G14 Element
Qualification Report

Abstract

This report summarizes element qualification test results obtained on TriQuint's G14 (TQHiP) process at FAB 3 in Hillsboro, Oregon. A comprehensive series of testing was performed on wafer in order to verify successful transfer of the process to TriQuint's new facility in Hillsboro.

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Method

It was determined to use three runs from FAB 3, the new facility. As of this writing, all three runs have completed air bake, autoclave and temperature cycle testing. These runs and wafers are given in Table 1. All tests were performed on whole wafers.

Table 1. Test Wafer Designation

Process	*Location*	*Run*	*Mask ID*	*Air Bake Wafer*	*Autoclave Wafer*	*Temperature Cycle Wafer*
G14	FAB 3	15847	4411	97731	97732	97728
G14	FAB 3	15886	4411	98234	98235	98233
G14	FAB 3	15916	4355	98486	98492	98490

Stresses

Air Bake was performed for acceleration of thermally activated failure mechanisms. A temperature of 275ºC was chosen for maximum acceleration. Test points were at 0 hours, 96 hours and 168 hours. *Note*: This test is intended to produce a 20% reduction in channel current of FETs representing approximately 100 years of life at 150ºC.

Autoclave followed JEDEC Standard Number 22, Method A102-B. The purpose of this test was to apply severe conditions of pressure, humidity and temperature that accelerate the penetration of moisture to the wafer. The test condition consisted of 121ºC with a 100% relative humidity at two atmospheres. Test points were at 0 hours, 48 hours and 96 hours.

Temperature Cycle followed JEDEC Standard Number 22, Method A104-A, Condition “G.” The purpose of this test was to determine the wafer resistance to alternating extremes of high and low temperatures in air. The test condition cycled at a low temperature of -40ºC to a high temperature of +125ºC with a ten minute dwell time at each extreme. Test points were at 0 cycles, 250 cycles, 500 cycles.

Table 2 summarizes the stresses performed.

Table 2. Stress Parameters

Test	*Test Condition*	*Test Point 1*	*Test Point 2*	*Test Point 3*
Air Bake	275ºC	0 hrs.	96 hrs.	168 hrs.
Autoclave	121ºC, 100% RH	0 hrs.	48 hrs.	96 hrs.
Temperature Cycle	-40ºC to +125ºC	0 cycles	250 cycles	500 cycles

The following were exceptions to the stresses above:
All wafers stressed in temperature cycle will be continued to 1000 cycles for information purposes only.

Test Structures

Four sets of structures were chosen to be analyzed for the qualification report. Structures from the X19C process control monitor (PCM) were used. Table 3 gives a general description of the structures used.

Table 3. Test Structures	
Structure	*Structure Description*
FETs	0.5um x 300um gate with 1.0um gate to drain/source distance BFET.
Metals	Metal0, Metal1, Air Bridge, Gate and MIM Metal lines. Dimension are W = 4um, L = 250um for all metal lines. Exceptions: W = 5um on Air Bridge and W = 0.6um on Gate.
Resistors	NiCr resistor, 2.0x2.0um long; N- resistor, 3.0x30.0um long; N+ resistor, 3.0x3.0um long.
Via/ Contact Chains	Metal0 to Gate, Metal1 to Air Bridge, Metal0 to Air Bridge, Metal0 to Ohmic, Metal0 to NiCr, Metal1 to Metal0 and MIM Metal to Metal1. Via/contact chains with minimum dimension contacts.

Table 4 lists the electrical tests conducted on each of the structures.

Table 4. Electrical Tests						
Structure	*Electrical Tests*					
FETs	Yield	Threshold Voltage	Drain Current	Gate Current	Transconductance	Breakdown Voltage
Metals	Yield	Sheet Resistance				
Resistors	Yield	Resistance				
Vias/ Contact Chains	Yield	Resistance				

Results

FETs

Most FET parameters remained stable through all three stresses. Mean values of FET parameters during stressing are given in Tables 6-8.

