How Clean is Clean Enough – At What Level Does Each of The Individual Contaminates Cause Leakage and Corrosion Failures in SIR?

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Abstract
In this investigation a test matrix was completed utilizing 900 electrodes (small circuit board with parallel copper traces on FR-4 with LPI soldermask at 6, 10 and 50 mil spacing): 12 ionic contaminants were applied in five concentrations to three different spaced electrodes with five replicas each (three different bare copper trace spacing / five replications of each with five levels of ionic concentration). The investigation was to assess the electrical response under controlled heat and humidity conditions of the known applied contamination to electrodes, using the IPC SIR (surface insulation resistance) J-STD 001 limits and determine at what level of contamination and spacing the ionic / organic residue has a failing effect on SIR.

Experimental
Using NIST traceable standards each individual ionic contaminant was doped on the electrode surface in a specific area and each was applied with 5µl doses until the total desired concentration was achieved on each sample. Ion chromatography analysis of extracted samples was performed to verify the actual inoculated concentrations prior to SIR testing. Then each electrode was placed into test chambers and socket tested on electrodes to collect SIR readings every 15 min with a 5 volt bias. All samples were exposed to 40°C/90%RH (non-condensing) for 168 hours with SIR monitoring. After SIR each sample was visually inspected and was then extracted and assessed for cleanliness. The evaluation used the IPC J-STD 001 SIR limits of values greater than 1.0e8 ohms of resistance or better as the pass / fail criteria with a comparison of the samples to the ionic cleanliness using ion chromatography.

The below list is the ionic contaminants evaluated in this study.

A – Chloride doped on 6, 10 and 50 mil spacing
B – Bromide doped on 6, 10 and 50 mil spacing
C – Fluoride doped on 6, 10 and 50 mil spacing
D – Acetate doped on 6, 10 and 50 mil spacing
E – Formate doped on 6, 10 and 50 mil spacing
F – Nitrite doped on 6, 10 and 50 mil spacing
G – Nitrate doped on 6, 10 and 50 mil spacing
H – Phosphate doped on 6, 10 and 50 mil spacing
I – Sulfate doped on 6, 10 and 50 mil spacing
J – WOA (Succinic Acid) doped on 6, 10 and 50 mil spacing
K – Sodium doped on 6, 10 and 50 mil spacing
L – Ammonium doped on 6, 10 and 50 mil spacing

Sample Preparation of Electrodes
Sample preparation of bare copper trace electrodes used for testing involved cleaning in an inline cleaner at 1.5 ft/min belt speed with only de-ionized (DI) water which was heated to 150°F. There was then rinsing in a circulated IPA/DI (75%/25%) in ambient conditions for 15 minutes followed by air drying for 30 minutes. Then there was baking in an oven for an hour at 80°C. There was testing prior to doping to verify that the electrodes were clean (<1.0 µg/in^2 of ionic residue). Each electrode was doped using calibrated, air displacement, pipette volumes of 5 µl up to 100 µl, dispensed repetitively in 5 µl applications, as required to achieve the proper concentration.

Table 1 – Ionic Contamination and Concentration Levels

Contaminants		Concentration Levels (µg/in^2)				
		1	2	3	4	5
Chlorides	Cl-	1.0	2.0	3.0	5.0	10.0
Bromides	Br-	1.0	3.0	6.0	12.0	15.0
Fluoride	F-	1.0	2.0	3.0	5.0	10.0
Acetate	CCOO-	1.0	3.0	5.0	7.0	10.0
Formate	COO-	1.0	3.0	5.0	7.0	10.0
Nitrite	NO2-	1.0	3.0	5.0	7.0	10.0
Nitrate	NO3--	1.0	3.0	5.0	7.0	10.0
Phosphate	PO4-	1.0	3.0	5.0	7.0	10.0
Sulfates	SO4-	1.0	3.0	5.0	7.0	10.0
Weak Organic Acid	WOA	10.0	20.0	25.0	35.0	50.0
Sodium	Na+	1.0	3.0	5.0	7.0	10.0
Ammonium	NH4+	1.0	3.0	5.0	7.0	10.0
Lithium*	Li+	1.0	2.0	3.0	5.0	10.0
Methane Sulfonic Acid*	MSA	0.1	0.2	1.0	3.0	5.0

(12) Contaminants x (5) Levels of Concentration x (5) Replications x (3) Trace Gap Spacing Test Matrix = 900 Coupons.
* Lithium, MSA and mixtures were not included in the testing due to time constraints and would be included in the next phase of testing.

Cross Sectional Images of Electrodes

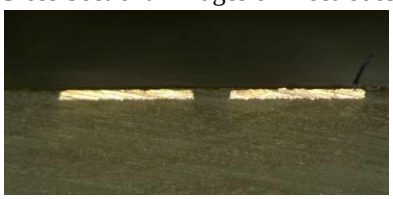

Figure 1 - Electrode (6 mil spacing)

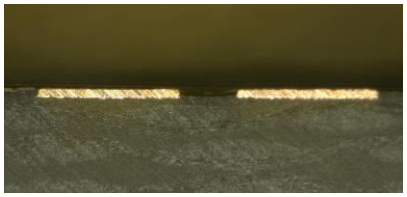

Figure 2 - Electrode (10 mil spacing)

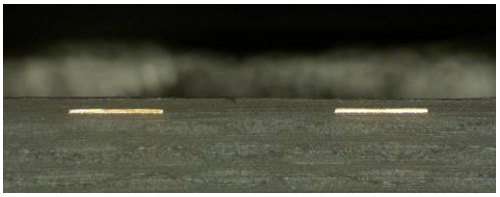

Figure 3 - Electrode (50 mil spacing)

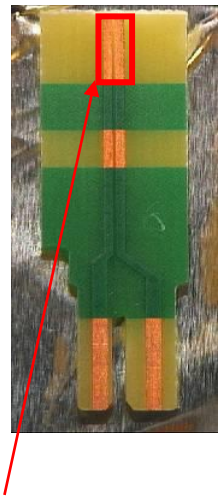

Figure 4 - Doping Area for 6 mil

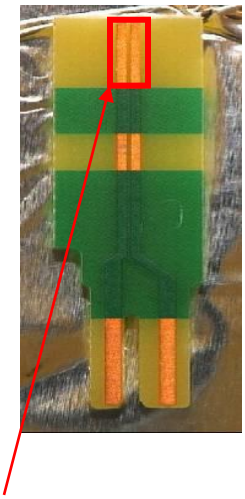

Figure 5 - Doping Area for 10 mil

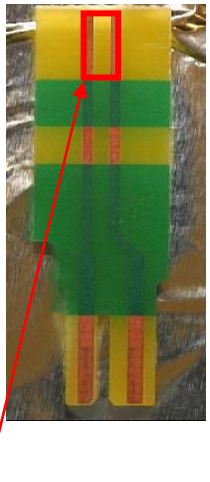

Figure 6 - Doping Area for 50 mil

Sample Doping Procedure (with 5 micro-liter pipette)

Figure 7 – Doping of Electrodes

Figure 8 – Doping of Samples

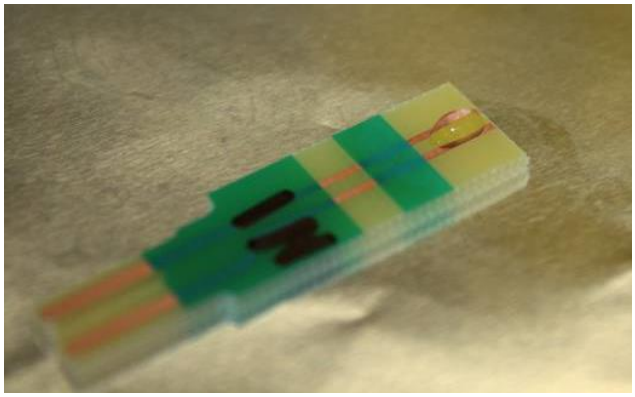

Figure 9a – Doped Sample Prior to Drying

Figure 9b: Tray of doped Electrodes in Oven at 37°C

After the samples were doped to the appropriate level and cleanliness analysis was conducted on a subset of samples before testing, all the sample electrodes were randomized in the chamber on 12 socketed assembly boards with 12 sockets per board. All samples were processed through the same production humidity chamber – which was ran for 168 hours at 40ºC/90%RH in a non-condensing humidity condition over 7 weeks. Figure 10 shows dendrite growth on the electrode.

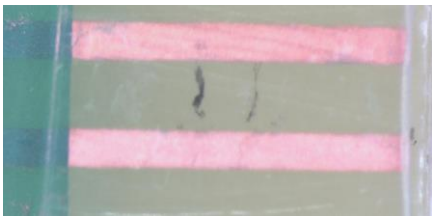

Figure 10- Post SIR Chloride Sample @ 5.0 µg/in^2 Showing Dendrites

Figure 11 – Environmental Chamber with Socketed Boards

Chloride Contamination

Chloride (Group "A") ionic species were doped on electrodes with 6, 10 and 50 mil spacing with NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 2, 3, 5, and 10µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 2 - Chloride Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Chloride of Prep Electrode	Cl of the Electrode after SIR	Localized test After SIR testing		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA of current	Current / Time	SIR results	SIR Minimum
A1-6-1 to 5	6	1	1.11	0.99	Clean	180	105	0.58	Passing >1.0e8	1.82E+10
A1-10-1 to 5	10	1	1.08	0.95	Clean	180	98	0.54	Passing >1.0e8	8.51E+09
A1-50-1 to 5	50	1	1.10	0.94	Clean	180	110	0.61	Passing >1.0e8	2.14E+10
A2-6-1 to 5	6	2	2.23	2.02	Clean	180	123	0.68	Passing >1.0e8	1.48E+09
A2-10-1 to 5	10	2	2.08	1.87	Clean	180	122	0.68	Passing >1.0e8	1.70E+09
A2-50-1 to 5	50	2	2.16	1.91	Clean	180	130	0.72	Passing >1.0e8	1.62E+09
A3-6-1 to 5	6	3	3.21	2.90	Clean	134	250	1.87	Passing >1.0e8	6.76E+09
A3-10-1 to 5	10	3	3.24	2.87	Clean	141	250	1.78	Passing >1.0e8	6.04E+09
A3-50-1 to 5	50	3	3.38	2.78	Clean	142	250	1.77	Passing >1.0e8	3.55E+09
A4-6-1 to 5	6	5	5.21	5.20	Dirty	112	250	2.24	Failing <1.0e8	8.60E+06
A4-10-1 to 5	10	5	5.18	5.21	Dirty	106	250	2.35	Failing <1.0e8	7.84E+06
A4-50-1 to 5	50	5	5.19	5.06	Dirty	101	250	2.48	Failing <1.0e8	1.38E+07
A5-6-1 to 5	6	10	9.98	9.54	Dirty	41	250	6.09	Failing <1.0e8	1.71E+06
A5-10-1 to 5	10	10	10.07	9.64	Dirty	36	250	6.99	Failing <1.0e8	1.20E+07
A5-50-1 to 5	50	10	10.36	9.84	Dirty	40	250	6.33	Failing <1.0e8	1.70E+07

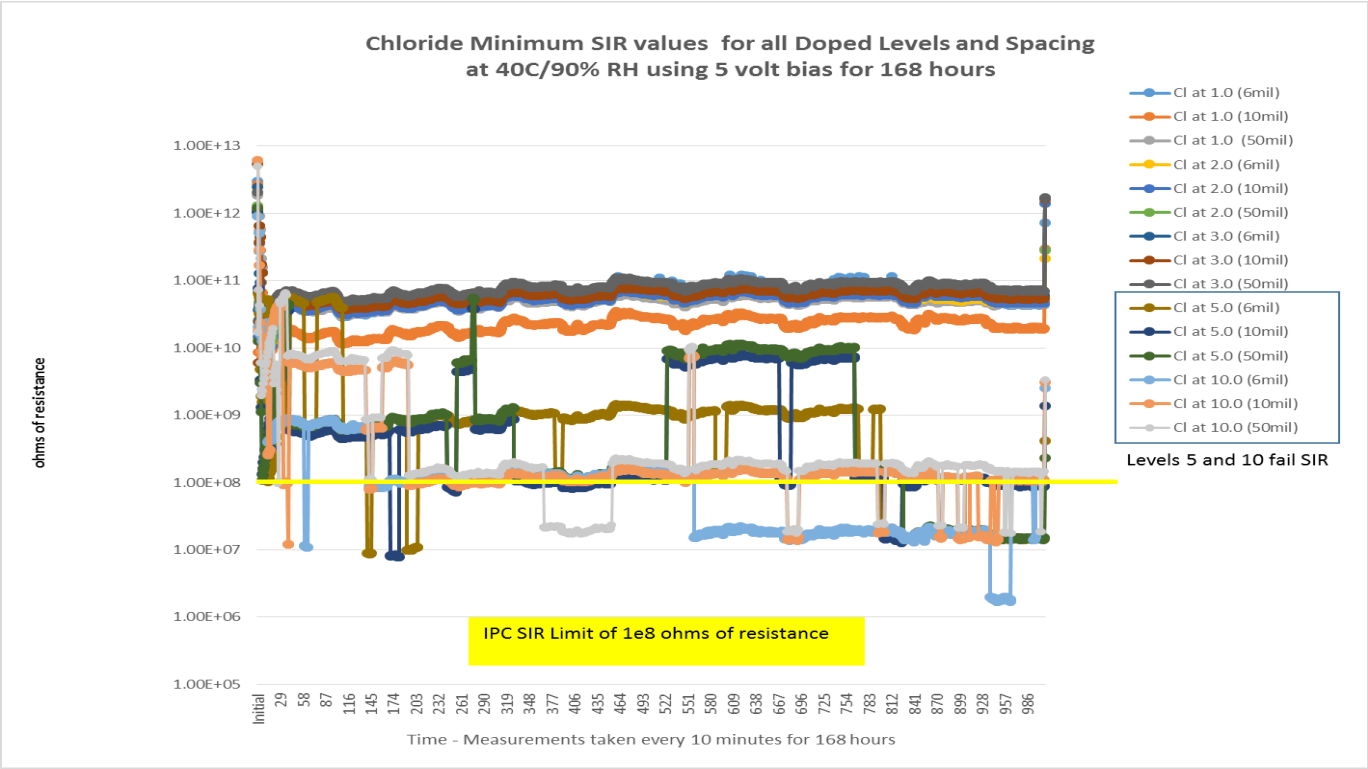

Figure 12 – Minimum SIR Values of the Chloride Doped Samples

Group A - Chloride findings of contamination levels of 3.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5 µg/in^2 and 10 µg/in^2 show low SIR values and the presence of dendrite shorting, which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Bromide Contamination

Bromide (marked "B") ionic species were doped on electrodes with 6, 10 and 50 mil spacing with NIST-traceable standards using 5µl doses in the gap between parallel bare copper traces. Target levels of contamination are 1, 3, 6, 12, and 15 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 3 - Bromide Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Bromide of Prep Electrode	Br of the Electrode after SIR	Localized test After SIR testing		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
B1-6-1 to 5	6	1	1.27	1.81	Clean	180	119	0.66	Passing >1.0e8	8.71E+09
B1-10-1 to 5	10	1	1.26	1.71	Clean	180	112	0.62	Passing >1.0e8	1.58E+10
B1-50-1 to 5	50	1	1.24	1.64	Clean	180	102	0.56	Passing >1.0e8	6.03E+09
B2-6-1 to 5	6	3	3.56	4.17	Clean	180	107	0.59	Passing >1.0e8	6.17E+09
B2-10-1 to 5	10	3	3.76	4.40	Clean	180	125	0.70	Passing >1.0e8	2.00E+09
B2-50-1 to 5	50	3	3.57	4.11	Clean	180	142	0.79	Passing >1.0e8	1.29E+09
B3-6-1 to 5	6	6	6.98	7.33	Clean	134	250	1.87	Passing >1.0e8	3.89E+09
B3-10-1 to 5	10	6	7.06	7.51	Clean	141	250	1.78	Passing >1.0e8	5.89E+09
B3-50-1 to 5	50	6	6.95	7.41	Clean	142	250	1.77	Passing >1.0e8	1.10E+09
B4-6-1 to 5	6	12	13.00	13.59	Dirty	112	250	2.24	Failing <1.0e8	5.61E+06
B4-10-1 to 5	10	12	12.97	13.68	Dirty	106	250	2.35	Failing <1.0e8	3.54E+06
B4-50-1 to 5	50	12	12.85	13.73	Dirty	101	250	2.48	Failing <1.0e8	9.10E+06
B5-6-1 to 5	6	15	17.01	17.62	Dirty	41	250	6.09	Failing <1.0e8	9.98E+06
B5-10-1 to 5	10	15	17.00	17.88	Dirty	36	250	6.99	Failing <1.0e8	7.75E+06
B5-50-1 to 5	50	15	16.95	17.86	Dirty	40	250	6.33	Failing <1.0e8	8.50E+07

