ACHIEVING MEMS OPTIMUM TEST RELIABILITY PERFORMANCE DRIVEN BY MOLD COMPOUND ELECTRICAL CONDUCTIVITY AS KEY IN ELIMINATING 3 TEST STEPS

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ABSTRACT

Moisture diffusion is one of the reliability concern specially for some Microelectromechanical Sensor, MEMS, devices which shows abnormal humidity sensitivity. The electrical behavior is not inline with some datasheet parameters after a thermal humidity stress (THS), 850 C /85%RH. To reduce exposure reaching customer, THS is introduce in the IC assembly and test flow to screen out this marginality. In assembly manufacturing moisture is closely linked to molding compound.

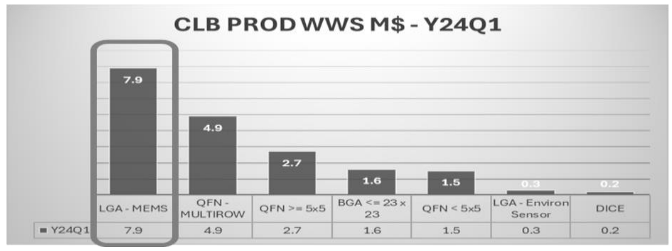
This paper will provide evidence in a high volume assembly manufacturing environment the previous study created about the electrochemical phenomenon in mold compound. By proper compound selection and evaluation of key molding chemical properties specifically electrical conductivity, we were able to identify a compound that yielded zero ppm for Gyro offset, Axl offset while comparable leakage of 200ppm test result after 24 hrs THS with passing reliability. This paved the way for the removal of THS, dry bake and cool down steps in the test flow for specific MEMS device using this mold compound and is planned to be the compound for future MEMS devices in ST Microelectronics Calamba.

1. 0 INTRODUCTION

ST Calamba is the operational leader in terms of assembly manufacturing and test for MEMS product. We are also supporting MEMS 2023 priorities to grow faster than the market leveraging new product portfolio with sensors Gen3 deployment.

1.1 Product stratification

MEMS in Calamba is the top production WWS in Q1'24 at 7.9M$. Amongst the MEMS devices MV9F is the highest volume at 22% of the total MEMS loading



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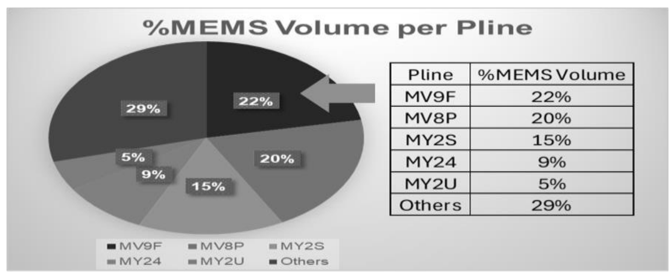
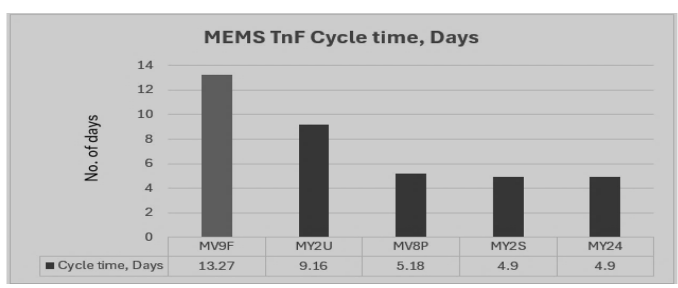


(b)

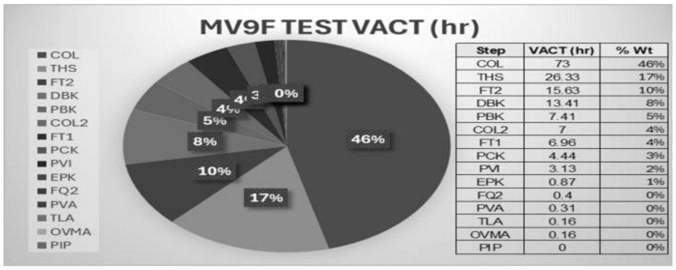
Fig. 1 (a) Calamba production world wide standard revenue in Q1'24 (b) MEMS volume distribution per product

