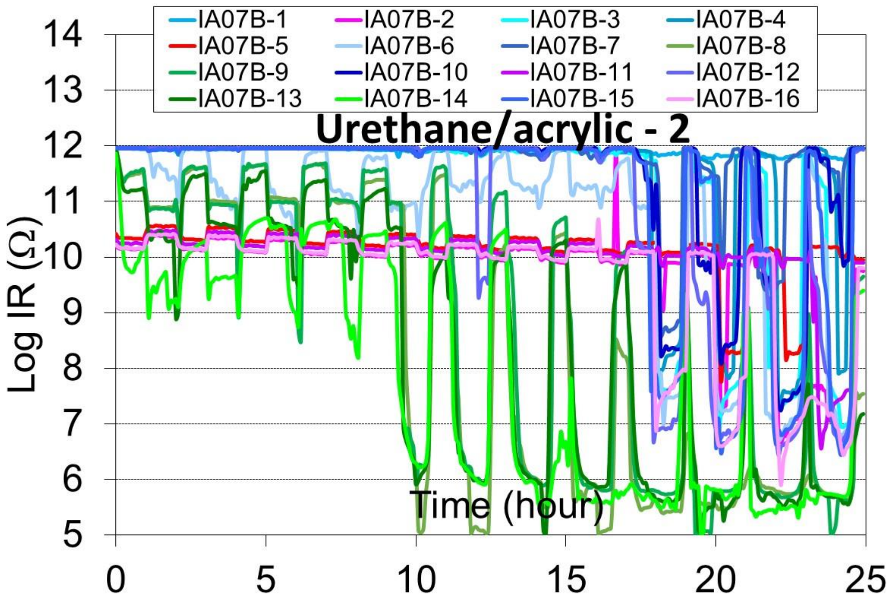

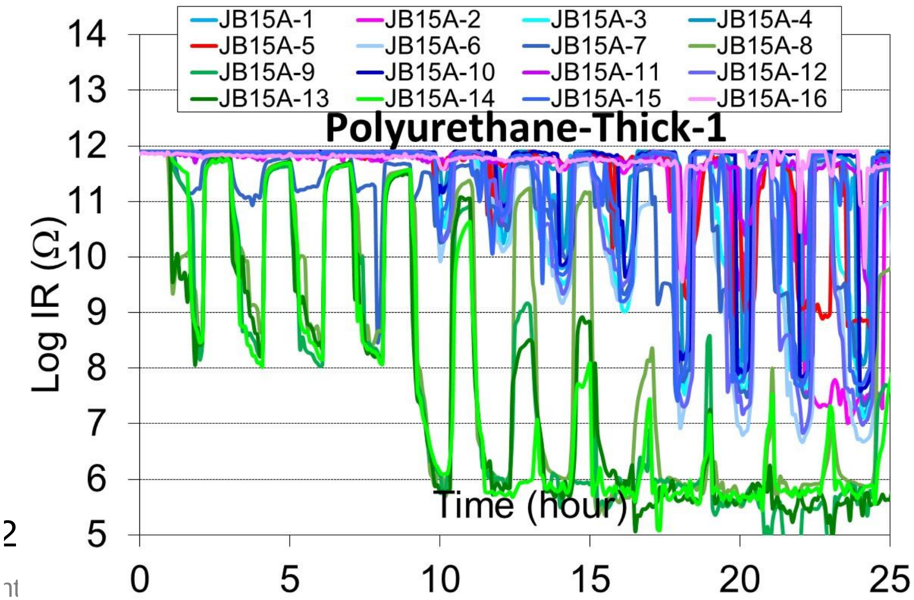

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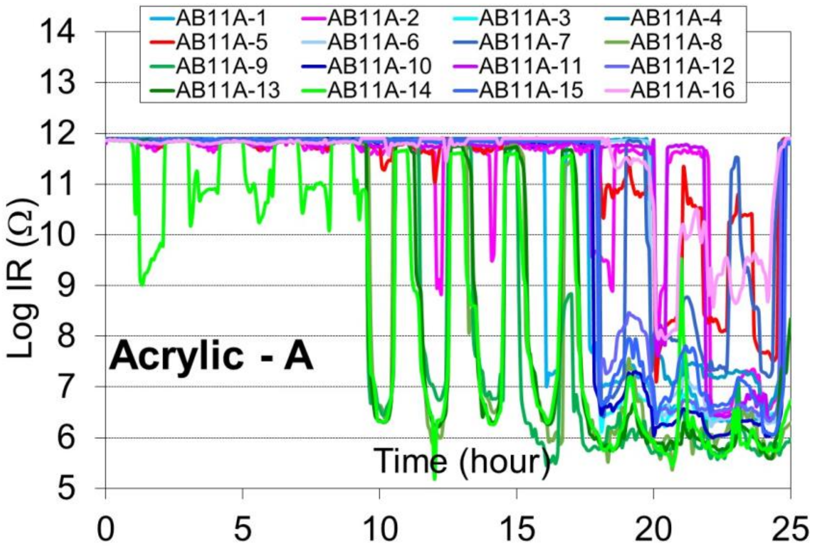

