Lessons Learned from Screening and Qualification of COTS PEMs for a Space Project

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Purpose and Outline

Purpose:

To discuss results of screening and qualification of more than 32,000 plastic parts of 28 different types.

Outline:

- Statistics of parts used.
- Results of DPA.
- Screening: Burn-in.
- Screening: Acoustic microscopy.
- Qualification: SMT simulation.
- Qualification: HAST results.
- Analysis of revealed problems.

Statistics of PEMs Used

Package types

SOIC-16	5
D2Pak	5
SOIC-5	1
8uMAX	1
uSOIC16	2
SOIC-28	1
SOT-23-3	1
SOT-23-5	1
SOT223	1
SOIC-8	10

Manufacturers	5
Part Types	28
Pack. types	10
Lots	44
Total QTY	32,700

Seven out of 10 parts in SOIC8 had silicone die coating

Part types

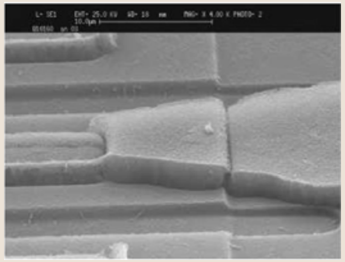
Power devices	6
Linear devices (comparators, Vref., opamps)	19
Mixed signal (ADC, DAC, switches)	3

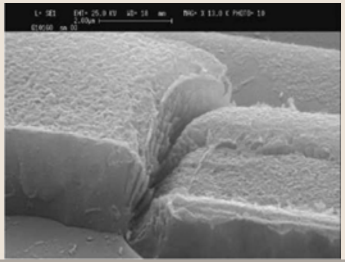
Manufacturers

AD	15
LT	2
On Semi	1
MAXIM	4
IR	6

DPA Results

- Out of 44 lots:
  - 4 failed due to metallization step coverage.
  - 3 failed due to delaminations in critical areas.
- 9 lots had delaminations in non-critical areas.
- All power HEXFETs in TO-220 style packages had no glassivation on the die surface.



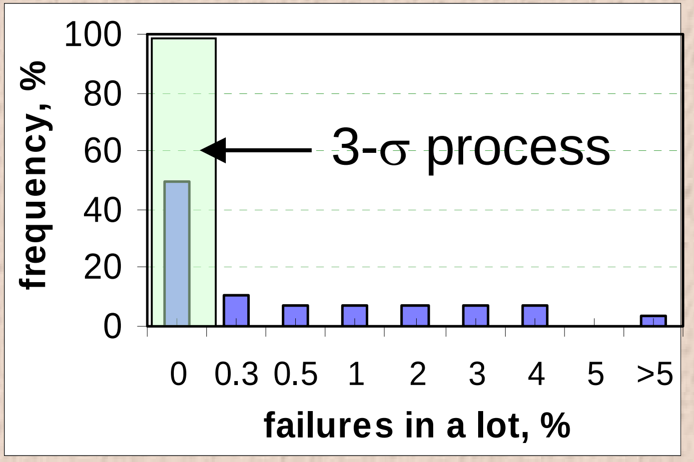


Transistors that failed metallization step coverage "successfully" passed BI with no-load conditions (HTRB: 150 ^{o}C/48hr VGS=-24V, VDS=0; Steady BI: 150 ^{o}C/168hr VDS=24V, VGS=-12V). However, current density calculations allowed acceptance of the lot.

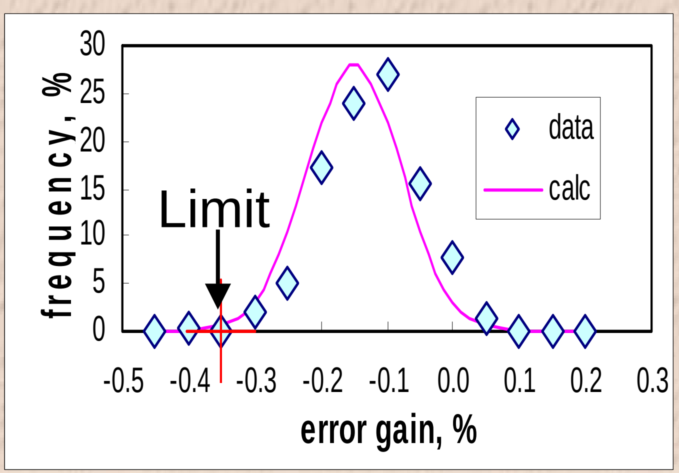
- DPA should precede S&Q testing.
- The test flow and conditions should address the revealed anomalies and intended applications.