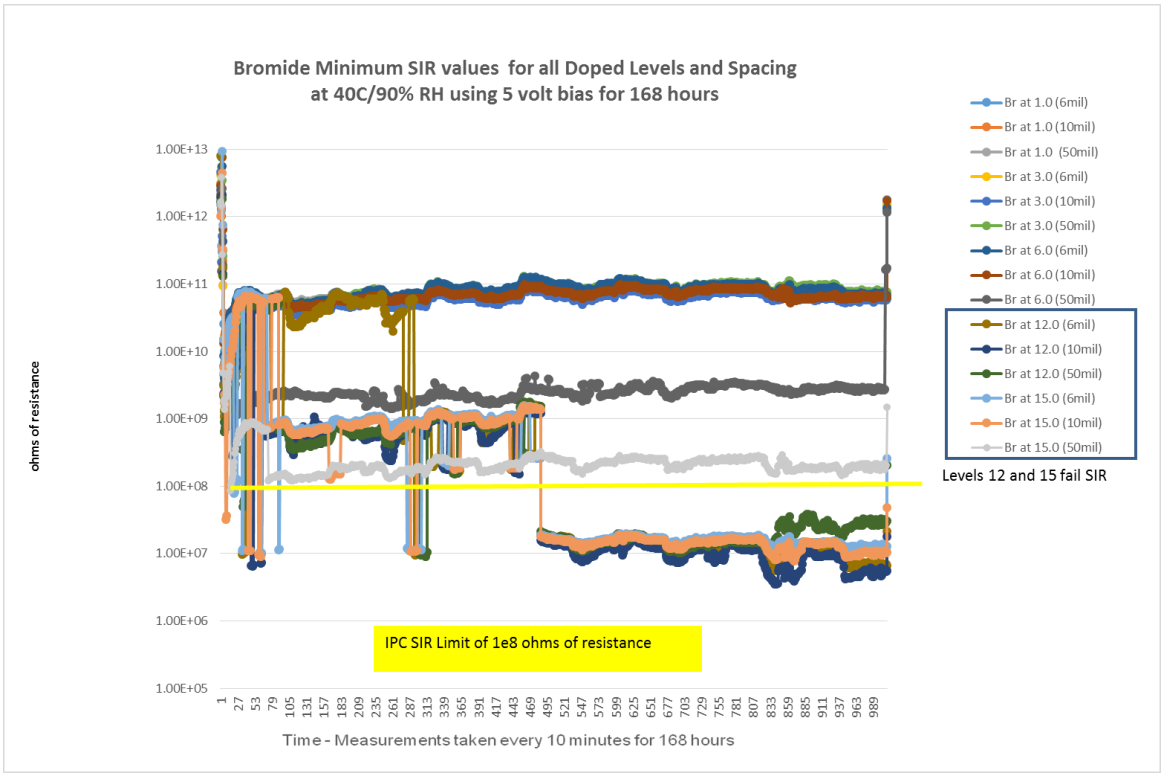

Figure 13 – Minimum SIR Values of the Bromide Doped Samples

Group B - Bromide findings of contamination levels of bromide below 7.0 µg/in^2 had good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5 µg/in^2 and 10 µg/in^2 showed low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Fluoride Contamination

Fluoride ("C") ionic species were doped on electrodes at 6, 10 and 50 mil spacing from NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 2, 3, 5, and 10 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 4 -Fluoride Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Flouride of Prep Electrode	Fl the Electrode after SIR	Localized Testing After SIR		Max Current	Corrosiv ity Index	SIR at 40C/90%RH w ith 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
C1-6-1 to 5	6	1	0.90	0.30	Clean	180	105	0.58	Passing >1.0e8	6.42E+09
C1-10-1 to 5	10	1	0.87	0.29	Clean	180	114	0.64	Passing >1.0e8	5.25E+09
C1-50-1 to 5	50	1	0.92	0.31	Clean	180	106	0.59	Passing >1.0e8	2.04E+09
C2-6-1 to 5	6	2	1.80	0.49	Clean	180	110	0.61	Passing >1.0e8	3.63E+09
C2-10-1 to 5	10	2	1.69	0.48	Clean	180	134	0.74	Passing >1.0e8	1.95E+09
C2-50-1 to 5	50	2	1.74	0.44	Clean	180	108	0.60	Passing >1.0e8	1.82E+09
C3-6-1 to 5	6	3	2.87	0.71	Clean	180	123	0.68	Passing >1.0e8	2.75E+09
C3-10-1 to 5	10	3	2.68	0.61	Clean	180	117	0.65	Passing >1.0e8	2.88E+09
C3-50-1 to 5	50	3	2.76	0.69	Clean	180	149	0.83	Passing >1.0e8	3.24E+09
C4-6-1 to 5	6	5	4.65	1.16	Clean	180	127	0.70	Passing >1.0e8	1.47E+10
C4-10-1 to 5	10	5	4.68	1.14	Clean	180	141	0.78	Passing >1.0e8	7.04E+09
C4-50-1 to 5	50	5	4.73	1.27	Clean	180	125	0.70	Passing >1.0e8	6.17E+09
C5-6-1 to 5	6	10	9.15	4.49	Dirty	110	250	2.27	Failing <1.0e8	7.71E+07
C5-10-1 to 5	10	10	9.29	4.83	Dirty	99	250	2.53	Failing <1.0e8	4.75E+07
C5-50-1 to 5	50	10	9.23	4.39	Dirty	96	250	2.62	Failing <1.0e8	1.26E+06

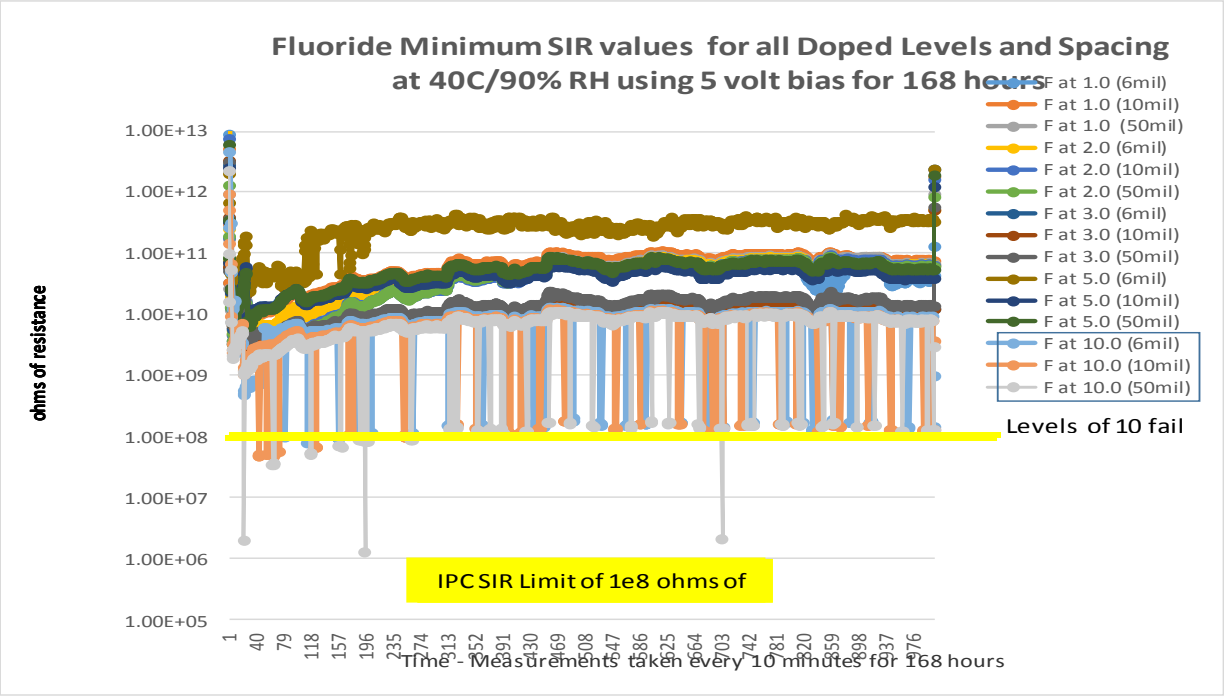

Figure 14 – Minimum SIR Values of the Fluoride Doped Samples

Group C - Fluoride findings of contamination levels of fluoride below 3.0 µg/in^2 had good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5.0 µg/in^2 and 10 µg/in^2 showed low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Acetate Contamination

Acetate ("D") ionic species were doped on electrodes at 6, 10 and 50 mil spacing with NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 3,5, 7, and 10 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 5 -Acetate Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Acetate of Prep Electrode	Acetate of the Electrode after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
D1-6-1 to 5	6	1	1.11	1.18	Clean	180	110	0.61	Passing >1.0e8	1.28E+09
D1-10-1 to 5	10	1	1.21	1.14	Clean	180	139	0.77	Passing >1.0e8	7.85E+08
D1-50-1 to 5	50	1	1.03	1.15	Clean	180	130	0.72	Passing >1.0e8	9.60E+08
D2-6-1 to 5	6	3	2.87	3.06	Clean	180	115	0.73	Passing >1.0e8	5.27E+08
D2-10-1 to 5	10	3	3.07	3.34	Clean	180	135	0.91	Passing >1.0e8	1.08E+09
D2-50-1 to 5	50	3	2.92	3.14	Clean	180	120	0.67	Passing >1.0e8	9.65E+08
D3-6-1 to 5	6	5	5.12	5.17	Clean	180	168	1.22	Passing >1.0e8	9.88E+08
D3-10-1 to 5	10	5	5.16	5.25	Clean	180	188	1.32	Passing >1.0e8	8.81E+08
D3-50-1 to 5	50	5	5.12	5.24	Clean	180	172	0.97	Passing >1.0e8	9.88E+08
D4-6-1 to 5	6	7	7.20	7.15	Dirty	180	250	2.37	Failing <1.0e8	4.67E+06
D4-10-1 to 5	10	7	7.27	7.26	Dirty	180	250	2.49	Failing <1.0e8	1.00E+06
D4-50-1 to 5	50	7	7.28	7.29	Dirty	180	250	2.45	Failing <1.0e8	1.00E+06
D5-6-1 to 5	6	10	10.42	10.26	Dirty	42	250	6.40	Failing <1.0e8	1.00E+06
D5-10-1 to 5	10	10	10.54	10.41	Dirty	49	250	5.28	Failing <1.0e8	1.00E+06
D5-50-1 to 5	50	10	9.23	10.21	Dirty	36	250	7.08	Failing <1.0e8	1.00E+06

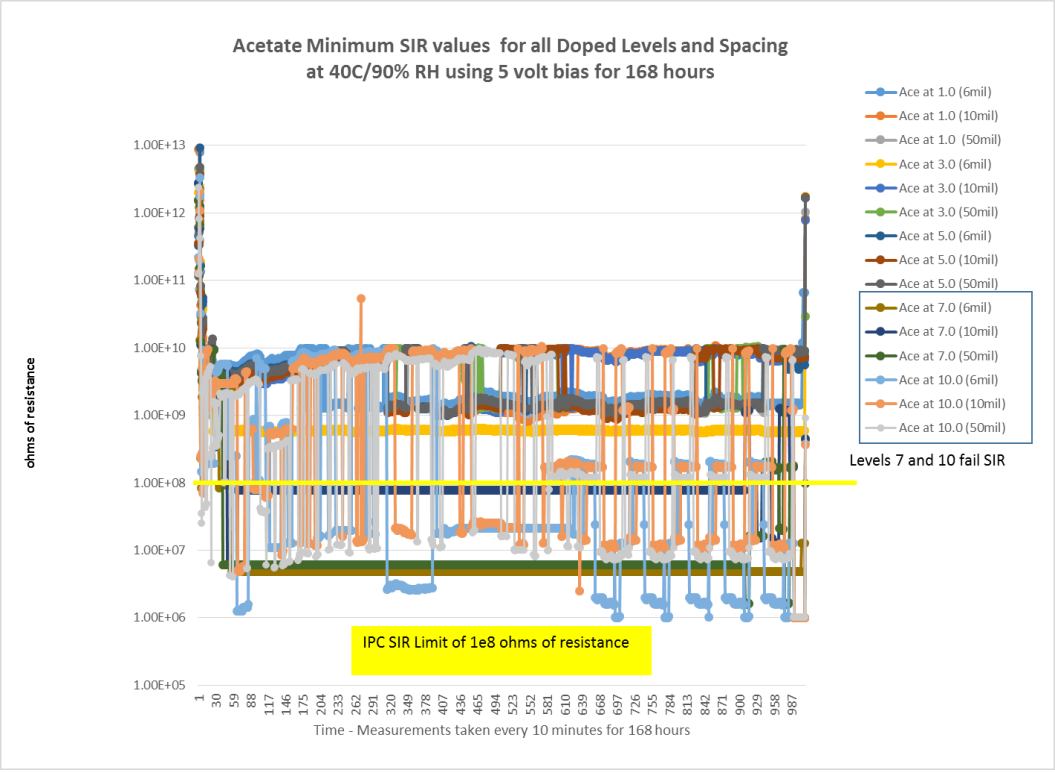

Figure 15 – Minimum SIR Values of the Acetate Doped Samples

Group D - Acetate findings of contamination levels of acetate below 5.0 µg/in^2 or less had good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 7.0 µg/in^2 and 10 µg/in^2 showed low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Formate Contamination

Formate ("E") ionic species were doped on electrodes at 6, 10 and 50 mil spacing from NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 3, 5, 7, and 10 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 6 -Formate Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Formate of Prep Electrode	Formate after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
E1-6-1 to 5	6	1	0.93	0.89	Clean	180	104	0.58	Passing >1.0e8	9.44E+08
E1-10-1 to 5	10	1	0.93	0.89	Clean	180	98	0.54	Passing >1.0e8	1.27E+09
E1-50-1 to 5	50	1	0.91	0.82	Clean	180	99	0.55	Passing >1.0e8	1.24E+09
E2-6-1 to 5	6	3	2.88	2.50	Clean	176	127	0.72	Passing >1.0e8	1.11E+09
E2-10-1 to 5	10	3	3.07	2.59	Clean	172	125	0.73	Passing >1.0e8	9.69E+08
E2-50-1 to 5	50	3	2.76	2.64	Clean	156	117	0.75	Passing >1.0e8	1.27E+09
E3-6-1 to 5	6	5	4.99	4.62	Clean	146	163	1.12	Passing >1.0e8	3.49E+09
E3-10-1 to 5	10	5	5.21	4.48	Clean	142	161	1.13	Passing >1.0e8	1.27E+09
E3-50-1 to 5	50	5	5.19	4.47	Clean	139	171	1.24	Passing >1.0e8	1.36E+09
E4-6-1 to 5	6	7	7.31	6.49	Clean	144	173	1.20	Passing >1.0e8	1.27E+09
E4-10-1 to 5	10	7	7.26	6.47	Clean	146	183	1.27	Passing >1.0e8	7.81E+08
E4-50-1 to 5	50	7	7.33	6.31	Clean	141	196	1.39	Passing >1.0e8	1.24E+09
E5-6-1 to 5	6	10	10.23	9.43	Dirty	100	250	2.51	Failing <1.0e8	5.72E+06
E5-10-1 to 5	10	10	10.34	9.50	Dirty	94	250	2.67	Failing <1.0e8	1.73E+07
E5-50-1 to 5	50	10	10.36	9.40	Dirty	91	250	2.77	Failing <1.0e8	2.35E+06