Initial threshold voltages on wafers from Run 15847 were slightly below the guaranteed specifications by no more than 1.88%. Although they were slightly negative, they remained stable throughout all stressing with total percent changes being less than one percent.

Data points were not available at the initial test point for Wafer 98235, Run 15886 due to tester issues. The subsequent test point and final test point showed acceptable stability during autoclave stressing.

Initial test points showed two FET anomalies occurring on all wafers from Run 15847. One site was a processing edge tile issue (site #28) and the other is an unconfirmed processing issue (site #3). Remaining sites continued to be stable throughout all reliability stressing.

One FET anomaly was noted on all wafers from Run 15886. Again, this site was a processing edge tile issue. Remaining sites remained stable during all three stresses.

A summary of the FET anomalies is located in Table 5. A pictorial depiction of the sites tested on wafer is found in Figure 1. Note that the highlighted sites are edge tiles where processing anomalies were noted. X's designate tiles on wafermap that were not used for reliability stressing.

Table 5. FET Anomalies				
Run	*Wafer*	*Stress*	*Test #*	*Site*
15847	97731	Air Bake	1000	3, 28
			1020	3
			1022	3
15847	97732	Autoclave	1000	3, 28
			1020	3
15847	97728	Temp Cycle	1000	3, 28
			1020	3
15886	98234	Air Bake	1000	28
15886	98235	Autoclave	1000	20, 28
15886	98233	Temp Cycle	1000	20, 28

Although some FET parameters had large percentage changes between initial and final test, most values stayed well within guaranteed specification ranges. For example, BFETs had decreases in drain current ranging up to 19%, but values fell well within the 165-305mA/mm guaranteed specification range. Results obtained from testing TriQuint's FETs has shown them to be high in both yield and reliability.

Note: 275ºC air bake is intended to produce a 20% reduction in channel current of FETs representing approximately 100 years of life at 150ºC.

