The Role of Permeability and Ion Transport In Conformal Coating Protection

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ABSTRACT

The level of protection offered by a range of conformal coatings on electronic assemblies has been evaluated. The role of permeability and ion transport is the primary interest. Testing was carried out on 6 coatings of the main generic types currently used by industry either conformally coated onto FR-4 laminate boards or, as free films. The coatings were evaluated in terms of the degradation caused by sodium chloride and a generic flux formulation based on dibasic acids. The methods utilised were surface insulation resistance (SIR), sequential electrochemical reduction analysis (SERA), PermeGear diffusion cells and gas chromatography mass spectrometry (GC-MS). Conformally coated boards were used for the SIR and SERA measurements while free films of the selected coatings were used for the diffusion and GC-MS measurements.

Each method revealed aspects of the level of protection offered by the coatings as well as the extent to which the coatings are permeable to contaminants in high environmental stress regimes. The coatings acted as an effective barrier to NaCl penetration but were permeable to dibasic acids found in electronic fluxes. The importance of board cleanliness is also highlighted by the results obtained from these investigations.

INTRODUCTION

Increasingly, safety critical systems, such as avionics and automotive, are being controlled by electronics. Furthermore, these systems are more often being mounted close to functional parts, e.g. sensors and actuators. This inevitably requires electronics to operate in high environmental stress regimes. To try to achieve reliable electronics in such situations, protective coatings can be applied to electronic circuits, and are commonly known as conformal coatings. Conformal coatings are typically applied to printed circuit boards in thin layers by dipping or spraying, and may cover all or part of the electronic assembly. They are able to achieve a high degree of protection even in environments that would normally be considered very detrimental for electronic equipment, by preventing corrosion or short circuits[1]. However, there is very little information currently available to engineers to accurately predict the performance over the lifetime of the product. It is not currently known what levels of protection are offered to specific contaminants, and what transport rates and degradation will be observed. For example it has now been shown that coatings let moisture permeate over timescales of less than a day[2, 3], contradicting the previously accepted understanding.

This paper characterises the protection properties provided by conformally coating of electronic assemblies, and to assess the level of protection offered by a range of conformal coating materials. The major criteria for success are not just based on the generic chemical base of the coating, as there are good and bad performing materials in all categories[1].

The conformal coatings and contaminants investigated were selected following industrial consultation. Six coatings were selected representing each of the main chemistries commonly in use, acrylic, silicone, epoxy, and polyurethane/alkyd. In addition two water based acrylic were included, as they represent a new alternative to the common solvent based versions. Each chemistry was taken from a different supplier so as to give a wide cross section of the market. The test coupons were coated by the coating suppliers in accordance with their recommended standard procedures.

The rate of degradation or permeability of these coatings was investigated using surface insulation resistance (SIR), sequential electrochemical reduction analysis (SERA), PermeGear diffusion cells and gas chromatography mass spectrometry. Salt, in the form of sodium chloride, wave soldering flux and solder paste were the contaminants used in these investigations.

Experimental

Board Design

The test coupons were 106.5 x 102.6 mm boards manufactured from epoxy FR-4 laminate. The test pattern comprised four identical combs of dimensions 25 mm x 25 mm with a 400µm track and 200µm gap. The boards, which were 1.6 mm thick, had an electroless NiAu finish. The design included large pad areas for SERA testing. The boards were coated by material manufacturers according to their own recommended procedures. All the coatings were dipped.

Test Methods

Surface Insulation Resistance (SIR)

The Surface Insulation Resistance (SIR) technique is widely used to assess the effect of flux residues, test methods exist in IPC[4], in a number of test methods, and IEC 61189-5[5], ISO 9455-17[6],to this end. The SIR measurement is of the resistance between two interdigitated combs while subjecting the test vehicle to a hot/humid environment. Tomlins et al[2] showed that a number of conformal coating types are permeable to water vapour.

A Concoat AutoSIR (Mk II) that has a current sensitivity of 1 x 10^{-11}A was used to monitor the SIR values on 16 channels at 10-minute intervals during the test period of 72 hours. A +50 V DC biased voltage was continuously applied across the comb patterns during the test period and a 10^6 **Ω** limiting resistor was included in each measurement channel.

The edge connector was masked on both sides during coating of the boards to ensure that the SIR measurements were a true reflection of the resistance of the test pattern and not influenced by contamination of the edge connector. The measured SIR values discussed later represent the average value for the four combs contained on each board.

Tests on the effect of exposure to contamination were carried out with some of the boards contaminated prior to coating and the majority after coating. The boards were contaminated with 50 μL of NaCl solution of varying concentration per each comb pattern and left to air dry for up to an hour before the boards were sent off for coating. The NaCl was applied with micro-pipette, dispensing with a number of micro drops over the surface. Drops dispersed to varying degrees, it was not possible to achieve a uniform contaminant thickness. How or where the coating was deposited did not correlate with any visible corrosion breakdown of the coating. In further experiments the coatings were also contaminated with 50µl of flux, the solutions are presented in Table 1.

Table 1. Flux formulations

Flux	IPA	DI water	Adipic Acid	Succinic Acid	Glutaric Acid	Rosin	Surfactant	Co-solvent
Solvent-based	93.2	-	1.7	1.7	1.7	1.7	-	-
Water-based	-	90.4	1.7	1.7	1.7	-	0.1	5.0
Water-based A	-	90.5	1.7	1.7	1.7	-	-	5.0
Water-based B	-	95.5	1.7	1.7	1.7	-	-	-

The flux formulations are given in weight percent, and are typical of wave soldering fluxes. The four fluxes are based around the same activator package of dibasic acids, and are either solvent or water based. Water based fluxes need a co-solvent and surfactant to work optimally. These two additions in themselves may contribute to a drop in SIR, hence the water based flux was evaluated without one or both of these components, as denoted by water-based flux A and B. The flux solutions dispersed more evenly than the NaCl solution. In addition 50µl of two no-clean solder paste vehicles, which were diluted to 5% in isopropyl alcohol, were also investigated.

Initially the SIR environmental conditions were selected to match the maximum temperature of the diffusion cell experiments (40 °C). However, preliminary measurements at 40 °C and 90% RH revealed the resistance values tended to be very high and showed very little effect of the contaminants on the SIR values. Changing the test conditions to 85°C and 85% RH resulted in a reduced resistance and greater differentiation of the effect of contaminants.

Sequential Electrochemical Reduction Analysis (SERA)

All SERA measurements were performed using a SurfaceScan QC-100™ as shown schematically in Figure 1. The electrode potential of the tested surface is measured as a function of time yielding a series of plateaus corresponding to the sequential reduction or oxidation of the compounds present on the surface[7].

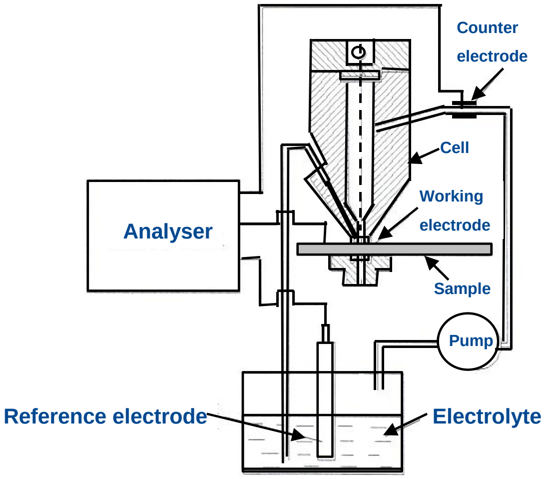


Figure 1 Schematic of SERA

Prior to SERA testing, the conformal coatings were stripped off the boards after 72 hours exposure at 85°C and 85% RH with isopropyl alcohol (IPA), acetone or dichloromethane, depending on the difficulty of removing the coating. An electrolyte made up of 10g/l potassium thiocyanate and 2.5g/l potassium hydroxide was used for the analysis. This electrolyte was deaerated prior to the tests by purging it with ultra high purity nitrogen for ten minutes, sufficient for the very small volumes.

The reduction potentials were measured versus an Ag/AgCl reference electrode using a pad area of 0.02cm^2 and a $30\ \mu\text{Acm}^{-2}$ applied current at room temperature.

Diffusion cell

Coatings were prepared as free films and tested, as a membrane, for diffusion of ions across the coating. The diffusivity of contaminants, such as NaCl, were measured using horizontal diffusion cells, as shown in Figure 2, with the test membrane (coating) fixed between 15 mm diameter orifices. When an excess amount of the diffusant of interest is added to one compartment the time evolution of its concentration in the other compartment reflects the diffusion of species through the membrane/coating. In this study, the diffusion of chloride ions and of flux was evaluated in separate tests. In both cases, 5 mol dm-3 NaNO3 was used as a supporting electrolyte.

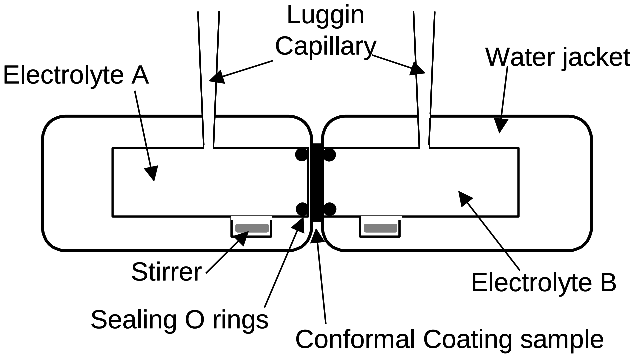


Figure 2 Schematic of diffusion cell. The coating is held between sealing o-rings.

Free films of the selected coatings were cast for the diffusion cell experiments to determine both chloride ion and flux migration. Due to temperature limitations on the effective use of the combined ion selective electrode used for taking measurements in the diffusion cell experiments, all measurements were carried out at 40°C.

Preparation of the films to act as a membrane in the diffusion cells was undertaken in the following way. The back of either a PTFE or polythene sheet was taped onto a metal panel using double sided tape.

The polymer sheets were then cleaned by wiping with acetone and water several times before finishing with an acetone wipe and then allowed to dry in ambient conditions before casting films. Films were prepared using various thicknesses of tape acting as shims to give the desired dry film thickness, and the coatings were drawn down using a doctor blade, two coats were applied. Samples of the coatings were prepared according to individual suppliers instructions, where possible, to give a dry film thickness of ~50µm. After 24 hours, the films were removed from the backing sheet and conditioned for 1 week at 23°C and 50% RH to allow stresses that build up in the films during removal to relax and allow any remaining solvent evaporation or curing mechanisms to complete.

The diffusion cell experiments were used to measure chloride ion diffusion for the NaCl contaminates and hydrogen ion diffusion for the flux contaminates. Solutions of 10, 50, 100, 250, 500, 750, 1000 and 5000 ppm of Cl^- ion were used. Chloride was added to the left hand chamber. Ion-selective electrodes were used to monitor the chloride level. For the flux testing water-based flux B (Table 1) was added to the left hand cell while deionised water was added to the right hand side. pH readings of both halves of the cell were taken at regular intervals over a 50-hour period. The cells were maintained at 40ºC.

The GC-MS was used to detect the presence of organic acids in the uncontaminated side of the cell after a period of 50 hours. This was done in order to determine unequivocally that organic species were diffusing through the coating membrane. Details of this and the diffusion experiments are given in Ref 8.

RESULTS

SIR results with NaCl contamination

The effect of NaCl contamination can be seen in Figure 3 for the solvent based acrylic coating, where SIR values of boards that have not been conformally coated are compared to boards contaminated either before or after conformal coating application. From this figure, it is evident that boards that were contaminated after conformal coating have much higher log SIR values than boards that are either contaminated before coating or not coated at all. A similar response to addition of contamination was seen with the other coatings.

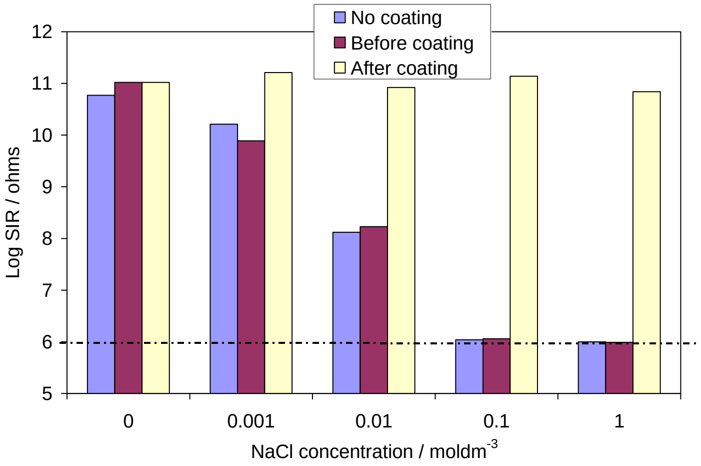


Figure 3
Final SIR values of boards with NaCl contamination
Applied before or after coating with solvent-based acrylic coating

Figure 4 shows a summary of the SIR measurements taken at 85°C and 85% RH for the various coatings when the boards were contaminated with NaCl after coating. The instrument has an inline resistor to limit the minimum resistance, equal to $10^6\Omega$, and is there to preserve corrosion dendrites if they should form. It is evident from the results that the various conformal coatings provide varying degrees of protection for the boards. It should however be noted that with the exception of the epoxy coating and the water-based acrylic (2) coating, the coatings provided similar levels of protection for the different NaCl concentrations. Also, a low log SIR value does not necessarily mean the coating was permeable to the NaCl contamination, as each coating will have a different level of moisture permeability, which will affect its SIR results under the set environmental conditions.

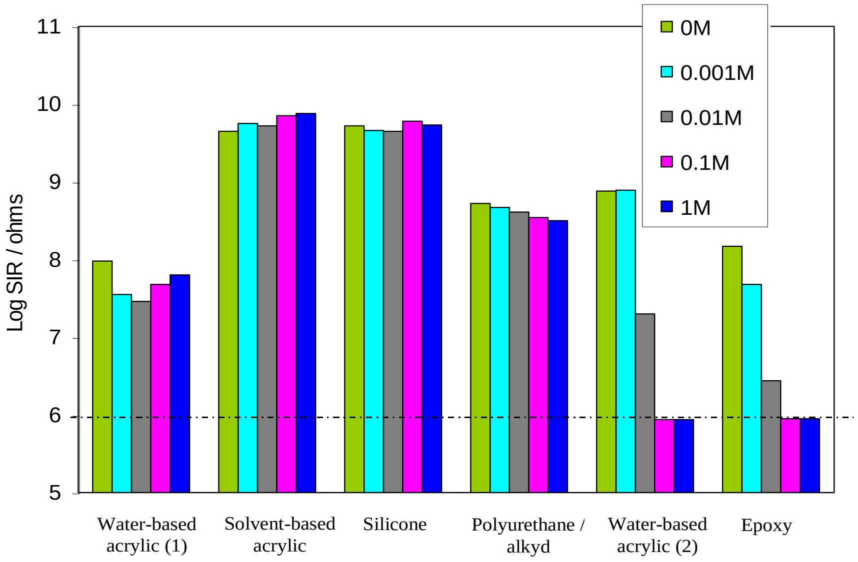


Figure 4 Final SIR values of conformally coated boards contaminated with NaCl after coating

SIR results with flux contamination

Flux contamination of the boards after conformal coating application showed a more significant decrease in SIR compared to the results from NaCl contamination. Figure 5 shows the summary of the SIR results from contaminating the boards with flux after coating.

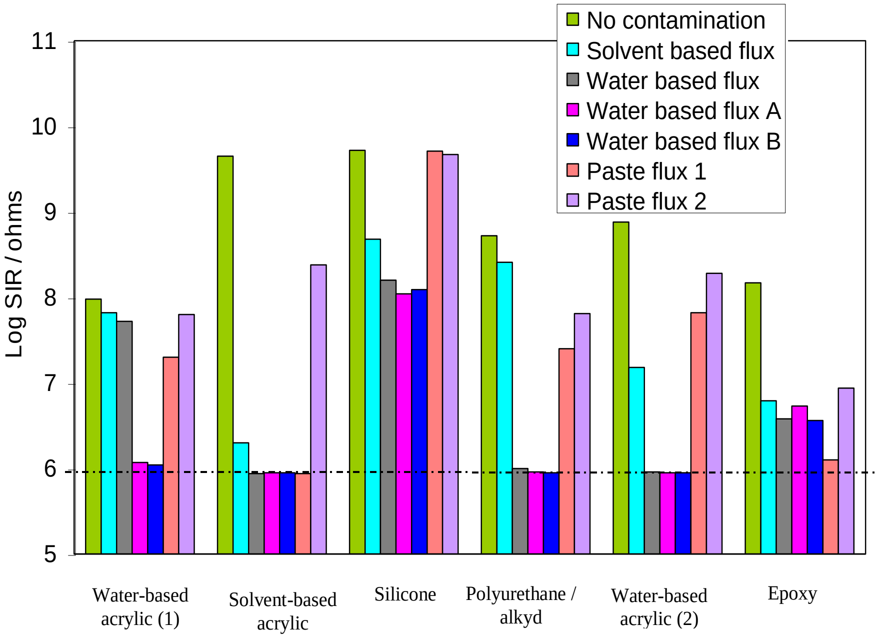


Figure 5 Final SIR values of conformally coated boards contaminated with flux after coating

SERA results with NaCl contamination

At ambient conditions, gold does not form any oxides when in contact with moisture and air; thus, upon application of the reduction current, gold does not undergo electrochemical reduction[9,10], and the potential therefore attains a value associated with the reduction of water, as seen in Figure 6.

Thus, for the boards that are sufficiently protected from contamination by conformal coatings the potential transient should be similar to that for gold. This is indeed observed for boards that were contaminated by NaCl after conformal coating application, as can be seen in Figure 9. This means the coatings were sufficiently robust against the NaCl contamination.

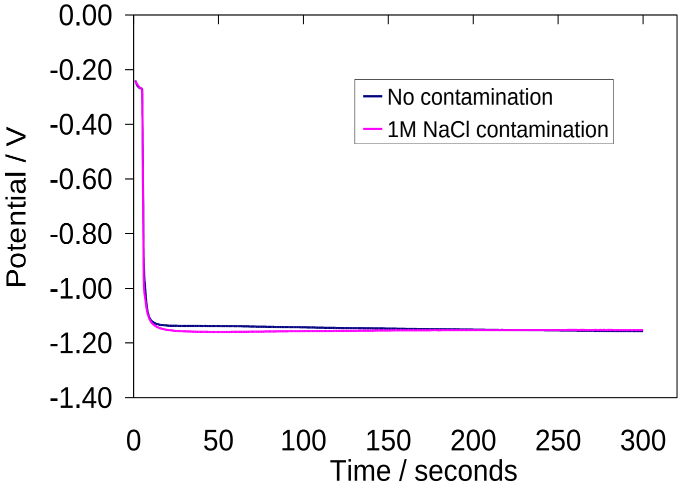


Figure 6 - Typical SERA curve of a board sufficiently protected from NaCl contamination by conformal coating

SERA results with flux contamination

A possible failure that might occur in electroless nickel/immersion gold finish boards is due to the oxidation of the nickel through any pores in the gold coating[11]. The presence of reducible species was evident on the boards where the conformal coatings were permeable to the applied contamination, the potential attaining values significantly more noble than that for gold.

The presence of reducible species in the presence of flux contamination is evident in Figures 7 to 12, which show the results from contaminating conformally coated boards with flux. This implies that the coatings were permeable to the fluxes. Table 2 gives the reduction potentials of some reducible species for copper though no data were available directly for nickel.

Table 2. Reduction potentials of surface species

Reducible compound	Reduction Potentials vs. Ag/AgCl electrode, V*
Cu_2O	-0.45 to -0.60
CuO	-0.60 to -0.70
Cu_2S	-0.85 to -0.90
Hydrogen on copper	-1.05 to -1.15

*Measured at 30 μAcm^{-2}

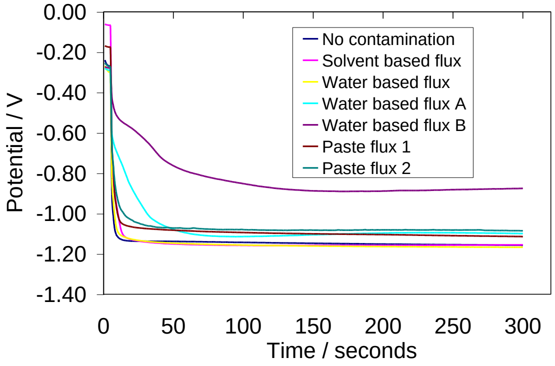


Figure 7. SERA curve of flux contamination on water-based acrylic (1) coated boards

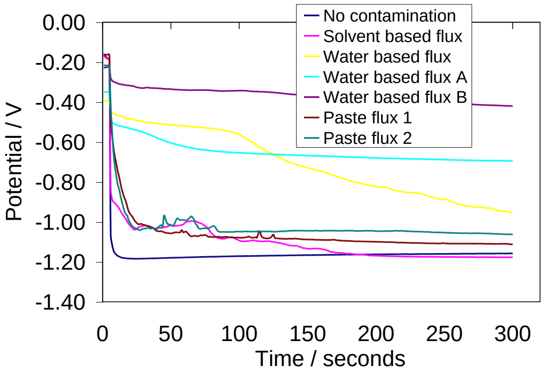
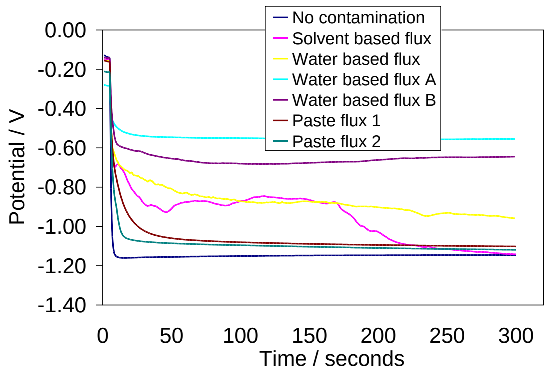


Figure 8. SERA curve of flux contamination on solvent-based acrylic coated boards



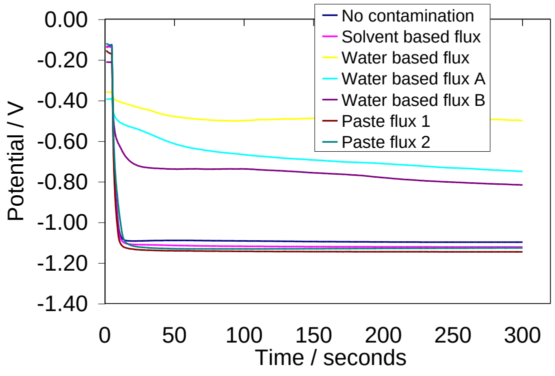
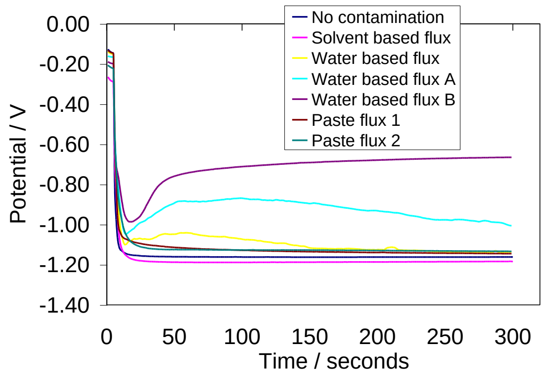


Figure 9. SERA curve of flux contamination on silicone coated boards

Figure 10. SERA curve of flux contamination on polyurethane / alkyd coated boards



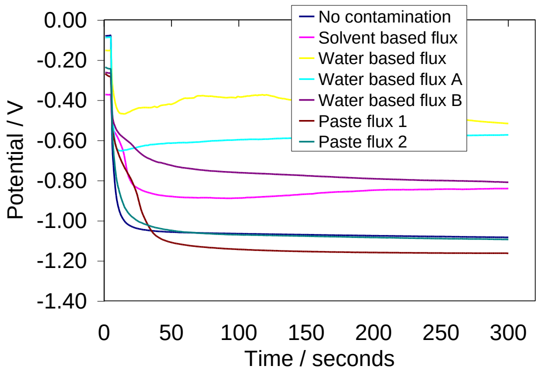
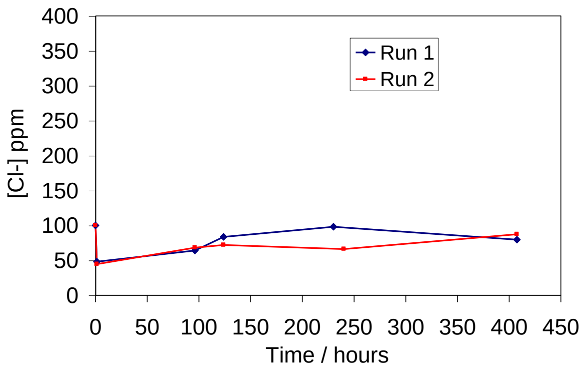


Figure 11. SERA curve of flux contamination on epoxy coated boards

Figure 12. SERA curve of flux contamination on water-based acrylic (2) coated boards

Results from chloride ion migration measurements

The initial results from measuring Cl^- ion migration across conformal coatings are shown in Figures 13 and 14 where the change in Cl^- ion concentration with time is monitored. These measurements were made at 40°C and show minimal change in the Cl^- concentration, indicating good barrier properties. This result compares well with the results obtained from the SIR measurements at the same temperature, where very little effect of Cl^- ions on the coatings' performance was observed. Hence, no further Cl^- diffusion measurements were made



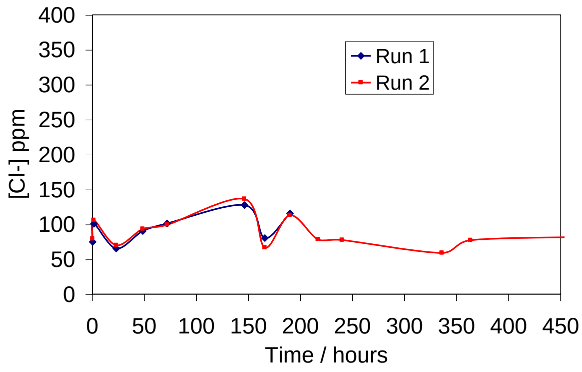


Figure 13. Chloride diffusion trends for water-based acrylic coated boards

Figure 14. Chloride diffusion trends for solvent-based acrylic coated boards

Results from flux migration measurements

Figures 15 to 20 show the pH measurements of both sides of the diffusion cell over the 50-hour test period. It should be noted that the left-hand side of the diffusion cell contained a sample of water-based flux B at about pH 2 while the right-hand side of the cell contained deionised water. The graphs below show the change in pH with time in both compartments.