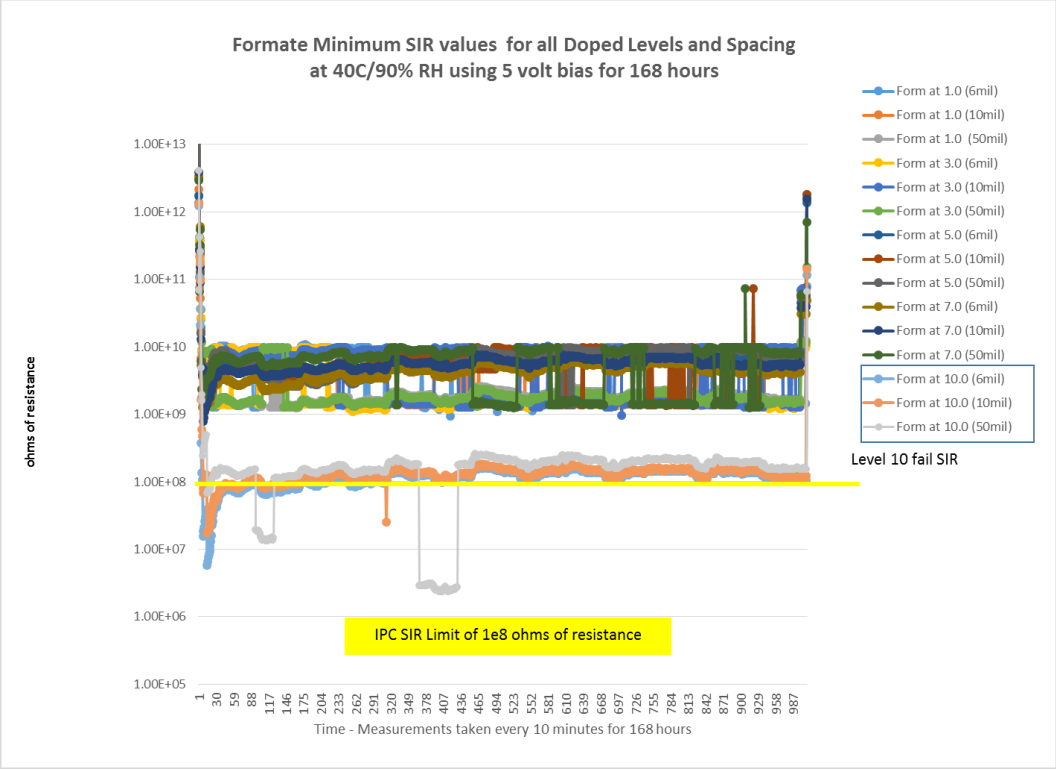

Figure 16 – Minimum SIR Values of the Formate Doped Samples

Group E - Formate findings of contamination levels of formate below 7.0 µg/in^2 have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Table 7 -Nitrite Levels (mean levels of the 5 replicas)										
Mean values of the Testing		Target Value	Nitrite of Prep Electrode	Nitrite after SIR	Localized Test After SIR results		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
F1-6-1 to 5	6	1	1.09	0.87	Clean	180	103	0.57	Passing >1.0e8	1.23E+09
F1-10-1 to 5	10	1	1.19	0.82	Clean	180	105	0.58	Passing >1.0e8	1.32E+09
F1-50-1 to 5	50	1	1.12	0.84	Clean	180	114	0.63	Passing >1.0e8	5.03E+08
F2-6-1 to 5	6	3	3.11	2.58	Clean	174	135	0.78	Passing >1.0e8	1.00E+09
F2-10-1 to 5	10	3	3.18	2.53	Clean	166	124	0.75	Passing >1.0e8	1.63E+09
F2-50-1 to 5	50	3	3.22	2.46	Clean	159	116	0.73	Passing >1.0e8	1.42E+09
F3-6-1 to 5	6	5	5.22	4.44	Dirty	101	250	2.47	Failing <1.0e8	1.03E+07
F3-10-1 to 5	10	5	5.19	4.40	Dirty	99	250	2.54	Failing <1.0e8	4.34E+07
F3-50-1 to 5	50	5	5.33	4.42	Dirty	98	250	2.58	Failing <1.0e8	3.78E+07
F4-6-1 to 5	6	7	7.31	6.39	Dirty	78	250	3.23	Failing <1.0e8	3.82E+06
F4-10-1 to 5	10	7	7.58	6.53	Dirty	64	250	3.93	Failing <1.0e8	5.34E+07
F4-50-1 to 5	50	7	7.40	6.32	Dirty	55	250	4.56	Failing <1.0e8	1.18E+07
F5-6-1 to 5	6	10	10.52	9.30	Dirty	34	250	7.48	Failing <1.0e8	1.18E+07
F5-10-1 to 5	10	10	10.57	9.16	Dirty	25	250	19.29	Failing <1.0e8	5.72E+07
F5-50-1 to 5	50	10	10.10	9.41	Dirty	27	250	9.51	Failing <1.0e8	1.09E+07

Nitrite Contamination

Nitrite ("F") ionic species were doped on electrodes at 6, 10 and 50 mil spacing from NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 3, 5, 7, and 10 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

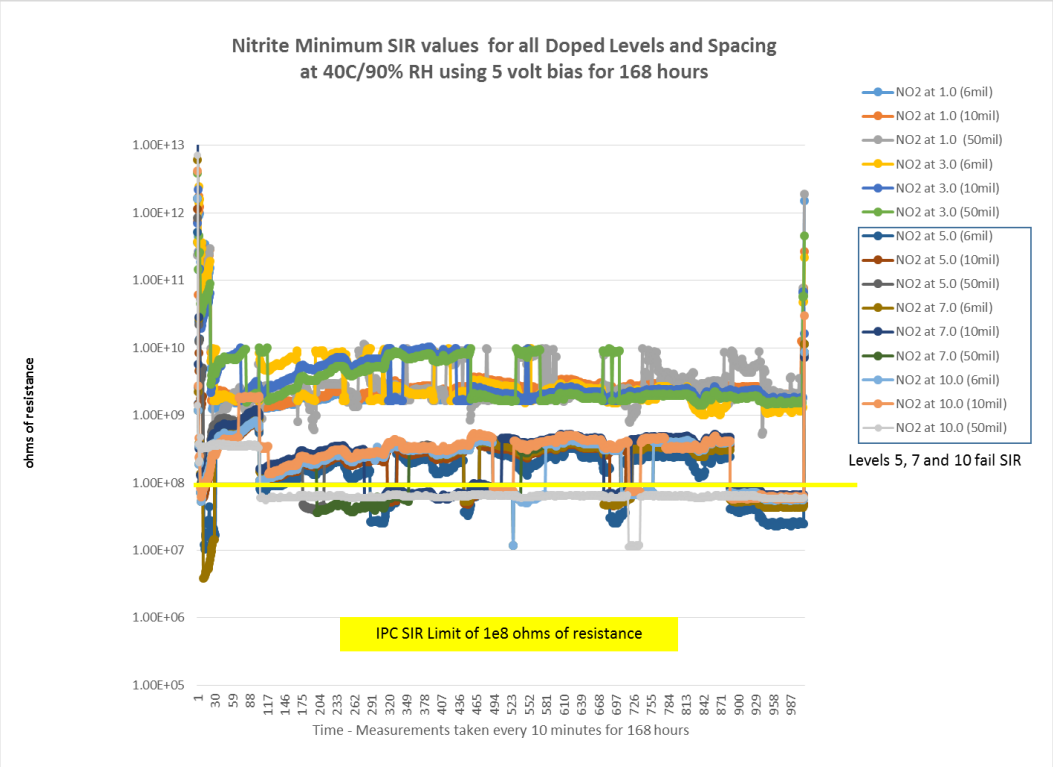

Figure 17 – Minimum SIR Values of the Nitrite Doped Samples

Group F - Nitrite findings of contamination levels of nitrite below 3.0 µg/in2 had good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5.0 up to 10 µg/in2 showed low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Nitrate Contamination

Nitrate ("G") ionic species were doped on electrodes at 6, 10 and 50 mil spacing from NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 3, 5, 7, and 10 µg/in2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 8 -Nitrate Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Nitrate of Prep Electrode	Nitrate after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
G1-6-1 to 5	6	1	1.27	0.92	Clean	180	112	0.62	Passing >1.0e8	1.47E+09
G1-10-1 to 5	10	1	1.18	0.67	Clean	180	129	0.71	Passing >1.0e8	1.53E+09
G1-50-1 to 5	50	1	1.29	0.76	Clean	180	139	0.78	Passing >1.0e8	9.91E+08
G2-6-1 to 5	6	3	3.27	2.76	Clean	174	250	1.44	Passing >1.0e8	1.68E+09
G2-10-1 to 5	10	3	3.37	2.62	Clean	174	250	1.44	Passing >1.0e8	1.80E+09
G2-50-1 to 5	50	3	3.58	2.52	Clean	168	246	1.47	Passing >1.0e8	3.21E+09
G3-6-1 to 5	6	5	5.42	4.69	Dirty	100	250	2.50	Failing <1.0e8	3.02E+07
G3-10-1 to 5	10	5	5.49	4.51	Dirty	82	250	3.08	Failing <1.0e8	1.91E+07
G3-50-1 to 5	50	5	5.37	4.49	Dirty	80	250	3.18	Failing <1.0e8	4.11E+07
G4-6-1 to 5	6	7	7.56	6.84	Dirty	57	250	4.52	Failing <1.0e8	4.21E+07
G4-10-1 to 5	10	7	7.62	6.62	Dirty	51	250	5.19	Failing <1.0e8	1.14E+07
G4-50-1 to 5	50	7	7.62	6.62	Dirty	42	250	6.00	Failing <1.0e8	2.52E+06
G5-6-1 to 5	6	10	10.67	9.89	Dirty	24	250	10.55	Failing <1.0e8	2.52E+06
G5-10-1 to 5	10	10	10.58	9.60	Dirty	36	250	7.22	Failing <1.0e8	1.22E+07
G5-50-1 to 5	50	10	10.52	9.35	Dirty	17	250	15.79	Failing <1.0e8	2.32E+06

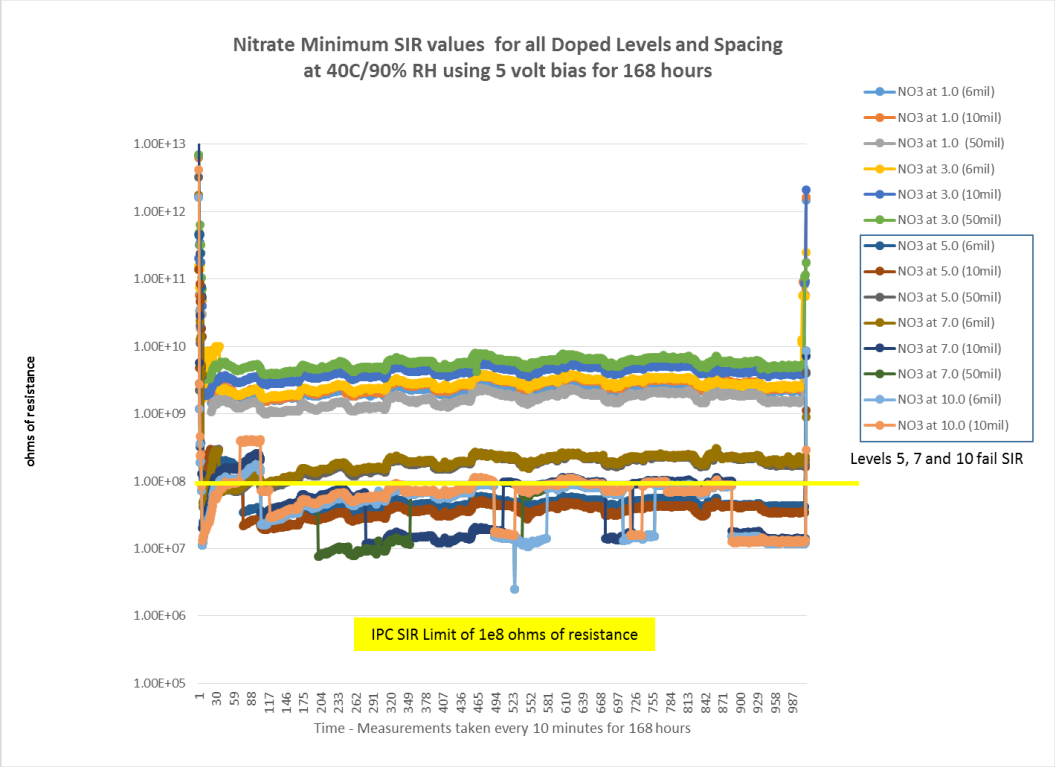

Figure 18 – Minimum SIR Values of the Nitrate Doped Samples

Group G - Nitrate findings of contamination levels of nitrate below 3.0 µg/in2 have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5.0 up to 10 µg/in2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Phosphate Contamination

Phosphate ("H") ionic species were doped on electrodes at 6, 10 and 50 mil spacing with NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 3, 5, 7, and 10 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 9 -Phosphate Levels (mean levels of the 5 replicas)

Mean values oG the Testing		Target Value	Phosphate of Prep Electrode	PO_4 after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
H1-6-1 to 5	6	1	0.92	0.85	Clean	180	98	0.55	Passing >1.0e8	1.15E+09
H1-10-1 to 5	10	1	1.01	0.86	Clean	180	112	0.62	Passing >1.0e8	1.21E+09
H1-50-1 to 5	50	1	1.24	0.79	Clean	180	113	0.63	Passing >1.0e8	7.80E+08
H2-6-1 to 5	6	3	3.18	2.68	Clean	170	241	1.43	Passing >1.0e8	1.33E+09
H2-10-1 to 5	10	3	3.21	2.56	Clean	168	247	1.48	Passing >1.0e8	1.42E+09
H2-50-1 to 5	50	3	3.27	2.42	Clean	170	242	1.43	Passing >1.0e8	2.53E+09
H3-6-1 to 5	6	5	5.34	4.47	Dirty	101	250	2.49	Failing <1.0e8	2.48E+06
H3-10-1 to 5	10	5	5.37	4.54	Dirty	88	250	2.83	Failing <1.0e8	1.50E+07
H3-50-1 to 5	50	5	5.39	4.44	Dirty	93	250	2.70	Failing <1.0e8	3.24E+07
H4-6-1 to 5	6	7	7.25	6.49	Dirty	47	250	5.43	Failing <1.0e8	5.56E+06
H4-10-1 to 5	10	7	7.32	6.54	Dirty	51	250	4.98	Failing <1.0e8	8.95E+06
H4-50-1 to 5	50	7	7.36	6.38	Dirty	51	250	5.01	Failing <1.0e8	6.05E+06
H5-6-1 to 5	6	10	11.19	10.29	Dirty	17	250	16.89	Failing <1.0e8	3.22E+06
H5-10-1 to 5	10	10	10.40	9.53	Dirty	14	250	18.36	Failing <1.0e8	9.59E+06
H5-50-1 to 5	50	10	10.53	9.07	Dirty	18	250	14.47	Failing <1.0e8	9.06E+06

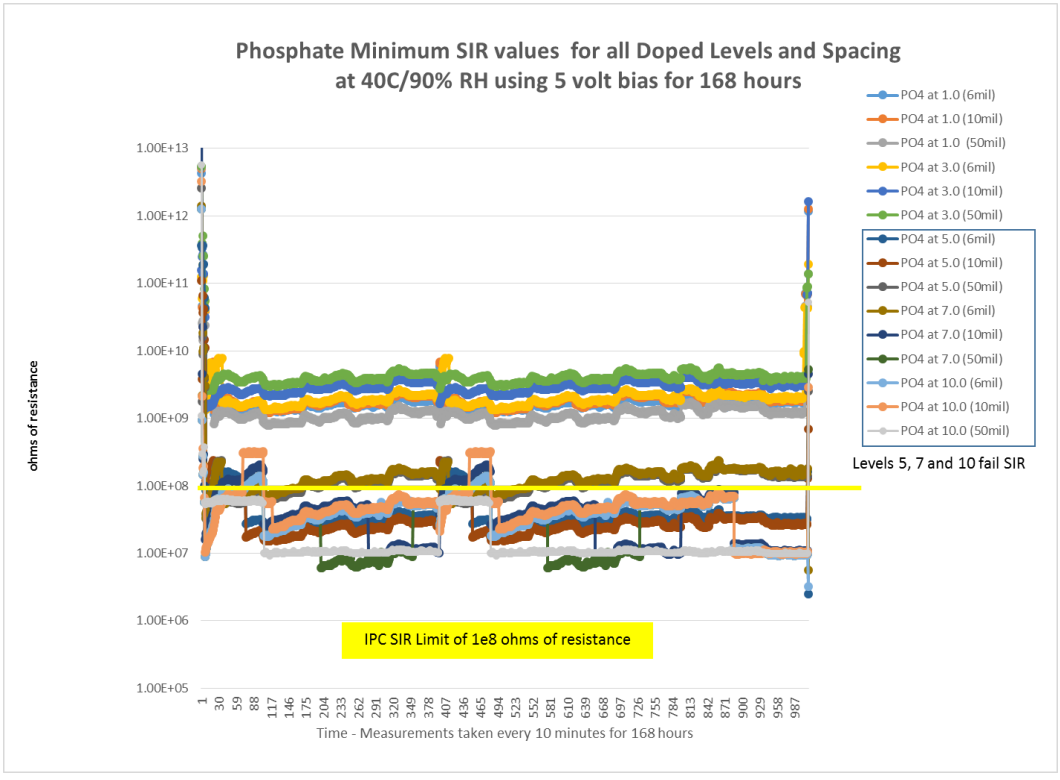

Figure 19 – Minimum SIR Values of the Phosphate Doped Samples

Group H - Phosphate findings of contamination levels of phosphate below 3.0 µg/in^2 have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5.0 up to 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Sulfate Contamination

Sulfate ("I") ionic species were doped on electrodes at 6, 10 and 50 mil spacing with NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 3, 5, 7, and 10 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 10 -Sulfate Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Sulfate of Prep Electrode	SO_4 of the Electrode after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
I1-6-1 to 5	6	1	0.93	0.79	Clean	180	127	0.71	Passing >1.0e8	1.81E+09
I1-10-1 to 5	10	1	0.91	0.68	Clean	180	95	0.53	Passing >1.0e8	2.07E+09
I1-50-1 to 5	50	1	0.92	0.76	Clean	180	170	0.96	Passing >1.0e8	1.31E+09
I2-6-1 to 5	6	3	2.70	2.27	Clean	171	229	1.35	Passing >1.0e8	2.10E+09
I2-10-1 to 5	10	3	2.56	2.36	Clean	172	214	1.25	Passing >1.0e8	2.22E+09
I2-50-1 to 5	50	3	2.39	2.66	Clean	172	240	1.40	Passing >1.0e8	3.95E+09
I3-6-1 to 5	6	5	5.16	4.50	Dirty	104	250	2.42	Failing <1.0e8	3.72E+07
I3-10-1 to 5	10	5	5.08	4.35	Dirty	97	250	2.58	Failing <1.0e8	2.35E+07
I3-50-1 to 5	50	5	5.32	4.35	Dirty	102	250	2.47	Failing <1.0e8	5.07E+07
I4-6-1 to 5	6	7	7.30	6.42	Dirty	50	250	5.12	Failing <1.0e8	5.19E+07
I4-10-1 to 5	10	7	7.33	6.40	Dirty	45	250	5.63	Failing <1.0e8	1.40E+07
I4-50-1 to 5	50	7	7.36	6.41	Dirty	58	250	4.34	Failing <1.0e8	9.46E+06
I5-6-1 to 5	6	10	10.33	9.57	Dirty	29	250	8.97	Failing <1.0e8	1.40E+07
I5-10-1 to 5	10	10	10.42	9.46	Dirty	22	250	11.51	Failing <1.0e8	1.50E+07
I5-50-1 to 5	50	10	10.35	9.41	Dirty	19	250	13.23	Failing <1.0e8	1.42E+07