Figure 1. Site Number Designation for Probing

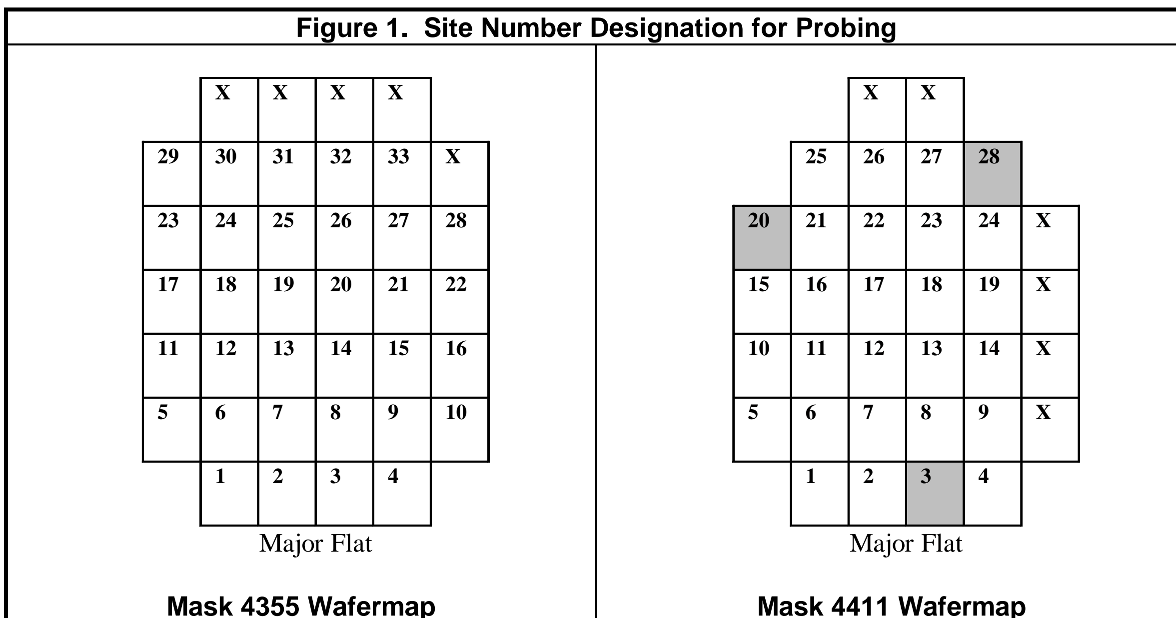


Table 6. Mean FET Parameters for Air Baked Wafers						
Wafer	Test Point	Vth (V)	Id (mA/um)	Gm (mhos)	Ig (A/um)	BVGD (V)
97731	0 hrs.	-2.649	0.288	1.26E-04	1.46E-07	12.639
	96 hrs.	-2.641	0.285	1.18E-04	2.19E-07	11.446
	168 hrs.	-2.627	0.285	1.35E-04	2.64E-07	10.926
	Total Percent Change	-0.84%	-1.12%	6.89%	81.24%	-13.56%
98234	0 hrs.	-2.344	0.254	1.42E-04	1.31E-07	14.063
	96 hrs.	-2.349	0.254	1.41E-04	2.51E-07	12.536
	168 hrs.	-2.337	0.254	1.39E-04	3.15E-07	11.886
	Total Percent Change	-0.32%	-0.04%	-1.47%	141.17%	-15.48%
98486	0 hrs.	-2.350	0.229	1.36E-04	4.66E-08	17.821
	96 hrs.	-2.318	0.193	1.10E-04	6.51E-08	18.594
	168 hrs.	-2.303	0.185	1.16E-04	7.98E-08	18.165
	Total Percent Change	-2.03%	-19.02%	-14.65%	71.38%	1.93%

Table 7. Mean FET Parameters for Autoclaved Wafers						
Wafer	Test Point	Vth (V)	Id (mA/um)	Gm (mhos)	Ig (A/um)	BVGD (V)
97732	0 hrs.	-2.640	0.288	1.22E-04	1.40E-07	12.765
	48 hrs.	-2.640	0.285	1.14E-04	1.62E-07	12.488
	96 hrs.	-2.639	0.296	1.26E-04	1.67E-07	11.930
	Total Percent Change	-0.05%	2.64%	3.33%	19.58%	-6.54%
98235	0 hrs.	N/A	N/A	N/A	N/A	N/A
	48 hrs.	-2.500	0.268	1.27E-04	4.34E-07	10.903
	96 hrs.	-2.506	0.269	1.28E-04	4.86E-07	10.772
	Total Percent Change	-0.22%	0.40%	0.39%	12.03%	-1.20%
98492	0 hrs.	-2.359	0.229	1.33E-04	4.21E-08	17.653
	48 hrs.	-2.348	0.223	1.19E-04	3.33E-08	18.795
	96 hrs.	-2.343	0.227	1.40E-04	4.21E-08	17.299
	Total Percent Change	-0.68%	-0.96%	5.82%	-0.01%	-2.01%

Table 8. Mean FET Parameters for Temperature Cycled Wafers						
Wafer	Test Point	Vth (V)	Id (mA/um)	Gm (mhos)	Ig (A/um)	BVGD (V)
97728	0 cycles	-2.622	0.287	1.24E-04	1.23E-07	12.630
	250 cycles	-2.625	0.285	1.58E-04	1.48E-07	12.324
	500 cycles	-2.625	0.287	1.36E-04	1.54E-07	12.197
	Total Percent Change	0.10%	-0.08%	9.94%	20.08%	-3.43%
98233	0 cycles	-2.480	0.270	1.16E-04	5.38E-07	9.905
	250 cycles	-2.424	0.269	1.16E-04	5.83E-07	9.884
	500 cycles	-2.483	0.270	1.15E-04	5.72E-07	9.850
	Total Percent Change	0.12%	0.05%	-0.51%	6.34%	-0.55%
98490	0 cycles	-2.427	0.233	1.39E-04	4.44E-08	17.617
	250 cycles	-2.412	0.231	1.41E-04	4.65E-08	17.358
	500 cycles	-2.420	0.190	1.15E-04	3.42E-08	19.529
	Total Percent Change	-0.28%	-18.18%	-17.69%	-23.05%	10.86%