Initial Electrical Measurements

Distribution of initial EM failures



Example of param. distribution

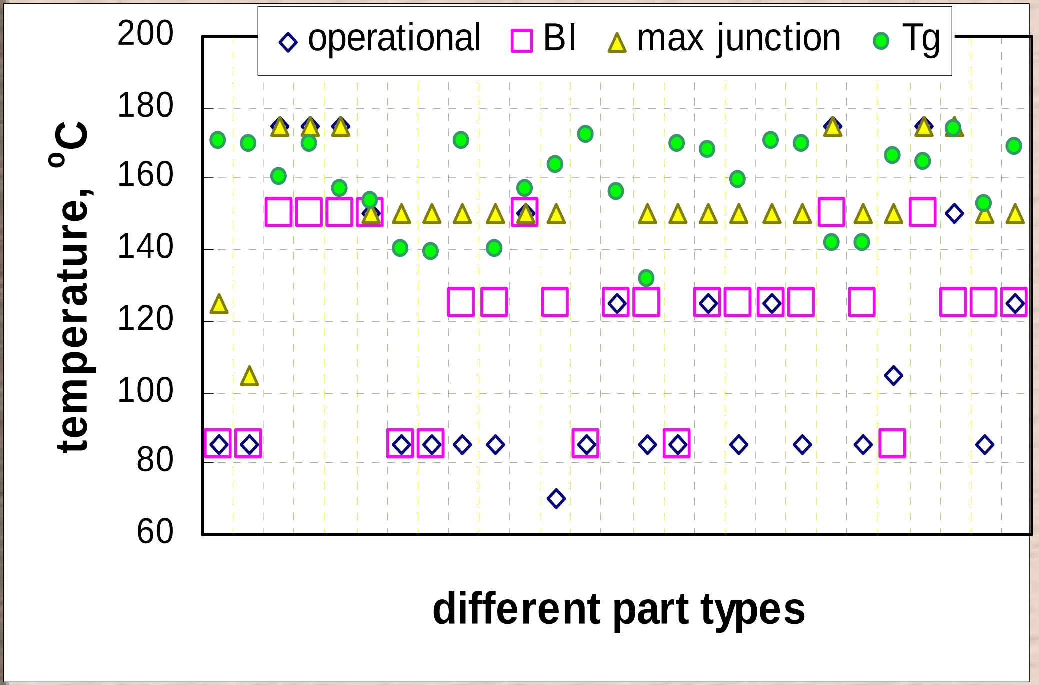


- 11 out of 28 part types had > 0.27% failures (mostly parametric).
- Most manufacturers declare at minimum a 3-sigma-level process.
- Excessive fallouts might indicate poor lot quality, problems with testing, or margins that are too tight.

Market-driven philosophy forces manufacturers to tighten performance margins.

BI Testing

Burn-in screening was performed at temperatures from 85 ^oC to 150 ^oC on 28 different part types (~32,700 pcs.)



Characteristic temperatures of devices and temperatures of BI testing:

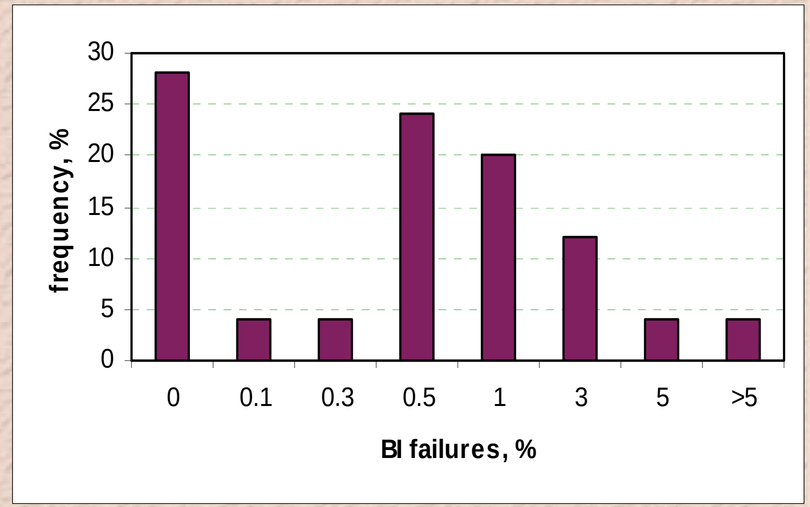
- All parts were tested below Tjmax.
- 30% of parts were tested above Top (no statistical difference).
- One part had T_{BI} above Tg of MC.

A methodology to choose BI temperature is needed.

BI Statistics

- 28% of the part types had no BI failures.
- 60% of the part types had 0.5% or less of BI failures.
- A significant proportion of failures was due to relatively minor parametric shifts.

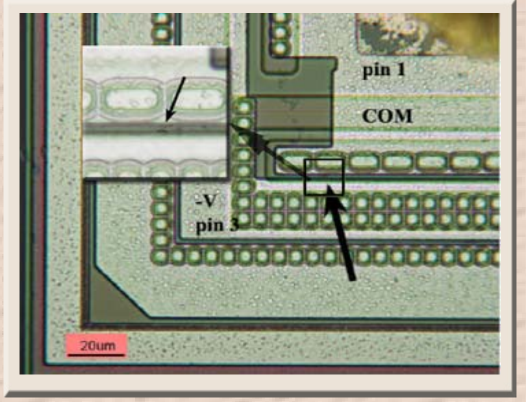
Distribution of BI failures



- 5% is a reasonable limit for PDA.
- Due to tight margins, a delta analysis should be a must for linear devices.

Damaging Testing: History Case.

- Out of 2400 pcs of a mixed-signal PEM 86 parts (3.6%) were rejected initially during screening.
- All screened devices failed when installed on the board.
- FA revealed that the parts had excessive leakage currents due to EOS/ESD damage caused by high-voltage spikes generated by ATE.
- A review of the ATE test program showed that the failing parameters had not ben tested.
- Inadequate test program failed to catch the problem.

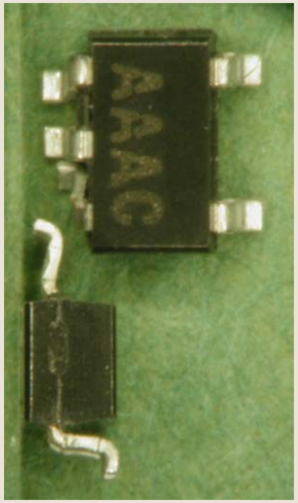


- Even established test labs can make serious mistakes.
- The algorithm of ATE programs should be inspected to catch mistaken test conditions or missed tests.

Screening: Effect of DC

Different date codes for COTS parts do not necessarily mean different wafer lots.

DC/ (QTY)	LAB	failed init EM, %	failed after BI, %	lost during screen, %	damaged during screen, %	damaged during AM, %
	LAB1				0.12	
	Gr I_1		1.63	0.00		0.62
0031	Gr I_2		1.22	0.00		0.00
(2407)	Gr I_3		1.02	1.02		0.21
	Gr I_4		2.04	1.43	0.20	1.74
	Gr I_5		1.30	1.32		0.00
average		**2.33**	**1.44**	**0.75**	**0.15**	**0.51**
	LAB1			0.40		
0128	Gr II_1		0.61	0.61	0.20	0.00
(988)	Gr II_2		0.00	0.20		0.00
average		**0.00**	**0.31**	**0.41**	**0.20**	**0.00**
0128	**LAB2**					
(600)		**0.00**			**0.67**	



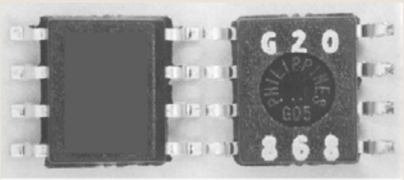
SOT-23 package

- Different date codes might indicate different quality.
- Small parts are easy to damage during electrical testing or AM

Screening: Effect of DC Cont'd.