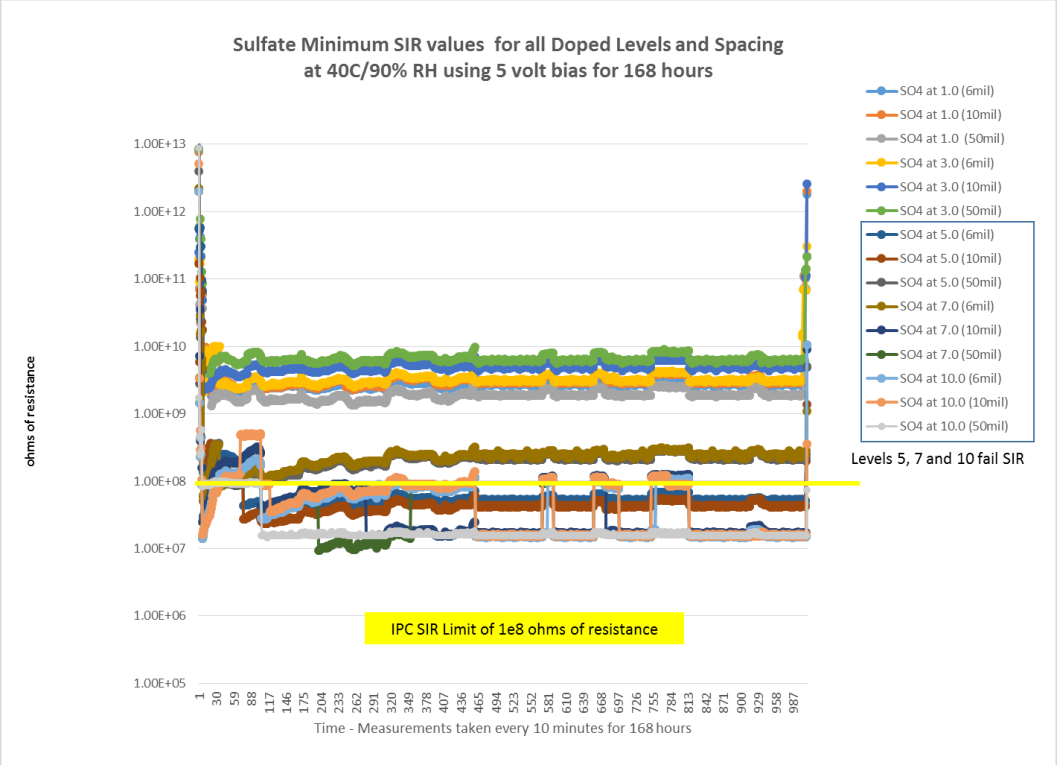

Figure 20 – Minimum SIR Values of the Sulfate Doped Samples

Group I - Sulfate findings of contamination levels of sulfate below 3.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5.0 up to 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

WOA (Succinic acid) Contamination

WOA ("J") ionic species were doped on electrodes at 6, 10 and 50 mil spacing with NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 10, 20, 25, 35, and 50 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 11 -WOA (Succinic Acid) Levels (mean levels of the 5 replicas)

Mean values oG the Testing		Target Value	WOA of Prep Electrode	WOAof the Electrode after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
J1-6-1 to 5	6	10	10.19	9.57	Clean	180	112	0.62	Passing >1.0e8	1.02E+09
J1-10-1 to 5	10	10	10.43	9.41	Clean	180	103	0.57	Passing >1.0e8	1.07E+09
J1-50-1 to 5	50	10	10.46	9.19	Clean	180	139	0.77	Passing >1.0e8	6.91E+08
J2-6-1 to 5	6	20	20.36	19.15	Clean	144	115	0.81	Passing >1.0e8	1.17E+09
J2-10-1 to 5	10	20	20.33	18.89	Clean	146	250	1.74	Passing >1.0e8	1.26E+09
J2-50-1 to 5	50	20	20.46	18.64	Clean	157	250	1.59	Passing >1.0e8	2.24E+09
J3-6-1 to 5	6	25	26.09	24.33	Clean	136	250	1.72	Passing >1.0e8	7.90E+08
J3-10-1 to 5	10	25	26.04	24.40	Clean	148	250	1.71	Passing >1.0e8	4.99E+08
J3-50-1 to 5	50	25	26.08	24.10	Clean	155	250	1.62	Passing >1.0e8	1.54E+09
J4-6-1 to 5	6	35	35.30	33.64	Dirty	96	250	2.62	Failing <1.0e8	2.94E+07
J4-10-1 to 5	10	35	35.83	33.96	Dirty	74	250	3.44	Failing <1.0e8	7.92E+06
J4-50-1 to 5	50	35	35.91	34.14	Dirty	68	250	3.81	Failing <1.0e8	5.36E+06
J5-6-1 to 5	6	50	50.76	48.38	Dirty	14	250	17.70	Failing <1.0e8	7.40E+06
J5-10-1 to 5	10	50	50.45	47.71	Dirty	15	250	17.18	Failing <1.0e8	8.49E+06
J5-50-1 to 5	50	50	50.40	45.60	Dirty	14	250	18.11	Failing <1.0e8	8.02E+06

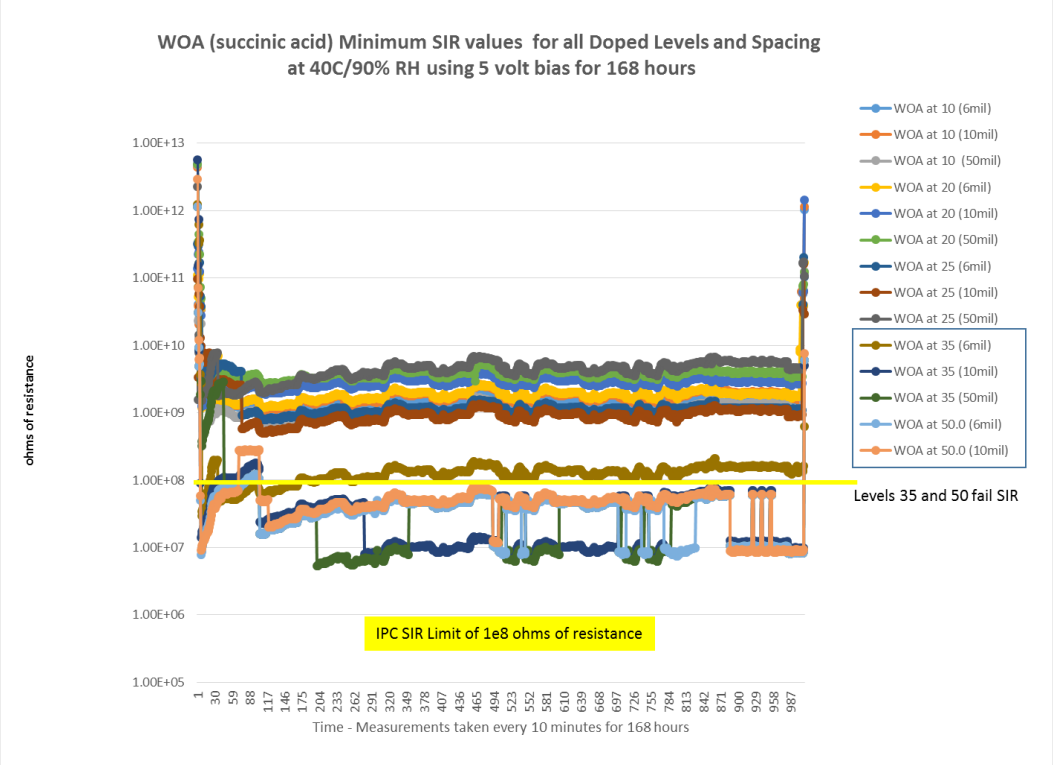

Figure 21 – Minimum SIR Values of the WOA Doped Samples

Group J - WOA findings of contamination levels of WOA below 25.0 µg/in^2 have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 35.0 up to 50 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Sodium Contamination

Sodium ("K") ionic species were doped on electrodes at 6, 10 and 50 mil spacing with NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 3, 5, 7, and 10 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 12 -Sodium Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Sodium of Prep Electrode	Sodium after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
K1-6-1 to 5	6	1	1.24	1.23	Clean	180	120	0.67	Passing >1.0e8	9.92E+08
K1-10-1 to 5	10	1	1.32	1.20	Clean	180	118	0.65	Passing >1.0e8	1.04E+09
K1-50-1 to 5	50	1	1.33	1.16	Clean	180	150	0.84	Passing >1.0e8	6.70E+08
K2-6-1 to 5	6	3	3.44	3.23	Clean	175	194	1.12	Passing >1.0e8	1.14E+09
K2-10-1 to 5	10	3	3.66	3.34	Clean	178	197	1.11	Passing >1.0e8	1.22E+09
K2-50-1 to 5	50	3	3.48	3.42	Clean	178	208	1.17	Passing >1.0e8	2.17E+09
K3-6-1 to 5	6	5	5.46	5.18	Dirty	99	250	2.53	Failing <1.0e8	2.04E+07
K3-10-1 to 5	10	5	5.49	5.31	Dirty	97	250	2.58	Failing <1.0e8	1.29E+07
K3-50-1 to 5	50	5	5.44	5.27	Dirty	95	250	2.66	Failing <1.0e8	4.60E+07
K4-6-1 to 5	6	7	7.54	7.46	Dirty	53	250	4.74	Failing <1.0e8	4.49E+07
K4-10-1 to 5	10	7	7.58	7.40	Dirty	45	250	5.56	Failing <1.0e8	7.69E+06
K4-50-1 to 5	50	7	7.57	7.30	Dirty	45	250	5.61	Failing <1.0e8	5.57E+06
K5-6-1 to 5	6	10	10.90	10.96	Dirty	20	250	13.46	Failing <1.0e8	7.69E+06
K5-10-1 to 5	10	10	10.69	10.69	Dirty	16	250	15.67	Failing <1.0e8	8.24E+06
K5-50-1 to 5	50	10	10.70	10.57	Dirty	13	250	19.74	Failing <1.0e8	7.78E+06

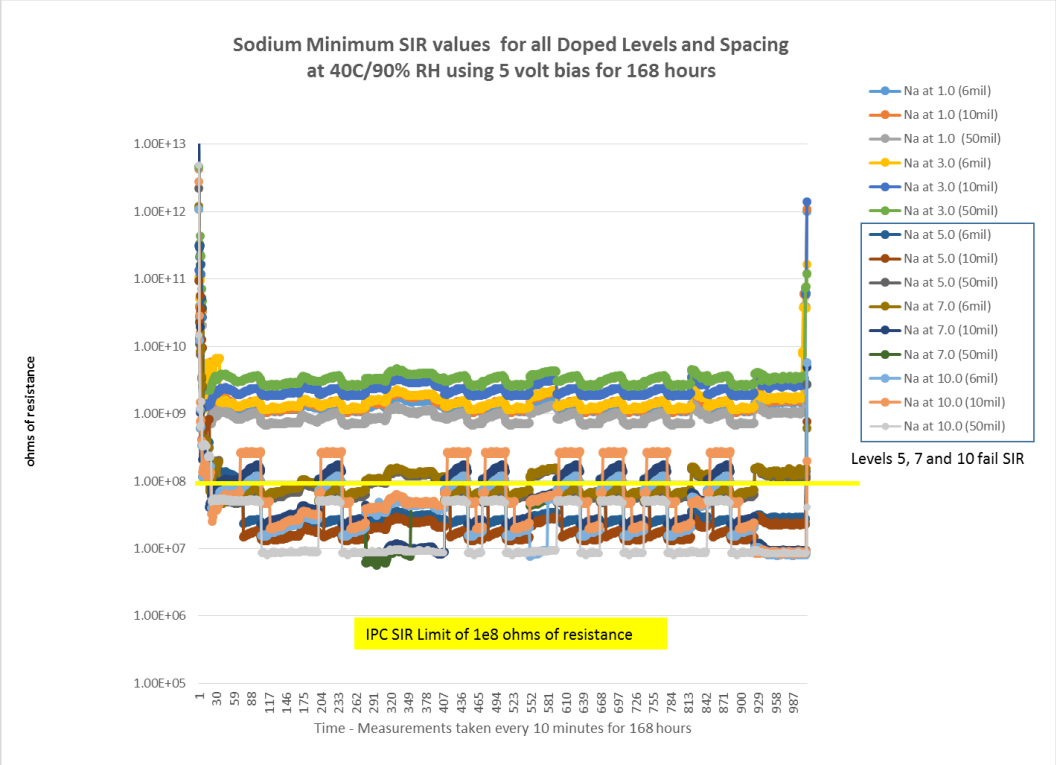

Figure 22 – Minimum SIR Values of the Sodium Doped Samples

Group K - Sodium findings of contamination levels of sodium below 3.0 µg/in^2 have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5.0 up to 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Ammonium Contamination

Ammonium ("L") ionic species were doped on electrodes at 6, 10 and 50 mil spacing with NIST-traceable standards using 5µl doses in the gap between the parallel bare copper traces. Target levels of contamination are 1, 3, 5, 7, and 10 µg/in^2 and were achieved by doping the electrode spacing with 5-100 µl of a 10 ppm control standard.

Table 13 -Ammonium Levels (mean levels of the 5 replicas)										
Mean values of the Testing		Target Value	Ammonium of Prep Electrode	NH_4 after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
L1-6-1 to 5	6	1	0.95	1.17	Clean	180	137	0.76	Passing >1.0e8	4.07E+09
L1-10-1 to 5	10	1	0.98	1.27	Clean	180	118	0.65	Passing >1.0e8	4.27E+09
L1-50-1 to 5	50	1	0.94	1.17	Clean	180	117	0.65	Passing >1.0e8	2.75E+09
L2-6-1 to 5	6	3	2.85	3.24	Clean	174	236	1.36	Passing >1.0e8	4.68E+09
L2-10-1 to 5	10	3	2.74	3.30	Clean	178	198	1.11	Passing >1.0e8	5.02E+09
L2-50-1 to 5	50	3	2.75	3.41	Clean	180	189	1.05	Passing >1.0e8	8.92E+09
L3-6-1 to 5	6	5	4.86	5.47	Dirty	98	250	2.57	Failing <1.0e8	1.79E+07
L3-10-1 to 5	10	5	4.85	5.50	Dirty	95	250	2.64	Failing <1.0e8	1.13E+07
L3-50-1 to 5	50	5	4.84	4.97	Dirty	91	250	2.76	Failing <1.0e8	4.02E+07
L4-6-1 to 5	6	7	6.85	7.42	Dirty	52	250	5.19	Failing <1.0e8	3.93E+07
L4-10-1 to 5	10	7	6.83	7.35	Dirty	55	250	4.59	Failing <1.0e8	7.89E+06
L4-50-1 to 5	50	7	6.80	7.47	Dirty	58	250	4.36	Failing <1.0e8	7.04E+06
L5-6-1 to 5	6	10	9.82	10.38	Dirty	14	250	18.36	Failing <1.0e8	6.72E+06
L5-10-1 to 5	10	10	9.78	10.44	Dirty	15	250	16.77	Failing <1.0e8	7.37E+06
L5-50-1 to 5	50	10	9.81	10.29	Dirty	19	250	13.62	Failing <1.0e8	6.80E+06

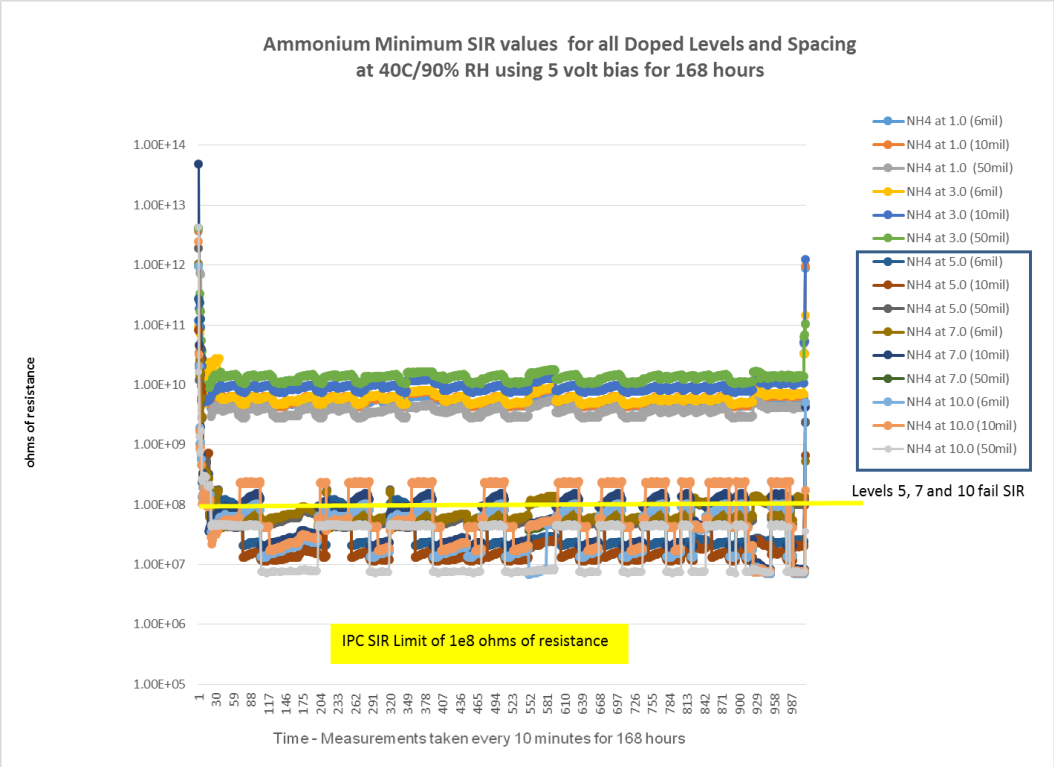

Figure 23 – Minimum SIR Values of the Ammonium Doped Samples

Group L - Ammonium findings of contamination levels of sodium below 3.0 µg/in^2 have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing. On the other hand levels of 5.0 up to 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or having signs of electrochemical migration debris.