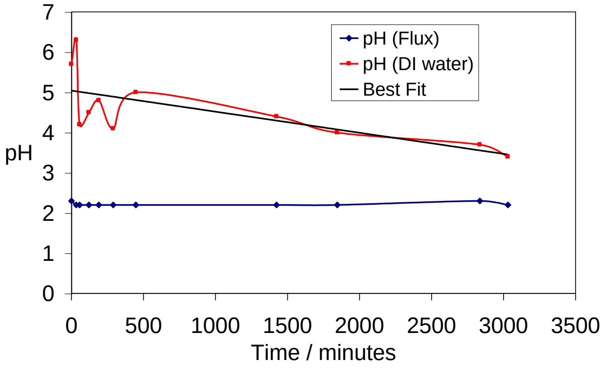


Figure 15. Variation in pH reflecting hydrogen ion diffusion trends for water-based acrylic (1) coated boards

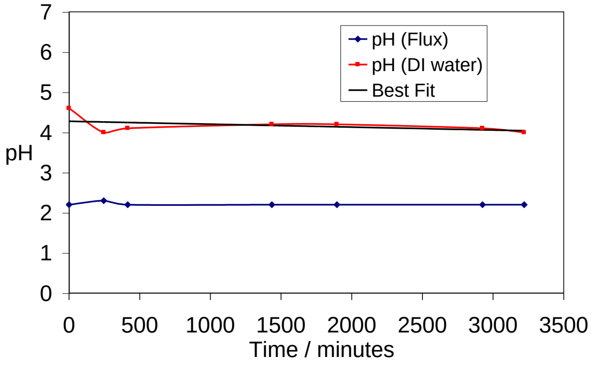


Figure 16. Variation in pH reflecting hydrogen ion diffusion trends for solvent-based acrylic coated boards

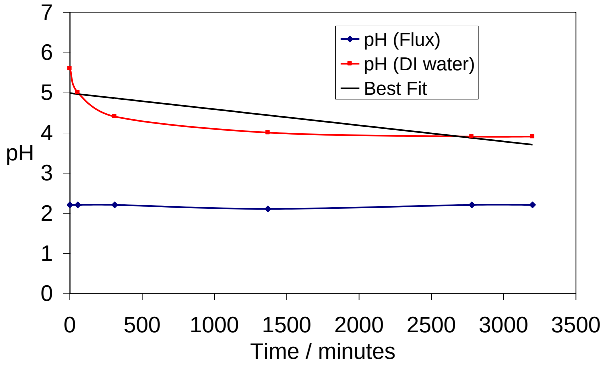


Figure 17. Variation in pH reflecting hydrogen ion diffusion trends for silicone coated boards

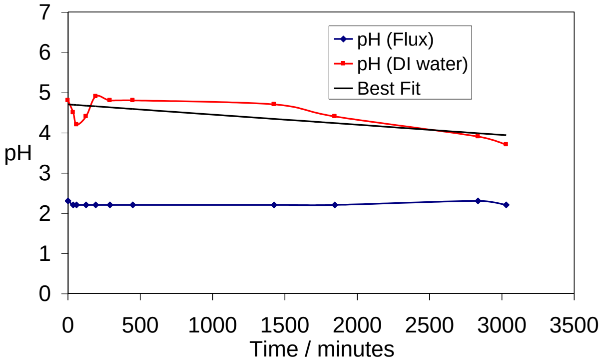


Figure 18. Variation in pH reflecting hydrogen ion diffusion trends for polyurethane / alkyd coated boards

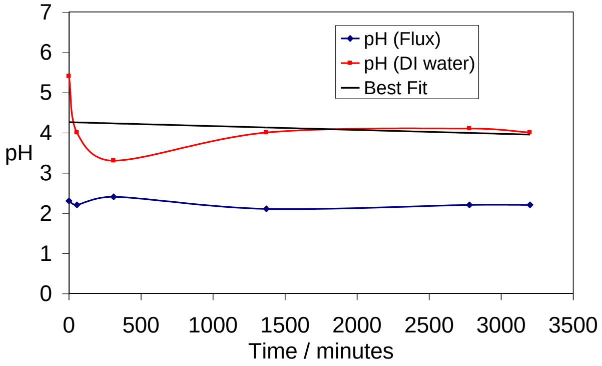


Figure 19. Variation in pH reflecting hydrogen ion diffusion trends for epoxy coated boards

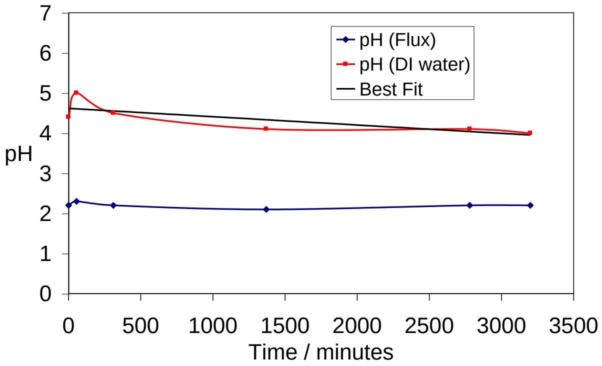


Figure 20. Variation in pH reflecting hydrogen ion diffusion trends for water-based acrylic (2) coated boards

The results from the GC-MS are reported in detail in NPL report DEPC-MPR 032[8]. These showed evidence of permeation of at least two of the acids present in the sample taken from the initially uncontaminated right hand cell of the diffusion equipment (Succinic acid and either Adipic and/or Glutaric acids).

DISCUSSION

These experiments have characterised, with a range of techniques, the protection capabilities of conformal coatings when exposed to sodium chloride solutions and flux components. The techniques have been used in a complementary manner and have led to a better understanding of coating capabilities.

SIR generally declines with increasing temperature. At constant temperature there was no effect on SIR after exposing the coated board to sodium chloride, as shown in Figure 3. This suggests that the conformal coatings are permeable to moisture even though they remained very much less permeable to NaCl. Tautscher[12] and Waryold[13] have observed that conformal coatings act as semi-permeable membranes allowing some moisture penetration to occur on exposure of boards to a damp atmosphere or immersed in water that reduces the SIR. Despite the decline in SIR, the coating will stop the circuit from water bridging following adventitious splashing or short term condensation and hence prevent signal cross talk or short circuits[2].

The preliminary SIR measurements carried out on boards that were contaminated before coating showed low SIR as compared to boards that were contaminated after conformal coating application, as shown in Figure 3. This indicates the importance of board cleanliness in maintaining the performance of circuitry. Hence, if Cl- ions were to penetrate the coating, then a notable effect on the SIR would be observed. This is an important point as Cl- ions do have a strong effect on SIR, but it has been shown here that conformal coatings in many cases acted as an effective barrier preventing Cl- reaching the PCB surface.

The SIR measurements were used to evaluate the application of flux residues and significant effects were observed, as shown in Figure 5. These fluxes were generic formulations from dibasic acids commonly used in industry. Only the silicone coating appeared resistant to these acids, and in general the water-based variants of the fluxes were more aggressive than the solvent based version. The SIR results were very important, showing relatively susceptibility to these acids and directing further work to monitor closely these effects.

The surface analysis of the boards by SERA provided information about the presence of reducible species on the surface. The boards that recorded very low SIR values, $10^6\ \Omega$, show the presence of reducible compounds on the surface during SERA. These reducible compounds are the products of nickel and oxygen. There is also the possibility of some copper oxides present in the SERA results where the nickel barrier has been compromised by the action of the flux. The SERA results are in agreement with, and complementary to, the SIR results as it shows the conformal coatings are more robust against the ionic contaminant than they are against flux.

A contaminated surface can cause a conformal coating to blister, as a result of underlying track corrosion, leading to loss of adhesion. This was evident in a number of the conformally coated boards that were contaminated with flux. The coatings appear to perform better against the solvent-based flux than they did against the water-based flux. Water-based flux B, which is made up of the weak organic acids (adipic, succinic and glutaric) show the lowest SIR values. This emphasizes the great influence these acids have on conformal coatings performance and is of primary concern as these organic acids are common in fluxes. Re-work repair is an issue of particular concern since it is quite possible for flux residues to be left following this operation, since the flux may wet into areas that are difficult to clean. The permeability of the coatings to the fluxes has also raised questions about their permeability to other fluids that have similar organic compounds as the main constituents.

The hydrogen ion diffusion cell experiments were carried out to establish whether the conformal coatings are actually permeable to these fluxes as suggested by the SIR and SERA measurements. The results show that shortly after the test set-up, there is a drop in pH on the uncontaminated side of the cell. This is due to H_3O^+ ions quickly migrating through the coating until equilibrium is reached. There is then a further change in pH with time, which could be due to either the diffusion of the organic acid molecules (and then dissociation) or the anions of the dissociated acids across the coating membrane. The GC-MS proved very sensitive to minute amounts of contaminants and samples from the uncontaminated side of the cell indeed showed small amounts of succinic acid and either adipic and/or glutaric acids were present. A more comprehensive study would be required if quantitative analysis of migrating species is to be determined.

New work will be performed at NPL to evaluate the permeability of conformal coatings to organic compounds. This is of primary concern because a large number of fluids, such as hydraulic fluids, de-icing fluids and surfactants, come into contact with conformally coated boards in-service, as indicated in a survey of conformal coatings users. It will therefore be useful to find out whether the coatings are as permeable to these organic compounds.

CONCLUSIONS

This study has shown that conformal coatings offer a range of protection depending on the coating and contaminant chemistry. Experiments revealed that a wide range of coatings were resistant to chloride ions, and acted as an effective barrier. But, with exposure to fluxes the coatings showed significant failures, with the permeation of organic acids. These results were derived from complimentary investigations using, SIR, SERA, diffusion cell and GC-MS. These measurements showed clearly that chloride did not penetrate the coatings, where as the dibasic acids did.

The SIR techniques proved capable of ranking the coatings. Where the final resistances values fell to the limiting resistance of $10^6\ \Omega$ the SERA technique proved very complimentary. SERA showed the degree of attack, and was able to differentiate when corrosion had ensued to extent that was beyond the SIR range.

The GC-MS experiments on solutions taken from the diffusion cell where the coating had been tested as a membrane against the diffusion of organic acids proved to be effective at proving coatings ability to pass these acids. This experiment confirmed that the drop in SIR, and corrosion seen in the SERA, were due to the diffusion of contaminants through the coating.

Permeability of the conformal coatings to the organic acids is an interesting development and future work at NPL will explore a wider family of similar organic compounds from a range of industrial applications.

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Measuring Conformal Coating Performance

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Environmental protection of coating
Presentation Aims

- Conformal coatings are used to improve reliability of electronic boards in harsh environments.
  - Moisture and contaminants
- Failure in protection can be due to permeation through the polymer structure or through failures in coverage.

Selected coatings

- Acrylic
  - Water based acrylic (1)
  - Water based acrylic (2)
  - Solvent based acrylic
- Silicone
- Polyurethane / Alkyd
- Epoxy

Contaminants

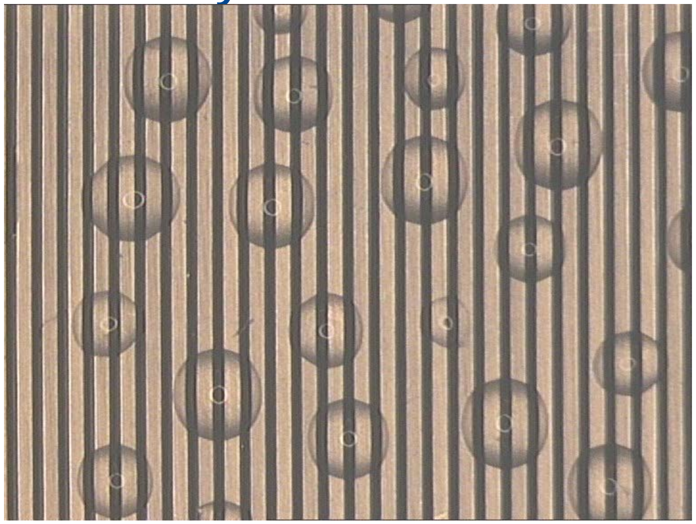
- Sodium chloride
- Flux
- Marine environment
- Industrial gas pollution(SO2, NO2, HCl)
- Hydraulic fluids
- De-icing fluids
- Surfactants

Evaluation techniques

- SIR
- SERA
- Diffusion Cell

Test board contamination

- 50 µl contaminants uniformly to cover
- 2.5 X 3 cm pattern area (~70µm thick liquid)
  - For NaCl, flux, sea water, acid rain & surfactants
    - SIR testing after contaminants dry in air,
  - For Hydraulic & De-icing fluids
    - SIR test start immediately after contamination

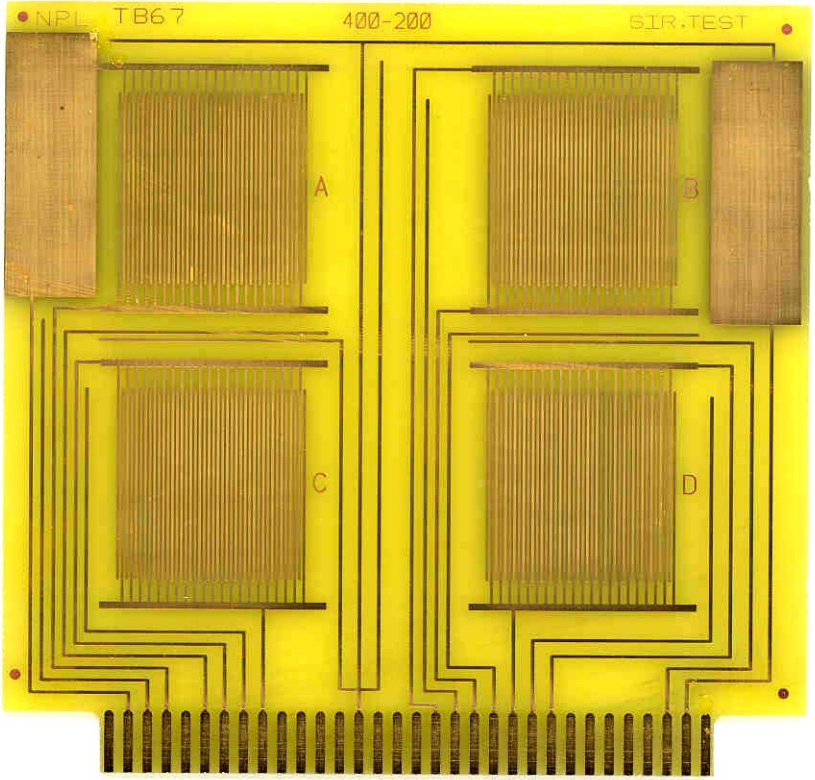


SIR evaluation

- SIR testing parameters:
  - 72 hours test
  - SIR continuous monitoring (10 mins)
  - Temp/humidity
    - 85°C / 85% RH & 50V
    - 40°C / 93% RH & 5V

SIR Test board

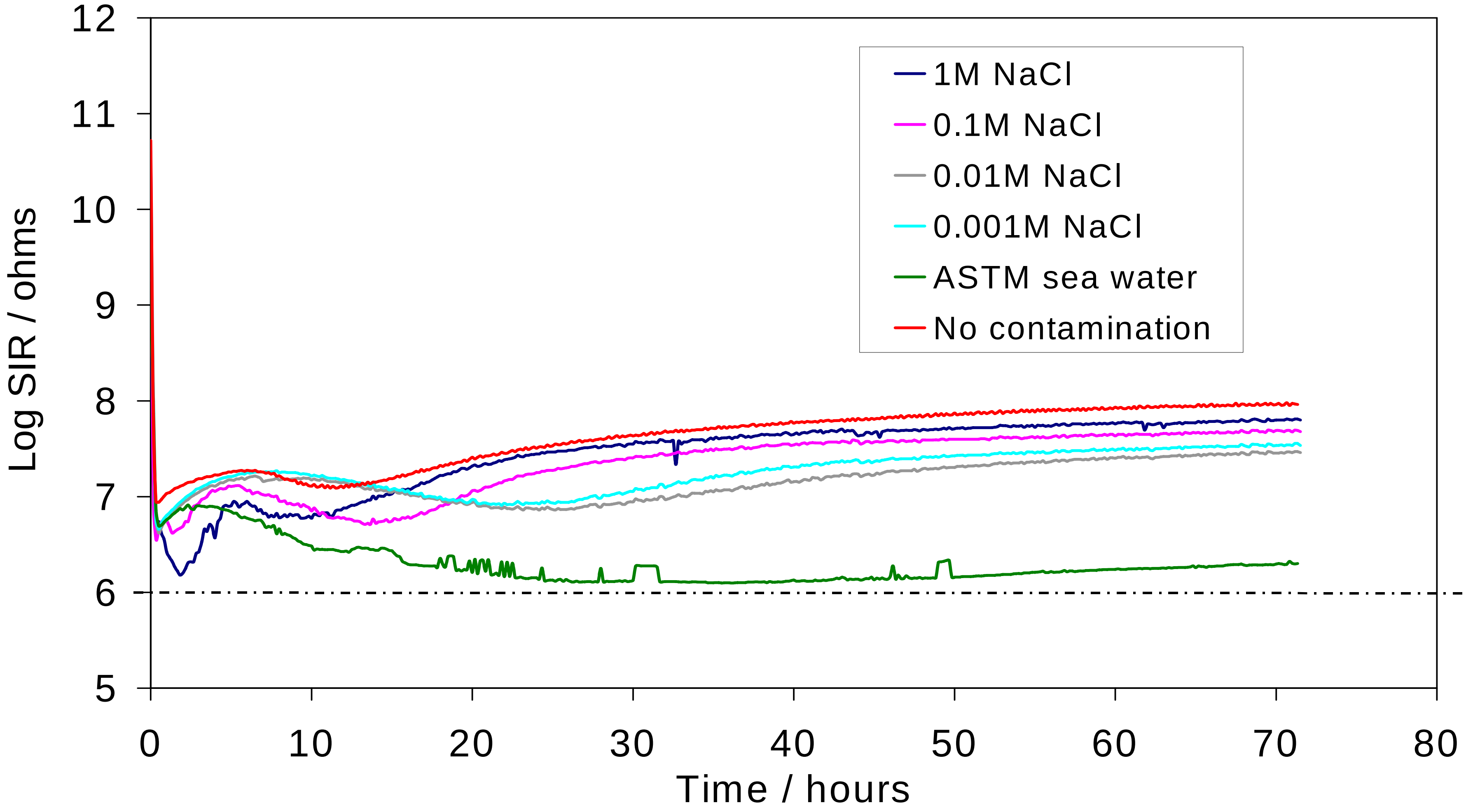
- **400/200µm track/gap with AuNi finish board (17µm Cu)**
- **Boards coated with six coatings**



