RELIABILITY ANALYSIS OF COTS WITH AS-DELIVERED DELAMINATIONS UNDER THERMAL SHOCK TO FUNCTIONAL FAILURE

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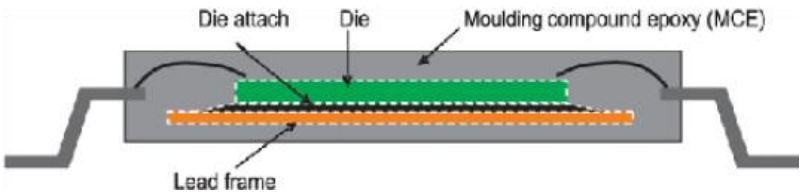
AGENDA

1. Scope
2. Setup
3. Results
   1. CSAM
   2. Electrical
4. Failure Analysis
5. Summary

SCOPE

Delamination

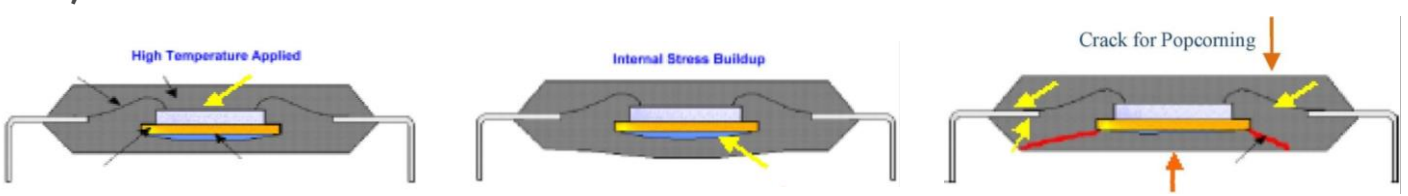
» **Delamination** is one of the most common failure mechanism in PEMs (Plastic Encapsulated Microcircuits)



» Where: may occur at interfaces between moulding, leadframe, die, die paddle, die attach material, etc.

» When: can occur during manufacturing, assembly and use

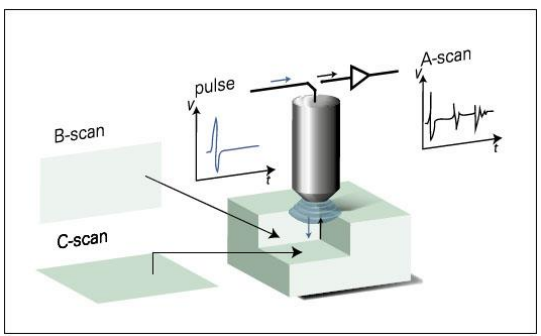
» Consequences: wire bonding degradation, bond lifting, cracking of the silicon, current leakages, corrosion, "popcornig" effect, etc.

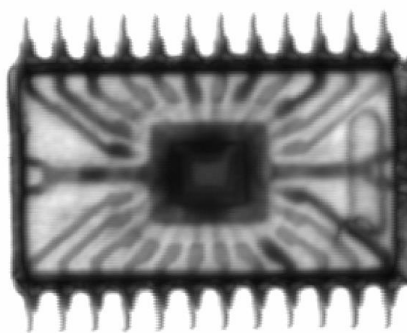


SCOPE

C-SAM

- **Scanning Acoustic Microscopy** is a non-destructive imaging analysis technique capable of providing high contrast images of void features inside plastic encapsulated devices using sound
- Called C-SAM because they most widely used scanning technique is C-scan (see different modes below – courtesy of PVA)
- TESAT's SAM equipment, from PVA TePla, has a movable through scan receiver that can be focused, which allows fast overview of voids and delaminations and very sharp images (see stadard image below)





- ECSS-Q-ST-60-13C requires C-SAM during evaluation and Lot acceptance test, test method according to JEDEC J-STD-020 (Moisture/Reflow sensitivity classification for non-hermetic solid state surface mount devices)

> This standard may be used to determine what classification level should be used for non-hermetic SMD qualification. Passing the criteria in this test method is not sufficient by itself to provide assurance of long-term reliability. The Moisture Sensitivity Levels (MSLs) rating generated for an SMD by this document is

- **How to justify the use of parts with delamination?**

SCOPE

Project

This study is founded by ESA in the frame of OSIP (Open Space Innovation Platform campaign) call on COTS for Space: New ideas for use of Commercial Off the Shelf Components

ESA Contract No. **4000136430/21/NL/GLC/ov**

Initial goals:

1. Provide a comprehensive overview of the state of research
2. Investigate the reliability impact of plastic encapsulated parts with delamination at delivery
3. Find a quantitative correlation between the occurrence of delamination at delivery and electronic parameters drift up to failure
4. Investigate the criticality of delamination occurring
   - in different locations within the component
   - in different plastic packages geometries

SCOPE

Project

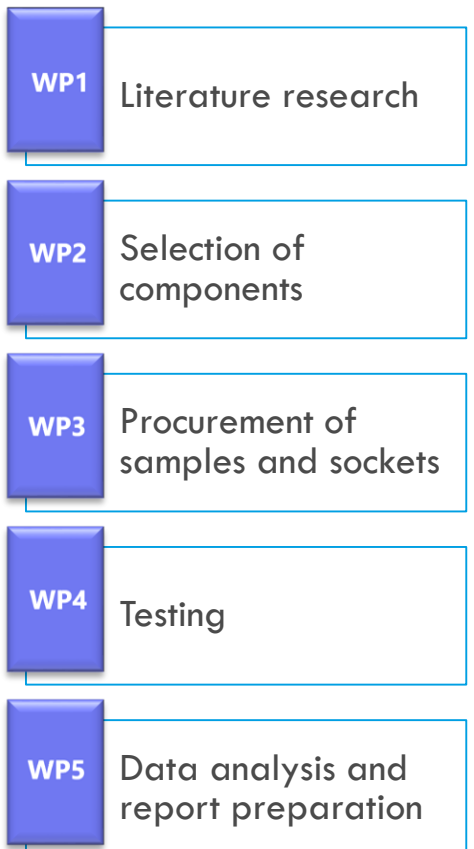
Project organized in 5 work packages

» Contractor: AIRBUS (FR)

» Subcontractor: TESAT Spacecom GMBH & CO.KG (DE)

AIRBUS

TESAT



SETUP

Parts

Selected parts show rejectable initial delaminations (as delivered)

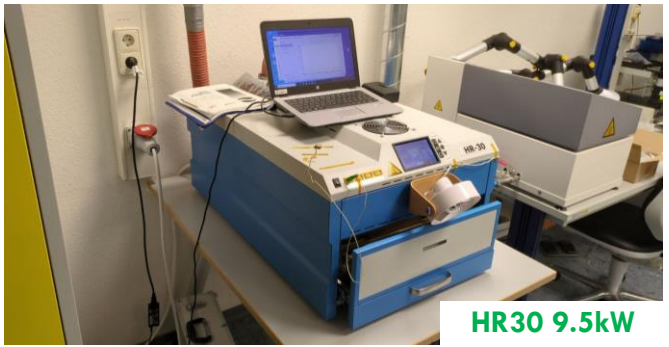
For each part type: 2 or 3 lots with each 10 tested samples + 2 control samples

Part #	Part type	Package	Test site	# lots	Manufacturer	MSL	Level
T1	Bipolar transistor	SOT-23 	Airbus Elancourt & TESAT	3	onsemi	1	AEC qualified
T2	Bipolar transistor	SOT-223 	TESAT	3	Nexperia	1	AEC qualified
T3	MOSFET	TO-263 	TESAT	3	Infineon	1	JEDEC
O1	Optocoupler	SO-5 	TESAT	2	Broadcom	1	AEC “compliant”
R1	Regulator	SOT-223 	TESAT	2	Texas Instruments	2	JEDEC

SETUP

Test equipment

- Paggen customised HR30 9.5kW reflow oven: Preconditioning
- PVA SAM 301: SAM (echo top & back + through)
- Unites M3000/Dingo: Electrical characterization
- ThermalAir TA-5000A: Temperature environment
- ESPEC TSA-71S-W: Thermal shock