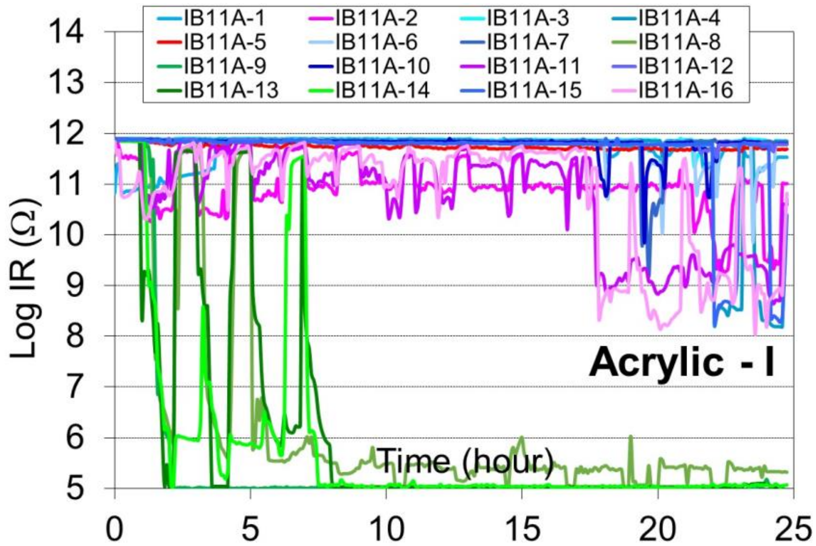

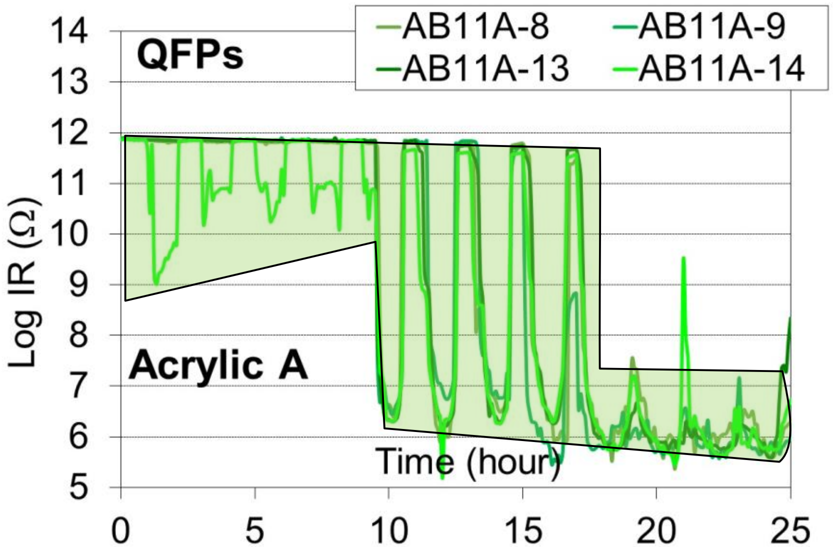

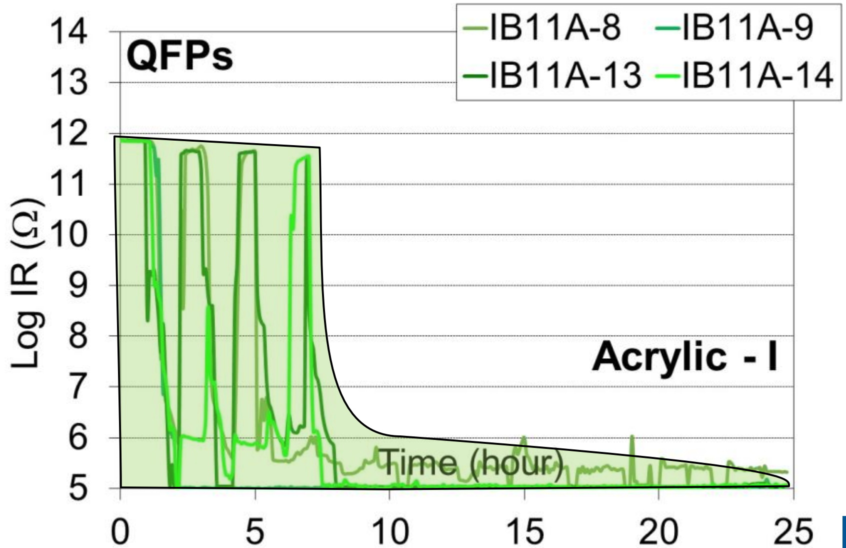

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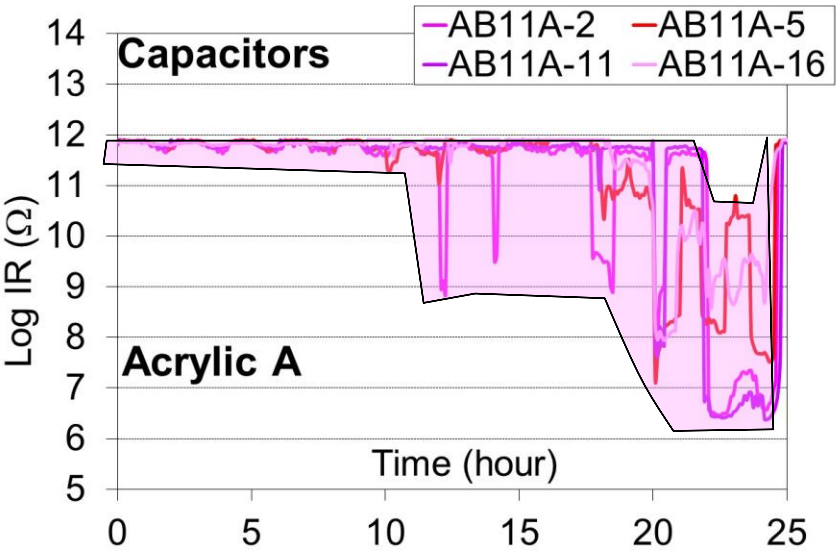
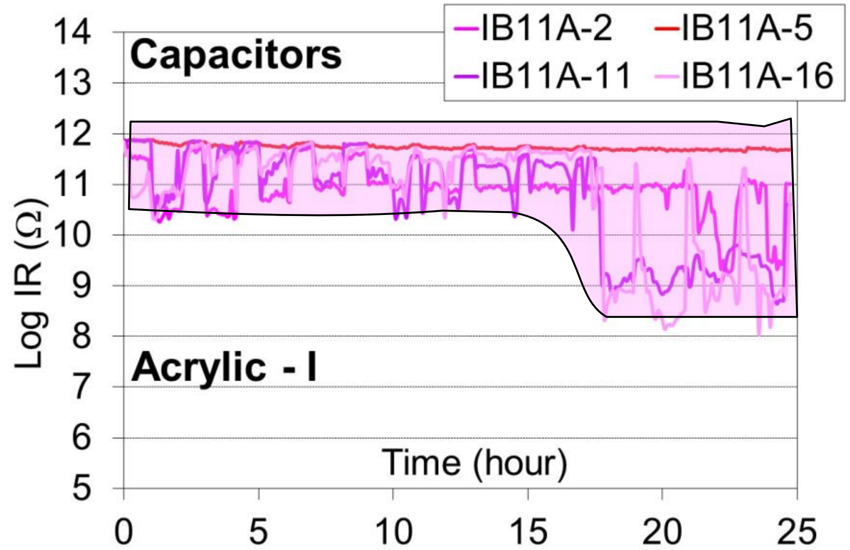
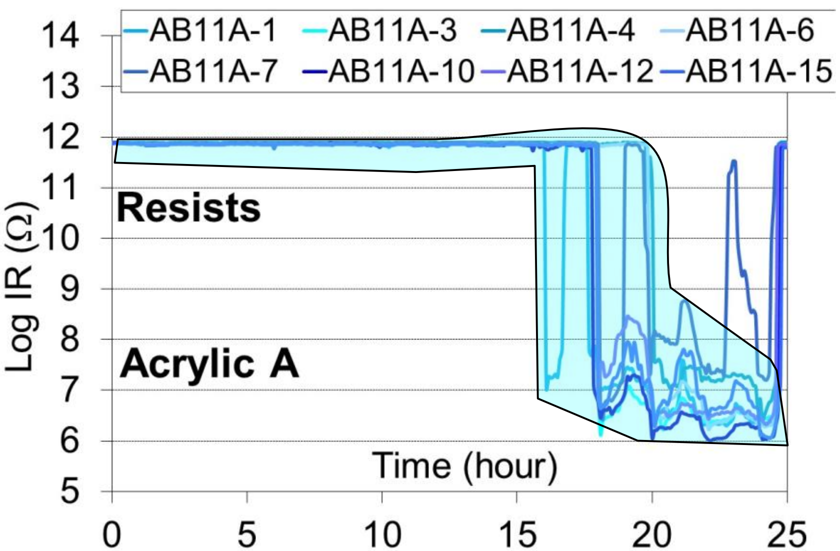
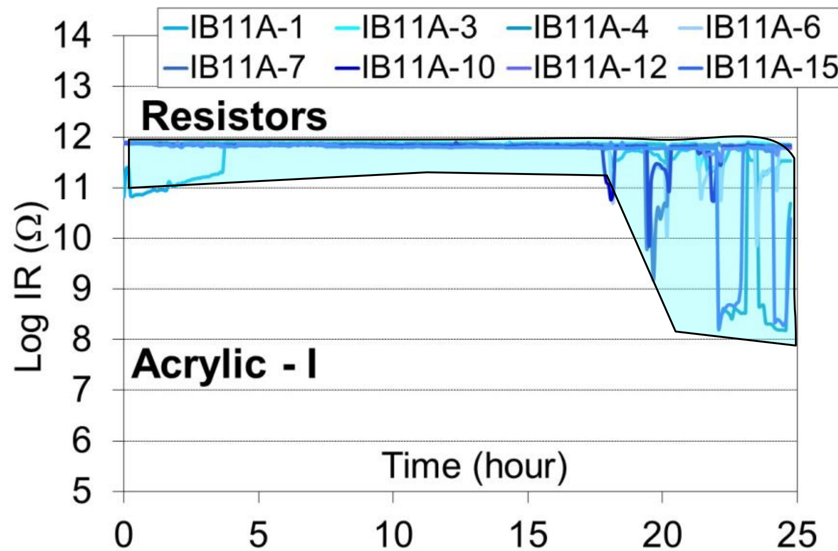
Typical SIR results for different coatings