1.1.1 MEMS Test stratification

MV9F is the highest test cycle time at 13.27 days. THS is the 2nd top VACT for MV9F at 26.33hrs or 17% of the total test VACT



(a)

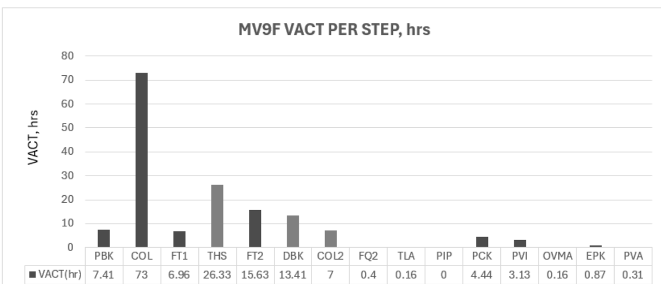


Step	VACT (hr)	% Wt
COL	73	46%
THS	26.33	17%
FT2	15.63	10%
DBK	13.41	8%
PBK	7.41	5%
COL2	7	4%
FT1	6.96	4%
PCK	4.44	3%
PVI	3.13	2%
EPK	0.87	1%
FQ2	0.4	0%
PVA	0.31	0%
TLA	0.16	0%
OVMA	0.16	0%
PIP	0	0%

(b)

Fig. 2 (a) MEMS Test & Finish(TnF) cycle time per product, (b) MV9F test CT per work step

THS is the 2nd top VACT in the MV9F test flow and removing it together with subsequent steps dry bake and cool down which sum up to 46hrs of the total 159hrs or 29% contribution to VACT



	PBK	COL	FT1	THS	FT2	DBK	COL2	FQ2	TLA	PIP	PCK	PVI	OVMA	EPK	PVA
VACT(hr)	7.41	73	6.96	26.33	15.63	13.41	7	0.4	0.16	0	4.44	3.13	0.16	0.87	0.31

Fig. 3 MV9F value added cycle time, VACT per step

1.1.1 MEMS THS at test flow

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Moisture diffusion is one of the reliability concern specially for some MEMS devices which shows abnormal humidity sensitivity. The electrical behavior is not inline with some datasheet parameters after a thermal humidity stress (THS), 85^0 C /85%RH. To reduce exposure reaching customer, THS is introduce in the IC assembly and test flow to screen out this marginality.

Molding compound is the top in mind when we talk about moisture in a IC packaging. One of the distinct advantage of mold compound is lower cost and light weight as compared to hermetic packaging. However one of the drawbacks is its moisture absorption after humidity exposure. Moisture diffusion is one of the top reliability concern for MEMS products.

The objective of this paper is to characterize different mold compound having different properties that can possibly influence MEMS test reliability performance and if successful can be an opportunity to remove THS and subsequent steps dry bake and cool down to improve test cycle time.

2. 0 REVIEW OF RELATED WORK

[1] The samples have been selected among a population of devices showing a specific sensitivity to the moisture. The investigation has then been addressed according to the failure mode. A small portion of the resin compound between MEMS and ASIC has been removed by laser ablation to cut the wires and allow a direct signal probing.

An electrical test has been executed after the resin removal and
before to interrupt the devices connections, in order to compare
the results. The cut area selection introduces a minimum package modification without significant effects on the measurement results as shown in Fig. 1. The probes shall be placed on the device side more affected by the humidity sensitivity. MEMS pads are identified as point of failure through experimental measurements, after few selective resin removal steps. On the contrary ASIC pads are not affected by the humidity sensitivity.

The equipment setup has been prepared to run the measurements on the MEMS side and to extract the parameters
of the following simple R-C-R equivalent circuit.