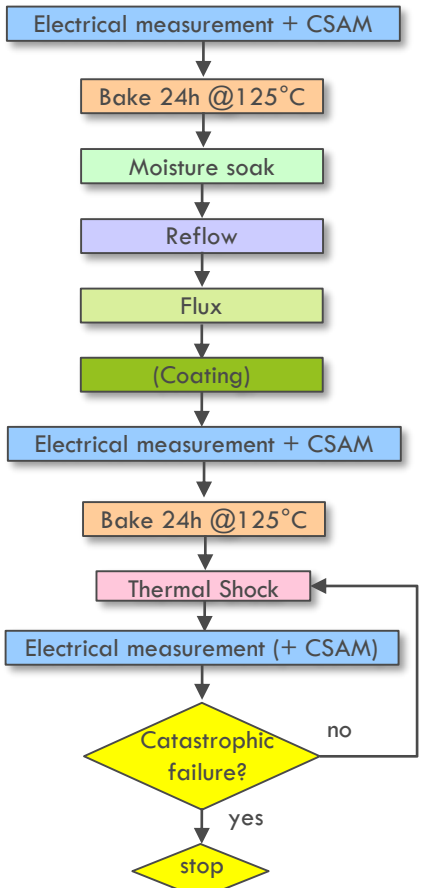
HR30 9.5kW

PVA SAM 301

M3000 / Dingo + TA-5000A

Setup

Test flow



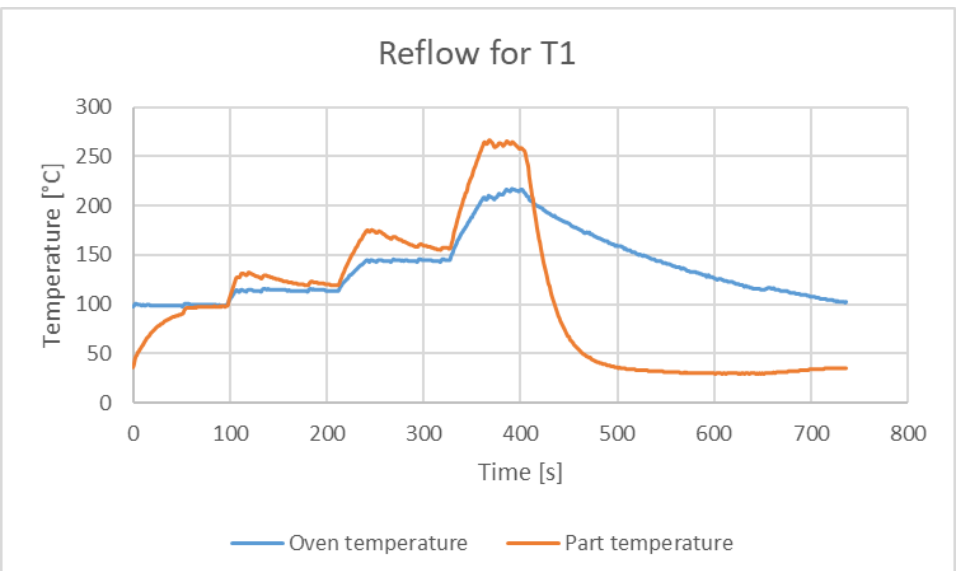
- Preconditioning as per J-STD-020
- C-SAM performed after 10 and 100 cycles, after that only if parts show electrical degradation
- Thermal shock:
  - -40°C to 125°C – temperature measured inside of the part
  - 1 min transition and 6 min dwell time – temperature reached within maximum 3 min
- Thermal shock testing shall provoke failure with a large acceleration factor with respect to typical thermal stress in a space mission [5]
  - 10 shocks
  - 100 shocks
  - 1000 shocks
  - 2000 shocks
  - 4000 shocks
  - 7000 shocks
  - 10000 shocks

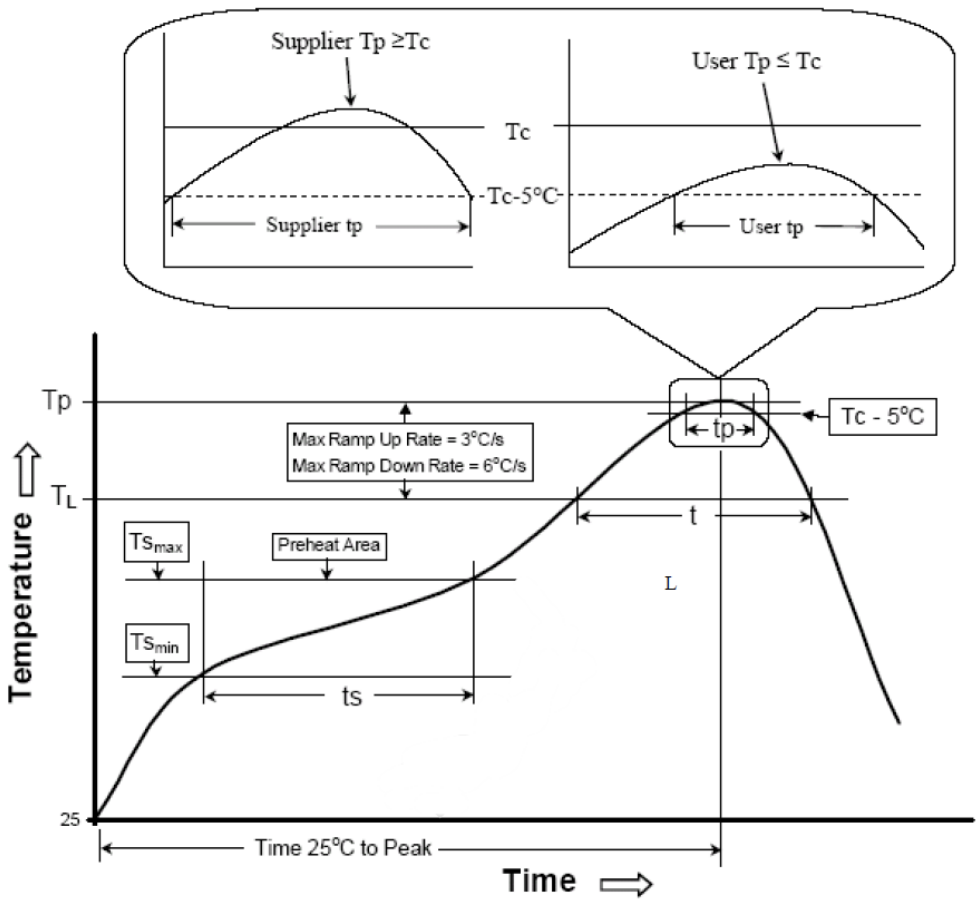
[5] R. Pufall, W. Kanert, "Can temperature shock tests speed up development of reliable components for automotive applications", *EurosimE 2008*

Setup

Reflow

- Reflow is worst-case according to J-STD-020
  - Tp > 260°C (245°C for T3)
  - Ramp-up 1.5-3°C/s
  - Ramp-down 4-6°C/s





RESULTS

Summary

Part type	Package		T0	precond	10 cycles	30 cycles	40 cycles	100 cycles	242 cycles	500 cycles	600 cycles	1000 cycles	1399 cycles	2000 cycles	3000 cycles	3600 cycles	4000 cycles	4799 cycles	6000 cycles	7000 cycles
T1 DC2305	SOT-23	Electrical	Pass	Pass	Pass			Pass				Pass		Pass			Pass			Pass
		CSAM		+	+			NA			NA	+								+
T1 DC2242		Electrical	Pass	Pass	Pass			Pass			Pass	Pass		Pass			Pass			Pass
		CSAM						NA			NA									+
T1 DC2011		Electrical	Pass	Pass	Pass			Pass			Pass	Pass		Pass			Pass			Pass
		CSAM		+	+			NA			NA	+								++
T1 ELC		Electrical	Pass	Pass	Pass			Pass												
		CSAM																		
T2 DC9D2251	SOT-223	Electrical	Pass	SN8 fails	SN3 fails	SN5,7,10 fails	SN4,6 fails													
		CSAM	+																	
T2 DC2224		Electrical	Pass	Pass	SN3, SN5, SN9 fails	SN6 fails	SN2 fails													
		CSAM																		
T2 DC1830		Electrical	Pass	Pass	Pass			Pass			Pass	SN1 fails		Pass			SN2,3,4,6,7,10 fail			
		CSAM																		
T3 DC2222	TO-263	Electrical	Pass	Pass	Pass			Pass	Pass		Pass	Pass		Pass			SN08 fails	Pass	Pass	
		CSAM			+				++			++					+++			
T3 DC2236		Electrical	Pass	SN4 fails	Pass															
		CSAM		+																
O1 Nov-21	SO-5	Electrical	Pass	Pass	Pass			Pass				Pass			Pass					Pass
		CSAM										+			+					
O1 2223		Electrical	Pass	Pass	Pass															
		CSAM																		
R1 DC 2246 (25pcs)	SOT-223	Electrical	Pass	Pass				Pass		Pass	Pass		Pass			Pass				
		CSAM																		
R1 DC 2309 (5pcs)		Electrical	Pass	Pass				Pass		Pass	Pass									
		CSAM	Leadframe del w/ water ingress	+				+		+										

	Leadframe	Die
Delamination %		
	25%	25%
	50%	50%
	100%	100%

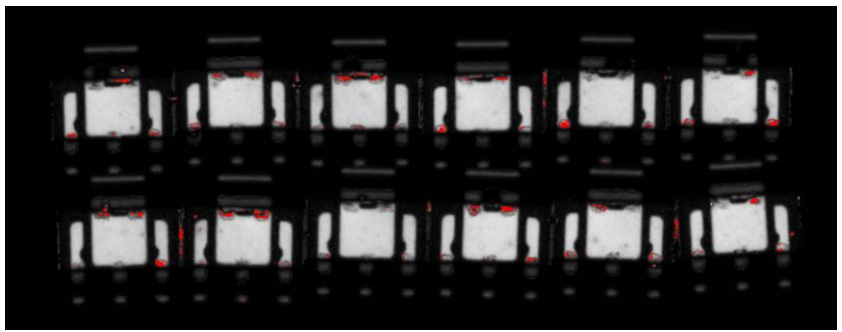
+: increased del but not enough for higher c

- T2: DC9D2251 and DC2224 first failure already after preconditiong, while DC1830 first failure at 1000 cycles
- T2 and R1: similar package → different delamination evolution