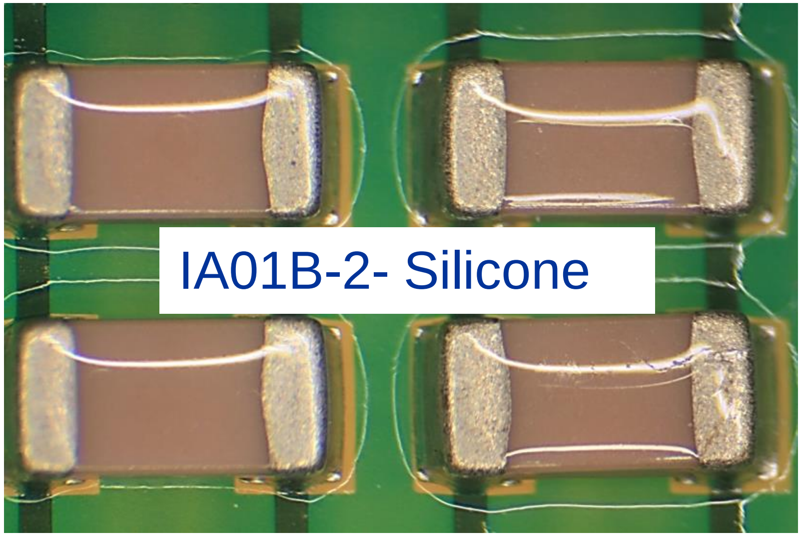


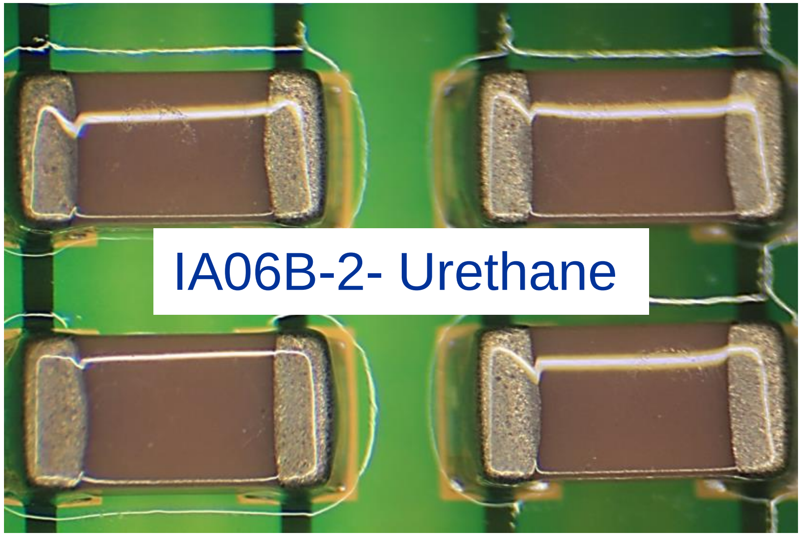


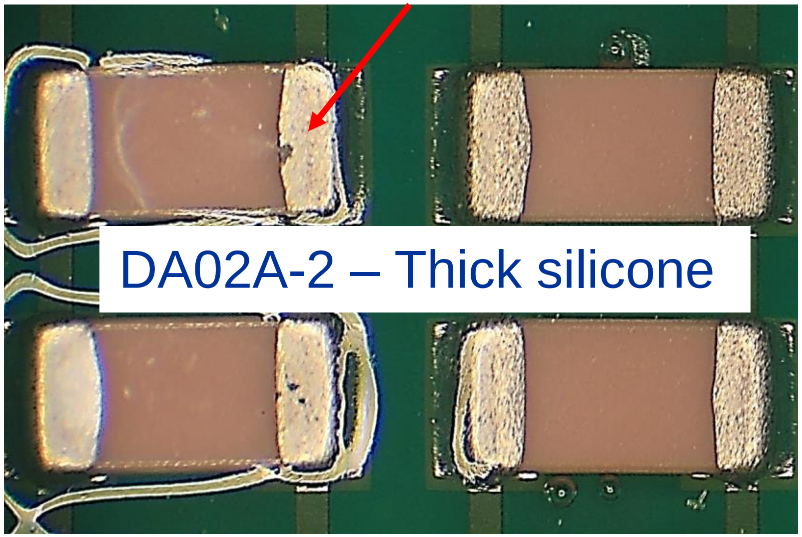




Coated capacitors

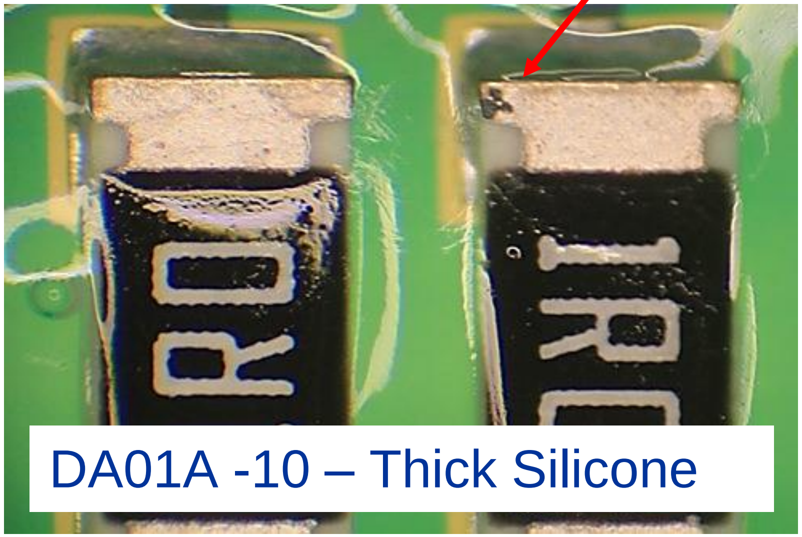




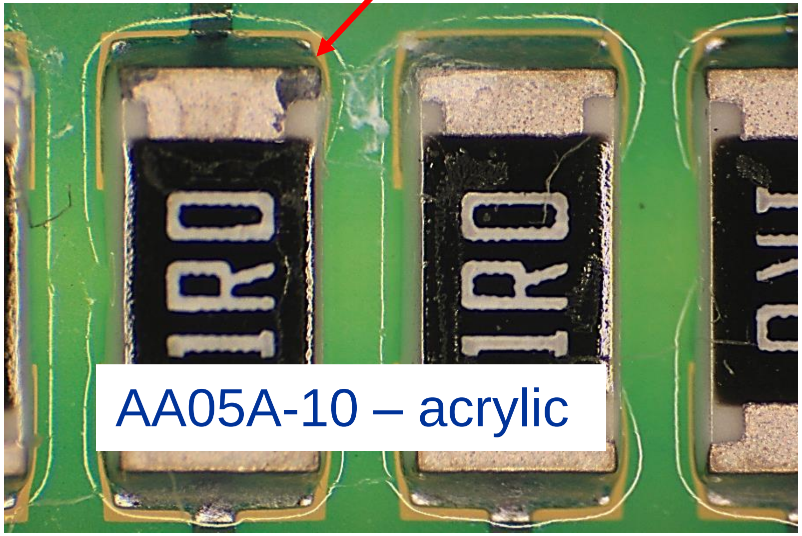


- There was hardly any corrosion observed even on very thin coatings.
- Corrosion occurred only in areas where the coating was damaged.

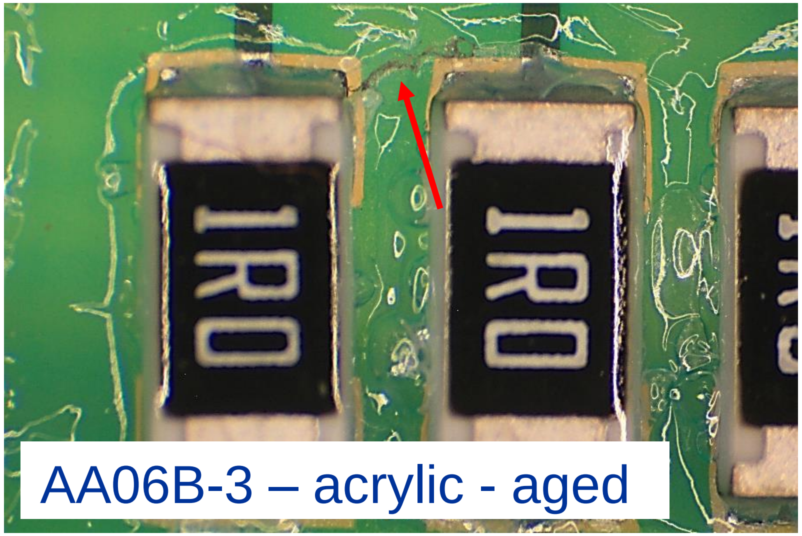
Coated resistors



DA01A -10 – Thick Silicone



AA05A-10 – acrylic



AA06B-3 – acrylic - aged

- Corrosions were founded on the sharp comers on some coatings
- Dendrites were only formed on damaged coatings (aged).