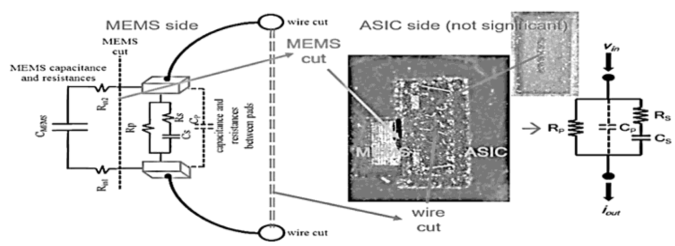


Fig 4. DC-AC electrical analysis

An approach oriented to the real phenomenon is necessary. After the moisture absorption, physical and chemical effects on the material must be considered.

The commercial epoxy compound lists a percentage of ions, as Na+ and Cl-, that are immersed in the dielectric after the resin
become wet., the physical-electrical system of the resin between each couple of MEMS pads may be considered as an electrolytic solution activated by water and free ions.

Two samples of epoxy bare material were placed between two copper plates acting as electrodes. One sample was maintained in boiling water for 9 hours. Another sample was maintained in a boiling water solution with sodium chloride (45g/l) for 9 hours in order to accelerate the phenomenon.

The bare sample submitted to a pure water contamination does
not change its intrinsic high resistance characteristic (red profile). The bare sample immersed in the enhanced electrolytic solution behaves like the failed devices previously investigated (green). The sampled devices show local irregularities that behave like an ions enriched solution.

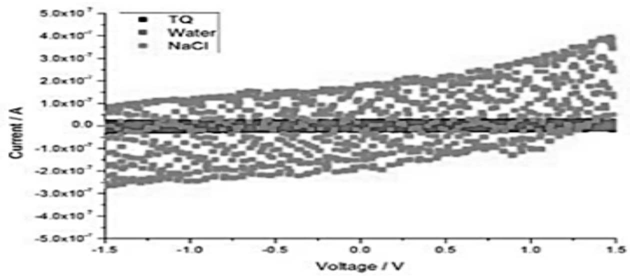


Fig. 5 Bulk experiment graphical result

According to the above presented experiments it looks like the resin material may locally exhibit electrical characteristics similar to those presented by an electrochemical solution. The electrochemical phenomena showing hysteresis loops diagrams are consistent with the so called "double layer capacitance effect".

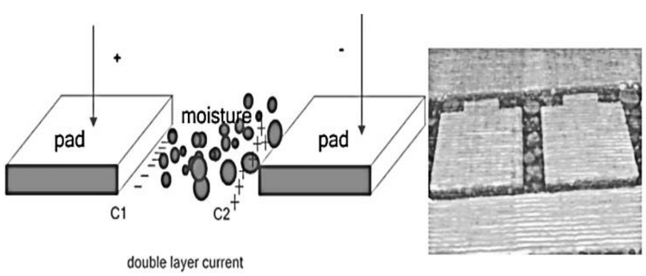


Fig.6 Double layer capacitance effect

J. E. B. Randles (Faraday Society, 1947) introduced an equivalent circuit to model the described phenomena.

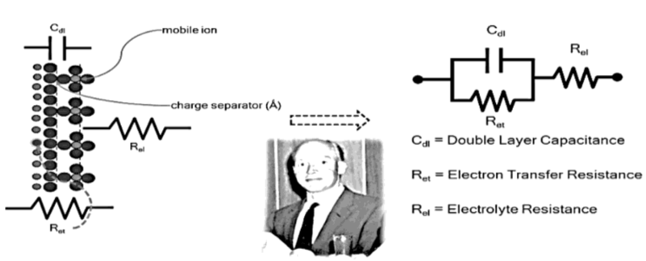


Fig.7 Randle circuit model

The capacitance double layer (CDL) can be evaluated by calculating the area subtended by the curves as reported in the figure, for a sample.

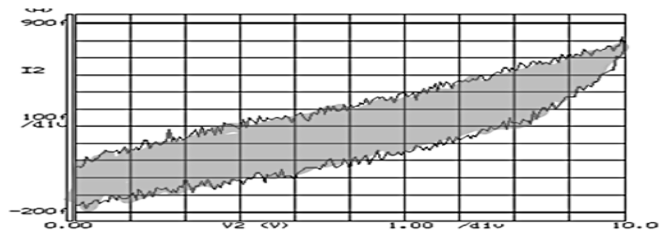


Fig.8 Capacitance Double layer curve

3.0 METHODOLOGY

3.1 Materials

A pre-selection of granular molding compound was created to compare current mold compound, compound A supplier A to other compound types (B,C,D,E) from supplier B by comparing first their chemical properties specifically electrical conductivity, EC, pH and concentration ppm of Na+, Cl- and Br-. Chemical properties of the mold compound is measured via water extraction under PCT, with condition of 1210C for 20hrs under test method EMC-TM-0009-1