Conclusions

The focus of this research was to determine at what level each ionic contaminant on nominal lead spacing in electronic hardware (IPC Class 2 and Class 3) will cause current leakage and corrosion problems to occur, using IPC J-STD 001 rev E SIR values for a pass/fail criteria. This limit has a historical value of SIR for passing above 1.0e8 ohms of resistivity during exposure to SIR humidity conditions of 40ºC/90%RH; a 5 volt bias with monitoring every ten minutes. The below levels of contamination correlate to good passing of SIR values for each of the individual ionic species.

A – Chloride limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

B – Bromide limit on 6, 10 and 50 mil spacing is 7.0 µg/in^2 to ensure good electrical performance.

C – Fluoride limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

D – Acetate limit on 6, 10 and 50 mil spacing is 5.0 µg/in^2 to ensure good electrical performance.

E – Formate limit on 6, 10 and 50 mil spacing is 7.0 µg/in^2 to ensure good electrical performance.

F – Nitrite limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

G – Nitrate limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

H – Phosphate limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

I – Sulfate limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

J – WOA (Succinic Acid) limit on 6, 10 and 50 mil spacing is 25.0 µg/in^2 to ensure good electrical performance.

K – Sodium limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

L – Ammonium limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

As noted, the subject tests showed little difference to the spacing of the electrode copper trace spacing during the 168 hours. The results of these tests show a similar concentration failure threshold for each trace spacing of the three tested. Follow on research will be done to show combined levels of ionic contamination and effects on sensitive active circuitry, such as battery, clock, RF, and high impedance circuits and SIR at 6 mil spacing.

How Clean is Clean Enough – At What Level Does Each of The Individual Contaminates Cause Leakage and Corrosion Failures in SIR

IPC APEX Conference

Presented by

Terry Munson of Foresite

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Abstract

- In this investigation a test matrix was completed
  - Utilizing 900 electrodes (small circuit board with parallel copper traces on FR-4 with LPI soldermask at 6, 10 and 50 mil spacing):
  - 12 ionic contaminants were applied in five concentrations to three different spaced electrodes with five replicas each (three different bare copper trace spacing / five replications of each with five levels of ionic concentration).
  - The investigation was to assess the electrical response under controlled heat and humidity conditions of the known applied contamination to electrodes, using the IPC SIR (surface insulation resistance) J-STD 001 limits and determine at what level of contamination and spacing the ionic / organic residue has a failing effect on SIR.

Introduction

- Using NIST traceable standards each individual ionic contaminant was doped on the electrode surface in a specific area and each was applied with 5µl doses until the total desired concentration was achieved on each sample.
- Ion chromatography analysis of extracted samples was performed to verify the actual inoculated concentrations prior to SIR testing.
- Then each electrode was placed into test chambers and socket tested on electrodes to collect SIR readings every 15 min with a 5 volt bias. All samples were exposed to 40° C/90%RH (non-condensing) for 168 hours with SIR monitoring.
- After SIR each sample was visually inspected and was then extracted and assessed for cleanliness. Using the IPC J-STD 001 SIR limits of values greater than 1.0e8 ohms of resistance or better as the pass / fail criteria and then comparing the samples to the ionic cleanliness using ion chromatography.

Ionic and Organic Residues Tested

- **A – Chloride** doped on 6, 10 and 50 mil spacing
- **B – Bromide** doped on 6, 10 and 50 mil spacing
- **C – Fluoride** doped on 6, 10 and 50 mil spacing
- **D – Acetate** doped on 6, 10 and 50 mil spacing
- **E – Formate** doped on 6, 10 and 50 mil spacing
- **F – Nitrite** doped on 6, 10 and 50 mil spacing
- **G – Nitrate** doped on 6, 10 and 50 mil spacing
- **H – Phosphate** doped on 6, 10 and 50 mil spacing
- **I – Sulfate** doped on 6, 10 and 50 mil spacing
- **J – WOA (Succinic Acid)** doped on 6, 10 and 50 mil spacing
- **K – Sodium** doped on 6, 10 and 50 mil spacing
- **L – Ammonium** doped on 6, 10 and 50 mil spacing

Sample Preparation of Electrodes

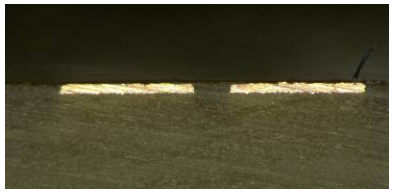
- Sample prep of bare copper trace electrodes used for testing:
  - cleaned in an inline cleaner at 1.5 ft/min belt speed with only de-ionized (DI) water heated to 150° F
  - rinsed in circulated IPA/DI (75%/25%) in ambient conditions for 15 minutes
  - air dried for 30 minutes and then baked in an oven for an hour at 80° C;
  - tested prior to doping to verify that the electrodes were clean (<1.0 µg/in^2 of ionic residue).
  - Each electrode was doped using calibrated, air displacement, pipette volumes of 5 µl up to 100 µl, dispensed repetitively in 5 µl applications, as required achieving the proper concentration.

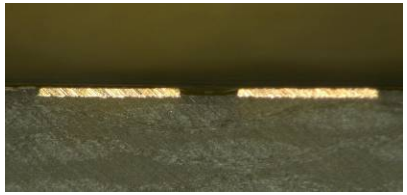
Table 1 – Ionic Contamination and Concentration Levels

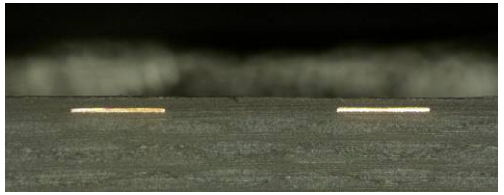
Contaminants		Concentration Levels (µg/in^2)				
		1	2	3	4	5
Chlorides	Cl-	1.0	2.0	3.0	5.0	10.0
Bromides	Br-	1.0	3.0	6.0	12.0	15.0
Fluoride	F-	1.0	2.0	3.0	5.0	10.0
Acetate	CCOO-	1.0	3.0	5.0	7.0	10.0
Formate	COO-	1.0	3.0	5.0	7.0	10.0
Nitrite	NO2-	1.0	3.0	5.0	7.0	10.0
Nitrate	NO3--	1.0	3.0	5.0	7.0	10.0
Phosphate	PO4-	1.0	3.0	5.0	7.0	10.0
Sulfates	SO4-	1.0	3.0	5.0	7.0	10.0
Weak Organic Acid	WOA	10.0	20.0	25.0	35.0	50.0
Sodium	Na+	1.0	3.0	5.0	7.0	10.0
Ammonium	NH4+	1.0	3.0	5.0	7.0	10.0
Lithium*	Li+	1.0	2.0	3.0	5.0	10.0
Methane Sulfonic Acid*	MSA	0.1	0.2	1.0	3.0	5.0

Electrodes

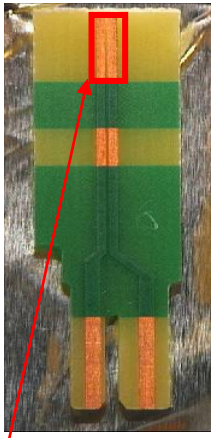
- (12) Contaminants x (5) Levels of Concentration x (5) Replications x (3) Trace Gap Spacing Test Matrix = 900 Coupons.
- * Lithium, MSA and mixtures were not included in the testing due to time constraints and would be included in next phase of testing.

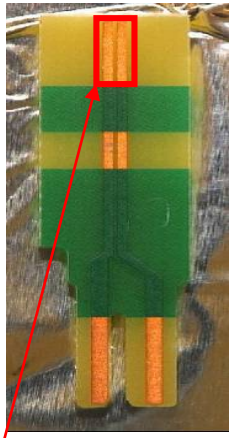


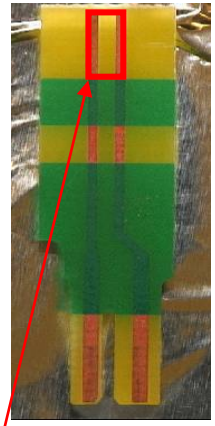




- Figure 1 - Electrode (6 mil spacing) Figure 2 - Electrode (10 mil spacing) Figure 3 - Electrode (50 mil spacing)





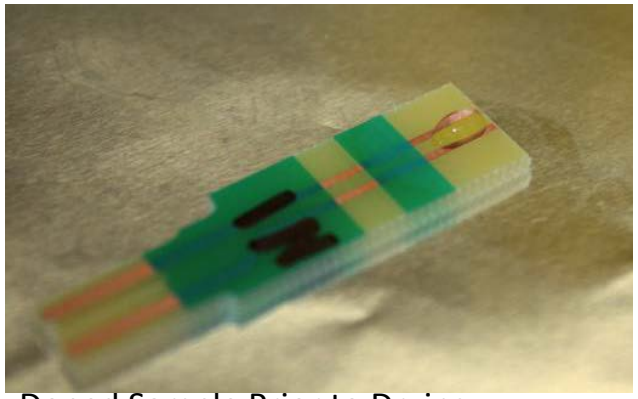


- Figure 4 - Doping Area for 6 mil Figure 5 - Doping Area for 10 mil Figure 6 - Doping Area for 50 mil

Sample Doping Procedure (with 5 micro-liter pipette)

Doping of Electrodes

Doping of Samples



Doped Sample Prior to Drying

Tray of doped Electrodes in Oven at 37° C

SIR Testing

- After the samples were doped to the appropriate level and cleanliness analysis was conducted on a subset of samples before testing
- All the sample electrodes were randomized in the chamber on 12 socketed assembly boards with 12 sockets per board.
- All samples were processed through the same production humidity chamber - ran for 168 hours at 40°C/90%RH in a non-condensing humidity condition over 7 weeks.

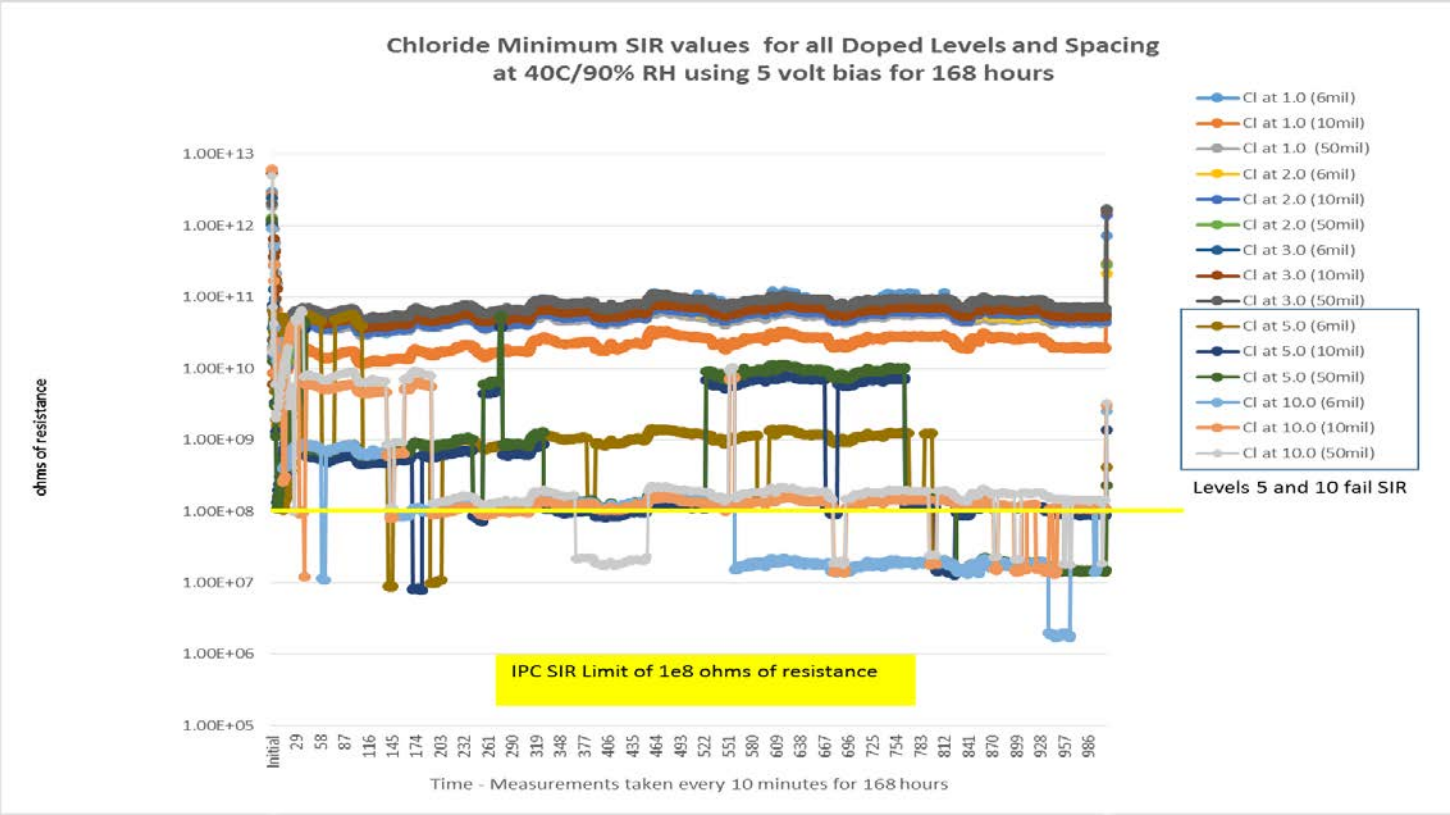
Test System

Chloride Contamination

Table 2 - Chloride Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Chloride of Prep Electrode	Cl of the Electrode after SIR	Localized test After SIR testing		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA of current	Current / Time	SIR results	SIR Minimum
A1-6-1 to 5	6	1	1.11	0.99	Clean	180	105	0.58	Passing >1.0e8	1.82E+10
A1-10-1 to 5	10	1	1.08	0.95	Clean	180	98	0.54	Passing >1.0e8	8.51E+09
A1-50-1 to 5	50	1	1.10	0.94	Clean	180	110	0.61	Passing >1.0e8	2.14E+10
A2-6-1 to 5	6	2	2.23	2.02	Clean	180	123	0.68	Passing >1.0e8	1.48E+09
A2-10-1 to 5	10	2	2.08	1.87	Clean	180	122	0.68	Passing >1.0e8	1.70E+09
A2-50-1 to 5	50	2	2.16	1.91	Clean	180	130	0.72	Passing >1.0e8	1.62E+09
A3-6-1 to 5	6	3	3.21	2.90	Clean	134	250	1.87	Passing >1.0e8	6.76E+09
A3-10-1 to 5	10	3	3.24	2.87	Clean	141	250	1.78	Passing >1.0e8	6.04E+09
A3-50-1 to 5	50	3	3.38	2.78	Clean	142	250	1.77	Passing >1.0e8	3.55E+09
A4-6-1 to 5	6	5	5.21	5.20	Dirty	112	250	2.24	Failing <1.0e8	8.60E+06
A4-10-1 to 5	10	5	5.18	5.21	Dirty	106	250	2.35	Failing <1.0e8	7.84E+06
A4-50-1 to 5	50	5	5.19	5.06	Dirty	101	250	2.48	Failing <1.0e8	1.38E+07
A5-6-1 to 5	6	10	9.98	9.54	Dirty	41	250	6.09	Failing <1.0e8	1.71E+06
A5-10-1 to 5	10	10	10.07	9.64	Dirty	36	250	6.99	Failing <1.0e8	1.20E+07
A5-50-1 to 5	50	10	10.36	9.84	Dirty	40	250	6.33	Failing <1.0e8	1.70E+07