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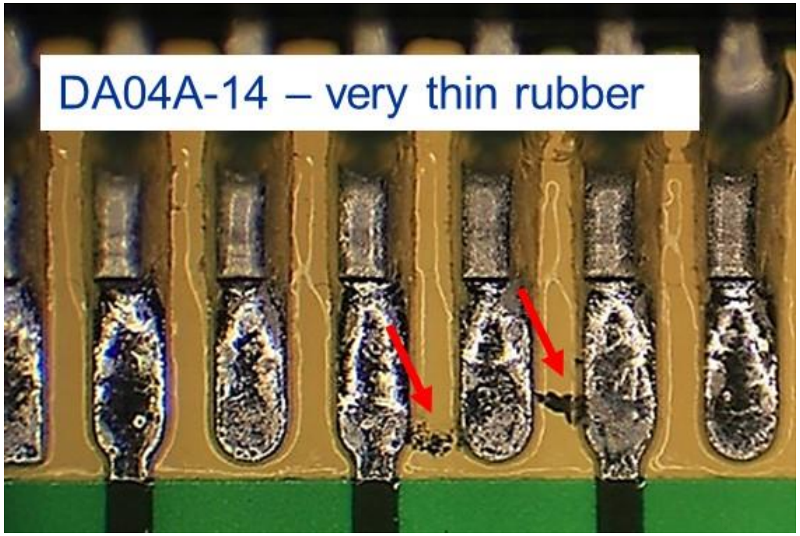
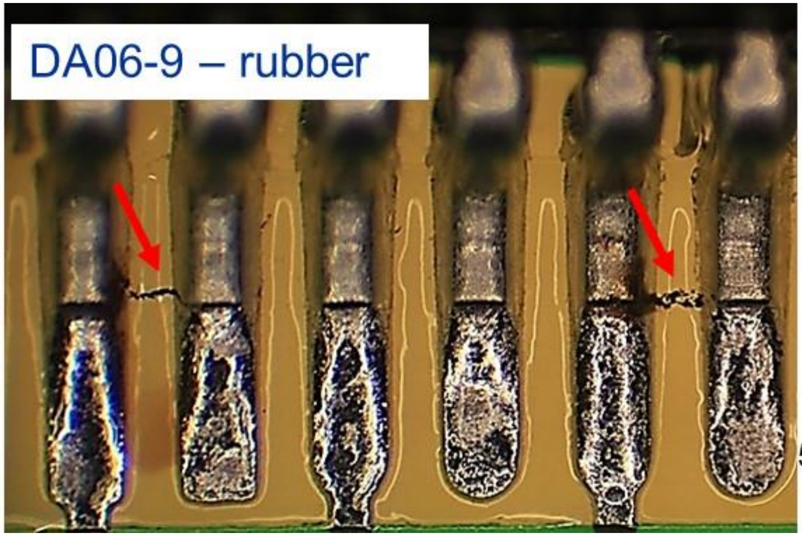
Coated QFPs





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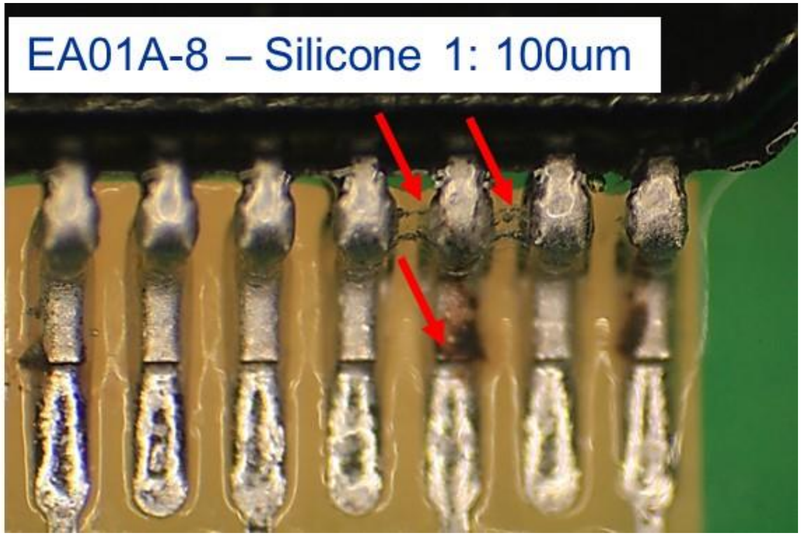

- For thinner coatings, dendrites tended to form between the ends of the soldered PCB lands.
- For thicker coatings, dendrites formed between the sharp cropped ends and between the top bends of QFP leads, where coating coverage may be poorer.

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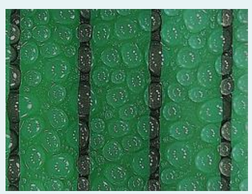
The definition of SIR score with condensations

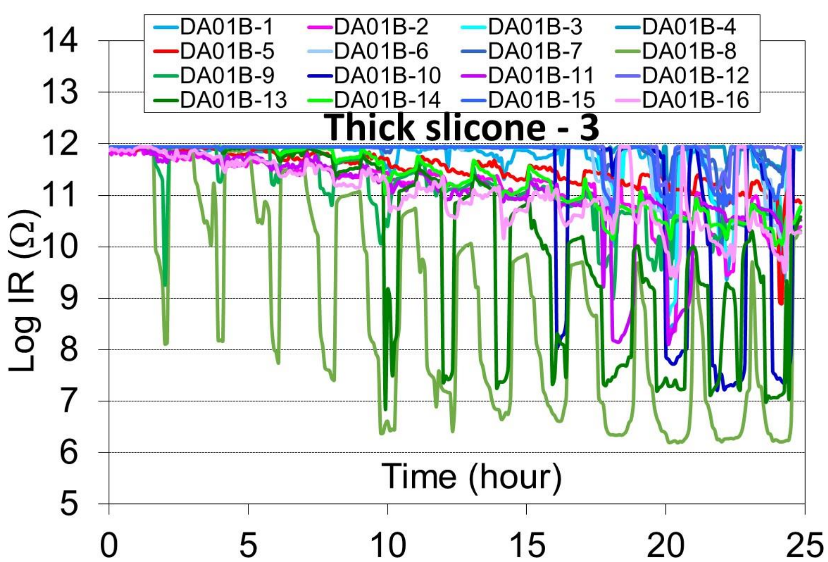
SIR (Ω)	Condensation level	Response score
<10^8	1 	0
>10^8	1 	1
>10^8	2 	2
>10^8	3 	3

- The SIR response can be scored for each SIR pattern under different condensation levels on uncoated and coated assemblies.

The definition of “Coating Protection Index”

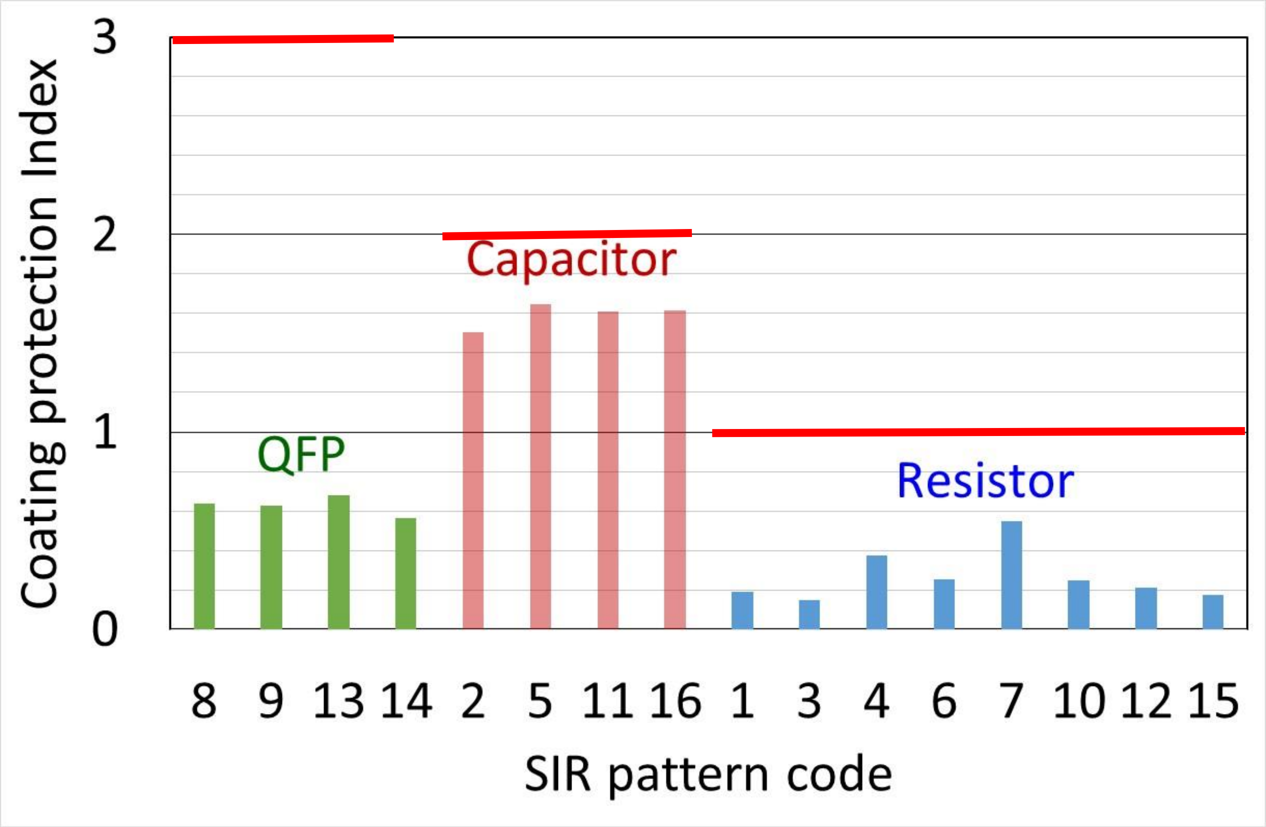
Response score for all patterns on bare and coated assemblies