DC / (QTY)	Group	failed init EM, %	failed after BI, %	lost during screen, %	Date of test
0019/ (4988)	Gr I_1		3.19	5.66	Dec-01
	Gr I_2		0.89	0.89	
	Gr I_3		0.53	0.00	
	Gr I_4		0.00	1.61	
	Gr I_5		1.75	0.41	
	Gr I_6		0.89	0.53	
	Gr I_7		1.43	1.23	
	Gr I_8		0.88	0.18	
	Gr I_9		0.46	1.84	
	average	**0.12**	**1.11**	**1.37**	
0029/ (2065)	Gr II_1		0.00	0.36	Apr-02
	Gr II_2		0.00	0.53	
	Gr II_3		0.00	0.00	
	Gr II_4		0.00	1.80	
	average	**0.15**	**0.00**	**0.67**	

Outliers per Grubbs' test at significance level of 0.05.



Parts in SOIC-8 packages should not have been damaged easily

- Parts with different DC had different BI results.
- Lost/damaged samples reduce confidence in screening.
- Statistical analysis might indicate screening problems.

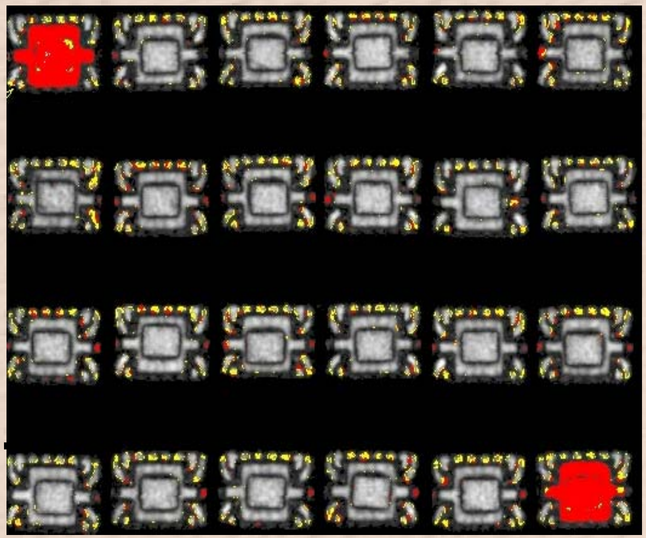
Statistics of Screening by Acoustic Microscopy (C-SAM-mode)

- Six types of power devices (2,775 pcs) in TO-220-style packages and 23 types of low power devices (26,027 pcs) in SOIC-style packages were screened by AM.
- Rejectable delaminations were observed in 4 out of 6 types of power devices and in 14 out of 23 types of linear devices.
- The proportion of rejects varied from 2.3% to 28% for power devices and from 0.14% to 83% for low-power devices.
- The cost of AM is relatively high, up to $4 to $7 per part, even for a large quantity lot.
- Out of 31,090 parts subjected to screening, 565 (1.8%) were rejected by electrical testing and 3,586 (11.5%) by CSAM.

Acoustic microscopy rejected far more parts than did electrical measurements. Are all these rejects potential failures, and if so, what is the confidence in quality of a lot with ~10% rejects?

CSAM Rejection Criteria

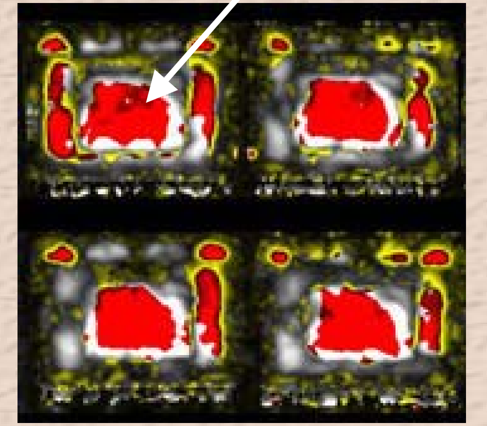
- Rejection criteria used:
  - >50% of back-side delaminations (BSD).
  - Any top of die (TOD) or finger tip delaminations.
  - >50% die paddle.
  - More than 2/3L of leads.
- These criteria are relatively easy to apply in a case like this.
- QSOP-16 packages:
  - 27/712 had BSD.
  - 11/712 had TOD delaminations.