Chemical Properties water extraction properties(PCT: 1210C x 20hrs)					
	Compound A Supplier A	Compound B Supplier B	Compound C Supplier B	Compound D Supplier B	Compound E Supplier B
EC, micro.s/cm	48.5	30	30	83	104
pH	6.1	5.0	5.7	6.9	7.2
Concentration, ppm Na^+	0.49	0.9	0.6	1.0	0.8
Concentration, ppm Cl^-	9.5	9	12	2	1
Concentration, ppm Br^-	0.4	0	0	0	0

Table 1 Molding compound chemical property comparison

Pre-Assessment trial below aims to compare current compound to the pre-selected compound after IV curve resin degradation study which will undergo 24hrs THS with traceability as below. Results between the two compound will be compared on the critical test parameters Axl offset, gyro offset and leakage using specified FAR limits

Trial	ASIC	MEMS	Note
T3S2237IB0316	VB79CAG (R8) G217640 wf22	GA08AD2 1204ZBN wf6	Compound A Supplier A Trial tested in Castelletto in December 2022
T3S2239IB0333	VB79CAG (R8) G217640 wf10,11	GA08AD2 1204ZBN	Compound B Supplier B Trial tested in Castelletto in December 2022

Table 2 THS trial traceability

Finally 2 split trial at168h preconditioning with 5x reflow and THS will be performed on the selected compound using QC and long term limits set with traceability as below

Trial	Lot	ASIC	MEMS	Note
T2S2251IB0442	783041BGZZ_1	VB79C8P	GA08AD2	Compound B Supplier B

Table 3 Reliability Trial traceability

3.2 Procedure

A study of the IV curve of degraded samples from the pre-selected mold compound material in a laboratory will determine which among the compound will proceed with THS 24hrs and Reliability qualification.

For the THS based Pre-Assessment below FAR limits will be applied for both trials

Test Name	Gyro Offset X, Y ,Z [dps]	Gyro Sensitivity X, Y, Z [gain]	Axl Offset X, Y, Z [mg]	Axl Sensitivity X, Y, Z [gain]	Axl Self Test Positive	Axl Self Tes Negative
Lower_Limit	-10	NA (0.75% @part level)	-80	NA (-2% @part level)	50	-1700
Higher_Limit	10	NA (0.75% @ part level)	80	NA (2% @part level)	1700	-50

Table 4 Applied test limits for THS

For the reliability at168h below are the QC and long term limits that will be applied.

Test Name	Gyro Offset X, Y ,Z [dps]	Gyro Sensitivity X, Y, Z [gain]	Axl Offset X, Y, Z [mg]	Axl Sensitivity X, Y, Z [gain]	Axl Self Test Positive	Axl Self T Negativ
Lower_Limit	-15	NA	-120	NA	50	-1700
Higher_Limit	+15	NA	120	NA	1700	-50

Table 5 Applied QC test limits for reliability

4.0 RESULTS AND DISCUSSION

Based from the I-V curves on degraded resins done in a laboratory at Politecnico Milano, the trial samples from different compound types submitted to a pure water contamination and enhance electrolytic solution shows local irregularities that indeed behave like an ion enriched solution. Experimental result shows that different compound types exhibit different electrical characteristics similar to those presented by an electrochemical solution. Amongst the compound types tested compound B supplier B has minimal residual signifying its intrinsic high resistance characteristic. It was identified in the study that electrical conductivity, EC is the significant characteristic for the selection wherein lower value is desired. Current compound type with EC of 48.5 while compound B Supplier B is 30. Understandably, mold compound should act as an insulator and minimize the flow of current in the package thereby not affecting the electrical or parametric performance of the MEMS device specially in a high temperature moisture environment. [4] This is because it has been shown that the presence of water at the filler/epoxy interfacial areas affects the low-frequency dielectric response of the materials and significantly increases their electrical conductivity, especially at higher temperatures. On the other hand, lower pH is indicative of a more acidity in the water extraction was found to also have a significant positive effect on the electrical performance. In terms of compound impurities, higher ppm concentration of Na+ and lower ppm concentration for Cl- and Br is desired.