	Component															
	QFP				Capacitor				Resistor							
SIR pattern	*8*	*9*	*13*	*14*	*2*	*5*	*11*	*16*	*1*	*3*	*4*	*6*	*7*	*10*	*12*	*15*
Response score (Uncoated)	0	0	0	0	1	1	1	1	2	2	2	2	2	2	2	2
Average (Uncoated, U)	0				1				2							
Response score (Coated)	0	3	2	3	3	3	3	3	3	3	3	3	3	2	3	3
Average (Coated, C)	2.0				3.0				2.9							
Coating Protection Index (C-U)	2.0				2.0				0.9							
Maximum Protection Index	3.0				2.0				1.0							



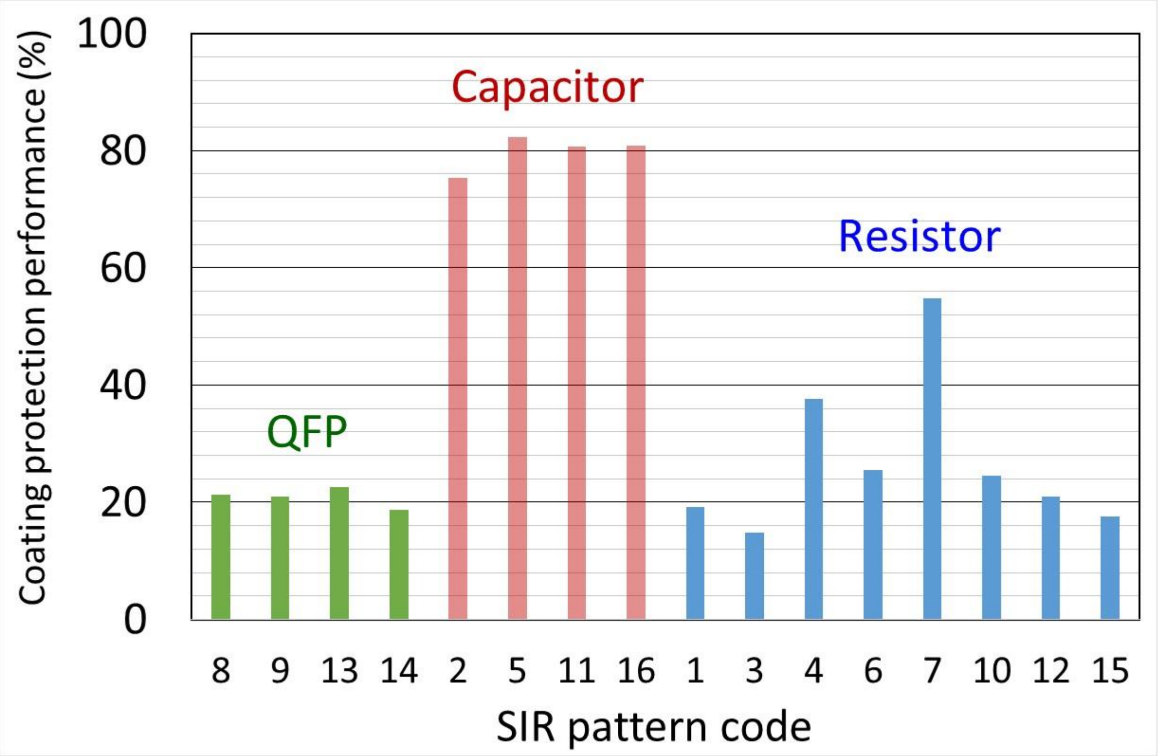
- **Coating Protection Index:**
  - **Coated response score – uncoated response score**
- **Coating Protection Index will be used to compare coating protection performance from different condensation levels for different components.**

Coating protection performance for different SIR patterns - Average for all samples



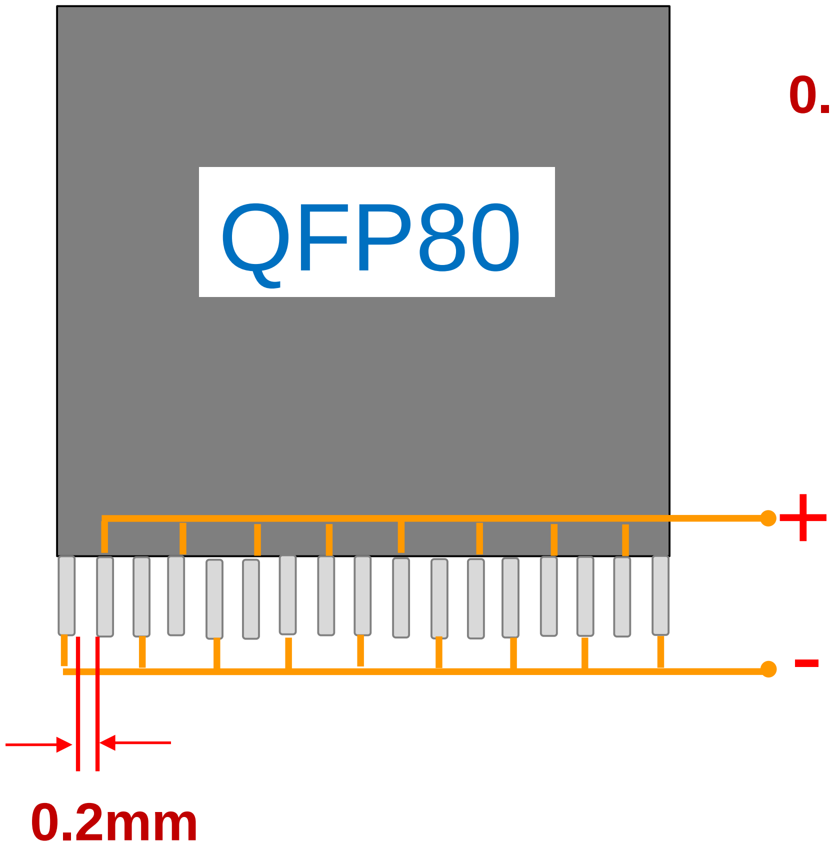
- Coatings provide different protection levels for different components.

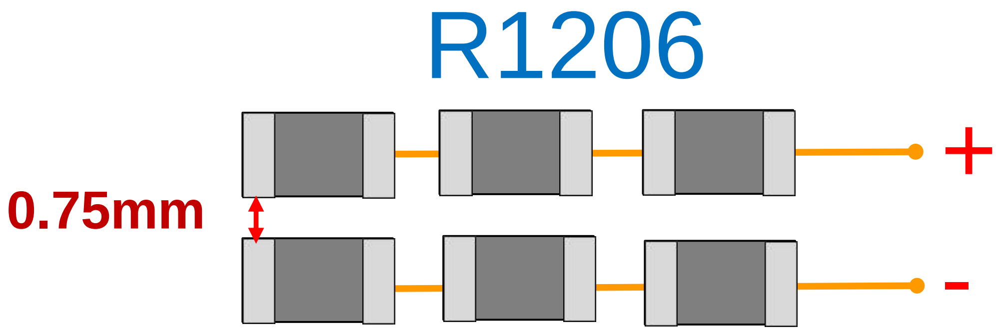
Normalised Performance - %

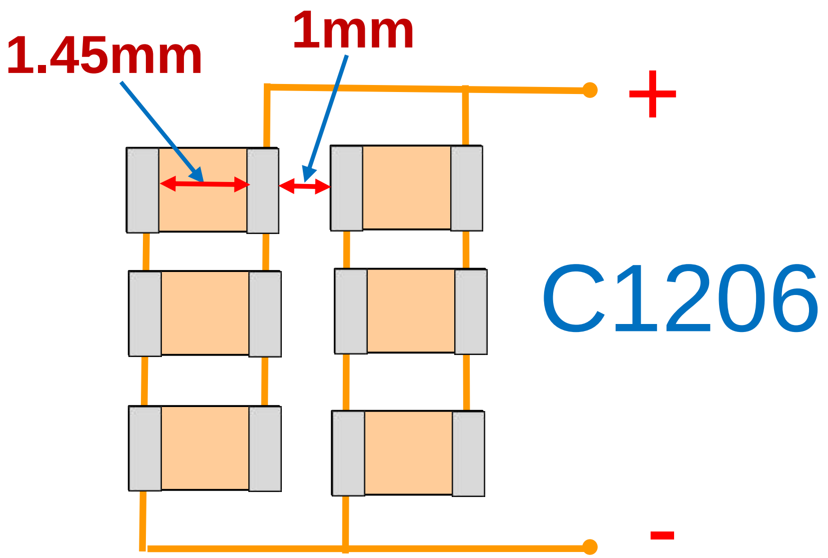


- Coating Protection Index / Maximum Coating Protection Index
- Capacitor > Resistor > QFP
- Component field strength
- Cap 7V/mm < Res 13V/mm < QFP 50V/mm