RESULTS

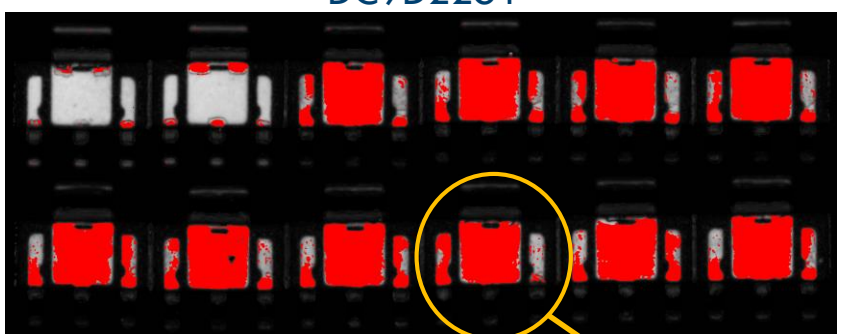
C-SAM T2

Bottom echo @ T0
DC9D2251



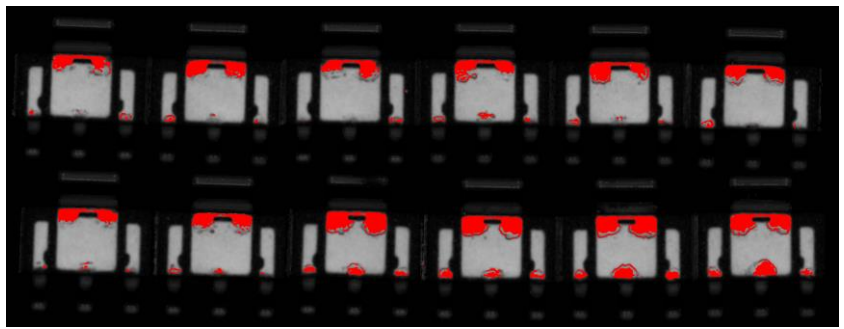
Preconditioning

Bottom echo post preconditioning
DC9D2251



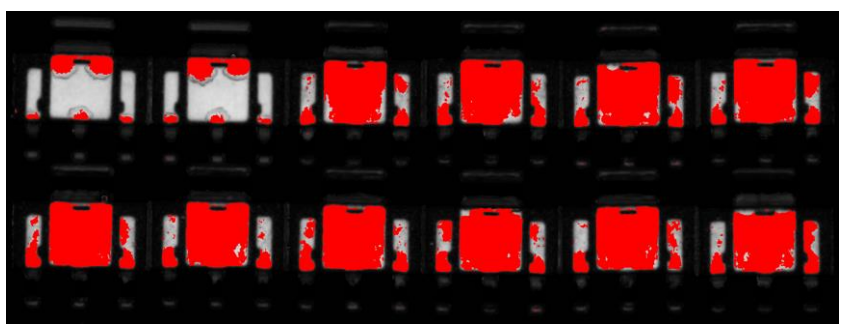
SN08 Electrical failure: ICB0, ICES

Bottom echo @ T0
DC2224



Preconditioning

Bottom echo post preconditioning
DC2224



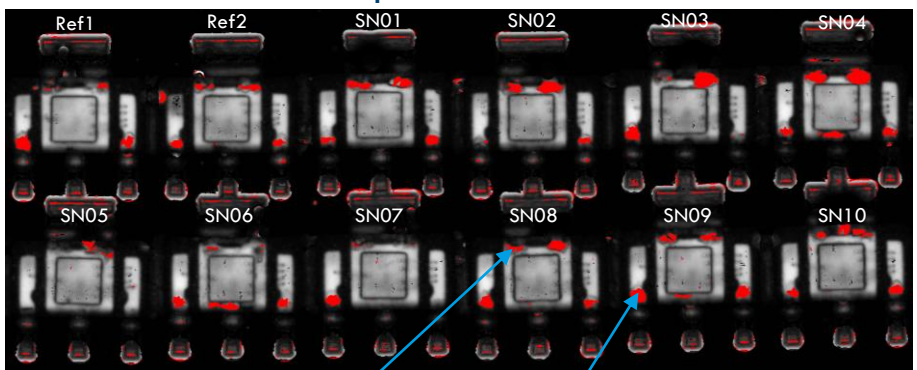
No electrical failures

RESULTS

C-SAM T2 - DC09D2251

TESAT-STANDARD

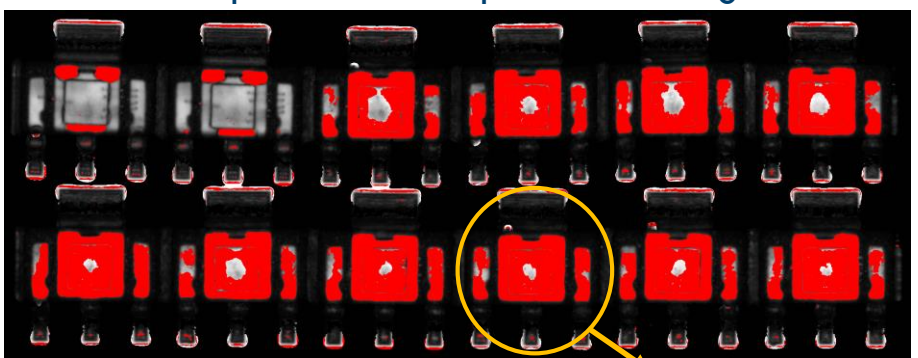
Top echo - T0



Delmination on die paddle/tie bar

Delmination on lead fingers

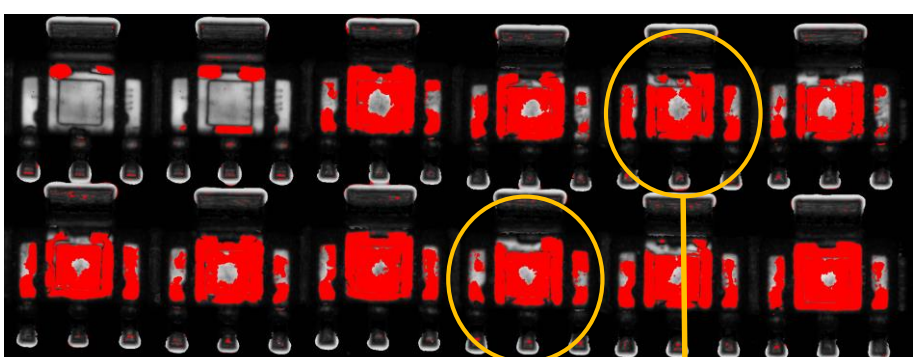
Top echo - after preconditioning



SN08 Electrical failure: ICB0, ICES

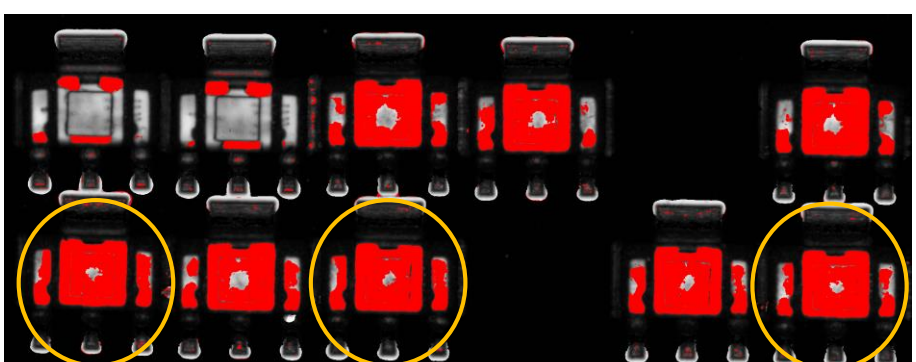
Die paddle and lead fingers almost completely delaminated