It is proposed to proceed large scale validation of compound B from supplier B as compared to other compound types and to current compound.

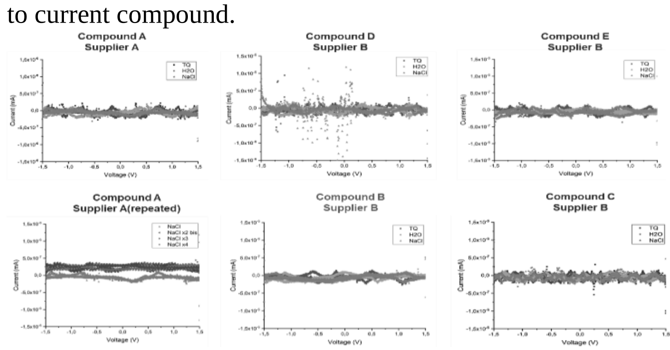


Fig.9 I-V curves on degraded resins

I-V curve analysis is a good methodology to analyze behavior of different compound types subject to moisture environment. It also aid in selection of compound type that can proceed to further qualification and reliability trial.

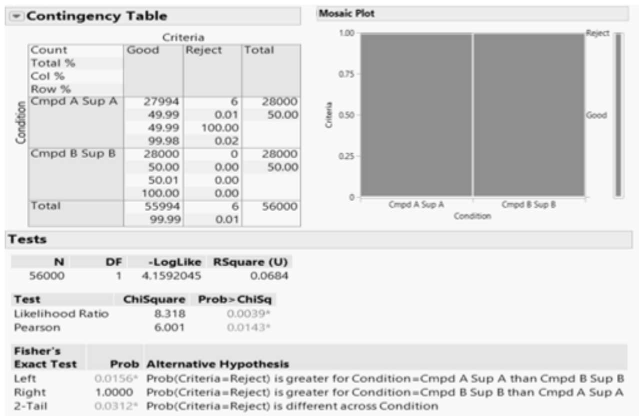
Based from the 24hrs pre-assessment, compound B supplier B resulted to a zero Axl and gyro offset while maintaining the same ppm level for leakage as compared with current compound.

		Compound A Supplier A	Compound B Supplier B
FT2 (24hrs THS)	Axl Offset	600ppm	0 ppm
	Gyro Offset	200ppm	0 ppm
	Leakage	200ppm	200ppm

Table 6 FT2 after 24hrs result

Results was also subject to 2 proportion test to test to prove if compound being compared have statistical significant difference with respect to Axl and Gyro offset.

At 95% confidence level, with a P value of 0.0156 there is a significant difference between Axl offset rejection between compound A supplier A and compound B supplier B favoring compound B supplier b. While for Gyro offset, at 95% confidence level with a P value of <0.0001 there is a significant difference between said compounds also favoring compound b supplier b as shown below.



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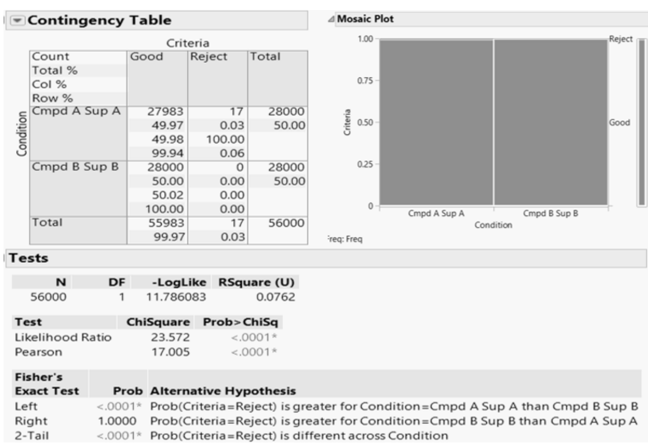

(b)

Figure 10. Two proportion test (a) Axl offset (b) Gyro offset

While based from the reliability at168h preconditioning with 5x reflow and THS both are passing. One part failed for X_LEAK_ST1[400 mg]. Submitted to BAKE this part recovered as Bin1.