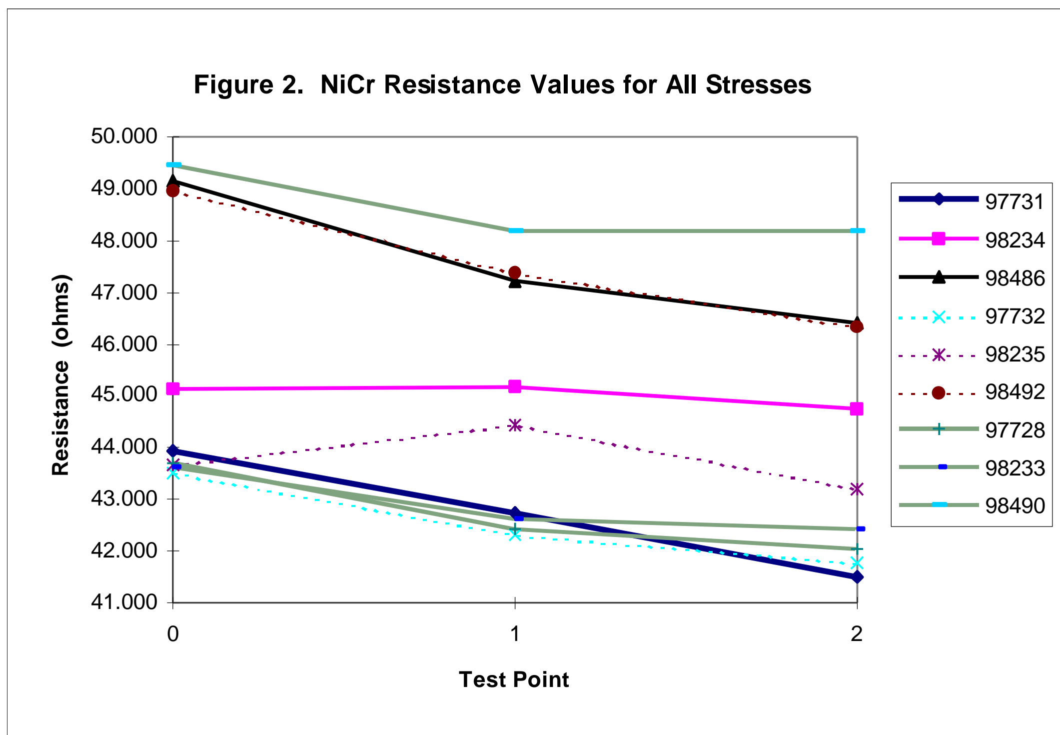
Metals

Gate, MIM Metal and Air Bridge to Metal1 remained stable during all stressing, maintaining 100% yield values. Metal0 averaged 89.53mΩ/sq., Metal1 averaged 11.3mΩ/sq. and Air Bridge averaged 5.94mΩ/sq. for all stresses combined. These fell well within the guaranteed specification ranges of 75-150mΩ/sq., 4-20mΩ/sq. and 1-15mΩ/sq., respectively.

TriQuint's G14 process shows satisfactory yield and reliability for metal lines.

Resistors

Two resistor anomalies were found in run 15847. Again, these occurred at edge tile sites 3 and 28 which are processing issues and do not affect reliability testing [refer to Figure 1]. Figure 2 shows the resistance values for nichrome resistors. Resistance values remained nearly unchanging, ranging between 41.5Ω-49.5Ω throughout all three stresses. The N+ and N- resistors followed a similar trend in stability. TriQuint's G14 process shows robust yield and reliability for resistors.