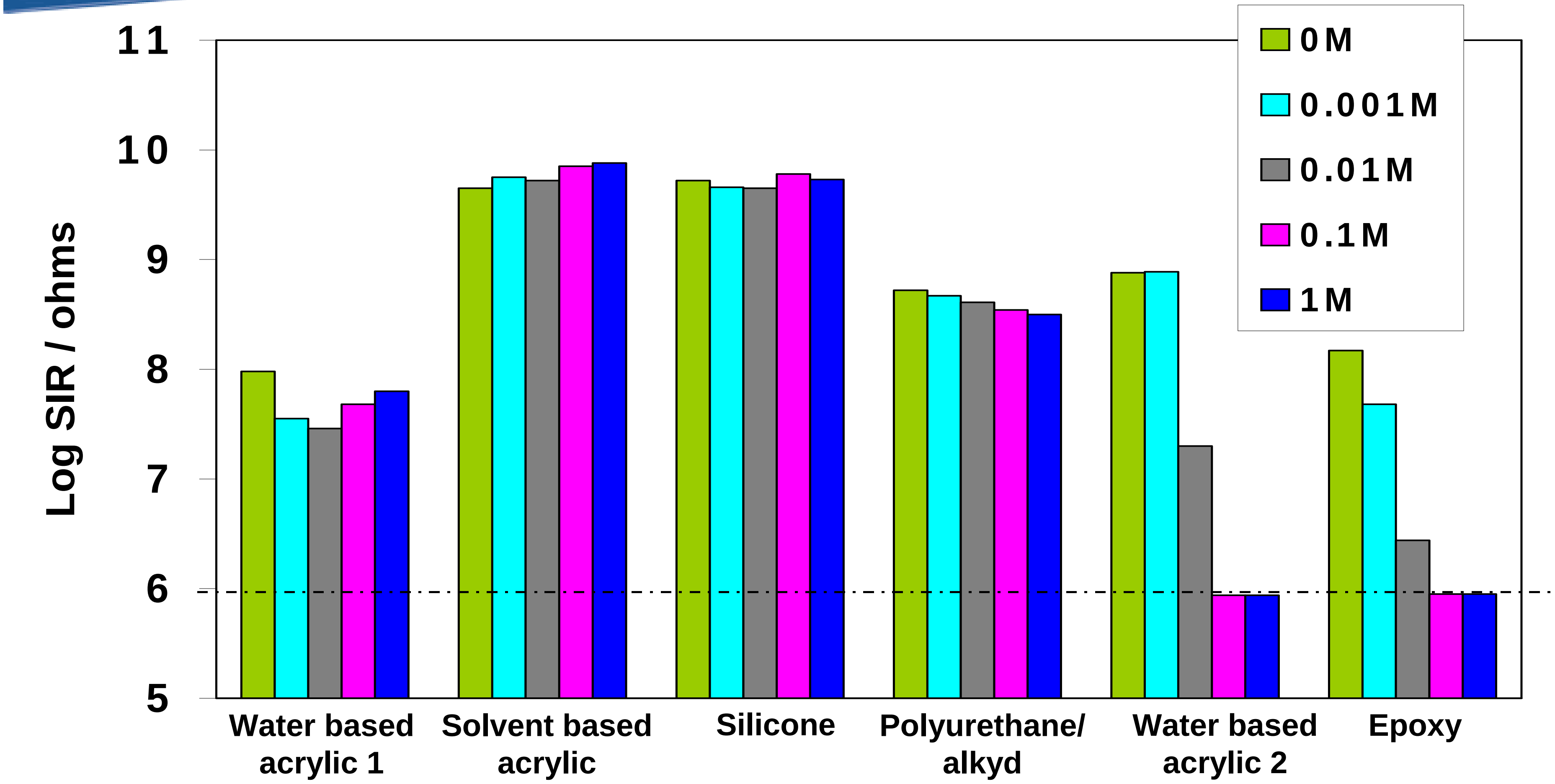
Initial studies

- Degradation effects of:
    - NaCl
    - Flux

Results – Water based acrylic 1



SIR Summary - NaCl



Flux formulation

- Solvent-based flux

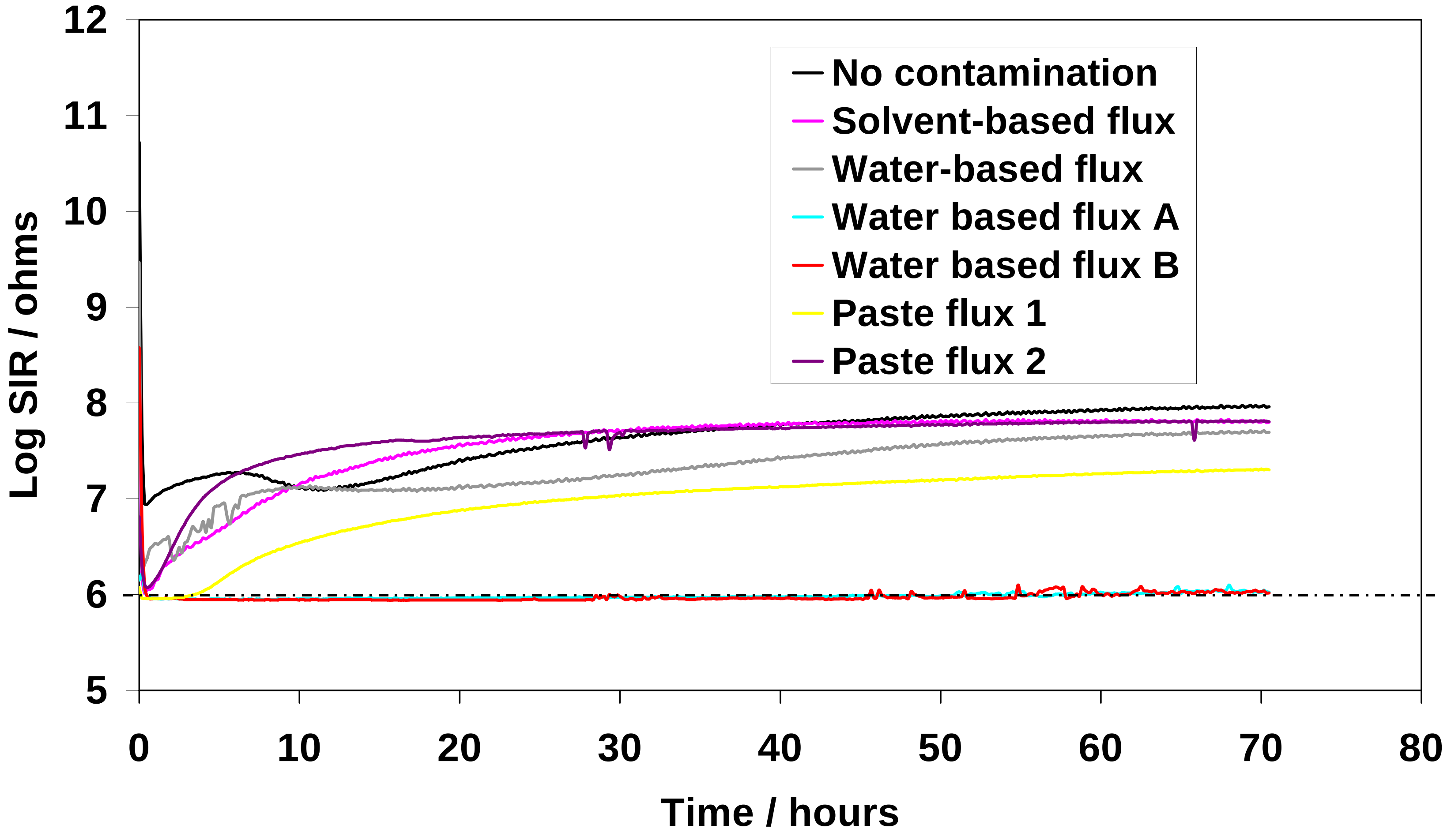
IPA	Adipic	Succinic	Glutaric	Rosin
93.2	1.7	1.7	1.7	1.7

- Water-based flux

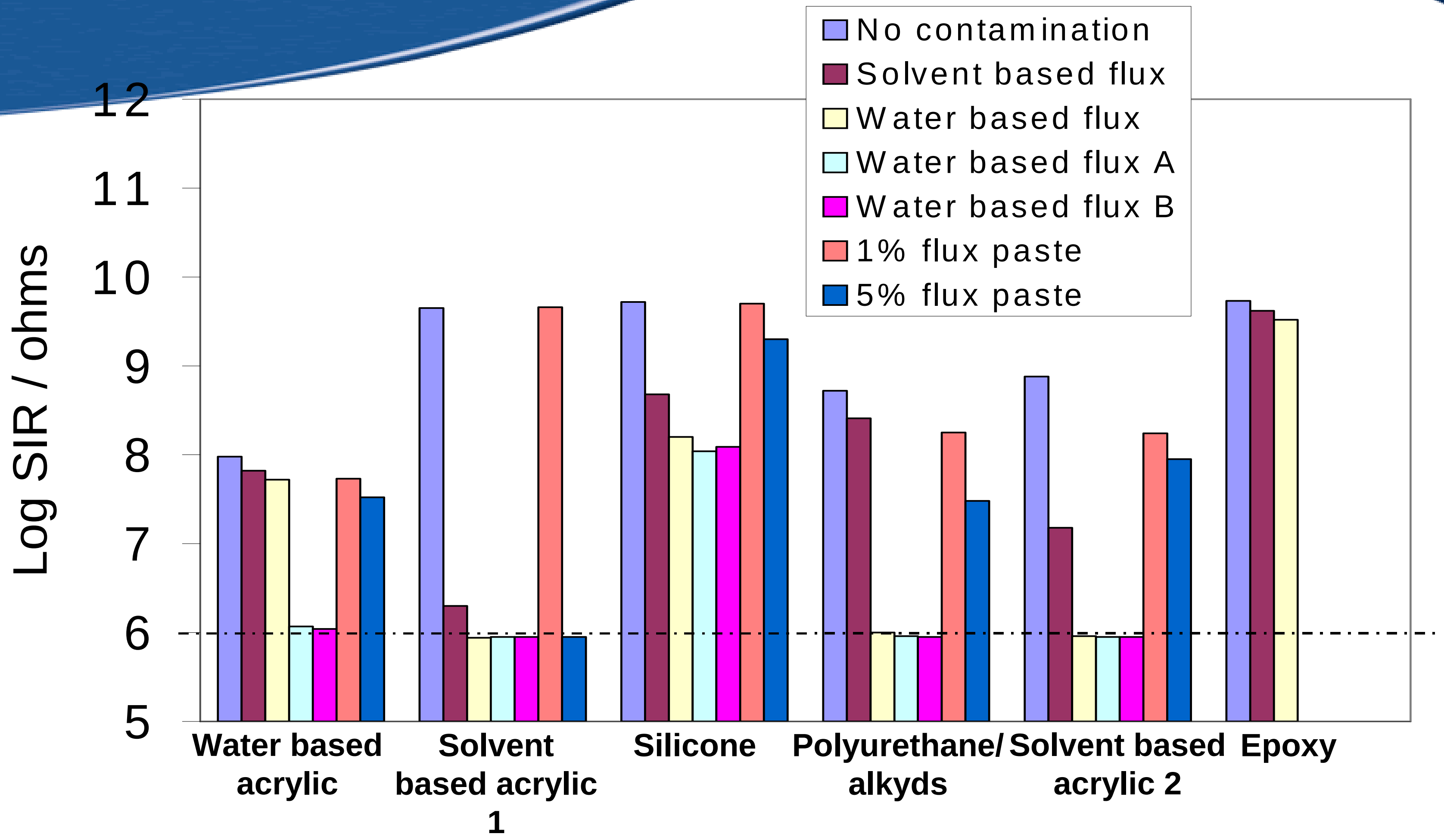
DI Water	Adipic	Succinic	Glutaric	Surfactant	Co-solvent
90.4	1.7	1.7	1.7	0.1	5.0

- Water-based flux A – No surfactant
- Water-based flux B – No surfactant or co-solvent
- Representative paste flux

Results – Water based acrylic 1



SIR Summary



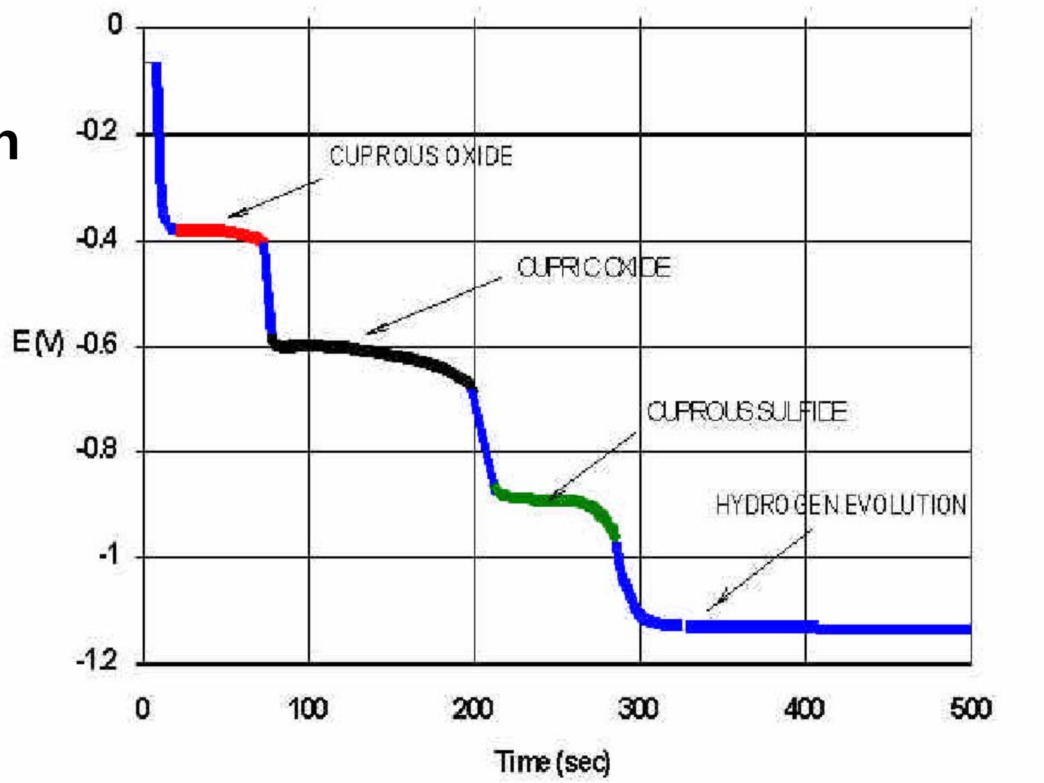
- Organic flux penetrates coatings to a greater degree than the ionic salt ions

SERA Evaluations

- SERA (Sequential Electrochemical Reduction Analysis)
  - Electrochemical technique used to determine a variety of key coating parameters
  - A small well-defined area is isolated for measurement
  - A controlled current is applied to reduce or oxidize surface species
  - Potential is followed as a function of time
  - Recording potential vs. time yields a series of plateaus corresponding to the sequential reduction or oxidation of surface compounds
  - The voltage levels identify the types of species present, and the time at each level measures the amount present

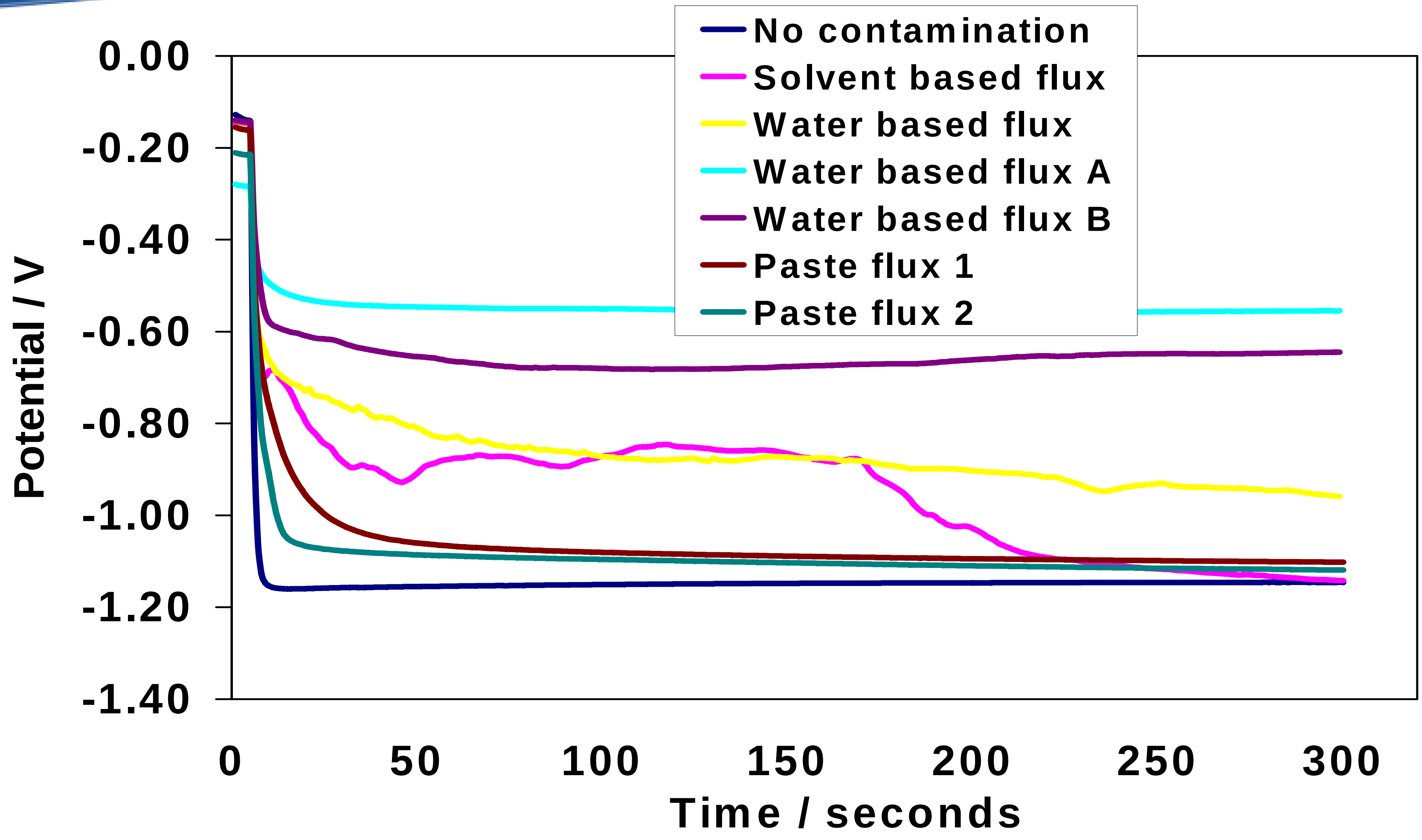
SERA Evaluations

Example of copper surface shown with different oxidation states of copper, and copper sulphide



Strip coatings after exposure and look for levels of oxide formation on surface

Results – Silicone

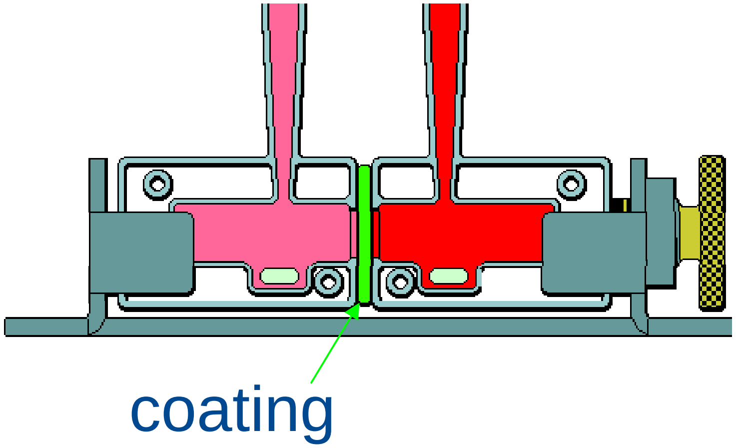


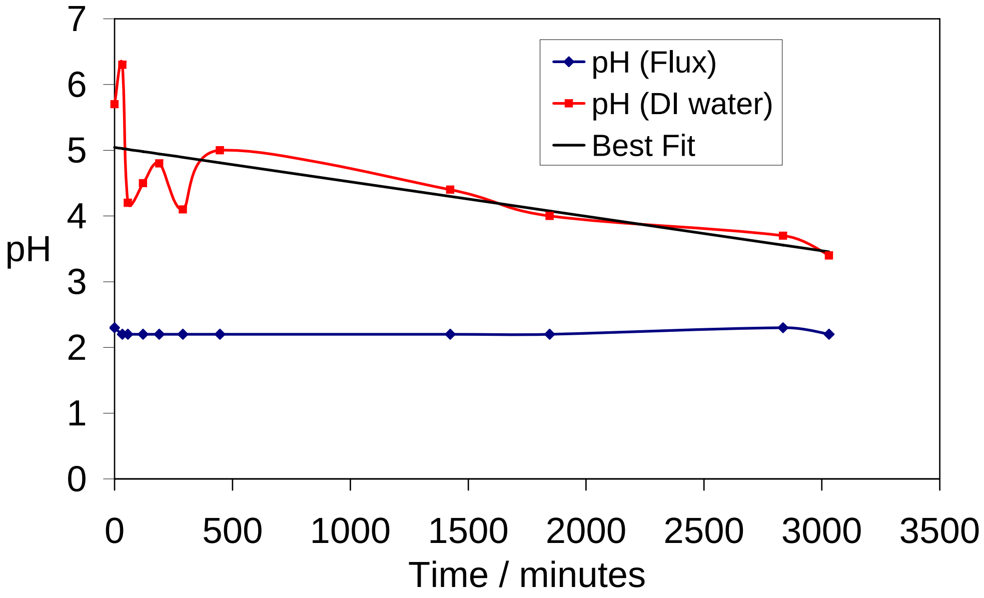
Summary

- **The various coatings protect the boards from corrosion induced by exposure to NaCl contamination when this is external to the coating.**
- **Exposure to weak organic acids can cause corrosion of the underlying metallisation.**
- **The SERA results complement the SIR evaluations.**

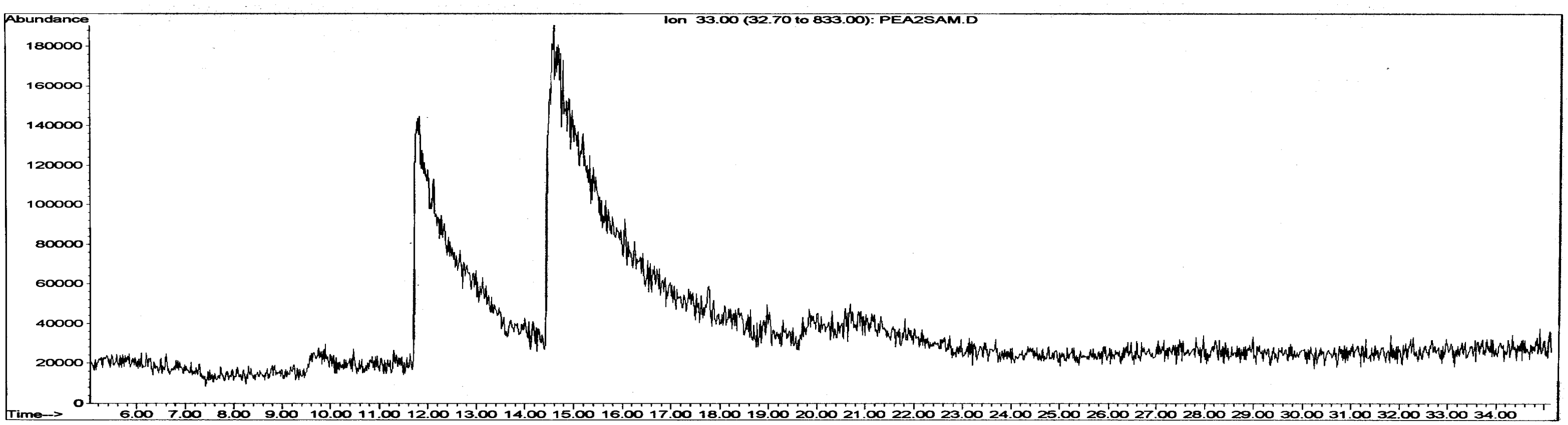
Diffusion Cell Measurements

- Dilute flux is added to left side cell.
- Electrode potential and pH are monitored
- Solution extracted for GCMS





Diffusion Summary

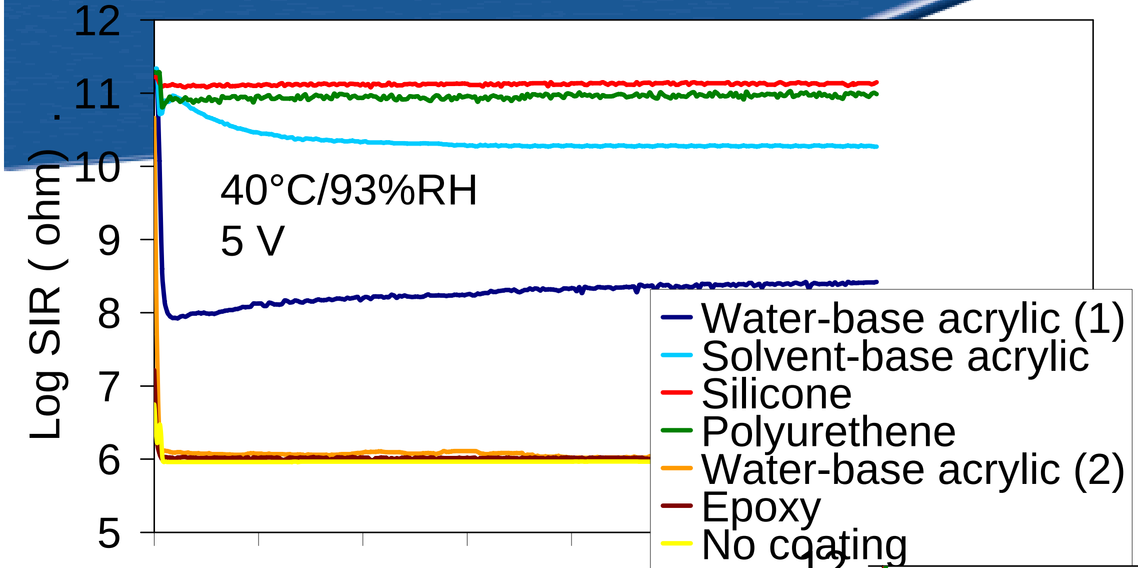


- The GCMS method is able to detect minute amounts of contamination.
- The components detected after 50 hours were
  - Succinic acid
  - Adipic and/or Glutaric Acid
- For quantitative results a more comprehensive method is needed