Chloride SIR Performance

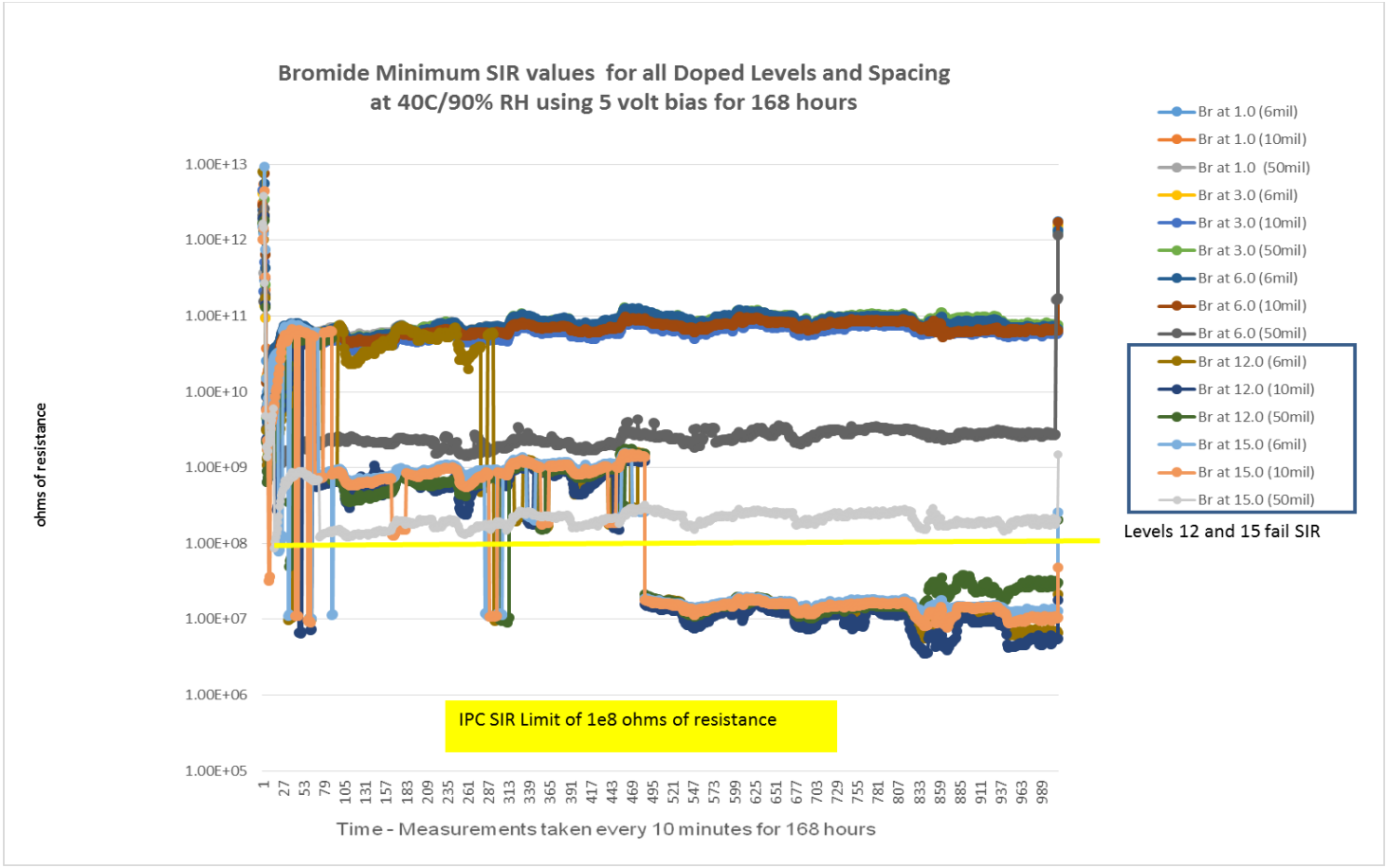


- Group A - Chloride findings of contamination levels of 3.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 5 µg/in^2 and 10 µg/in^2 show low SIR values and the presence of dendrite shorting, which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

Bromide Contamination

Table 3 - Bromide Levels (mean levels of the 5 replicas)										
Mean values of the Testing		Target Value	Bromide of Prep Electrode	Br of the Electrode after SIR	Localized test After SIR testing		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
B1-6-1 to 5	6	1	1.27	1.81	Clean	180	119	0.66	Passing >1.0e8	8.71E+09
B1-10-1 to 5	10	1	1.26	1.71	Clean	180	112	0.62	Passing >1.0e8	1.58E+10
B1-50-1 to 5	50	1	1.24	1.64	Clean	180	102	0.56	Passing >1.0e8	6.03E+09
B2-6-1 to 5	6	3	3.56	4.17	Clean	180	107	0.59	Passing >1.0e8	6.17E+09
B2-10-1 to 5	10	3	3.76	4.40	Clean	180	125	0.70	Passing >1.0e8	2.00E+09
B2-50-1 to 5	50	3	3.57	4.11	Clean	180	142	0.79	Passing >1.0e8	1.29E+09
B3-6-1 to 5	6	6	6.98	7.33	Clean	134	250	1.87	Passing >1.0e8	3.89E+09
B3-10-1 to 5	10	6	7.06	7.51	Clean	141	250	1.78	Passing >1.0e8	5.89E+09
B3-50-1 to 5	50	6	6.95	7.41	Clean	142	250	1.77	Passing >1.0e8	1.10E+09
B4-6-1 to 5	6	12	13.00	13.59	Dirty	112	250	2.24	Failing <1.0e8	5.61E+06
B4-10-1 to 5	10	12	12.97	13.68	Dirty	106	250	2.35	Failing <1.0e8	3.54E+06
B4-50-1 to 5	50	12	12.85	13.73	Dirty	101	250	2.48	Failing <1.0e8	9.10E+06
B5-6-1 to 5	6	15	17.01	17.62	Dirty	41	250	6.09	Failing <1.0e8	9.98E+06
B5-10-1 to 5	10	15	17.00	17.88	Dirty	36	250	6.99	Failing <1.0e8	7.75E+06
B5-50-1 to 5	50	15	16.95	17.86	Dirty	40	250	6.33	Failing <1.0e8	8.50E+07

Bromide SIR Performance



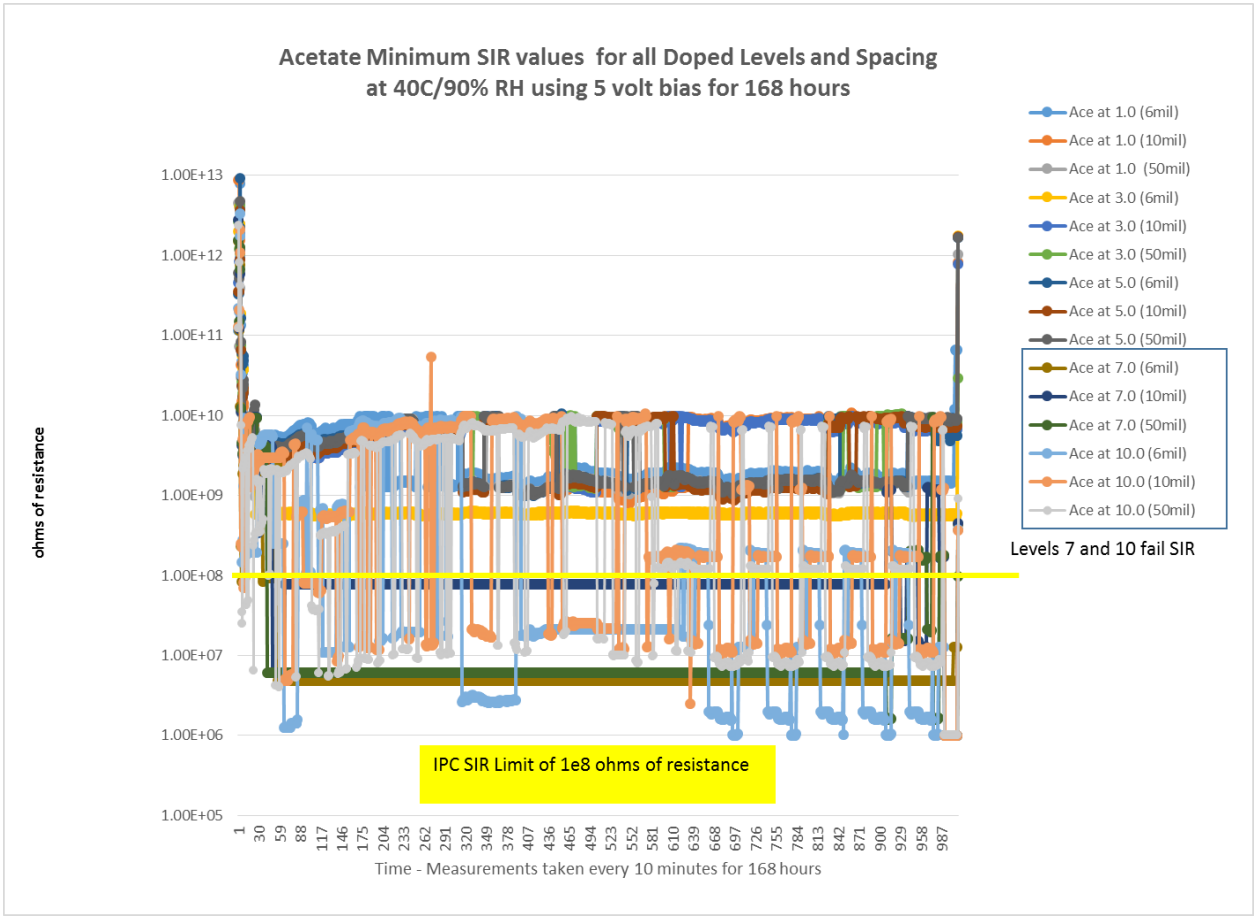
- Group B - Bromide findings of contamination levels of bromide below 7.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 5 µg/in^2 and 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

Acetate Contamination

Table 5 -Acetate Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Acetate of Prep Electrode	Acetate of the Electrode after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
D1-6-1 to 5	6	1	1.11	1.18	Clean	180	110	0.61	Passing >1.0e8	1.28E+09
D1-10-1 to 5	10	1	1.21	1.14	Clean	180	139	0.77	Passing >1.0e8	7.85E+08
D1-50-1 to 5	50	1	1.03	1.15	Clean	180	130	0.72	Passing >1.0e8	9.60E+08
D2-6-1 to 5	6	3	2.87	3.06	Clean	180	115	0.73	Passing >1.0e8	5.27E+08
D2-10-1 to 5	10	3	3.07	3.34	Clean	180	135	0.91	Passing >1.0e8	1.08E+09
D2-50-1 to 5	50	3	2.92	3.14	Clean	180	120	0.67	Passing >1.0e8	9.65E+08
D3-6-1 to 5	6	5	5.12	5.17	Clean	180	168	1.22	Passing >1.0e8	9.88E+08
D3-10-1 to 5	10	5	5.16	5.25	Clean	180	188	1.32	Passing >1.0e8	8.81E+08
D3-50-1 to 5	50	5	5.12	5.24	Clean	180	172	0.97	Passing >1.0e8	9.88E+08
D4-6-1 to 5	6	7	7.20	7.15	Dirty	180	250	2.37	Failing <1.0e8	4.67E+06
D4-10-1 to 5	10	7	7.27	7.26	Dirty	180	250	2.49	Failing <1.0e8	1.00E+06
D4-50-1 to 5	50	7	7.28	7.29	Dirty	180	250	2.45	Failing <1.0e8	1.00E+06
D5-6-1 to 5	6	10	10.42	10.26	Dirty	42	250	6.40	Failing <1.0e8	1.00E+06
D5-10-1 to 5	10	10	10.54	10.41	Dirty	49	250	5.28	Failing <1.0e8	1.00E+06
D5-50-1 to 5	50	10	9.23	10.21	Dirty	36	250	7.08	Failing <1.0e8	1.00E+06

Acetate SIR Performance

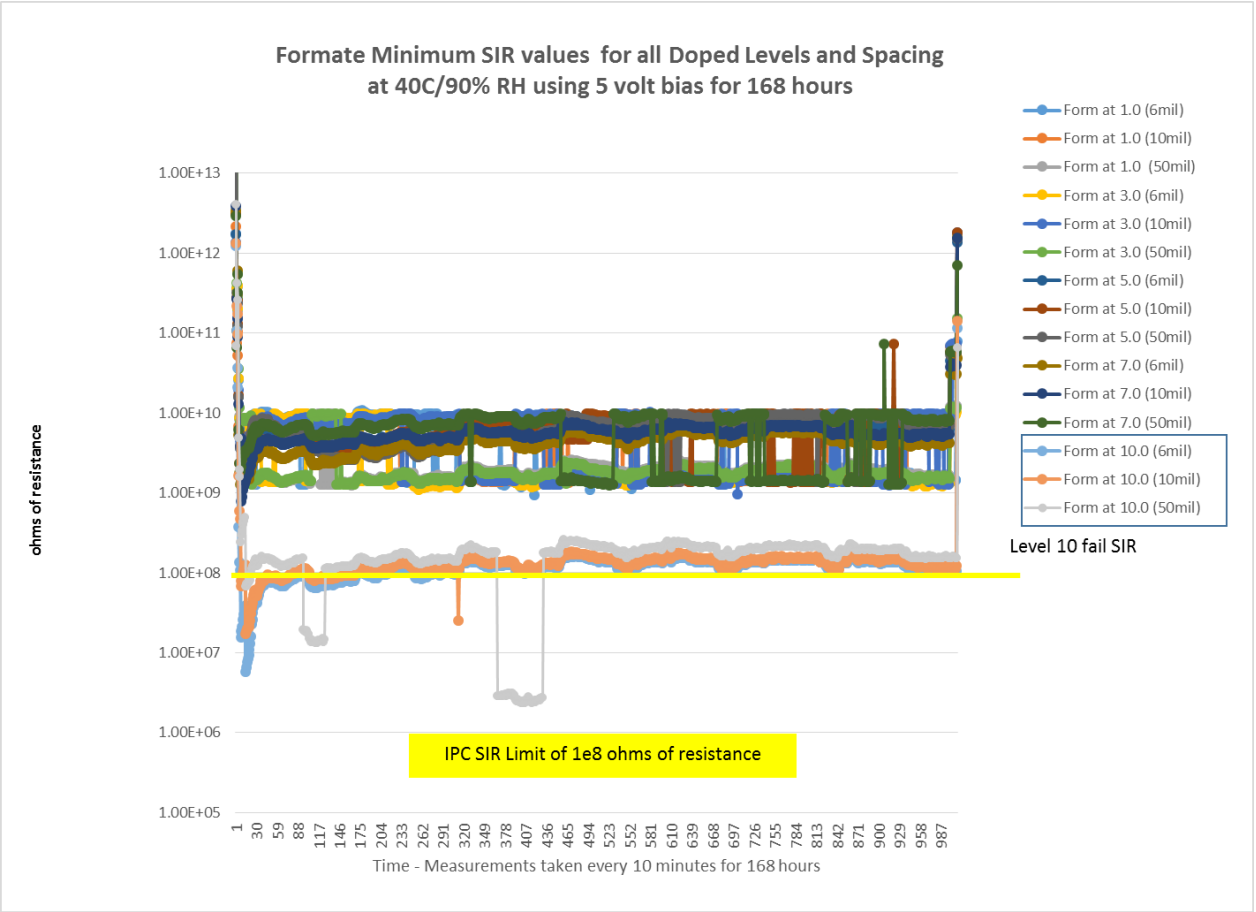


- **Group D -** Acetate findings of contamination levels of acetate below 5.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 7.0 µg/in^2 and 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