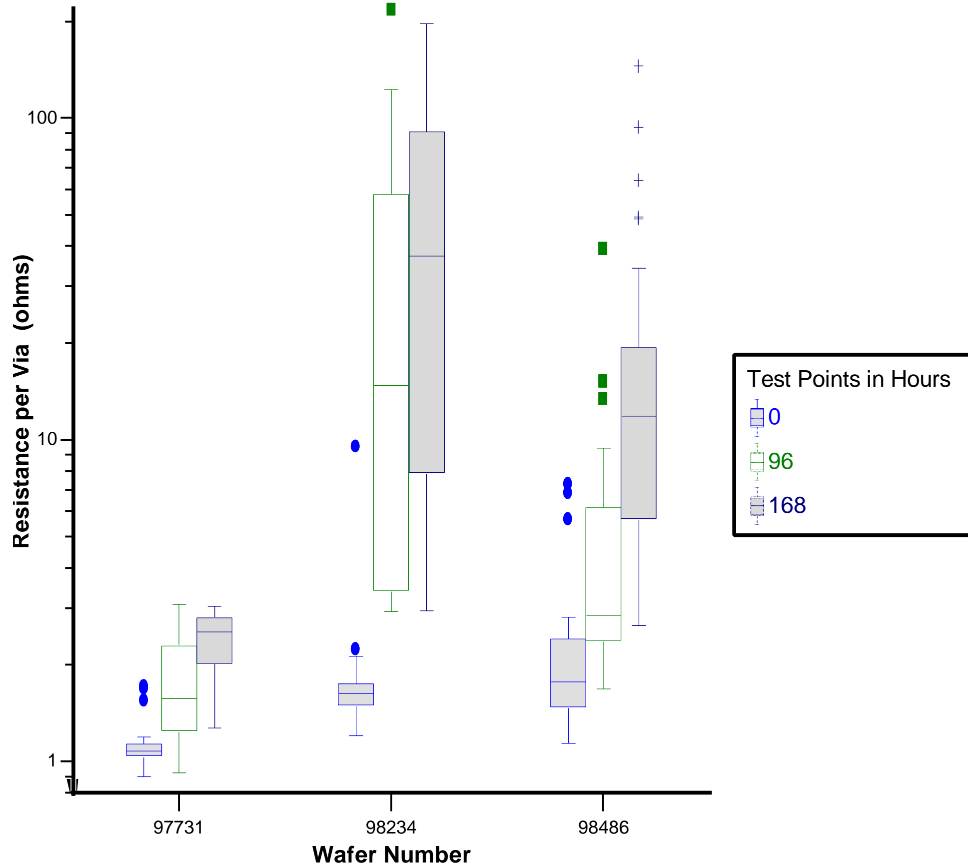
Via/Contact Chains

Overall, via/contact chains showed very little movement in resistance. Mean via/contact chain parameters are shown in Tables 9-11.

For air baked wafers, 5Ω was selected as the failure criteria limit for Metal0 to Ohmic contact chains. Contact chains from Run 15847, Wafer 97731 produced 100% yield on all sites tested, remaining well below 5Ω limit throughout stressing. Figure 3 shows the box plot resistance values from all three runs [see Appendix A for box plot description].

Figure 3. Resistance Values of Metal0 to Ohmic

G14 Air Bake (275ºC)
Metal0 to Ohmic Contact Chain



Initial yield for wafers 98234 and 98486 was 96.4% and 89.3%, respectively. Subsequent stressing in air bake showed a significant increase in resistance per via values. At the final test point, 75% and 57.6% of all sites from wafers 98234 and 98486, respectively, exceeded the 5Ω failure criteria limit.