Harsh environments for electronic boards

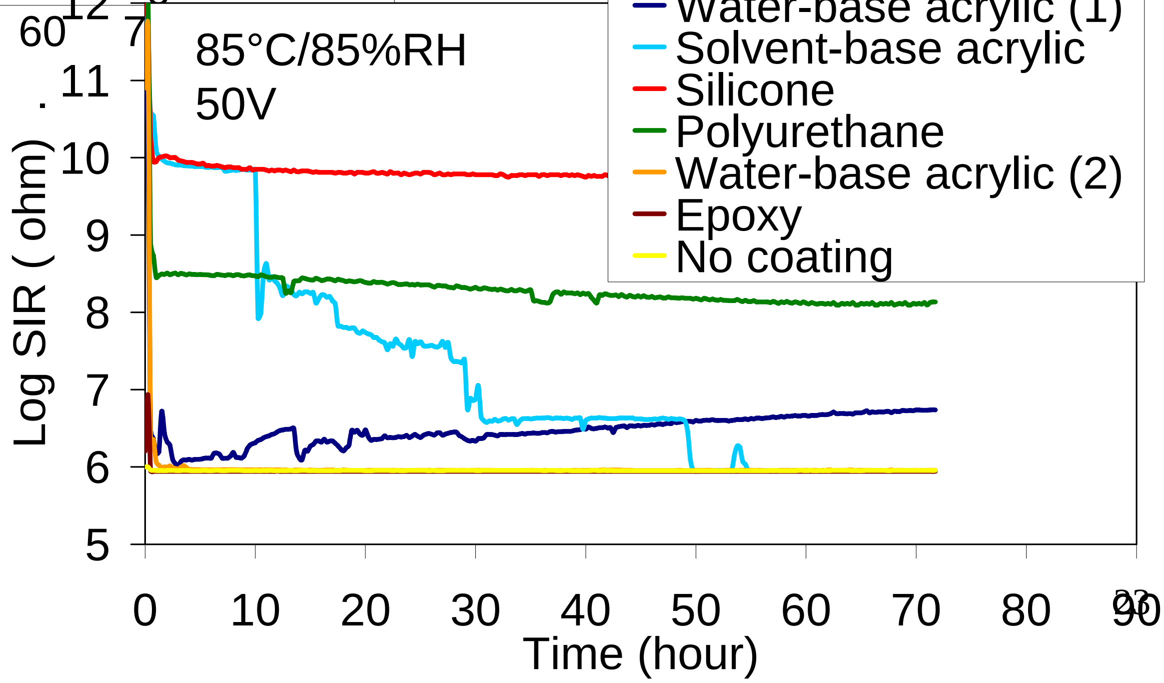
- Marine environment
- Industrial gas pollution(SO_2, NO_2, HCl)
- Hydraulic fluids
- De-icing fluids
- Surfactants

Results – Sea water

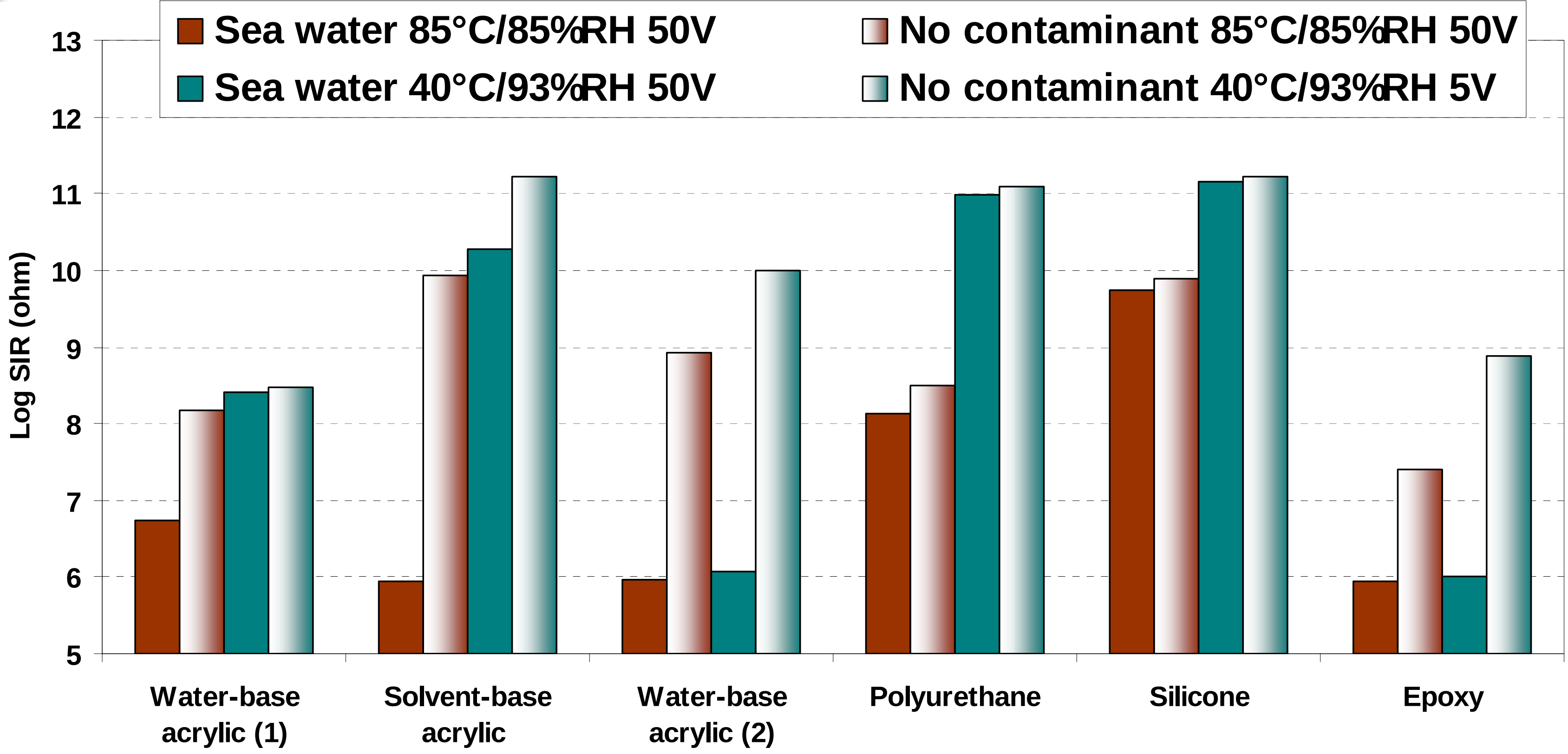


Chemicals	Concentration (g /100 g DI water)
NaCl	2.46
NaSO4	0.41
MgCl2.6H2O	1.11
CaCl2.6H2O	0.23
KCl	0.07
NaHCO3	0.02
KCl	0.01
Total	4.31

IM NaCl: 6.8 %



Sea water – Summary

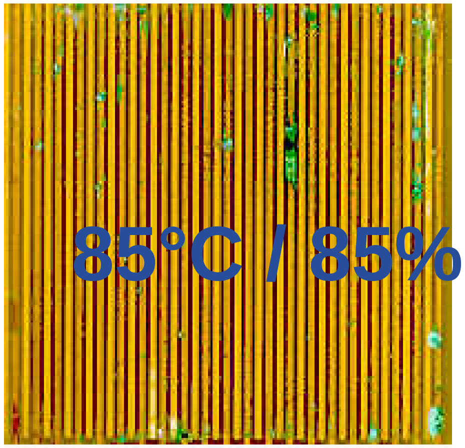


Tested boards

More corroded →

Solvent base

acrylic

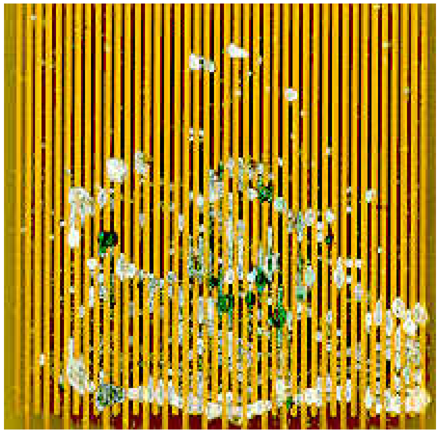


Water base

Acrylic (1)

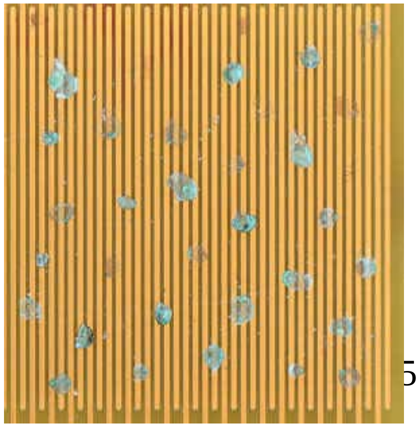
Water base

Acrylic (2)



Epoxy

85°C / 85% RH & 50V



40°C / 93% RH & 50V

Conclusions – Sea water

- Test condition 85°C / 85% RH & 50V is more severe than 40°C / 93% RH & 5V for sea water
- Coating Protection from sea water
  - Silicone > Polyurethane > solvent based acrylic >water based acrylic > epoxy

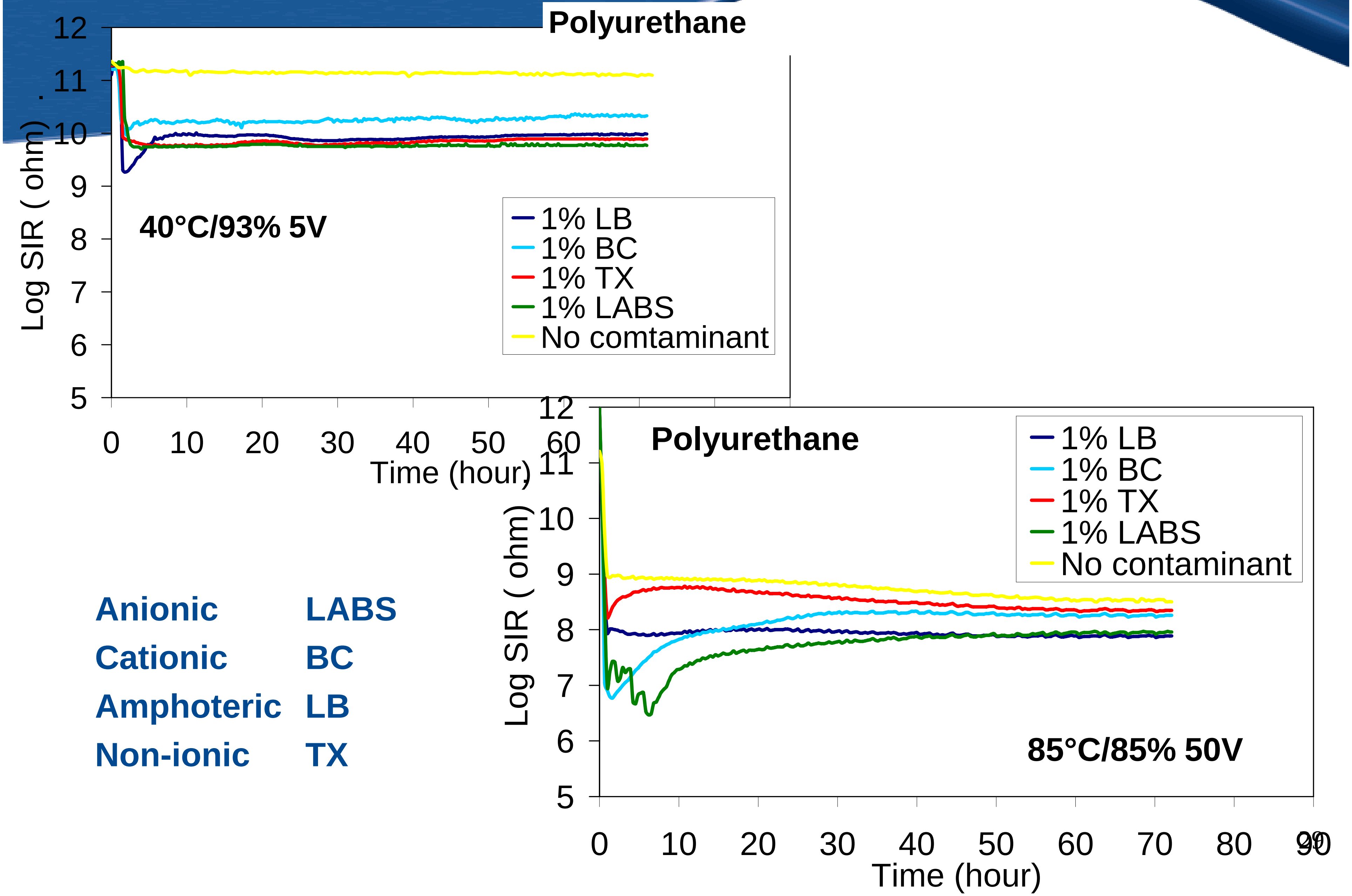
Results

Surfactants

Surfactants

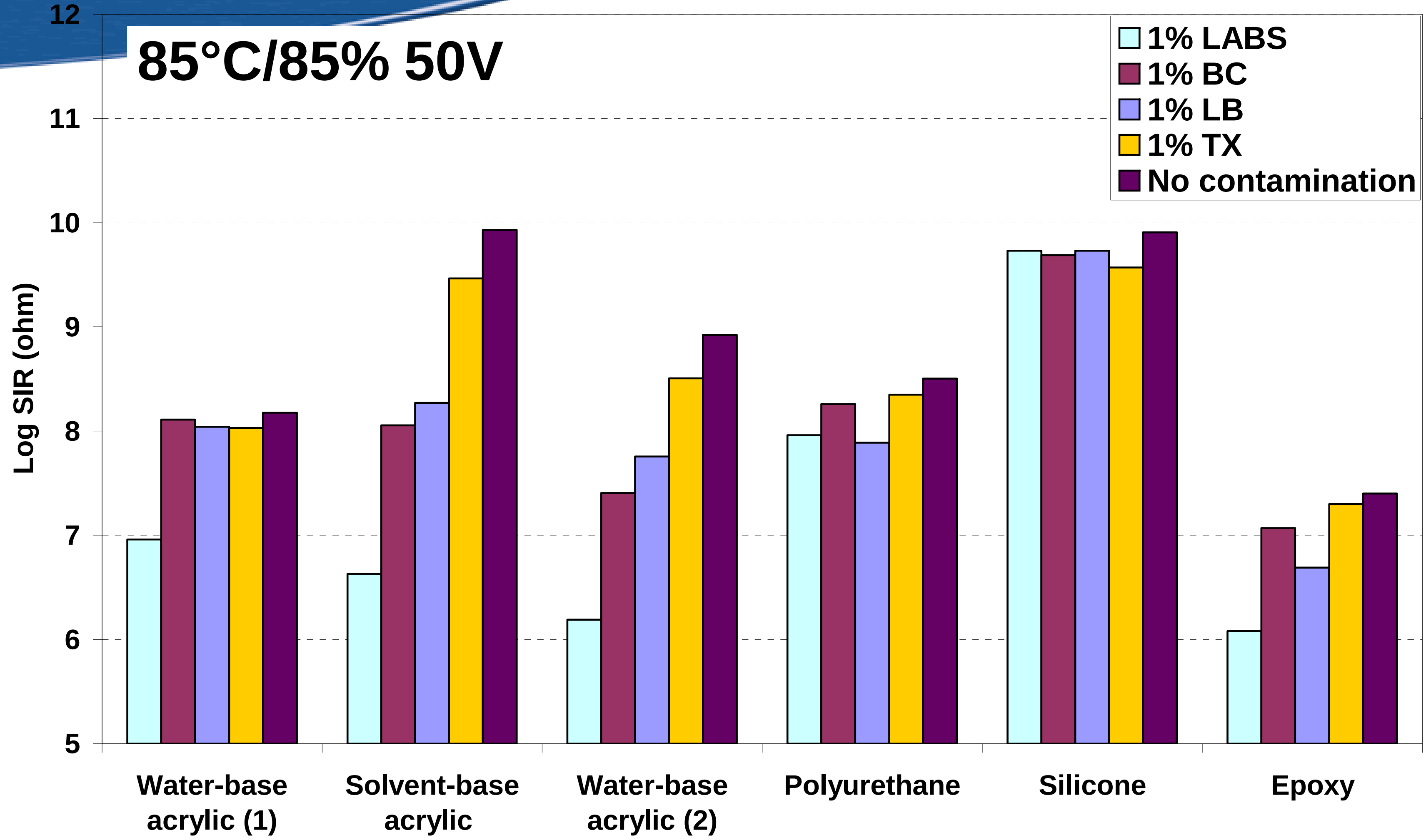
- Anionic
  - Laurybenzolsulfonsaeure (LABS)
- Cationic
  - Benzalkonium chloride (BC)
- Amphoteric
  - Lauryl betaine (LB)
- Non – ionic
  - Triton X-100 (TX)

Results – Polyurethane



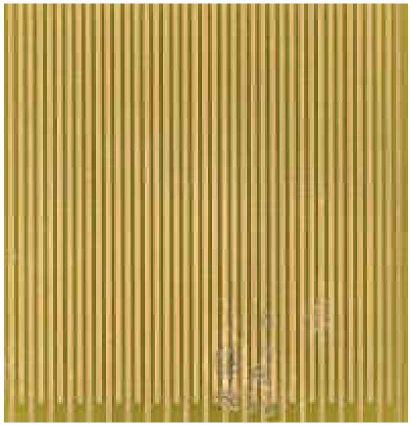
Anionic	**LABS**
Cationic	**BC**
Amphoteric	**LB**
Non-ionic	**TX**

Summary- Surfactants



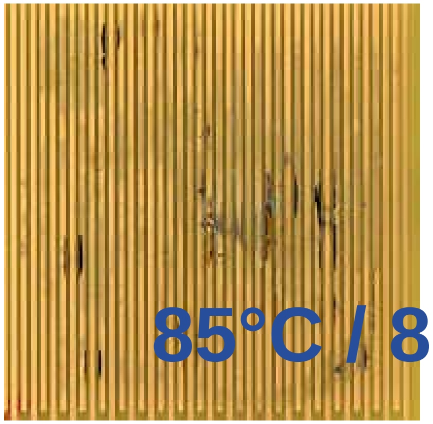
Tested boards
Surfactant results

More corroded →



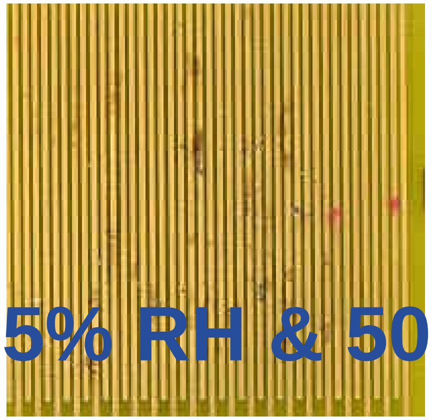
Solvent base

acrylic



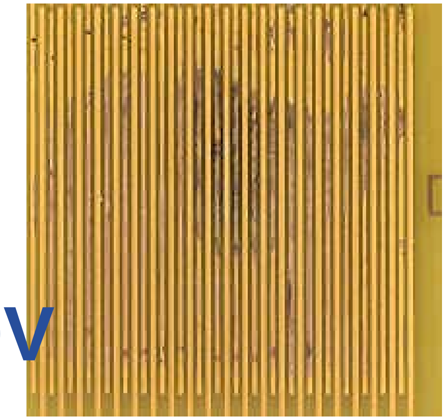
Water base

Acrylic (1)



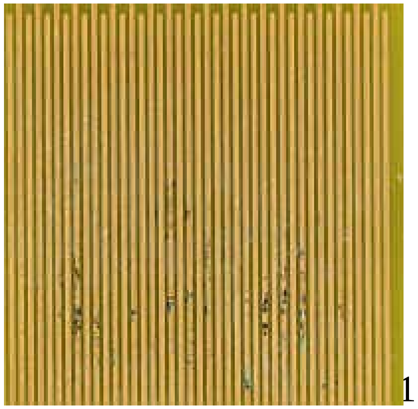
Water base

Acrylic (2)



Epoxy

85°C / 85% RH & 50V



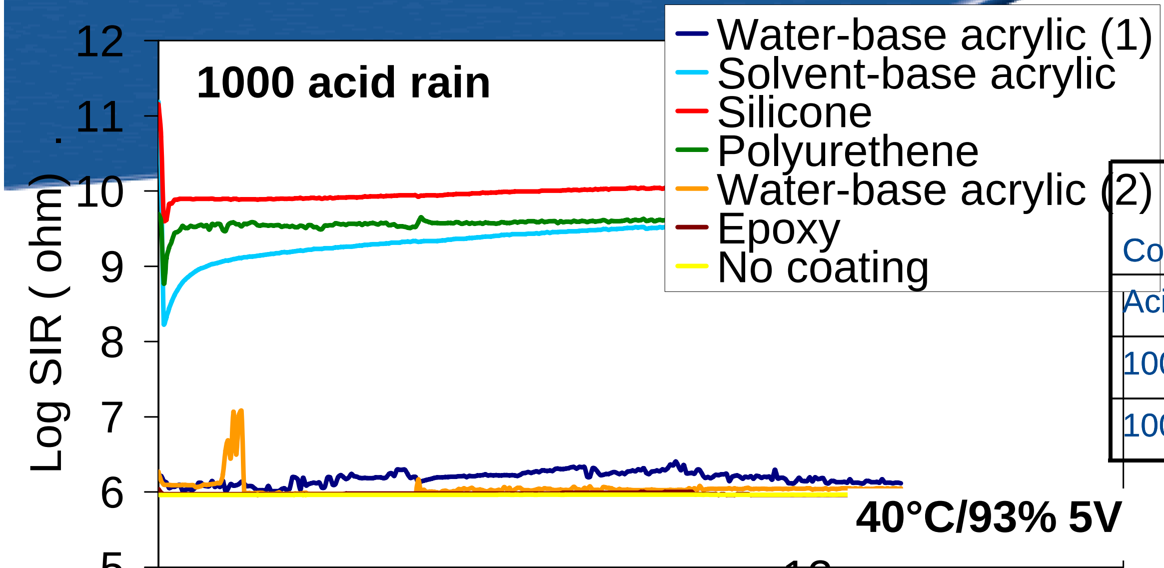
40°C / 93% RH & 50V

Conclusions – Surfactant

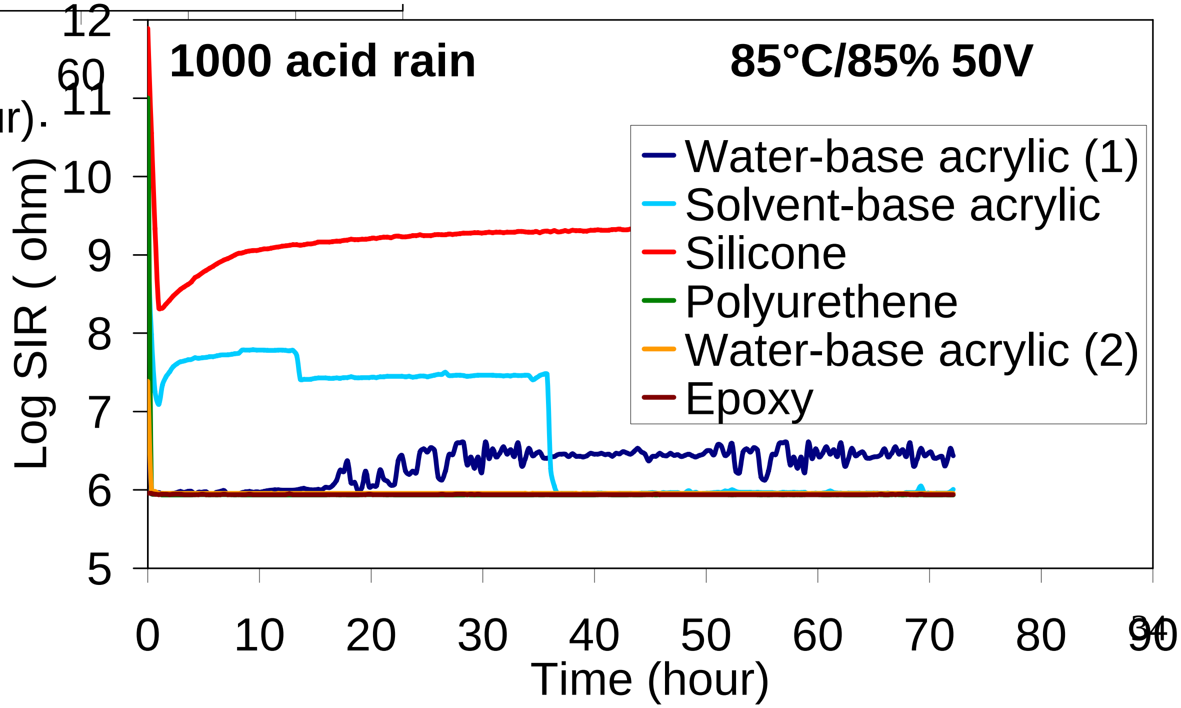
- Both test conditions gave very similar results
- Protection of the coating from surfactant
  - Silicone > Polyurethane > solvent based acrylic >water based acrylic > epoxy