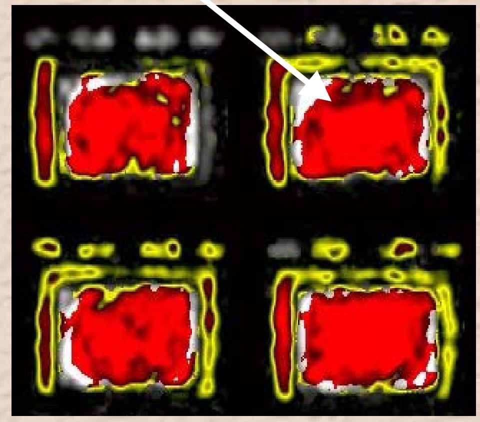


Finger-tip delaminations are questionable due to the small size of the leads and the package cut.

C-SAM Rejection Criteria Cont'd.

A large proportion of linear devices in SOIC-8 packages (7 out of 10 tested part types) had silicone die coatings.





Typical AM images of two opamps with die coating.

Most parts with silicone die coating had excessive delaminations at the paddle and finger-tips. Should these lots be rejected?

Statistics of SMT Simulation

Preconditioning (SMT simulation) was performed per JESD 22-A113. Out of 24 part types 6 had post-SMT failures varying from 1.7 to 53%.

Part/Pack.	Qty	SMT failures	SMT failures, %	Characteristic of failure	Coments
Opamp/ SOIC8	60	1	1.67	IOS> 2 nA.	
Vref/ SOIC8	120	12	10.00	Parametric shift.	Devices were continued through the testing. 10 devices recovered after HAST.
HEXFET/ SOT223	60	1	1.67	VGTH <1V	
JFET/ SOT23	25	3	12.00	2 failed IG, 1 failed VGS(OFF).	
Opamp/ SOIC16	30	16	53.33	Failed IOS and/or AOL.	Devices were continued through the testing. 15 devices recovered after HAST.
Opamp/ SOIC16	30	2	6.67	Unknown	

Solder reflow process might cause parametric shifts due to changes in mechanical stresses in plastic packages.

HAST Statistics

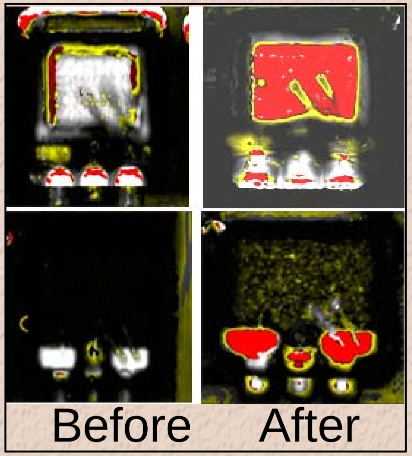
HAST testing was performed at 130 ^{o}C/85%RH/250hrs under bias conditions.

- From 1.1% to 100% failures were observed after HAST in 8 out of 18 linear devices.
- From 26% to 98% of samples in all power MOSFETs (180 pcs., 5 part types) failed HAST.

- For part types consistently failing HAST, the probability of moisture-related failures at normal conditions should be estimated.
- Applicability of HAST testing per JESD22-A110-B for space applications requires additional analysis.