Top echo - 10 TS



SN3 + 8 - Electrical failure: ICB0, ICES

Top echo - 30 TS

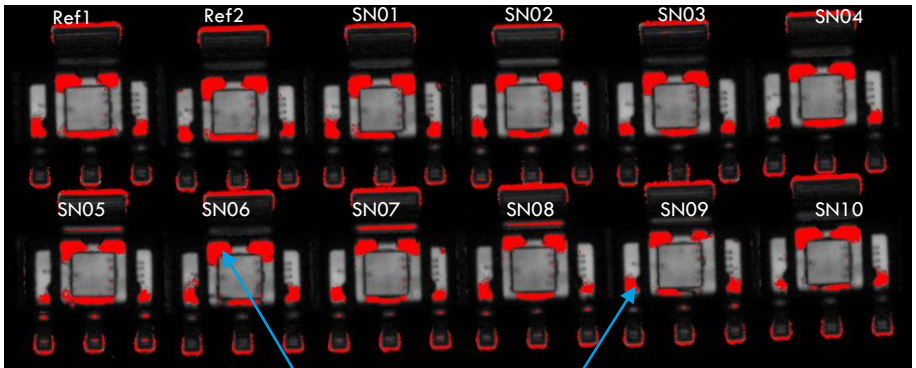


SN05, SN07 and SN10: Electrical failure: ICB0, ICES, IEB0, hfe

RESULTS

C-SAM T2 - DC1830

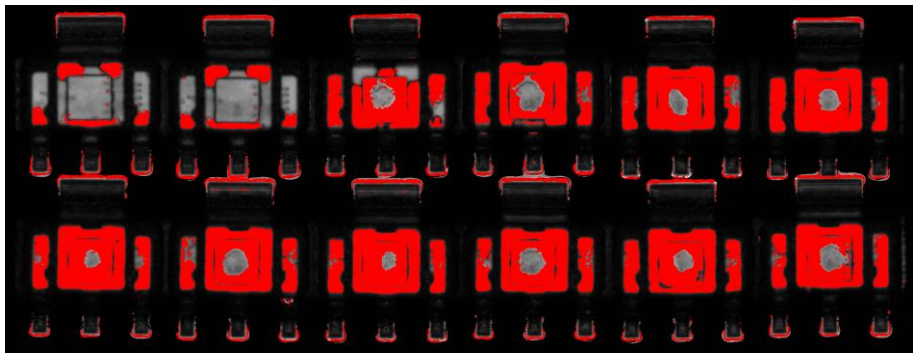
Top echo - T0



Delmination on die paddle/tie bar

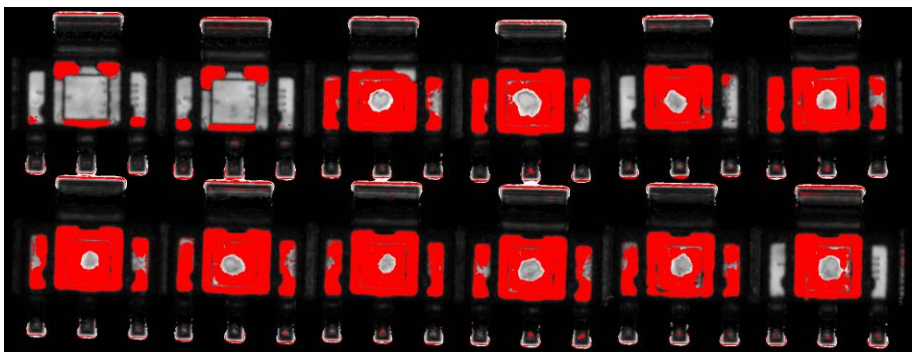
Delmination on lead fingers

Top echo - after preconditioning



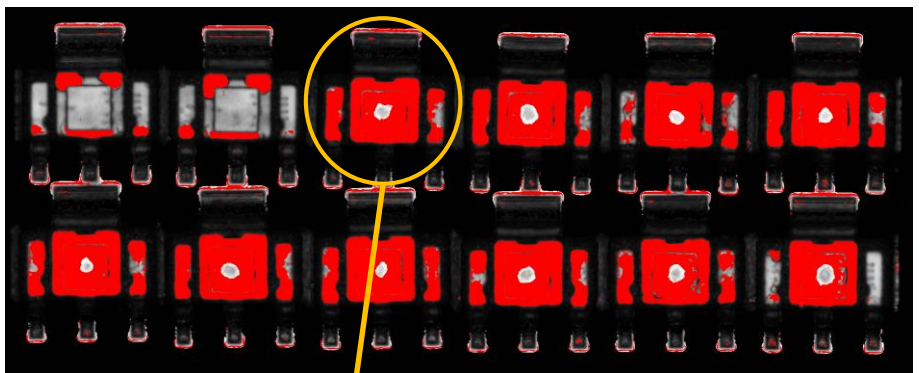
Die paddle and lead fingers almost completely delaminated, no electrical failures

Top echo - 10 TS



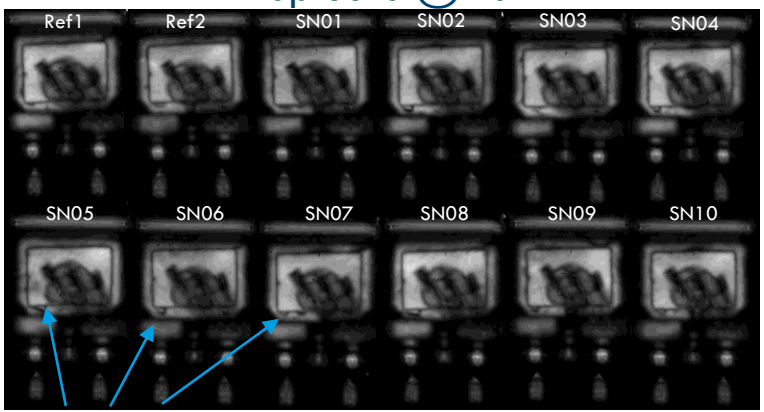
Die paddle and lead fingers almost completely delaminated, no electrical failures