Components incorporated into SIR patterns

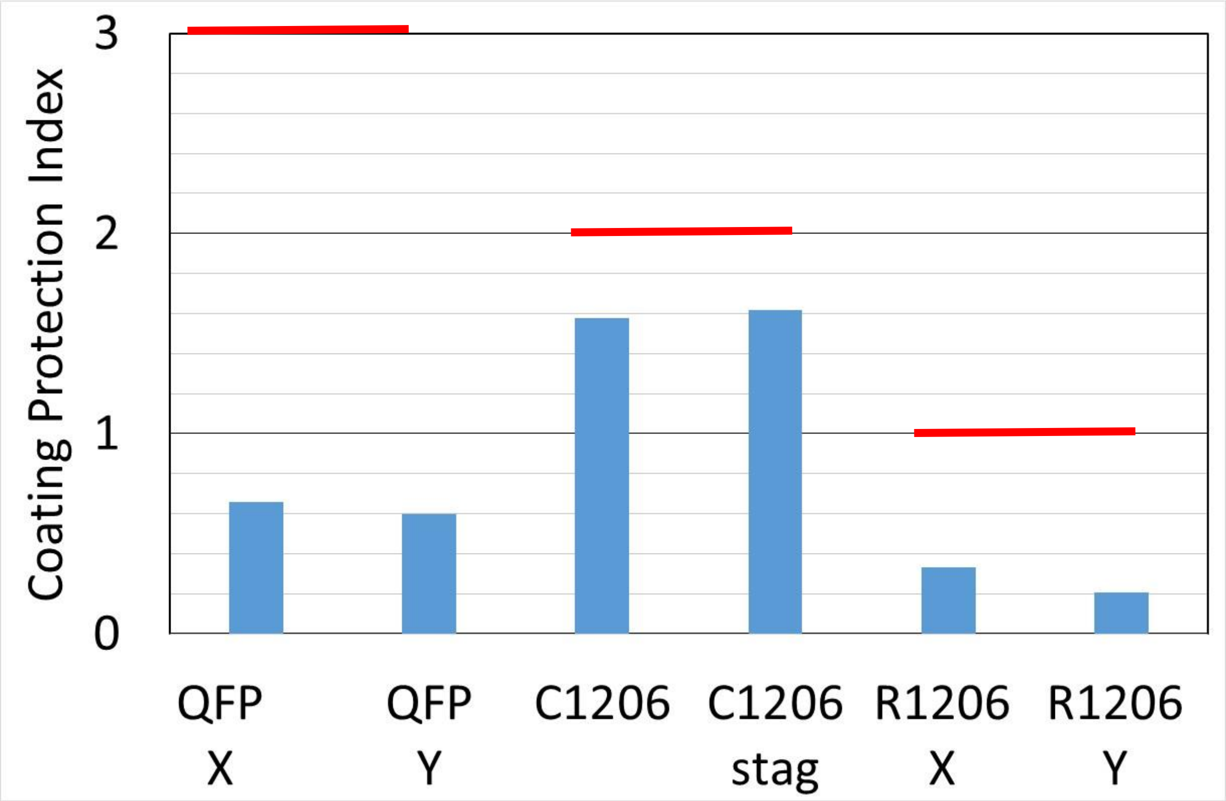






To be addressed in Phase 2

Coating protection performance for different SIR patterns - Average for all samples



- Component orientation or staggering did not significantly affect coating protection performance.

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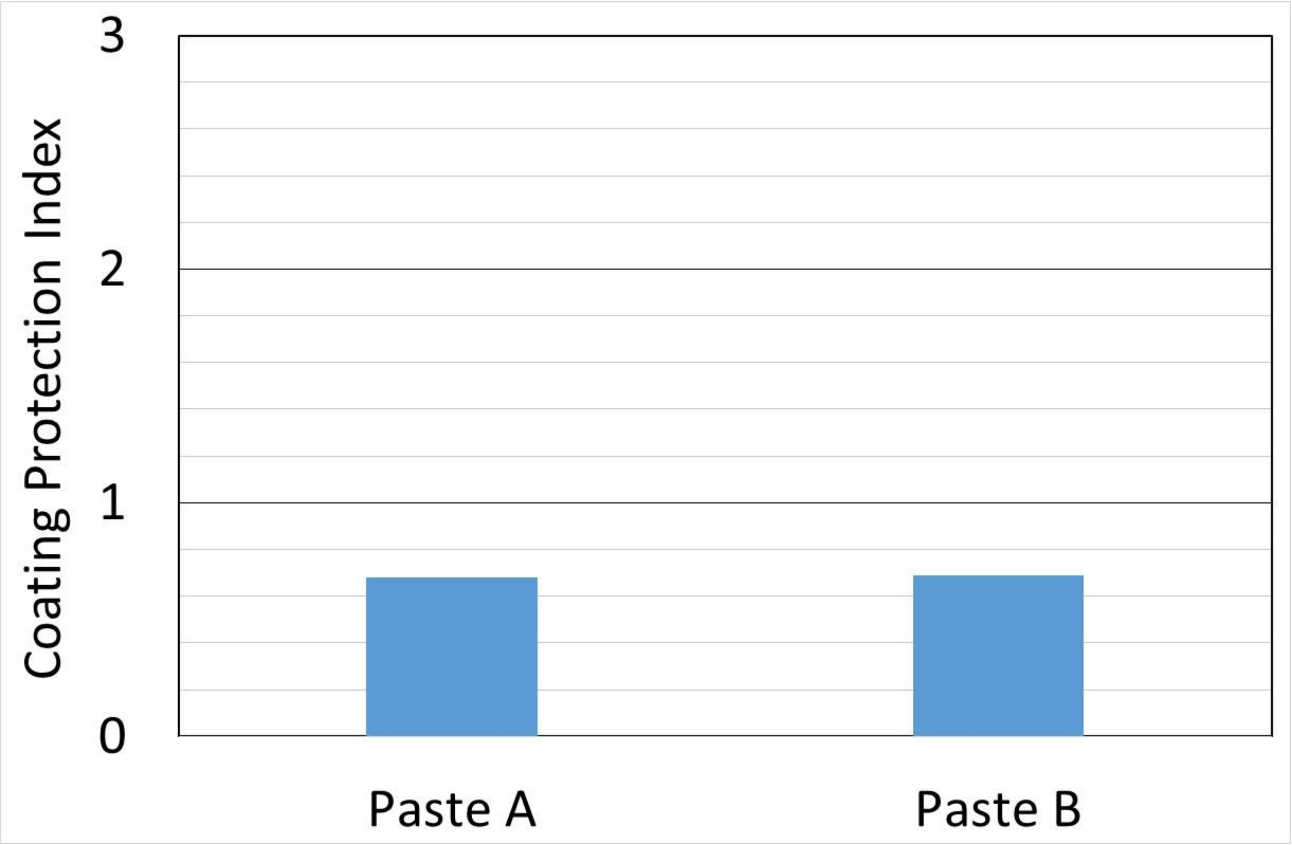
Coating protection performance for different paste assembly - Average for all samples



- There was no significant difference in coating protection performance between paste A and B assemblies.