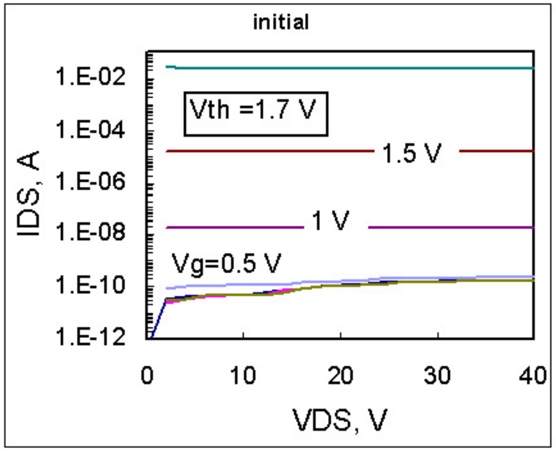
HAST Failures of Power MOSFETs

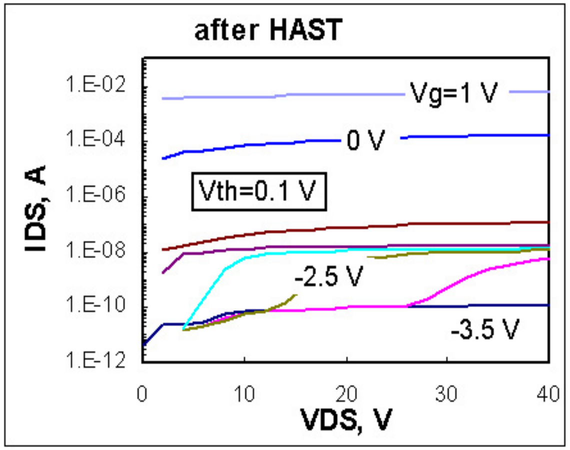
- MOSFET failures were related not only to corrosion, but also to parametric degradation.
- Most HAST failures had delaminations.



HAST-induced delaminations

HAST-induced charge instability



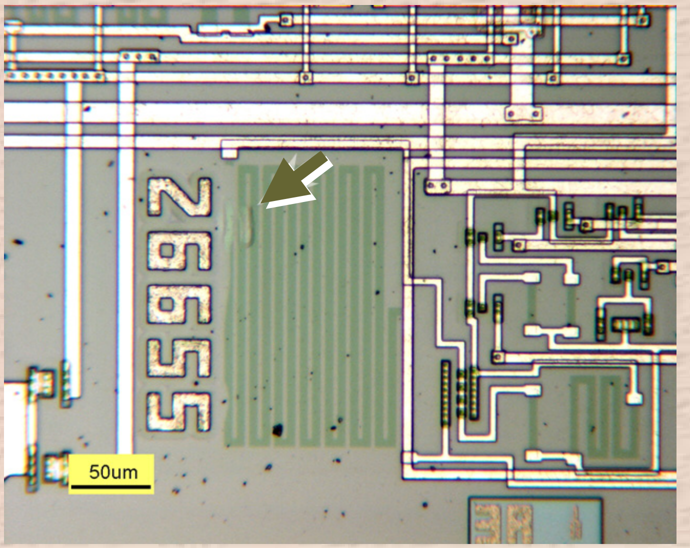


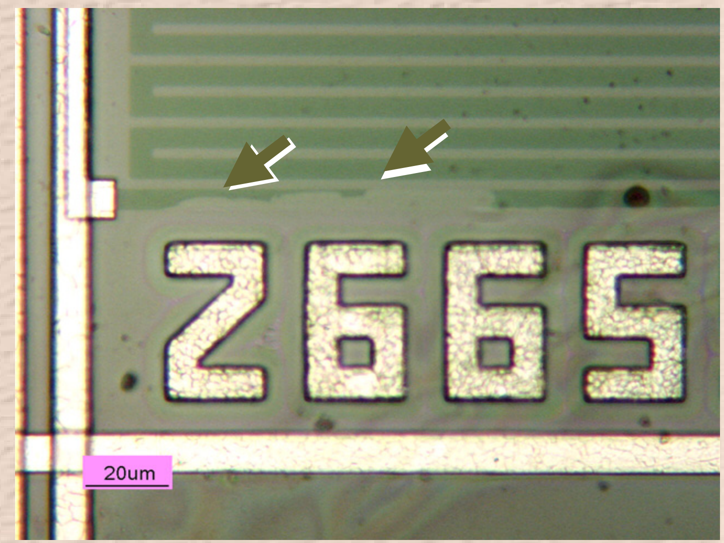
Additional investigation is ongoing to analyze moisture-induced degradation in power devices and to assess the possibility of failures during the testing and integration period.

Precision Opamp HAST Failures

Out of 8 different opamps, only one PN had multiple HAST failures (90% in one lot and 100% in another).