Acid rain

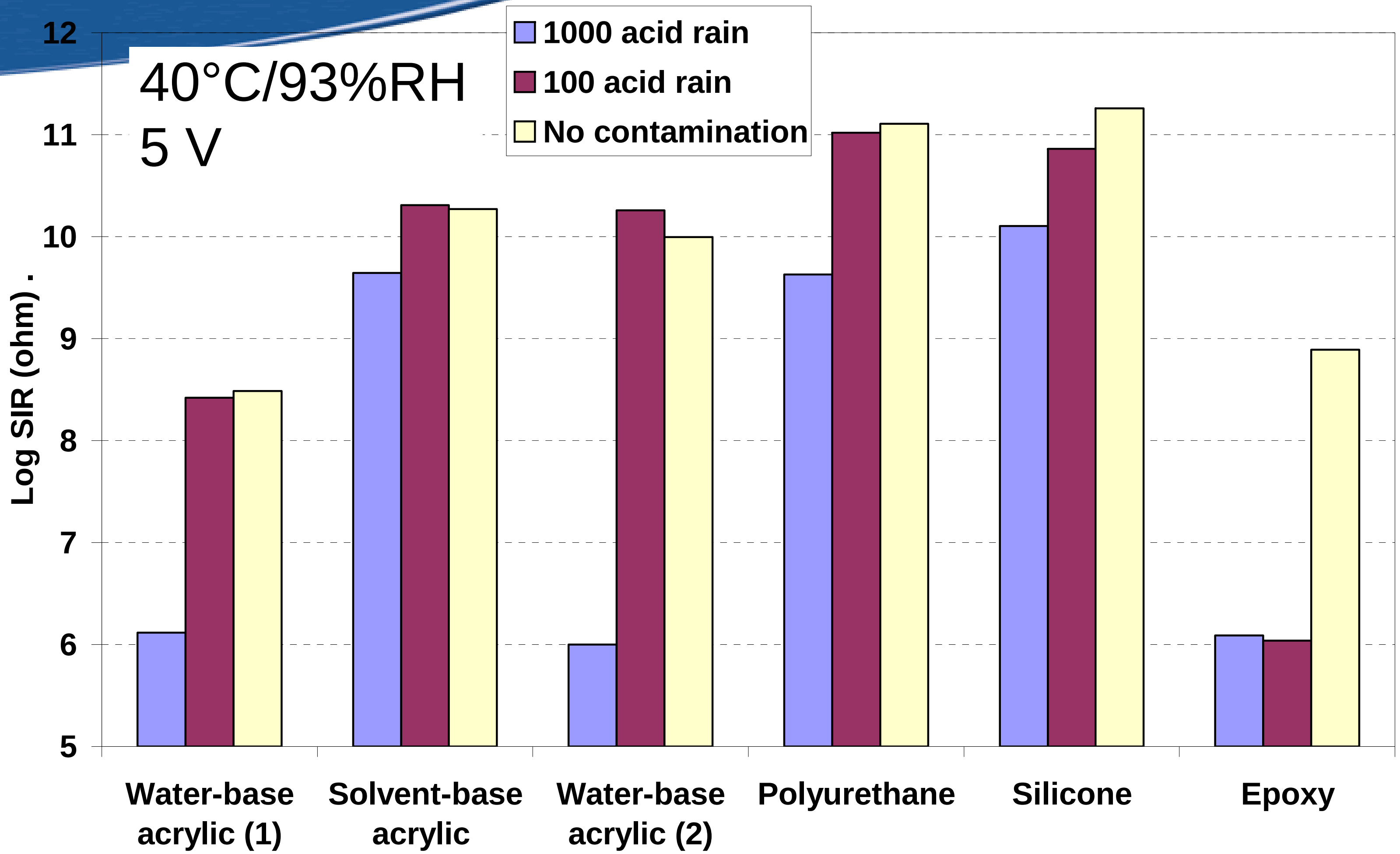
Results – Acid Rain (1000x)



Chemical	H_2SO_4	HNO_3	HCl
Code	mg/l		
Acid rain	11	7	1
100x conc	1100	700	100
1000x conc	11000	7000	1000

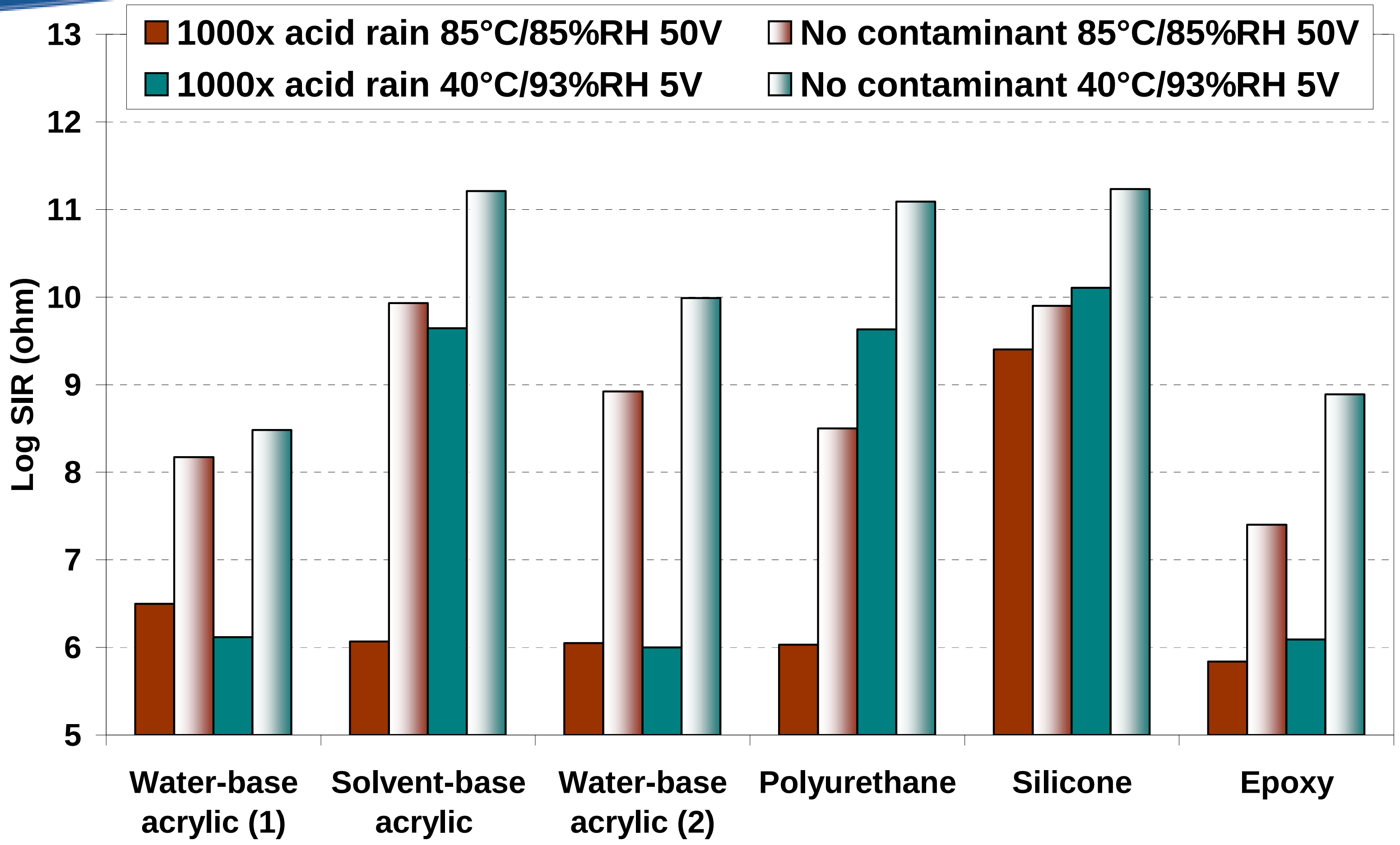


Summary – Acid Rain



Concentration effects

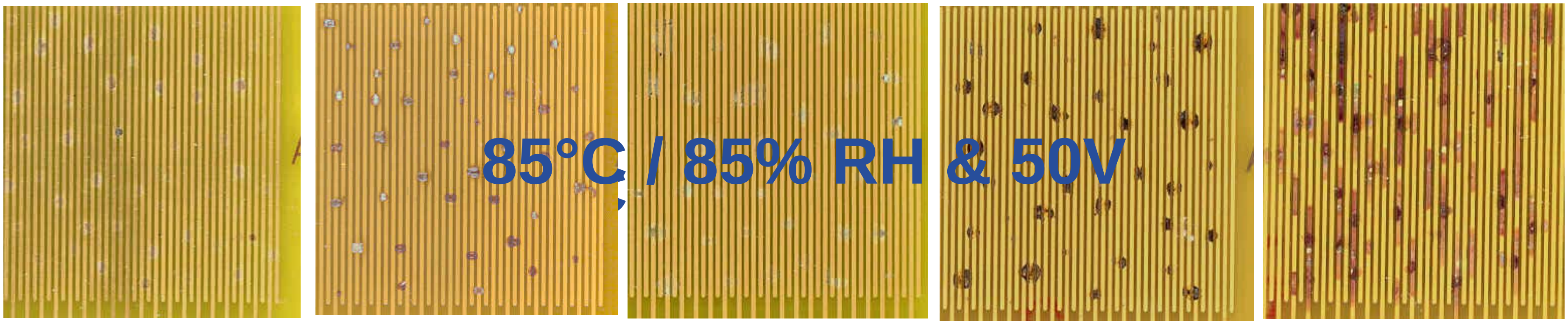
Summary – Acid Rain



Testing Conditions

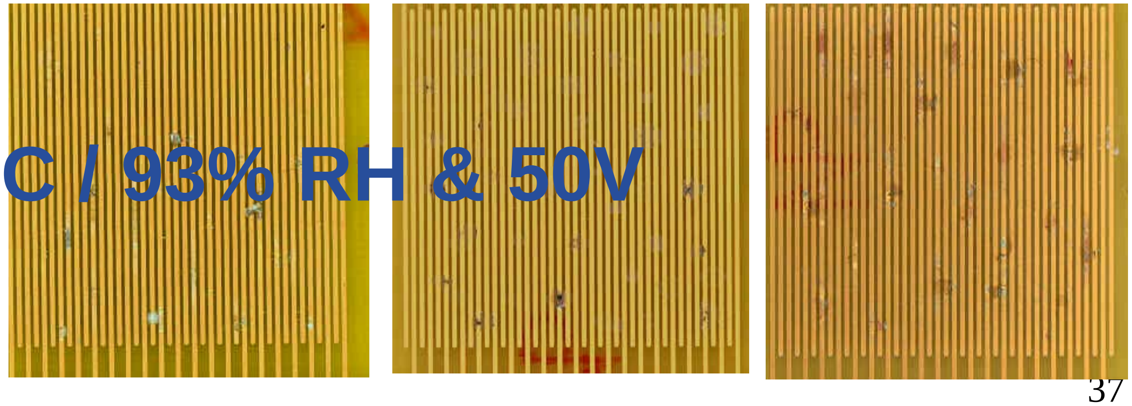
Tested boards
Acid rain results

More corroded →



85°C / 85% RH & 50V

Solvent base acrylic | **Polyurethane** | **Water base Acrylic (2)** | **Water base Acrylic (1)** | **Epoxy**

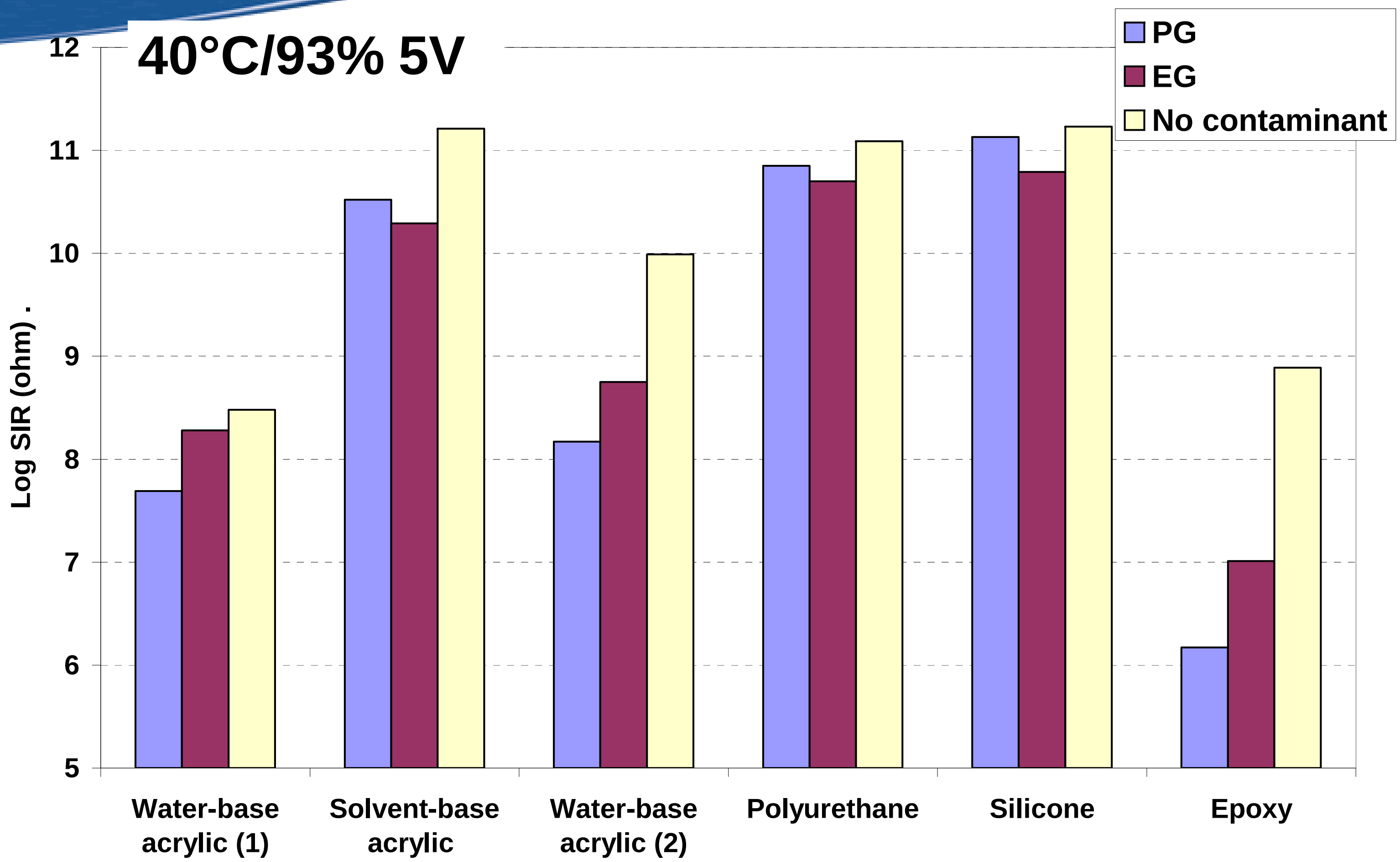


40°C / 93% RH & 50V

Conclusions – Acid rain

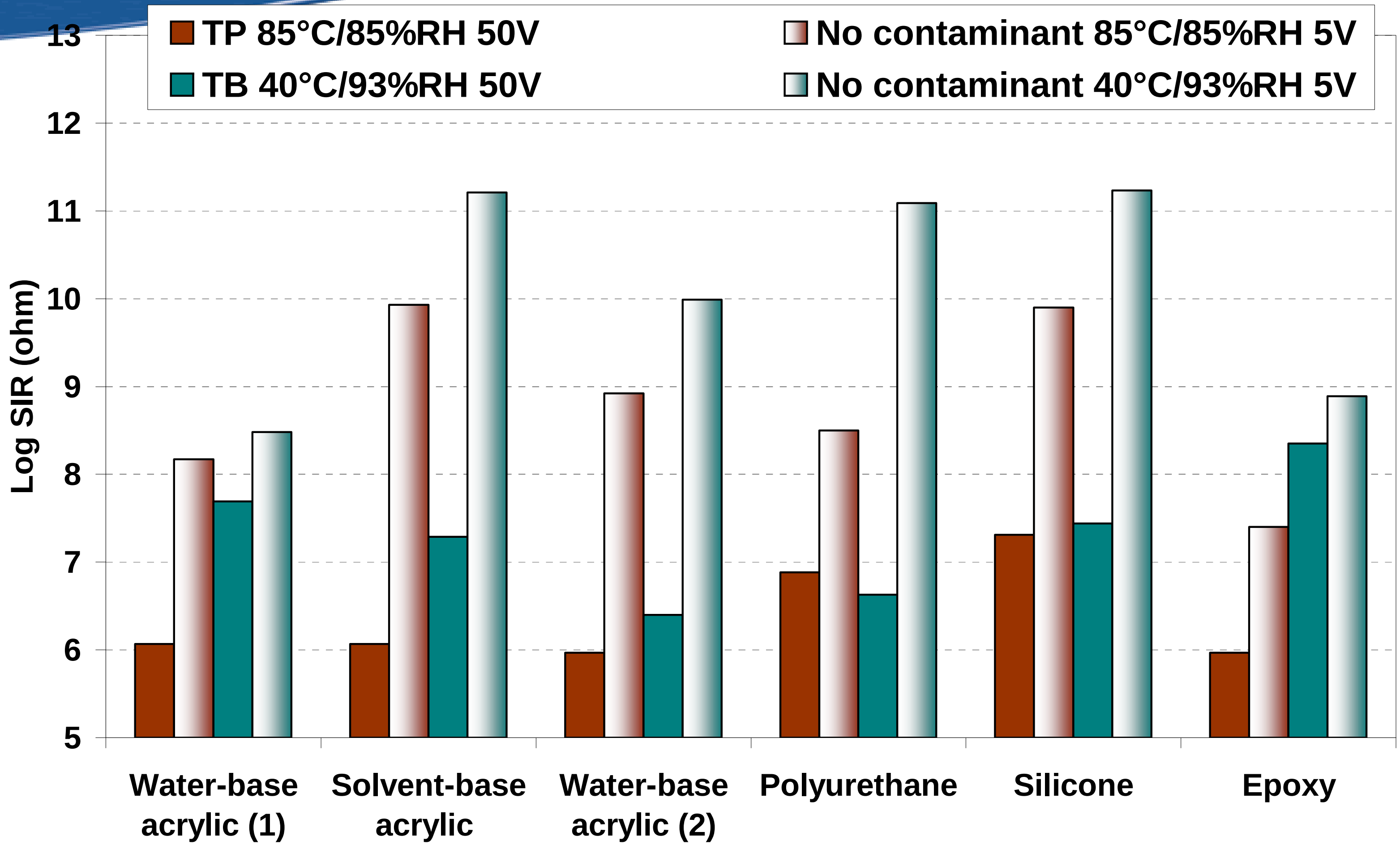
- Test condition 85°C / 85% RH & 50V is more severe than 40°C / 93% RH & 5V for sea water
- Protection of the coating from surfactant
  - Silicone > Polyurethane > solvent based acrylic >water based acrylic > epoxy

Results - De-icing Fluids



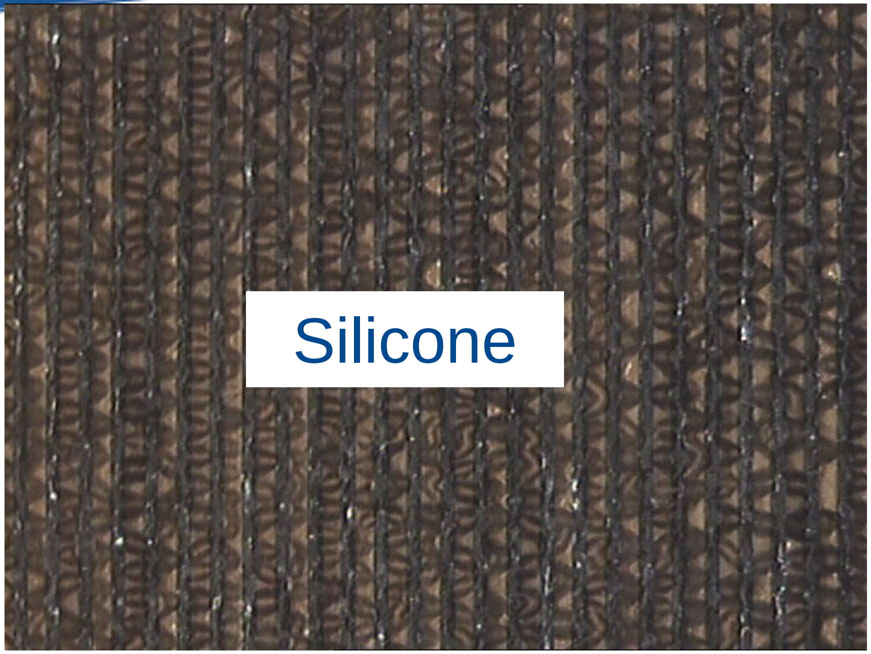
Ethylene glycol (EG) Propylene glycol (PG)

Summary - hydraulic fluids

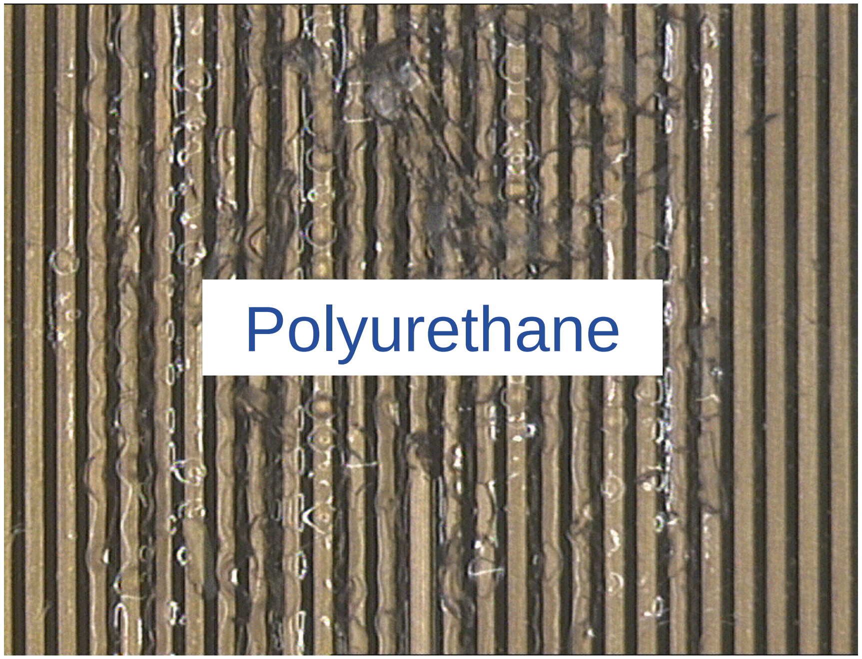


Triphenyl phosphate (TP) Tributyl phosphate (TB)

Coating damage



Silicone



Polyurethane

- **Hydraulic fluids cause blister for all coatings after SIR testing**

Coating thickness

Silicone > Polyurethane > solvent based acrylic >
water based acrylic – (1) >water based acrylic – (2) > epoxy


Silicone


Polyurethane


Solvent based acrylic


water based acrylic - (1)


water based acrylic - (2)