Conclusions

- The approach has successfully evaluated coating protection performance for different condensation levels on a variety of coatings and component types.
- In general coatings provided better protection for 1206 capacitors than QFP and 1206 resistors.
  - May be due to coverage issues. The sharp edges of resistors and the sharp ends and top bends of QFP leads represent a significant challenge for coating coverage, and it is in these areas that failures occurred.
  - Additionally the field strengths were higher for the 1206 resistors and QFPs
- Thicker coatings generally give better coverage, and performed better than thinner coatings. The results indicate that the extent of coating coverage is more important than coating material used for protection from condensation.
  - Thicker coatings may have other issues (reliability during thermal cycling?)

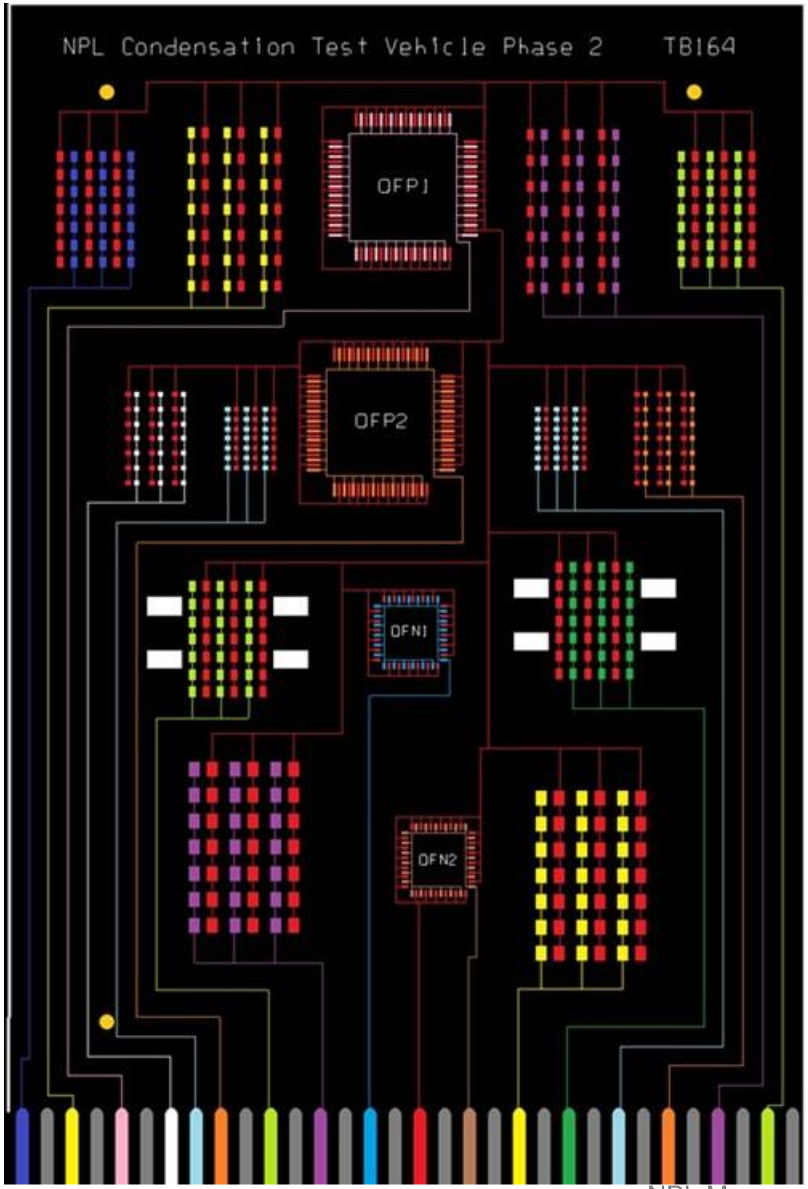
Conclusions

- For uncoated QFPs and coated QFPs with thin coatings, dendrites formed mainly between the ends of the soldered PCB lands, where flux residues may be more concentrated.
- For thicker coatings, dendrites formed between the sharp cropped ends and between the top bends of QFP leads, where coating coverage may be poorer.
- Neither the two different solder pastes used nor the component orientation significantly affected coating protection performance
- Condensation levels and coating coverage dominated the SIR responses and failures.

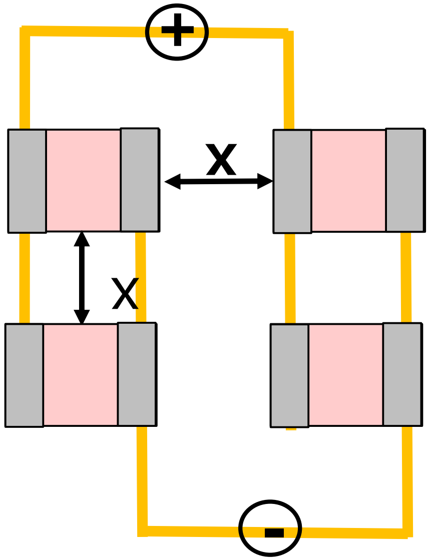
Phase 2 work plan

- Round robin to evaluate partners coating processes
- Single solder paste
  - Paste did not significantly affect condensation results.
- Modify the PCB design, introduce smaller components (QFN, C0402, C0603 and C0805) on closer pitches
  - Field strengths closer to QFP
  - Closer to partners minimum design clearances
- Two coatings for each partner, but more repeats to verify condensation method.

Board design for phase 2



SIR pattern	X (mm)
2 x C0402A	0.5
2 x C0402B	1.0
2 x C0603A	0.8
2 x C0603C	0.8 with taller Tantalum
2 x C0603B	1.6
2 x C0805	1.25
2 x QFP80	0.5mm pitch
2 x QFN48	0.5mm pitch