Failures caused by corrosion of thin film resistors.

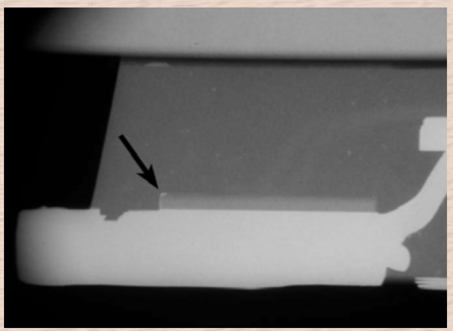


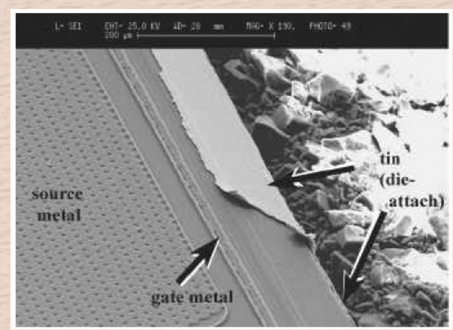


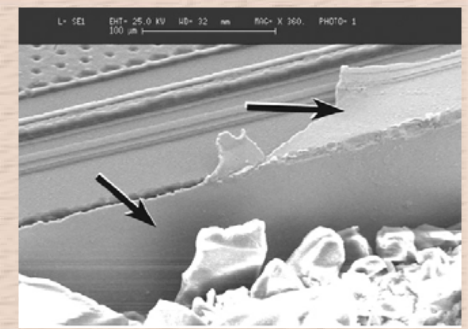
- Are these failures a concern for normal conditions?
- A follow-up analysis has been initiated; the results will be reported later this year.

Assembly Failures of Power FETs

- The parts had top-of-die delaminations and the dies were not protected with glassivation.
- Three parts failed short circuit after manual soldering to boards.
- FA: Overheating of parts resulted in melted solder squeezing up to the die surface along the die-molding compound interface.
- To assure reliability of assemblies, the parts were screened by radiography and C-SAM after assembly.







- Manual soldering of SMT power parts might be damaging.
- Additional analysis is necessary to develop recommendations for manual assembly of this type of device.

Conclusion

- Testing Problems:
  - DPA should precede S&Q to specify test conditions in case of anomalies.
  - Failure modes during electrical easurements should be identified and recorded, no “go/no-go” testing.
  - A methodology for choosing BI temperature is necessary.
  - Applicability of HAST for space applications is controversial. Alternative testing for moisture resistance evaluation might be necessary.
  - Test labs can make mistakes. Test plans and ATE programs for electrical measurement should be reviewed.
  - Handling procedures should be updated and reinforced; special care should be taken during handling of small parts.

Conclusion Cont'd.

- <u>Parts problems:</u>
  - SMT solder reflow might cause parametric shifts related to changes in mechanical stresses in packages.
  - Three repeatable failures, which require follow-up investigations to assess reliability and mitigate risks, have been revealed:
    - Corrosion of thin film resistors.
    - Die attach solder reflow in power FETs during manual soldering.
    - Moisture-induced parametric failures in power FETs.
- <u>Acoustic microscopy problems:</u>
  - The significance of different types of delaminations for reliability of PEMs should be investigated.
  - Criteria for evaluation of results of C-SAM examinations should be refined.

The Use of Lessons Learned to Improve the QAS for COTS PEMs

Item	Lesson Learned	Guideline change	Parts Engineers	Specialist	Follow-up investigation
1	DPA should precede S&Q.	✔			
2	Failure modes should be recorded.	✔	✔		
3	Methodology for BI temperature.		✔	✔	
4	Applicability of HAST.		✔	✔	
5	Alternative to HAST.			✔	✔
6	Review of test plans.	✔	✔		
7	Upadate handling procedures.	✔			
8	Failures due to corrosion of resistors.				✔
9	Manual soldering of power devices.		✔		✔
10	HAST parametric failures in FETs.				✔
11	The significance of delaminations.			✔	✔
12	Criteria for C-SAM evaluation.			✔	✔