Table 9. Mean Via/Contact Chain Parameters for Air Baked Wafers

		M0-G	M1-AB	M0-AB	M0-OHM	M0-NiCr	M1-M0	MIM-M1
Wafer	*Test Point*	*Resistance (ohms)*						
97731	0 hrs.	0.184	0.027	0.165	1.126	22.341	0.146	0.297
	96 hrs.	0.188	0.032	0.187	1.781	22.398	0.161	0.317
	168 hrs.	0.189	0.032	0.189	2.389	22.387	0.164	0.320
	Total Percent Change	2.37%	17.93%	14.23%	112.12%	0.20%	12.36%	7.44%
98234	0 hrs.	0.185	0.028	0.175	1.925	22.653	0.154	0.301
	96 hrs.	0.190	0.031	0.190	38.651	22.729	0.166	0.314
	168 hrs.	0.191	0.031	0.191	56.751	22.722	0.167	0.316
	Total Percent Change	2.81%	10.28%	9.23%	2848.53%	0.31%	9.04%	5.04%
98486	0 hrs.	0.197	0.029	0.180	2.249	24.863	0.159	0.299
	96 hrs.	0.200	0.031	0.193	5.650	24.835	0.170	0.310
	168 hrs.	0.201	0.031	0.187	23.568	24.822	0.172	0.312
	Total Percent Change	2.04%	8.14%	3.72%	947.71%	-0.17%	7.94%	4.39%

Table 10. Mean Via/Contact Chain Parameters for Autoclaved Wafers								
		M0-G	M1-AB	M0-AB	M0-OHM	M0-NiCr	M1-M0	MIM-M1
Wafer	*Test Point*	*Resistance (ohms)*						
97732	0 hrs.	0.189	0.026	0.163	1.101	21.976	0.144	0.293
	48 hrs.	0.188	0.029	0.166	1.082	21.976	0.144	0.293
	96 hrs.	0.188	0.093	0.350	1.073	21.979	0.144	0.293
	Total Percent Change	-0.33%	254.05%	114.11%	-2.53%	0.01%	0.11%	0.12%
98235	0 hrs.	0.188	0.029	0.173	2.191	22.183	0.150	0.303
	48 hrs.	0.190	0.032	0.176	1.793	22.446	0.152	0.303
	96 hrs.	0.187	0.031	0.183	1.751	22.447	0.152	0.302
	Total Percent Change	-0.70%	4.58%	5.29%	-20.10%	1.19%	1.19%	-0.30%
98492	0 hrs.	0.197	0.029	0.180	2.180	24.776	0.161	0.300
	48 hrs.	0.198	0.033	0.179	2.154	24.864	0.161	0.301
	96 hrs.	0.197	0.051	0.243	2.083	24.781	0.161	0.303
	Total Percent Change	-0.01%	76.40%	35.06%	-4.42%	0.02%	0.16%	0.88%

Table 11. Mean Via/Contact Chain Parameters for Temperature Cycled Wafers								
		M0-G	M1-AB	M0-AB	M0-OHM	M0-NiCr	M1-M0	MIM-M1
Wafer	*Test Point*	*Resistance (ohms)*						
97728	0 cycles	0.187	0.024	0.164	0.996	22.201	0.143	0.293
	250 cycles	0.187	0.024	0.164	0.975	22.205	0.143	0.293
	500 cycles	0.187	0.025	0.164	0.967	22.206	0.143	0.293
	Total Percent Change	0.09%	1.03%	0.08%	-2.83%	0.02%	0.15%	-0.04%
98233	0 cycles	0.195	0.029	0.177	1.476	21.913	0.154	0.305
	250 cycles	0.194	0.029	0.177	1.359	21.917	0.154	0.305
	500 cycles	0.193	0.029	0.177	1.328	21.920	0.154	0.305
	Total Percent Change	-0.55%	-0.15%	-0.03%	-10.06%	0.03%	-0.09%	-0.18%
98490	0 cycles	0.197	0.029	0.180	2.069	25.107	0.160	0.298
	250 cycles	0.197	0.029	0.179	1.961	25.113	0.160	0.298
	500 cycles	0.194	0.029	0.179	2.181	25.176	0.160	0.296
	Total Percent Change	-1.18%	-1.76%	-0.38%	5.41%	0.27%	-0.11%	-0.72%

Summary

Overall, TriQuint's G14 process produces exceptional yield and reliability for all wafers before and after stressing. Most parameters stayed well within the guaranteed specification ranges for the approximate 600 parameters tested during all reliability testing.