Top echo - 1000 TS



Electrical failure: ICB0, ICES

Top echo @ T0

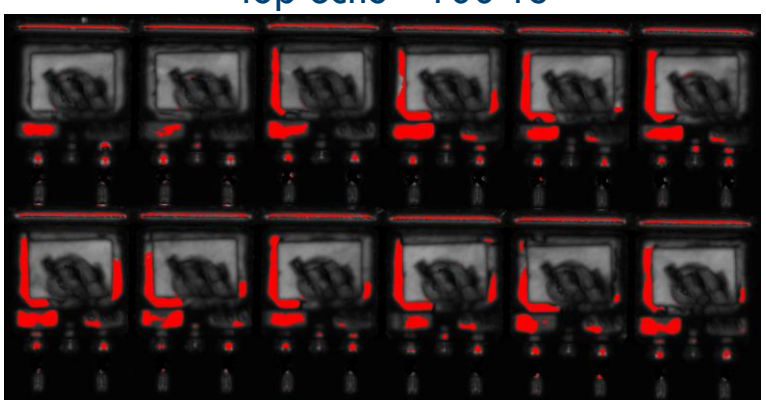


Delamination on die paddle

Top echo - after preconditioning

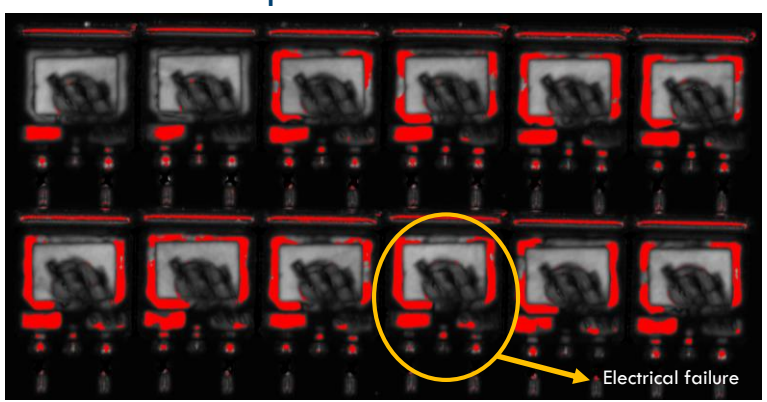
Increase of delamination on die paddle

Top echo - 100 TS



No significant evolution of delamination after 100 cycles

Top echo - 4000 TS

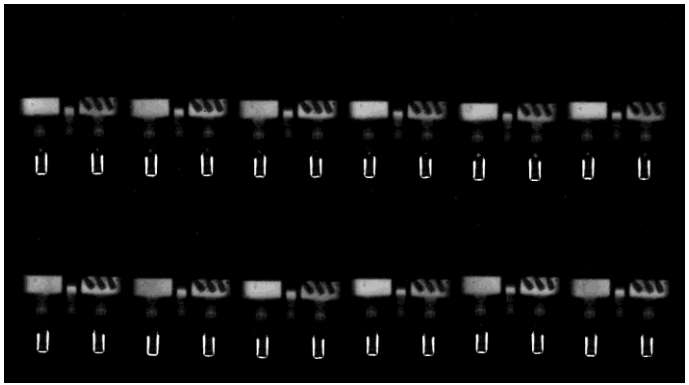


No significant evolution of delamination after 4000 cycles

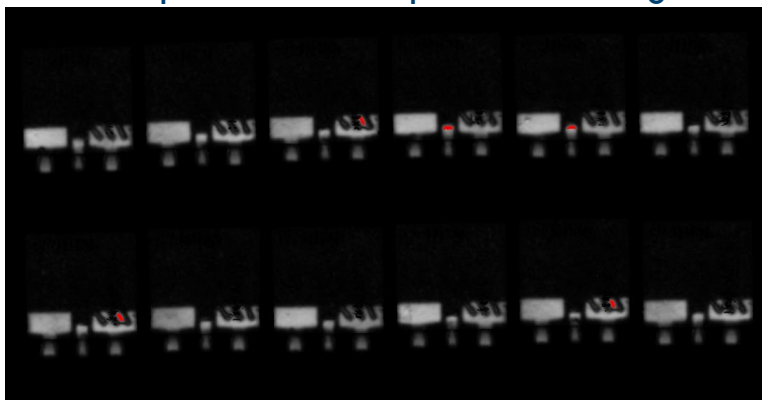
RESULTS

C-SAM T3 - DC2222

Top echo - initial

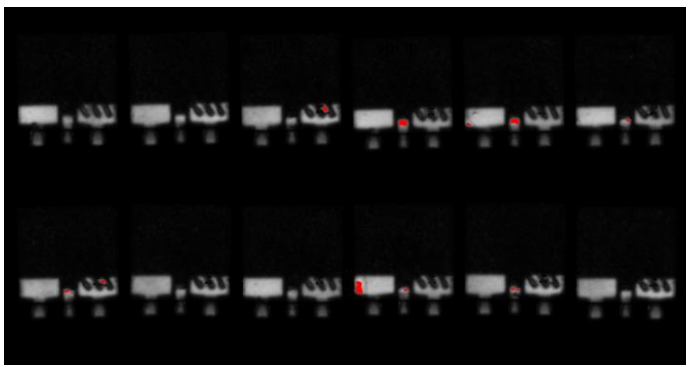


Top echo - after preconditioning



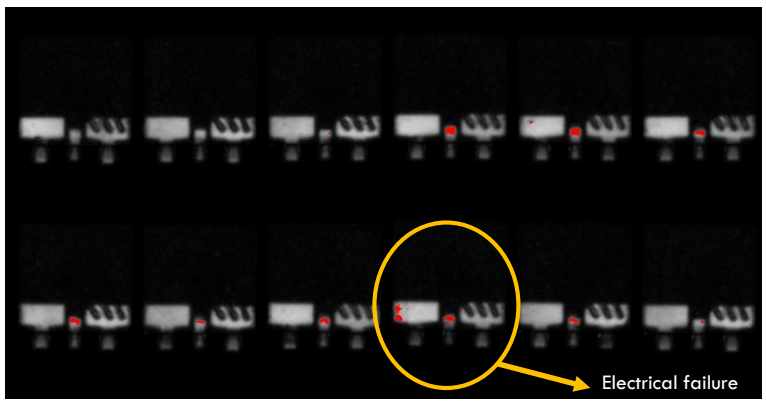
Gate post in SN8 starts to delaminate

Top echo - 10 TS



Gate post in SN8 delaminated

Top echo - 4000 TS

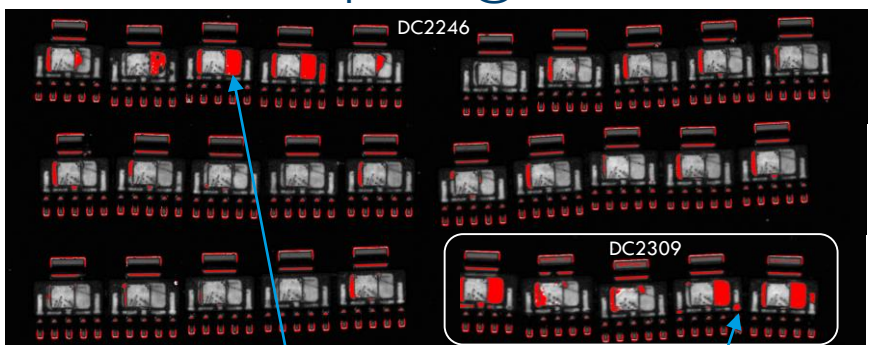


No significant evolution of delamination after 4000 cycles

RESULTS

C-SAM R1

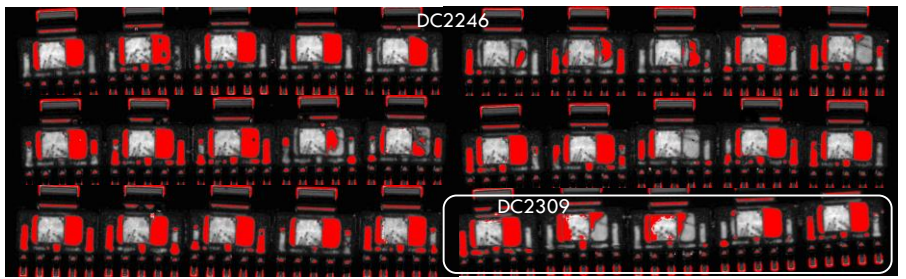
Top echo @ T0



Delmination on die paddle

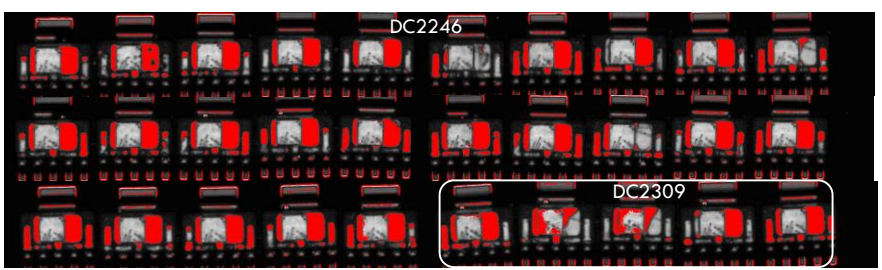
Delmination on lead finger

Top echo - after preconditioning



Increase of delamination on die paddle topside and lead finger in both DCs

Top echo - 100 TS

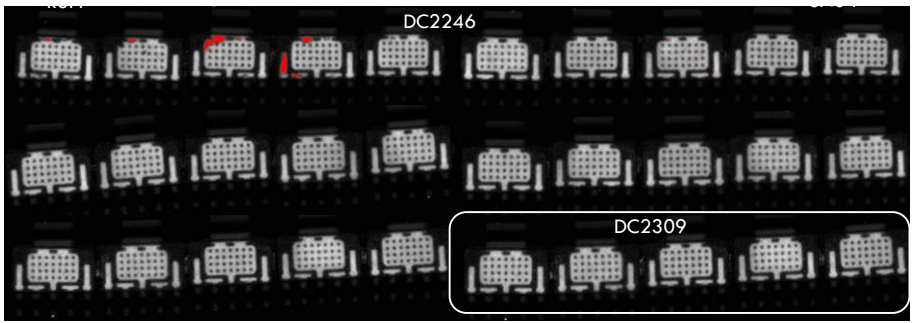


Increase of delamination especially on the bottom side (see next slide)

Top echo - 600 TS

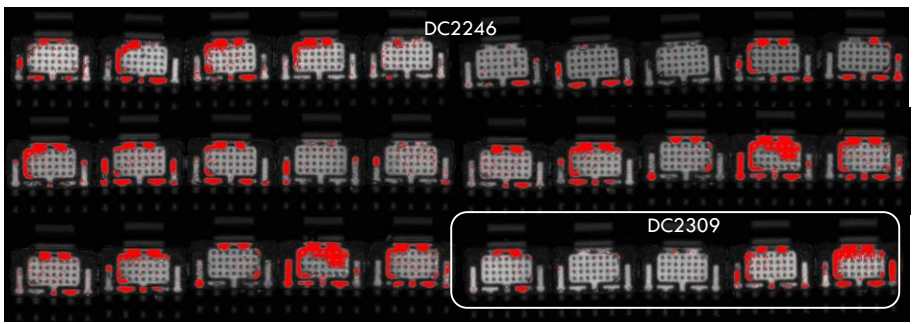
No significant increase of delamination.

Bottom echo - T0



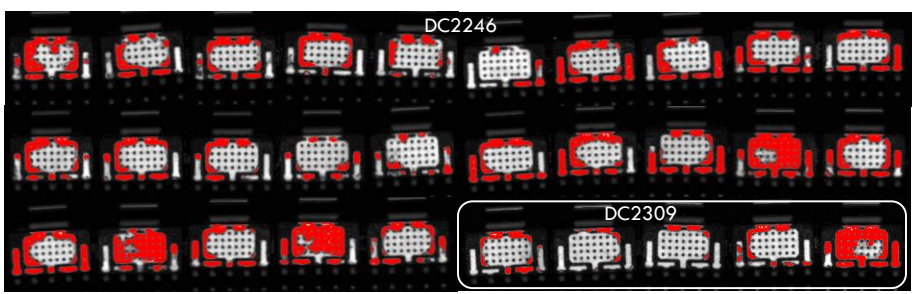
Mainly no delamination

Bottom echo - after preconditioning



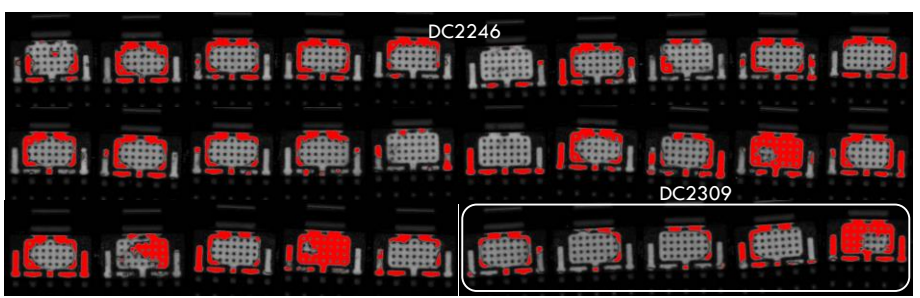
Increase of delamination on bottom side

Bottom echo - 100 TS



Increase of delamination.

Bottom echo - 600 TS

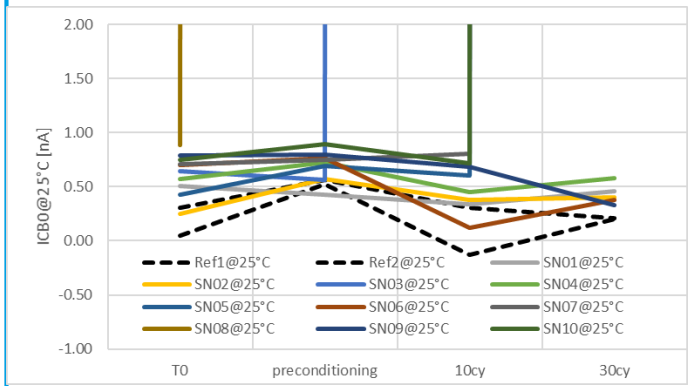


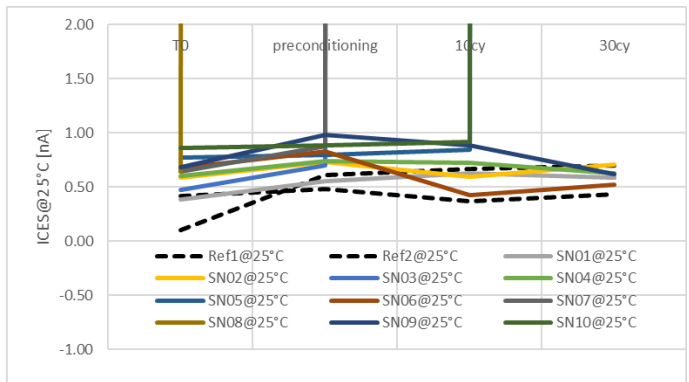
No significant increase of delamination.