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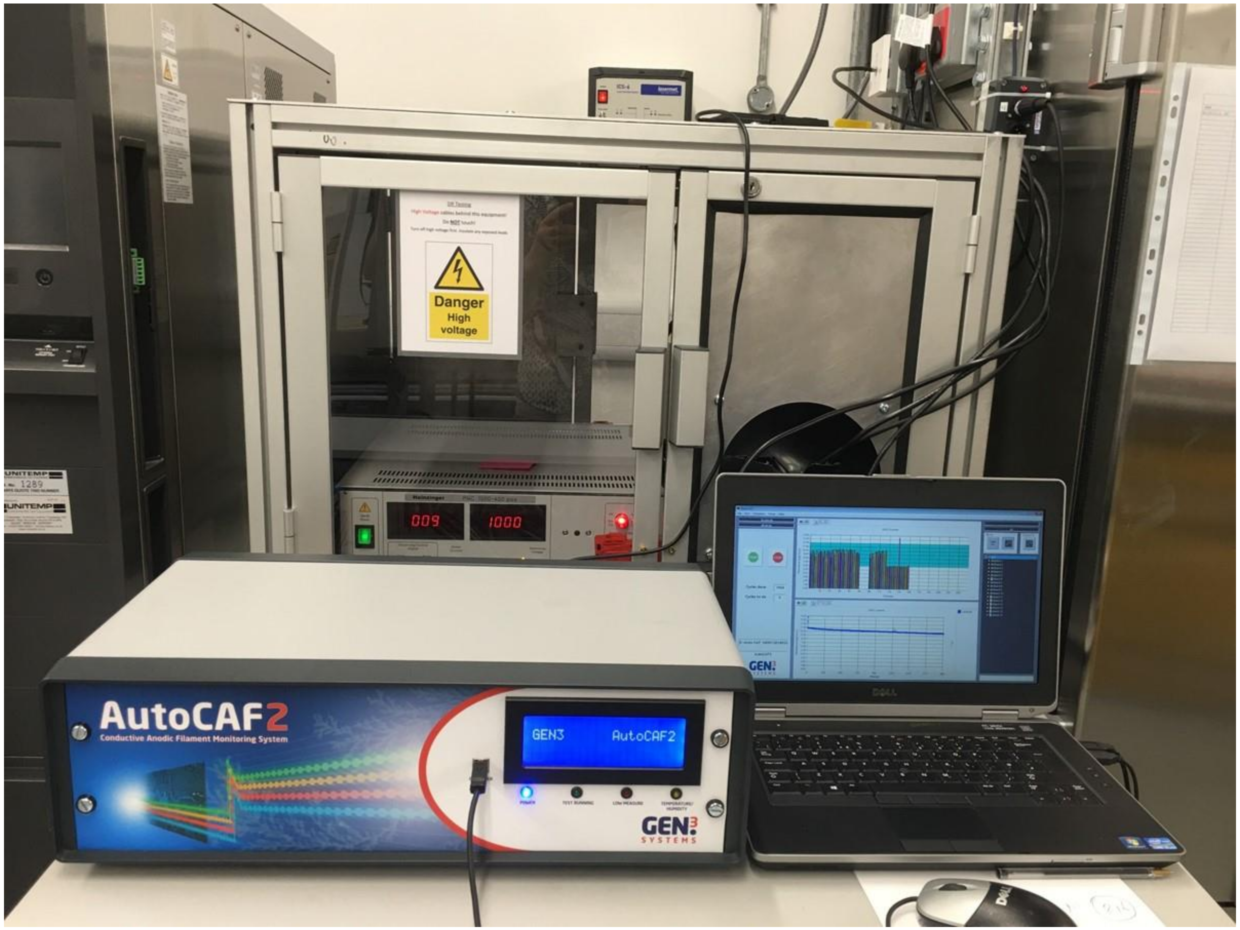
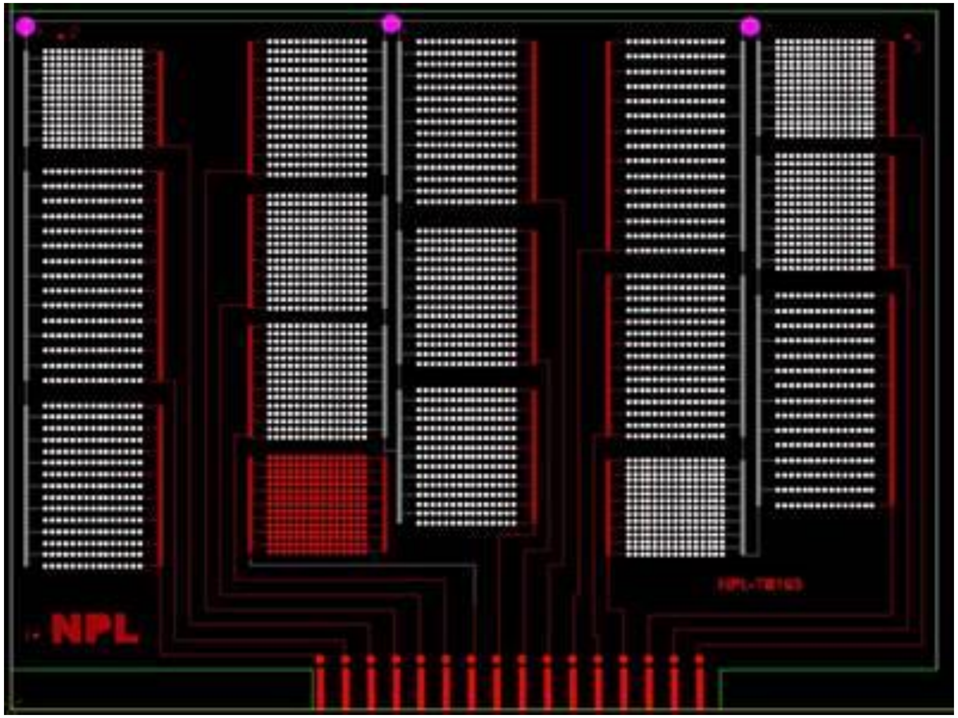
1000V SIR or CAF Test Capability

- Test voltage play a very important role for circuit reliability.
- The test voltages for existing measurements are only up to 300V. The aerospace and automotive industries are looking to increase operating voltages above 250V to understand potential new failure mechanisms when using voltages up to1000V.
- NPL has commissioned a 1000V SIR or CAF test facility.

1000V SIR or CAF testing



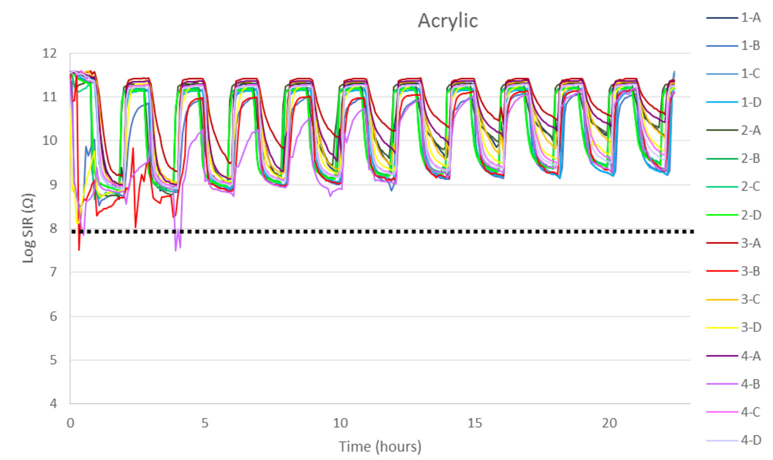
Bias effect on Conductive Anodic Filament (CAF) failure

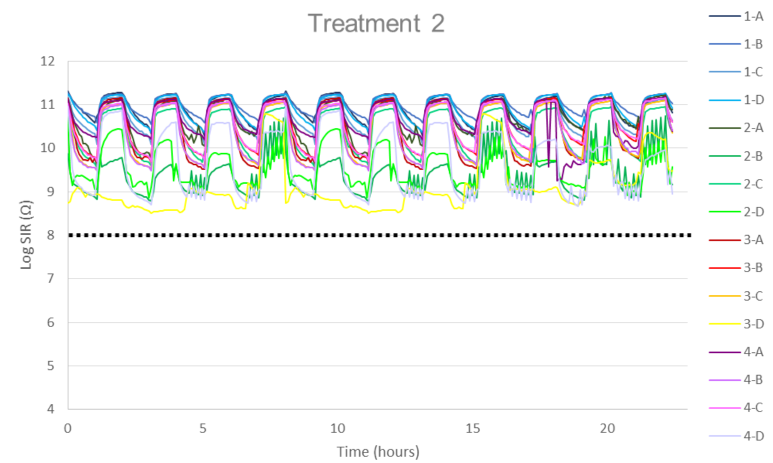


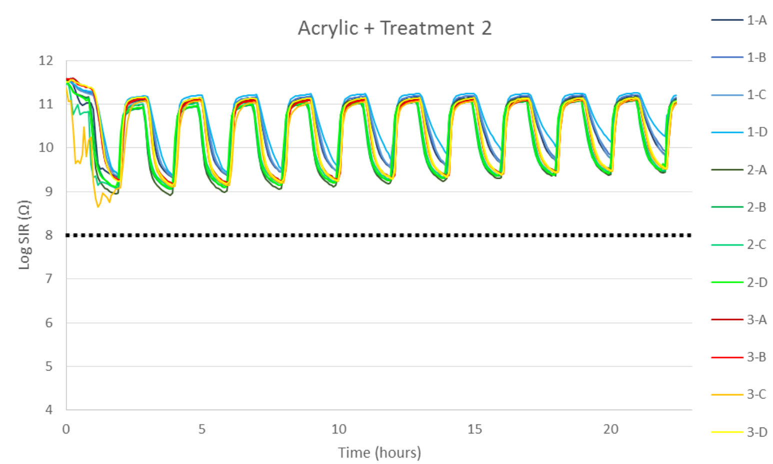
H-H distance	Diameter	Test voltage
500	800	100
800	800	250
1100	800	500
1500	800	1000
2200	800	1000 AC

Hydrophobic Coatings Condensation Test

- Initial assessment of SIR comb patterns
  - Showed that a higher contact angle doesn't necessarily mean a better condensation
  - Improved performance in combination with traditional conformal coating
- Next phase will be a collaborative project to determine - effectiveness of hydrophobic and combinational coatings on real assemblies including robustness studies
- Web Meeting on 26th November 2018 to outline project proposal to interested parties
  - Please email laura.kent@npl.co.uk for an invite







NPL measurement service

- SIR or CAF testing up to 300V
  - Four Auto-SIR systems.
  - 256 channels can be measured for each
- SIR or CAF testing up to 1000V
- Condensation testing.
- Please contact us
  - For advise on the technique.
  - Measurements.
- Contact detail

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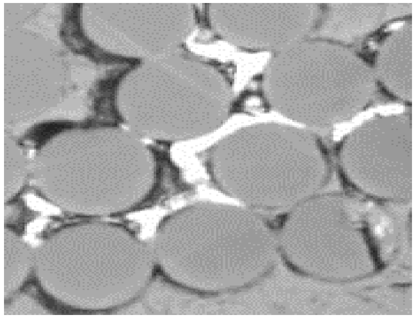
Tel: 0208 943 6065



Dendrite short two conductors

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