Formate Contamination

Table 6 -Formate Levels (mean levels of the 5 replicas)										
Mean values of the Testing		Target Value	Formate of Prep Electrode	Formate after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
E1-6-1 to 5	6	1	0.93	0.89	Clean	180	104	0.58	Passing >1.0e8	9.44E+08
E1-10-1 to 5	10	1	0.93	0.89	Clean	180	98	0.54	Passing >1.0e8	1.27E+09
E1-50-1 to 5	50	1	0.91	0.82	Clean	180	99	0.55	Passing >1.0e8	1.24E+09
E2-6-1 to 5	6	3	2.88	2.50	Clean	176	127	0.72	Passing >1.0e8	1.11E+09
E2-10-1 to 5	10	3	3.07	2.59	Clean	172	125	0.73	Passing >1.0e8	9.69E+08
E2-50-1 to 5	50	3	2.76	2.64	Clean	156	117	0.75	Passing >1.0e8	1.27E+09
E3-6-1 to 5	6	5	4.99	4.62	Clean	146	163	1.12	Passing >1.0e8	3.49E+09
E3-10-1 to 5	10	5	5.21	4.48	Clean	142	161	1.13	Passing >1.0e8	1.27E+09
E3-50-1 to 5	50	5	5.19	4.47	Clean	139	171	1.24	Passing >1.0e8	1.36E+09
E4-6-1 to 5	6	7	7.31	6.49	Clean	144	173	1.20	Passing >1.0e8	1.27E+09
E4-10-1 to 5	10	7	7.26	6.47	Clean	146	183	1.27	Passing >1.0e8	7.81E+08
E4-50-1 to 5	50	7	7.33	6.31	Clean	141	196	1.39	Passing >1.0e8	1.24E+09
E5-6-1 to 5	6	10	10.23	9.43	Dirty	100	250	2.51	Failing <1.0e8	5.72E+06
E5-10-1 to 5	10	10	10.34	9.50	Dirty	94	250	2.67	Failing <1.0e8	1.73E+07
E5-50-1 to 5	50	10	10.36	9.40	Dirty	91	250	2.77	Failing <1.0e8	2.35E+06

Formate SIR Performance



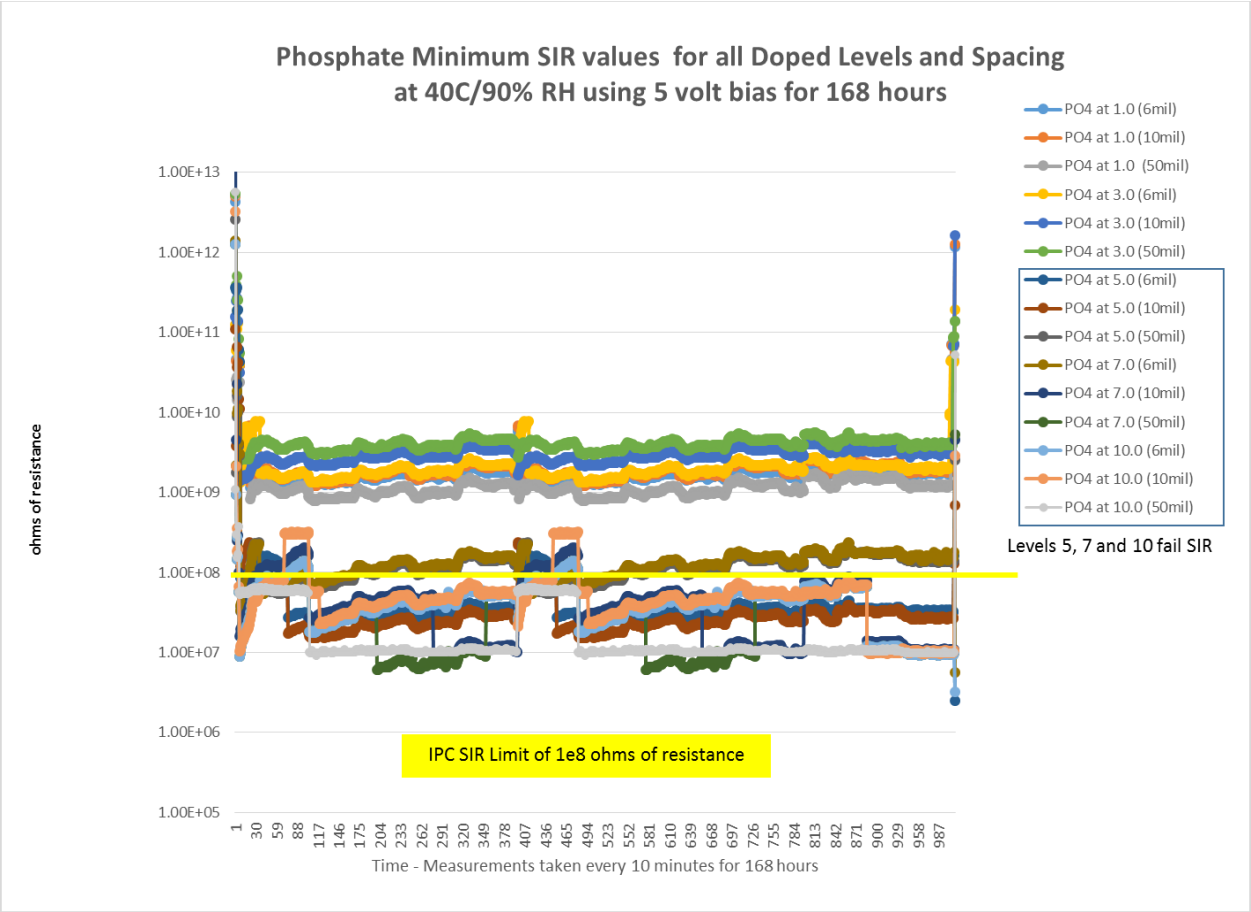
- **Group E -** Formate findings of contamination levels of formate below 7.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

Phosphate Contamination

Table 9 -Phosphate Levels (mean levels of the 5 replicas)

Mean values oG the Testing		Target Value	Phosphate of Prep Electrode	PO_4 after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
H1-6-1 to 5	6	1	0.92	0.85	Clean	180	98	0.55	Passing >1.0e8	1.15E+09
H1-10-1 to 5	10	1	1.01	0.86	Clean	180	112	0.62	Passing >1.0e8	1.21E+09
H1-50-1 to 5	50	1	1.24	0.79	Clean	180	113	0.63	Passing >1.0e8	7.80E+08
H2-6-1 to 5	6	3	3.18	2.68	Clean	170	241	1.43	Passing >1.0e8	1.33E+09
H2-10-1 to 5	10	3	3.21	2.56	Clean	168	247	1.48	Passing >1.0e8	1.42E+09
H2-50-1 to 5	50	3	3.27	2.42	Clean	170	242	1.43	Passing >1.0e8	2.53E+09
H3-6-1 to 5	6	5	5.34	4.47	Dirty	101	250	2.49	Failing <1.0e8	2.48E+06
H3-10-1 to 5	10	5	5.37	4.54	Dirty	88	250	2.83	Failing <1.0e8	1.50E+07
H3-50-1 to 5	50	5	5.39	4.44	Dirty	93	250	2.70	Failing <1.0e8	3.24E+07
H4-6-1 to 5	6	7	7.25	6.49	Dirty	47	250	5.43	Failing <1.0e8	5.56E+06
H4-10-1 to 5	10	7	7.32	6.54	Dirty	51	250	4.98	Failing <1.0e8	8.95E+06
H4-50-1 to 5	50	7	7.36	6.38	Dirty	51	250	5.01	Failing <1.0e8	6.05E+06
H5-6-1 to 5	6	10	11.19	10.29	Dirty	17	250	16.89	Failing <1.0e8	3.22E+06
H5-10-1 to 5	10	10	10.40	9.53	Dirty	14	250	18.36	Failing <1.0e8	9.59E+06
H5-50-1 to 5	50	10	10.53	9.07	Dirty	18	250	14.47	Failing <1.0e8	9.06E+06

Phosphate SIR Performance

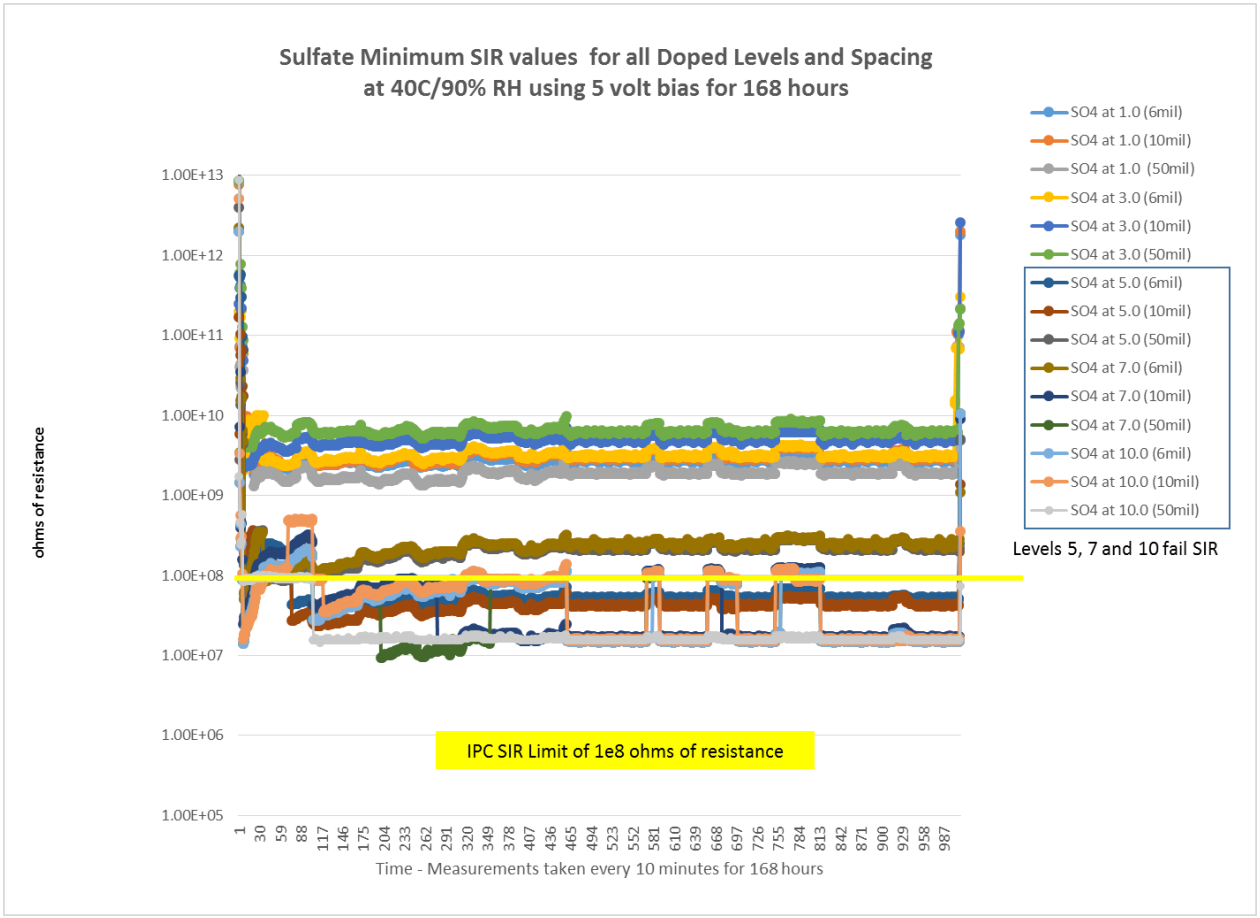


- **Group H -** Phosphate findings of contamination levels of phosphate below 3.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 5.0 up to 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

Sulfate Contamination

Table 10 -Sulfate Levels (mean levels of the 5 replicas)										
Mean values of the Testing		Target Value	Sulfate of Prep Electrode	SO_4 of the Electrode after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
I1-6-1 to 5	6	1	0.93	0.79	Clean	180	127	0.71	Passing >1.0e8	1.81E+09
I1-10-1 to 5	10	1	0.91	0.68	Clean	180	95	0.53	Passing >1.0e8	2.07E+09
I1-50-1 to 5	50	1	0.92	0.76	Clean	180	170	0.96	Passing >1.0e8	1.31E+09
I2-6-1 to 5	6	3	2.70	2.27	Clean	171	229	1.35	Passing >1.0e8	2.10E+09
I2-10-1 to 5	10	3	2.56	2.36	Clean	172	214	1.25	Passing >1.0e8	2.22E+09
I2-50-1 to 5	50	3	2.39	2.66	Clean	172	240	1.40	Passing >1.0e8	3.95E+09
I3-6-1 to 5	6	5	5.16	4.50	Dirty	104	250	2.42	Failing <1.0e8	3.72E+07
I3-10-1 to 5	10	5	5.08	4.35	Dirty	97	250	2.58	Failing <1.0e8	2.35E+07
I3-50-1 to 5	50	5	5.32	4.35	Dirty	102	250	2.47	Failing <1.0e8	5.07E+07
I4-6-1 to 5	6	7	7.30	6.42	Dirty	50	250	5.12	Failing <1.0e8	5.19E+07
I4-10-1 to 5	10	7	7.33	6.40	Dirty	45	250	5.63	Failing <1.0e8	1.40E+07
I4-50-1 to 5	50	7	7.36	6.41	Dirty	58	250	4.34	Failing <1.0e8	9.46E+06
I5-6-1 to 5	6	10	10.33	9.57	Dirty	29	250	8.97	Failing <1.0e8	1.40E+07
I5-10-1 to 5	10	10	10.42	9.46	Dirty	22	250	11.51	Failing <1.0e8	1.50E+07
I5-50-1 to 5	50	10	10.35	9.41	Dirty	19	250	13.23	Failing <1.0e8	1.42E+07

Sulfate SIR Performance



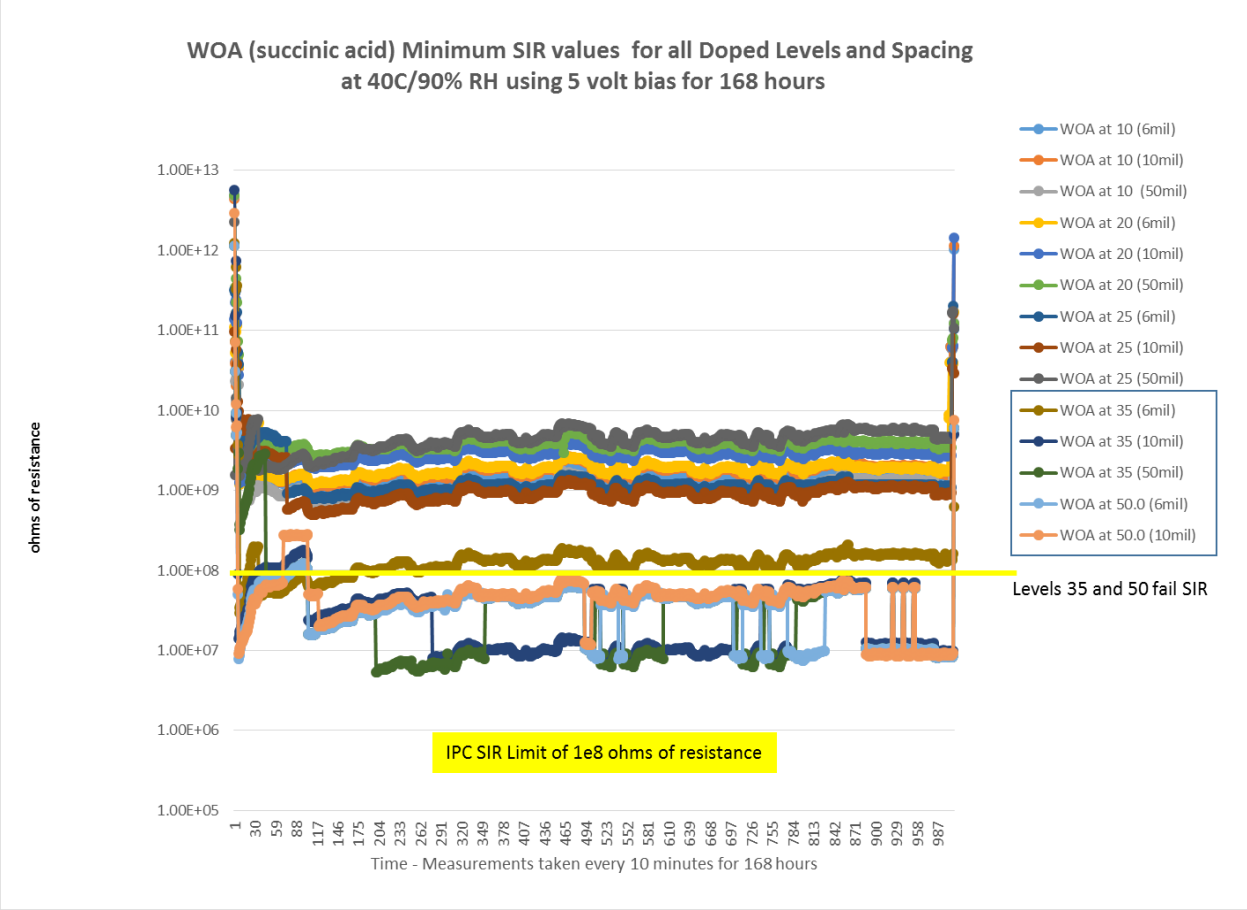
- **Group I -** Sulfate findings of contamination levels of sulfate below 3.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 5.0 up to 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

WOA (Succinic acid)

Table 11 -WOA (Succinic Acid) Levels (mean levels of the 5 replicas)