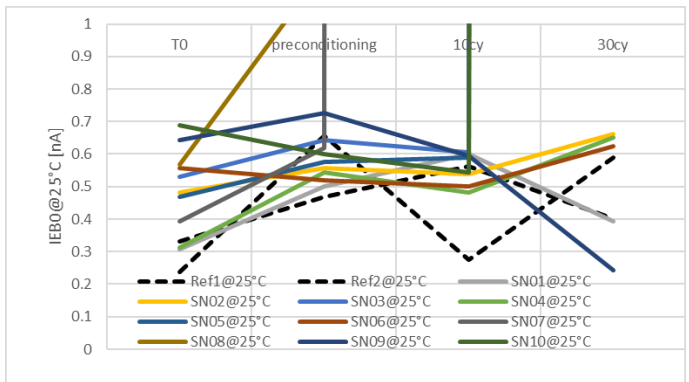
RESULTS

Electrical drift T2

DC09D2251

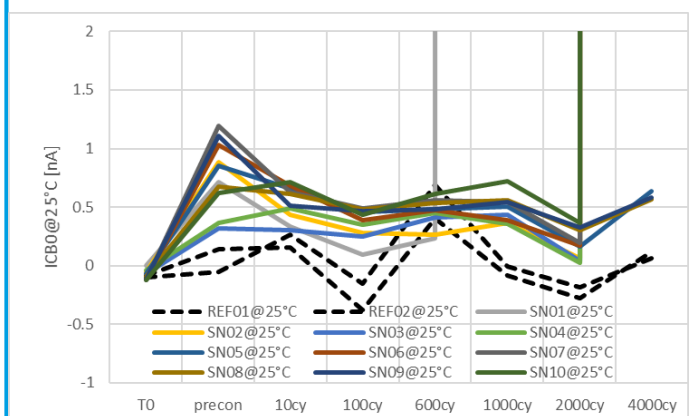


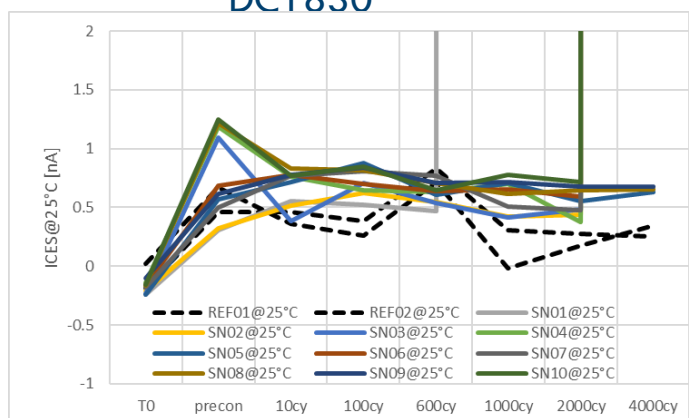


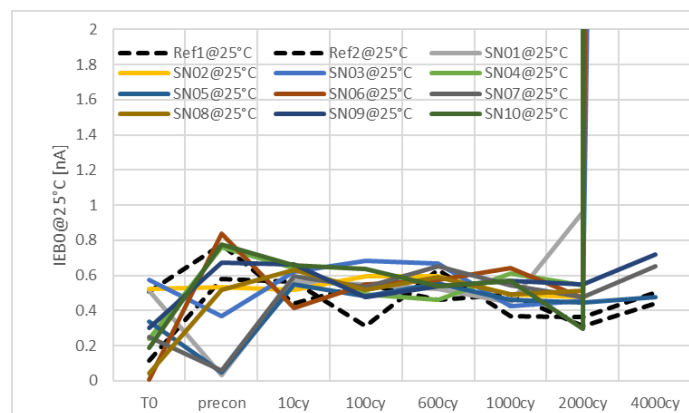


No parametric degradation observed before failures

DC1830







RESULTS

Electrical T2

- SN9 fails after 10 TS
- SN6 fails after 30 TS

Device #	Result	1.1 ICB0@25°C	2.1 ICB0@150°C	3.1 ICES@25°C	4.1 IEB0@25°C	5.1 hfe1(DC)@25°C	6.1 hfe2(DC)@25°C	7.1 hfe3(DC)@25°C	8.1 hfe4(DC)@	9.1 hfe5(DC)@	10.1 VCE1(sa	11.1 VCE2(sa	12.1 VCE3(sa	13.1 VCE4(sa	14.1 VCE5(sa	15.1 VCE6(sa	16.1 VBE(sat	17.1 VBE(sat
Unit		nA	uA	nA	nA						mV	mV	mV	mV	mV	mV	mV	mV
Lower limit						200.000	200.000	200.000	150.000	120.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Upper limit		100.000	55.000	100.000	100.000	2000.000	1000.000	1000.000	1000.000	1000.000	63.000	125.000	150.000	195.000	175.000	285.000	900.000	1050.000
Ref1@25°C	Pass	-0.17	0.00	0.11	0.49	329.79	311.96	279.50	231.74	191.85	1.24	76.29	91.85	121.56	106.53	177.54	809.96	930.78
Ref1@150°C	Fail	54.74	0.06	1269.51	42.20	570.81	535.43	473.80	373.21	288.11	1.69	89.53	109.81	144.95	127.69	207.82	643.67	809.03
Ref2@25°C	Fail	1276.69	127.66	1270.85	4.37	0.00	0.00	17509.30	529.71	332.56	1.39	74.41	91.50	122.02	106.81	178.78	810.63	931.44
SN01@25°C	Pass	-0.07	0.00	0.09	0.42	339.64	322.27	292.47	239.18	197.40	1.23	75.17	90.58	120.41	105.84	175.48	808.83	930.85
SN01@150°C	Fail	86.90	0.09	1271.21	59.95	586.09	548.33	484.45	378.38	281.51	1.77	90.26	110.50	146.23	128.98	209.97	640.36	807.20
SN02@25°C	Pass	0.24	0.00	0.19	0.42	314.59	299.20	269.56	223.52	183.82	1.21	81.65	98.78	131.66	114.95	193.17	808.71	931.91
SN02@150°C	Fail	79.96	0.09	1274.08	58.73	544.73	511.36	448.88	350.84	257.34	1.78	97.03	118.77	156.88	137.62	226.42	641.46	807.03
SN04@25°C	Pass	0.23	0.00	0.32	0.34	322.52	306.82	276.66	230.44	191.55	0.98	74.98	90.36	119.79	105.33	174.61	810.10	932.18
SN04@150°C	Fail	60.81	0.06	1275.05	40.64	549.86	517.83	457.40	361.68	275.83	1.61	90.14	110.17	145.73	128.69	209.16	644.41	810.08
SN06@25°C	Fail	1279.29	127.91	1272.98	119.81	0.00	0.00	0.00	849.35	414.44	1.28	72.16	89.88	121.14	106.12	176.73	808.71	930.51
SN06@150°C	Fail	1280.78	128.07	1275.29	1461.03	0.00	0.00	0.00	1065.97	572.87	1.66	85.83	109.14	146.86	129.65	211.01	637.65	804.92
SN07@25°C	Pass	0.21	0.00	0.24	0.78	339.64	322.77	290.81	240.59	200.29	1.19	72.03	87.51	117.70	104.26	170.88	811.38	932.67
SN07@150°C	Fail	71.69	0.08	1275.29	55.11	587.44	549.80	485.02	380.14	292.92	1.72	87.37	107.81	144.39	128.48	207.29	639.83	807.37
SN08@25°C	Pass	0.38	0.00	0.48	0.54	324.56	308.67	277.98	231.09	191.85	1.43	74.13	89.10	119.07	104.82	173.11	810.85	933.07
SN08@150°C	Fail	71.62	0.08	1277.25	55.58	560.34	524.46	463.61	364.90	278.96	1.53	89.83	110.09	146.58	129.78	209.96	639.66	806.89
SN09@25°C	Fail	1286.92	128.69	1283.31	404.96	0.00	0.00	0.00	718.28	368.46	1.21	128.95	202.76	347.23	712.98	1442.79	744.68	792.16
SN09@150°C	Fail	1274.70	127.42	1268.41	1157.11	0.00	0.00	0.00	1189.83	600.88	1.72	85.88	109.09	146.55	129.52	210.73	636.00	802.92
SN10@25°C	Pass	0.18	0.00	0.32	0.54	325.60	310.54	278.55	230.44	190.36	1.26	76.30	91.34	120.44	105.21	176.13	810.99	933.14
SN10@150°C	Fail	76.32	0.08	1271.12	64.32	565.72	529.88	467.31	368.18	277.70	1.49	91.82	111.99	147.54	129.81	211.97	639.58	807.03