The Metal0 to Ohmic contact chain issue has now been addressed. Failure analysis was completed by process engineering to address the increase in resistance on Metal0 to Ohmic contact chains. Contact resistance was degraded as a result of the Ohmic contact being attacked and partially dissolved during processing. The degradation appeared to be caused by the following sequence of events:

1. Following Ohmic lift-off in water, the Ohmic metal pulled away from the neighboring dielectric when it was alloyed. A gap was then open between the Ohmic metal and the dielectric.
2. Gate PSN did not fully passivate the edge of the Ohmic due to this gap. A crack remained to allow fluid penetration to the Ohmic metal.
3. During the dump rinse/spin rinse dry (DR/SRD) prior to MIM PSN deposition, the Ohmic metal is exposed to the rinse water with a large gold contact (Metal0) exposed to the water as well. The result was an electrochemical reaction that attacked the Ohmic metal and increased the contact resistance.

These factors explain why Metal0 connected Ohmic pads were degraded. A change in the process to improve contact resistance was implemented in late June of 1998. The MIM DR/SRD

was removed from the process. There was an immediate improvement in Metal0 to Ohmic contact chain resistance. Figure 10. shows the distribution histogram of Metal0 to Ohmic contact chains prior to the removal of the MIM DR/SRD process step. The mean resistance value was 1.325Ω. The subsequent graph, Figure 11., shows the distribution histogram of Metal0 to Ohmic contact chains after the removal of the MIM DR/SRD process step. The mean resistance value was 1.135Ω, a significant improvement with decrease of fourteen percent in contact resistance.

Figure 4.

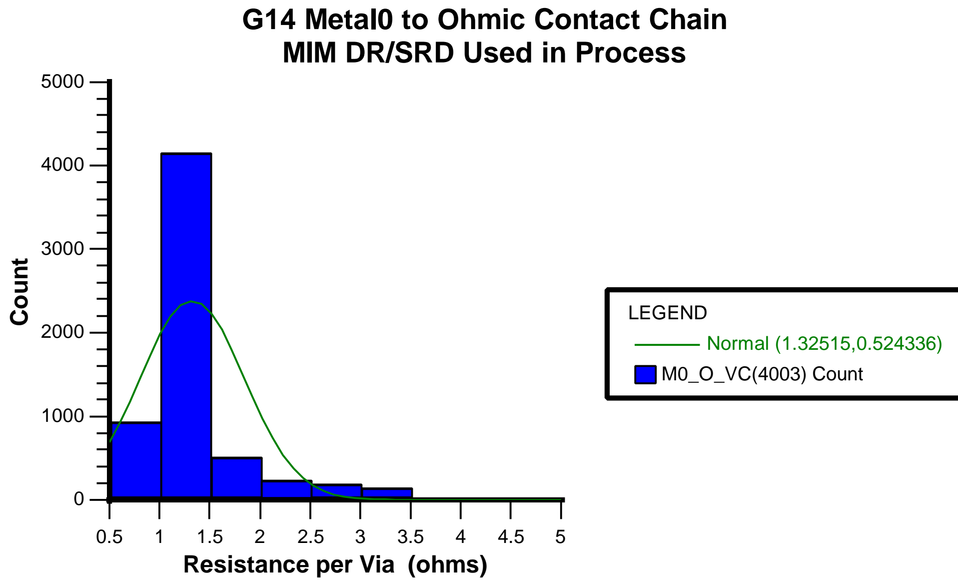
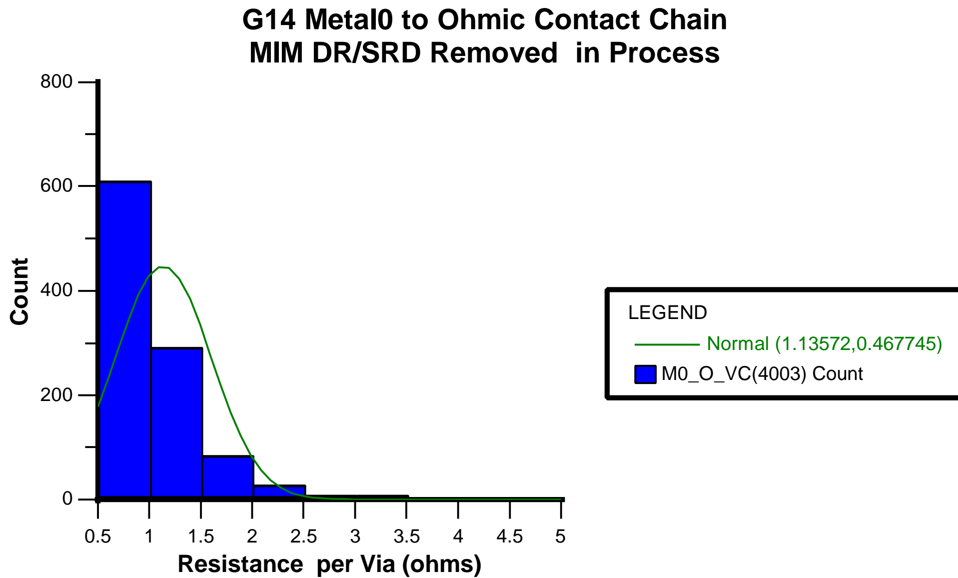