Epoxy

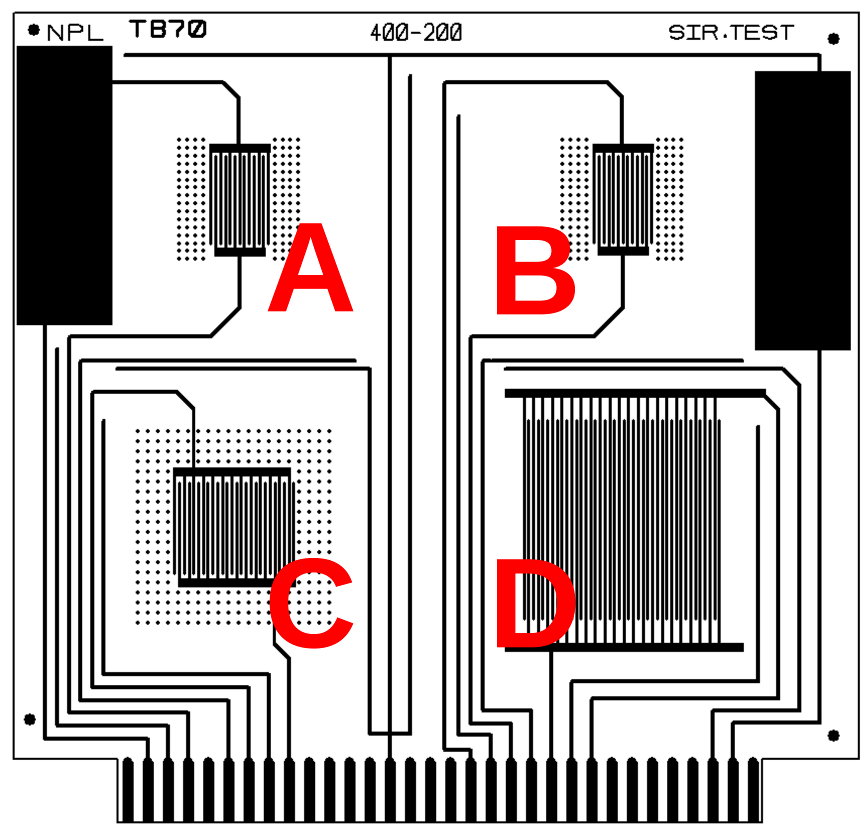
Summary

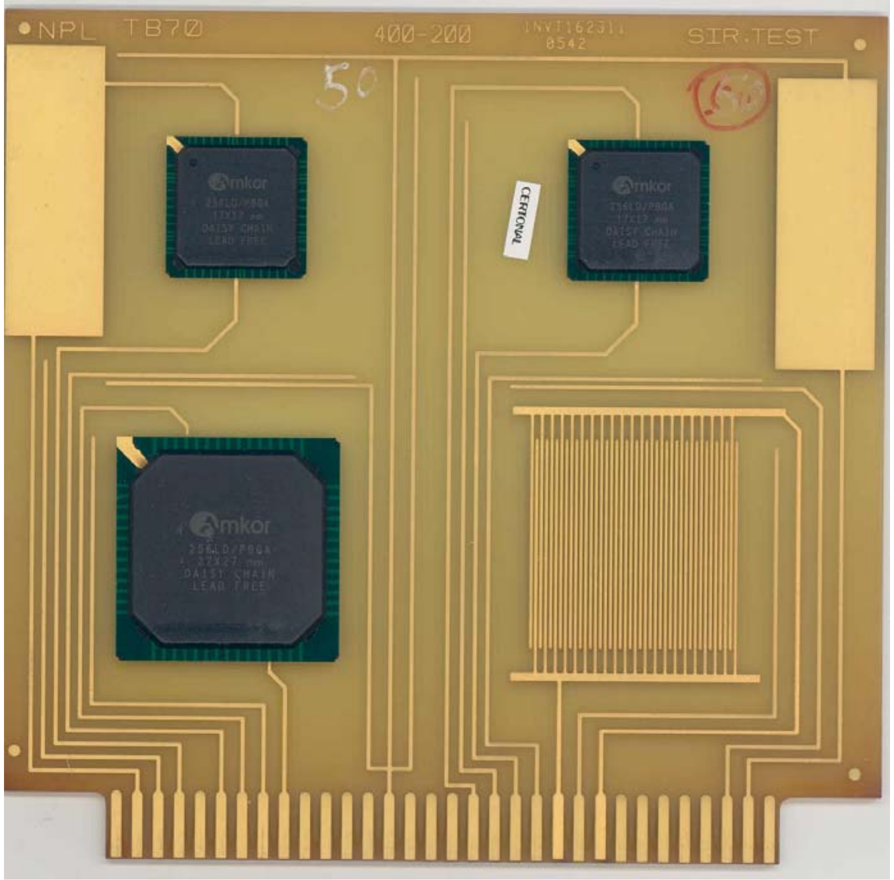
- Different coatings offer different levels of protection against the selected contaminants except for epoxy:
  - Silicone > Polyurethane > solvent based acrylic >water based acrylic > epoxy
- Coating thickness seems to play a important role for the protection
- Hydraulic fluids significantly reduce SIR for all coatings due to blistering
- The test method approach discriminates between different coatings and contaminants

Coverage Issues

- Uniformity and thickness of coating may affect protection performance
- Coverage issues of coating on thick copper tracks and SIR patterns underneath of components are investigated

Test Vehicle





- 400 x 200µm pattern
- AuNi finish

SIR patterns A & B

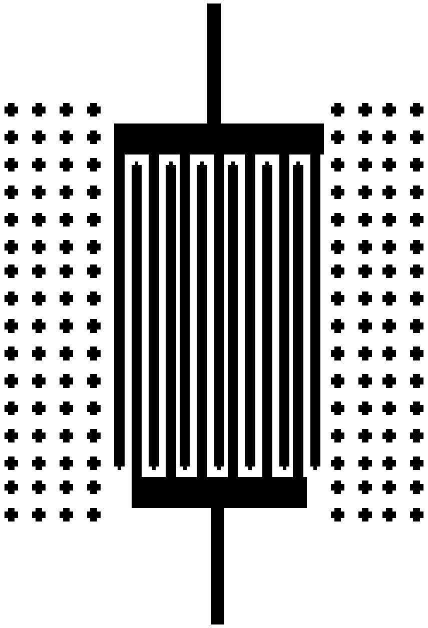
BGA256

1mm pitch

0.4mm ball diameter

Remove unwanted balls

400/200 µm SIR pattern with 70 µm copper track



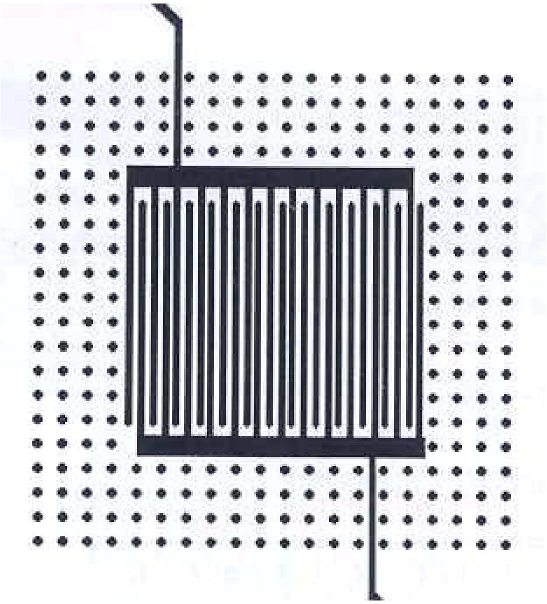
SIR patterns C

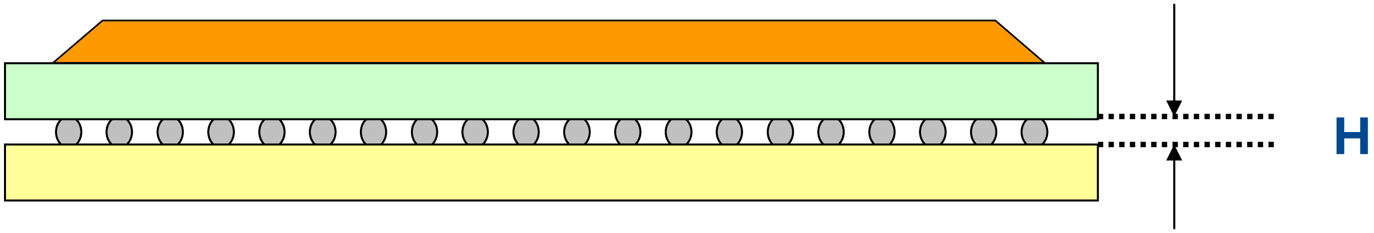
BGA256T1.27C-DC200

1.27mm pitch,

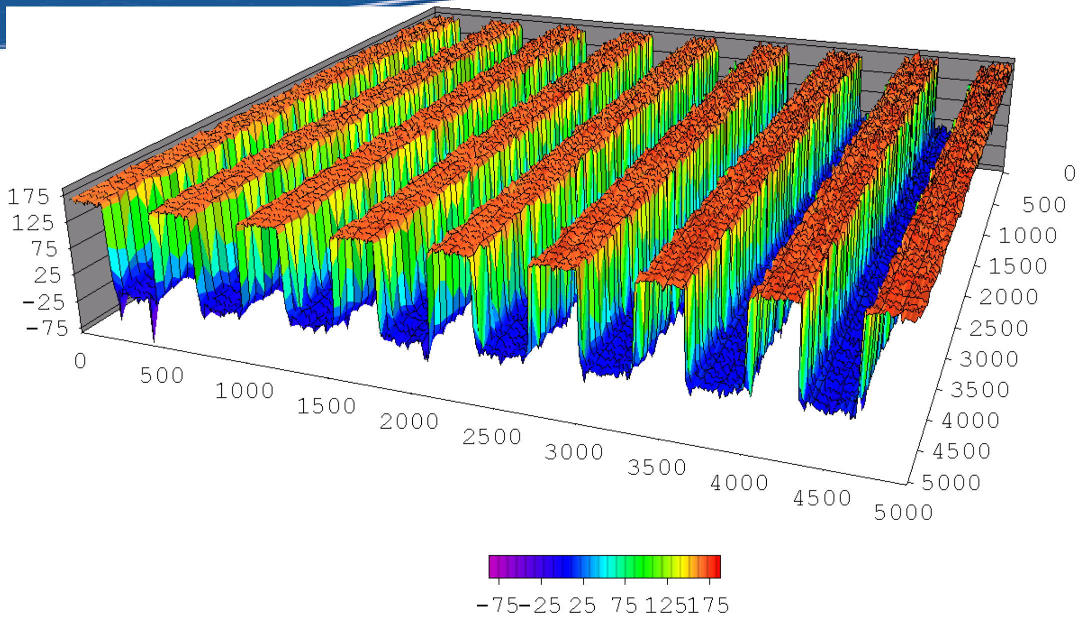
0.75mm ball diameter

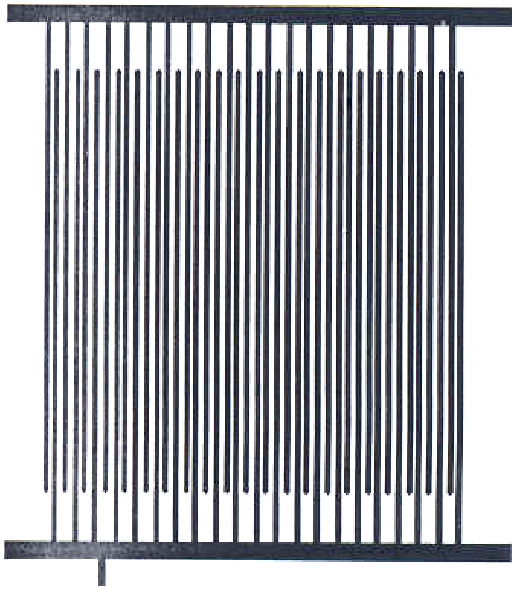
400/200 µm SIR pattern with 70 µm copper track





SIR pattern D



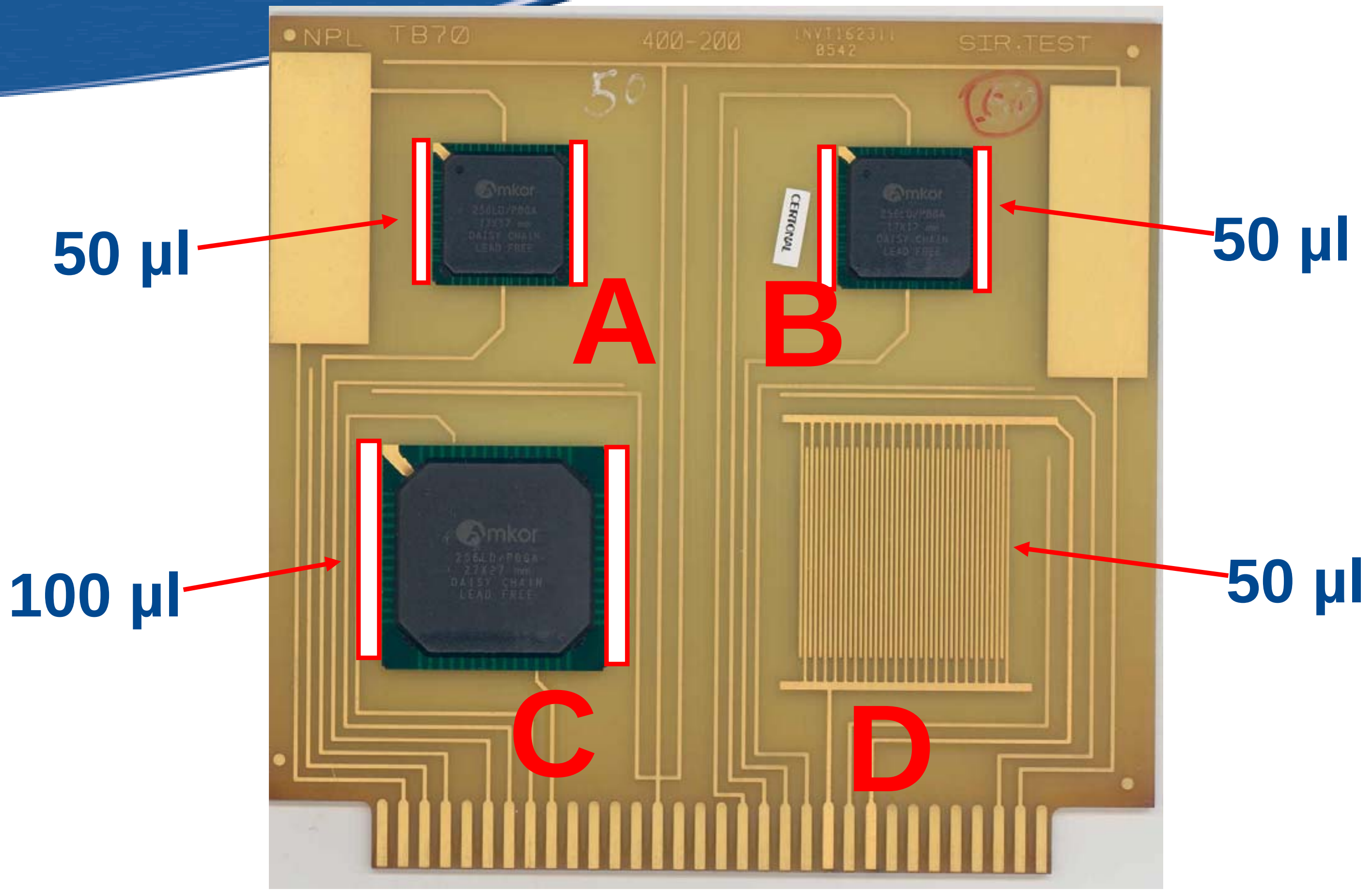


400/200 µm SIR pattern with 140 µm copper track

Contaminants

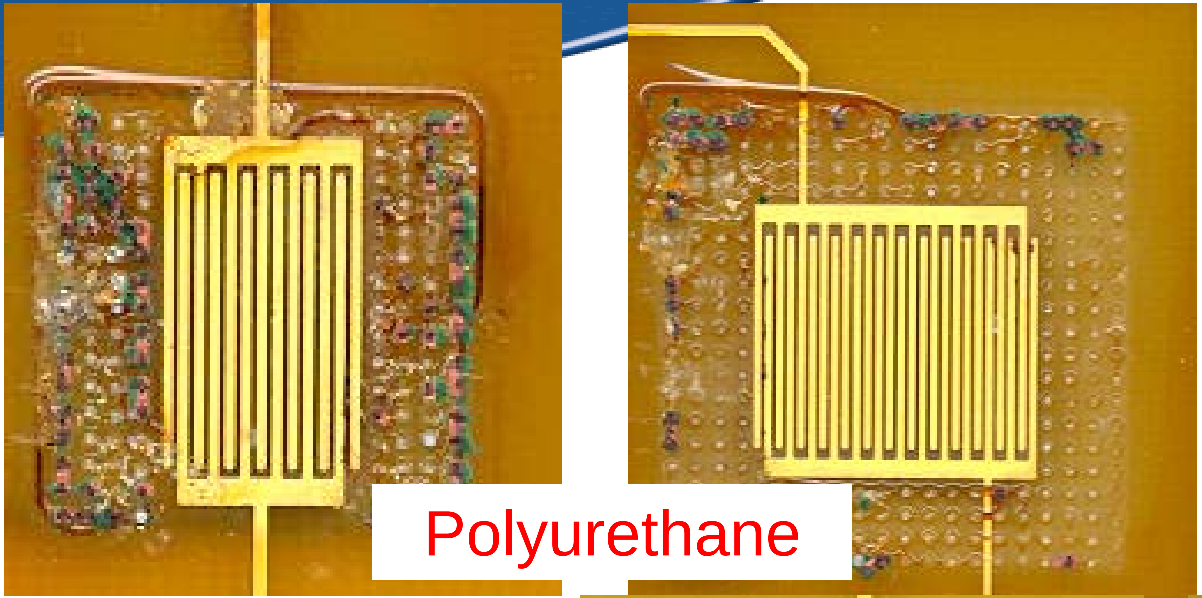
Contaminant	Chemistry	Concentration
Anionic Surfactant	Laurybenzolsulfonsaeure (LABS)	1%
Solvent flux	Adipic, succinic, glutaric acid & rosin	1.7%

Test board contamination

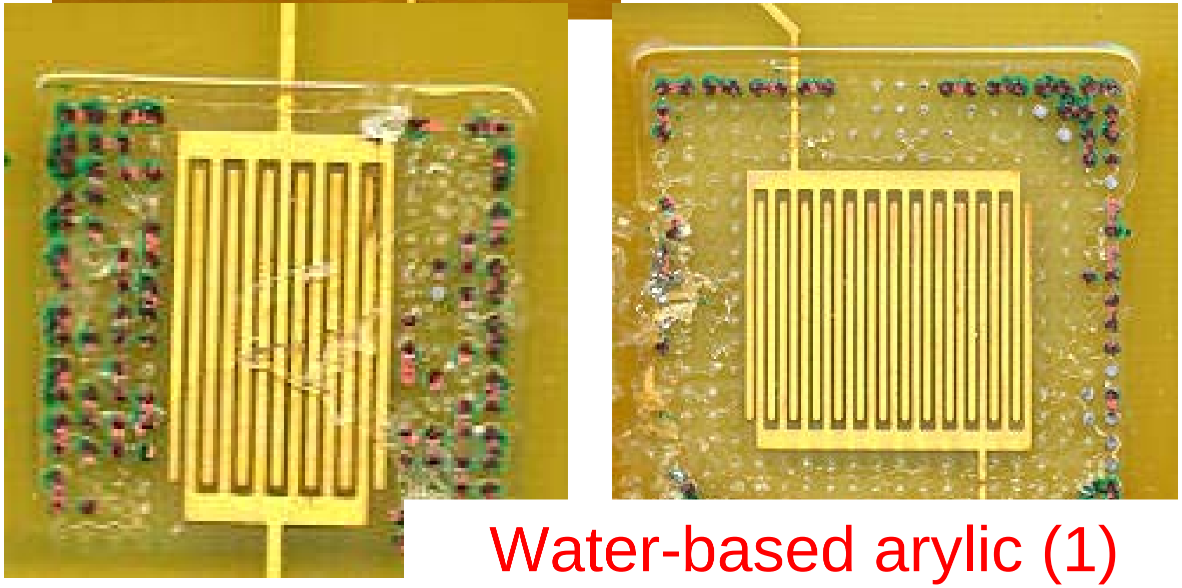


SIR testing after contaminants dry in air,

Coating coverage

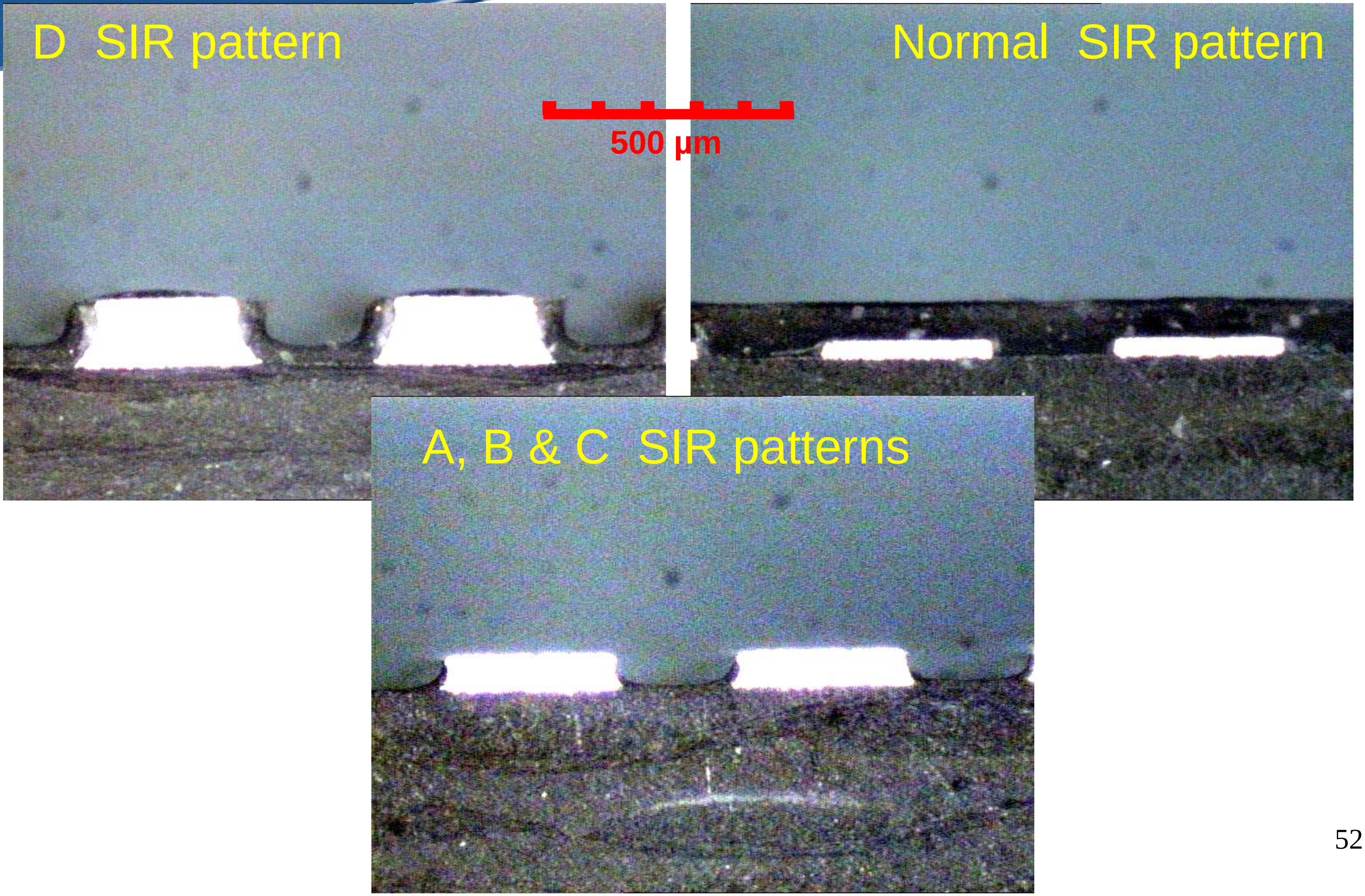


Polyurethane

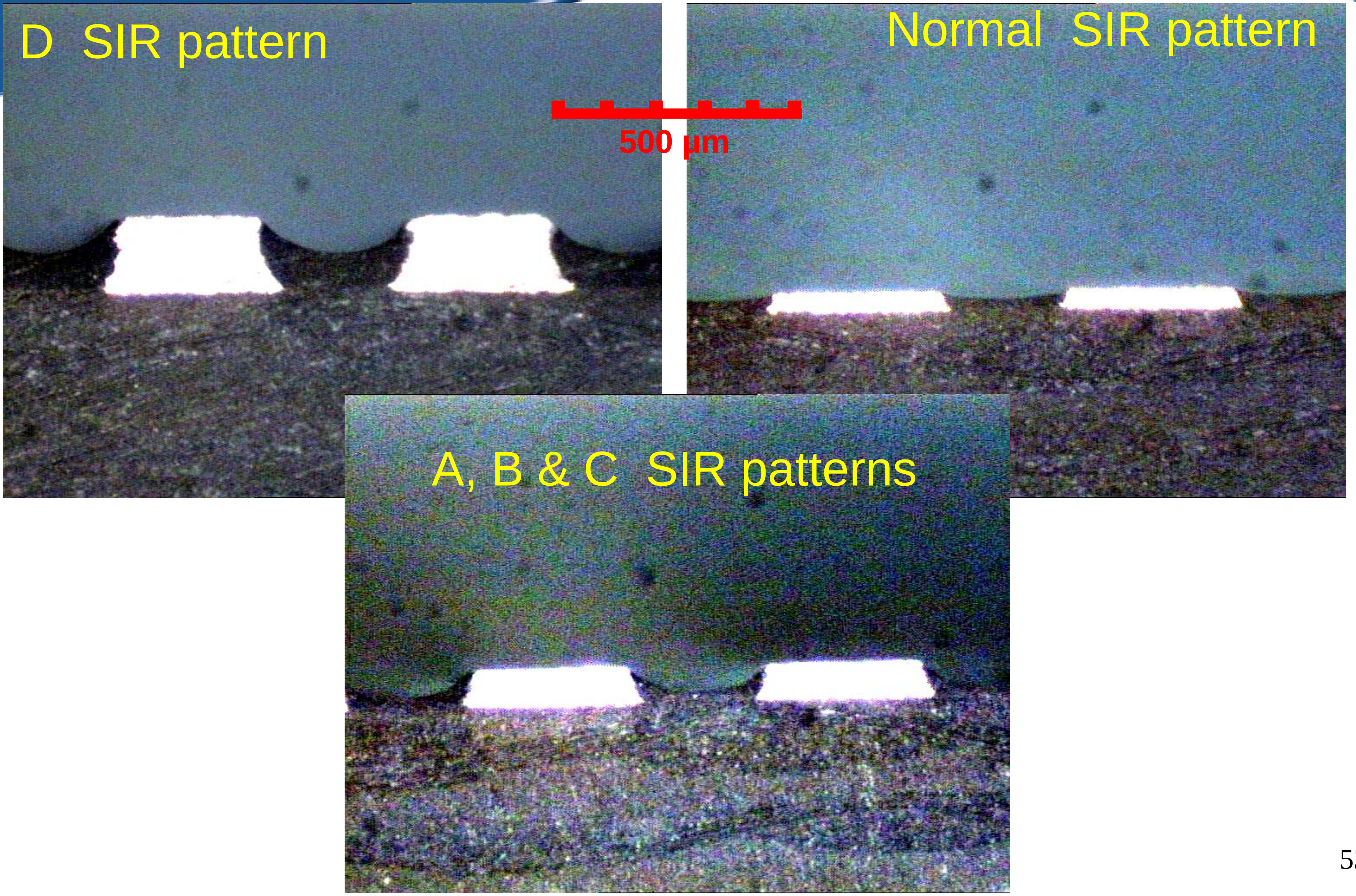


Water-based arylic (1)