TESAT-STANDARD

TESAT

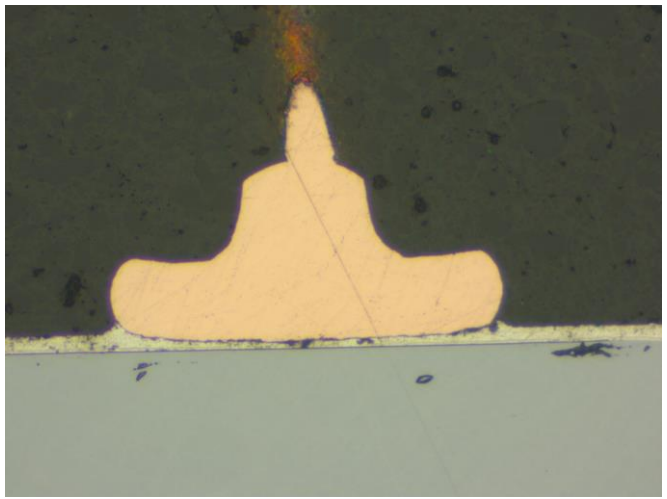
» SN8 failure after 4000 TS

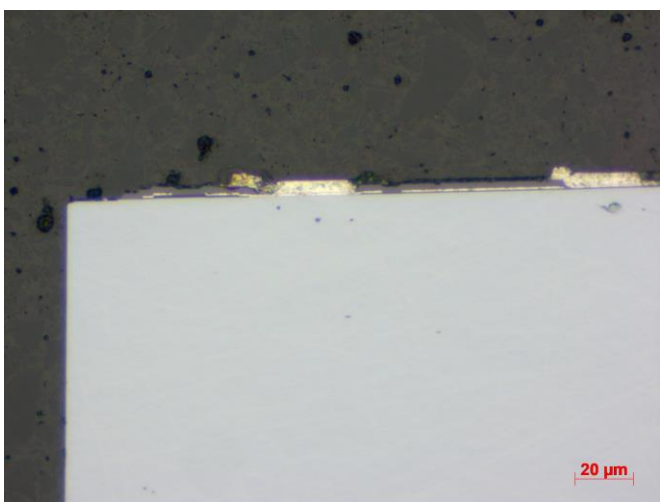
Device #	Result	1.1 V(BR)DSS@25°C	2.1 VGS(th)@25°C	3.1 IDSS@25°C	4.1 IDSS@125°C	5.1 IGSS(f)@25°C	6.1 IGSS(r)@25°C	7.1 RDS(on)@25°C
Unit		V	mV	nA	uA	nA	nA	Ohm
Lower limit		150.000	2000.000					0.000
Upper limit		300.000	4000.000	1000.000	100.000	100.000	100.000	0.007
Ref1@25°C	Fail	168.58	1981.13	2.14	0.00	0.23	0.24	0.01
Ref1@125°C	Fail	179.70	1944.88	1287.02	1.59	28.26	12.34	0.01
Ref1@-55°C	Pass	158.83	2003.69	0.68	0.00	0.46	0.33	0.00
SN07@25°	Fail	167.24	1978.50	1.82	0.00	0.46	0.39	0.01
SN07@125°	Fail	178.80	1934.56	1286.39	1.84	32.38	21.18	0.01
SN07@-55°	Fail	158.16	1999.44	0.73	0.01	0.36	0.39	0.00
SN08@25°	Fail	168.63	1988.31	1.74	0.00	0.18	0.32	0.01
SN08@125°	Fail	2.03	12342.19	151.25	0.15	26.61	9.84	0.25
SN08@-55°	Fail	2.12	13537.94	0.55	0.01	0.19	0.08	0.25
SN08@25°1	Fail	0.16	14.19	1287.94	128.81	1288.16	1288.53	0.02
SN09@25°	Fail	168.67	1978.56	1.88	0.00	0.46	0.31	0.01
SN09@125°	Fail	178.75	1943.06	1049.91	1.05	17.47	4.65	0.01
SN09@-55°	Fail	160.07	1998.81	0.52	0.01	0.17	0.23	0.00
SN08@25°2	Fail	0.16	13.63	1287.71	128.82	1288.12	1288.53	0.02
SN08@25°C	Fail	0.33	13.13	1289.13	128.88	1289.28	1289.28	0.02
SN08@125°C	Fail	0.23	16.94	1290.38	128.98	1290.20	1290.14	0.02
SN08@-55°C	Fail	0.21	16.06	1290.15	128.96	1289.91	1289.81	0.03

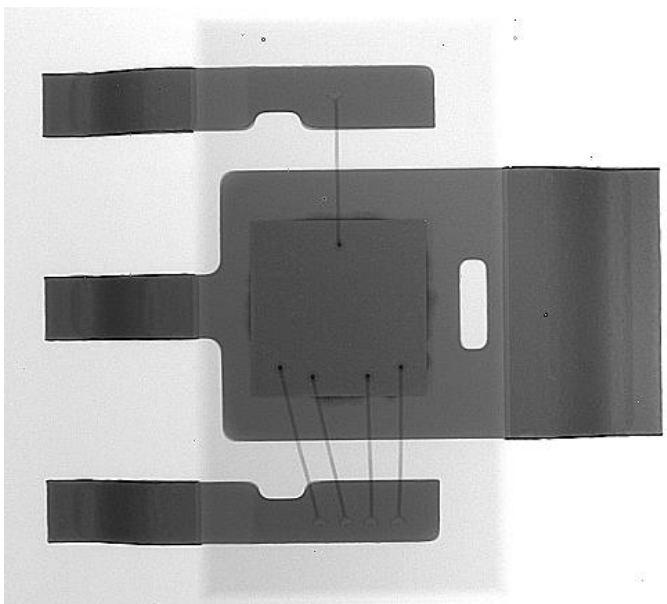
Failure Analysis

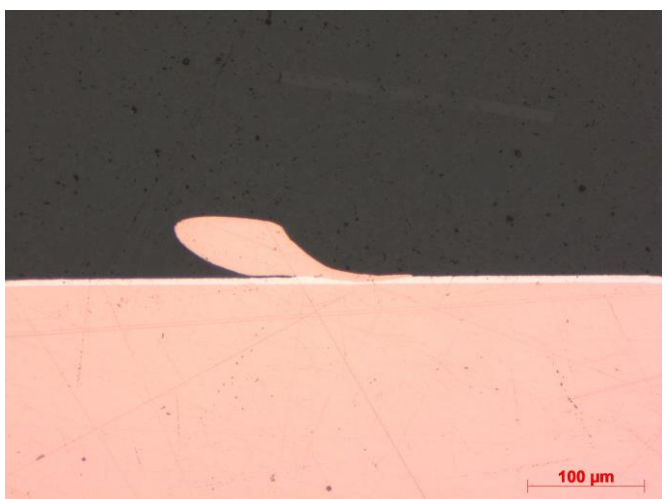
T2 - Microsection

- So far, microsections on DC 1830 SN1 and DC 9D2251 SN5
- Die top delaminations are very significant
- Post bonds seem fine
- Some die bonds may have been lifted