Mean values oG the Testing		Target Value	WOA of Prep Electrode	WOAof the Electrode after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
J1-6-1 to 5	6	10	10.19	9.57	Clean	180	112	0.62	Passing >1.0e8	1.02E+09
J1-10-1 to 5	10	10	10.43	9.41	Clean	180	103	0.57	Passing >1.0e8	1.07E+09
J1-50-1 to 5	50	10	10.46	9.19	Clean	180	139	0.77	Passing >1.0e8	6.91E+08
J2-6-1 to 5	6	20	20.36	19.15	Clean	144	115	0.81	Passing >1.0e8	1.17E+09
J2-10-1 to 5	10	20	20.33	18.89	Clean	146	250	1.74	Passing >1.0e8	1.26E+09
J2-50-1 to 5	50	20	20.46	18.64	Clean	157	250	1.59	Passing >1.0e8	2.24E+09
J3-6-1 to 5	6	25	26.09	24.33	Clean	136	250	1.72	Passing >1.0e8	7.90E+08
J3-10-1 to 5	10	25	26.04	24.40	Clean	148	250	1.71	Passing >1.0e8	4.99E+08
J3-50-1 to 5	50	25	26.08	24.10	Clean	155	250	1.62	Passing >1.0e8	1.54E+09
J4-6-1 to 5	6	35	35.30	33.64	Dirty	96	250	2.62	Failing <1.0e8	2.94E+07
J4-10-1 to 5	10	35	35.83	33.96	Dirty	74	250	3.44	Failing <1.0e8	7.92E+06
J4-50-1 to 5	50	35	35.91	34.14	Dirty	68	250	3.81	Failing <1.0e8	5.36E+06
J5-6-1 to 5	6	50	50.76	48.38	Dirty	14	250	17.70	Failing <1.0e8	7.40E+06
J5-10-1 to 5	10	50	50.45	47.71	Dirty	15	250	17.18	Failing <1.0e8	8.49E+06
J5-50-1 to 5	50	50	50.40	45.60	Dirty	14	250	18.11	Failing <1.0e8	8.02E+06

WOA SIR Performance

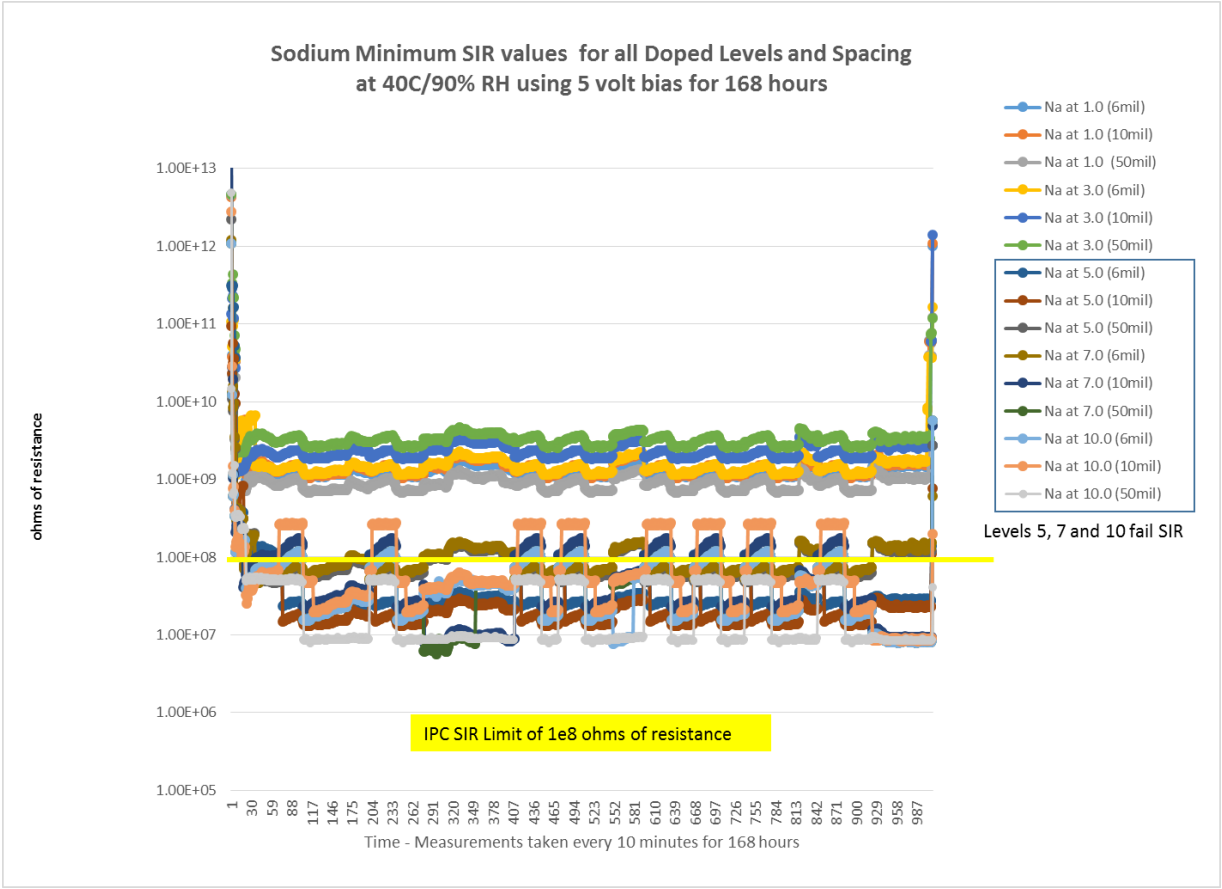


- **Group J -** WOA findings of contamination levels of WOA below 25.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 35.0 up to 50 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

Sodium Contamination

Table 12 -Sodium Levels (mean levels of the 5 replicas)										
Mean values of the Testing		Target Value	Sodium of Prep Electrode	Sodium after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
K1-6-1 to 5	6	1	1.24	1.23	Clean	180	120	0.67	Passing >1.0e8	9.92E+08
K1-10-1 to 5	10	1	1.32	1.20	Clean	180	118	0.65	Passing >1.0e8	1.04E+09
K1-50-1 to 5	50	1	1.33	1.16	Clean	180	150	0.84	Passing >1.0e8	6.70E+08
K2-6-1 to 5	6	3	3.44	3.23	Clean	175	194	1.12	Passing >1.0e8	1.14E+09
K2-10-1 to 5	10	3	3.66	3.34	Clean	178	197	1.11	Passing >1.0e8	1.22E+09
K2-50-1 to 5	50	3	3.48	3.42	Clean	178	208	1.17	Passing >1.0e8	2.17E+09
K3-6-1 to 5	6	5	5.46	5.18	Dirty	99	250	2.53	Failing <1.0e8	2.04E+07
K3-10-1 to 5	10	5	5.49	5.31	Dirty	97	250	2.58	Failing <1.0e8	1.29E+07
K3-50-1 to 5	50	5	5.44	5.27	Dirty	95	250	2.66	Failing <1.0e8	4.60E+07
K4-6-1 to 5	6	7	7.54	7.46	Dirty	53	250	4.74	Failing <1.0e8	4.49E+07
K4-10-1 to 5	10	7	7.58	7.40	Dirty	45	250	5.56	Failing <1.0e8	7.69E+06
K4-50-1 to 5	50	7	7.57	7.30	Dirty	45	250	5.61	Failing <1.0e8	5.57E+06
K5-6-1 to 5	6	10	10.90	10.96	Dirty	20	250	13.46	Failing <1.0e8	7.69E+06
K5-10-1 to 5	10	10	10.69	10.69	Dirty	16	250	15.67	Failing <1.0e8	8.24E+06
K5-50-1 to 5	50	10	10.70	10.57	Dirty	13	250	19.74	Failing <1.0e8	7.78E+06

Sodium SIR Performance



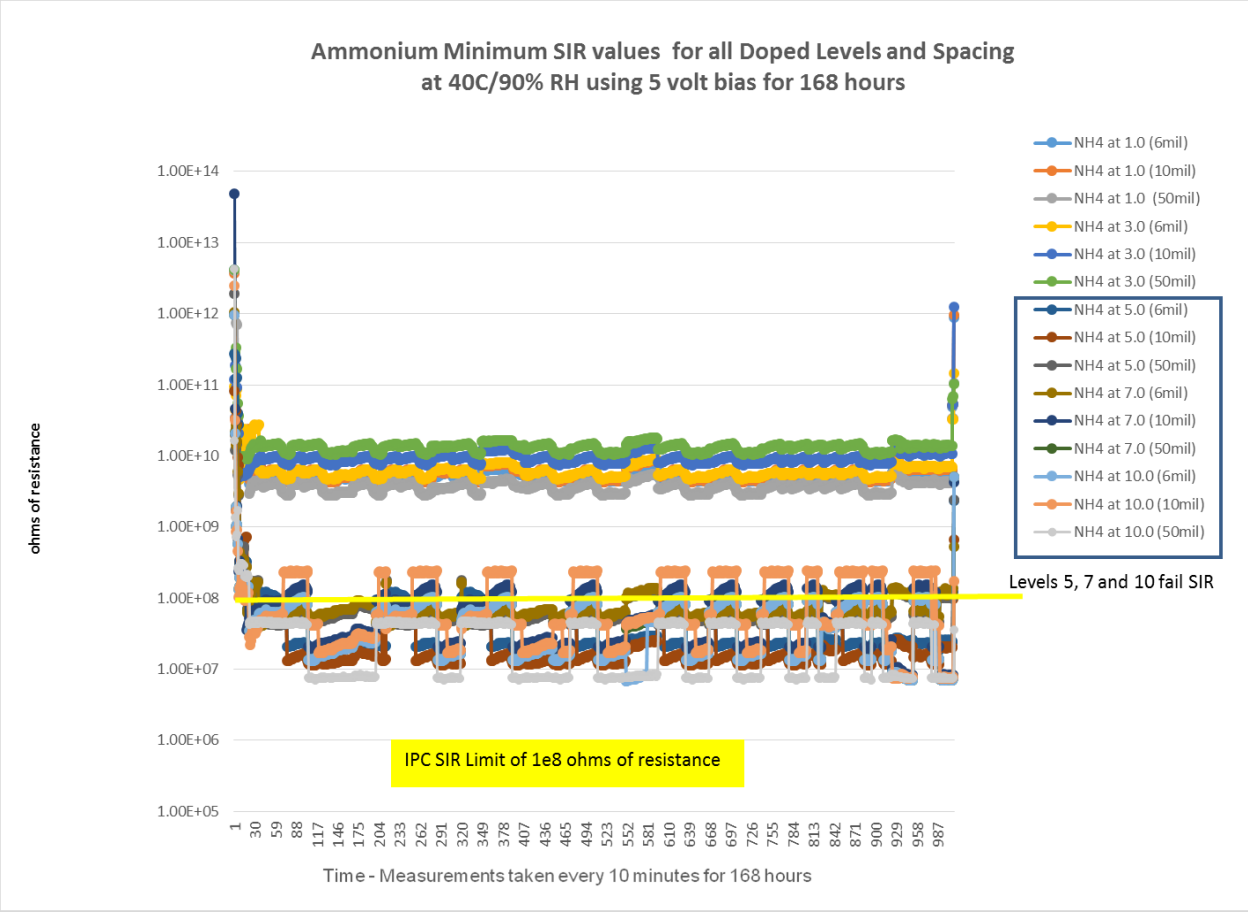
Group K - Sodium findings of contamination levels of sodium below 3.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 5.0 up to 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

Ammonium Contamination

Table 13 -Ammonium Levels (mean levels of the 5 replicas)

Mean values of the Testing		Target Value	Ammonium of Prep Electrode	NH_4 after SIR	Localized Test After SIR		Max Current	Corrosivity Index	SIR at 40C/90%RH with 5 v 168 hrs	
	Spacing (mil)	ug/in2	ug/in2	ug/in2	Results	Time	uA from C3	Current / Time	SIR results	SIR Minimum
L1-6-1 to 5	6	1	0.95	1.17	Clean	180	137	0.76	Passing >1.0e8	4.07E+09
L1-10-1 to 5	10	1	0.98	1.27	Clean	180	118	0.65	Passing >1.0e8	4.27E+09
L1-50-1 to 5	50	1	0.94	1.17	Clean	180	117	0.65	Passing >1.0e8	2.75E+09
L2-6-1 to 5	6	3	2.85	3.24	Clean	174	236	1.36	Passing >1.0e8	4.68E+09
L2-10-1 to 5	10	3	2.74	3.30	Clean	178	198	1.11	Passing >1.0e8	5.02E+09
L2-50-1 to 5	50	3	2.75	3.41	Clean	180	189	1.05	Passing >1.0e8	8.92E+09
L3-6-1 to 5	6	5	4.86	5.47	Dirty	98	250	2.57	Failing <1.0e8	1.79E+07
L3-10-1 to 5	10	5	4.85	5.50	Dirty	95	250	2.64	Failing <1.0e8	1.13E+07
L3-50-1 to 5	50	5	4.84	4.97	Dirty	91	250	2.76	Failing <1.0e8	4.02E+07
L4-6-1 to 5	6	7	6.85	7.42	Dirty	52	250	5.19	Failing <1.0e8	3.93E+07
L4-10-1 to 5	10	7	6.83	7.35	Dirty	55	250	4.59	Failing <1.0e8	7.89E+06
L4-50-1 to 5	50	7	6.80	7.47	Dirty	58	250	4.36	Failing <1.0e8	7.04E+06
L5-6-1 to 5	6	10	9.82	10.38	Dirty	14	250	18.36	Failing <1.0e8	6.72E+06
L5-10-1 to 5	10	10	9.78	10.44	Dirty	15	250	16.77	Failing <1.0e8	7.37E+06
L5-50-1 to 5	50	10	9.81	10.29	Dirty	19	250	13.62	Failing <1.0e8	6.80E+06

Ammonium SIR Performance



- **Group L -** Ammonium findings of contamination levels of sodium below 3.0 µg/in^2 or less have good high SIR values and no signs of electromigration for 6, 10 and 50 mil spacing, while levels of 5.0 up to 10 µg/in^2 show low SIR and the presence of dendrite shorting which is considered failing per the IPC criteria with values less than 1.0e 8 ohms of resistivity or signs of electrochemical migration debris.

Conclusions

- The focus of this research was to determine at what level each ionic contaminant on nominal lead spacing in electronic hardware (IPC Class 2 and Class 3) will cause current leakage and corrosion problems to occur, using the IPC J-STD 001 rev E SIR for a pass fail criteria.
- This limit has a historical value of SIR for passing above 1.0e8 ohms of resistivity during exposure to SIR humidity conditions of 40°C/90%RH; a 5 volt bias; monitoring every ten minutes.
- The below levels of contamination correlate to good passing SIR values for each of the individual ionic species.

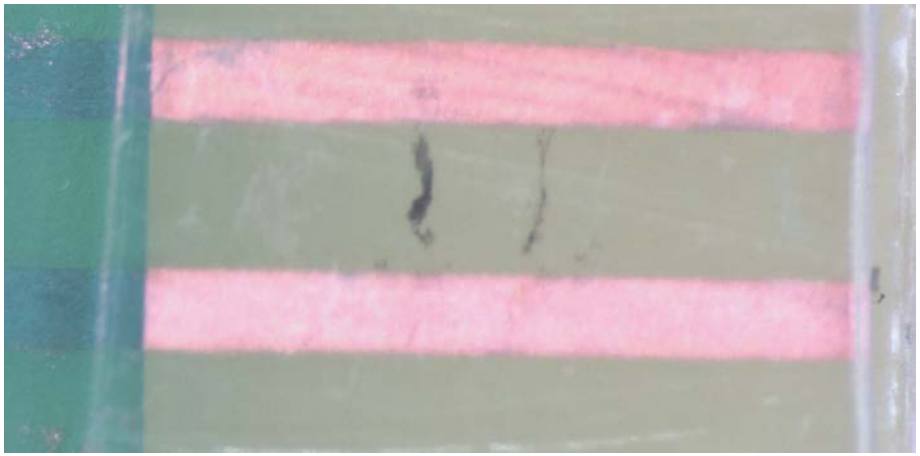


Figure 10- Post SIR Chloride Sample @ 5.0 µg/in^2 Showing Dendrites

Cleanliness Limits

A – Chloride	limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.
B – Bromide	limit on 6, 10 and 50 mil spacing is 7.0 µg/in^2 to ensure good electrical performance.
C – Fluoride	limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.
D – Acetate	limit on 6, 10 and 50 mil spacing is 5.0 µg/in^2 to ensure good electrical performance.
E – Formate	limit on 6, 10 and 50 mil spacing is 7.0 µg/in^2 to ensure good electrical performance.
F – Nitrite	limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.
G – Nitrate	limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.
H – Phosphate	limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.
I – Sulfate	limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.
J – WOA (Succinic Acid)	limit on 6, 10 and 50 mil spacing is 25.0 µg/in^2 to ensure good electrical performance.
K – Sodium	limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.
L – Ammonium	limit on 6, 10 and 50 mil spacing is 3.0 µg/in^2 to ensure good electrical performance.

As noted, the subjected tests showed little difference to spacing of the electrode copper trace spacing during the 168 hours.

The results of these tests show a similar concentration failure threshold for each trace spacing of the three tested. Follow on research is to show combined levels of ionic contamination and effects on sensitive active circuitry, such as battery, clock, RF, and high impedance circuits and SIR at 6 mil spacing.