Coating – Silicone



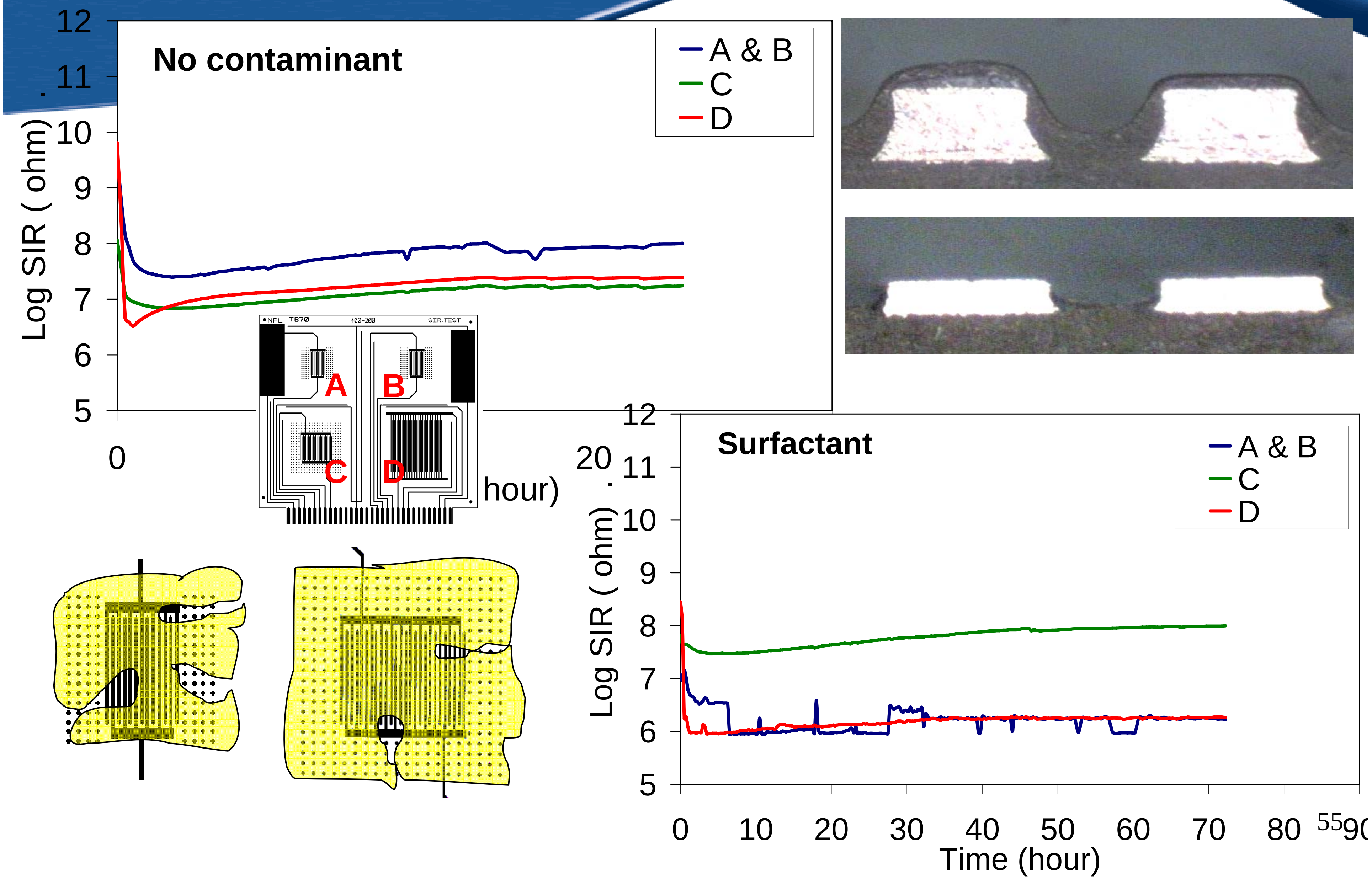
Coating – Epoxy



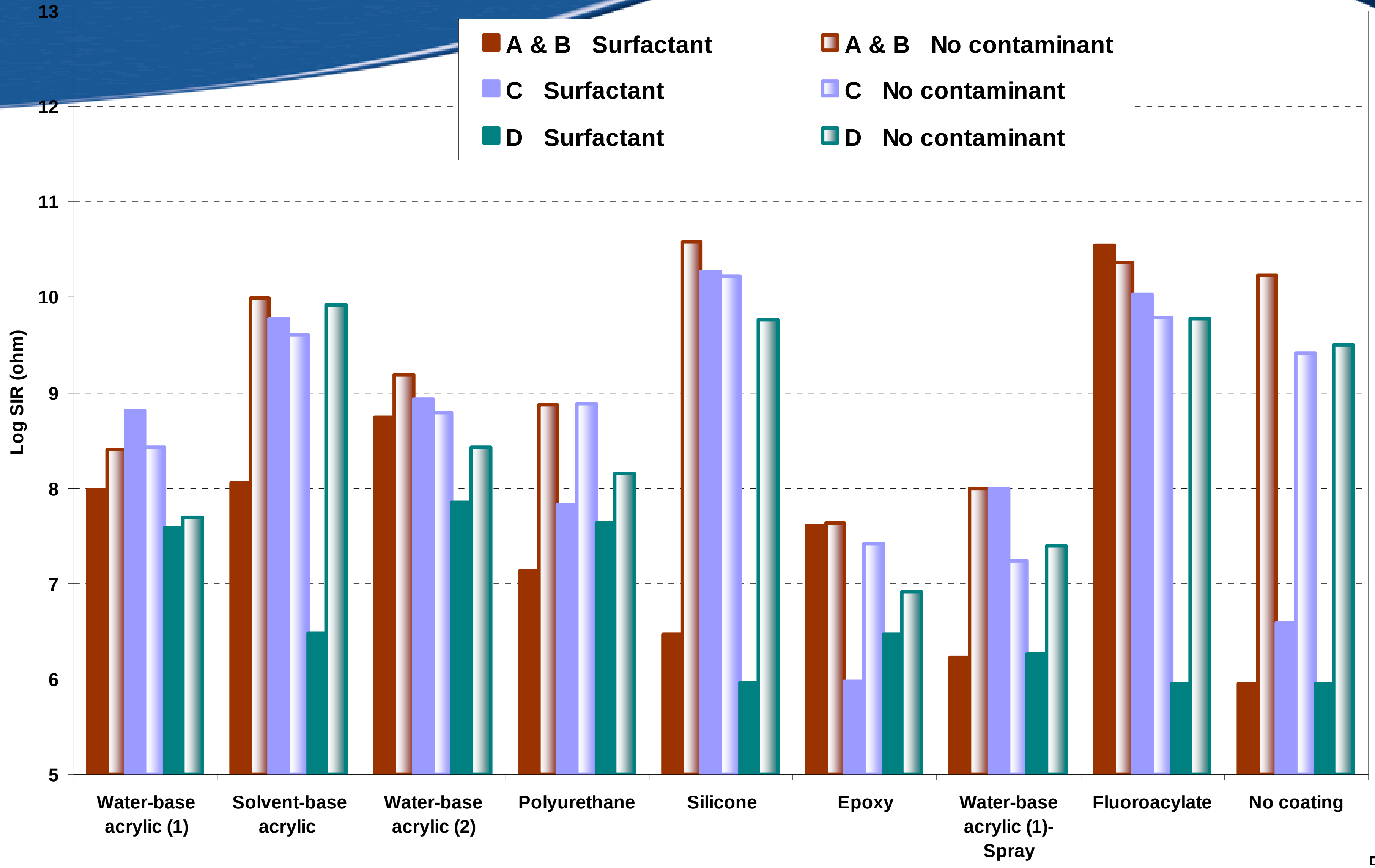
SIR Results

Surfactants

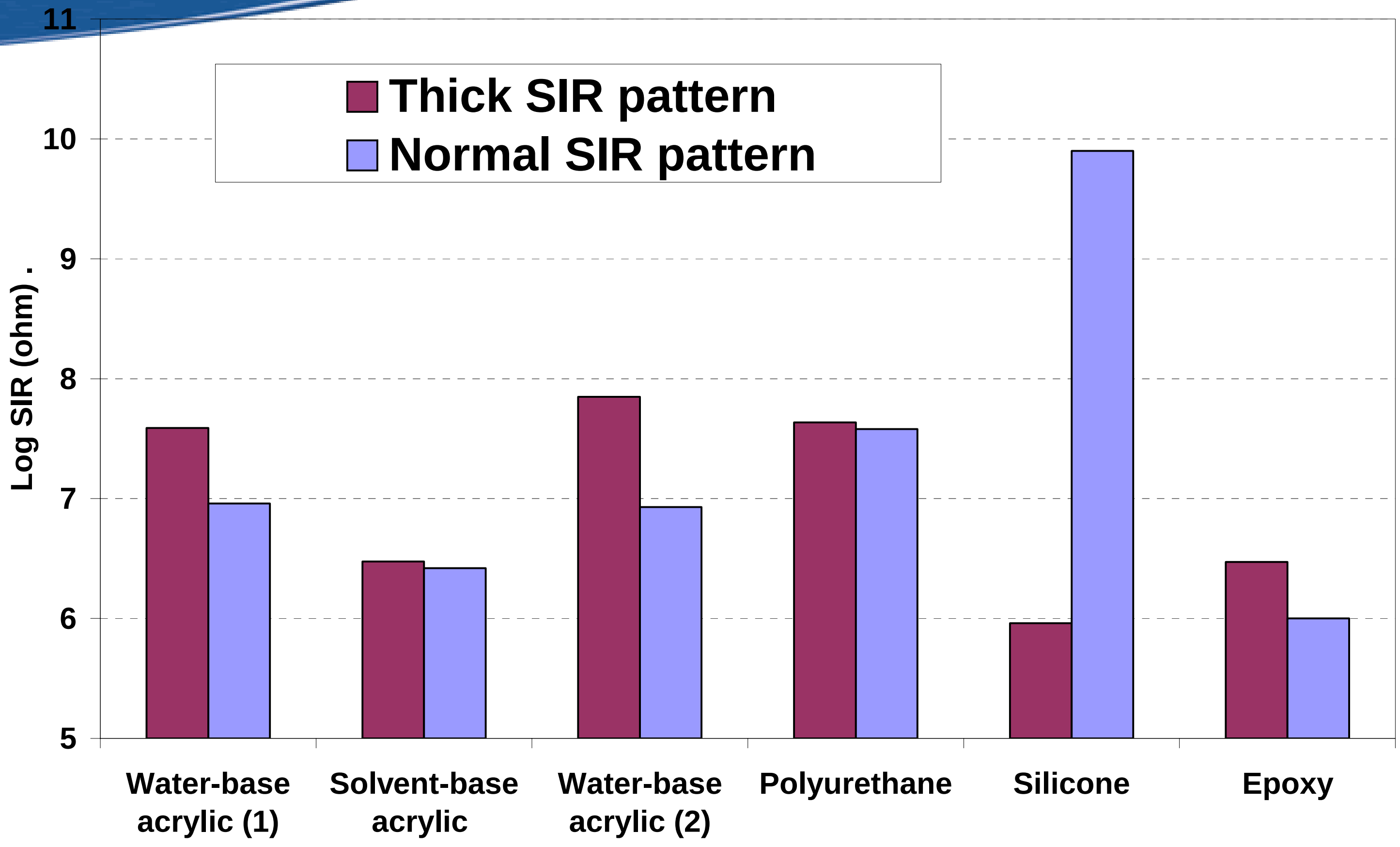
Results – Water based acrylic 1 Spray



Summary – Surfactant



Compare – D SIR patterns

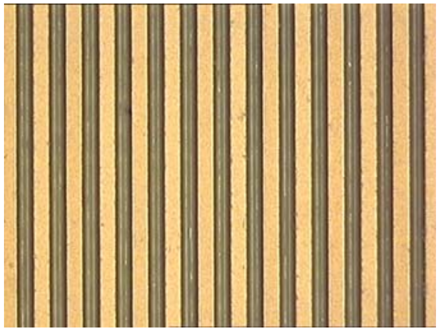


Anionic Surfactant

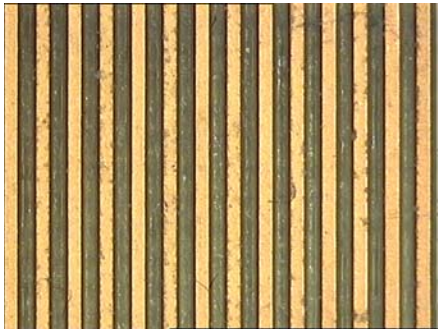
Laurybenzolsulfonsaeure (LABS)

Tested board – Surfactant – D SIR pattern

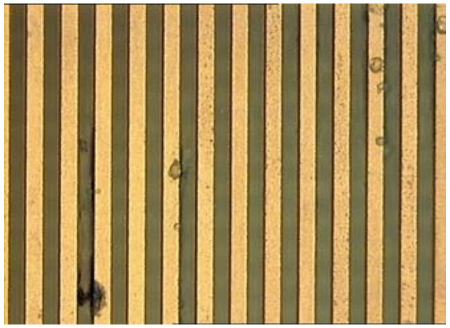
Increasing corrosion →



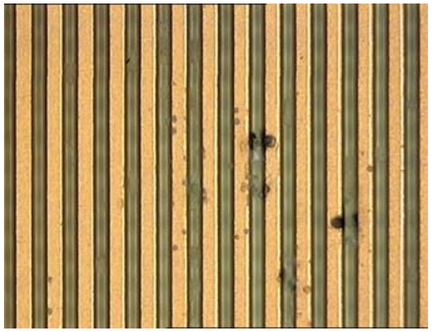
Polyurethane



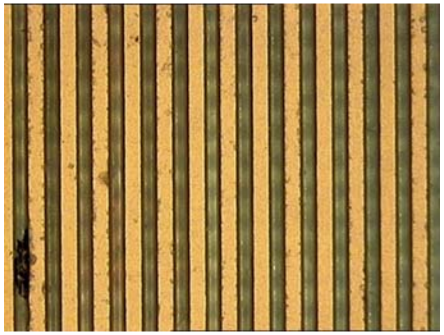
Solvent base Acrylic



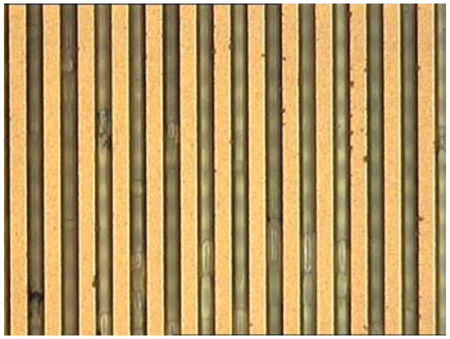
Fluoroacrylate



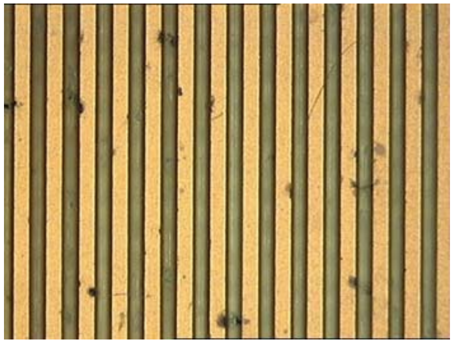
Silicone



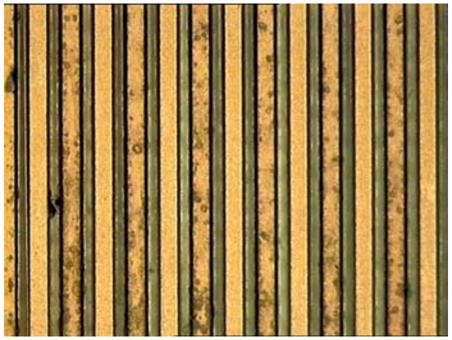
Water base Acrylic (2)



Water base Acrylic (1)-Spray



Water base Acrylic (1)



Epoxy

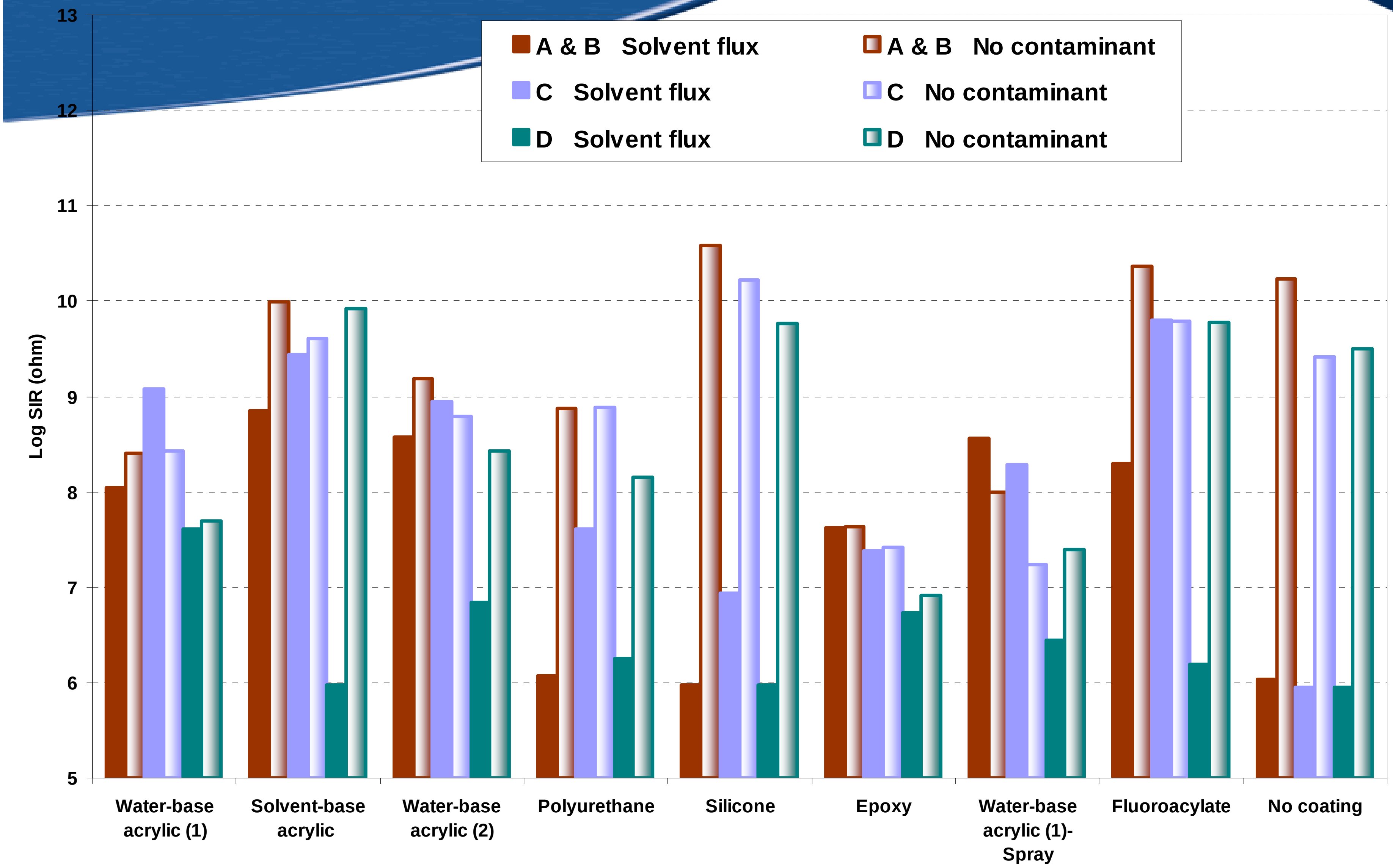
SIR results – Surfactant

Decreasing SIR

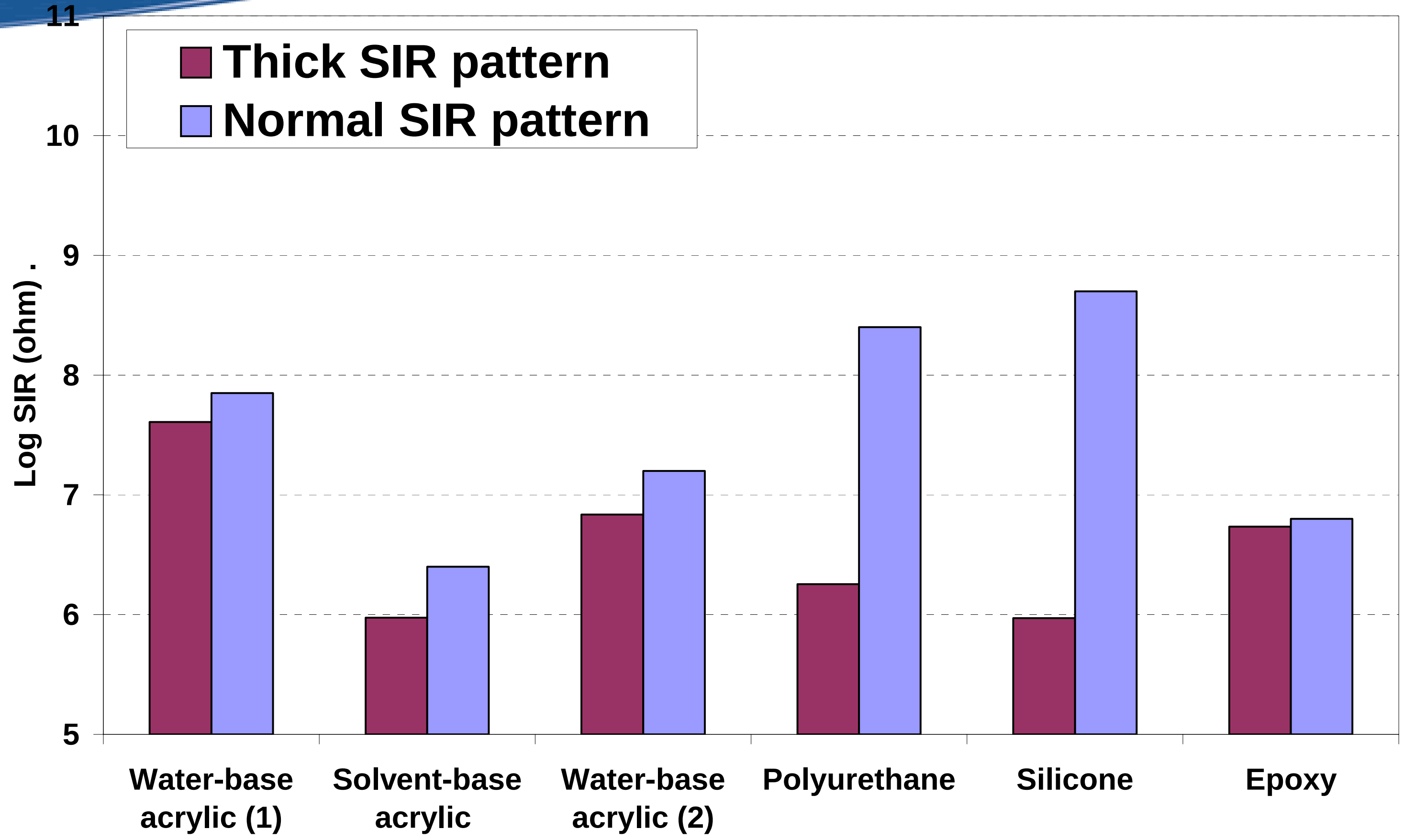
Polyurethane | **Water base Acrylic (2)** | **Water base Acrylic (1)** | **Solvent base Acrylic**