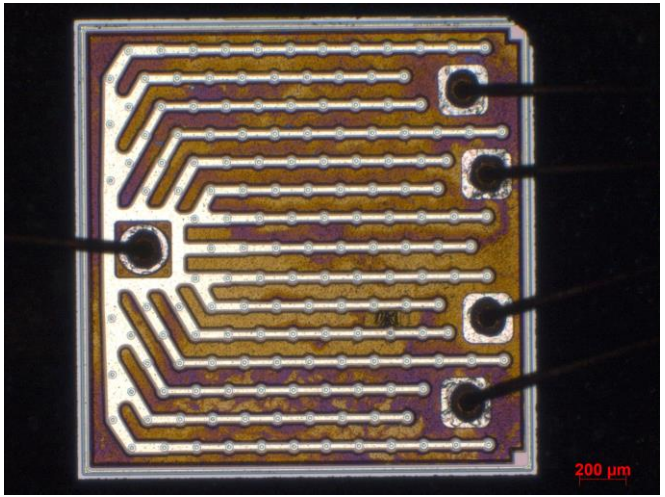




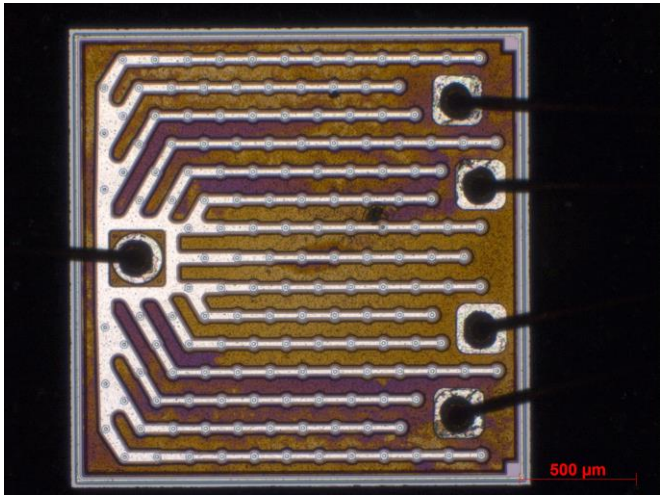


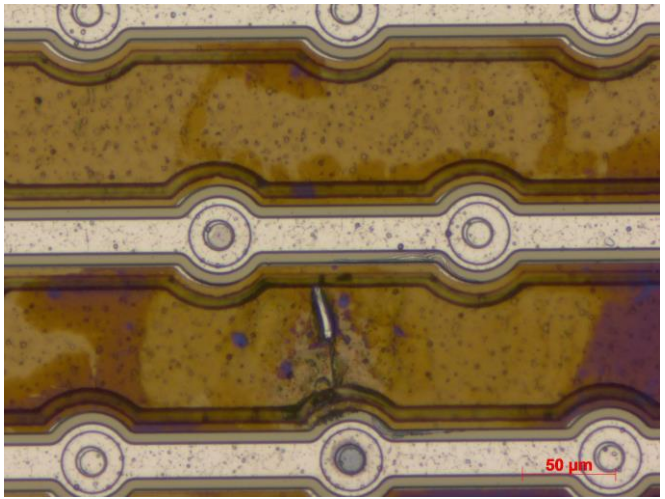
Failure Analysis

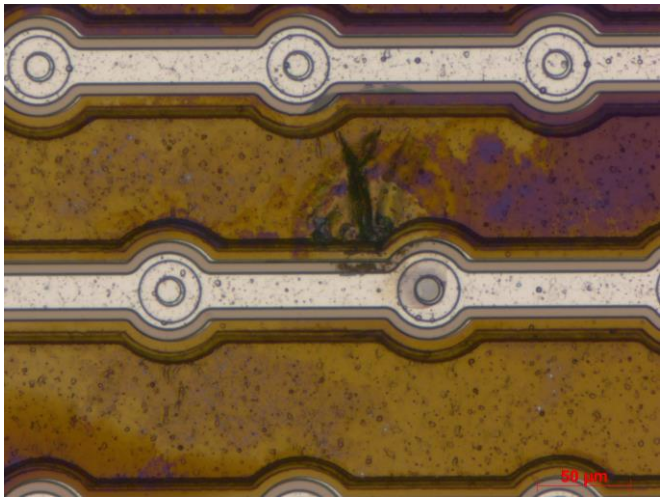
T2 - Decapsulation

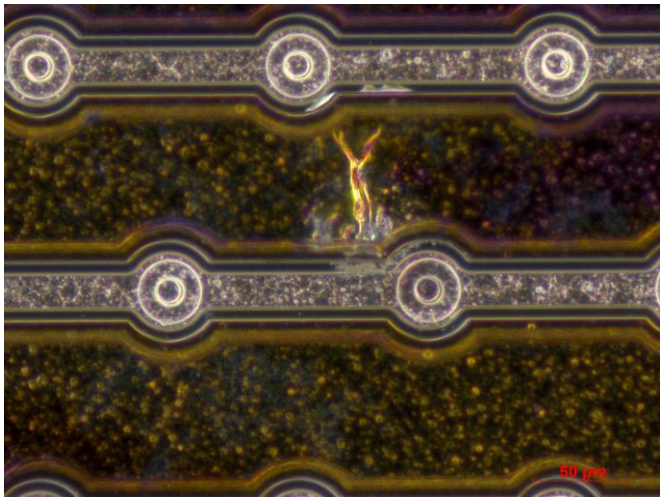


- Decapsulation of DC2224 SN3 (left) and DC 9D2251 SN3 (right)
- Short-circuits are clearly visible

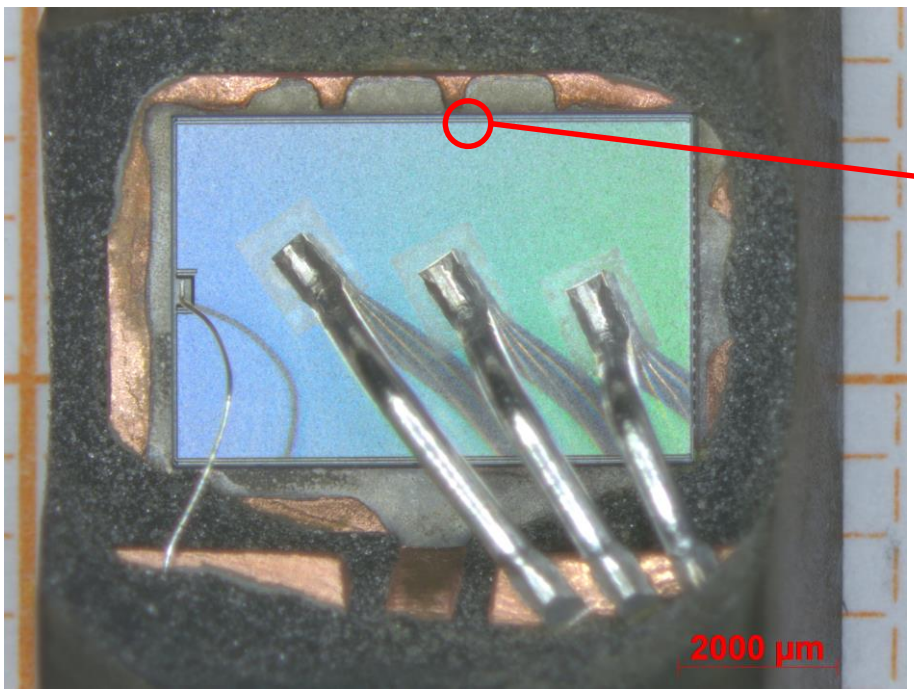


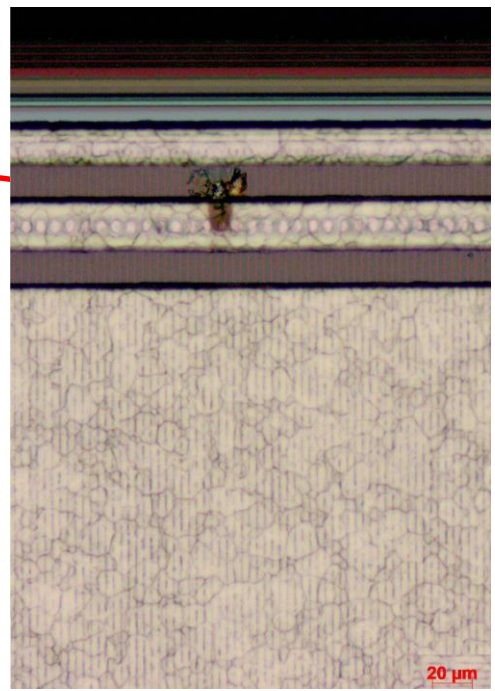


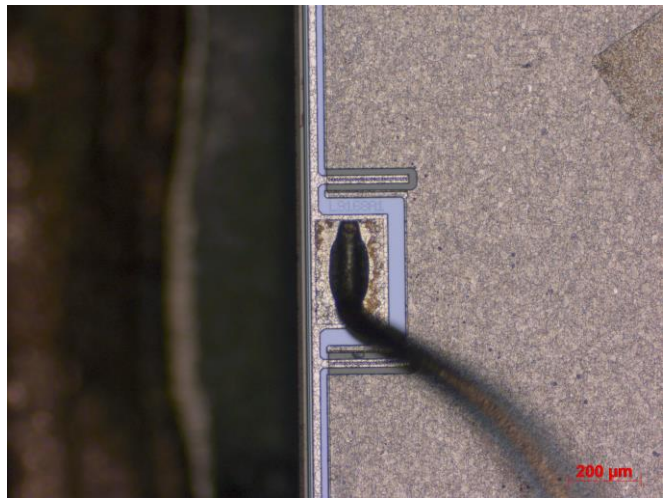


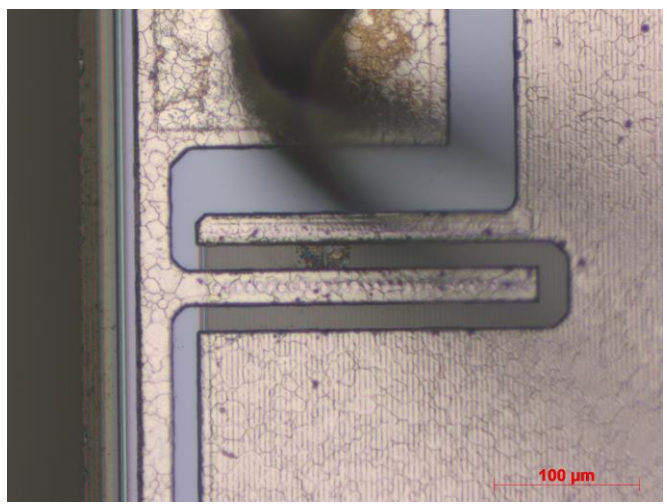


- DC 2222 SN8 and DC 2236 SN3 have been decapsulated
- The short-circuits are clearly visible. They are at different locations.









SUMMARY

- Conclusions
  - Significant variations in failure rates among part types, even those with similar initial delaminations and constructions. Rejectable initial delaminations did not compromise the functionality of certain part types.
  - Pronounced differences across date codes of the same part type
  - MSL1 parts are normally robust but some fail before mission-equivalent cycles
  - TESAT has adopted this test methodology as a standard procedure for parts with initial delaminations

- Next steps
  - Complete failure analyses
  - Apply conformal coating before the shocks
  - Test more parts, especially with MSL3 or higher

- We can test your parts via our Parts Agency
  - Cost-effective methodology to assess criticality of initial delaminations
  - Very fast (1000 cycles in one week)

THANK YOU FOR YOUR ATTENTION

Acknowledgements:
Alexander Vorobev, Sylvie Heude-Verneyre (AIRBUS), Marcus Witzany

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