Figure 5.



APPENDIX A

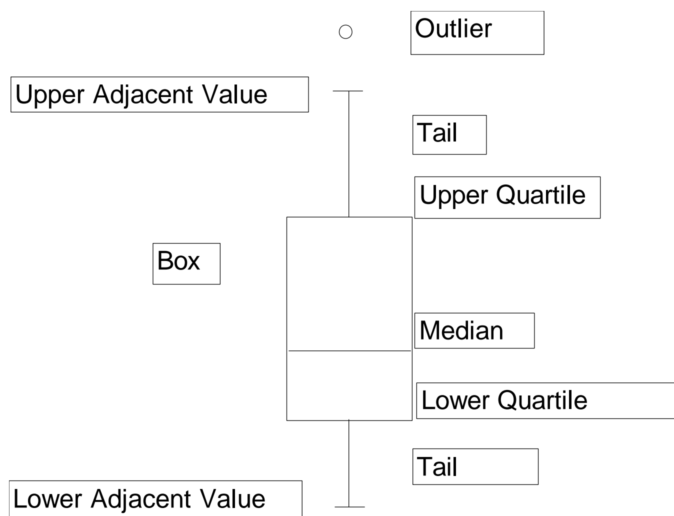
Box plots

A box plot is a summary graph that represents the distribution of data for a continuous dependent variable in relation to a discrete independent variable. A box plot that summarizes the distribution of the continuous variable is plotted for each unique value of the discrete variable. The box plot displays five measurements of the data:

• Maximum and minimum adjacent range
• Upper and lower quartiles
• Median

Reading a box plot

A box plot is made up of a two tails, a box, and a median bar:



These components summarize five data values:

• The line through the box marks the data's median.
• The upper edge of the box defines the upper quartile of the data.
• The lower edge of the box marks the lower quartile.
• The upper tail reaches to the upper adjacent value.
• The lower tail reaches to the lower adjacent value.

The upper adjacent value is the largest observation that is less than or equal to the upper quartile plus 1.5 x IQR. The lower adjacent value is defined as the smallest observation that is greater than or equal to the lower quartile minus 1.5 x IQR.
The box encloses the interquartile range (IQR). The IQR defines the range of the half of the data that clusters around the middle of the data.
Any outliers are plotted as data markers beyond the ends of the tail. An outlier is a data point that falls above the upper adjacent value or below the lower adjacent value.