Epoxy | **Water base Acrylic (1)-Spray** | **Fluoroacrylate** | **Silicone**

Summary – Solvent flux



Compare – D SIR patterns

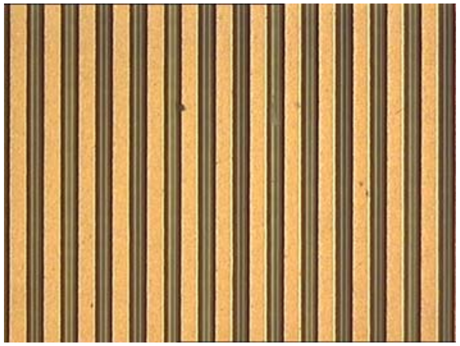


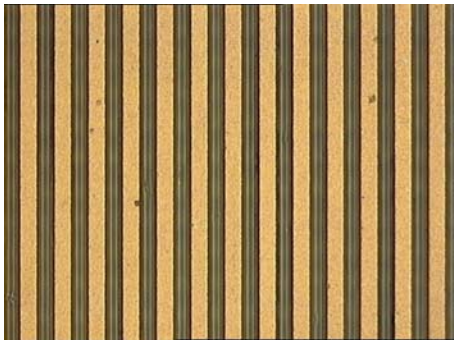
Solvent flux

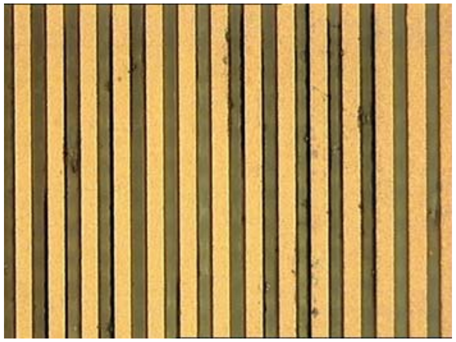
Adipic, succinic & glutaric acid

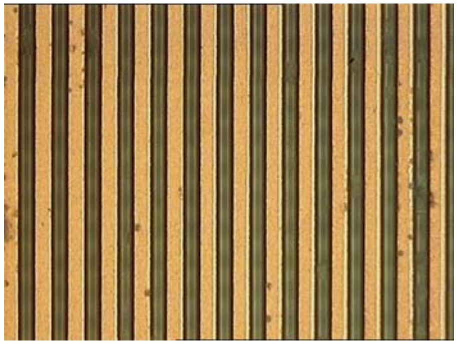
Tested board – Flux – D pattern

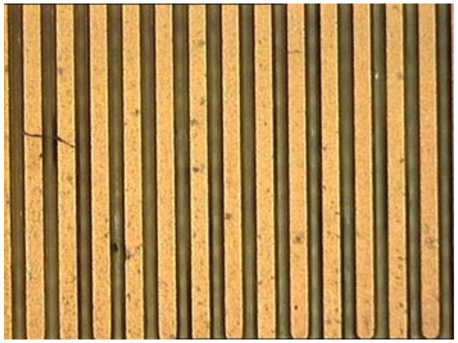
Increasing corrosion →

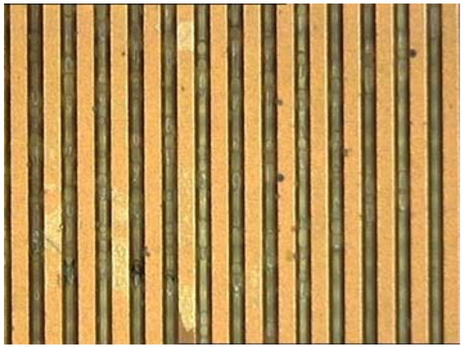

Polyurethane


Solvent base Acrylic

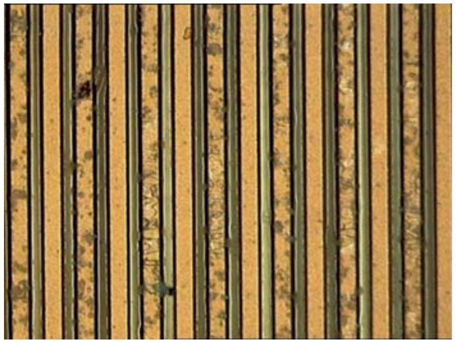

Fluoroacrylate


Silicone


Water base Acrylic (2)


Water base Acrylic (1)-Spray


Water base Acrylic (1)


Epoxy

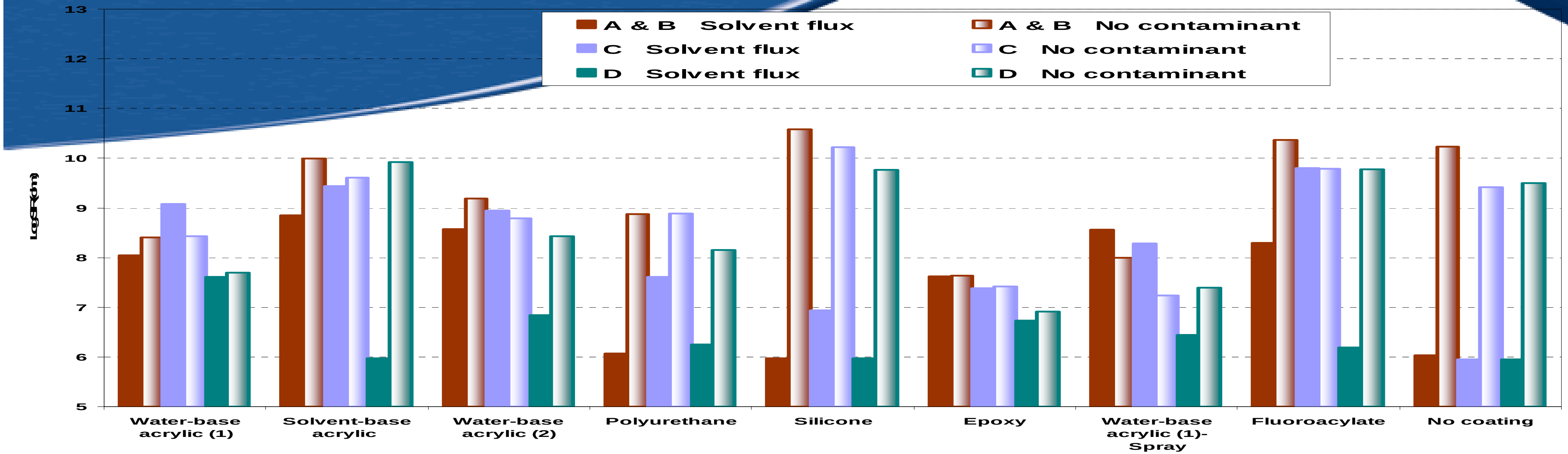
SIR results – Flux

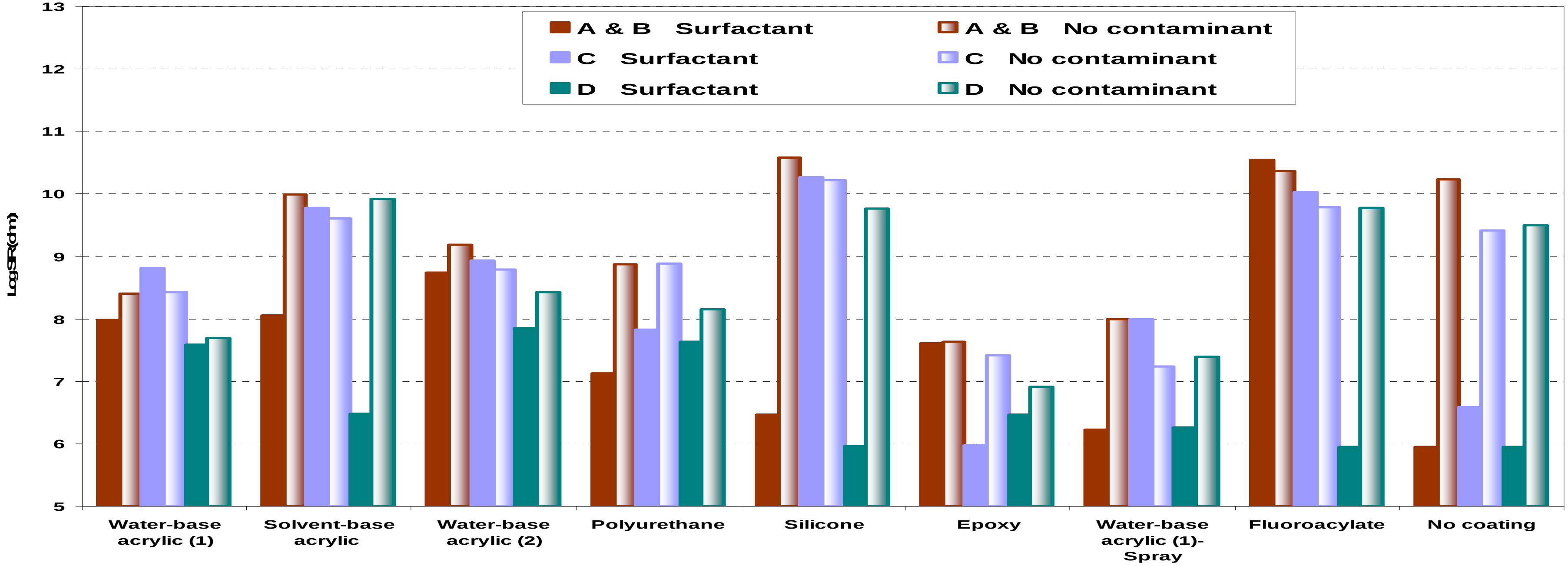
Decreasing SIR →

Water base Acrylic (1)-Spray	**Water base Acrylic (2)**	**Water base Acrylic (1)**	**Epoxy**
Polyurethane	**Fluoroacrylate**	**Solvent base Acrylic**	**Silicone**

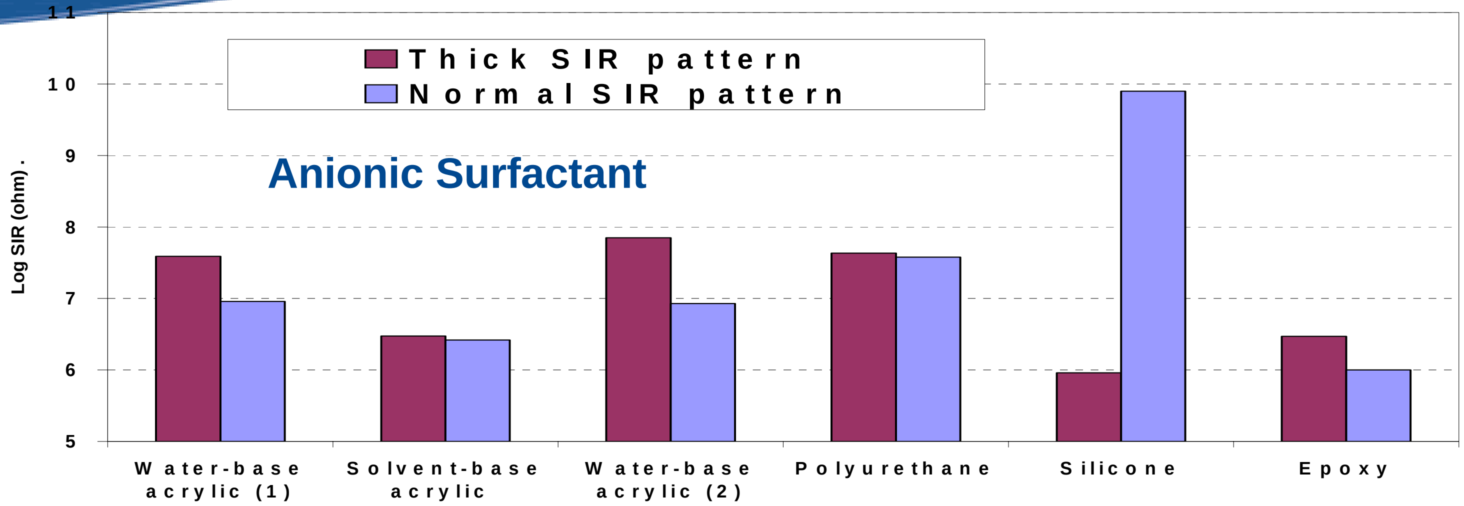
Similar results to those with surfactant

Comparing contaminants

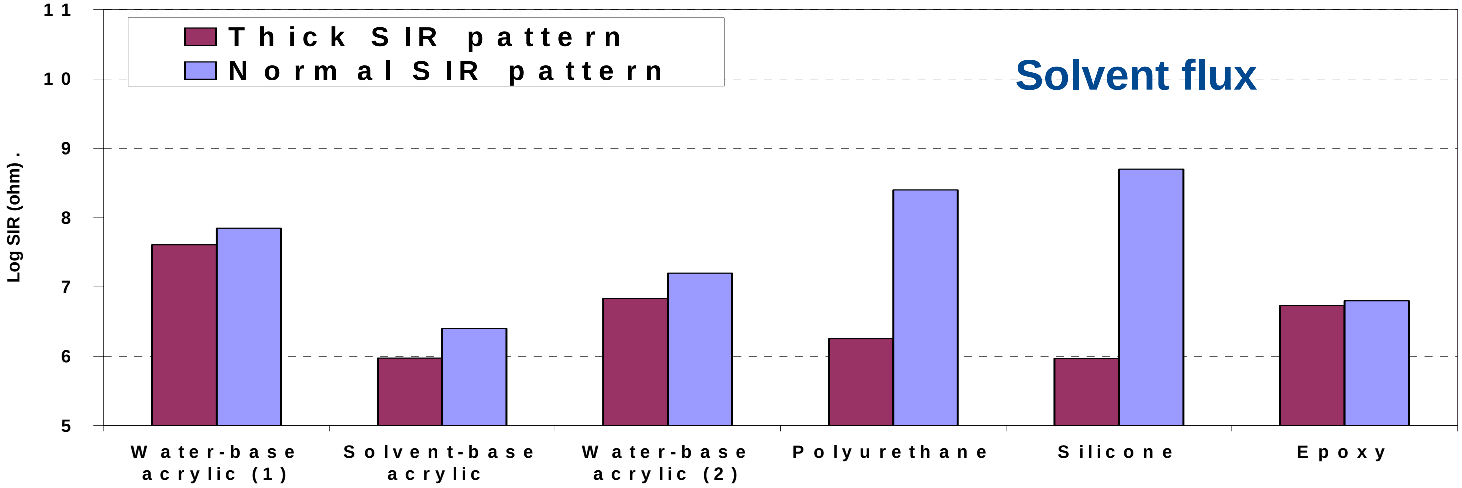




Comparing contaminants on open SIR patterns

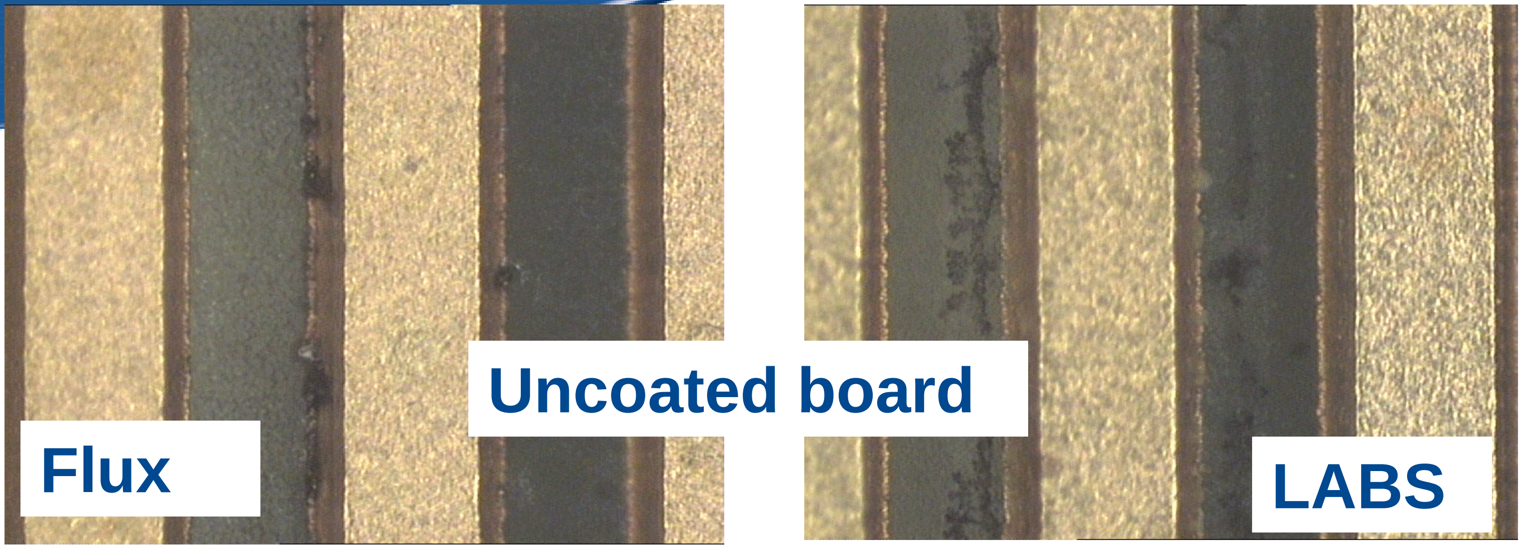


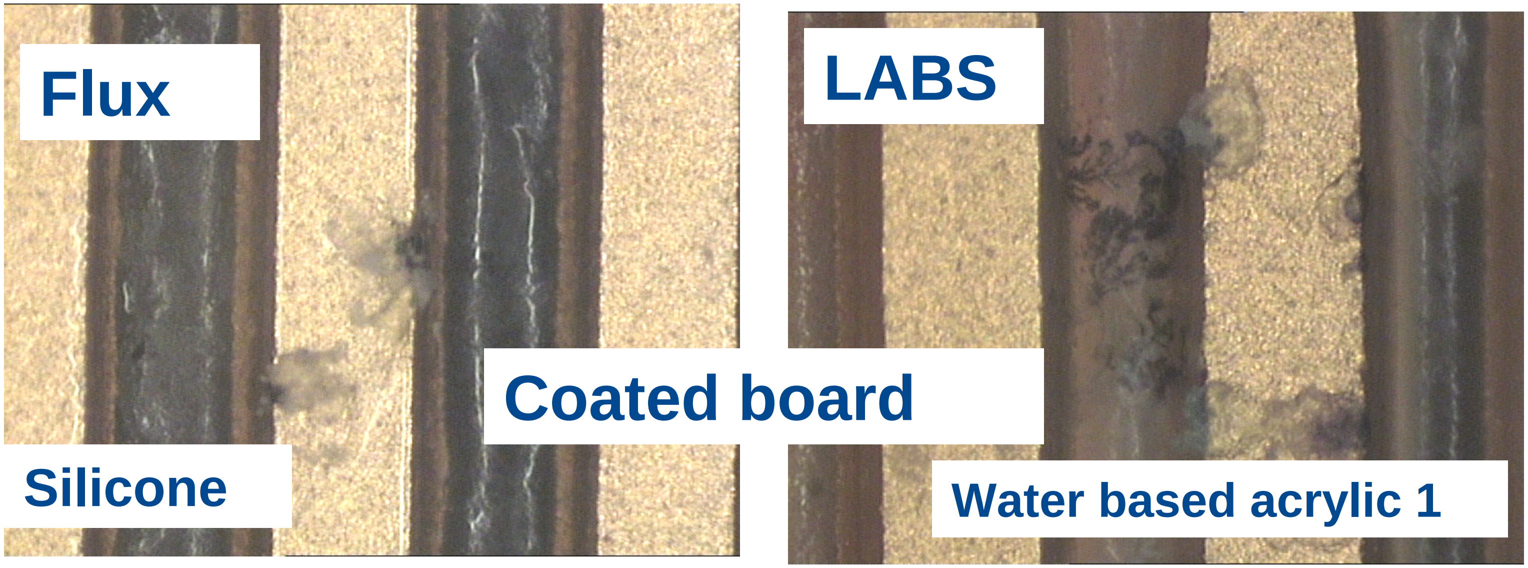
Anionic Surfactant



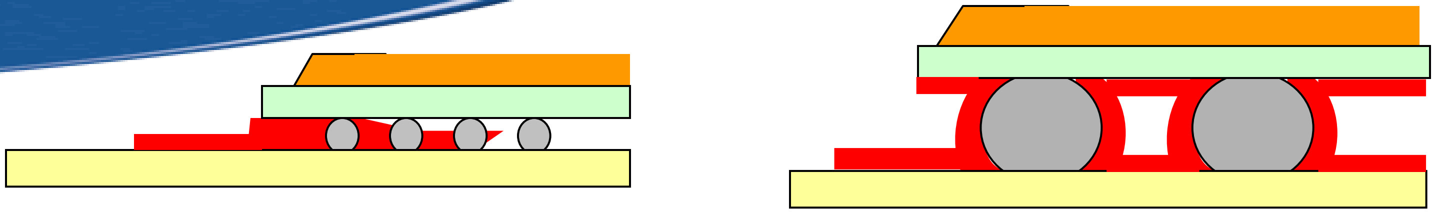
Solvent flux

Tested board – Thick SIR pattern





Summary
A, B, C Patterns



- Component SIR patterns were protected by coatings via two approaches:
  - Coverage by the coating of the SIR pattern
  - Or /and coatings surround BGA balls blocking, or impeding, wetting of contaminant to reach the SIR pattern
- Both coating and contaminants penetration depend on the coating type, gap and component size.
- There is no clear relationship between stand off and penetration. There is a trade off between the wetting (& capillarity) forces and the viscosity. Surface tension of the liquid coating and surface energy of the surfaces vary and interact with the process.

Summary of D Pattern

- For silicone coatings the SIR is much lower on thick SIR pattern, than on the normal SIR patterns, due to thinner coating on critical areas of the thick SIR pattern
  - Polyurethane struggled to get coverage under the BGA, and the SIR was relatively lower
- For the other coatings the protection performance is less sensitive to coatings thickness
- For uncoated boards corrosion initiates from the bottom of the copper track, but initiates from top of copper track for coated board

Conclusions

- Coverage, uniformity and thickness of the coating are very important for coating protection for 3D.
- Protection always fail on weak points of the coating
- SIR test method reveals sensitivity to different contaminants
- SIR results directly represent reliability of electronic board
  - Where there are coverage issues isolated areas can suffer attack but not influence SIR
  - Loss in SIR is not always associated with visible attack

NPL