Test	Trial: T3S2251IB0442 Lot:783041BGZZ_1
PREC with 5x Reflow	2000/2000 PASS
PREC + THS	168h: 1996 /1997 PASS *1x Leakage* *MEMS – ASIC*

Table 7 Reliability result of new compound

Based from the result, compound B supplier B is robust in terms of electrical performance subject to moisture via THS 24 hrs. This can be attributed to its combined characteristic of electrochemical, EC, pH and compound impurities compared to other compound types. Further reliability stress shows consistency of the results in favor of compound B supplier B.

The result lead to the reduction of MV9F Test and Finish VACT from 159.2 hours to 112.47 hours by eliminating THS, DBK and COL2

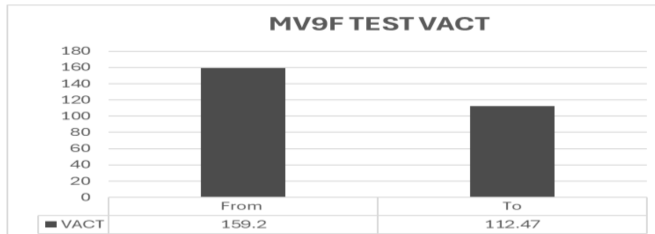

Fig. 10 Comparison of tect cycle time before and after THS,dry bake and cool for MV9F

In terms of UC impact, this THS step is not critical step but once THS is removed, 2nd dry bake step will also be removed which is a critical step. Impact in UC of removing 2nd dry bake is ~ 0.11 cts/unit. Cum savings at ~92k$ in 10mons for Calamba Removal of THS and subsequent steps was also proliferated to subcon assembly of the same device. Energy savings was also not yet included in this computation.

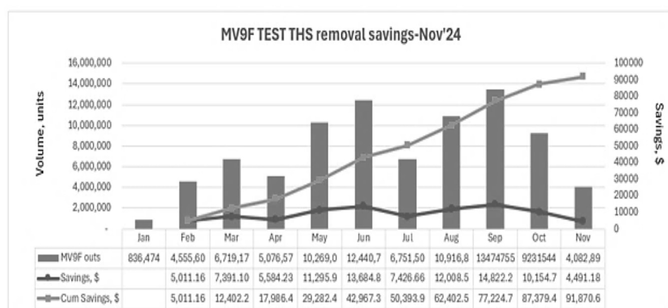

Figure 11. MV9F test THS removal cost savings

With this favorable result on the 1st product implementation of compound B, supplier B all new product qualification of MEMS is now using this compound and same test reliability performance are being assess to warrant no THS at test in the flow.

5.0 CONCLUSION

We conclude that electrical conductivity parameter (EC) is key factor for better performances wherein lower the EC, better the resin behavior in humid environment. Better material has relatively higher Na+ ionic content.

This chemical compound properties of the mold compound is key in eliminating Axl and Gyro offset ppm while maintaining the same leakage ppm as compared to current mold compound.

6.0 RECOMMENDATIONS

It is recommended to fanout the new compound having a lower electrical conductivity with typical value of 30 and a pH that is more leaning towards acidic with typical value of 5.0 for future generation of moisture sensitive MEMS product to improve reliability performance.

It is also beneficial with the favorable result to remove THS process at test if device uses the same compound proposed in this experiment. This new compound needs to be further optimized in the aspect of manufacturability at mold process.

7.0 ACKNOWLEDGMENT

I bring back all the glory and honor first and foremost to GOD who gave as the strength and knowledge to make this possible.
My respective families who serve as our inspiration to persevere in work. I also would like to acknowledge Aliou Lo our GM and my mentor, Joseph Tuazon, for their guidance and support. To my supportive staff in process engineering, MEMS Division counterpart and mold compound suppliers.

8.0 REFERENCES

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9.0 ABOUT THE AUTHORS

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10.0 APPENDIX